TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

COMPENDIUM 9

Control of Erosion

Control de erosión

Contrôle de l'érosion

prepared under contract AID/OTR-C-1591, project 931-1116,
U.S. Agency for International Development

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Notice

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Cover photo: Eroded 8.5-m embankment (Brazil).

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Project Description

The development of agriculture, the distribution of food, the provision of health services, and the access to information through educational services and other forms of communication in rural regions of developing countries all heavily depend on transport facilities. Although rail and water facilities may play important roles in certain areas, a dominant and universal need is for road systems that provide an assured and yet relatively inexpensive means for the movement of people and goods. The bulk of this need is for low-volume roads that generally carry only 5 to 10 vehicles a day and that seldom carry as many as 400 vehicles a day.

The planning, design, construction, and maintenance of low-volume roads for rural regions of developing countries can be greatly enhanced with respect to economics, quality, and performance by the use of low-volume road technology that is available in many parts of the world. Much of this technology has been produced during the developmental phases of what are now the more developed countries, and some is continually produced in both the less and the more developed countries. Some of the technology has been documented in papers, articles, and reports that have been written by experts in the field. But much of the technology is

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Descripción del proyecto

En las regiones rurales de países en desarrollo, el desarrollo de la agricultura, la distribución de víveres, la provisión de servicios de sanidad, y el acceso a información por medio de servicios educacionales y otras formas de comunicación, dependen en gran parte de los medios de transporte. Aunque en ciertas áreas los medios de ferrocarril y agua desempeñan un papel importante, existe una necesidad universal y dominante de crear sistemas viales que provean un medio asegurado pero relativamente poco costoso para el movimiento de gente y mercancías. La mayor parte de esta necesidad se solucionaría con la construcción de caminos de bajo volúmen que generalmente moverían únicamente de 5 a 10 vehículos por día y que pocas veces moverían tanto como 400 vehículos por día.

El planeamiento, diseño, construcción y mantenimiento de caminos de bajo volúmen para regiones rurales de países en desarrollo pueden ser mejorados, con respecto al costo, calidad, y rendimiento, por el uso de la tecnología de caminos de bajo volúmen que se encuentra disponible en muchas partes del mundo. Mucha de esta tecnología ha sido producida durante las épocas de desarrollo de lo que ahora son los países más desarrollados, y alguna se produce contínuamente en estos países así como en los países menos desarrollados. Parte de la tecnología se ha documentado en disertaciones, artículos, e informes que han sido escritos por expertos en el campo. Pero mucha de la tecnología no está documentada y existe principalmente en la memoria de aquellos que han desa-

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Description du projet

Dans les régions rurales des pays en voie de développement, l'exploitation agricole, la distribution des produits alimentaires, l'accès aux services médicaux, l'accès aux matériaux et aux marchandises, à l'information et aux autres services, dépendent en grande partie des moyens de transport. Bien que les transports par voie ferrée et par voie navigable jouent un rôle important dans certaines régions, un besoin dominant et universel éxiste d'un réseau routier qui puisse assurer avec certitude et d'une façon relativement bon marché, le déplacement des habitants, et le transport des marchandises. La plus grande partie de ce besoin peut être satisfaite par la construction de routes à faible capacité, capables d'accommoder un trafic de 5 a 10 véhicules par jour, ou plus rarement, jusqu'à 400 véhicules par jour.

L'utilisation des connaissances actuelles en technologie, qui sont accéssibles dans beauundocumented and exists mainly in the minds of those who have developed and applied the technology through necessity. In either case, existing knowledge about low-volume road technology is widely dispersed geographically, is quite varied in the language and the form of its existence, and is not readily available for application to the needs of developing countries.

In October 1977 the Transportation Research Board (TRB) began this 3-year special project under the sponsorship of the U.S. Agency for International Development (AID) to enhance rural transportation in developing countries by providing improved access to existing information on the planning, design, construction, and maintenance of low-volume roads. With advice and guidance from a project steering committee, TRB defines, produces, and transmits information products through a network of correspondents in developing countries. Broad goals for the ultimate impact of the project work are to promote effective use of existing information in the economic development of transportation infrastructure and thereby to enhance other aspects of rural development throughout the world.

In addition to the packaging and distribution of technical information, personal interactions with users are provided through field visits, con-

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rrollado y aplicado la tecnología por necesidad. En cualquier caso, los conocimientos en existencia sobre la tecnología de caminos de bajo volúmen están grandemente esparcidos geográficamente, varian bastante con respecto al idioma y su forma, y no se encuentran fácilmente disponibles para su aplicación a las necesidades de los países en desarrollo.

En octubre de 1977 el Transportation Research Board (TRB) comenzó este proyecto especial de tres años de duración bajo el patrocinio de la U.S. Agency for International Development (AID) para mejorar el transporte rural en los países en desarrollo acrecentando la disponibilidad de la información en existencia sobre el planeamiento, diseño, construcción, y mantenimiento de caminos de bajo volúmen. Con el consejo y dirección de un comité de iniciativas para el proyecto, el TRB define, produce, y transmite productos informativos a través de una red de corresponsales en países en desarrollo. Las metas generales para el impacto final del trabajo del proyecto son la promoción del uso efectivo de la información en existencia en el desarrollo económico de la infraestructura de transporte y de esta forma mejorar otros aspectos del desarrollo rural a través del mundo.

Además de la recolección y distribución de la

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coup de pays, peut faciliter l'étude des projets de construction, tracé et entretien, de routes à faible capacité dans les régions rurales des pays en voie de développement, surtout en ce qui concerne l'économie, la qualité, et la performance de ces routes. La majeure partie de cette technologie a été produite durant la phase de développement des pays que l'on appelle maintenant développés, et elle continue à être produite à la fois dans ces pays et dans les pays en voie de développement. Certains aspects de cette technologie ont été documentés dans des articles ou rapports écrits par des experts. Mais une grande partie des connaissances n'existe que dans l'esprit de ceux qui ont eu besoin de développer et appliquer cette technologie. De plus, dans ces deux cas, les écrits et connaissances sur la technologie des routes à faible capacité, sont dispersés géographiquement, sont écrits dans des langues différentes, et ne sont pas assez aisément accessibles pour être appliqués aux besoins des pays en voie de développement.

En octobre 1977, le Transportation Research Board (TRB) initia ce projet, d'une duré de 3 ans, sous le patronage de l'U.S. Agency for International Development (AID), pour améliorer le transport rural dans les pays en voie de développement, en rendant plus accessible la documentation existante sur la conception, le tracé, la construction, et l'entretien des routes à faible capacité. Avec le conseil, et sous la conduite d'un comité de direction, TRB définit, produit, et transmet cette documentation à l'aide d'un réseau de correspondants dans les pays en voie de développement. Nous espérons que le résultat final de ce projet sera de favoriser l'utilisation de cette documentation, pour aider au développement économique de l'infrastructure des transports, et de cette façon mettre en valeur d'autres aspects d'exploitation rurale à travers le monde.

ferences in the United States and abroad, and other forms of communication.

Steering Committee

The Steering Committee is composed of experts who have knowledge of the physical and social characteristics of developing countries, knowledge of the needs of developing countries for transportation, knowledge of existing transportation technology, and experience in its use.

Major functions of the Steering Committee are to assist in the definition of users and their needs, the definition of information products that match user needs, and the identification of informational and human resources for development of the information products. Through its membership the committee provides liaison with project-related activities and provides guidance for interactions with users. In general the Steering Committee gives overview advice and direction for all aspects of the project work.

The project staff has responsibility for the preparation and transmittal of information products, the development of a correspondence network throughout the user community, and interactions with users.

Information Products

Three types of information products are prepared: compendiums of documented information on relatively narrow topics, syntheses of knowledge and practice on somewhat broader

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información técnica, se provee acciones recíprocas personales con los usuarios por medio de visitas de campo, conferencias en los Estados Unidos de Norte América y en el extranjero, y otras formas de comunicación.

Comité de iniciativas

El comité de iniciativas se compone de expertos que tienen conocimiento de las características físicas y sociales de los países en desarrollo, conocimiento de las necesidades de transporte de los países en desarrollo, conocimiento de la tecnología de transporte en existencia, y experiencia en su uso.

Las funciones importantes del comité de iniciativas son las de ayudar en la definición de usuarios y sus necesidades, de productos informativos que se asemejan a las necesidades del usuario, y la identificación de recursos de conocimientos y humanos para el desarrollo de los productos informativos. A través de sus miembros el comité provee vínculos con actividades relacionadas con el proyecto y también una guía para la interacción con los usuarios. En general el comité de iniciativas proporciona consejos y dirección general para todos los aspectos del trabajo de proyecto.

El personal de proyecto es responsable de la preparación y transmisión de los productos informativos, el desarrollo de una red de corresponsales a través de la comunidad de usuarios, y la interacción con los usuarios.

Productos informativos

Se preparan tres tipos de productos informativos: los compendios de la información documentada sobre temas relativamente limitados, la síntesis del conocimiento y práctica sobre temas

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En plus de la dissémination de cette documentation technique, des visites, des conférences aux Etats Unis et à l'étranger, et d'autres formes de communication permettront une interaction constante avec les usagers.

Comité de direction

Le comité de direction est composé d'experts qui ont à la fois des connaissances sur les caractéristiques physiques et sociales des pays en voie de développement, sur leurs besoins au point de vue transports, sur la technologie actuelle des transports, et ont aussi de l'expérience quant à l'utilisation pratique de cette technologie.

Les fonctions majeures de ce comité sont d'abord d'aider à définir les usagers et leurs besoins, puis de définir leurs besoins en matière de documentation, et d'identifier les ressources documentaires et humaines nécessaires pour le développement de cette documentation. Par l'intermédiaire des ses membres, le comité pourvoit à la liaison entre les différentes fonctions relatives au projet, et dirige l'interaction avec les usagers. En général, le comité de direction conseille et dirige toutes les phases du projet.

Notre personnel est responsable de la préparation et de la dissémination des documents, du développement d'un réseau de correspondants pris dans la communauté d'usagers, et de l'interaction avec les usagers.

La documentation

Trois genres de documents sont preparés: des recueils dont le sujet est relativement limité, des subjects, and proceedings of low-volume road conferences that are totally or partially supported by the project. Compendiums are prepared by project staff at the rate of about 6 per year; consultants are employed to prepare syntheses at the rate of 2 per year. At least one conference proceedings will be published during the 3-year period. In summary, this project aims to produce and distribute between 20 and 30 publications that cover much of what is known about low-volume road technology.

Interactions With Users

A number of mechanisms are used to provide interactions between the project and the user community. Project news is published in each issue of *Transportation Research News.* Feedback forms are transmitted with the information products so that recipients have an opportunity to say how the products are beneficial and how they may be improved. Through semiannual visits to developing countries, the project staff acquires first-hand suggestions for the project work and can assist directly in specific technical problems. Additional opportunities for interaction with users arise through international and in-country conferences in which there is project participation. Finally, annual colloquiums are held for students from developing countries who are enrolled at U.S. universities.

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un poco más amplios, y los expedientes de conferencias de caminos de bajo volúmen que están totalmente o parcialmente amparados por el proyecto. El personal de proyecto prepara los compendios a razón de unos 6 por año; se utilizan consultores para preparar las síntesis a razón de 2 por año. Se publicará por lo menos un expediente de conferencia durante el período de tres años. En breve, este proyecto pretende producir y distribuir entre 20 y 30 publicaciones que cubren mucho de lo que se conoce de la tecnología de caminos de bajo volúmen.

Interacción con los usuarios

Se utilizan varios mecanismos para proveer las interacciones entre el proyecto y la comunidad de usuarios. Se publican las noticias del proyecto en cada edición de la *Transportation Research News.* Se transmiten, con los productos informativos, formularios de retroacción para que los recipientes tengan oportunidad de decir cómo benefician los productos y cómo pueden ser mejorados. A través de visitas semianuales a los países en desarrollo, el personal del proyecto adquiere directamente de fuentes originales sugerencias para el trabajo del proyecto y puede asistir directamente en problemas técnicos específicos. Surgen oportunidades adicionales para la interacción con los usuarios a través de conferencias internacionales y nacionales en donde participa el proyecto. Finalmente, se organizan diálogos con estudiantes de países en desarrollo que están inscriptos en universidades norteamericanas.

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synthèses de connaissances et de pratique sur des sujets beaucoup plus généraux, et finalement des comptes-rendus de conférences sur les routes à faible capacité, qui seront organisées complètement ou en partie par notre projet. Environ 6 recueils par an sont preparés par notre personnel. Deux synthèses par an sont écrites par des experts pris à l'extérieur. Les comptes-rendus d'au moins une conférence seront écrits dans une période de 3 ans. En résumé, l'objet de ce projet est de produire et disséminer entre 20 et 30 documents qui couvriront l'essentiel des connaissances sur la technologie des routes à faible capacité.

Interaction avec les usagers

Un certain nombre de mécanismes sont utilisés pour assurer l'interaction entre le personnel du projet et la communauté d'usagers. Un bulletin d'information est publié dans chaque numéro de *Transportation Research News.* Des formulaires sont joints aux documents, afin que les usagers aient l'opportunité de juger de la valeur de ces documents et de donner leur avis sur les moyens de les améliorer. Au cours de visites semi-annuelles dans les pays en voie de développement notre personnel obtient de première main des suggestions sur le bon fonctionnement du projet et peut aider à résoudre sur place certains problèmes techniques spécifiques. En outre, des conférences tenues soit aux Etats Unis, soit à l'étranger, sont l'occasion d'un échange d'idées entre notre personnel et les usagers. Finalement, des colloques annuels sont organisés pour les étudiants des pays en voie de développement qui étudient dans les universités américaines.

Foreword and Acknowledgments

This compendium is the ninth product of the Transportation Research Board's project on Transportation Technology Support for Developing Countries under the sponsorship of the U.S. Agency for International Development. The objective of this book is that it provide useful and practical information for those in developing countries who have direct responsibility for control of erosion. Feedback from correspondents in developing countries will be solicited and used to assess the degree to which this objective has been attained and to influence the nature of later products.

Acknowledgment is made to the following publishers for their kind permission to reprint the selected text portions of this compendium:

American Association of State Highway and Transportation Officials; Institution of Highway Engineers, London; PTRC Education and Research Services, Ltd.; Purdue University; Roads and Transportation Association of Canada; Soil Conservation Society of America; Transport and Road Research Laboratory, U.K.; and U.S. Federal Highway Administration.

Prefacio y agradecimientos

Este compendio es el noveno producto del proyecto del Transportation Research Board sobre Apoyo de Tecnología de Transporte para Países en Desarrollo bajo el patrocinio de la U.S. Agency for International Development. El objetivo de este libro es el de proveer información útil y práctica para aquellos en países en desarrollo quienes tienen responsabilidad directa para el control de la erosión. Se pedirá a los corresponsales en los países en desarrollo información sobre los resultados, para utilizarse en el asesoramiento del grado al cual se ha obtenido ese objetivo y para influenciar la naturaleza de productos subsequentes.

Se reconoce a los siguientes editores por el permiso dado para reimprimir las porciones de texto seleccionadas para este compendio.

American Association of State Highway and Transportation Officials; Institution of Highway Engineers, London; PTRC Education and Research Services, Ltd.; Purdue University; Roads and Transportation Association of Canada; Soil Conservation Society of America; Transport and Road Research Laboratory, U.K.; y U.S. Federal Highway Administration.

Avant-propos et remerciements

Ce recueil représente le neuvième volume du projet du Transportation Research Board sur la Technologie des transports à l'usage des pays en voie de développement. Ce projet est placé sous le patronage de l'U.S. Agency for International Development. L'objet de ce recueil est de réunir une documentation pratique et utile qui puisse aider les personnes responsables du contrôle de l'érosion. La réaction des correspondants des pays en voie de développement sera sollicitée et utilisée pour évaluer à quel point le but proposé de ce projet a été atteint, et pour influencer la nature des ouvrages à venir.

Nous remercions les éditeurs qui ont gracieusement donné leur permission de reproduire les textes sélectionnés pour ce recueil:

American Association of State Highway and Transportation Officials; Institution of Highway Engineers, London; PTRC Education and Research Services, Ltd.; Purdue University; Roads and Transportation Association of Canada; Soil Conservation Society of America; Transport and Road Research Laboratory, U.K.; et U.S. Federal Highway Administration.

Appreciation is also expressed to libraries and information services that provided references and documents from which final selections were made for the selected texts and bibliography of this compendium. Special acknowledgment is made to the U.S. Department of Transportation Library Services Division and to the Library and Information Service of the U.K. Transport and Road Research Laboratory (TRRL). Any photographs provided by TRRL have been reproduced by permission of Her Majesty's Stationery Office.

Finally, the Transportation Research Board acknowledges the valuable advice and direction that have been provided by the project Steering Committee and is especially grateful to Kermit L. Bergstralh, Bergstralh Associates, Inc., Lynne H. Irwin, Cornell University, and Adrian Pelzner, U.S. Forest Service, who provided special assistance on this particular compendium.

También se reconoce a las bibliotecas y servicios de información que proveen las referencias y documentos de los cuales se hacen las selecciones finales para los textos seleccionados y la bibliografía en este compendio. Se hace un especiai reconocimiento a la Library Services Division del U.S. Department of Transportation y el Library and Information Service del U.K. Transport and Road Research Laboratory (TRRL). Las fotografías proveídas por TRRL fueron reproducidas con la autorización de Her Majesty's Stationery Office.

Finalmente, el Transportation Research Board agradece el consejo y dirección valiosos provistos por el comité de iniciativas, con especial reconocimiento a los señores Kermit L. Bergstralh, Bergstralh Associates, Inc., Lynne H. Irwin, Cornell University, y Adrian Pelzner, U.S. Forest Service, que prestaron ayuda especial para este compendio en particular.

Nos remerciements aussi aux bibliothèques et bureaux de documentation qui nous ont fourni les documents et les références utilisés dans les textes choisis et bibliographie de ce recueil. Nous remercions spécialement la U.S. Department of Transportation Library Service's Division et les Library and Information Service of the U.K. Transport and Road Research Laboratory (TRRL). Les photos fournies par le TRRL ont été reproduites avec la permission de Her Majesty's Stationery Office.

Finalement, le Transportation Research Board reconnait la grande valeur de la direction et de l'assistance des membres du comité de direction et les remercie de leur concours et de la façon dont ils dirigent le projet, spécialement Messieurs Kermit L. Bergstralh, Bergstralh Associates, Inc., Lynne H. Irwin, Cornell University, et Adrian Pelzner, U.S. Forest Service, qui ont bien voulu prêter leur assistance à la préparation de ce récueil.

Overview

Background and Scope

Erosion is the wearing away and removal of materials of the earth's crust by natural forces. Erosion is usually caused by running water, waves, moving ice, and wind currents. Compendium 9 focuses on erosion control, one of the major factors in the design, construction, and maintenance of roads. It must be considered in every phase of highway engineering.

On the other hand, weathering is a chemical or physical process acting at or near the earth's surface to bring about the disintegration, decomposition, and pulverization of rocks. Weathering occurs in place with no transportation of loosened or altered particles. Although this compendium does not deal with principles of weathering, it does refer to the erosion of weathered material.

Many selected texts in previous compendiums considered erosion control as an integral part of their subject matter. They could have been included in this compendium as well because they are important to the technology of erosion con-

Vista General

Antecedentes y alcance

La erosión consiste en el desgaste y remoción de materiales de la corteza terrestre por parte de fuerzas naturales. Es causada generalmente por un flujo de agua, olas, hielo en movimiento, y corrientes de aire. El Compendio 9 enfoca sobre el control de la erosión, que es uno de los factores más importantes en el diseño, construcción, y conservación de caminos. Deberá considerarse en cada fase de la ingeniería vial.

Por otro lado, el desgaste por acción de la intemperie es un proceso químico o físico que actúa sobre o cerca de la superficie de la tierra para provocar la desintegración, descomposición, y pulverización de las rocas. Esto ocurre en un lugar fijo, sin el traslado de partículas sueltas o alteradas. Aunque el compendio no trata sobre los principios de desgaste por acción de la intemperie, sí habla de la erosión de material intemporizado.

En compendios previos muchos textos seleccionados consideraban el control de la erosión como parte íntegra del tema tratado. Podrían haber sido incluídos en este compendio también, ya que son importantes para la tecnología del control de la erosión. Algunos de estos textos son, por ejemplo, ***Practical Guidance for Design of Lined Channel Expansions at Culvert Outlets*** (Una guía práctica para el diseño de extensiones de canal revestidas en bocas de salida de alcantarillas) (Compendio 3); ***Handbook of Methods and Procedure for Low-Cost Service Roads*** (Manual de métodos y procedimientos

Exposé

Historique et objectif

On appelle érosion les processus d'usure et de déplacement des matériaux de la croûte terrestre par les forces de la nature. L'érosion est causée par l'eau courante, les vagues, la glace et le vent. Ce recueil a pour thème le contrôle de l'érosion, un des facteurs les plus importants de chaque phase de la conception, construction et entretien des routes.

On appelle désagrégation les processus chimiques ou physiques qui agissent à la surface de la croûte terrestre et résultent en la désintegration, la décomposition et la pulvérisation des roches. La désagrégation se fait sur place, sans déplacement des particules altérées ou désagrégées. Bien que ce recueil ne traite pas des principes de la désagrégation, il examine l'érosion des matériaux désagrégés.

Plusieurs textes choisis des recueils précédents ont considéré le contrôle de l'érosion comme faisant partie intégrale de leur objectif.

trol. Some of these texts, for example, are *Practical Guidance for Design of Lined Channel Expansions at Culvert Outlets* (Compendium 3); *Handbook of Methods and Procedure for Low-Cost Service Roads* and *Causeways or Submersible Bridges* (Compendium 4); and *Design of Roadside Drainage Channels* (Compendium 5).

Erosion has been studied by agricultural specialists for many years. Highway engineers have always realized that erosion is one of the major problems in the maintenance of all roads in any environment from tropical rain forests to major deserts. More recently, as the realization has grown that the earth's resources are finite, more emphasis is being given to the control of erosion during the construction phases of civil-engineering works. This is so not only to protect the immediate site from loss of material, but also to prevent eroding soil from damaging the environment outside of the construction area.

Rationale for This Compendium

Erosion control results from a conscientious effort by road planners, designers, and builders. An understanding of the causes and magnitude of erosion is necessary before any workable control methods can be devised. A firm policy of erosion control for highway construction must be

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para caminos de servicio de bajo volúmen) y *Causeways or Submersible Bridges* (Arrecifes o puentes sumergibles) (Compendio 4); y *Design of Roadside Drainage Channels* (El diseño de canales de drenaje del borde del camino) (Compendio 5).

Los especialistas de agricultura han estudiado la erosión durante muchos años. Los ingenieros constructores de carreteras siempre han sabido que la erosión es uno de los problemas más importantes en la conservación de cualquier camino, sea en las selvas tropicales o en los grandes desiertos. Con la reciente comprensión de que los recursos de la tierra son finitos, se ha puesto énfasis en el control de la erosión durante las etapas de construcción de las obras de ingeniería civil. Esto tiene doble propósito. Primero se protege la ubicación de la obra contra pérdida de materiales, y también se impide que el suelo llevado por la erosión dañe el medio ambiente fuera del área de construcción.

Exposición razonada para este compendio

El control de la erosión resulta de un esfuerzo concienzudo por parte de los planificadores, proyectistas y constructores viales. Antes de poder idear métodos de control practicables, es necesario comprender las causas y la magnitud de la erosión. Se debe establecer una política firme para el control de la erosión en la construcción vial para tener éxito mediante esfuerzos combinados.

Nous aurions pû les citer dans ce recueil aussi car ils sont importants à la technologie du contrôle de l'érosion. Certains de ces textes sont, par exemple: *Practical Guidance for Design of Lined Channel Expansions at Culvert Outlets* (Guide pratique pour le dimensionnement des ouvrages d'extrémité, Recueil no. 4); *Handbook of Methods and Procedure for Low Cost Service Roads* (Manual de méthodes et procédés pour routes latérales économiques) et *Causeways or Submersible Bridges* (Levées ou ponts submersibles, Recueil no. 4); et *Design of Roadside Drainage Channels* (Dimensionnement des fossés de drainage des bas-côtés de la route, Recueil no. 5).

Les phénomènes d'érosion ont, depuis longtemps, été étudiés par les agronomes. Les ingénieurs routiers ont compris, depuis toujours, que l'érosion est un des problèmes majeurs de l'entretien des routes, que celles-ci soient dans les forêts tropicales ou traversent les grands déserts. Plus récemment, avec la prise de conscience de la limite des ressources naturelles, on met l'emphase sur le contrôle de l'érosion au moment de la construction des ouvrages de génie civil. Ceci non seulement pour protéger le site contre les pertes de matériaux, mais aussi pour empêcher que le sol érodé ne cause des dommages à l'environment en dehors du lieu de construction.

Objectif de ce recueil

Le contrôle de l'érosion est le résultat d'un effort conscientieux de la part des responsables de la planification, du calcul et de la construction. Il faut bien comprendre les causes et l'importance de l'érosion avant de pouvoir concevoir des mesures de contrôle fonctionnelles. Dans la construction routière, il faut que la politique de contrôle de l'érosion soit fermement établie avant de pouvoir être sûr que les efforts combiestablished before any combined efforts will be fruitful.

Highway drainage is an integral part of erosion control, but erosion control refers to more than just the activities of drainage engineers. Because drainage design and erosion control are inseparable, previous compendiums discussed the erosion of ditches, slopes, and watercourses along with the hydraulics of removing water from and through the highway structure.

Erosion is not limited to waterways or to the flow of water. The design and protection of slopes from both water and wind erosion require the combined efforts of the soils engineer, who determines the erodibility of the soil, and the geometric design engineer, who determines the grade, configuration, and stabilization of the slopes. On low-volume roads these three disciplines (i.e., drainage, soils, and geometric design) are not necessarily represented by three individuals. Often the low-volume road engineer must act in all three capacities if erosion control is to be successful. The techniques of erosion control vary depending on climate, topography, geology, soil, vegetation, water resources, and adjacent land use. Compendium 9 presents many erosion-control methods that have been used under varying conditions throughout the world. The complexity of water erosion may be

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El desagüe del camino forma parte íntegra del control de la erosión, pero este control se refiere a más que las actividades de los ingenieros de desagüe. Ya que el diseño de desagüe y el control de la erosión son inseparables, los compendios anteriores hablaron sobre la erosión de zanjas, pendientes, y vaguadas, junto con la hidráulica de la eliminación del agua de la superficie, y su traslado a través de la estructura vial.

La erosión no se limita a las vías de agua ni al flujo de agua. El diseño y protección de las pendientes contra la erosión por acción del agua o del viento exigen los esfuerzos combinados del ingeniero de suelos, quien determina cuánto puede desgastarse el suelo, y el ingeniero de diseño geométrico, quien determina la rasante, configuración y estabilización de las pendientes. En los caminos de bajo volúmen no hay siempre un ingeniero de cada una de las tres especialidades mencionadas (es decir, desagüe, suelos, y diseño geométrico). Para que el control de la erosión tenga éxito, en muchos casos hace falta que el ingeniero de caminos de bajo volúmen tenga conocimiento de las tres. Las técnicas de control varían dependiendo del clima, topografía, geología, suelo, vegetación, recursos de agua, y uso del terreno adyacente. El Compendio 9 presenta muchos métodos que se han utilizado bajo condiciones variadas a través del mundo. Se puede comprender el problema complejo de la erosión de agua si se considera la posible trayectoría de una gota de lluvia. Cuando esta gota de lluvia cae sobre la tierra posee energía de impacto. Esta energía tiende a desprender partículas de la superficie del suelo y la erosión comienza. Si la gota corre sobre la superficie, introduce movimiento a las partículas desprendidas (llamado erosión en extensión) ("sheet erosion") y así se completa la verdadera definición de la erosión. Por lo tanto,

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nés de tous soient fructueux.

Le drainage de la route fait partie intégrale du contrôle de l'érosion mais celui-ci engage beaucoup plus que les activités de l'ingénieur de drainage. Puisque le dimensionnement du drainage et le contrôle de l'érosion sont inséparables, on a discuté dans les recueils antécédents de l'érosion des fossés, des talus et des cours d'eau, en même temps que l'on discutait de l'hydraulique pour enlever l'eau de la chaussée ou la faire passer en dessous.

L'érosion n'est pas limitée aux cours d'eau ou à l'écoulement de l'eau. Le dimensionnement et la protection des talus demandent les efforts combinés de l'ingénieur des sols, qui détermine l'érodibilité du sol, et de l'ingénieur responsable du dimensionnement géometrique, qui determinera la pente, la forme et la stabilité des talus. Quand il s'agit de routes économiques, ces trois disciplines (drainage, sols et dimensionnement géométrique) ne sont pas nécessairement représentées par trois personnes. Souvent, en fait, l'ingénieur en charge de ces routes doit remplir ces trois fonctions s'il veut réussir à contrôler l'érosion. Les méthodes employées pour la protection contre l'érosion diffèrent selon le climat, la topographie, la géologie, le sol, la végétation, les eaux, et l'utilisation du terrain adjacent. Dans ce recueil nous allons présenter plusieurs méthodes de lutte antiérosive, utilisées à travers le monde dans des circonstances variées. On pourra mieux apprécier la complexité de l'érosion dûe à l'action de l'eau, en considérant le chemin éventuel parcouru par une goutte de pluie. Quand cette goutte de pluie tombe sur le sol, elle a une force d'impact. Cette force a tendance à désagréger ou à détacher des particules de la surface du sol, et le processus érosif understood by considering the possible routing of a single raindrop. When this raindrop strikes the ground, it has impact energy. This energy tends to loosen or detach particles from the soil surface and erosion begins. If the raindrop runs down the surface, it introduces movement to the detached particles (called sheet erosion) and the true definition of erosion is complete. Therefore, the first erosion-control measures are to reduce raindrop impact and to slow down soil-particle movement. To accomplish this, the simplest method is to provide a vegetative cover on the soil. Because vegetation does not occur instantaneously, some temporary method, usually mulch, must be used until the vegetation is established.

As the raindrop continues on its way, it is joined by other raindrops and may be collected in a ditch or watercourse. The shape, roughness, and slope of the watercourse, combined with the number of raindrops (quantity of runoff) determine the speed of the ditch flow. At low velocities, this flow will not dislodge or move the soil particles (called hydraulic erosion or scour) in the ditch bed. As the velocity increases, vegetation may again prevent erosion if the ditch carries only intermittent flow so that the vegetation can survive. Higher velocities require a more positive protective lining in the ditch or the use of ditch checks (small dams) to reduce the velocity. Protective linings may be concrete (either Portland cement or asphalt) that increases the

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las primeras medidas de control consisten en reducir el impacto de la gota de lluvia y reducir el movimiento de las partículas de suelo. El método más simple para lograr esto consiste en establecer una cubierta vegetativa sobre el suelo. Ya que la vegetación no ocurre instantáneamente, se debe utilizar un método provisorio, generalmente materiales como estiércol y paja, hasta que se establezca la vegetación.

A medida que se traslada la gota de lluvia, se junta con otras gotas y todas se recolectan en una zanja o vaguada. La forma, aspereza, y pendiente de la zanja, combinadas con la cantidad de gotas de lluvia (cantidad de agua de desagüe) determinan la velocidad del flujo en la zanja. A bajas velocidades este flujo no desprenderá ni moverá las partículas de suelo (erosión hidráulica o socavación) en el lecho de la zanja. A medida que aumenta la velocidad, otra vez más la vegetación puede impedir la erosión únicamente si el flujo en la zanja es intermitente, para que la vegetación pueda sobrevivir. Se requiere un revestimiento más protectivo para velocidades más altas, con impedimentos en la zanja (pequeños diques) para reducir la velocidad. Los revestimientos protectivos pueden ser de hormigón — cemento Portland o asfalto — que debido a la lisura de su superficie aumenta la velocidad del agua, o de piedra que debido a su superficie áspera disminuye la velocidad del agua. Cada tipo de revestimiento tiene desventajas. El aumento de velocidad con los revestimientos de hormigón provoca problemas en las desembocaduras, y el desbordamiento o el descalce de estos revestimientos provocan el fracaso completo. Los revestimientos de roca

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commence. Si cette goutte de pluie se met à ruisseler, elle met en mouvement ces particules détachées (érosion en nappe), ce qui, d'après sa définition, complète le phénomène d'érosion. Nous voyons donc que les premières mesures de lutte antiérosive auront pour objectif de réduire la force d'impact des gouttes d'eau, et de ralentir le déplacement des particules de sol. La méthode la plus simple pour en arriver à ce but, est de nantir le sol d'une couverture végétale. Comme la végétation ne pousse pas instantanément, on doit employer des méthodes temporaires, comme une couverture de mulch jusqu'à ce que les plantes soient levées.

La goutte d'eau continue son chemin, d'autres gouttes d'eau se joignent à elle, et elles se rassemblent toutes dans un fossé ou dans un cours d'eau. La forme, la rugosité et la pente du fossé, combinées avec le nombre de gouttes d'eau (débit) déterminent la vitesse d'écoulement du fossé. A basse vitesse, cet écoulement ne déplacera pas les particules de sol (érosion hydraulique ou affouillement) du lit du fossé. Quand la vitesse augmente, la végétation peut encore prévenir l'érosion s'il n'y a de l'eau dans le fossé qu'à certaines périodes, de façon à ce que la végétation ait la possibilité de survivre. Si la vitesse du débit est élevée, il faut soit revêtir les parois et le fond du fossé, afin de le protéger, soit y installer des petits barrages de sédimentation pour réduire la vitesse du courant. Le revêtement peut être soit en béton, ciment Portland ou bitume asphaltique — ce qui augmentera la vélocité de l'eau à cause de sa surface lisse, soit en pièrres — ce qui ralentira la vitesse d'écoulement à cause de sa rugosité. Ces deux sortes de revêtements ont d'ailleurs chacun leurs inconvénients. La plus grande vitesse obvelocity of the flowing water because of its smooth surface or stone that decreases velocity because of its rough surface. Each type of lining has its drawbacks. The added velocity of the concrete linings causes exit problems, and overtopping or undermining of these linings causes complete failure. Rock linings require larger channels (because of the lower velocities); the rocks can move, and the fines under the rocks can be sucked out causing settlement.

When the flow in the channel reaches a constriction, such as a pipe culvert, further erosion problems arise. Eddies (whirlpools) occur at the entrance loosening more soil. Erosion problems downstream from the pipe result from the added exit velocity due to (a) constriction of the pipe, (b) increased pipe slope, or (c) reduced pipe friction. These problems may be reduced by the use of headwalls and energy-dissipation structures at pipe outlets.

Even after the original raindrop reaches a natural watercourse it causes erosion problems. In floods it can erode the toe of slope of adjacent roadways. At bridges where the waterway is constricted, flood water causes general scour (the lowering of the channel bed by erosion) and local scour around piers, abutments, and noses of guide banks and embankments. Even at bridges where the waterway is not constricted (i.e., where there is no significant constriction or realignment of natural flows imposed by the bridge approaches or training works), natural scour due to river bends and bed migration and local scour at piers occur. While channel and local scour must be considered in the overall design of the bridge piers, abutments, and training works, river-bank erosion may be reduced by bank protection, groins, and dikes.

The selected texts in this compendium provide solutions to many of these problems and

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necesitan canales más grandes (a causa de las velocidades más bajas), las rocas pueden moverse, y los finos debajo de las rocas pueden ser extraídos y causar asentamiento.

Cuando el flujo en el canal llega a un estrechamiento, tal como una alcantarilla de tubo, ocurren más problemas de erosión. Ocurren remolinos (vórtices) en la entrada, que desprenden más tierra. Los problemas de erosión aguas abajo del tubo son el resultado del aumento en la velocidad a la salida debido a (a) constricción del tubo, (b) aumento en la pendiente del tubo, o (c) reducción de la fricción en el tubo. Estos problemas pueden reducirse por el uso de muros de cabeza y estructuras para disipar la energía, en las salidas de los tubos.

Aún después de llegar a una vía natural de agua, la gota original de lluvia causa problemas de erosión. En tiempos de inundación puede desgastar el pie de talud de caminos adyacentes. En los puentes donde existe una constricción de la vía de agua, las aguas de inundación causan la socavación general (el desgaste del lecho del canal a causa de la erosión) y la socavación local alrededor de pilares, estribos, y extremos de muelles de guía y terraplenes. Aún en los puentes donde no existe un estrechamiento (es decir, donde no hay constricción o realineamiento del flujo natural por razón de accesos de puentes o canalizaciones), ocurren la socavación natural causada por curvas del río y migración del lecho y la socavación local en los pi-

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tenue avec des revêtements en béton cause des problèmes aux éxutoires, en outre, les déversements et les affouillements causent leur rupture complète. Les revêtements de pierre exigent des fossés plus grands (à cause de la vitesse d'écoulement qui est plus basse) les pierres peuvent bouger, en causant l'aspiration des fines qui sont en dessous, et provoquer un tassement. Quand l'eau courante rencontre un rétrécissement du lit, tel qu'un passage de buse, un autre genre d'érosion se produit. Un tourbillon, ou vortex se forme à l'entrée et désagrège le sol encore plus. L'érosion se produit aussi en aval de la canalisation, causée par une vitesse de débit plus grande, celle-ci étant le résultat de (a) le rétrécissement de la canalisation, (b) sa pente plus accentuée, ou (c) sa paroi moins rugueuse. Ces problèmes peuvent être réduits en installant des têtes de buse ou des dissipateurs d'énergie aux extrémités des ouvrages.

Même si notre goutte d'eau arrive jusqu'à un cours d'eau naturel, elle va causer des problèmes d'érosion. En période de crue, elle peut affouiller le pied des talus des routes avoisinantes. Au passages des ponts, où il se produit un rétrécissement du débouché, les crues peuvent être la cause d'affouillement général (rabaissement du niveau du lit du cours d'eau) et d'affouillement local autour des piles, des culées, des musoirs des défléceurs et des berges. Même pour les ponts où il n'y a pas de rétrécissement, (C'est à dire où les approches du pont ou les ouvrages de guidage ne modifient pas les conditions naturelles d'écoulement du cours d'eau) un affouillement naturel se produit, causé also expand upon the erosion problems particular to the tropics and to mountainous and desert terrain.

Discussion of Selected Texts

The first text, *Guidelines for Erosion and Sediment Control in Highway Construction* (American Association of State Highway Officials, 1973), introduces a policy for erosion. It indicates that, although some standardization of methods for minimizing soil erosion in highway construction is possible, national guidelines for the control of erosion must be general in nature. This is because of the wide variation in climate, topography, geology, soil vegetation, water resources, and land use that may be encountered in different parts of a country.

The policy for erosion prevention is described in the Introduction to this text: "Erosion prevention is one of the major factors in the design, construction and maintenance of highways. Erosion can be controlled to a considerable degree by geometric design, particularly that relating to the cross section. In some respects the control is directly associated with proper provision for drainage and for fitting landscape development. Effect on erosion should be considered in the location and design stages."

The text states that erosion and maintenance are minimized by the use of (a) flat side slopes, rounded and blended with the natural terrain; (b)

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lares. Mientras que se debe tener presentes la socavación local y la del canal en el diseño general de los pilares, estribos, y canalizaciones de los puentes, la erosión de las orillas puede reducirse por medio de la protección de las orillas, y con espigones y diques.

Los textos seleccionados de este compendio ofrecen soluciones para muchos de estos problemas, y también examinan con detalle los problemas de erosión que se encuentran en los trópicos y en los terrenos montañosos y de desierto.

Presentación de los textos seleccionados

El primer texto, *Guidelines for Erosion and Sediment Control in Highway Construction* (Pautas para el control de erosión y sedimentos en la construcción vial, American Association of State Highway Officials, 1973), introduce una política para controlar la erosión. Indica que, aunque es posible establecer uniformidad hasta cierto punto en los métodos para reducir la erosión del suelo en la construcción vial, las pautas nacionales para el control deberán ser por naturaleza muy generales teniendo en cuenta la gran variación en el clima, topografía, geología, vegetacíon del suelo, recursos de agua, y uso del terreno en distintas partes del país.

La política para la prevención de la erosión se describe en la introducción a este texto: "La prevención de la erosión es uno de los factores más importantes en el diseño, construcción y conservación de los caminos. Se puede controlar la erosión con considerable éxito por medio del diseño geométrico, especialmente el que se refiere al perfil transversal. Hasta cierto punto el control se asocia directamente con una buena provisión para el desagüe y para el desarrollo apropiado del paisaje en rededor. El efecto sobre la erosión deberá considerarse en las etapas de ubicación y diseño."

El texto dice que la erosión y la conservación se aminoran por el uso de (a) pendientes laterales planas, redondeadas y amoldadas al terreno natural; (b) diseños de canales de desagüe que toman en consideración los anchos, profundidades, pendientes, alineamientos, y tratamien-

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par les méandres de la riviére, le déplacement du lit et l'affouillement des piles. Alors que l'on doit prendre en considération l'affouillement du lit et l'affouillement local au stade du dimensionnement des piles, des culées et des ouvrages de guidage, l'érosion des berges peut être réduite par la construction d'ouvrages de protection tels que des épis et des digues.

Les textes choisis que nous présentons dans ce recueil, offrent des solutions à beaucoup de ces problèmes. De plus, les problèmes d'érosion spécifiques aux tropiques et aux terrains désertiques et montagneux y sont traités particulièrement.

Discussion des textes choisis

Le premier texte, *Guidelines for Erosion and Sediment Control in Highway Construction* (Guide pour le contrôle de l'érosion et des sédiments en construction routière, American Association of State Highway Officials, 1973), introduit une politique pour la lutte contre l'érosion. Il est indiqué que bien qu'une certaine normalisadrainage channel designs that give proper consideration to the widths, depths, slopes, alignments, and protective treatments of the ditches and other waterways; (c) drainage-channel locations and spacings that are determined with erosion control in mind; (d) erosion-prevention measures at culvert outlets; (e) proper facilities for ground-water interception; (f) dikes, berms, and other protective devices; and (g) protective ground covers and planting.

Erosion-control guidelines are presented for the following highway engineering activities: (a) the evaluation of natural drainage patterns, geology, and soils in the planning and location of a road; (b) the design of a road including both geometrics and drainage; (c) the scheduling, work-area control, and grading operations during the construction of the road, including both temporary and permanent erosion-control measures; and (d) the maintenance of the finished road.

The second text is excerpted from ***Principles of Highway Drainage and Erosion Control*** (Purdue University, 1962). This manual describes the interrelation between erosion control and highway drainage. Uncontrolled water is a primary

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tos protectivos de las zanjas y otras vías de agua; (c) ubicaciones y espaciamiento de canales de desagüe que se determinan teniendo presente el control de la erosión; (d) medidas de prevención de la erosión en las salidas de alcantarillas; (e) medios apropiados para la intercepción de agua freática; (f) diques, bermas, y otros dispositivos protectivos; y (g) vegetación y plantaciones protectivas.

Se presentan pautas para el control de la erosión en las siguientes actividades ingenieriles: (a) la evaluación de sistemas naturales de desagüe, geología, y suelos en el planeamiento y ubicación de un camino; (b) el diseño de un camino que incluye la geométrica y el desagüe; (c) el planeamiento, control del área de trabajo, y operaciones de nivelación durante la construcción del camino, incluyendo las medidas provisorias y las permanentes para el control de la erosión; y (d) la conservación del camino terminado.

El segundo texto fué extraído de ***Principles of Highway Drainage and Erosion Control*** (Principios de desagüe de caminos y control de la erosión, Purdue University, 1962). Este manual describe la relación recíproca entre el control de la erosión y el desagüe de caminos. El agua no controlada es una de las principales causas de defectos en los caminos y de altos costos de conservación; por lo tanto, el texto subraya la necesidad de una mínima interferencia del desagüe natural. Una mínima interferencia con la

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tion des méthodes utilisées pour minimiser les effets de l'érosion dans la construction routière soit possible, s'il on établit des normes nationales, celles-ci doivent être, par nature, très générales. Ceci à cause des différences considerables de climat, topographie, géologie, végétation, ressources en eau, et utilisation des terrains, que l'on peut trouver dans un pays.

La politique de lutte preventive contre l'érosion est décrite dans l'introduction: "La lutte préventive contre l'érosion est un des facteurs les plus importants à considérer lors de la conception, de la construction et de l'entretien d'une route. L'érosion peut être contrôlée en grande mesure en calculant bien les caractéristiques géométriques, particulièrement celles du profil en travers. Sous certains aspects, le contrôle est associé directement à un système de drainage adéquat, et à une bonne utilisation de la topographie. Il est donc important de considérer leur influence sur l'érosion au stade de la conception et du tracé de la route."

L'érosion et l'entretien sont minimisés par l'emploi de: (a) une pente de talus faible, arrondie, et qui s'allie aux contours naturels du terrain; (b) un dimensionnement adéquat des canaux de drainage en prenant en considération la largeur, la profondeur, le tracé et les traitements protectifs des fossés et autres écoulements d'eau; (c) une localisation et un espacement des canaux de drainage determinés en pensant au contrôle de l'érosion; (d) l'utilisation de moyens préventifs aux émissaires des ponceaux ou des buses; (e) une installation adéquate pour intercepter l'eau souterraine; (f) la construction de digues, bermes et d'autres dispositifs de protection; (e) l'utilisation de dispositifs de protection du sol, et d'une couverture végétale.

Des directions, pour assurer le contrôle de l'érosion durant les travaux routiers suivants, sont présentées (a) évaluation des réseaux naturels de drainage, de la géologie et des sols au stade de la conception et du tracé; (b) calcul de la route, y compris le dimensionnement géométrique et hydraulique (c) programme d'exécution, contrôle de l'érosion sur le chantier et les terrassements au cours de la construction, y compris les mesures de lutte temporaires et permanentes et (d) entretien de la route.

Le deuxième texte est extrait de ***Principles of*** cause of road failures and high maintenance costs; therefore, the text stresses the need for minimum interference to natural drainage. Minimum interference with nature is defined as (a) stablizing earth surfaces with some kind of cover, (b) providing a place for water to run freely over the surface in ditches or underground in culverts and subdrains, and (c) conducting the collected water safely to a natural watercourse.

The text is divided into four major areas of drainage and erosion control: slope protection, roadside ditches, culverts, and subdrains. It describes the fundamental principles that should be followed in the design, construction, and maintenance of each of these categories and presents some specific applications of these principles. The fundamental principles apply to roads everywhere. However, some of the specific applications described in this text and some of the other texts in this compendium are particular to the climatic conditions of the area for which the text was written. This is especially true of recommendations for vegetal cover. ***The Use and Control of Vegetation on Roads and Airfields Overseas*** (Selected Text 5) should be re-

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naturaleza se define como (a) la estabilización de superficies de tierra con algún tipo de cobertura, (b) provisión de algún lugar donde el agua pueda correr libremente sobre la superficie en zanjas o subterráneamente en alcantarillas y drenajes, y (c) conducción del agua recolectada hasta alguna vía de agua natural.

El texto se divide en cuatro secciones principales de desagüe y control de erosión: protección de la pendiente, zanjas del borde del camino, alcantarillas, y subdrenaje. Describe los principios fundamentales que deberán seguirse en el diseño, construcción y conservación de cada una de estas categorías y presenta algunas aplicaciones específicas de estos principios. Los principios fundamentales se pueden aplicar a los caminos en todos lugares. Sin embargo, algunas de las aplicaciones específicas que se describen en este texto y en algunos de los otros textos de este compendio son particulares a las condiciones climáticas del área para la cual se escribió el texto. Esto es especialmente cierto en cuanto a las coberturas vegetativas que se recomiendan. Se deberá referirse a *The Use and Control of Vegetation on Roads and Airfields Overseas* (Texto Seleccionado N.°5 — El uso y control de la vegetación en los caminos y aeropistas foráneos) para una evaluación más detallada de los materiales de cobertura apropiados.

El tercer texto es un informe titulado *Control of Erosion on Highways* (Control de la erosión en caminos, *Proceedings of the Seminar on Highway Design in Developing Countries,* PTRC, 1975). Amplifica los principios de erosión que se describen en el texto precedente y ofrece algunas aplicaciones específicas de los métodos de control que se utilizan en varias partes del mundo.

El texto compara la intensidad pluvial en los climas templados y tropicales. Llega a la conclusión de que aunque la lluvia total típica de los trópicos puede ser el doble de la del clima templado, la lluvia erosiva asociada (es decir, más de 25 mm/h) posee una energía cinética de más de 16 veces la del clima templado. Por esta

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Highway Drainage and Erosion Control (Principes de drainage et mesures de contrôle de l'érosion en construction routière, Purdue University, 1962). Ce manuel décrit la corrélation entre le contrôle de l'érosion et le drainage de la route. Un écoulement d'eau qui n'est pas contrôlé est une des causes principales de la rupture de la chaussée et d'un prix d'entretien prohibitif: par conséquent il est souligné que l'on doit contrarier le moins possible le drainage naturel. Contrarier le moins possible la nature veut dire, dans ce cas: (a) revêtir d'une facon ou d'une autre, les surfaces de terrain dénudées par la construction; (b) permettre à l'eau de s'écouler sans obstacle à l'aide de fossés, de ponceaux ou de drains souterrains et (c) guider cette eau en toute sécurité vers un cours d'eau naturel.

Le texte est divisé en quatre sections principales sur le drainage et le contrôle de l'érosion: protection des talus, fossés latéraux, ponceaux et drains souterrains. Les lois fondamentales qui régissent la conception, construction et l'entretien de ces travaux sont expliquées, et on présente quelques exemples spécifiques d'application. Ces lois fondamentales régissent la construction routière d'une façon universelle. Cependant, certains exemples, cités ci-dessus et dans plusieurs autres textes de ce recueil, sont particuliers aux conditions climatiques des régions pour lesquelles le texte a été écrit. Ceci est spécialement vrai dans le cas des recommandations sur les couvertures végétales. Le texte, *The Use and Control of Vegetation on Roads and Airfields Overseas* (Texte no. 5 — Utilisation et contrôle de la végétation sur les routes ferred to for a more detailed evaluation of appropriate cover materials.

The third text is a paper entitled *Control of Erosion on Highways (Proceedings of the Seminar on Highway Design in Developing Countries,* PTRC, 1975). It amplifies the erosion principles described in the preceding text and offers some specific applications of erosion-control measures used in various parts of the world.

The text compares rainfall intensity in temperate and tropical climates. It concludes that, although a typical total tropical rainfall may be twice that of the temperature climate, the associated erosive rainfall (i.e., greater than 25 mm/h) has a kinetic energy of greater than 16 times that of the temperate climate. Particular attention must therefore be paid to erosion control in highway design in the tropics.

This text also presents an evaluation of the "universal soil-loss equation," developed by the U.S. Department of Agriculture. This empirical equation attempts to identify the major factors in soil erosion and to establish their functional relationships to soil loss. It has been adapted for sediment prediction and erosion-control planning in construction areas. The text uses the equation to illustrate some of the factors that influence erosion rates. It does not recommend the use of the equation for roads in developing countries because the equation is invalid for slopes steeper than 5:1, and because the soil erodibility factor (developed for the United States) probably overestimates the erodibility of many cohesively-bonded tropical soils. (See Ref. 16 in this compendium for a detailed analysis of this equation.)

The text notes some specific vegetal types used for erosion control throughout the world and compares erosion yield from roadbanks with no cover and with vegetation. It also notes that on low-volume roads maintained by graders, the ditch is periodically cleaned by the grader to recover material for the road surface. Vegetation cannot be used as an erosion-control measure in such ditches. The water must therefore be diverted from the side ditch into contour drains cut at intervals along the ditch. The spacing of the contour drains is a function of the permissible

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razón se debe prestar especial atención al control de la erosión en el diseño de caminos en los trópicos.

Este texto también presenta una evaluación de la "ecuación universal de pérdida de suelo," desarrollada por el Departamento de Agricultura de los Estados Unidos de Norte América. Esta ecuación empírica trata de identificar los factores más importantes en la erosión del suelo y de establecer su relación funcional con la pérdida de suelo. Se ha adaptado para predicciones de sedimento y planeamiento del control de la erosión en las áreas de construcción. El texto utiliza la ecuación para ilustrar algunos de los factores que influyen en los aumentos proporcionales de la erosión. No recomienda su uso en los caminos de países en desarrollo ya que la ecuación es inválida para pendientes más graves que 5:1, y porque probablemente el factor de desgaste del suelo, que se desarrolló para los Estados Unidos de N.A., sobreestima la tendencia a erosión de muchos de los suelos cohesivamente ligados de los trópicos. (Para un análisis detallado de esta ecuación ver la Ref. 16 de este compendio.)

El texto presenta algunos tipos vegetativos específicos que se utilizan para el control de la erosión a través del mundo y compara la cantidad de erosión en cunetas con y sin vegetación. Menciona que en los caminos de bajo volúmen

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et terrains d'aviation d'outre-mer), devrait être utilisé s'il l'on a besoin d'une évaluation plus détaillée des couvertures végétales idoines.

Le troisième texte est une communication intitulée *Control of Erosion of Highways* (Contrôle de l'érosion des routes, *Proceedings of the Seminar on Highway Design in Developing Countries,* PTRC, 1975). Cette communication développe en plus grand détail les principes décrits dans le texte précédent, et offre quelques exemples spécifiques d'application des procédés utilisés dans certaines parties du monde pour le contrôle de l'érosion. Les régimes pluviométriques des climats tempérés et des climats tropicaux sont comparés. Il est déterminé que, bien que le montant des précipitations annuelles typiques des pays tropicaux peut être deux fois plus grand que celui d'un pays tempéré, ces chûtes de pluie érosives (plus que 25 mm/h) ont une énergie cinétique seize fois plus grande que celles des pays tempérés. Il est donc particulièrement nécessaire dans les tropiques, de penser au contrôle de l'érosion lorsque l'on projette de construire une route.

Dans ce texte on nous présente aussi une évaluation de l' "Universal soil-loss equation" qui a été développée par le U.S. Department of Agriculture. Cette formule empirique tente d'identifier les facteurs principaux de l'érosion des sols, et d'établir leurs rôles relatifs dans le maximum-flow velocity of the ditch. The allowable velocity depends on the hydraulic erodibility of the soil in which the ditch is cut.

The fourth text, ***Protecting Steep Construction Slopes Against Water Erosion (Highway Research Record 206,*** Highway Research Board, 1967), is a report detailing evaluation of the use of mulch. It describes studies made under controlled conditions to evaluate the relative merits of several mulches that are coverings placed over the soil not only to temporarily protect the soil from erosion but also to maintain temperature and moisture conditions favorable to the germination of seeds.

Each of 13 mulches was evaluated for three different types of losses: (a) the erosion of the soil as measured by the sediment lost during the tests; (b) the loss or movement of grass seed; and (c) the loss of fertilizer as determined by the amount of phosphorus contained both in the soil and in the water of each run-off sample.

The results show that jute netting and hay are highly ranked in providing both protection from raindrop impact and adherence to the soil surfaces. These mulches are locally available in many developing countries.

The fifth text, ***The Use and Control of Vegetation on Roads and Airfields Overseas*** (Road Research Laboratory, 1961), is a compilation of information gathered from public-works organizations and other governmental agencies in 33 former British territories. It lists the kinds of vegetation that commonly occur at roadsides in the various locations. The listings also include the

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conservados con una niveladora, ésta periódicamente limpia la zanja para reclamar material para la superficie del camino. No se puede utilizar la vegetación para controlar la erosión en tales zanjas. Por esto se debe desviar el agua de la zanja del borde del camino a drenajes perfilados cortados a intervalos a su largo. El espaciamiento de los drenajes perfilados es una función de la velocidad máxima permisible de flujo de la zanja. La velocidad máxima permisible depende del desgaste hidráulico del suelo en que está cortada la zanja.

El cuarto texto, ***Protecting Steep Construction Slopes Against Water Erosion*** (Protección contra la erosión en las pendientes fuertes de obras, ***Highway Research Record 206,*** Highway Research Board, 1967), es un informe que detalla la evaluación del uso de coberturas protectivas. Describe estudios hechos bajo condiciones controladas para evaluar los méritos relativos de varias coberturas que se colocan sobre el suelo para protegerlo en forma provisional contra la erosión y para mantener condiciones de temperatura y humedad favorables para la germinación de semillas.

Se evaluaron 13 coberturas para tres distintos tipos de pérdidas: (a) la erosión del suelo medida por la pérdida de sedimentos durante los ensayos; (b) la pérdida o traslado de semillas de pasto; y (c) la pérdida de fertilizante determinada por la cantidad de fósforo en el suelo y en el agua de cada muestra de agua de desagüe.

Los resultados indican que la red de yute y el heno son altamente efectivos en la protección contra el impacto de gotas de lluvia y en adherencia a las superficies de suelo. Estas coberturas se encuentran localmente en muchos países en desarrollo.

El quinto texto, ***The Use and Control of Vegetation on Roads and Airfields Overseas*** (El uso y control de la vegetación en los caminos y aeropistas foráneos, Road Research Laboratory,

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mécanisme de déperdition du sol. Cette formule a été adaptée pour l'estimation des sédiments, et l'élaboration des mesures de contrôle de l'érosion sur les chantiers. On utilise l'équation pour illustrer plusieurs facteurs qui influencent le taux d'érosion. L'auteur ne recommande pas l'utilisation de cette équation pour les routes des pays neufs, car elle n'est pas valable pour les talus dont la pente est plus de 5/1, de plus le facteur d'érodibilité du sol, calculé pour les Etats Unis, probablement surestime l'érodibilité de beaucoup de sols cohérents des tropiques (voir la référence no. 16 de ce recueil pour une analyse détaillée de cette équation).

Des types spécifiques de végétation utilisés dans le monde entier pour lutter contre l'érosion sont présentés, et on compare l'érosion des talus sans protection à celle des talus protégés par un tapis végétal. On remarque aussi que dans le cas des routes économiques dont l'entretien est fait à la niveleuse, on fait périodiquement le curage des fossés pour récupérer des matériaux pour la chaussée, ce qui exclut effectivement les couvertures végétales comme instrument de lutte contre l'érosion. Dans ces cas, l'eau doit être détournée des fossés latéraux, et dirigée vers des saignées latérales de dégagement (arêtes de poissons). La distance entre ces saignées est fonction de la vitesse d'écoulement maximale admissible du fossé, qui elle même dépend de l'érodibilité hydraulique du sol du fossé.

Le quatrième texte, ***Protecting Steep Construction Slopes Against Water Erosion*** (La provegetation type (i.e., grasses, herbs and shrubs, and woody species) and the main factors that appear to affect the distribution of the vegetation at roadsides (i.e., rainfall and geographical location).

The text evaluates the problems that vegetation presents in the more humid regions of the tropics such as blockage of drainage channels, disruption of road pavements, and obstruction of driving vision. It also considers the advantages of vegetation such as control of wind and rain erosion. The purpose of the paper is to discover which biological species are useful and which present difficulties.

The text also discusses methods of vegetation control and costs including (a) mechanical methods, such as handcutting, hoeing, mechanical cutting, and burning; (b) biological methods, such as grazing and use of parasites; and (c) chemical methods, such as nonselective and selective herbicides. Appendix 2 of this work lists the local names (in English) of the vegetation species discussed throughout the text.

The sixth text is an article entitled ***Erosion-Proofing Drainage Channels (Journal of Soil and Water Conservation,*** Vol. 28, No. 2, March-April 1973). It addresses the serious problem of lined-channel erosion. Three types of lined

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1961), es una compilación de información que se recogió de las organizaciones de obras públicas y otras agencias gubernamentales en 33 territorios posteriormente británicos. Detalla las clases de vegetación que comunmente ocurren en los bordes de camino en diversas localidades. También incluye el tipo de vegetación (es decir, pastos, hierbas y arbustos, y especies leñosas) y los factores más importantes que aparentemente afectan la distribución de la vegetación en los bordes de camino (es decir, lluvia y ubicación geográfica).

El texto evalúa los problemas causados por la vegetación en las regiones más húmedas de los trópicos, tales como la obstrucción de los canales de desagüe, destrucción de los pavimentos, y obstrucción de la visibilidad en el manejo. También se consideran sus ventajas, tales como el control de la erosión por parte del viento y de la lluvia. El objectivo del informe es la determinación de las especies biológicas que son útiles y las que presentan problemas.

El texto también habla sobre los métodos de control de la vegetación y los costos, incluyendo (a) los métodos mecánicos, tales como corte a mano, sachadura, corte mecánico, y quema; (b) los métodos biológicos, tales como el pastoreo y el uso de parásitos; y (c) los métodos químicos, tales como los herbicidas selectivos y no selectivos. El Apéndice 2 de este texto detalla los nombres locales (en inglés) de las especies de vegetación mencionadas en el texto.

El sexto texto es un artículo titulado ***Erosion-Proofing Drainage Channels*** (Preservando los canales de desagüe de la erosión, ***Journal of Soil and Water Conservation,*** Vol. 28, No. 2, March-April, 1973). Habla sobre el grave problema de la erosión de los canales revestidos. Hace referencia a tres tipos de canal revestido. El control de la erosión de canales vegetativos se limita a aquellos canales con flujo de relativamente baja velocidad. Si la vegetación es sometida a un flujo contínuo, en casi todos los casos la humedad la destruirá. Revestimiento de

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tection des pentes de talus de forte déclivité contre l'érosion de l'eau dans les projets de construction, ***Highway Research Record 206,*** Highway Research Board, 1967), est un rapport detaillé sur l'utilisation du mulch. On décrit des études qui ont été faites sous conditions controlées, pour évaluer les qualités relatives de plusieurs sortes de mulch. Ce mulch sert non seulement à couvrir le sol et le protéger temporairement contre l'érosion, mais aussi à maintenir les conditions de chaleur et d'humidité propices à la germination des graines.

Treize sortes de mulch sont évaluées pour trois genres de déperdition: (a) l'érosion du sol mesurée par les sédiments perdus durant les essais; (b) la perte ou le mouvement des semences; et (c) les pertes d'engrais determinées par la teneur en phosphore du sol et de l'eau de chaque échantillon soumis à une chute de pluie simulée.

Le cinquième texte, ***The Use and Control of Vegetation on Roads and Airfields Overseas*** (Utilisation et contrôle de la végétation sur les routes et les terrains d'aviation d'outre-mer, Road Research Laboratory, 1961) est une compilation de documents publiés par les travaux publics et autres organismes gouvernementaux de 33 territoires anciennement britanniques, qui liste les sortes de végétation trouvées généralement le long des routes de ces territoires. Cette liste inclut tant les genres de végétation (plantes herbacées et espèces ligneuses), que les facteurs principaux qui semblent affectér la répartition de la végétation le long des routes, c'est à dire les précipitations et la situation géographique.

channels are discussed. Vegetative channel-erosion control is limited to channels with flows of relatively low velocity. Vegetation must not be subjected to constant flow or the moisture will kill the lining in most cases. Asphalt or concrete lining used for channel erosion control introduces high-velocity flow for relatively low quantities of water due to the smoothness of the lining material. High velocities may introduce scour at the downstream limit of the channel lining; this, in turn, may undermine the lining and may start progressive failure. If these linings are overtopped or undermined, they are apt to be completely destroyed. Rock lining used for channel erosion control reduces the velocity of the channel flow but is subject to two types of failure, i.e., the rocks may not remain in place and the finer material under the rocks may be gradually washed out.

The main subject of the text is the prevention of the failure of rock-lined channels. The obvious solution to rock movement is to use bigger rocks; however, large stones may not be available. Containers full of smaller rocks (i.e., rock sausages, gabions) are recommended in such a case or when the channel slope is over 10 percent. The leaching of the finer material from underneath the rocks can be prevented by use of a filter layer or layers between the rock and the parent soil. This reverse-flow filter was originally designed by Terzaghi to prevent soil movement from dams by seepage. The criteria for and use of this type of filter are described in the text.

The seventh text, ***Suggestions for Temporary Erosion and Siltation Control Measures*** (Federal Highway Administration, 1973), is a handbook of temporary erosion-control features that may be required during the construction of a road. (This

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asfalto u hormigón, para el control de la erosión, introduce un flujo de alta velocidad para cantidades relativamente bajas de agua, debido a la lisura del material de revestimiento. Las altas velocidades pueden introducir socavación en el límite aguas abajo del revestimiento del canal; esto, en su turno, puede causar el descalce del revestimiento y el comienzo del desmoronamiento. Si se derraman o se descalzan estos revestimientos es probable que se destruirán completamente. Si se utiliza revestimiento de roca, la velocidad del flujo se reduce pero hay dos posibilidades de fracaso — la roca puede no permanecer en su lugar y el material más fino debajo de las rocas puede ser gradualmente llevado por el agua.

El tema principal del texto es la prevención del fracaso en los canales revestidos con roca. Para evitar el movimiento de las rocas la solución obvia es la utilización de rocas más grandes; sin embargo, puede que no haya disponibles tales rocas. En tal caso, o donde la pendiente del canal excede 10 por ciento, se recomiendan recipientes llenados con rocas más pequeñas (es decir, cestones o salchichones de rocas). Para evitar el lavado del material fino debajo de las rocas se pueden colocar una capa o capas de material de filtro entre la roca y el suelo nativo. Originalmente Terzaghi diseñó este tipo de filtro de flujo inverso para evitar el movimiento de suelo debido a la filtración en las presas. Se describen en el texto los criterios

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Une évaluation des problèmes que la végétation présente dans les régions les plus humides des tropiques est présentée. Ces problèmes comprennent, entre autres, l'obstruction des canalisations de drainage, la rupture de la chaussée, la création d'entraves à la visibilité du conducteur. On considère aussi les avantages de cette végétation tels que le contrôle de l'érosion dûe à la pluie et au vent. Le but de ce texte est de découvrir les espèces biologiques qui sont utiles et celles qui offrent des difficultés.

Dans ce texte on discute aussi du contrôle de la végétation et du coût de ce contrôle: (a) méthodes mécaniques, comme le fauchage à la main, le sarclage, le fauchage mécanique, et l'incendie; (b) méthodes biologiques, telles que faire brouter l'herbe par les troupeaux, ou la détruire en introduisant des parasites (insectes, chenilles); et (c) méthodes mécaniques, comme l'emploi d'herbicides selectifs ou non-selectifs. L'annexe 2 de cet ouvrage donne les noms locaux (en anglais) des espèces de végétation dont on discute dans le texte.

Le texte no. 6 est un article intitulé ***Erosion Proofing Drainage Channels*** (La protection des canaux de drainage contre l'érosion, ***Journal of Soil and Water Conservation,*** Vol. 28, No. 2, March-April 1973). Le sérieux problème de l'érosion du revêtement des canaux de drainage est considéré. Trois sortes de canaux revêtus sont discutés. Le contrôle de l'érosion par une couverture végétale est limité aux canaux dont l'écoulement se fait à une vitesse relativement faible. La végétation ne doit pas avoir à subir un écoulement constant car l'humidité la tuera la plupart du temps. Les revêtement de bitume ou de béton utilisés pour la lutte contre l'érosion sont la cause d'écoulement rapide pour des quantimanual is also available in Spanish; see Ref. 20.) These controls are not intended to replace the permanent erosion-control features mentioned in the previous texts, such as vegetation on the slopes, construction of proper drainage channels at correct locations, and erosion prevention measures at culverts.

The text includes the following types of temporary erosion-control features: (a) sedimentation pools used to trap eroded material before it reaches a natural waterway, (b) berms and slope drains used during the construction of fill slopes, (c) toe-of-slope protection to intercept siltation before it enters the ditch or waterway, (d) check dams to protect new ditches from siltation, (e) check dams with spillways for streams where flow must be maintained, (f) run-off barriers to protect drainage inlets, (g) erosion protection for pipe outlets, and (h) linings for diversion channels.

The eighth text is a paper entitled *Impacts of High-Intensity Rainstorms on Low-Volume Roads and Adjacent Land (Low-Volume Roads;* Special Report 160, Transportation Research Board, 1975). It evaluates damage done to a network of low-volume logging roads in mountainous terrain by 2 days of intensive rain.

The text groups the failures into general classifications. It describes some common road construction techniques that could have been used to prevent or minimize those failures. The problems experienced included (a) the overtopping of roadways and subsequent washout due to debris-plugged culverts in drainageways, (b) the inability of debris-plugged ditch relief culverts to handle the ditch flow that caused ex-

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para este tipo de filtro y su uso.

El séptimo texto, ***Suggestions for Temporary Erosion and Siltation Control Measures*** (Sugerencias para medidas provisorias de control de la erosión y sedimentación, Federal Highway Administration, 1973), es un manual de medidas provisorias para el control de la erosión que podrían exigirse para la construcción de un camino. (Este manual también se encuentra disponible en español: ver Ref. 20.) Estos controles no reemplazan los controles permanentes mencionados en textos previos, tales como la vegetación en las pendientes, la construcción de canales adecuados de desagüe en las correctas ubicaciones, y medidas de prevención de la erosión en las alcantarillas.

El texto incluye los siguientes tipos de control provisorio de la erosión: (a) lagunas de sedimentación que se utilizan para recobrar el material desgastado antes de que llegue a una vía natural de agua, (b) las bermas y drenajes de pendiente que se utilizan durante la construcción de los pendientes de relleno, (c) protección del pie de talud para interceptar la sedimentación antes de que llegue a una zanja o vaguada, (d) diques de contención para proteger las nuevas zanjas contra la sedimentación, (e) diques de contención con aliviaderos para los arroyos donde se debe mantener el flujo, (f) barreras para proteger las entradas de drenaje contra el escurrimiento, (g) protección contra la erosión para las salidas de los tubos, y (h) revestimien-

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tés relativement petites d'eau, car leurs parois sont lisses. Une vitesse d'écoulement rapide peut causer un affouillement à l'extrémité aval du revêtement, ce qui ensuite peut saper ce revêtement et éventuellement en causer la rupture progressive. Si ces revêtements sont soumis à une action de sapement, ou si l'eau dèborde par dessus leurs parois, ils ont des chances d'être complètement détruits. Les revêtements de pierre utilisés pour la lutte contre l'èrosion réduisent la vitesse d'écoulement, mais peuvent être soumis à deux sortes de rupture — les pierres peuvent se deplacer — les particules fines qui sont sous les pierres risquent d'être entrainées graduellement par l'eau.

Le thème principal de ce texte est la prévention de la rupture des perrés. La solution manifeste du problème du déplacement des pierres, est de se servir de pierres plus grosses, mais quelquefois elles ne sont pas disponibles. Des cages en grillage remplies de moellons de dimensions inférieure (gabions) sont recommendées quand la pente du canal est de plus de 10%. Le lessivage des particules fines peut être prévenu par l'emploi d'une ou de plusieurs couches filtrantes entre les pierres et le sol d'origine. Ce filtre inversé a été inventé par Terzaghi pour empêcher le déplacement du sol par écoulement d'infiltration sous les barrages. Les critères pour l'emploi de ces filtres et leur utilisation sont inclus.

Le septième texte, *Suggestions for Temporary Erosion and Siltation Control* (Suggestions pour des mesures temporaires de contrôle de l'érosion et de l'envasement, Federal Highway Administration, 1973), est un manuel sur les mesures temporaires de lutte contre l'érosion qui peuvent être requises durant la construction d'une route. (Ce manuel est traduit en Espagnol, voir ref. 20.) Ces mesures ne sont pas destinées à remplacer treme ditch erosion leading to washouts, (c) the bank erosion and eventual washout of roads that closely paralleled the grade and alignment of streams (i.e., river grade roads), (d) the failure of some embankments due to saturation, and (e) the failure of cut slopes either from saturation of the soil, excessively steep cut banks, or undermining of the slope by ditch erosion. Still other failures were due to land-management practices in areas adjacent to the roads but beyond the control of the design engineer.

The types of erosion failures described in this text can happen to roads in any terrain. These failures are particularly common in mountainous terrain where the interrelationship between the road and the surrounding environment is extremely critical.

The ninth text is an article entitled *Road Geotechnics in Hot Deserts (The Journal of the Institution of Highway Engineers,* October 1976). Hot deserts provide a variety of design and construction problems for engineers that stem from the nature of the dry climatic regime and the desert landforms. These problems include erosion by water and wind. Engineering solutions to these problems, based on good practice in other regions, may not necessarily be successful. An engineer must have a working knowledge of desert geomorphological forms and processes in order to properly diagnose the design and construction problems particular to desert areas.

This text discusses desert highway engineering problems in the context of a simple model based on mountain and plain desert terrain and

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tos para los canales de desvío.

El octavo texto es un informe titulado *Impacts of High-Intensity Rainstorms on Low-Volume Roads and Adjacent Land* (El impacto de tormentas de alta intensidad sobre los caminos de bajo volúmen y los terrenos adyacentes, *Low-Volume Roads,* Special Report 160, Transportation Research Board, 1975). Evalúa el daño sufrido por una red de caminos de bajo volúmen utilizados para el transporte de troncos cortados en terreno montañoso durante una tormenta intensiva de lluvia de 2 días de duración.

El texto agrupa los fracasos en clasificaciones generales. Describe algunas técnicas comunes de construcción de caminos que podrían haber prevenido o aminorado aquellos fracasos. Algunos de los problemas fueron (a) la inundación de los caminos y subsecuentes hundimientos debido a alcantarillas obstruidas por desechos en las vías de desagüe, (b) alcantarillas de alivio para las zanjas tan rellenadas de desechos que no pudieron contener el flujo de las zanjas y que causaron excesiva erosión y consecuente hundimiento, (c) la erosión de los terraplenes y el eventual hundimiento de caminos que igualaban la pendiente y alineamiento de arroyos (es decir, caminos con pendiente de río), (d) terraplenes que fracasaron debido a su saturación, y (e) el fracaso de taludes cortados debido a la saturación del suelo, terraplenes con pendientes excesivamente fuertes, o socavamiento de la talud por erosión de la zanja. Otros fracasos ocurrieron debido a las prácticas de empleo del terreno adyacente a los caminos y fuera del control del ingeniero de diseño.

Los tipos de fracasos debido a la erosión descritos en este texto pueden suceder en caminos en cualquier tipo de terreno. Son particularmente comunes en el terreno montañoso donde es extremadamente crítica la relación recíproca entre el camino y el medio ambiente circundante.

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les mesures de contrôle permanent de l'érosion, dont nous avons parlé dans les textes précédents, telles que l'enherbement des pentes de talus, la construction de canaux de drainage adéquats à des emplacements corrects, et les mesures de prévention contre l'érosion aux extrémités des ponceaux.

Dans ce texte, on décrit les éléments temporaires de lutte contre l'érosion suivants:
(a) les bassins de sedimentation utilisés pour retenir les matériaux érodés avant qu'ils ne soient emportés dans un cours d'eau ; (b) les bermes et les canalisations de drainage pour les pentes des remblais et des deblais lors des terrassements; (c) les mesures de protection des pieds des talus pour intercepter la vase avant qu'elle atteigne les fossés ou les cours d'eau (d) les petits barrages pour protéger les fossés neufs de l'envasement; (c) les barrages avec déversoirs pour les cours d'eau dont on doit assurer l'écoulement; (f) les barrages pour protéger les avaloirs; (g) la protection des exutoires, et (h) les revêtements des saignées latérales ou canaux divergents.

Le huitième texte est une communication intitulée *Impact of High Density Rainstorms on Low-Volume Roads and Adjacent Land* (Impacts d'averses de forte intensité sur les routes économiques et les terrains adjacents, *Low-Volume Roads,* Special Report 160, Transportation Research Board, 1975). On y évalue les dégats causés par deux jours de pluie intensive sur un natural desert processes. The model consists of four zones, each with different desert characteristics and different engineering behavior. Because deserts are formed by erosion, every facet of desert highway engineering has its foundation in the understanding of the continuing erosion process.

The water erosion characteristics for each zone are tabulated in Table 2 — Outline Summary of Runoff and Soil Characteristics of Desert Zones — and wind-erosion problems are tabulated in Table 5 — Objectives and Methods of Dune and Drift Sand Control.

This text refers to the "Casagrande symbol" in the identification of soils. These symbols, which are now a part of the Unified Soil Classification System are explained in ***A Review of Engineering Soil Classification Systems*** (see Compendium 6).

The tenth text is a report entitled ***Observations on the Causes of Bridge Damage in Pennsylvania and New York Due to Hurricane Agnes (Highway Research Record 479,*** Highway Research Board, 1973). In 1972 Hurricane Agnes caused floods that have been called the greatest natural disaster in the history of the

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El noveno texto es un artículo titulado ***Road Geotechnics in Hot Deserts*** (La geotecnia de caminos en desiertos cálidos, ***Journal of the Institution of Highway Engineers***, October 1976). Los desiertos cálidos presentan a los ingenieros una variedad de problemas de diseño y construcción debido al régimen climático seco y formas de terreno desérticas. Tales problemas incluyen la erosión por agua y viento. No serán necesariamente satisfactorias las soluciones ingenieriles basadas en las buenas prácticas de otras regiones. El ingeniero deberá poseer un conocimiento práctico de las formas y procesos geomorfológicos desérticos antes de poder diagnosticar los problemas de diseño y construcción particulares a las áreas de desierto.

Este texto habla sobre los problemas ingenieriles de caminos de desierto en el contexto de un simple modelo basado en terrenos desérticos llanos y montañosos y procesos naturales de desiertos. El modelo consiste en cuatro zonas, cada una con distintas características desérticas y distinto proceder en lo que respecta a lo ingenieril. Ya que los desiertos son formados por la erosión, cada aspecto de la ingeniería de desierto tiene su origen en la comprensión del proceso contínuo de la erosión.

Las características de la erosión por acción del agua de cada zona se tabulan en la Tabla 2 — Resumen Esquemático de las Características del Suelo y del Escurrimiento en Zonas Desérticas, y los problemas de la erosión eólica se tabulan en la Tabla 5 — Objetivos y Métodos de Control de las Arenas Movedizas y de Dunas.

Este texto se refiere al "símbolo Casagrande" en la identificación de suelos. Estos símbolos,

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réseau de routes forestière en terrain montagneux. Les types de dégats sont classés d'une façon générale. Des techniques de construction routière, que l'on aurait pû employer pour prévenir ou minimiser les dégats, sont décrites. Les problèmes qui on dû être affrontés sont les suivants: la chaussée submergée et effondrée à cause de l'obstruction des ponceaux par des débris; (b) l'incapacité des divergents, obstrués par les débris, de décongestionner les fossés, causant ainsi un affouillement massif menant jusqu'à l'effondrement du fossé; (c) l'érosion des rives et, éventuellement, l'éffondrement de la chaussée des routes construites parallèlement (alignement et pente) au lit d'un cours d'eau; (d) l'éboulement de certains remblais dû à une saturation excessive; et (e) l'éboulement de déblais causé soit par la saturation du sol, soit par une pente trop forte, soit par l'affouillement de la pente à cause de l'érosion du fossé. D'autres sortes de dégats sont cités, ceux-ci causés par l'aménagement des terrains adjacents, mais cela n'est pas du ressort de l'ingénieur routier.

Ces sorte de dégats dûs à l'érosion, peuvent se produire dans tous les types de terrain, mais ils sont beaucoup plus fréquents dans les terrains montagneux, où le rapport entre la route et les alentours est particulièrement crucial.

Le neuvième texte est un aritcle intitulé ***Road Geotechnics in Hot Deserts*** (Géotechnique routière des déserts chauds, ***The Journal of the Institution of Highway Engineers,*** October 1976). Les déserts chauds sont pour l'ingénieur la source d'une variété de problèmes, tant pour le calcul que pour la construction. Ces problèmes proviènnent du régime climatique sec, et de la forme du terrain désertique. Parmi ces problèmes, on trouve l'érosion éolienne et l'érosion de l'eau. Des solutions qui seraient basées sur des méthodes prouvées dans d'autres régions, peuvent ne pas être couronnées de succès dans ce cas. L'ingénieur routier doit avoir une connaissance pratique de la géomorphologie climatique et structurale du désert, pour pouvoir diagnosti-

United States. This paper evaluates the performance of bridges subjected to that flooding. The two major causes of bridge damage were scour at abutments and piers and impacting debris. The U.S. Army Corp of Engineers has labeled Hurricane Agnes a 500-year storm.

Bridge design is based on the occurrence of an event that has small chance of happening in any given year. In developed countries the standard criteria vary from a 1 to 2 percent chance per year that the design flow will be exceeded (i.e., a 100-year or a 50-year storm). Bridges for low-volume roads do not need to be so conservatively designed but the basic calculations are the same. Because bridges designed to pass a 50-year storm are so costly and the chance of finding or recognizing a 50-year storm is so remote, most hydraulic bridge design is based on flume tests of models. This approach introduces the possibility that the model test results are not directly transferable to actual on-site conditions. Experience has quickly exposed that part of the technology which is too speculative because the bridge fails. However, too conservative a technology may continue in use for years.

This text is included because it can be evaluated as a full-scale laboratory experiment in which bridges, embankments, and training works were tested to failure. It describes one of the few opportunities engineers have had to evaluate those design procedures on a large scale. The text that follows discusses design procedures developed to prevent scour and bank erosion.

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que ahora forman parte del Sistema de Clasificación de Suelos "Unified", se explican en *A Review of Engineering Soil Classification Systems* (Repaso de los sistemas ingenieriles de clasificación de suelos; ver el Compendio 6).

El décimo texto es un informe titulado *Observations on the Causes of Bridge Damage in Pennsylvania and New York Due to Hurricane Agnes* (Comentarios sobre las causas de daño sufrido por puentes debido al huracán Agnes en Pennsylvania y Nueva York, *Highway Research Record 479,* Highway Research Board, 1973). En 1972 el huracán Agnes causó inundaciones que se consideran el desastre natural más grande en la historia de los Estados Unidos. Este estudio evalúa el rendimiento de los puentes afectados por aquella inundación. Las dos razones más grandes de daño de puente fueron el desgaste por acción del agua en los estribos y pilares y el impacto de desechos. El U.S. Army Corps of Engineers considera el huracán Agnes como una tormenta que ocurre cada 500 años.

El diseño de puentes se basa en el acontecimiento de un evento que tiene poca posibilidad de ocurrir en cualquier año dado. En los países desarrollados el criterio normal es que hay una posibilidad de 1 a 2 en cien por año de que el flujo previsto será excedido (es decir, una tormenta que ocurre cada 100 o 50 años). No es necesario que los puentes para caminos de bajo volúmen sean diseñados en forma tan cauta, pero los cálculos básicos son los mismos. Por razón de que los puentes diseñados para resistir una tormenta de cada 50 años son muy costosos, y es remota la posibilidad de encontrar y reconocer tal tormenta, casi todo diseño hidráulico de puente se basa en ensayos de canal con modelos. Se introduce la posibilidad de que los resultados de los ensayos con modelos no sean directamente transferibles a

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quer correctement les problèmes de dimensionnement et de construction propres à ces régions.

Dans ce texte on discute des problèmes de construction routière en prenant un modèle simple, basé sur des terrains désertiques de montagne et de plaine et sur la géomorphologie du désert. Le modèle se compose de quatre zones, qui ont des caractéristiques désertiques différentes et un comportement routier différent. Comme les déserts sont formés par le processus érosif, toutes les phases de la construction routière en régions désertiques sont fondées sur une connaissance solide de ce processus.

Les caractéristiques de l'érosion de l'eau dans chaque zone sont classées dans le tableau no. 2: Schéma sommaire du débit et des caractéristiques des sols désertiques; les problèmes de l'érosion éoliènne sont présentés dans le tableau no. 5: Objectifs et méthodes de contrôle des dunes et des amoncellements de sable.

Dans ce texte, on mentionne les "symboles de Casagrande" en rapport avec l'identification des sols. Ces symboles, qui maintenant font partie de la Classification Unifiée des Sols, sont expliqués dans notre recueil no. 6, texte no. 1, A Review of Engineering Soil Classification Systems.

Le dixième texte est un rapport intitulé *Observations on the Causes of Bridge Damage in Pennsylvania and New York Due to Hurricane Agnes* (Observations sur les origines des dommages causés aux ponts des états de Pennsylvania et de New York par l'ouragan Agnès, *Highway Research Record 479,* Highway Research Board, 1973). En 1972, un ouragan, nommé Agnès par les services météorolo-

The eleventh text is excerpted from *Guide to Bridge Hydraulics* (Roads and Transportation Association of Canada, 1973). It presents procedures used to design waterway openings and channel training works to prevent the types of failures described in the previous text.

The first excerpt, *Chapter 4: Design of waterway opening for scour and backwater,* defines the principal categories of bridge scour (the lowering of the channel bed by erosion) and presents methods of estimating (a) general scour in controlled waterway openings due to constriction of flood flows through the opening, (b) local scour around piers and abutments due to vortex systems caused by obstructions to the flow, and (c) natural scour in alluvial and tidal channels due to variations in flow conditions and related channel processes. Four methods are presented for estimating general scour in controlled waterways. At least two of them should be tried and the results compared. Because no method has yet been devised that is completely reliable, discrepancy between methods can be expected. However, great caution should be exercised if large differences occur that cannot be justified using the various criteria given in the text.

Local scour around piers and abutments occurs in addition to general scour. Therefore, calculated local-scour depths should be added to the general-scour depths. Local-scour calculations use simplified relationships derived from model tests that give an indication of the worst scour that might occur. Debris accumulations around piers may substantially increase the actual local scour so that refined estimates of local

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las condiciones de la verdadera ubicación. La experiencia y los fallos en los puentes han descubierto aquella parte de la tecnología que es demasiada teórica. Sin embargo, una tecnología demasiado cauta puede seguir utilizándose durante años.

Se incluye este texto porque puede evaluarse como un experimento de laboratorio en escala natural en donde los puentes, terraplenes y obras de canalización se ensayaron hasta el punto de fracaso. Describe una de las pocas oportunidades en que los ingenieros han podido evaluar aquellos procedimientos de diseño en escala grande. El texto que sigue habla sobre los procedimientos de diseño desarrollados para evitar la socavación y la erosión de las orillas.

El onzavo texto fué extraído de *Guide to Bridge Hydraulics* (Guía para la hidráulica de puentes, Roads and Transportation Association of Canada, 1973). Presenta los procedimientos que se deben utilizar en el diseño de entradas de vías de agua y obras de canalización para evitar los tipos de fracaso que se describen en el texto previo.

El primer extracto, *Chapter 4: Design of waterway opening for scour and backwater* (Capítulo 4: El diseño de entradas de vías de agua

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giques, causa des inondations qui furent jugées le plus grand cataclysme naturel de l'histoire des Etats Unis. Dans ce rapport, on évalue le comportement des ponts qui ont été soumis à ces inondations. Les plus grands dégats furent causés par l'affouillement des culées et des piles et l'impact des débris flottants. Le U.S. Army Corps of Engineers (Génie militaire des Etats Unis) a estimé cet ouragan comme ayant une probabilité de survenance d'une fois tous les 500 ans.

Le calcul des ponts est basé sur un événement qui a une probabilité de survenance annuelle très réduite. Dans les pays développés, les critères de dimensionnement d'un pont varient d'une à deux chances sur cent que le débit pour lequel il a été conçu soit surpassé (c'est à dire une probabilité de survenance d'une fois tous les 100 ans ou une fois tous les 50 ans). Les ponts des routes économiques n'ont pas besoin d'être calculés de façon aussi modérée, mais le calcul de base reste le même. Puisque les ponts dimensionnés pour pouvoir écouler le débit d'une crûe ayant une probabilité de survenance d'une fois tous les 50 ans sont si coûteux, et que d'autre part, la probabilité de trouver, ou de reconnaitre, une telle crûe est si distante, le dimensionnement hydraulique des ponts est en fait calculé, la plupart du temps sur des modèles d'essais sur canal. Seulement ce genre d'approche introduit la possibilité qu'on ne puisse transférer directement les résultats des essais en laboratoire aux conditions telles qu'elles sont sur le chantier. L'expérience à démontré rapidement cette partie de la technologie qui était trop spéculative, en causant l'éffondrement des pont. Cependant une technologie trop conservatrice peut continuer à être utilisée pendant des années.

Ce texte est inclus car il peut être considéré comme un essai de laboratoire en vraie grandeur dans lequel, les ponts, les digues, et les ouvrages de guidage, ont été testés jusqu'á la rupture. Ce texte décrit un des rares moments scour are often not warranted in debris-laden waterways.

Natural scour at uncontrolled bridge crossings is estimated where the proposed waterway is so wide that it does not constrict the flood flow. In such cases, it is still necessary to allow for natural scour of the channel and for local scour caused by the piers. This is especially important where an uncontrolled crossing is located on a channel bend because bends on alluvial streams are usually subject to significant scour during flood periods.

The second excerpt, ***Chapter 5: Scour protection and channel training works,*** presents the general principles of design that will ensure a structure's withstanding scouring at the depths determined by using the methods presented in Chapter 4. Several solutions are offered. The

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para evitar el desgaste por acción del agua y contracorrientes), define las principales categorías de socavación en los puentes (el desgaste del lecho del canal por erosión) y presenta métodos para calcular (a) la socavación general en las entradas controladas de vías de agua debido a la constricción del caudal de avenidas por la abertura, (b) la socavación local alrededor de los pilares y estribos debido a sistemas de remolinos causados por obstrucciones en el flujo, y (c) la socavación natural en los canales aluviales y los de mareas debido a variaciones en las condiciones de flujo y otros procesos de canal conexos. Se presentan cuatro métodos para estimar la socavación general en las vías de agua controladas. Se deberán probar por lo menos dos y comparar los resultados. Se puede esperar diferencias ya que aún no se ha ideado un método completamente infalible. Sin embargo, si ocurren grandes diferencias que no se justifican utilizando los criterios dados en el texto, se deberá emplear cuidado.

Además de la socavación general, ocurre la socavación local alrededor de los pilares y estribos. Por eso, profundidades calculadas de la socavación local deberán agregarse a las profundidades de la socavación general. Los cálculos para la socavación local utilizan relaciones simplificadas derivadas de ensayos de modelos que dan una indicación de la socavación peor posible que pueda ocurrir. La socavación local verdadera puede ser considerablemente aumentada por acumulaciones de desechos y de esta forma no se justifican los cálculos detallados de socavación local en las vías de agua repletas de desechos.

La socavación natural en cruces de puente no controlados se calcula donde la vía de agua es tan ancha que no obstruye el caudal de avenidas. En tal caso es aún necesario tener pre-

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où les ingénieurs ont eu la possibilité d'évaluer en grandeur naturelle leurs méthodes de calcul. Le texte qui suit discute des méthodes de calcul amenées à prévenir l'affouillement et l'érosion des berges.

Le onzième texte est extrait du livre ***Guide to Bridge Hydraulics*** (Guide de l'hydraulique des ponts, Roads and Transportation Association of Canada, 1973). Des méthodes, utilisées pour calculer les passages d'eau et les ouvrages de protection et de contrôle pour prévenir les genres de fiascos cités dans le texte précédent, sont présentées.

Le premier extrait est le chapitre 4: ***Design of waterway opening for scour and backwater*** (Le calcul des passages d'eau en évitant l'affouillement et les remous). Ce chapitre donne une définition des catégories principales d'affouillement des ponts (rabaissement du lit par érosion) et présente des méthodes pour estimer (a) l'affouillement géneralisé des passages d'eau contrôlés, causé par la réduction de largeur du lit au droit de l'ouvrage, (b) l'affouillement local des piles et des culées dû aux remous causés par des obstructions, (c) l'affouillement naturel des cours d'eau alluvionnaires et à marées, dû aux variations du débit et autres processus naturels. Quatre méthodes pour estimer l'affouillement généralisé des passages d'eau controlés, sont présentées. On devrait au moins essayer deux de ces méthodes et comparer les résultats. On peut s'attendre à trouver une différence entre les résultats car il n'existe pas encore une méthode absolument sûre pour faire le calcul. Cependant, on devrait faire extrêmement attention si on se trouve en face de grosses différences qu'on ne peut expliquer en utilisant les differents critères utilisés dans le texte.

En plus de l'affouillement généralisé, il se produit un affouillement local autour des piles et des culées. Donc, à la profondeur d'affouillement généralisé, on doit ajouter la profondeur d'affouillement local. Le calcul de l'affouillement local se fait en utilisant des rapports simplifiés dérivés de modèles d'essais qui indiquent l'affouillement maximum possible. L'accumulation choice among various alternatives depends on a great many factors, including load-bearing requirements, subsoil conditions actually encountered, economics, feasible construction methods and schedules, and inspection procedures.

It also discusses bank protection and training works used to protect a bridge and its approaches from flood-water damage. These erosion prevention measures should be considered when the location of the bridge is being decided. Often their use will make naturally unfavorable sites usable. However, their costs should not exceed the benefits to be derived (i.e., their use should cost less than the cost of routing the road to a more favorable bridge site). The types of bank protection discussed include (a) bank and slope revetments, (b) guide banks or spur dikes, (c) spurs or groins, (d) dikes, and (e) channel diversions.

The third excerpt includes ***Appendix III: Example of partial design of waterway opening.*** It illustrates some of the procedures for selecting the width of waterway openings and estimating general scour as discussed in Chapter 4 (calculations included do not cover a complete hydraulic design); ***Appendix IV: Sampling and***

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sente la socavación natural del canal y la socavación local causada por los pilares. Esto es especialmente importante donde los cruces no controlados se ubican en una curva en el canal, porque las curvas en los arroyos aluviales normalmente sufren mucha socavación durante los períodos de inundación.

El segundo extracto, ***Chapter 5: Scour protection and channel training works*** (Capítulo 5: Protección contra la socavación y obras de canalización), presenta los principios generales de diseño que asegurarán que una estructura resistirá la socavación a las profundidades determinadas utilizando los métodos presentados en el Capítulo 4. Se ofrecen varias soluciones. La que se elige entre las varias alternativas depende de muchos factores, tales como los requisitos de capacidad de carga, las condiciones del subsuelo que realmente se encuentran, la economía política, métodos y programas de construcción factibles, y procedimientos de inspección.

También habla sobre la protección de las orillas y las obras de canalización que se utilizan para proteger el puente y los accesos contra el daño causado por inundaciones. Se deberán considerar estas medidas de prevención al escoger la ubicación del puente. Es común que su uso haga posible la utilización de una ubicación poco favorable. Sin embargo, el costo no deberá exceder los beneficios acumulados (es decir, su uso deberá costar menos que dirigir el camino hacia un cruce más favorable). Los tipos de protección de orilla mencionados en el texto incluyen (a) muros de contención de orilla y terraplén, (b) muelles de guía o contradiques, (c) puntales o espigones, (d) diques, y (e) desvíos de canal.

El tercer extracto incluye ***Appendix III: Example of partial design of waterway opening*** (Apéndice III: Un ejemplo del diseño parcial de una entrada de vía de agua). Ilustra algunos de los procedimientos utilizados para seleccionar el

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de débris autour des piles peut accroître de façon substantielle l'affouillement local. Pour cette raison on n'a pas besoin de calculer de très près l'affouillement local des passages d'eau qui sont souvent encombrés de débris.

L'affouillement généralisé des passages d'eau non-contrôlés, c'est à dire où il n'y a pas de constriction du débit, ou de déplacement du lit car le cours d'eau est très large, est estimé. Dans ces cas on doit quand même calculer l'affouillement généralisé et l'affouillement local causé par les piles. Ceci est très important, spécialement dans le cas où le passage d'eau non-contrôlé est placé dans un coude de la rivière, car dans les rivères alluvionnaires, ces coudes sont l'objet d'un affouillement assez considérable durant les périodes de crues.

Le second extrait, le chapitre 5: ***Scour protection and channel training works*** (Protection contre l'affouillement et ouvrages de contrôle), offre les principes géneraux de calcul qui assurerons la résistance d'un ouvrage à l'affouillement, aux profondeurs déterminées en utilisant les méthodes présentées au chapitre 4. Plusieurs choix sont offerts. Le sélection de la méthode dépend d'un éventail de facteurs, entre autres, les critères de capacité portante, les conditions du sous-sol, les facteurs économiques, les méthodes et les délais de construction possibles, et enfin les procédés d'inspection.

On discute aussi la protection des berges, et les ouvrages de protection et de contrôle utilisés pour préserver les ponts et leurs accès des dégats dûs aux inondations. Ces méthodes préventives contre l'érosion devraient être prises en considération au moment où on fait le choix de l'emplacement du pont. Souvent, leur utilisation permettra de se servir d'un site qui, à l'état natu-

analysis of channel bed materials; and *Appendix V: Theoretical basis for competent velocity data, Figure 4.12 and Table 4.1,* which are also referred to in Chapter 4.

Bibliography

The selected texts are followed by a brief bibliography containing reference data and abstracts for 24 publications. The first 11 describe the selected texts. The other 13 describe publications related to the selected texts. Although there are many articles, reports, and books that could be listed, it is not the purpose of this bibliography to contain all possible references related to the subject of this compendium. The bibliography contains only those publications from which a text has been selected or basic publications that would have been selected had there been no page limit for this compendium.

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ancho de entradas de vías de agua y para calcular la socavación general según explicado en el Capítulo 4 (los cálculos que se incluyen no componen un diseño hidráulico completo); *Appendix IV: Sampling and analysis of channel bed materials* (Apéndice IV: Muestreo y análisis de materiales del lecho del canal); y *Appendix V: Theoretical basis for competent velocity data, Figure 4.12 and Table 4.1* (Apéndice V: Base teórica para datos adecuados de velocidad, Figura 4.12 y Tabla 4.1), a los cuales también se refiere en el Capítulo 4.

Bibliografía

Se sigue a los textos seleccionados con una breve bibliografía que contiene los datos y abstractos de referencia para 24 publicaciones. Los primeros 11 describen los textos seleccionados. Los otros 13 describen las publicaciones que se relacionan con los textos seleccionados. Aunque hay muchos artículos, informes, y libros que podrían ser nombrados, no es el propósito de esta bibliografía contener todas las posibles referencies que se relacionen con el tema de este compendio. La bibliografía contiene únicamente aquellas publicaciones de las cuales se ha seleccionado texto y las publicaciones básicas que hubieran sido seleccionadas si no hubiera un límite al número de páginas en este compendio.

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rel, n'est pas très favorable. Cependant, le prix de revient de ces ouvrages ne doit pas excéder les bénefices dérivés de leur construction (c'est à dire, il devrait être moindre que le coût de changer le tracé de la route pour arriver à un site favorable). Les genres de protection des berges qui sont discutés sont (a) le revêtement des berges et des pentes; (b) les ouvrages de déflection, ou digues en épis; (c) les épis; (d) les digues et (e) le détournement du lit du cours d'eau.

Le troisième extrait inclut *Appendix III: Example of partial design of waterway opening* (Annexe III: Exemple de calcul partiel des passages d'eau). Il illustre certains des procédés utilisés pour choisir la largeur du passage et estimer l'affouillement généralisé, qui ont été discutés ou chapitre 4 (les calculs ne comprennent pas celui du dimensionnement hydraulique complet); *Appendix IV: Sampling and analysis of channel bed materials* (Annexe IV: Echantillonnage et analyses des matériaux du lit du cours d'eau); et *Appendix V: Theoretical basis for competent velocity data, Figure 4.12 and Table 4.1* (Annexe V: Base théorique pour données de vitesse acceptables).

Bibliographie

Les textes choisis sont suivis d'une brève bibliographie contenant des données de références et des analyses de 24 publications. Les premiers onze décrivent les textes choisis. Les autres treize décrivent des publications apparentées au thème des textes choisis. Bien qu'il y ait beaucoup d'autres articles, rapports et livres qui pourraient être inclus, l'objectif de cette bibliographie n'est pas d'énumérer toutes les références possibles ayant rapport au sujet de ce recueil. Donc, cette bibliographie, telle qu'elle, se rapporte seulement aux publications dont nous avons choisi des extraits, ou aux textes de base que nous aurions choisis aussi, s'il n'y avait pas de limites quant au nombre de pages de ce recueil.

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This section of the compendium contains selected pages from each text that is listed in the table of contents. Rectangular frames are used to enclose pages that have been reproduced from the original publication. Some of the original pages have been reduced in size to fit inside the frames. No other changes have been made in the original material except for the insertion of occasional explanatory notes. Thus, any errors that existed in the selected text have been reproduced in the compendium itself.

Page numbers of the original text appear inside the frames. Page numbers for the compendium are outside the frames and appear in the middle left or middle right outside margins of the pages. Page numbers that are given in the table of contents and in the index refer to the compendium page numbers.

Each text begins with one or more pages of introductory material that was contained in the original publication. This material generally includes a title page, or a table of contents, or both. Asterisks that have been added to original tables of contents have the following meanings:

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VOLUME III-HIGHWAY DRAINAGE GUIDELINES

Guidelines for Erosion and Sediment Control In Highway Construction

Prepared by

Task Force on Hydrology and Hydraulics
AASHO Operating Subcommittee on Roadway Design

341 National Press Building
Washington, D.C. 20004

EROSION AND SEDIMENT CONTROL IN HIGHWAY CONSTRUCTION

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EROSION AND SEDIMENT CONTROL IN HIGHWAY CONTRUCTION

1.0 Introduction

The impact of highway location on the environment is a major concern of the highway engineer and the public. Highways not properly located, designed, constructed, or maintained are at times subject to erosion and may contribute sediment to streams. Serious erosion not only results in unsightly conditions and increased maintenance costs, but can be a safety hazard.

The control of soil and water is basic to the protection of the road structure and the conservation and environmental effort; therefore, highway design, construction and maintenance procedures must be continually evaluated to minimize erosion and sedimentation problems. The success of erosion control measures is evidenced by the many miles of highways now serving the traveling public without serious erosion.

The policy for erosion prevention is well stated in the American Association of State Highway Officials publication, "A Policy on Geometric Design of Rural Highways," (1)[1] as follows:

> "Erosion prevention is one of the major factors in the design, construction and maintenance of highways. Erosion can be controlled to a considerable degree by geometric design, particularly that relating to the cross section. In some respects the control is directly associated with proper provision for drainage and fitting landscape development. Effect on erosion should be considered in the location and design stages."

> "Erosion and maintenance are minimized largely by the use of: flat side slopes, rounded and blended with natural terrain; drainage channels designed with due regard to width, depth, slopes, alignment, and protective treatment; located and spaced with erosion control in mind; prevention of erosion at culvert outlets; proper facilities for ground water interception; dikes, berms, and other protective devices; and protective ground covers and planting."

Although some standardization of methods for minimizing soil erosion in highway construction is possible, national guidelines for the control of erosion are of a general nature because of the wide variation in climate, topography, geology, soils, vegetation, water resources, and land use encountered in different parts of the country. Also, since the erosion process is a natural phenomenon accelerated by man's activities, technical competency in evaluating the severity of erosion problems and in planning and designing preventive and corrective measures is essential in obtaining economical and environmentally satisfactory methods for erosion control.

Erosion control guidelines should encompass all phases of highway engineering. To realize economical and effective control of erosion, therefore, the major headings used here are: Planning and Location, Design, Construction, Maintenance, Research and Development, and Legal Requirements and Responsibilities.

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[1]Underlined numbers in parenthesis refer to publications listed in references.

2.0 Sources of Information

Publications containing information on erosion and sediment control are listed in Section 11, References.

Most state highway organizations have specifications for establishing ground cover and planting trees, shrubs, vines and various erosion control measures. Qualified personnel within the highway organization should be consulted in the preparation of plans and in supervising erosion control construction.

Local Soil Conservation Service field offices of the U.S. Department of Agriculture and various state agencies can provide valuable assistance to the highway agency in solving local erosion problems by suggesting vegetation suitable for the locality. Aerial photographs can be used to identify soil types (2) and study land forms and erosion potential.

3.0 The Erosion Process

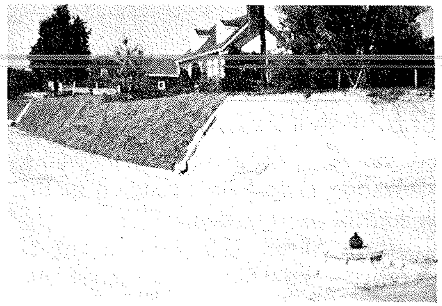
An understanding of the process of erosion is necessary as a basis for adequate control measures.

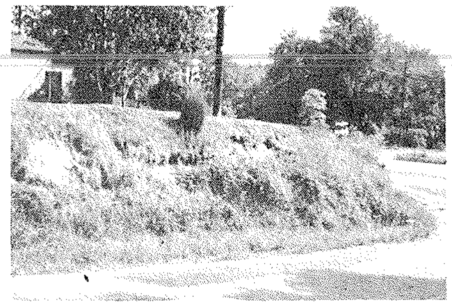
Soil erosion is caused by rainfall which displaces soil particles on inadequately protected areas and by water running over soil which carries some soil particles away. The rate of removal of the soil particles is proportional to the intensity and duration of the rainfall and to the volume and characteristics of the water flow and soil properties. In some areas, erosion is caused by wind or runoff from snow melt. Deposition of water-borne sediment occurs when the velocity is reduced and the transport capacity of the flowing water becomes insufficient to carry all of its sediment load.

Soil erosion can be classified as either natural or accelerated. Natural erosion is a geological process over which man has little or no control and may be very slow or rapid depending upon various factors. Where man has disturbed land by construction, there may be a sudden large increase in erosion, producing accelerated erosion. Accelerated erosion is the type of erosion that should be controlled during highway construction and after the highway is completed. In areas of considerable natural erosion, the quantity of sediment that reaches a stream before highway construction begins should be documented, at least in a qualitative way. Seldom can control measures taken by highway agencies reduce the natural base sediment production of the area. Locations with a high erosion potential should be avoided, if possible.

The causes of erosion suggest some basic principles for erosion and sediment control. Some of these principles are:

a. Select a route where soil erosion will not be a serious problem.
b. Design slopes consistent with soil limitations.
c. Reduce the area of unprotected soil exposure.
d. Reduce the duration of unprotected soil exposure.
e. Protect soil with vegetative cover, mulch, or erosion resistant material.
f. Control concentration of runoff.
g. Retard runoff with planned engineering works.
h. Trap sediment by temporary or permanent barriers, basins or other measures.





Steep banks save right-of-way costs, but are difficult to maintain. Steep bank in photo at left eroded and sluffed to that shown at right. Such slopes are difficult to maintain and can be a safety hazard.

i. Maintain erosion control work.
j. Obtain easements for legal control, where necessary.

4.0 Planning and Location

Effective erosion control begins in the planning and location of a highway route. All possible highway routes have a base erosion potential and this potential varies from route to route. Unless damage to the environment is considered in selecting the route, the cost of solving problems that might have been avoided sometimes becomes great. The initial cost of the erosion control measures and the maintenance costs of such control over the anticipated life on each of the routes under study should be considered as a part of the economic analysis in route selection.

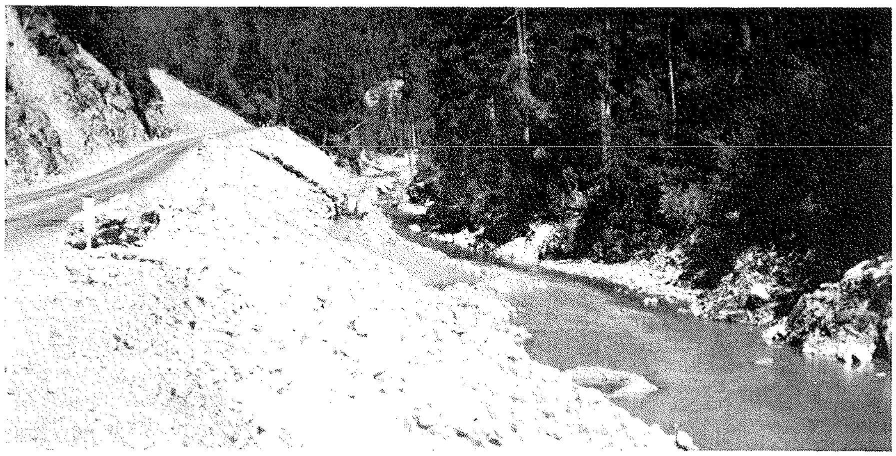
4.1 Natural Drainage Patterns

The natural drainage pattern, including subsurface flow, should be examined for the alternate routes considered. The drainage pattern beyond the vicinity of the proposed highway location must also be studied to minimize and avoid damage to adjacent property or streams or to anticipate expensive preventive or corrective measures.

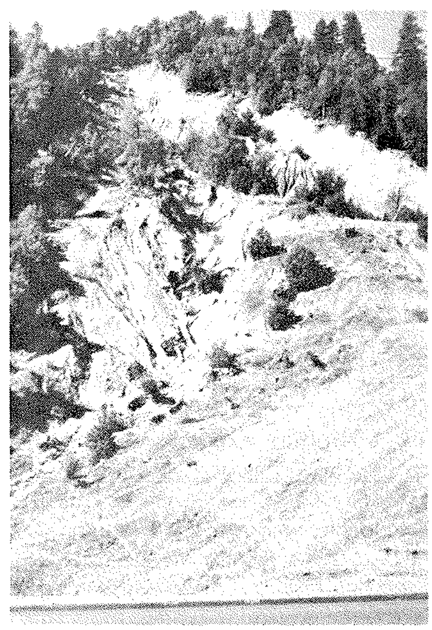
4.1.1 Stream Crossings

Whenever practical, stream crossings should be made at stable reaches of a stream, avoiding meanders that are subject to shifting. A highway constructed on the neck of a horseshoe bend that is subject to overflow is a poor location because the correct location of relief bridges sometimes varies with the flood stage. The direction and amount of flood flow at various stages must always be considered in the location of bridge openings to avoid undue scour and erosion which might result in a complete change in the river channel.

Crossings should be made as nearly as practical at a right angle to the direction of flow with consideration for the direction of the floodflow where it is different from that of the low water. Every effort should be made to minimize the number of stream crossings and the disturbance of stream beds.



Problems involved with stream encroachment must be recognized in the planning phase or costs of construction and maintenance become excessive and the stream environment could be jeopardized.



Slides in natural landslide areas are often triggered by highway construction. Such features should be recognized in the planning phase.

4.1.2 Encroachments

If a highway alignment is being studied that will encroach upon a stream, every consideration should be given to moving the highway away from the stream to avoid erosion and sedimentation problems. Channel changes to avoid encroachments, or for other reasons, should be made with caution.

4.2 Public and Industrial Water Supplies and Catchment Areas

The crossing of a catchment area of a water supply should be avoided, if possible. Such crossings could entail building costly temporary facilities for the water supply. Problems with industrial water supplies may be as great as those with a public water supply. Some industries require a higher quality process water than is required for drinking water.

When the crossing of a water supply catchment area cannot be avoided, any corrective measures and their cost should be determined before the choice of the route is made.

4.3 Geology and Soils

The ground conditions encountered in the field are the direct result of geologic processes operating on and within the earth. A knowledge of the geology of the area allows the highway engineer to detect potential problem areas and anticipate subsidence, landslides, and erosion problems. Such areas and problems can sometimes be avoided in route selection.

Terrain features are the result of past geologic and climatic processes. Erosion and deposition by running water are major geologic processes in shaping the terrain. A study of the terrain and the nature of natural erosion can aid in judging the complexity of the erosion and what erosion control measures are required.

4.3.1 Soil Classification

The classification of soils for engineering purposes is described in the American Association of State Highway Officials publication, "Manual on Foundation Investigations" (3). The state highway planning agencies' maps, "Engineering Classification of Geologic Material," are valuable aids in soil classification.

For erosion control, the U.S. Department of Agriculture's classification of soils is helpful. The Soil Conservation Service's soil survey maps, prepared by the state agriculture experiment station in cooperation with the Soil Conservation Service, show this classification as well as the engineering classification of soils. Research on a particular soil type can often be applied to soils of the same type in other locations. Some soil types are known to be more erosive than others and their identification is a valuable aid in route selection and erosion control. Local offices of the Soil Conservation Service can give much assistance in both soil identification and erosion control measures applicable to the local area.

4.3.2 Problem Areas

Areas with unstable or troublesome soils, such as landslide areas, loess soils, alluvial fans and some glacial deposits, are potential problem areas, particularly if disturbed by highway construction. Soil reports and investigations by knowledgeable engineers should be made during the route location stage so that potentially serious erosion and sediment problems can be identified.

A publication, "Landslide Investigation," (5) describes methods of recognizing and dealing with slide areas.

4.4 Coordinating with Other Agencies

Local offices of the Corps of Engineer, Soil Conservation Service, and particularly natural or water resource agencies should be contacted at an early stage in planning. Their plans or projects might affect or be affected by the location of a proposed highway. They should also be contacted to learn of their projects for controlling bank erosion, plans for protective works, and particularly stream grade control structures or channel modifications. Early recognition of potential conflicts in program plans and mutual cooperation can be of considerable public benefit.

5.0 Design

Many erosion problems that occur during and after construction can be avoided by proper design and adequate specifications. Erosion control measures, both temporary and permanent, should be specified on the plans and special provisions, and not left for subsequent contracts or for maintenance forces to provide after construction has been completed. Contour grading plans, coordinating grading and drainage should be prepared for special areas including interchanges and rest areas.

5.1 Geometrics

Geometrics can be used to advantage in minimizing soil erosion. Independent roadway grade lines which fit the terrain with a minimum of cuts and fills reduces exposed areas subject to erosion. Depressed roadways and underpasses require careful consideration to drainage design to avoid deposition of sediment and debris on the highway and in drainage facilities.

5.1.1 Alignment and Grade

Careful selection of alignment and grade of a highway is as important to successful erosion control as the general location. Alignment and grade, consistent with highway safety criteria, should be blended or fitted to the natural landscape to minimize cut and fill sections and reduce erosion and costly maintenance. These geometric features should be selected so that both ground and surface water can

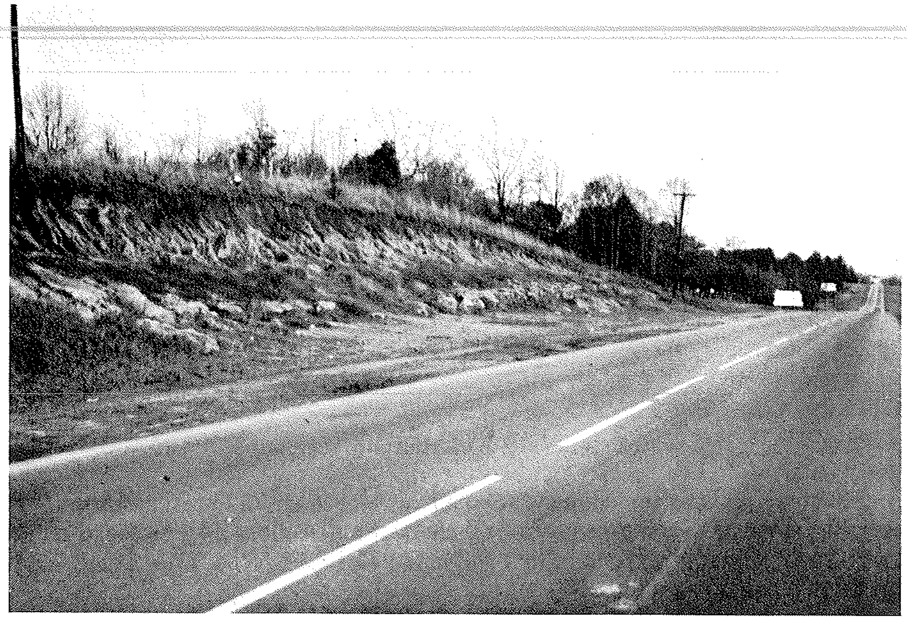
Independent roadways fitted to the landscape minimize erosion and sediment problems.

pass through the highway right-of-way or can be intercepted with minimum disturbance to streams or without causing serious erosion problems.

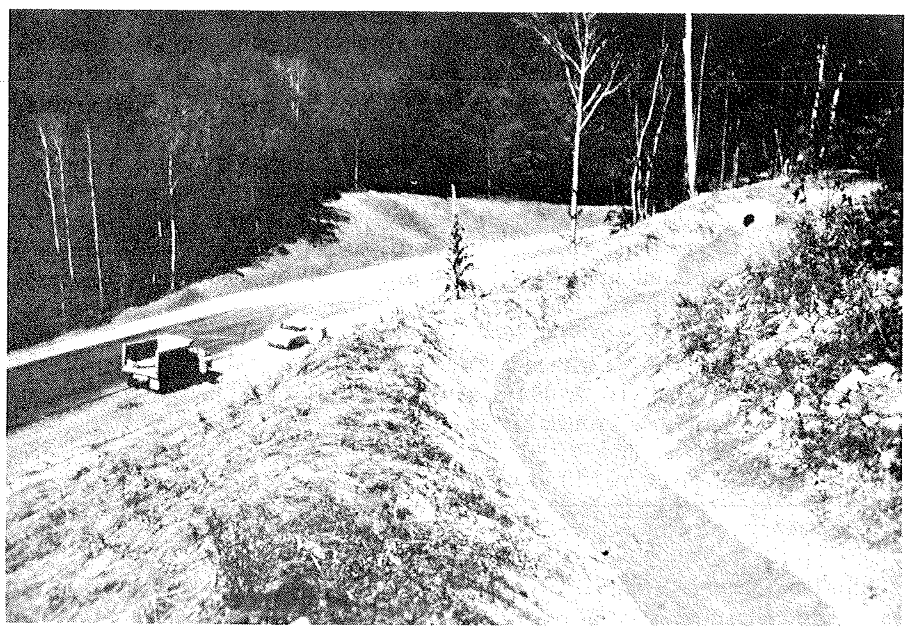
5.1.2 Cross Section

Slopes of the roadway cross section should be as flat as possible and consistent with soil stability, climatic exposure, geology, proposed landscape treatment and maintenance procedures. The cross section should be varied, if necessary, to minimize erosion and to facilitate safety and drainage. Generally, good landscaping and drainage design are compatible with both erosion control and safety to vehicles.

Severe erosion of earth slopes is usually caused by a concentration of storm water flowing from the area at the top of cut or fill slopes. The concentration of storm water at the top of cuts should be avoided. A dike, preferably of borrow material to avoid disturbance of the natural ground, in conjunction with a grassed channel or paved ditch, should be constructed at the top of the cut to prevent water from running down the slope. Water can be spread over the natural slope or carried to lower elevations in chutes, preferably closed pipes. Outlets for such high velocity chutes must be protected from scour. Occasionally, streams in cut sections cannot be avoided and require special attention.



Location, as well as cross section, should be considered for general esthetics and to reduce maintenance costs from soil erosion.



Interception at top of cut slope carries water to down drain and reduces slope erosion.

Serrated slopes aid in establishing vegetation.

In some parts of the country, serrated cut clopes aid in the establishment of vegetative cover on decomposed rock or shale slopes. Serrations may be constructed in any material that is rippable or that will hold a vertical face for a few weeks until vegetation becomes established.

Where vegetation cannot be established or flow down the fill slope is objectionable, provision should be made for collecting the runoff at the shoulder edge and directing it to an adequate inlet and chute.

5.2 Drainage

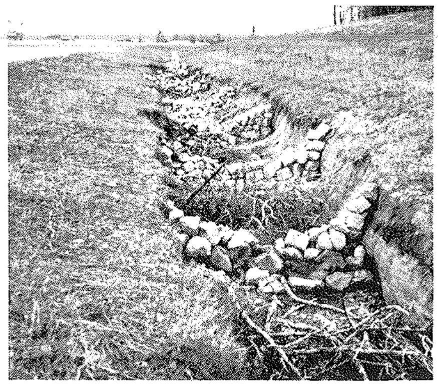
Facilities for handling surface water in highway construction are numerous and vary greatly as to type and applicability. The design of such facilities is important in that unsatisfactory operation or failure can result in serious erosion and sedimentation problems.

The erosion potential should be estimated and measures to control or prevent erosion selected on the basis of both the effectiveness of the control measures and the consequences of the erosion. In most instances, the designer has a wide range of choice in type of erosion control measures. Climatic conditions at the time of construction, type of soil and cost must all be considered in the design selected. Design for erosion control can be complex and should be done or reviewed by trained specialists.

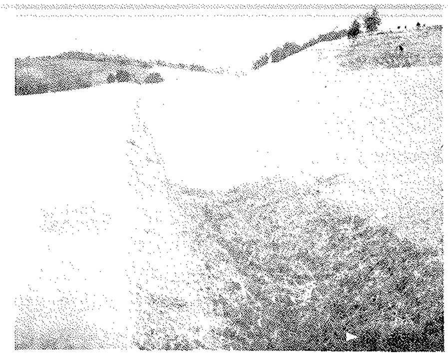
Channel and chute design and protective treatments are discussed in (5). Hydraulic design of culverts is discussed in (6), and (7), drainage of highway pavements in (8), and flow through bridges in (9).

5.2.1 Channels and Chutes

Surface channels, natural or man-made, are usually the most economical means of collecting and disposing of runoff in highway construction if concentration of flows cannot be avoided.



An eroded gutter is a costly maintenance problem and a safety hazard.



Well designed channels have flat side slopes for safety and should be installed as soon as grading operation permits.

A well-designed channel carries storm water without erosion or hazard to traffic, and with the lowest overall cost, including maintenance. To minimize erosion and avoid a safety hazard, channels should have flat side slopes and wide rounded bottoms. Such channels can be protected from erosion by lining with grass, rock, concrete or other material.

Chutes generally have steep slopes and carry water at high velocities. Pipe chutes are preferable to open chutes because the water cannot jump out of the chute and erode the slope. Provision for dissipating the energy along the chute or at the outlet is usually necessary. In highly erosible soil, it may be necessary to provide water tight joints to prevent failure of the facility. Caution must be exercised to avoid splash which causes erosion.

5.2.1.1 Alignment and Grade

Variations in channel alignment should be gradual, particularly if the channel carries flow at high velocity. Whenever practical, changes in alignment should be made on the flatter gradients to prevent erosion by overtopping the channel walls. Although usually more expensive, rectangular channel sections are preferred on curves of paved channels to give a more positive control of the flow.

5.2.1.2 Channel Linings

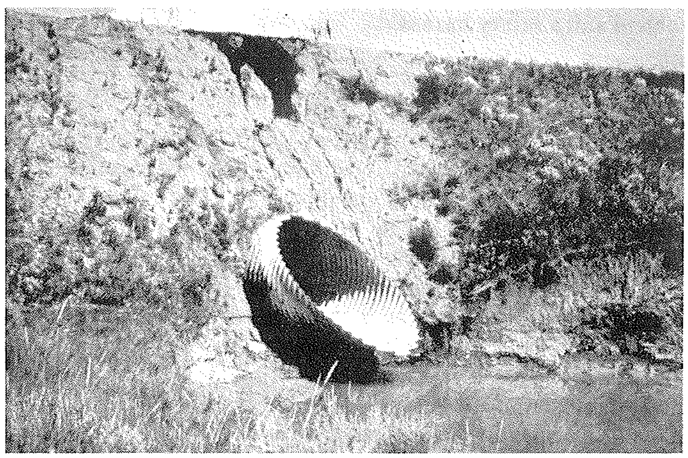
Channels should be lined if the bank and bed material will erode at the prevailing velocities. Protective linings for channels and streams can be very expensive and a considerable percentage of the highway dollar is spent on this item of work. A special effort should be made to develop the lowest-cost erosion protection, including maintenance, for the particular location. Channel design and protective treatments, including filter requirements, are discussed in References 5, 10, 11, 14 and various state highway manuals. Field manuals and publications of the Soil Conservation Service, Corps of Engineer, and Bureau of Reclamation also contain valuable channel design information.

5.2.2 Cross Drainage – Culverts and Bridges

Culverts and bridges generally constrict the floodflow and increase velocities, giving a higher erosion potential. In many instances erosion and scour at these locations are damaging to the highway embankment, the structure itself or the downstream channel, if not designed and protected properly. Special care must be exercised to avoid creating safety hazards and to prevent expensive maintenance.

The energy of the high velocity flow at the outlet of culverts and chutes should be dissipated where necessary or the area subject to scour should be protected by riprap or other types of protection.

The potential of scour at bridge piers and abutments must be recognized at the design stage to provide adequate foundation and embankment protection, i.e., setting pile penetration and determining the need for spur dikes and riprap.



Scour at a culvert outlet can cause both culvert and embankment failure. Head-cutting from downstream can cause a similar failure.

5.2.2.1 Culvert Alignment and Outlet Protection

Culverts should be located so that the least possible channel change will be required. Consideration should be given to constructing culverts on curved alignment to minimize channel relocation and reduce the volume of structural excavation.

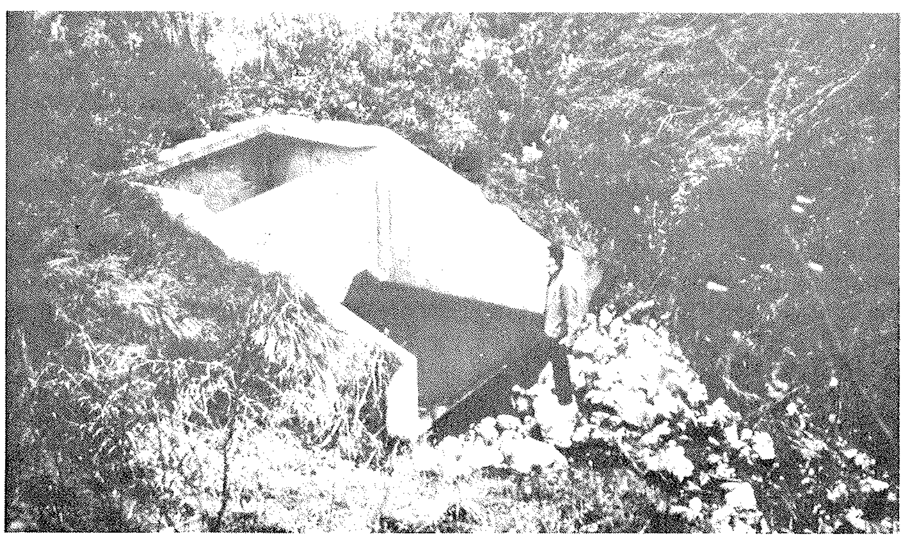
Care should be taken to protect culvert outlet channels from severe erosion. Usually rock riprap offers sufficient protection, but in locations where rock is not available or is inadequate, various types of energy dissipators can be constructed.

5.2.3 Underdrains

Subsurface water is a frequent cause of landslides, unstable shoulders, and other disturbed areas that add to the erosion problem when surface water flows over these areas. Special underdrain systems can alleviate such an unstable condition and minimize potential erosion.

5.2.4 Detention and Sedimentation Basins

Small dams can be placed in a waterway to form reservoirs or basins for detaining water and trapping sediment caused by erosion. Such dams can be of the



Impact type energy dissipator at culvert outlet. Some kind of protection should be provided at most culvert outlets to prevent failure.

Saving fish and fingerlings is important. A dike separates "blue-water" river (at left) from borrow pit during gravel removal operation. Borrow pits in a stream should be avoided.

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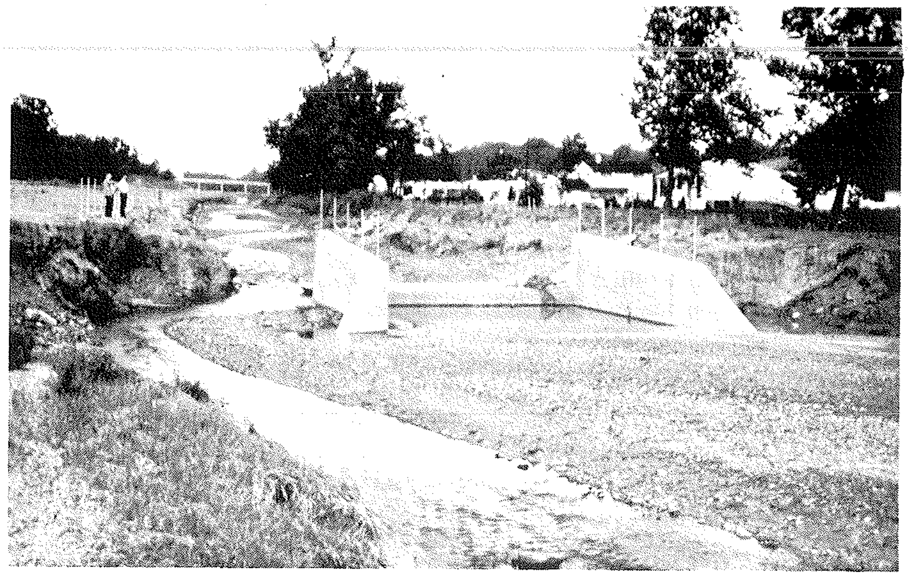
temporary or permanent type, depending on the need. A highway embankment can serve as a dam for this purpose at some locations, but special designs are usually necessary for a satisfactory and safe dam. The Soil Conservation Service and several highway departments have developed special culvert designs that control degrading of stream channels and detain sediment and flood water.

Dams for trapping sediment must be properly located and designed because failure during a major flood could have consequences far greater than most sediment problems created by highway construction. Health and safety hazards, methods of disposing of the trapped sediment and the future flood potential must also be evaluated. The Soil Conservation Service and some highway agencies have prepared specifications and design data for sediment basins, (12).

5.2.5 Grade-Control Structures

Grade-control structures prevent excessive velocities in channels by reducing the channel slope. Such structures vary in type and many are not applicable to highway construction because they present a safety hazard to traffic. Also, some of the most effective structures are costly; therefore, they should be recommended for use only after it has been determined that vegetation, rock, or other types of



Grade control structures are expensive and create a safety hazard if placed too close to the travelled way. Floods larger than the design flood may damage or destroy the structure and the channel.

treatment will not control the anticipated erosion. Where possible, large accumulations of flowing water should be avoided by disposing of water at frequent intervals onto vegetated areas, such as woods or pasture. Also a type of erosion protection that keeps velocities to less than the erosive velocity will minimize erosion and avoid the need for costly erosion-control structures. Where such structures are required, designs should receive careful attention since these structures are vulnerable to failure, particularly when flows exceed the design discharge or when they are not designed to accommodate a range of flows.

Most highway departments have standard designs for various types of grade-control structures. Considerable use is made of Soil Conservation Service (12) and Bureau of Reclamation publications containing designs for this purpose. If unusual and expensive designs are contemplated, model testing is often desirable to study performance. Models frequently show needed modifications or refinements in design that improve performance and effect considerable saving in construction costs.

5.3 Construction Practices

The plans, specifications, and special provisions of a highway contract should be explicit in showing the location, scope, and manner of performing erosion-control measures. Sufficient erosion-control measures should be included as a part of the initial grading contract. Disposal areas for spoil should be considered in the planning stage so that soil will not get into streams. Where some spill is unavoidable, temporary dikes or other means should be specified to avoid contaminating streams.

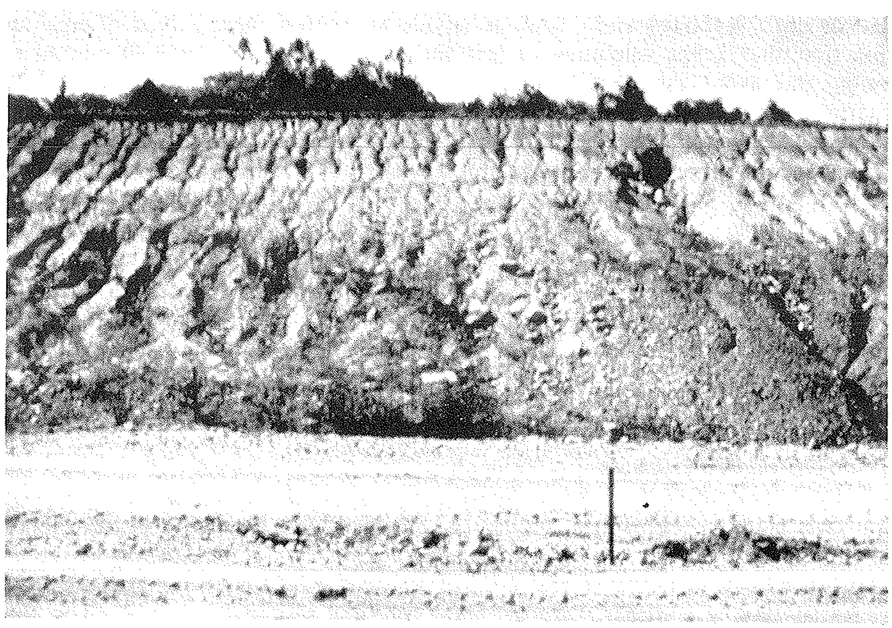
Proper planning and scheduling of construction operations are major factors in controlling erosion. The schedule should consider the probable weather conditions and the occurrence of storms, particularly if work in or adjacent to a stream is involved. A construction schedule that meets the highway agency's requirements for erosion control should be made a part of the construction project proposal or a schedule should be submitted by the contractor for approval by the engineer at the preconstruction conference. To avoid misunderstandings, a prebid conference might be desirable.

On subsequent paving or other contracts, the project engineer should not allow construction operations which contribute to or initiate soil erosion. The contractor should be made responsible for repairing damage to erosion control measures in place.

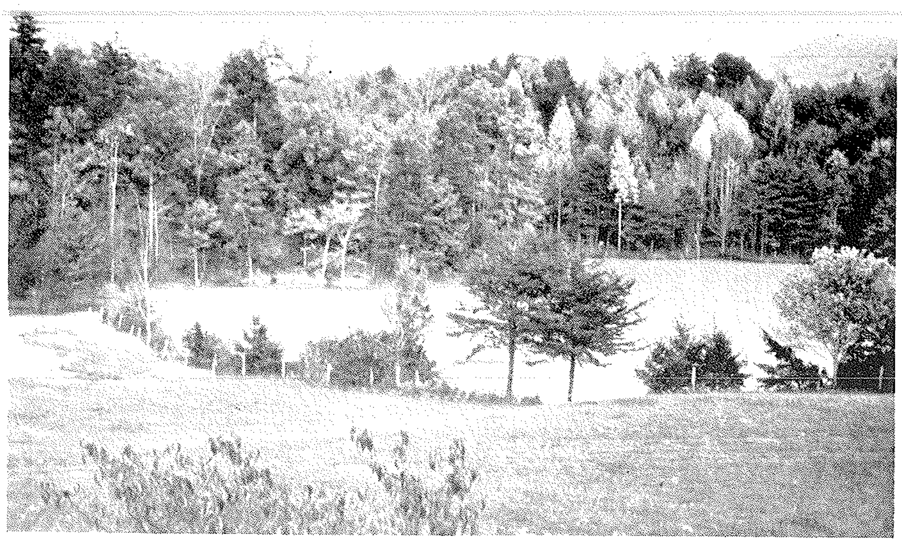
Specifications should include adequate control for the prevention of grass and brush fires since burned-over areas are usually highly vulnerable to erosion. In areas where a severe fire hazard exists, fire equipment should be available for ready use. The contract should provide for suspending fire-hazardous operations at the discretion of the engineer or local fire control agency and compliance with local fire regulations should be required.

5.3.1 Temporary Erosion Control Measures

Insofar as practicable, temporary erosion control measures should be stated in the construction contract and should include bid items for the work to be done.



Accelerated erosion in a new cut section can cause serious downstream sediment deposits and extra costs to contractors.



Downstream ponds receive sediment deposits detrimental to fish and recreation.

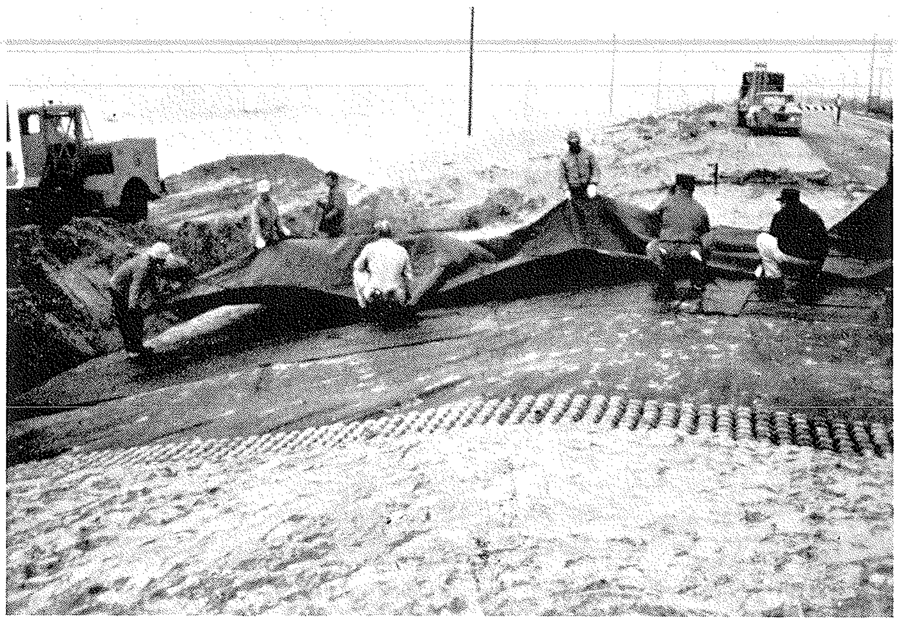
During the construction of the roadway, the roadbed should be maintained in such condition that it will be well drained at all times without serious erosion. Side ditches or gutters emptying from cuts to embankments should be constructed in such a manner that embankments will not be damaged by erosion. Liberal use should be made of fast growing grasses to provide protection until the permanent cover can be established. Mulch, matting, plastic or other temporary protection can be used to retard erosion until permanent measures become effective. Barriers of baled hay or straw or bundles of brush placed at the foot of erosible slopes will trap silt. Temporary sediment traps or basins (Sec. 5.2.4) can be used during grading operations.

5.3.2 Permanent Erosion Control Measures

Permanent soil protection and drainage facilities should be completed as early as practicable, particularly intercepting channels and similar controls that will divert runoff from work areas and unprotected soil. Sections of bare earth and the time of their exposure to erosion should be controlled by proper scheduling. Work areas should be limited in extent with consideration given to the capability of the contractor, climatic conditions, and the erosion potential on the specific project involved.

Permanent erosion control measures and wherever possible, temporary measures, should be shown on the construction or drainage plans and provision made for direct payment for the work to be done. Such measures include preparing soils for planting as well as structural controls, such as channel linings.

The use of grasses or other plants for landscaping and erosion control which are not adapted to a particular area usually results in poor erosion control and



Filter cloth is becoming a recognized substitute for a gravel blanket. Photo shows filter cloth being laid under precast revetment blocks for beach protection. (See Ref. 15)

increased maintenance. Every effort should be made to use hardy, indigenous types of vegetation that will thrive in a particular area with minimum maintenance. Proven soil conservation practices, including the use of mulches and temporary protective measures, are all important in developing permanent vegetative covers. Irrigation is often required to establish ground cover or maintain a satisfactory stand in semi-arid areas. Dust palliatives may be effective in erosion control, particularly in arid areas where wind erosion is a problem. Extremely flat slopes, on the order of 10:1 to 20:1, are effective in reducing wind erosion in arid and semi-arid areas. Disc anchored mulches, rough tilled soil surfaces, and wind breaks can also be effective in reducing wind erosion. Agronomists have a technical knowledge of soils and plants and can be very helpful in suggesting methods and kinds of treatments.

6.0 Construction

At the preconstruction conference, the contractor should be required to submit for acceptance his schedules for accomplishing the specified temporary and permanent erosion control work on the project. In addition, the contractor should submit for approval his proposed method of erosion control on haul roads and borrow pits and his plan for disposal of waste materials.

6.1 Scheduling Operations

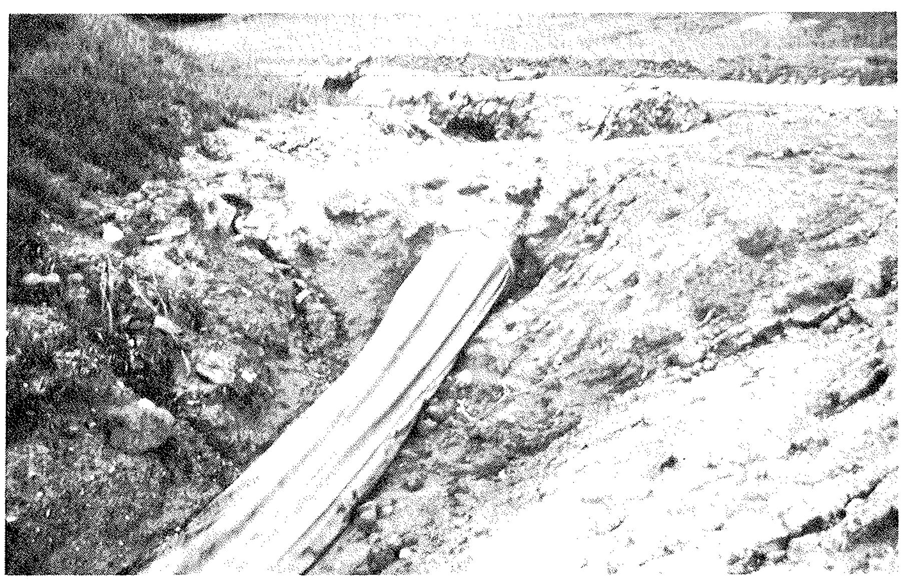
Construction operations should be scheduled with erosion control in mind giving consideration to the rainfall occurrence during the construction period. Construction of drainage facilities as well as performance of other contract work which will contribute to the control of siltation should begin with the clearing and grubbing and be carried out in conjunction with earthwork operations.

6.2 Control of Work Areas

Adequate inspection during construction is essential for erosion control. The engineer should require strict adherence to the work schedule particularly in regard to the order in which the operations should be performed. If deficiencies in the design or performance of erosion control measures are discovered during construction, the engineer should take immediate steps for correction, including notification of design engineers to avoid a recurrence of the problem. Formal field reviews and inspections, involving design, construction and maintenance engineers, are desirable to correct deficiencies and improve erosion control procedures. Measures left to the discretion of the engineer should be as few as practicable and the method of measurement and payment for such work should be stated in the contract.

The contractor should not be allowed to deface, injure, or destroy vegetation outside construction limits.

Prior to suspension of construction operations for any appreciable length of time, the contractor should be required to shape the top of earthwork in such a manner as to allow runoff of rainwater without undue erosion. Earth dikes may be



A temporary on-grade sediment basin with collapsible outfall pipe.

required along the top edges of embankments to intercept runoff water. Temporary slope drains should be provided to carry runoff from cuts and from embankments which are located in the immediate vicinity of rivers, streams and impoundments. Should such preventive measures fail and an appreciable amount of sediment is likely to enter a river, stream or impoundment, corrective action should be taken immediately to bring the problem under control.

Temporary erosion control measures should be continued until the permanent drainage facilities have been constructed and the vegetative cover on slopes is sufficiently established to be an effective erosion deterrent.

6.2.1 Minimize the Extent of Bare Soil

Clearing operations should be so scheduled and performed that grading and permanent erosion control measures can follow immediately thereafter, if project conditions permit; otherwise, temporary erosion control should be required between successive construction stages. The maximum surface area of erosible soil exposed at any one time should be specified. This specified surface area should be subject to modification depending upon the contractor's capability and progress and the erosion potential of the area. Either temporary or permanent erosion control measures should follow, as closely as practicable, operations that disturb the soil.

6.2.2 Temporary Protection

Permanent soil protection and drainage facilities should be completed as early as practicable, particularly intercepting channels and similar controls that will divert runoff from work areas and unprotected soil. Temporary protection such as fiber mats, plastic, chemicals, compounds, straw, dust palliatives, and fast-growing grasses may be required to prevent erosion from water or wind on exposed areas. Partially completed drainage facilities should be inspected carefully during the construction period to detect and correct damage that might occur.

6.2.3 Streams in the Work Area

Fording of streams with equipment should be kept to a minimum. In locations where frequent crossings of streams are contemplated, temporary bridges, culverts or stone fords should be constructed if the sediment created by fording is detrimental to fish and wildlife, water supplies, and irrigation systems or the integrity of the streambank is jeopardized. Specifications or special provisions should include controls for the contractor's operation in performing work in streams, particularly requiring conformance with regulations of water resource and fish and wildlife agencies. The contractor should not be permitted to disturb streambanks and beds or destroy vegetation existing on them. Some types of construction and stream conditions may necessitate the construction of diversion dikes or other protective measures to avoid sediment problems. These dikes should be designed and constructed in such a way that their failure would not significantly increase the sediment problem. Embankment slopes that encroach on stream channels should be adequately protected against erosion. Where practical, a protective area of vegetative cover should be left or established between the highway embankment and adjacent stream channels. At some locations, temporary or permanent training works placed in the channel can reduce bed or bank scour.

Construction operations in rivers, streams and impoundments should be restricted to those areas where channel changes are shown on the plans and to those areas which must be entered for the construction of temporary or permanent structures. Rivers, streams and impoundments should be promptly cleared of all falsework, piling, debris, or other obstructions placed therein or caused by the construction operations.

Excavation from the roadway, channel changes, cofferdams, or other material should not be deposited in or so near to rivers, streams or impoundments where it might be washed away by high water or runoff to the detriment of the general environment.

6.2.4 Borrow Pits, Waste Areas and Haul Roads

Areas for borrow pits and waste disposal should be selected with full consideration of erosion and sediment control during waste or borrow operations, and the final treatment or restoration of the area. When it becomes necessary to locate such areas near streams, special precautions should be taken to minimize erosion and accompanying sediment problems. Regardless of the responsibility for the selection of borrow areas, whether it be the contractor or the contracting agency, plans of operation and of restoration, or cleanup and shaping should be approved by the engineer. 25

Sedimentation basin built with cooperation of landowner to catch sediment from highway project. Note riser type outlet pipe in pond.

Waste material dumped over an embankment can cause serious stream pollution and kill vegetation and trees. Spoil areas should be selected with care.

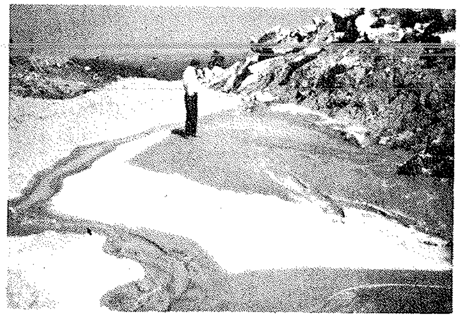
Before borrow or disposal operations are begun, plans for the control of drainage water should include measures to keep sediment from entering streams. Diversion channels, dikes, and sediment traps may be used for this purpose. Good topsoil from the borrow pit area should be saved for use in restoring the excavated area. Final restoration of borrow or waste disposal areas should include grading, establishment of vegetative cover, and other necessary treatment that will blend the area into the surrounding landscape and prevent unnecessary erosion. The restored area should be well drained unless approval is given to convert the pit area into lakes for fish and wildlife, recreation, stock water, or irrigation.

Waste should be placed only in designated areas. Earth should be distributed in a manner that can be stabilized and landscaped to blend into the surrounding area without serious erosion scars.

Haul or construction roads should be located and constructed as shown on the contractor's approved work plan. Special precautions should be taken in the use of construction equipment to prevent operations which promote erosion. Wheel tracks from heavy equipment are especially vulnerable to erosion from the concentration of water.

6.2.5 Channel Work

Construction operations in or adjacent to a stream channel should be done with caution to avoid adding sediment to a stream. Operations should be done in the dry, if possible, and bank protection placed before water is let into the new channel. When working in or adjacent to a stream, the work area should be diked

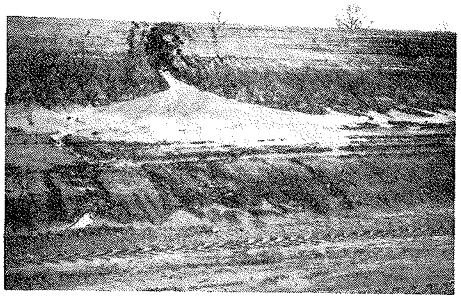


Small basins or holes on project can retain storm water and catch considerable amount of sediment. Frequent cleaning and judicious disposal of deposited materials are required.

off. Waste material of any nature should not be dumped into or allowed to fall into a stream. Sediment traps or dams can be used to remove sediment from water in work areas before releasing water into a stream.

6.3 Grading Operations

Grading operations should be conducted in such a way that the area of unprotected soil is kept to a minimum. The work area should be kept well drained and concentration of water avoided. Temporary chutes should be provided to conduct any concentration of water to a lower level. Small dikes, brush, or bales of hay placed at the foot of cuts or fills can be used to trap sediment as the work progresses. When the final grading is completed during a season not favorable to the immediate establishment of permanent vegetative cover, the area should be



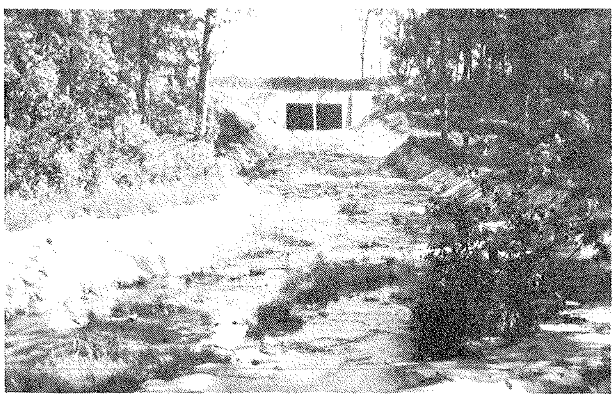
Care must be taken to control erosion and sediment during construction or large volumes of earth will be washed downstream.

protected by mulch, fast growing annuals, or, in some extreme cases, sheets of plastic. Permanent erosion control measures should be installed as rapidly as the climate and progress of the work permits.

Cleanup and dressing should be conducted according to specifications insuring that erosion control measures are not disturbed. Causes of any erosion or sediment should be corrected rather than merely filling the eroded spots. Every effort should be taken to prevent erosion ditches from developing since they are very difficult to correct and often reappear as a maintenance problem.

7.0 Maintenance

Preventive maintenance built into the highway in the location, design, and construction phases will save many dollars in maintenance costs. Experts in soil conservation, agronomy, and drainage can be helpful in assisting on maintenance inspections and in recommending appropriate erosion-control measures.



Masonry riprap culvert outlet channel.

Same channel as above photo showing failure one year after construction. Foundation was not stable, undermining riprap.

7.1 Inspections

Inspections should be made according to recommendations in the AASHO publication "An Informational Guide for Physical Maintenance" (13).

Periodic inspections of drainage and erosion-control measures should be made shortly after completion of construction so that deficiencies can be located and corrected before they develop into major problems. Deficiencies in design or in construction procedures should be discussed with the engineering staff so that similar deficiencies can be prevented on future projects. Coordination of responsibilities for erosion-control measures among design, construction, and maintenance departments needs to be emphasized.

7.2 Maintenance Records

Maintenance records should include sufficient detail to permit analysis of maintenance problems, particularly those related to erosion control. Electronic computers and better coding and tabulating of maintenance costs for the various elements of the highway allows for better analysis of data for use in making improvements in design and construction practices that will reduce erosion problems and lower maintenance costs.

7.3 Training of Personnel

After road construction is completed, highway maintenance personnel must find and correct any deficiencies in the erosion control measures as well as maintain

In maintaining roadsides, care must be taken to avoid stripping well-established grass and promoting ditch erosion.

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the efficiency of the measures. Periodic inspections, especially after heavy runoff, are of prime importance in a good maintenance operation. Frequent training schools should be conducted in maintenance techniques, including methods of making inspections, care or management of vegetative plants, and in measures for preventing and correcting erosion.

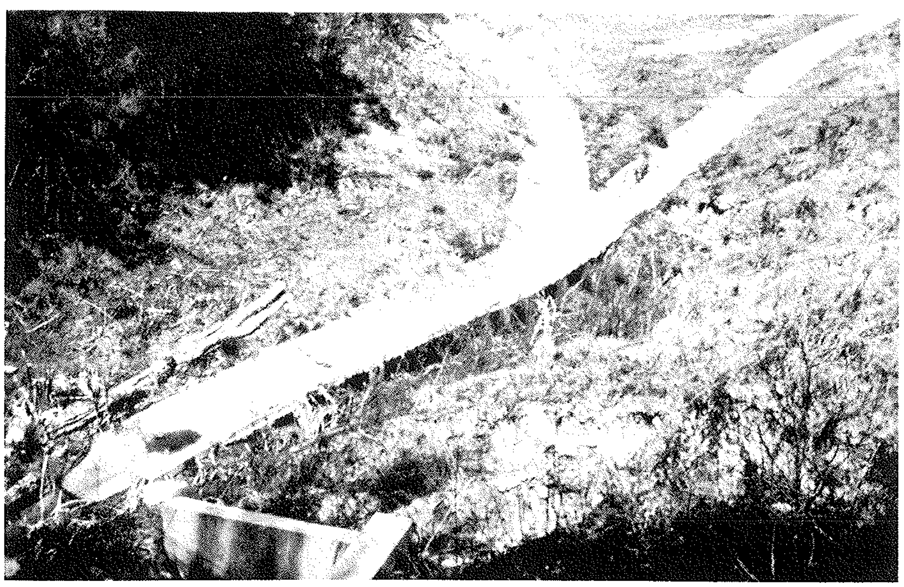
Supervisors and instructors of the training schools should attend courses given by other agencies or highway departments in order to keep abreast of new developments in erosion control practices.

7.4 Embankments and Cut Slopes

Embankments and cut slopes are particularly vulnerable to erosion. Operators of maintenance equipment should be made aware that damage to ground cover at such locations can create serious erosion problems that are difficult to correct. Surveillance of these areas needs to be stressed since they are not easily seen from the roadway.

7.5 Channels

Channels, whether active streams or open roadside drainageways, are vulnerable to erosion, especially for a period of time after construction. It is important, therefore, that maintenance personnel inspect these facilities periodically for any erosion that will lead to expensive or major remedial work. Such inspections are particularly important after unusual storms.



Rigid channels are vulnerable to undermining from splash and overflow, particularly on curves and channel confluences.

Connecting culverts in median minimizes erosion and improves safety. Median drainage can be dropped into culverts through traffic safe inlets.

7.5.1 Roadway, Median and Intercepting Channels

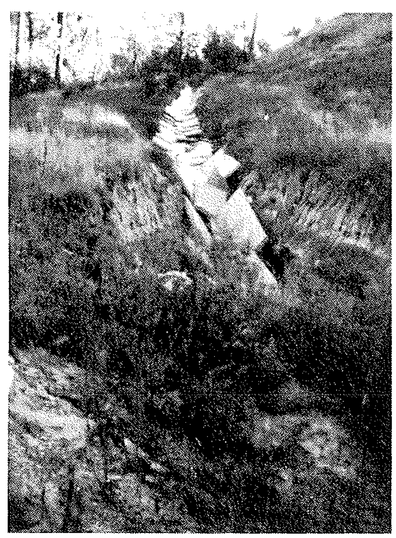
Channels should be kept clean and free of brush, trees, tall weeds, and other material that would lower the capacity of the channel. When channel deterioration reduces channel capacity, overflow may occur, often with erosion or deposition in the area adjacent to the channel.

7.5.2 Paved Channels

High velocity flow in chutes or ditches often overtops the sides and erodes the adjacent area. Care should be taken to inspect for holes and eroded areas under paved channels to prevent collapse of rigid sections. Projections and joint offsets that cause splash and possible erosion should be removed or repaired. The channel entrance should not permit water to flow either along the side or underneath the channel.

7.5.3 Channel Changes

Periodic inspection of channel changes is necessary to avoid costly repairs. Failures should be analyzed carefully by the design staff before performing remedial work because changes in the original construction may be indicated. It is of utmost importance that maintenance supervisors understand the degree and kind of maintenance required on channel changes as intended by the designer.



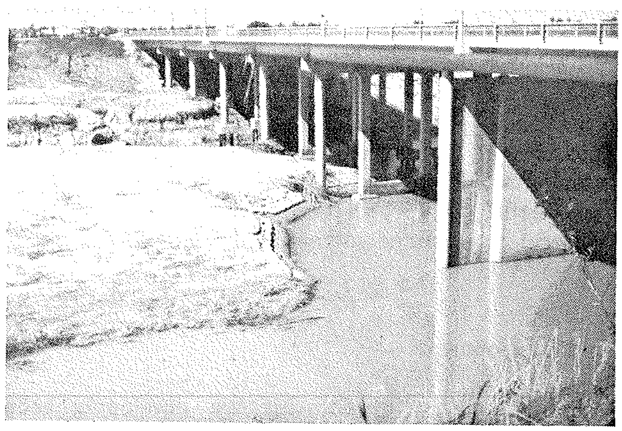
High velocity flow at the outlet of smooth rigid channels must be dissipated or the channel lining will fail. Progressive failure by head cutting will occur if ditch lining is terminated too high. Overtopping of sides and flow through cracks in the lining cause similar failure.

7.6 Disposal of Waste Material

Waste material from maintenance operations often consists of soils or sediment. Such material should not be dumped in areas where erosion will cause an unsightly scar or sediment can reach a stream. Wherever possible waste areas should be formed to permit revegetation and prevent unnecessary erosion.

7.7 Maintenance of Vegetation

The fertility of the soil must be maintained if vegetation is to thrive and erosion is not to become a problem. At times, vegetation may require watering. The need for special attention should be determined by qualified agronomists in consultation with the maintenance staff. Grass cover should not be bladed off by maintenance operations. Care must be taken in selecting and dispensing pesticides and weed killers to avoid polluting streams and reservoirs.



During unusual floods, channel banks erode and channel beds scour. Piling become exposed and some piers fail because of scour and inadequate foundations.

7.8 Repair of Storm Damage

Storm damage should be repaired as quickly as possible to prevent additional damage. Such damage may indicate that additional protection is needed. A damaged area only restored to its preflood condition will usually be damaged again when a flood of like magnitude recurs. When maintenance personnel discover excessive scour or erosion near a bridge or other major drainage structure, the bridge engineer or others responsible should be advised so that proper measures can be taken to protect the structure.

7.9 Sedimentation and Detention Basins

Sedimentation and detention basins usually require cleaning from time to time, particularly during the period when vegetation is becoming established. Access for such operations must be planned and provision made to move equipment to and from the basins without damaging the vegetation or causing erosion.

7.10 Remedial Work

Maintenance personnel may find a need for additional erosion control measures due to design omissions, changed conditions or limited design information. Consultation should be made with the design and construction staff for assistance in selecting the proper corrective measures and for keeping the responsible administrators informed so that similar conditions can be avoided on future projects.

8.0 Research and Development

Although State highway departments are developing economical and practicable measures to control erosion, additional research is needed to improve present methods and provide more economical and effective means for preventing erosion both during and subsequent to construction.

Methods and sequence of construction require further study in many areas of the country. Weather conditions, soil characteristics, and types of effective erosion-control measures vary, thus requiring different approaches to the erosion problem. Investigations are needed to develop protective covers and treatment of soils to avoid expensive practices and reduce cost. Further development in the use of dust palliatives could prove beneficial in areas subject to wind erosion.

Data on the amount of sediment transported to streams due to erosion during the construction of a highway are very limited and further research is needed. The increase of sediment and turbidity in a stream due to highway construction and its estimated damage over that produced under natural conditions are not well defined. Such information is necessary to evaluate the extent of controls needed for the control of sediment during the construction of a highway.

A continuous effort in developing vegetation and in improving soil conservation methods, should be actively promoted to provide assurance that the best methods for preventing erosion are being used.

9.0 Legal Requirements and Responsibilities

Legal requirements and governmental responsibilities in matters related to water vary throughout the States. The responsibility for damage to upstream and downstream property must be considered in highway design, particularly with respect to flooding, erosion, and sediment. Statutes in some States establish rigid controls in matters related to fish and wildlife, pollution of streams and water supplies, irrigation, and diversions of natural stream courses.

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COUNTY HIGHWAY SERIES

principles of highway drainage and erosion control

compiled by

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Project for Indiana Counties

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HIGHWAY DRAINAGE AND EROSION CONTROL

PURPOSE AND IMPORTANCE

Excess water is Highway Enemy No. 1. Uncontrolled water is the primary cause of broken or soft surfaces, mudholes, rutting, washed out shoulders, and even loss of complete sections of roadway or structures. Prevention of such failures makes roads safer for motorists and pedestrians, reduces maintenance costs, and adds immeasurably to the pleasure and satisfaction in use of the roads for business and recreation.

The cost of controlling water is a significant part of total highway expense, which indicates the importance of the subject to highway personnel. Approximately a quarter of the cost of new construction is for drainage or erosion control. The proportion of maintenance costs directly related to control of water is probably much greater. Erosion is a particularly expensive factor because it costs money in two ways—soil lost must be replaced and soil deposited in drainage structures must be cleaned out. It is important, therefore, to plan and develop, carefully, adequate facilities for drainage, and measures for controlling erosion.

Control of nearly 80 per cent of the road mileage in Indiana is in the hands of local highway personnel The extent to which they apply sound principles of highway drainage and erosion control determines in part the condition and cost of Indiana roads. What are these principles?

A cardinal rule would be to **interfere with nature's drainage as little as possible.** Ideally, this might be done by putting all roads along ridges or drainage divides. For most roads, however, location is already determined and minimum interference with nature will mean to stabilize earth surfaces with some kind of cover, to provide a place for water to run freely over the surface in ditches or underground in culverts and subdrains, to conduct the collected water safely to a natural watercourse, and to encourage landowners to use the soil in accordance with good agricultural and conservation practice.

This manual is an attempt to describe the important principles involved in these measures, and to describe some specific applications of those principles.

SLOPE PROTECTION

Sound slope protection is based on six fundamental principles:

1. **Keep slopes flat and edges well rounded to reduce erosion potential to a minimum.**
2. **Establish a healthy, continuous vegetal cover as quickly as possible.**
3. **Intercept water from higher ground before it reaches slopes susceptible to erosion.**
4. **Provide safe outlets for water collected in intercepting ditches and gutters.**
5. **Protect slopes from freely flowing underground water.**
6. **Take special precautions around structures which protrude above slope surfaces.**

Steepness of Slope

Highway slopes should be stable so as to remain uniform with a minimum of maintenance. The first step in accomplishing this is to construct cuts and fills as flat as is economically feasible. In flat or gently rolling country many slopes can be 3:1 or 4:1. (A slope of 3:1 means 3 ft of horizontal distance per foot of vertical distance.) In hilly country and around structures, high costs and

Fig. 1. A flatter cut slope would improve sight distance and establishment of vegetal cover.

limited right-of-way will require slopes as steep as 2:1. Though most soils will stand at slopes of 1½:1, such steep slopes are difficult to maintain and are generally undesirable for earth cuts and fills. Rock cuts, of course, can be much steeper—up to ½:1 or ¼:1 in sound rock.

Flat slopes have advantages of ease of construction and seeding, fewer washouts during early stages of cover growth and permitting use of machinery for maintenance. Tractor operated equipment tends to dig up turf on slopes steeper than 3:1 and generally cannot be operated at all on slopes steeper than 2:1. Water flows gently, in sheets, over flat slopes, but rapidly, in erosive streams, on steep slopes. The "streamlined" shape of relatively flat slopes presents little interference to the wind, therefore reduces snow drifting and encourages the sweeping action of the wind on the roadway, helping to keep costs of snow removal down. In addition, flat

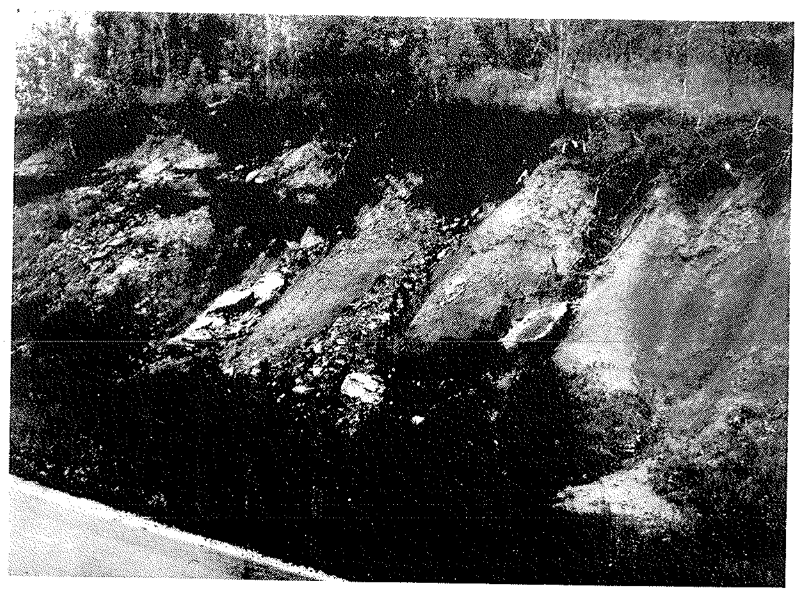

Fig. 2. A vigorous turf cover is needed to stabilize this slope. Stopping erosion would improve drainage and eliminate the clean up problem.

slopes (4:1 or less) are safer because a vehicle can move onto these slopes in an emergency with little danger of serious accident. Flat cut slopes on curves also provide greater sight distance.

Even though flat slopes require larger volumes of cut and fill than steep slopes, their benefits in increased safety and reduced maintenance justify their use. For these reasons cut and fill slopes of 4:1 or flatter are preferred whenever practical. In rugged, hilly country, as is typical in the southern counties of Indiana, slopes as steep as 3:1, and 2:1, will be necessary in most cases. Even in relatively flat areas, when fills higher than 5 to 10 ft are necessary, right-of-way limitations will require the steeper slopes. In any case, 2:1 should be considered a maximum acceptable slope except in extremely difficult conditions of steep land and insufficient right-of-way.

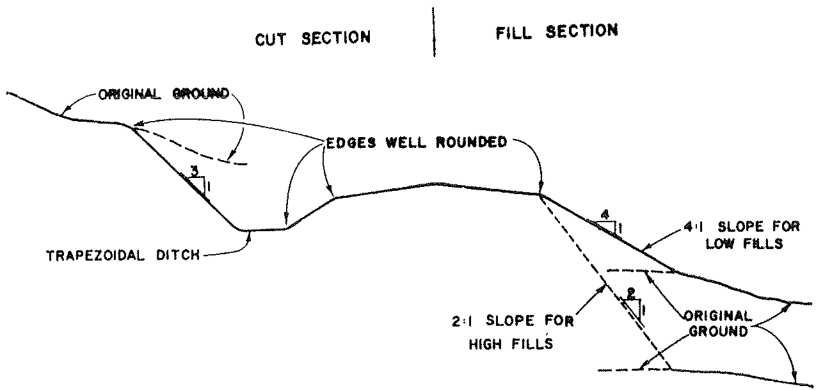

Fig. 3. Cross section properties which are especially important in maintaining stable roadways include flat slopes with well rounded edges and adequate ditches. Slopes preferably should be 4:1 or flatter. Vegetal protection is essential.

Edges of slopes where cut or fill surfaces meet the natural ground surface should be well rounded. Sharp edges encourage water and wind erosion, and are difficult places to get vegetation started. At sharp intersections of surfaces water forms gullies which get progressively worse. Also, wind eddies are created at sharp edges, picking up soil and blowing it away. This is greatly reduced by blending surfaces in freely rounded intersections.

For Maximum Stability and Safety Strive for Slopes of 4:1 or Flatter and Round the Intersections of Slopes with Natural Ground.

Vegetal Cover

Flat slopes are desirable for stability, but no exposed slope will remain uniform unless protected from rain and wind by a healthy stand of some vegetation, usually grass, legumes, or shrubs.

Choice of Species

If soil and moisture conditions are suitable, grass is usually the most economical cover for protecting slopes from erosion. In Indiana an excellent turf is formed by a 4 to 1 mixture of tall fescue and bluegrass. The fescue (either Alta or Kentucky 31) is quick starting and will provide early protection. Bluegrass fills out the turf forming a firm uniform sod which, with proper maintenance, will provide a satisfactory permanent cover.

Where conditions are unfavorable for grasses, such as low fertility and free draining soil, where the soil is particularly erosive, or where slopes are too steep to operate mowing equipment, Penngift Crown Vetch will provide a strong, dense cover. The Vetch is slow to develop, therefore slopes must also be seeded to fescue and bluegrass to get early temporary protection. The advantages appear after two or three growing seasons, when the Crown Vetch is well established, because it practically eliminates maintenance. Weeds are choked out; spraying and mowing are unnecessary; fertilizing is reduced to a minimum; and dense root systems, stems and foliage so thoroughly protect the soil that very little is washed away to be deposited in ditches or culverts. A desirable by-product of protecting slopes with Crown Vetch is the attractive appearance when the plant is in bloom for several weeks each summer. 43

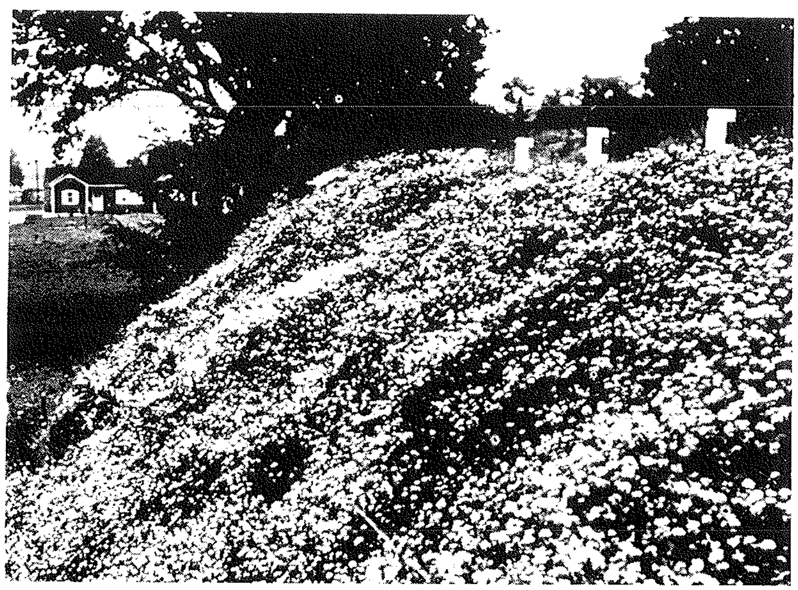

Fig. 4. The excellent protection provided by Crown Vetch is illustrated on this steep embankment slope. (Courtesy W. H. Daniels)

When the road runs through wooded areas extensive slopes of mowed grass may look out of place. In such cases a basic grass mixture may be sown for quick protection of an exposed slope, but natural growth encouraged to take over. Once the grass is there to hold soil in place only that area necessary for sight distance and for clear, open ditches is mowed. In the remainder of the slopes natural woody growth may be allowed to come in to provide a ground cover which blends into the surroundings pleasantly and at the same time eliminates a great deal of mowing and fertilizing.

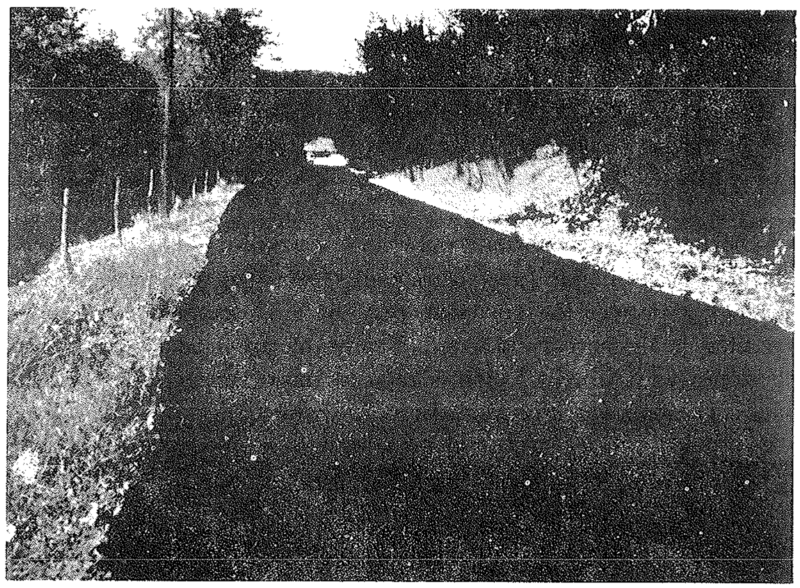

Fig. 5. A well protected slope where native woody growth has been allowed to take over.

Another use for woody plants is to keep costs down in an area where shrubs are readily available near the road. Such ground hugging plants as juniper, lowbush blueberry and sweet fern will serve very satisfactorily where erosive conditions are not too severe, and if they can be acquired freely adjacent to the work they may prove an economical solution to the problem of stabilizing a slope face.

Soil Preparation

Proper soil preparation is essential to insure rapid establishment of cover. The soil surface should be loosened by scarifying, harrowing, or raking. How much fertilizer and lime should be used?

One hundred pounds per acre each of nitrogen, phosphorus, and potassium is a good standard application for seedbeds. This can be provided by 20 lb per 1000 sq ft or 870 lb per acre of 12-12-12 or equal. It is still better to get a soil test and follow the recommendation of the testing agency. A soil test should always be obtained before applying lime to the seedbed as many Indiana soils will not require any lime. With this treatment most Indiana soils will support a satisfactory turf. In cases of exceptionally clean and well drained gravels it is desirable to spread 3 to 4 in. of topsoil as a seedbed. For best results fertilizer, and lime when needed, should be well mixed into the soil before seeding.

Seeding and Planting

Small areas are usually seeded by hand. After the soil is loosened and fertilized, seed is spread either by broadcasting handfuls in a broad, sweeping action or with a small mechanical spreader of the lawn seeding variety. A standard mixture of 80 per cent fescue and 20 per cent bluegrass sown at the rate of 40 to 80 lb per acre or 1 to 2 lb per 1000 sq ft is generally satisfactory. For Crown Vetch, 5 to 10 lb per acre, or ¼ lb per 1000 sq ft is recommended.

A more satisfactory method of starting Crown Vetch is to plant crowns at about 3-ft intervals in staggered rows about 3 ft apart beginning at the top of the slope. This is more expensive than seeding but it will give the Vetch a much earlier foothold on the slope.

When shrubs are used they should be delivered in such a manner as to avoid damage by drying out. If plants must be held more than a few hours before planting they should be placed in a shady area, the roots covered with earth if not balled and burlaped, and kept watered. Holes should be dug twice as large as the transplanted root system and the roots spread out naturally with no bending or crowding. Fill is placed carefully to avoid breaking roots when it is firmed in place. Care should be taken to avoid placing fertilizer directly on roots or under plants. It is best to mix fertilizer with the backfill before placing, or to apply it to the surface, with mulch, after planting.

Protection During Establishment

Seeding and/or planting should be followed immediately by a mulch which serves to protect the slope until seedlings are established and helps to provide conditions of temperature and moisture favorable to germination. The usual mulch is straw or hay spread evenly by hand, or blown over the surface with a mechanical spreader. About 1½ tons per acre or 70 lb per 1000 sq ft, giving 1 to 2 in. of cover over the soil, is most effective.

On very steep slopes or windy exposures the mulch needs to be tied down. This may be accomplished with binder twine criss-crossed and pegged, by running over the surface with a disc harrow set straight, by placing soil or asphalt strips over the mulch, or by spraying with "mud-slurry" or a light asphalt spray.

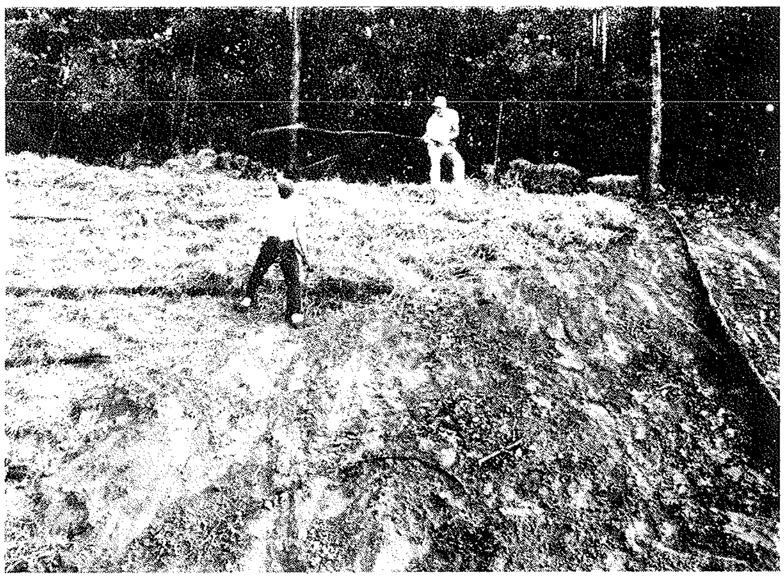

Fig. 6. Mulch is being applied to this slope immediately after seeding to give temporary protection until cover is established and to assist in establishment of grass. If the slope were flatter, mulching would be easier and cheaper.

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Other materials that have been used for mulching are sawdust, commercially processed wood fibre, asphalt emulsions, chemical sprays, and paper or jute netting. The particular advantage of the commercially produced mulches (wood fibre, asphalt, and chemicals) lies in their use with hydraulic seeding methods.

Hydraulic seeding is an alternate method of seeding roadsides which is especially useful for large areas. In this process, fertilizer and seed are mixed together in a water slurry and sprayed over the prepared soil surface in a single operation. Some of the commercially produced mulches can be added to the fertilizer and seed slurry, and thus mulching is accomplished in the same operation.

Fig. 7. Application of the principles of slope protection is well illustrated on this county road. Note the flat slopes with well rounded edges, and the turf cover over the entire slope.

The equipment required is relatively expensive, so this method is usually employed only when large amounts of seeding are to be done, or for small areas, when done on a contract basis.

Whatever the species or method, the important principle is—*Fertilize and Seed for a Turf Cover Immediately After Grading, and Mulch to Provide Immediate Protection.*

Intercepting Ditches and Gutters

Cut faces are frequently subject to large amounts of water running down from higher ground. To prevent this water doing serious damage it should be collected in an intercepting ditch in the form of a small berm or trench a few feet above the slope face. A berm may be formed by placing a ridge of earth about 6 to 12 in. high and 1 to 2 ft wide along the surface and then seeding for vegetal cover just as in the slope face. If possible the berm should be placed where the up-slope side of the ditch will be quite flat and where there is established natural vegetation to slow the water as it enters the ditch section.

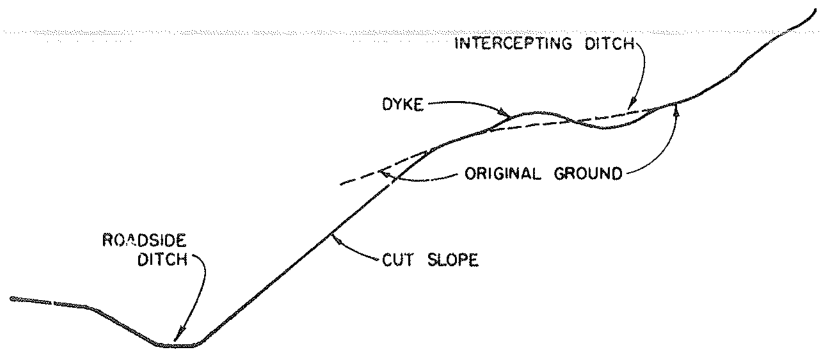

Fig. 8. Cut slopes may be protected from surface water from above by constructing intercepting ditches as shown here. The ditch must run full length of the slope and have a safe outlet.

On a long grade the roadway itself may collect erosive quantities of water. This can be collected in a gutter formed by an asphalt dyke 4 to 8 in. high and released at intervals into prepared waterways. In this situation it is desirable to have the gutter as far away from traffic as possible to minimize splash and ice problems in the roadway and to encourage traffic to use the full width of the road. This may be done by surface treating the shoulder and forming the gutter at the outer edge of the shoulder.

Water collected in gutters and intercepting ditches should be released down slopes at controlled outlets—the ends of cut slopes and the low point of the roadway profile, and at intermediate points if the ditch or gutter is very long. This is an extremely important consideration in using intercepting ditches, because unless properly outletted, concentrated flow in such ditches can do more damage than the same water flowing over the slope face.

On many miles of unpaved county roads a berm has been inadvertently formed along the edge of the traveled surface by continual grading and scraping of the road and neglect of the shoulders. In some places these berms may be useful in serving as a gutter. However, water collected by these berms and ponded at low points in the road are a traffic hazard, and tend to saturate the base of the road, leading to serious rutting. Where these berms do not serve as necessary protection for shoulders or fill slopes, they should be removed to permit water to drain directly to the side ditches. When

Fig. 9. This berm has no outlet. The water collected saturates and softens the roadway so that traffic creates ruts.

the berms are retained it is important to cut openings through them and form channels to drain the collected water away from the roadway.

A third principle—*Intercept Erosive Surface Water Before it Reaches Long, Steep Slope Faces.*

Down Drains

Outlets from intercepting ditches and gutters may be shallow, depressed sections in the slope face or may be paved troughs or pipe sections. The main difficulty with these channels is getting protection established because the concentrated water at each rainfall tends to wash away seed and mulch. Sodding is one way to overcome this problem. A depression is formed in the slope and the soil loosened and fertilized. Sod strips are then placed snugly in the trench and rolled or tamped. The sod should be watered frequently as weather demands during the first few weeks after planting. Using shallow cut sod—about ¾ in. deep—will keep cost of transportation and placing to a minimum, and sod should be mowed short before cutting, as excess foliage hastens drying out of the sod.

Fig. 10. This curb contains water from the long grade, so it will not destroy the side slope. Outlets both at the end of the curb and midway up the hill carry water safely to the foot of the slope.

Another approach which has proved successful is to seed the channel depression as usual then cover it with an open mesh burlap, or jute matting. This net, with openings about 1 in. square, when tied down with wire stables 8 to 12 in. long at about 6-ft intervals, will hold the soil and seed in place until the turf is established. The mat need not be removed since it ultimately rots away and serves as humus.

Where water must be carried down steep slopes, or quantities are especially large, turf linings, even if they can be established, may not give adequate protection against severe scour. In this situation it is necessary to protect the sluice with a paved lining or a half section of pipe.

The turf on the adjacent slope should be well established right up to the edges of whatever lining is used. If necessary, sod strips may be placed along the edge of the lining.

Whatever kind of channel is formed, it is essential to flare the ends to avoid scour at entrance and exit. The water should enter in a broad sheet from the ditch or gutter and converge in the sluice. At the bottom the channel should level out and widen again, to spread the water out into a relatively slow moving sheet at the bottom of the slope. The area at the bottom of a sluice may be protected by a layer of coarse gravel or crushed stone, or may even be paved if the discharge tends to undercut the cut slope or erode the roadway fill.

Provide Safe Outlets for all Water Collected in Channels.

Subdrains

Veins of free running water intersecting a cut face will wash away the slope regardless of surface treatment. This type of erosion can be prevented by intercepting the water before it reaches the surface. A subdrain installed in a trench back of the slope will serve this function as will a perforated pipe driven or drilled horizontally into the cut face. The trench is cut to a depth 3 to 6 in. below the water bearing material, and drain tile placed in the bottom. Backfill must be a pervious material tamped firmly in place. The top foot of fill should be a relatively impervious silty or clayey material to keep surface water out of the drain. This subdrain must be extended the full width of the cut and outletted safely, as ditches and

Fig. 11. No amount of grass will hold this slope which is softened by subsurface water. Subdrains must intercept the water in back of the slope to keep the soil dry.

gutters are, either to the roadside ditch or to natural drainage. In cases where the pervious material is very deep, it may be more economical to drive or drill a pipe horizontally from the slope face into the pervious layer, or to place riprap over the slope face to the height of the seepage layer.

Protection from Underground Water Depends on Intercepting and Diverting Subsurface Streams or Providing a Safe Outlet at the Slope Face.

Fig. 12. Subdrains in the slope on the right keep the soil dry and stable. Notice the water in the ditch from the subdrains even during dry weather.

Special Problems

Special attention is demanded wherever surface water tends to collect and run along a structure. As it collects, the quantity of water is built up and speed increases. Because the erosive power of water is primarily a function of depth and velocity of flow, the conditions at such points of concentration are especially critical. To avoid this problem, surface water should be diverted to the ditch or natural stream before it reaches bridge abutments or culvert headwalls. Water collecting on a structure should be dropped through scuppers or contained by curb or gutter sections until it

Fig. 13. Water has washed out both the original headwall here and the timber replacement. The correction of this problem is diverting the water down the side slope before it reaches the structure.

can be released well away from critical points around the structure. Some water, however, is bound to reach protruding objects. When erosion starts, such points should be sodded, or seeded and protected with jute matting, to insure rapid establishment of a strong turf.

Divert Surface Water Before it Reaches Protruding Structures.

Fig. 14. Asphalt curbs contain water in this roadway, carrying it away from the structure and steep slopes.

Maintenance

Maintenance of slopes is primarily good management, just as it is for any cultivated area. It is important, however, that where drainage or erosion problems occur a minimum of work be done on the symptoms and the major efforts be directed at eliminating the causes of the difficulty.

Grasses must be mowed regularly and fertilized occasionally if they are to remain healthy and continue to protect the slopes. Every grassed area should be mowed at least once a year and preferably three to four times. Equipment should not be operated on turfed areas when the ground is very wet, however. Nitrogen fertilization is most important for grasses because this element is readily leached away and is most depleted by plant usage. Therefore, maintenance fertilizer should be high in nitrogen, such as 18-6-6. An established dense cover may not need annual fertilization. However, it is desirable to provide for grassed slopes to be fertilized on a rotational basis, so that some areas are covered each year—at least those areas where cover is thin. An amount of fertilizer providing 40 lb of nitrogen per acre, or 1 lb per 1000 sq ft, is satisfactory for one application. For best results fertilizer should be spread in the spring and in the fall. For slopes with Crown Vetch or other legumes nitrogen should not be included as these plants contribute usable nitrogen to the soil. If cover is thin, an application of 50 to 100 lb each of phosphorus and potassium per acre, or 1 to 2 lb each per 1000 sq ft will hasten growth, but this need not be a regular practice. This coverage would be provided by 200 to 400 lb per acre of 0-25-25, or equivalent.

Where shrubs or natural woody growth is used, occasional thinning will help to keep the cover vigorous. An adequate herbicide program to keep noxious weeds and rank growth from taking over the slopes is part of good maintenance. Stands of Crown Vetch should *not* be sprayed, however, since this plant is susceptible to weed killing sprays. Weeds and brush will not be a problem because the Crown Vetch chokes out all other growth.

Whenever damage to turf occurs it should be repaired promptly because any break in the vegetal cover is a point where erosion will proceed rapidly. It is far less expensive maintenance to repair damaged spots at once than it is to repair extensive scarred slopes and clean out ditches and culverts where the eroded material was deposited.

Except where entire slopes are being reworked it is best not to use road graders or other heavy equipment on maintenance operations because they tend to tear up established vegetation, creating new points for erosion to occur.

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ROADSIDE DITCHES

Establishing cover on earth slopes must be accompanied by providing stable waterways for the collection of surface water if erosion control is to be adequate. The water concentrated by roadway surfaces and cut slopes can quickly reach erosive quantities and velocities, and unless the roadside is protected from this flow serious damage to slopes and roadway will occur. A secondary function of roadside ditches is to drain the base of the roadway to prevent saturation and loss of support for traffic.

In order to serve these purposes roadside ditches should be built and maintained in accordance with these principles:

1. **Provide enough area to accommodate storm flow and depth enough to drain the base course.**
2. **Protect the surface of ditches from erosion with turf cover or other suitable lining.**
3. **Keep velocities low enough to prevent erosion but great enough to prevent deposition or silting.**
4. **Maintain a continuous and unobstructed waterway.**
5. **Provide stable outlets to natural channels or drainage ditches.**

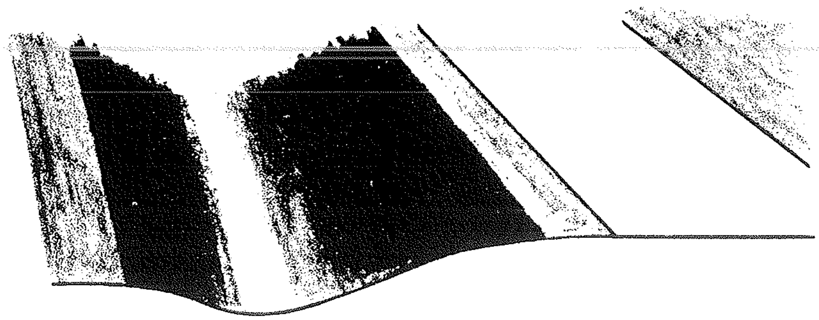
Cross Section

Roadside ditches are constructed with parabolic, trapezoidal and triangular, or "V" shaped, cross sections. The parabolic section is hydraulically the best and the most erosion resistant. The trapezoidal section is easier to construct and makes an adequate and stable ditch for most locations. It is used far more generally than the parabolic section. The "V" ditch is easily blocked with debris and is highly susceptible to erosion, and, therefore, is generally not recommended.

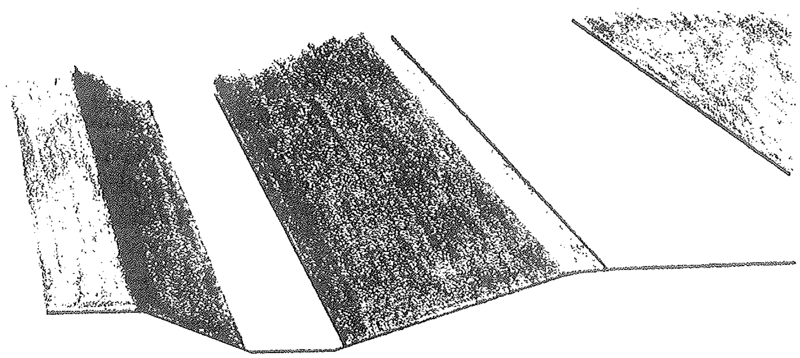
Ditch side slopes, as earth slopes generally, should be flat—4:1 to 2:1— and their intersections freely rounded. The liberal rounding of corners or edges is important because it makes establishment of grass easier and encourages a continuous turf.

The bottom of the ditch may be 1 to 4 ft wide, depending on the quantity of water, the length of the ditch and the grade. Generally the grade is parallel to the roadway grade, but in flat land the ditch may be steeper than the road and in rugged country the ditch grade may have to be flatter than the road grade.

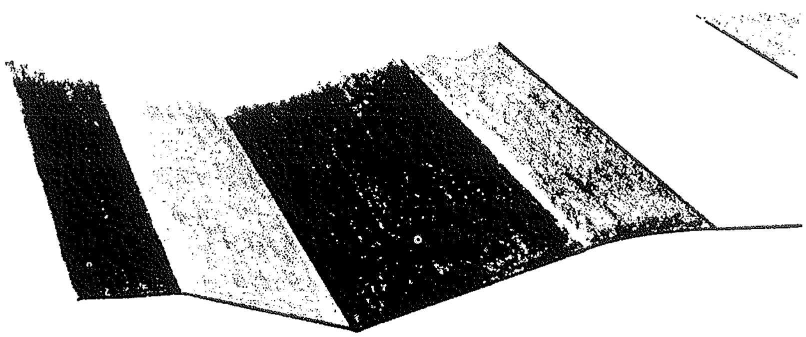
The secondary function of the ditch (draining the base course) is accomplished by cutting the ditch bottom to a depth 1 to 2 ft below



a. A parabolic ditch is the most efficient ditch section, and the least subject to erosion.



b. A compromise between hydraulic efficiency and ease of construction is achieved with this trapezoidal ditch. If the corners are well rounded, erosion is not severe. It is also much safer for traffic than triangular ditches.



c. The triangular ditch section, illustrated here, is the easiest ditch to construct. However, it is hydraulically inefficient and subject to erosion.

Fig. 15. Typical Ditch Cross Sections

the shoulder, at least so that normal water level is below the pervious base material. This will help to keep the roadway dry and stable enough to support traffic without rutting. It is best to extend the base course through the shoulder so it can drain freely into the ditch. However, even where cost precludes this construction, the free water level should be kept below the bottom of the base.

As a rule ditches satisfying these criteria will have adequate capacity. It should be noted, however, that further judgment of capacity can be made, without extensive hydrologic and hydraulic studies, simply by observing ditches during and shortly after an intense rain. The occasion of a spring rain accompanying a thaw is a excellent time to determine which ditches are serving adequately and which need improving. It may be perfectly safe for a ditch to be filled nearly to the shoulder provided this level is not maintained for long periods. Only on long, relatively flat channels will it ordinarily be necessary to provide extra capacity.

The shape and size of the ditch need not be constant. Capacity may be increased as necessary on a long channel without making the entire length to the extra size. A minimum width which will accommodate mowing and fertilizing equipment may be established, however, for efficient maintenance.

The first principle then—*Provide Capacity for Peak Flows and Depth Enough to Drain the Base Course.*

Surface Lining

Bare earth surfaces will stand only a limited amount of flow without serious erosion. Therefore, ditches should be given a protective lining to keep them serviceable and to prevent expensive and dangerous erosion.

Grass Lining

The most practical lining in most situations is grass. It is more economical than other linings to establish and will provide adequate protection indefinitely if a small amount of maintenance is done faithfully.

The important requirement for the grass is that it form a firm, dense turf. Bluegrass serves this function well in Indiana, with some tall fescue to give quick protection. The 4:1 mixture of fescue and bluegrass seed suggested for slopes can also be used in ditches. Reed canary grass also serves well as a ditch lining, giving good protection and requiring little care.

The rapid establishment of a vegetal lining in ditches is not difficult but requires attention to the same fundamentals as starting cover on slopes. The sides and the bottom of the ditch should be even and the edges smoothly rounded. Fertilizer should be applied at a rate of about 20 lb of 12-12-12 per 1000 sq ft, or equivalent, and worked into the soil. If lime is required, as shown by a soil test, it may be applied at the same time as the fertilizer. Seed is then broadcast at the rate of 1½ lb to 3 lb per 1000 sq ft and covered with 70 lb to 80 lb of straw or hay mulch.

In areas and seasons subject to considerable rainfall there may be difficulty in holding seed and mulch in the ditch. To overcome this problem an open mesh matting of paper or jute may be used instead of straw or hay mulch. The matting is laid down after seeding and pegged in place with staples of No. 8 wire. Where more than one

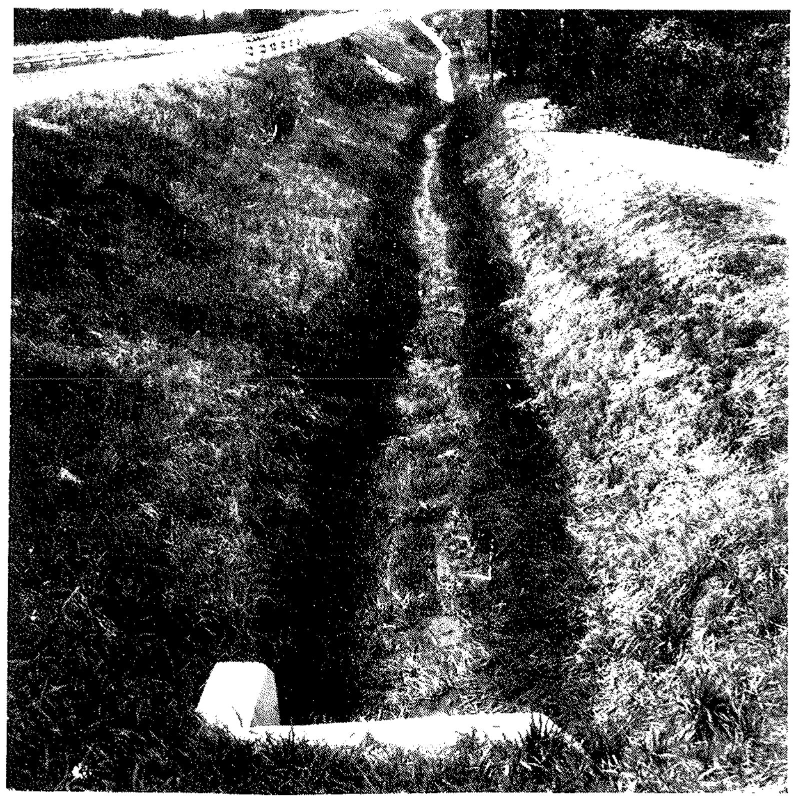


Fig. 16. A ditch and slope both protected with a healthy turf. The slopes were seeded and mulched. The thick, darker growth in the ditch illustrates the advantage of sod in providing immediate protection and more rapid development.

width of matting is required, as is usually the case, the adjacent strips should be overlapped 2 to 3 in. and stapled at 6 to 8 ft intervals. Care must be taken that the matting is everywhere in contact with the soil, for if water gets under the matting the seed and soil will wash away. The effectiveness of this installation depends on making the water flow over the net. When properly used this matting effectively prevents erosion until vegetation is established, even when subjected to substantial flows.

Another alternative is lining the ditch with sod, freshly cut, to a depth of about ¾ in., from a well established, dense turf. Sod strips should be placed across the ditch rather than lengthwise. Joints should be staggered and strips pressed firmly against one another. After sod is in place it is tamped or rolled to produce a smooth continuous surface. To keep the sod alive and insure a permanent lining it should be watered, as conditions require to prevent drying out, for several weeks after placing. This must, of course, be considered in estimating the cost of sod as a lining for ditches. However, a healthy bluegrass turf placed in this manner will withstand a considerable flow of water immediately after placing.

Paved Linings

60 There are two extreme situations where grass may be an unsatisfactory lining for roadside ditches—very flat grades and very steep grades.

On grades less than 0.5 per cent flow over a grass lining is likely to be too slow. (The per cent grade expresses the slope of the ditch bed in feet of rise or fall per 100 ft of horizontal distance —0.5 per cent is ½ ft fall per 100 ft; 2 per cent slope is 2 ft of fall per 100 ft.) When flow is too slow, silting or deposition occurs, creating a clean-up problem. Also, water remains in the ditch for long periods, killing the grass and providing a breeding place for mosquitoes.

Extremely steep grades, on the other hand, tend to create erosive velocities, scouring the turf and ultimately destroying such a lining completely if it were possible to obtain at all. On slopes between 5 per cent and 10 per cent the primary problem is establishing the turf. If it can be started, and is kept healthy by good maintenance, a grass lining will probably be satisfactory. On steeper grades it is difficult or impossible to establish and maintain a turf lining.

Alternative linings for these conditions can be constructed of asphaltic materials, portland cement concrete, or rubble masonry. These are all relatively expensive solutions, however, and are not recommended except where essential.

Bituminous Lining

Where a paved lining is clearly justified an asphalt concrete surface may be constructed. For this purpose a well-graded, dense, rich mix is desirable, using a paving grade asphalt of penetration between 60 and 100. Aggregate should be clean, sound and well graded with a maximum size of 3/8 in. to 1/2 in. Final thickness of the lining should be 1 in. to 1 1/2 in. Compaction is an important part of this construction. After the mix is spread over the surface it should be thoroughly rolled or tamped to produce a dense lining with a smooth surface.

In areas where weeds and brush are common it is well worth while to apply a soil sterilant to the ditch before a bituminous lining is placed because vegetation is one of the major causes of deterioration of such linings. Monuron, diuron, simazine, or comparable chemicals recommended for highway use may be used for this purpose.

Concrete Lining

Perhaps the most practical concrete lining construction for county highway operations is the prefabricated type. In this construction, panels are cast in standard forms at a convenient central location and hauled to the ditch site.

The ditch section is first shaped to line and grade, and the surfaces smoothed. The slabs are then placed in the ditch with joints

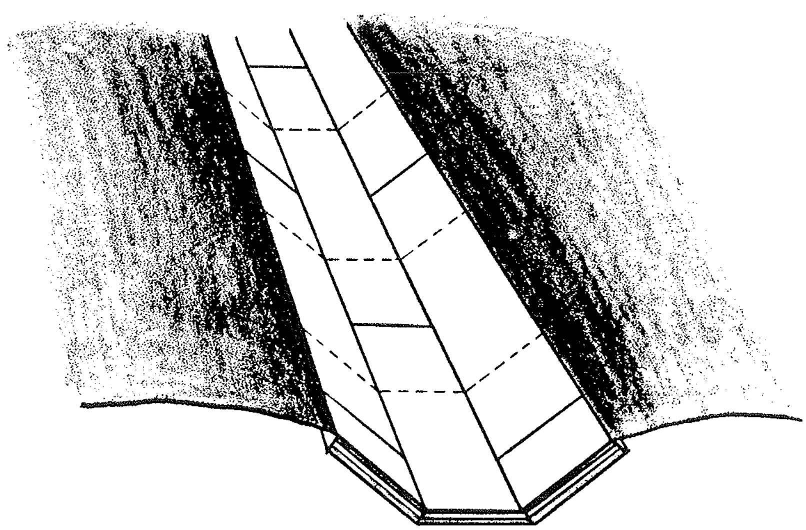


Fig. 17. Precast concrete slabs provide a convenient means of lining steep sections of ditches where turf does not give adequate protection. Slabs are cast at a central location and assembled in the ditch.

staggered. Galvanized No. 8 wire is run through holes in the panels and fastened with a loop, or "pigtail," on each end to lace the units into a continuous mat. The concrete should extend up the sides at least 6 in. higher than normal flow. The banks above the concrete are then sodded, or seeded and mulched, to establish a turf right up to the edge of the lining.

Prefabricated panels for this purpose can be constructed easily either out of doors on smooth bare ground, or inside on a hard floor. A panel 1 ft by 3 ft by 2 in. thick weighs about 75 lb and is a practical size for handling, although narrower units may be cast for the bottom of small ditch sections.

Concrete for precast slabs should be of a medium consistency, using a ¾ in. maximum size aggregate and not more than 5 gal of water per sack of cement. The slabs should be kept wet continuously for at least three days, and preferably seven days, after placing in order to get full strength in the concrete.

Only rarely will it be necessary to use a paved lining. Generally, turf, with proper attention to ditch capacity and water velocity, will serve well and be most economical. Regardless of choice of material, however, the fundamental principle is—*Establish an Erosion Resistant Lining to Protect Ditches from Scour.*

Velocity

There are two limiting velocities for proper functioning of roadside ditches. Flow must be rapid enough to prevent silting, or deposition, yet not so fast as to cause damaging scour. It is not easy to measure or predict the exact velocity of flow in a ditch. In addition, the minimum allowable velocity depends in part on the amount of material the water carries from adjacent land, and the maximum value depends on the ditch lining. Therefore, a major portion of roadside ditch construction and maintenance is based on understanding of factors which influence velocity of flow, and judgment of the conditions in existence at the ditch in question. Fortunately the allowable velocity range is great enough so that most of the county highway system can be well drained with a minimum of maintenance by using a basic ditch section, roughly parallel to the road, and lined with turf. A few situations will require attention to the limiting velocities.

Low Velocity

In flat terrain the problem may be to get the water to flow.

Grasslined ditches should have a slope of at least 0.5 per cent. When the roadway grade is less than 0.5 per cent the ditch must have a steeper grade than the roadway. This means that the ditch will get deeper as it moves down grade, and, if one is to keep the side slopes flat, the ditch will move farther away from the centerline of the road. The grade of a ditch should always be smooth, with no sudden changes of direction. It is especially important in the case of flat ditches that the grade be checked with a survey instrument because a flattening of the grade at any point may reduce velocity enough to cause serious silting. One approach

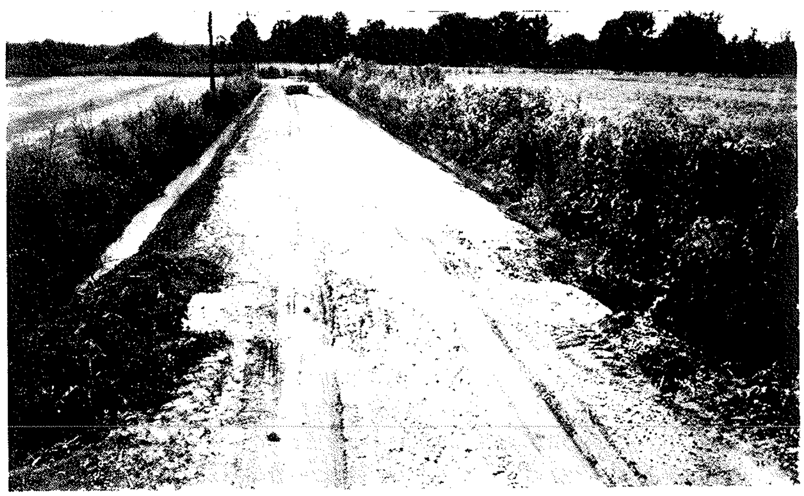


Fig. 18. This ditch illustrates two weaknesses—the outlet is plugged with debris, and the slope is too flat. Even when the outlet is cleaned out, this ditch will need more slope to drain all the water.

to the problem of silting is to concentrate low flow in a small V-shaped secondary channel in the bottom of the ditch. This should be seeded also to protect it from erosion under storm flow, but concentrating the low flows will sometimes give adequate velocity. If flow is still too slow, or if sustained flow over long periods makes it imposible to maintain the turf lining, a half section of pipe may be placed in the secondary channel. The smoother lining will give greater velocity and still protect the soil from substantial flow. The turf in the main channel must be well established right up to the pipe to prevent scour or undercutting at that point.

High Velocity

Steep, hilly country, in contrast to the plains, is likely to present the problem of preventing excessive velocities. A good strong turf lining will withstand velocities up to 6 to 8 ft per second—that is, about 4 to 5½ miles per hour. One way to get a rough idea of velocity of flow is to throw a wood chip into the ditch during an intense storm. If a man can keep up with the chip at a moderate walk the velocity is safely below the maximum. If he must walk as fast as possible to keep up with the chip the velocity is at, or above, the safe maximum. That is, a turf lining would not withstand more than short periods of such a flow, and is likely to require excessive maintenance if it is to give adequate protection.

Excessive velocities are likely to occur where grades are more than 6 per cent. Therefore it is desirable to keep ditch grades less than that. If the roadway grade is not much steeper than 6 per cent it is sometimes possible to keep the ditch grade flat enough by making the ditch deeper at the upper end than at the lower end. In this case the location is fixed by the lower end, and, if possible, the ditch centerline moves away from the roadway as it moves uphill to keep the side slopes flat.

On steep grades a series of checks can be installed in the ditch so that the ditch grade is considerably flatter than the roadway, and the excess fall is taken up at the drops. Such checks may be constructed of sod, rubble or timber planking. If rubble or plank is used, it should be set well into the ditch banks and bottom to protect against undercutting. Checks may be 6 to 24 in. high and must have an apron of rubble or pavement for 3 to 4 ft on the downstream side. The top should be perfectly level to distribute the flow evenly.

An alternative solution to the problem of high velocities is to pave the ditch with rubble, bituminous concrete or portland cement concrete. It is important to remember, however, that paved linings result in still greater velocities representing erosive energy which must be controlled at lower levels. If the water cannot be emptied directly into a stream that is deep enough to absorb the flow without scouring it may be necessary to build a drop structure or stilling basin to absorb the excessive energy. Therefore it is recommended that paved linings not be used unless a turf lining is clearly inadequate or impossible to establish.

The guiding principle with respect to velocity is—*Keep Flow Fast Enough to Prevent Deposition Yet Slow Enough to Prevent Scour.*

Continuity

One often neglected principle of a satisfactory drainage system is to have a continuous waterway, unobstructed by cross roads, driveways, turnouts and the like. It is evident that if a ditch is so obstructed that the water is ponded, drainage is less than satisfactory. Stagnant pools tend to saturate the road bed, destroying its stability, and they also are breeding places for mosquitoes.

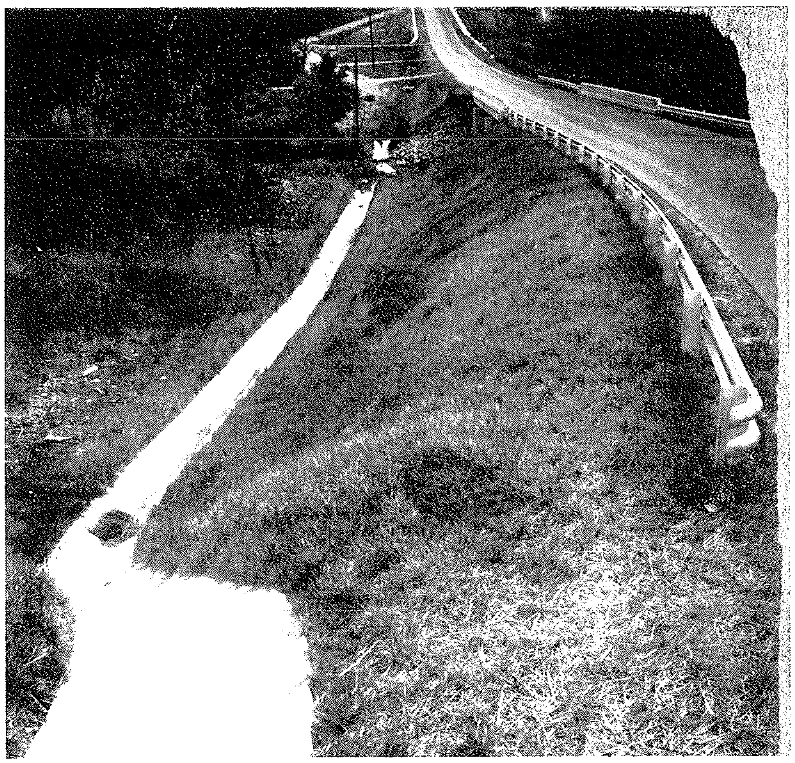
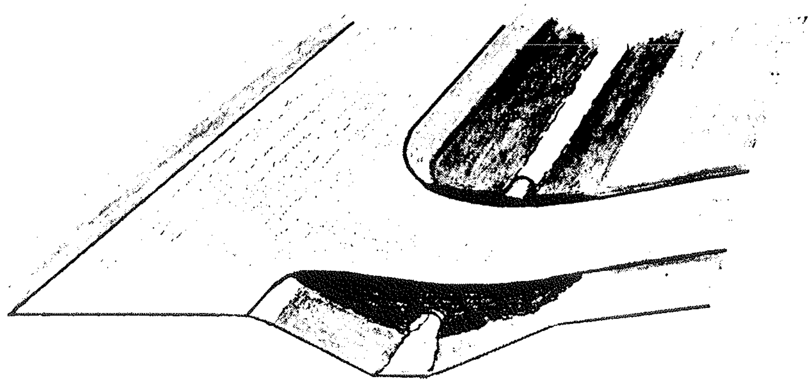


Fig. 19. An excellent example of a continuous ditch is shown here. Note culverts (top center) under each driveway, paved lining on steep sections, and the outlet to the stream.

There are two ways to get around this difficulty. The usual approach is to install a culvert under the obstruction. This is generally corrugated metal pipe or reinforced concrete pipe of standard strength. The pipe should be large enough to carry the storm flow in the ditch, and at least 8 to 12 in. in diameter. Smaller pipes are easily clogged by leaves and sticks and are difficult to clean. If the fill is subject to heavy loads, such as an entrance to a gravel pit, the specifications of the manufacturer should be checked to see that the pipe will carry these loads with the amount of cover which is proposed. The invert of the pipe should be placed in line with, and at the same grade as, the ditch bottom. Also the culvert should be long enough so that an easy turn can be made by traffic moving off or onto the road. It is desirable to depress driveways where they cross the ditch line to avoid shedding surface water from higher ground onto the roadway.

The other approach, where topography permits, is to put a dip in the profile of the fill or driveway. The dip must be to the depth of the bottom of the ditch, and the ditch sides graded to meet the



a. A culvert is provided under a driveway to provide a *continuous* waterway so that collected water is not ponded above the obstruction. Note the low point in the driveway to shed water from the drive into the ditch, rather than onto the roadway.

b. Where topography permits, the driveway may dip into the ditch instead of using a culvert. Full depth of the ditch must be maintained and the edges of the driveway graded naturally into the ditch sides.

Fig. 20. Typical Driveway Profiles.

profile of the driveway. This construction will not be acceptable for traffic of any substantial speed, however, and should be used with care.

A great deal of good work in ditches is wasted if this principle is neglected—*Make Roadside Ditches Continuous, Unobstructed Waterways to Natural Watercourses.*

Outlets

A large portion of ditch erosion occurs at points of outlet to natural waterways or drainage channels. When outlets are not made safe from erosion serious damage frequently occurs to the road as well as to bridges and culverts. Therefore it is essential to provide a well protected sluice or chute to carry water from the ditch level to the stream level, or to build an outlet structure.

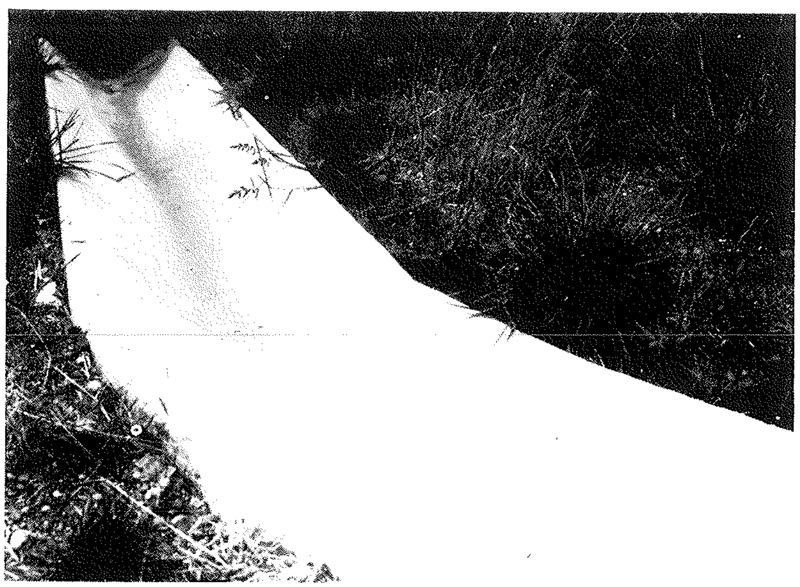


Fig. 21. A paved sluice, such as this, is a stable outlet for a ditch. The lining protects the slope from erosion.

In most situations a sluice can be made to serve safely and is less expensive to construct than a structure. The grade should be as flat as possible—preferably less than 10 per cent. Since there usually is a considerable drop from ditch to collecting channel it is necessary to divert the sluice well away from the road as it drops to the stream in order to meet the grade requirement. Turf is the most economical lining where it can be used. Frequently however, the problems of establishing it will require some of the special measures for starting grass linings. The most common approach is to sod the channel as described for ditch lining. Because of the concentrated flow that may occur at the outlet it is wise to peg the sod strips down with wooden stakes driven flush to the surface. Also, the lining should be extended far enough up the sides of the sluice to insure that the water will not rise above it, for that could cause the entire lining to be washed away.

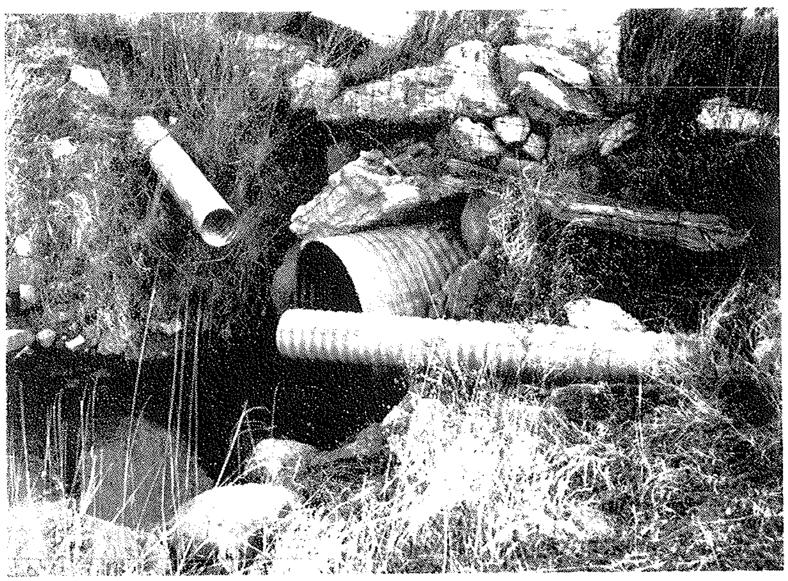


Fig. 22. Two pipes overhanging the stream provide outlets to the ditch from both sides of this stream.

If the grade is not too steep or the quantities great, the method of seeding and covering with jute or paper matting may be used. It is especially important here that the matting be in contact with the ground at all points because it protects the soil only by making the water run over the mesh. If water gets under the matting the seed bed may be completely destroyed. The staples should be closely spaced. The matting along the sides of the sluice should be above the highest water and turned under the soil at the top edges.

Where conditions are too severe to permit establishing a turf lining, or if right-of-way is too limited to permit flaring the sluice, a paved surface may be used instead, or an outlet structure may be installed. Frequently such a structure may consist simply of a

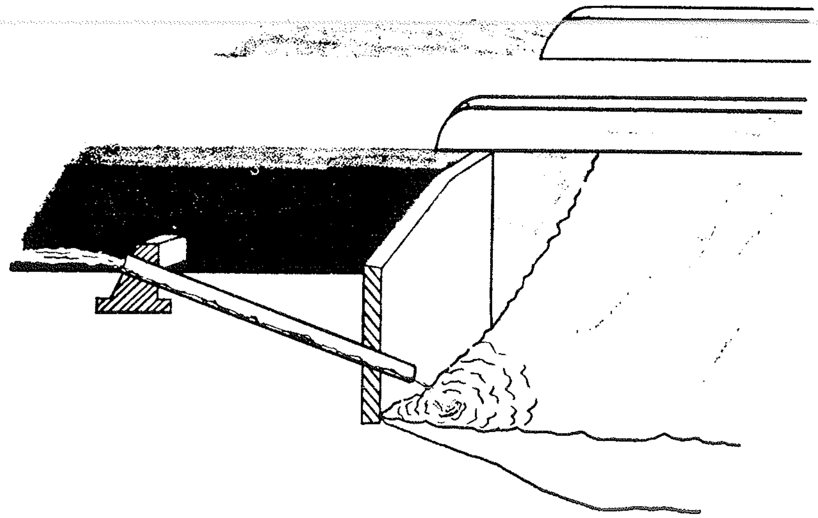


Fig. 23. A straight pipe may be used to outlet a ditch where the drop is too steep to maintain a sluice without erosion.

pipe running from the end of the ditch to the stream. The outlet end should be at least 1 ft above the water level in the stream and, preferably, should extend out from the stream bank far enough so the flow does not fall on the bank. If this is impossible, the bank may be protected with rubble or paving. When the drop is very 69

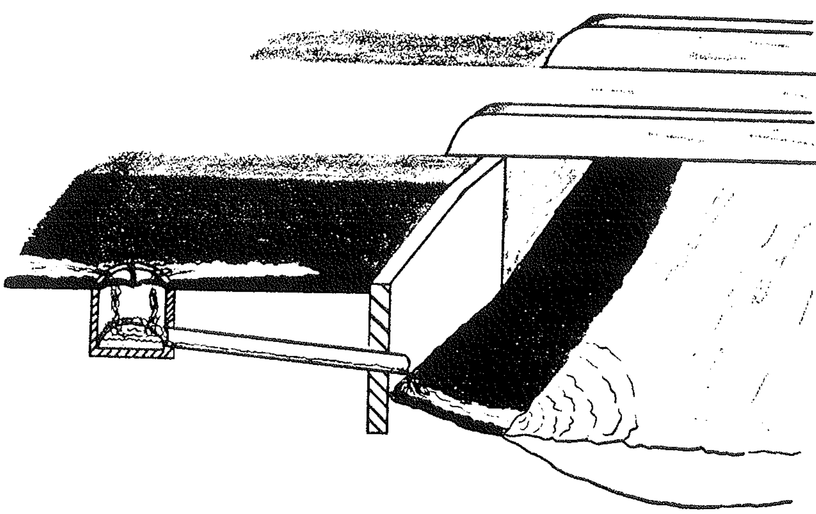


Fig. 24. For high drops into shallow waterways, a drop inlet may be used to reduce the grade of the outlet pipe. Here the excess energy is dissipated in the drop inlet, so erosion does not occur in the stream.

high, or when the collecting waterway has a small flow so that scour of the channel is likely, the outlet may be a vertical drop at the end of the ditch with a pipe from the bottom of the drop to the stream. The drop may be a section of large diameter pipe or may be constructed of bricks, concrete block or cast-in-place concrete, but it should be large enough to permit cleaning. Whatever structure is used the inlet end should be protected with a device to keep trash from entering.

In some areas the road is built above the surrounding ground and the accumulated runoff from the road joins the general surface drainage. It is important in such situations that where the ditch ends the concentrated flow be spread into a broad sheet so as not to cause gullying and serious erosion on the adjacent land. If the quantity of water is so great that this cannot be done satisfactorily the ditch section may be continued at a level below the surrounding ground to carry the accumulated flow to a stream or drainage channel.

Concrete or metal pipe crossovers may be installed to drain water from one side of the road, where there is no natural outlet, to the other side, if the flow can be carried away in a ditch or over the surface.

An important principle for all ditches—*Provide Safe Outlets to Natural or Artificial Watercourses.*

Field Drains

In areas of agricultural drainage roads often pass through areas that are crossed with tile or open ditch drainage systems. These systems should empty into their own collecting lines which carry flow to a main ditch or natural watercourse. They should not discharge directly into a roadside ditch because they interfere with maintenance operations, they contribute additional flow which may require extra ditch capacity, and they may contribute sustained low flows which make it difficult to keep turf alive. Also, the erosion hazard is greatest at points where concentrated flow enters the ditch, each tile outlet, therefore, represents a potential maintenance problem for the highway department.

Landowners should be encouraged to correct these situations where they exist. Where it is clearly of mutual benefit to county and landowner a single ditch may be made to serve both the road and the adjacent land rather than building two parallel ditches. However, the maintenance, as well as the benefits, of the ditch then should be shared by the county and the affected landowners.

Maintenance

Maintenance of open ditches, to be most effective, should be directed toward causes of problems rather than effects. To this end, observation of drainage conditions during and immediately after heavy storms is particularly helpful in determining what needs to be done to correct existing problems or improve a drainage system.

A first requisite for ditches, of course, is to keep them clean and free of obstructions. Culverts and outlets should be checked regularly. These points are especially susceptible to plugging with branches, brush or other debris. If they are kept open a great deal of damage from water backing up is prevented.

Fig. 25. This culvert is almost completely useless until it is cleaned out and the erosion which produced the silt is stopped.

Regular mowing and occasional fertilizing will keep turf healthy and reduce problems of weeds and brush. Where undesirable growth does get started a sound herbicide program can be especially helpful in improving the drainage. Dead brush, branches, leaves and trash should be removed from the ditch.

Where silting has occurred it is important to find the source of the material and to take measures to prevent further erosion. Secondary steps will include removal of the deposited soil. On a turf lined ditch cleaning operations are best done by hand. Blade graders have been used for ditch cleaning, but unless blading is part of a general reshaping and seeding, or sodding, project it should be avoided wherever possible. The blade tends to dig into established turf, exposing the earth and creating points where erosion will proceed much more rapidly. Material removed from ditches should be hauled away rather than spread on the shoulders to be washed back into the ditch.

Wherever the protective lining is damaged it should be repaired immediately to forestall further erosion. Points to be watched especially for this are outlets from ditches and places where concentrated flow enters. Efforts, such as these, directed toward prevention of erosion and maintaining well drained roads will help to stretch the highway dollar over the most miles.

Fig. 26. Two extremes—above, a well constructed and maintained ditch; below, a ditch completely overgrown with weeds and brush.

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CULVERTS

Culverts may serve county highway drainage in almost every location where roads intersect or a driveway enters a highway, in locations where water in a roadside ditch must cross the highway to reach natural drainage, and at many stream crossings. In any of these situations, a culvert separates the water and traffic streams to permit continuous flow of both.

Though culverts are constructed in several different forms and of various materials, the selection and installation of culverts for all locations are based on the same fundamental principles. In the case of large structures for stream crossings, waterway area and strength may be the controlling factors, while for a pipe under a driveway, ease of cleaning and limited headroom may be more important considerations. However, in all cases these are the guiding principles:

1. **Choose a culvert type and material to suit conditions at the particular location.**
2. **Provide enough area to take care of flood flows and strength enough for the loads to be applied.**
3. **Establish a grade and alignment which will give smooth, steady flow.**
4. **Provide a firm foundation and compact backfill for complete support around the structure.**
5. **Protect entrances and exits from scour, and flare entrances for maximum capacity.**

Culvert Type

Pipes

A large number of small culverts are constructed of standard pipe sections of concrete, corrugated metal, vitrified clay or other material. Pipe culverts are an economical solution to a great many drainage problems because they are readily available, easy to handle and install, and can be placed in almost any location.

What kind of pipe should be used? This is primarily a question of economics. The most frequently used materials are concrete and corrugated metal. Because of its smooth surface concrete pipe will have slightly greater capacity than a corrugated metal pipe of equal size. Concrete pipe has good resistance to abrasion and is not likely to produce silting during low flows, therefore it is often desirable for streams carrying large amounts of silt and sand or other debris.

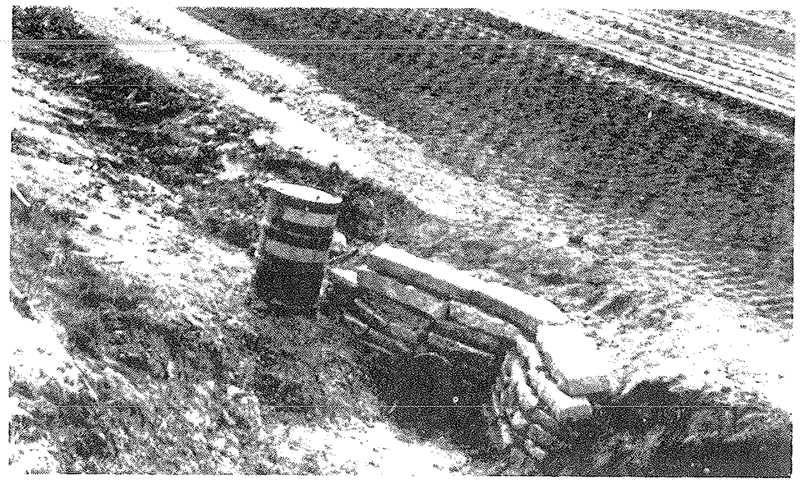

Fig. 27. The majority of county highway drainage structures are simply pipe culverts such as those shown here. (Courtesy Armco Drainage and Metal Products, Inc.)

Corrugated metal pipe has an advantage in its flexibility for use on soft foundation materials or where there is danger of settlements or slides. Corrugated metal helps to minimize erosive power of streams, especially if the pipe is long.

Vitrified clay pipe is quite durable in areas where soil or water are contaminated with corrosive substances. Before choosing a pipe for a location near a coal mining operation, or in the vicinity of peat or muck deposits it is best to have soil and water samples tested by a laboratory. Highly acid or alkaline soils and water (pH less than 5 or greater than 8) are especially corrosive to metal and concrete pipe. Soils contaminated with sodium or magnesium sulphates are also damaging to these materials. In locations so contaminated, vitrified clay is the best material. If it is necessary to use metal pipe it should be protected with a bituminous coating.

Box and Multiplate Culverts

Capacities greater than that provided by standard pipe sections are sometimes required. Reinforced concrete box culverts and multiplate pipe or arches are sometimes used to get the extra capacity. Such structures may also be used where unusually high fills will create extreme loads on the culvert, or where the span length required would involve a bank of several pipe culverts. With structures of this size, however, economic solutions cannot be achieved by rule of thumb procedures. It is necessary in these cases to make use of careful design both for hydraulic and structural conditions.

The first principle of culvert practice—*Select a Culvert Type and Material Suited to the Conditions of the Particular Location.*

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NOTE: The deleted text presents information about the sizing and structural design of pipe culverts. That information is more fully covered in Compendium 3: Small Drainage Structures.

Grade and Alignment

In general, the best location for a culvert is in the natural channel or at the center of the ditch, following the alignment and average grade of the bed. This is especially important in rolling and rough country where water velocities are relatively high.

In flat land, where velocities are low, alignment may be varied from the natural channel to permit placing the culvert in the dry or to make a square, rather than a skew, crossing. Generally the grade should be straight with the inlet and outlet conforming to the existing channel bed.

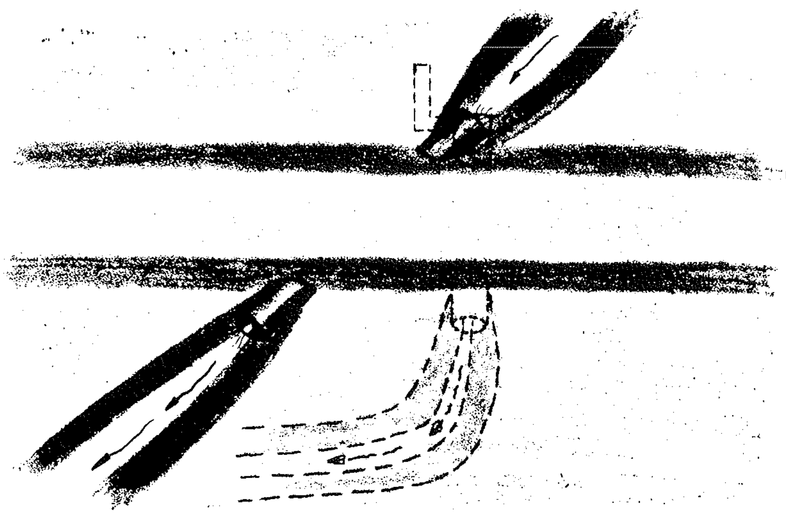

Fig. 30. Usually the extra length of pipe required by a skew crossing pays for itself in better drainage conditions, with no erosion or deposition problems. The alternate location indicated often results in a continuous maintenance problem.

In steep areas with high water velocity it is best to maintain the direction of the channel, even where it requires a skew crossing. A sudden change in direction of fast moving water results in a highly erosive condition on one side of the channel and, frequently, silting on the other side. Where it is essential to change the alignment, the inlet end should be placed in the natural channel and the adjustment made at the outlet end as necessary. Stream velocity may sometimes be reduced by placing the first few feet of pipe on a steep grade and placing the remainder on a flat slope. If the stream bed is in rock or coarse gravel so that erosion is not a problem, the grade line of the culvert may follow the natural ground rather than making rock cuts to get a straight grade or flat slope.

Culvert locations above the natural channel should be avoided where possible because such locations create ponding on the upstream side of the road and may endanger the embankment.

Deposition is usually not a problem in culverts with a straight alignment and direct inlet and outlet because flow is faster in the culvert than in the channel. In roadside ditches at culvert entrances and crossovers control of silting is primarily a question of controlling erosion, as discussed in previous section. Culverts can create erosive conditions, however, by increasing velocity. In such locations corrugated pipe can have an advantage over smooth pipe, especially if the culvert is long, by helping to keep velocity low. Sharp bends at entrances should be avoided. If the channel has

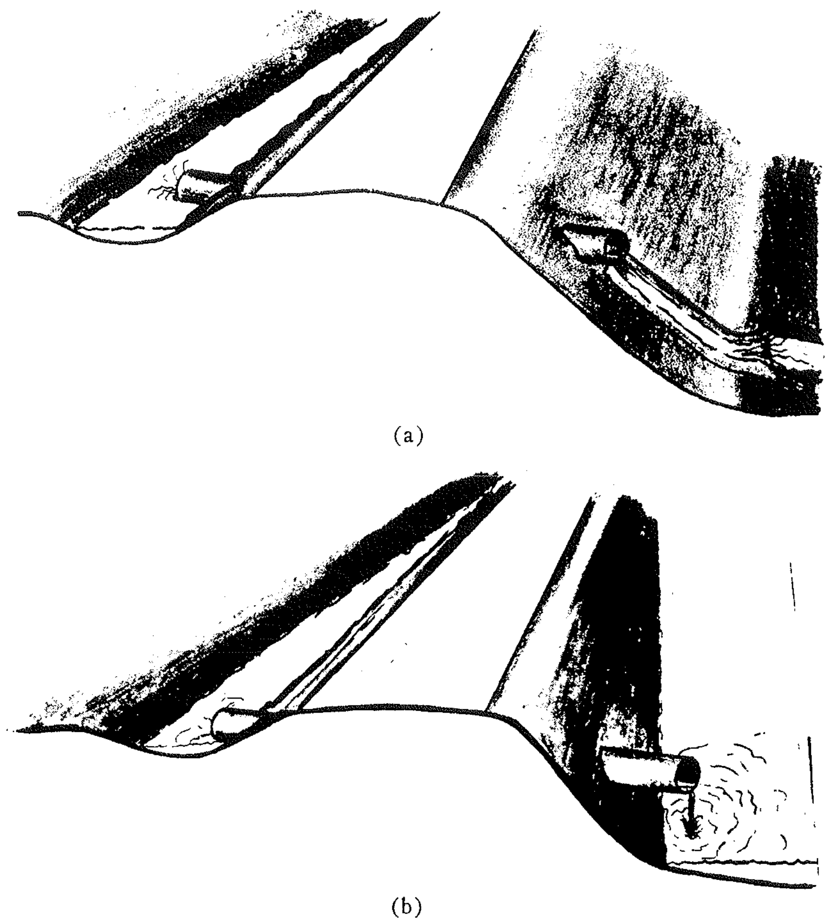

Fig. 31. Culvert grades can be reduced by either of these techniques. Protection from erosion at the outlet is essential. Less pipe is required in (a) but maintenance of a sluice is eliminated in (b).

a steep grade, the pipe may be placed at a flatter grade than the channel with a free fall at the outlet end. The outlet end of the pipe should be extended out from the fill far enough so that the flow will not fall on the toe of the slope. A basin may be formed below the exit to absorb the energy of the falling water without erosion. An alternate possibility is to pave the earth slope below the pipe or protect it with riprap. This approach should not be used, however, for a steam which carries a large amount of silt and debris, because the reduced grade of the pipe will reduce water velocity which will result in deposition.

Culverts placed under high fills tend to settle more in the center than at the ends. In order to prevent a sag occurring, the pipe may be laid with the center slightly higher than the ends so the settlement will result in a straight grade.

Principle number three is—*Place Culverts on a Line and Grade to Give Smooth Flow and Complete Drainage Without Erosion.*

Installation

Pipe culverts depend on the soil surrounding them for much of their strength. Therefore, it is important that they be installed with careful attention to foundation and backfill conditions.

Bedding

All pipe should be bedded thoroughly to give adequate support. In firm earth this is accomplished by shaping the bottom of the trench to fit the pipe. This fitted foundation should be about half

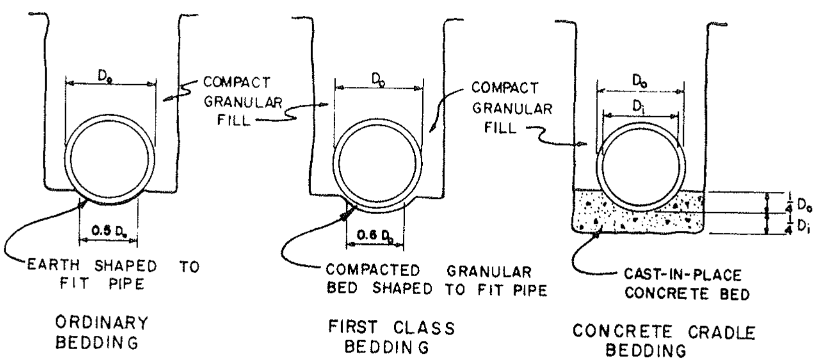

Fig. 32. Bedding classes for culvert pipe. The foundation for pipe culverts should *always* be shaped to fit the pipe. Most culverts are placed with ordinary bedding. Extra strength is provided by first class and concrete cradle bedding. (Concrete cradle should not be used with flexible pipe such as corrugated metal).

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as wide as the pipe diameter. When bell-end pipe is used extra depth must be provided for the bells in order to get continuous support through the straight portion of pipe.

Shaping the earth to fit the pipe is satisfactory for most installations and is called ordinary bedding. First class bedding will give greater strength needed for heavy loads or high fills. Rigid pipe may be placed in a concrete cradle for extremely heavy loads. These bedding classes are illustrated in Figure 41. No pipe, of any material, should be placed directly on rock or extremely hard earth. Rock foundations require an over-excavation 8 to 12 in. below the bottom of the pipe and about as wide as the pipe diameter. The excavation is then backfilled with compacted granular fill and shaped to fit the pipe.

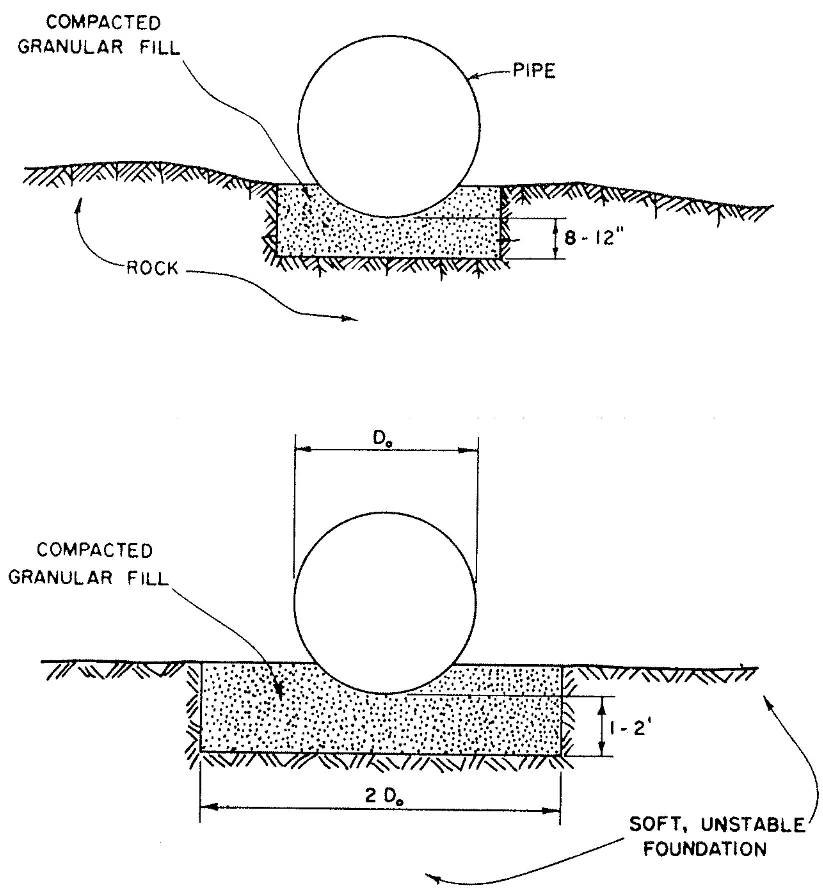

Fig. 33. Foundations in hard and soft materials. Gravel mats should be provided as bedding for pipes both in very hard and very soft material.

Soft, unstable foundations also require special treatment. A gravel mat may be used to support the pipe, as in rock foundation, but a larger layer of fill is generally required. A trench is excavated in the undesirable material about twice as wide as the pipe diameter and 1 to 2 ft deep, as necessary. The trench is then backfilled with compacted gravel and shaped to receive the pipe. In swamp and muck areas a timber or brush mat may be placed on the foundation material and covered with an earth cushion before installing the pipe. Concrete pipe may be placed directly on timber supports.

Placing

As soon as the foundation is prepared, laying of the pipe can begin. Work should begin at the downstream end and progress upstream. Bell or groove ends, if used, should be placed upstream. Line and grade should be checked carefully as each section is placed. Joints are completed as placing proceeds.

Corrugated metal pipe sections are usually joined with corrugated metal bands which go around the pipe, covering several corrugations of each section. The band is fastened with bolts, using clamps or chain hoists on the larger diameter culverts to help get

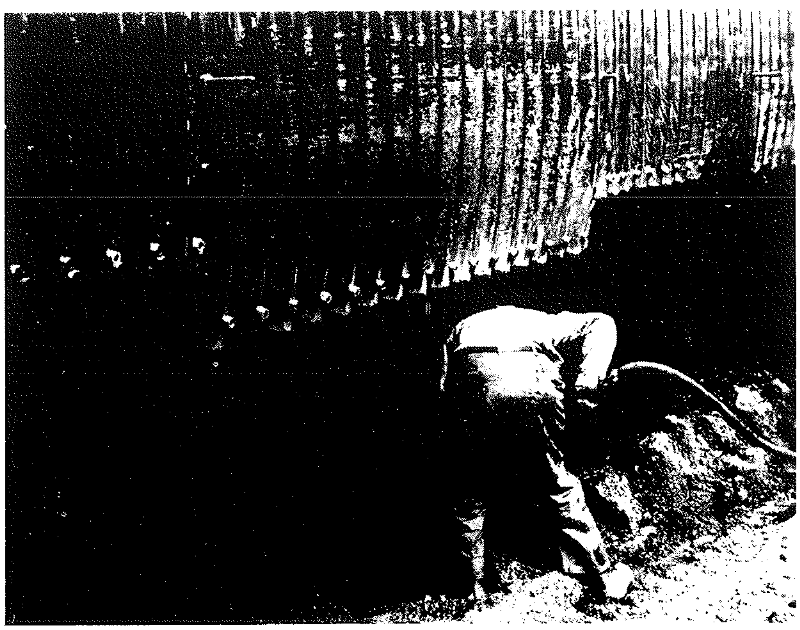

Fig. 34. Backfilling is a most important part of the installation of pipe culverts of all sizes. Note the clean, granular fill and the thorough tamping under the sides of the pipe. (Courtesy Armco Drainage and Metal Products, Inc.)

the band tight. Concrete or clay pipe may be easily joined with rubber gaskets which fit between the tongue and groove ends. Otherwise, joints may be made with portland cement mortar or grout. After the joint is complete, the inside should be finished smooth and even with the surface. For pipe larger than 30 in. in diameter this finishing is usually done after the backfill has been placed. Backfilling can proceed immediately following the jointing, care being taken to prevent displacing the pipe.

Backfill

Backfilling, as pointed out, is a most important phase of culvert installation. The material should be free of stones and debris. Soil should be placed in 6 to 8 in. layers and thoroughly compacted with mechanical or hand tampers. Special care must be taken to insure compaction under the sides of the pipe. Layers are brought up equally on both sides of the culvert to avoid shifting. It is best to have some cover over the culvert before equipment is run over it.

Endwalls and Headwalls

Frequently it is not necessary to use endwalls and headwalls for pipe culverts. When they are used, as where right-of-way is limited, they should be constructed on a firm foundation to prevent settlement or tipping. Footings should be placed well below stream bed to prevent undermining. Shifting of an endwall can pull apart sections of culvert pipe, ultimately causing complete failure. Therefore, they should be constructed so as to prevent movement.

A most important principle for all culverts is—*Provide a Continuous Firm Foundation and a Uniform Well Compacted Backfill for Adequate Support.*

End Treatment

Ends of pipe culverts require special attention to assure effective flow conditions and prevent scour. The length of a culvert, too, may be affected by the type of end treatment.

One common practice is to make the pipe long enough to project beyond the toe of the roadway fill at both ends. The fill is protected with sod or riprap, but no other special treatment is given for small diameter pipes. For larger diameter pipes, the ends are often beveled to conform to the fill slope both to improve appearance and to make a more effective entrance for water on the upstream end.

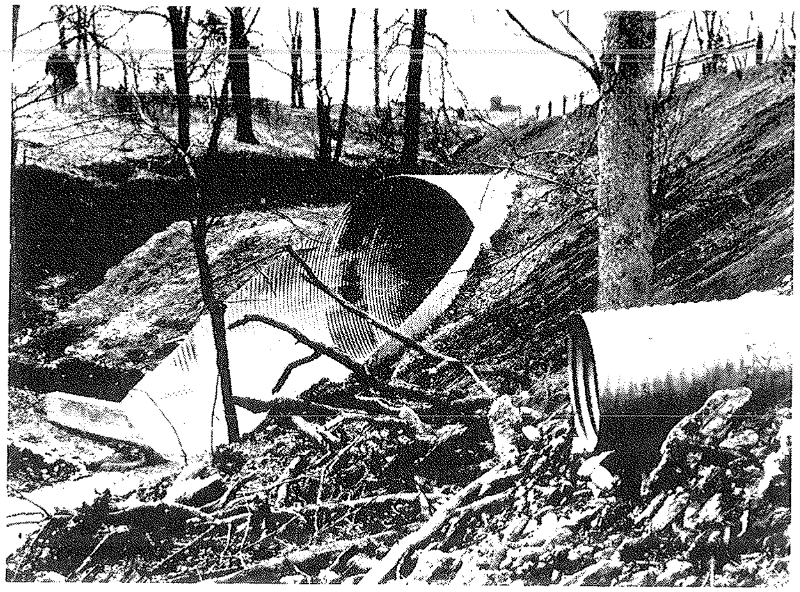

Fig. 35. Two end treatments are illustrated here. Note the smaller pipe extended straight beyond the toe of the embankment, and the larger pipe beveled to fit the slope. A concrete sill at the invert of the large pipe prevents undermining. (Courtesy Armco Drainage and Metal Products, Inc.)

Culvert length may be shortened considerably where necessary, especially if fill slopes are flat, by installing a headwall and endwall to retain the fill above the pipe. Such a structure may also be used to help prevent scour in a fast moving stream. Total cost, however, is likely to be more than a longer pipe with no end structures.

With the exception of long culverts on flat grades, the entrance conditions are important in determining the capacity of pipe culverts. Straight, sharp entrances, or headwalls with square corners cause water to back up on the upstream side of the fill. This ponding can be reduced by rounding the edges at the entrance or by flaring the entrance to make a gradual transition for the stream. The bell or groove end of concrete and clay pipe provides a reasonably good entrance. Standard flared metal ends are available for the ends of corrugated metal pipe. Where headwalls are used, the corners at the pipe entrance should be well rounded. Wing walls projecting at an angle to the headwall also will provide a flared effect to help converge the flow. Also, as noted, beveling the ends of large diameter pipes to fit the fill slopes improves the entrance condition.

Fig. 36. A typical standard flared end section will improve entrance conditions and protect streambed and embankment from erosion. (Courtesy Armco Drainage and Metal Products, Inc.)

Where the stream bed is erosible, or velocities are high, a paved apron may be constructed, extending 3 to 4 ft from the pipe entrance and exit to prevent gullies from forming. At the end away from the pipe, a sill, or cut-off wall, should extend 1 to 2 ft below stream bed to prevent undercutting.

A major problem with cross drains is to turn the water from the ditch into the culvert. If the cross drain occurs at the end of a ditch this may be accomplished by installing an L-shaped headwall, the projecting leg of the headwall turning the water into the pipe. A better practice, where possible, is to place the culvert deeper under the road with a drop inlet or vertical pipe section at the ditch line. The opening should be protected with a grate.

A fifth principle—*Protect Ends of Culverts From Scour and Flare Entrances for Maximum Capacity*.

Maintenance

The first requirement of culvert maintenance is regular inspection. A major cause of failures is the accumulation of debris at the culvert entrance or on a fence line just above the entrance. The ponds resulting from such barriers saturate the road bed and back up ditches preventing proper drainage. A fence piled high with brush may give way sending a sudden surge of water which washes out the culvert completely. These maintenance problems are best cured before they occur. Regular inspections will show where cleaning is required and simplify the job of keeping the entire highway drainage system operating properly. Culvert locations should be marked with a stake or iron post near the entrance. On paved roads an arrow and a distance to the upstream end may be painted on the surface.

When inspection shows damaged or separated pipe sections, repair or replacement should be made promptly. If storm flows occur through damaged culverts, the surrounding fill becomes saturated and much of the supporting fill may be washed away.

Scour at inlet or outlet should be controlled by sod, riprap or paving before undermining can endanger the structure.

Silt and sand deposited at culvert entrances may not be a serious problem normally. Where this does accumulate, it is important to recognize that excessive erosion is occurring upstream. Location and correction of the erosion is generally more important that the clean-up operation at the culvert. When silt accumulation reaches serious proportions it should be removed. Sometimes silt can be flushed out with a pump and high pressure stream. Frequently, a hand shovel is a more effective tool. Silt accumulation removed from culverts should, of course, be hauled away from the site rather than be dumped on the shoulder to wash into the ditch again in the next rain.

Winter maintenance should include checking all culverts after snow plowing operations. Snow piled at culvert entrances and exits can effectively block drainage, creating serious ice problems.

Culverts carefully planned with regard to size and location, properly installed, and maintained regularly will go far toward an effective highway drainage system.

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SUBDRAINS

As has been noted, many highway problems are related to excess water. Unfortunately, an excess of water cannot always be prevented by providing only proper surface drainage. Sometimes eroding slopes and soft pavements are the result of water moving through pervious layers of soil, or of a high water table. In order to correct these problems it is necessary to install drains below ground which will intercept and carry the ground water to a stream or open drainage system.

Below are listed a few fundamental principles and guides to successful use of subdrains:

1. **Make subdrains deep enough, long enough, and so located as to drain excess water from critical locations.**
2. **Provide a protected outlet to a stream or open ditch.**
3. **Select a clean, pervious backfill material to serve as a filter.**
4. **Install subdrains on a firm foundation with a well compacted backfill.**

Application

Cut Slopes

Cut slopes which continually slough away at a point where free draining water reaches the face can be stabilized by installing a subdrain back of the cut face. Figure 37 shows such a drain installed to a depth slightly below the pervious material and backfilled with clean sand. The underground water is carried away in the drain to an outlet at a stream, removing the cause of sloughing. Then a normal grass cover will prevent ordinary slope erosion from surface water. This, in some situations, however, may not be possible due

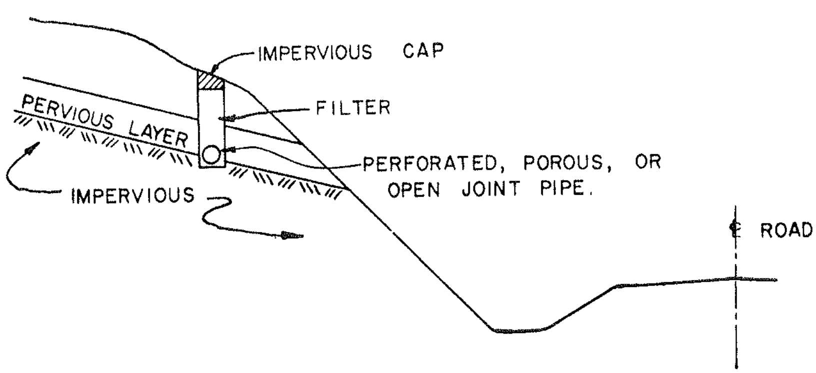

Fig. 37. This shows a subdrain intercepting free water in a slope before it reaches the face where it would cause sloughing or sliding.

to excessive depth of ditching. In cases such as this consideration may be given to installing drilled or driven horizontal drains. An accurate detailed survey must be made by competent persons before such a treatment is attempted.

Subgrade Drainage

Another application of subdrains is shown in Figure 38. Here, the underground water flows in a layer near the road surface. This water can weaken the road and create soft spots and rutting. The drain is installed in the pervious layer, beside the road, to intercept the water before it reaches the roadway.

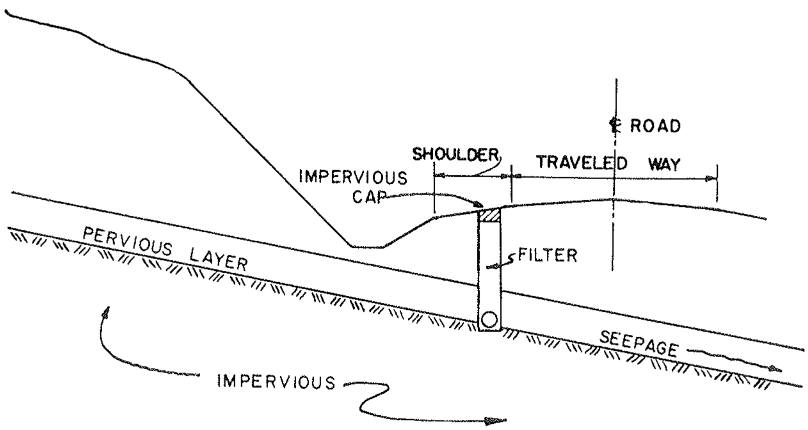

Fig. 38. This subdrain intercepts water flowing under a road to keep the base dry and stable.

A similar installation can be used when the natural ground water level is near the surface. Drains placed along each side of the road will lower the water level under the road to make the base stronger. It should be noted, however, that this system will not be effective if the subgrade is very silty or clayey as the water will not drain from these fine-grained soils. In that case, it is more satisfactory to raise the grade of the road with a free-draining material.

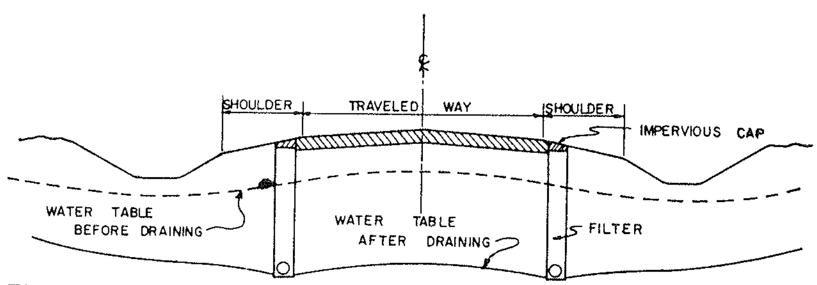

Fig. 39. Subdrains may be used to lower a free water table to strengthen the road and reduce effects of frost.

Another, but less frequently used, application of subdrains is to eliminate deep ditches with steep sides near the traveled surface. This may occur in deep cut sections or on extremely narrow rights-of-way.

Where such ditches are a distinct hazard a subdrain may be placed where the ditch would normally be, and backfilled with sand to a level only slightly lower than the road surface. The shoulder should still slope away from the road at about 1 in. per ft to insure proper surface drainage. Surface water can be conducted into the drain by placing drop inlets or blind drains at intervals along the roadside, connected to the subdrain.

Base Drainage

Subdrains are also used to drain the base course in cut areas where it is not practical to carry the base through the shoulder. These drains do not serve to lower the water table, but carry off water which permeates through the surface rather than running off into ditches. Where subgrade drains are used, they can serve to drain the base course as well. However, where dense graded aggregates are used in the base course, subdrains should not be installed because these materials do not drain freely.

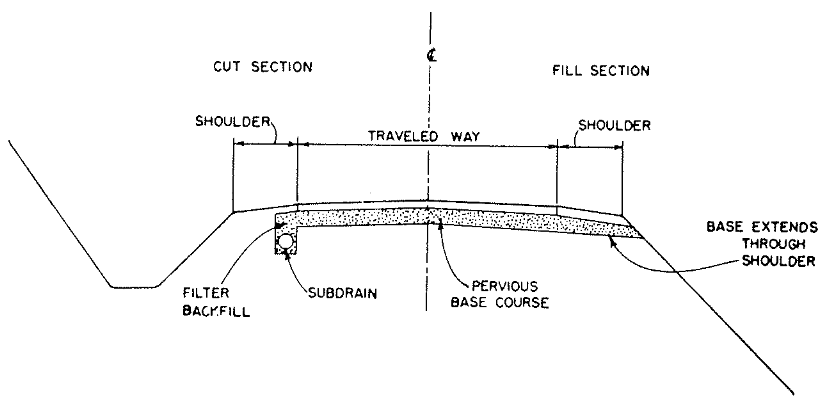

Fig. 40. In cut areas subdrains may be used to drain water that seeps into the base from the surface.

Drain Type

Subdrains, or underdrains, may be perforated pipe, porous concrete pipe, solid pipe laid with open joints or simply a free draining material in a trench with no pipe (French drains).

Perforated Pipe, Porous Pipe, or Open Joints

Generally the most satisfactory type of subdrain is perforated or porous pipe, laid in a trench, backfilled with a granular, free-draining material, and covered at the surface with a relatively impervious soil. Pipe is usually 4 to 6 in. in diameter with holes in two or more lines on one side of the pipe. It may be metal, concrete, or vitrified clay. The same factors that are considered in choosing culverts will affect the choice of material for subdrains—cost, foundation conditions, corrosive substances.

Solid pipe, laid with joints unsealed, can effectively serve as a subdrain. Open joints are likely to permit silt and fine sand to enter the pipe unless special precautions are taken. Where open joints are used they should be covered with burlap, tarpaper, or broken tile, or they may be surrounded with gravel or crushed stone before backfilling.

French Drains

French drains are constructed with no open conduit in them. These drains depend on water flowing more readily through the porous backfill than through the surrounding material. As long as the filter is not clogged, this type of drain is satisfactory. However, it is far more likely to get plugged with fine material than is a pipe drain, and it then becomes a severe maintenance problem. Therefore, as a rule it is best to place a pipe in the trench to insure positive removal of water.

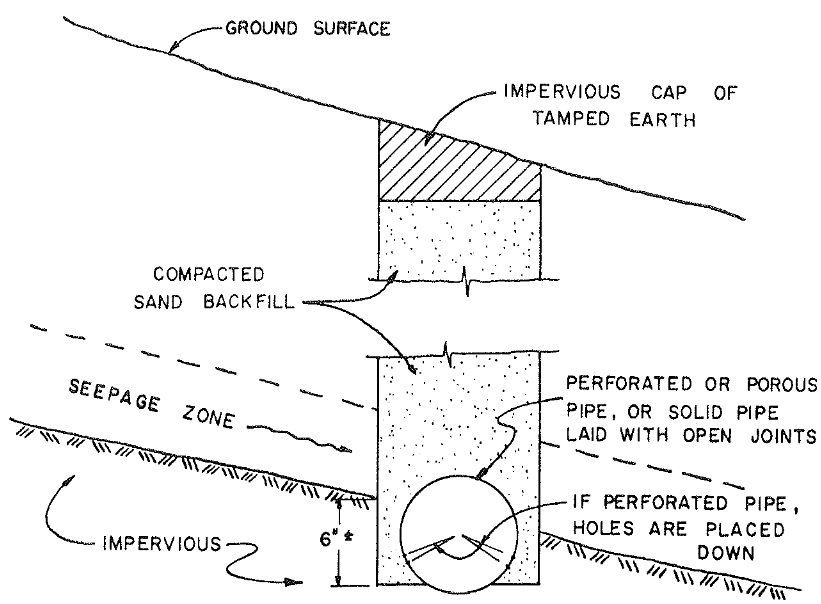

Fig. 41. Typical details of subdrains. Note especially that the invert of the drain is below the bottom of the water bearing material, the backfill is a clean sand, and holes are placed down.

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Location

The location of subdrains is a critical part of their installation. In each case, careful attention must be given to exactly what job the drain is to perform.

In intercepting veins, or layers, of moving water, the drain must be placed at the bottom of the layer where water is flowing, and on the side of the structure nearest the source of the water. The trench is dug to a depth 4 to 6 in. below the pervious layer and shaped to fit the pipe. This will insure complete drainage of the pervious layer. The subdrain should extend the full length of the troublesome layer of soil and must run to a proper outlet.

Subdrains for protecting slopes are placed well back of the cut face. The trench is usually dug from a point above the top of slope. Subdrains used to intercept water which runs under a road are preferably installed under the shoulder, but they may be located at the ditch line. In order to lower the ground water table, subdrains should be installed close to the edge of the traveled surface. However, it is recommended that such drains not be installed across the road because settlements over the drains are likely to cause a series of dips. Subdrains installed to lower the water table have to be at least 4 ft deep to be effective, and they are useful only in fairly coarse soils. The required depth depends on depth of frost penetration and fineness and compactness of the soil. Where possible subdrains should be placed with a slope toward the outlet of at least 0.15 per cent—that is, a drop of 0.15 ft per 100 ft. Flatter slopes are necessary in some locations, however, to obtain a free outlet, which is essential.

The location of subgrade subdrains must ordinarily be decided in the field on the basis of observed conditions. Base drains, of course, can be planned before construction since they do not depend on the location of water in the subgrade. The guide to remember is—*Locate Subdrains Deep Enough and in a Position to Drain all of the Troublesome Water Away from the Roadway.*

Outlet

Every subdrain must have a free outlet in order to function properly. The best installation will fail if the end is underwater, plugged with debris, or if animals nest in it. For this reason subdrains should be carried to a discharge at a stream, culvert, or open ditch. The bottom of the pipe is kept above high water in the ditch and the end protected with a grate or screen. The outlet pipe may

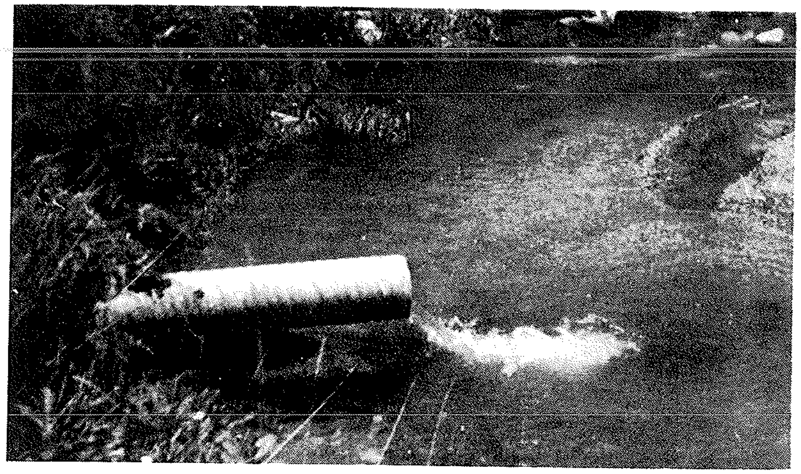

Fig. 42. This outlet discharges into deep water where there is no danger of erosion. Note the height above free water to insure that the outlet will not be submerged. (Courtesy Armco Drainage and Metal Products, Inc.)

project from the bank to keep it free of debris. If plowed snow covers the outlet it should be removed promptly to insure continuous drainage and prevent the pipe from filling and freezing.

An important principle for subdrains—*Provide an Unobstructed and Protected Outlet to a Stream or Open Drain.* 91

Filter

The backfill around subdrains must serve as a filter as well as provide support for the pipe. The essential requirements of filter material are that water flow through it more readily than through the surrounding soil, and that it not be plugged with fine particles from the surrounding soil. To satisfy the first requirement, the fill should be a clean granular material. To prevent clogging with fines it must not be too coarse. In most soils a clean sand such as used for concrete will serve satisfactorily as a filter material. Open joints must be protected to prevent the sand washing into the pipe. This can be done with tarpaper, burlap, broken tile, or crushed stone.

For permanent, effective underground drainage—*Surround Subdrains with a Clean, Pervious Filter Material.*

Installation

Installation procedures for subdrains are essentially the same as for pipe culverts. Firm, continuous bedding is essential to prevent destructive settlements and/or crushing of pipe. The supporting earth should be shaped to fit the pipe. Pipe should be laid with the holes on the lower side.

The filter backfill provides the support for subdrains. It must be brought up equally on both sides of the pipe and thoroughly compacted. The top foot of backfill should be clay or other impervious soil unless the subdrain is intended to serve surface drainage as well as underground drainage.

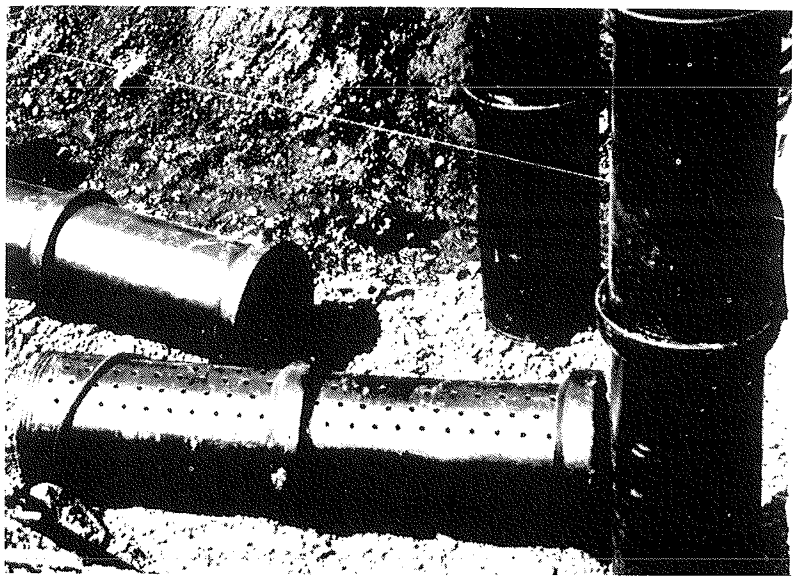

Fig. 43. In this installation of a subdrain perforated pipe is used and installed with holes down. Note the string line to assure installation to proper grade and alignment. (Courtesy Clay Products Association)

Where a deep subdrain is installed to intercept water in a pervious layer of soil, the filter backfill is sometimes used only for 1 to 2 ft above the pipe. The remainder of the trench is backfilled with the soil which was removed from the trench, or any suitable fill. However, if clean sand is available, it is desirable to use the filter material for the entire backfill, except the seal at the top. This provides a maximum area for seepage into the filter and least likelihood of clogging by fines washing into the filter.

To insure long-lived, maintenance-free subdrains—*Provide a Firm Foundation and Well Compacted Backfill.*

Maintenance

The inspection program in the maintenance of culverts should include inspection of subdrains to insure their continuous operation. Outlets should be well marked or mapped so they will not be overlooked on inspection trips. If outlets become covered by snow and ice, brush, or debris, it is essential that they be cleared if the drains are to work as planned. Subdrains that never carry any water are either ineffectively located, the pipe is plugged, or the filter clogged with fines. In any case, the only correction is removing and reinstalling the drain. It is evident, therefore, that care in installation is a most important factor in minimizing maintenance of subdrains.

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ADJOINING LAND

Drainage and erosion control problems are not restricted to the highway right-of-way. Water does not recognize boundaries of land ownership or political responsibility. Therefore, proper drainage and erosion control requires cooperation between highway personnel and owners of land adjacent to the highway.

One way to encourage landowners to use good conservation practice is to set an example of good management on the right-of-way. In addition, highway departments have a major responsibility to prevent damage to property adjacent to the road from concentrated streams of water running from the right-of-way. Outlets of drainage facilities should be to established watercourses wherever possible, and should be protected from erosion so as to remain stable and effective in disposing of runoff.

Even though county highway departments have no direct control over property owners they can encourage good conservation practices. Choice of crops and method of cultivation can have a great influence on the amount of soil which is washed into roadside ditches and even onto the roadway itself. Assistance in planning and promoting erosion control is readily available from the Soil Conservation Service of the Department of Agriculture and from the Indiana Agricultural Extension Service.

Frequently, county officials may improve the highway drainage conditions and save money by assisting landowners in carrying out an erosion control plan. Highway department equipment might be

Fig. 44. This pond is created by using the highway embankment as a dam. Note the culvert outlet safely below road level at the far side of the pond.

used in grading, ditching or terracing operations to expedite a program. Landowners might contribute materials, and the highway department labor and equipment to improve a driveway or install a culvert. Some landowners will contribute right-of-way at little or no cost to the county for improving the drainage conditions, provided the county will provide a new fence.

Occasionally, a highway embankment may be made to serve as a dam for a farm pond. When such a dual purpose can be served by a planned improvement with proper design so the road is not undermined and the dam is effective, the benefits in good will and cooperation of landowners and the subsequent savings in maintenance cost may far outweigh the extra cost involved in construction.

Cooperative efforts of county highway personnel, landowners, and interested state and federal agencies, directed toward effective drainage and erosion control and guided by sound principles will reduce highway failures and make travel safer and more pleasant for all.

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APPENDIX

GLOSSARY

AASHO American Association of State Highway Officials.

Alignment The horizontal direction of a road, ditch or other structure as shown in a plan view.

Asphalt A solid or semisolid material generally obtained as a residue in the refining of petroleum.

ASTM American Society for Testing and Materials.

Backfill Earth fill surrounding a structure and providing support for the sides.

Backslope That part of the roadway, in a cut section, from the ditch line to the original ground surface.

Base course A layer of granular material which lies immediately beneath the wearing surface of a pavement.

Bedding The foundation materials and condition for pipe.

Bell and spigot Pipe designed so that the end of one section fits inside the end of the next section.

Bitminous material A general term used to indicate a material containing asphalt or tar.

Bridge A structure with a span equal to or greater than 20 ft for carrying a road over a stream, another road, railroad or other obstruction. (See Culvert).

Clay A fine grained soil (passing the No. 200 sieve) which has considerable strength when dry and is plastic, or putty-like, at some water contents.

Cross drain A culvert which carries an accumulation of water from a roadside ditch to the opposite side of the road.

Culvert A structure for carrying water. beneath a road. The term is usually restricted in application to structures less than 20 feet long measured parallel to center line of roadway.

Cut slope Backslope; the limit of excavation from the ditch line to the surface of undisturbed ground.

Deposition Accumulation of soil and/or debris deposited by a stream.

Ditch A depression or trough in the ground for carrying water.

Drainage Structures and facilities for collecting and carrying away water. Also, the water that is carried away.

Drainage area Of a given point, that area of land from which all water drains past that point.

Embankment An earth, or rock and earth, fill for carrying a road above the surrounding ground.

Endwall A structure, usually concrete or rubble masonry, at the downstream end of a culvert, which retains the fill and anchors the culvert.

Erosion Movement of soil by the action of water and wind.

Filter A backfill which readily permits the flow of water but restricts the washing of fines from the soil.

Foundation The material on which a structure is placed, or the lowest part of a structure, which distributes the load to the underlying material.

Grade The rate of rise or fall in the profile of a road, ditch, or other structure.

Gravel That fraction of soil consisting of particles smaller than 3 in. which will not pass through a No. 4 sieve.

Ground water level The elevation of the free water surface—the elevation to which the water surface will rise in an observation well.

Headroom The distance from the top of a pipe or other structure to the road surface.

Headwall A structure, usually concrete or rubble masonry, at the upstream end of a culvert, which retains the fill and anchors the culvert.

Impervious A property of soil or other material which prevents or inhibits the flow of water through the material.

Intercepting ditch A trough or gutter, at the top of a slope, which collects surface water and prevents it from washing over the slope face.

Invert The inside bottom surface of a culvert.

Mulch A covering over the soil which temporarily protects it from erosion and maintains temperature and moisture conditions favorable to germination of seeds.

Multiplate Pre-curved corrugated metal sheets which are bolted together to form a pipe or arch structure.

Permeable A property of soil or other material which permits the flow of water through the material.

Pervious A property of soil or other material which permits the flow of water through the material.

Profile The vertical direction of a road, ditch, or other structure; a view of a vertical section of the structure.

Portland cement A product obtained by pulverizing a clinker that is made by burning a carefully proportioned mixture of calcareous and argillaceous material, usually limestone and clay.

Riprap A layer of large stones placed to protect soil from erosion.

Rubble masonry A type of construction using stone or broken rock laid dry or cemented in place with mortar.

Sand That fraction of soil which passes a No. 4 sieve but will not pass a No. 200 sieve.

Scour The washing away of soil around and beneath a structure.

Scupper An opening in a bridge floor or curb to permit water to drain from the surface.

Silt A fine grained soil (passing the No. 200 sieve) which has little or no strength when dry and is not plastic or putty-like at any water content.

Silting The depositing in a stream or ditch of fine soil carried from higher ground.

Skew The angle a stream or structure makes with a line perpendicular to the roadway.

Slope The surface of an earth fill or cut, or the grade of that surface expressed as the ratio or horizontal to vertical distance.

Sluice A channel, with a protective lining, which carries water over a slope.

Sod A layer of grass and soil cut in sections or strips from an established turf.

Span The length of the opening of a bridge or culvert, from support to support, in the direction of the road. For pipe culverts, the greatest width of the pipe.

Subbase course A layer of material beneath the base course of a pavement and above the subgrade.

Sudrain A structure beneath the ground surface for collecting underground water and carrying it to an outlet.

Subgrade The natural ground or an embankment upon which a pavement is constructed.

Subsurface drainage Collection and removal of underground water.

Surface drainage Collection and removal of water from the surface of the road and the ground.

Tar A liquid or semisolid material generally obtained as a by-product of the production of coke from coal.

Underdrain A structure beneath the ground surface for collecting and removing underground water.

Vegetal cover A continuous growth of grass, legumes, vines, shrubs or other plants which protect surface soil from washing or blowing away.

Vitrified clay A product of clay which has been formed under pressure and hardened at high temperature.

Waterway area The area of the opening in a culvert or bridge through which water may flow.

Highway Design in Developing Countries

Proceedings of the Seminar on Highway Design in Developing Countries held during the PTRC Summer Annual Meeting, 10 - 11 July 1975, at the University of Warwick, England.

PTRC would like to thank all members of the Programme Committee who have so willingly given their time in helping to organise the programme for this seminar.

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The 1975 Seminar on Road Design in Developing Countries was the first in an annual series and was related to the three day Seminar on Transport Planning in Developing Countries, the proceedings of which are also available. The Programme Committee for the 1976 Seminar would be pleased to have comments on the papers in this volume. If readers have any suggestions about the programme for future seminars or would be interested in contributing a paper, please contact the Programme Secretary.

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CONTROL OF EROSION ON HIGHWAYS

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1. INTRODUCTION

The objectives of erosion control should be,in order of priority:

(a) to protect the road structure so that it continues its function of permitting uninterrupted flow of traffic at its design speed in safety,

(b) to protect the earthworks and drainage structures, in order of importance: fill slopes; ditches and drainage structures;cut slopes,

(c) to prevent damage to the land adjacent to the road reserve (in fact quite often the neglect of control measures on adjacent land creates serious problems of erosion within the road reserve),

(d) to reduce soil loss from the road reserve which silts up drainage ways,water storage reservoirs, and pollutes rivers,

(e) to contribute to the improvement of the aesthetics of the landscape. 101

2. MECHANISM OF EROSION

In order to make provision for erosion control in design, it is important to understand the mechanism of erosion and the effect of the principal factors which affect the rate of erosion and soil loss. Much research has been done by agronomists on sheet erosion of agricultural land and attempts have been made to apply the results to roadside slopes which tend to be much steeper particularly in the tropics.

A generally applicable method of estimating the rate of soil loss on roadsides has not yet been developed. The main problem is that it is still not possible to classify the erodibility of a soil from a knowledge of its physical or chemical properties. One suspects that the relationship is so complex that when it is eventually better understood, it will be of little practical value to the highway engineer.

Erosion may be considered as the detachment of particles from a soil surface and the transportation of the detached particles to a new location. First, raindrops hit the slope surface and the impact detaches particles of soil. Then the run-off water flowing down the slope, transports the detached particles and may also contribute to detachment. The rate of detachment by impact is a function of the energy dissipated at impact,which is equal to the kinetic energy of the drops (= ε½ MV^2) where M is the mass of the drop and V is the terminal velocity. Comparing the kinetic energy dissipated by impact with that possessed by the same mass of water flowing relatively slowly down the slope, one realises that energy of impact must be many times that of the flowing water. This simple argument illustrates that the most significant energy causing erosion is in falling rain rather than in flowing surface water. Thus, it is clear that erosion can be reduced in the first place by protecting the soil surface from direct impact of rain with, for example, a stone or straw mulch, a man-made close textured netting or more usually a covering of vegetation.

Hudson (1) showed that the kinetic energy per unit quantity of rain increased rapidly with intensity particularly over the lower range of intensities (0 to 50 mm/h.) as shown in Fig.1. Recently Kinnell (2) disputed Hudson's findings and showed that there was an approximately linear relationship between kinetic energy per unit area per unit time and intensity. It is clear that the relationship does vary according to rain type and geographical location. At low intensities, the energy dissipated is too low to cause any significant erosion and it is generally considered that about 25 mm/hour is the threshold intensity at which erosion starts.

102 Figs.2(a) and (b) show what might be typical rainfall intensity diagrams for temperate and tropical climates. While the total tropical rainfall may be twice that of the temperate climate, the erosion rain which falls is 16 times that of the temperate climate. Taking account of the relation in Fig.1. it is obvious that the kinetic energy of the tropical erosive rain must be even greater than 16 times that of the temperate. Hence there is an obvious need to pay particular attention to erosion control in highway design in the tropics. As part of an investigation for a proposed highway it would seem useful to assess the erosion power of the rainfall from meterological observations of the area (2,3) as well as assess the erodibility of the soils.

3. ERODIBILITY OF SITE

A way of quantifying erodibility of a site is to measure the rate of soil-loss per unit area of site per unit time (e.g. tonnes/hectare/annum). Erodibility is a function of the erosivity of the rain, the soil properties, the topography, land cover and management. When applied to a single slope the topographical factors are simply the slope length and its steepness.

The U.S. Agricultural Research Service have published a Soil Loss Equation (3) which is supposed to permit one to predict the average annual sediment yield 'A' from construction sites.

The equation is A = KRLSCP ...... (1)

K is the soil erodibility factor depending only on soil properties.

R is the rainfall factor or erosivity.

CP are reduction factors representing the effect of slope cover and conservation practices.

LS is a topographical factor and is expressed in terms of slope length l (in m units) and percentage slope S. For slopes up to 20%

$$LS = 3.28\ l^{0.5}(0.0076 + 0.0053\ S + 0.00076\ S^2) \quad .....(2)$$

Equation 2 shows that erosion is proportional to the square root of length.

This suggests that one should perhaps find a way of breaking up a slope by interrupting the flow downslope using contour ridging, berms or strip sodding. The equation also indicates that erosion increases rapidly as the percentage slope increases. However, this relationship only applies on slopes up to 20%. Both cutting and embankment slopes commonly exceed 20% in road reserves and in the tropics cutting slopes in some soils can be at very steep angles up to vertical (4).

Rowlinson and Martin (5) carried simulated rainfall tests on inclined surfaces of a compacted cohesive soil and measured sediment yield. They showed that as the slope angle was increased the normal component of raindrop impact force decreased, resulting in a reduction in the rate of soil detachment. However, the increased slope led to an increased velocity of surface water flow which increased the rate of sediment transport. While on low slopes the rate of sediment transportation determines the rate of erosion, on steep slopes the rate of detachment determines the amount of sediment available for transportation. Because this rate of detachment falls as the angle increases, there must be an optimum gradient (Fig.3.) at which erosion rate is highest. It is clear that this optimum value must vary quite considerably with numerous variables which must include soil type, rain intensity and the depth of flowing surface water. The relationship is not understood and the effect of slope gradient above 20% on the rate of erosion cannot be predicted. 103

While agronomists advise that erosion can be reduced by reducing slope gradients, engineers should remember that their advice applies only to low gradients and that erosion can perhaps be reduced by making slopes very steep. Also, if a slope of a cutting is made less steep, the length of the slope is automatically increased, a factor which increases sediment yield. Stability conditions permitting, vertical faces can sometimes be cut in erodible soils. These remain intact simply because rain impact forces in the slope faces are too low to cause detachment.

3. INFLUENCE OF SLOPE SHAPE

The rate of erosion of a slope is affected by its shape. It has been shown (6) that for slopes of the same overall steepness, a concave shape is most resistant to erosion. The steepness of the bottom portion of a slope (over which all the run-off flows) has a major influence on the relative erosion. It has been observed after a large number of periods of erosion that a slope will naturally develop a concave profile. It is suggested (7, 8) that the most resistant slope shape will be one which is concave over most of its length, with a short convex portion just at the top of the slope in order to avoid a sharp change of gradient between the natural ground surface and the start of the slope, as illustrated in Figure 4.

4. SOIL ERODIBILITY FACTOR

Perhaps the least quantifiable factor in the soil-loss equation is the soil erodibility factor K. Wischmeier and Meyer (3) proposed a complex equation relating the soil factor to soil properties based on regression analyses of numerous field studies in the U.S.A. east of the Rockies. K is defined as the soil loss in tons/acre/unit of rainfall (R) from a standard plot of soil in a fallow and continuously ploughed state (downhill) on a 9 percent slope 72.6 feet long.

The magnitude of K is dependent on

(i) the percentage of silt and very fine sand (0.002 to 0.10 mm)

(ii) the percentage of sand (0.10 to 2.0 mm)

104 (iii) the percentage organic content

(iv) the soil Structure Index defined as:

1 - very fine granular
2 - fine granular
3 - medium or coarse granular
4 - blocky, platy or massive

(v) the Permeability Class defined as:

1 - rapid
2 - moderate to rapid
3 - moderate
4 - slow to moderate
5 - slow
6 - very slow

A nomograph (Figure 5) has been produced which facilitates the use of the empirical equation. The authors claim to have correctly estimated the soil erodibility factor on several construction sites. However the validity of the nomograph remains to be tested on subsoils high in clay content, on residual soils or on those chemically cemented. In the tropics on surfaces exposed to rapid evaporation, iron-oxides tend to concentrate in some soils and within a few weeks of exposure, a soil slope can build up a layer of iron oxide on the surface which forms a protective crust against erosion (4). It is almost certain that the nomograph would overestimate the erodibility of any such soils with cohesive bonds and future research is required to provide an additional parameter to take account of the effect of cementation in residual soils, indurated sedimentary deposits and salt rich soils.

Parallel work on erodibility has been carried out in Portugal (9). A study of 26 different soils on slopes near Lisbon were classified as erodible or not erodible according to the way in which the slopes behaved over a number of years. After carrying out an exhaustive series of physical and chemical tests on each of the samples, it was found that two simple criteria could be used. Erodible soils either contained between 49 and 96% passing No. 40 ASTM. sieve, or a swelling test conducted on compacted material passing No. 40 sieve exhibited swelling > 11%. These criteria were confirmed by a further series of tests conducted in the Lisbon area(10). The Portuguese intended to test the criteria on sites in East Africa but the results have not so far been reported.

There have been several attempts at devising simple laboratory tests for assessing the rain erodibility of small soil samples (11). The more sophisticated use rain simulators on soil in boxes tilted at an angle (12). Inderbitzen (13) used water flowing down an inclined plane in the middle of which the face of a cylinder of soil was placed flush with the surface. Philipponnat (14) pointed out that the impact of rain was an important mechanism in erosion and devised a simple test in which a fine jet of water was discharged on to the inclined surface of a cylinder of soil. Erodibility (Er) was defined as the product of the depth of the groove cut by the jet (cm) and the weight of soil lost (gm). Very erodible soils had Er > 60. He found this test useful for classifying the erodibility of soils in Madagascar. Several interesting results emerged from his tests. Micaceous fine grained soils were extremely erodible; laterites generally had a low erodibility; well compacted soils had a significantly lower erodibility than poorly compacted soils and intact decomposed rocks of moderately high in-situ density were much less erodible than the same materials compacted to the same density.

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5. CONSERVATION PRACTICE (P in the soil-loss equation)

This can be regarded as the superimposed measures which reduce the effective slope length and runoff concentration. On slopes steeper than 1 in 3 it is difficult to stabilise vegetation and in the period just following construction when slopes are bare, they are particularly vulnerable to erosion change. The following practices assist conservation.

6. CONTOUR RIDGING

Catchment ridges may be cut by hand implements along contours about 300 mm apart. These serve to retain both seed and water (15).

7. LIGHT SCARIFICATION

Where slopes are between 1:2 and 1:3, it may be sufficient to lightly scarify the surface in preparation for seeding (15).

8. SERRATIONS OR STEPPING

Steps may be cut by hand to a depth of 150 to 200 mm so that topsoil can be spread over the bank and held in place. This is a very expensive treatment and can only be considered when the in situ material is too poor to support plant growth (8, 15). On steep slopes in weathered rock, slightly larger steps have been successfully used (16).

9. STRIP SODDING

A technique commonly used in Korea is to lay narrow strips of grass turf along contours about 900 mm apart on slopes up to about 1:1 (17). On the steeper slopes the strips have to be fixed in position by driving stakes through the sods. The grass eventually spreads between the strips to provide full cover. Diagonally laid turf strips are used in the wetter areas of Australia (18).

10. SLOPE FASCINES

In West Africa temporary stabilisation of steep slopes has been achieved by bundles of brushwood fascines staked in lines along slope contours (19). Wattling is a similar technique involving staking a series of poles diagonally across the batter face (18).

11. RIP RAP

106 There are locations where it may be justifiable to utilise rip-rap protection of steep cutting slopes. On the new expressways designed and built by the South Korean government, some steep cutting slopes proved to be difficult to stabilise. Ground water seepage which occurred after a prolonged wet spell tended to break out in springs which caused internal erosion and local instability. The problem was solved by covering the most erodible parts of the slope with stone rip rap (17) and forming contour drains and chutes to collect seepage and surface water. This technique would never gain general acceptance as a means of controlling erosion but given that waste rock was readily available from nearby cuttings, that the unit cost of labour was very low and that the presence of the rip rap saved the slope from being regraded to a lower angle after construction, the solution was not as uneconomical as it appears.

On the Seoul - Pusan Expressway one can find at one location a cutting slope protected by precast concrete units interlocking to form a widely spaced mesh (17). This was used for the same purpose as the rip rap but undoubtedly was not economically justified.

12. SOIL-CEMENT

In the U.S.A. soil stabilised with a small percentage of cement (up to 3%) has successfully been used as facing for highway embankments to give erosion protection (20).

13. USE OF BENCHES

Benches are commonly used as a device to reduce the overall slope angle, to catch debris and prevent it falling on to the road and to avoid the accumulation of the total runoff at the toe of the slope. In some soils of low shear strength and stability, it is probably harmful to employ benches since they can permit the penetration of water into the slope. In stiff soils or soft rocks where steeply sloping faces are possible, benches can be justified. Ideally each bench should have a rearward grassed slope drained by a lined longitudinal channel with a good fall. Benches have been successfully used in laterised soils where the slopes of between 5 in 1 and vertical have been safely formed.

14. CREST INTERCEPTOR DITCHES

It is advisable to prevent surface runoff from rising ground behind a slope, running down the slope, particularly if the catchment area is large. The usual solution is to install an interceptor ditch a few metres back from the crest of the slope. Care must be taken in positioning and design of this ditch because any damming up of water in the ditch through lack of maintenance could result in a 'lubrication' of a potential earth slip. Sometimes excavation for a crest ditch will cut through a resistant soil into an erodible or a very pervious stratum which would obviously be detrimental (11). In such a case it may be more practical to divert the runoff from higher ground by means of a diversion bank. This must be laid along a low gradient to prevent it being eroded. The cheapest ditches will be unlined but, as will be seen below, unlined ditches must be laid to a gradient which will not permit the flow velocity to exceed the critical value at which erosion of the invert occurs. French engineers commonly use lined crest ditches of concrete or precast sections and often lay these on steep gradients. This is sometimes necessary but very often flood waters erode the soil along the sides of such drains or leak through an open joint or crack and then undercut the structure. Care must therefore be given to designing precast sections with joints which are both flexible and leakproof. 107

15. ASPHALT DYKES AND CHUTES

For the purpose of reducing sheet erosion of embankment slopes the Koreans adopted a standard procedure of constructing a sand asphalt dyke on the edge of highway shoulders to prevent surface runoff from flowing over the edge and down the slope (17). Water is channelled by the dyke into a collection chamber from which it is discharged into a chute running down the embankment slope as shown in Figure 6. The kinetic energy of water discharging down the chute is destroyed by a baffle constructed at the toe just prior to connection with a ditch.

Although undoubtedly efficient, these drainage structures are expensive. Depending on the soil erodibility and rain erosivity it may be adequate simply to encourage growth of grass cover on soil slopes which would resist the erosion otherwise caused by pavement runoff in the absence of the dyke. If there is danger that severe erosion may be caused before vegetal cover can be established, it may be economic to construct temporary soil dykes such as sand filled burlap protectors (21) and temporary chutes made with jute, rice straw bags, or some such sheeting.

16. COVER AND MANAGEMENT (C in the soil-loss equation)

It was shown above that slope erosion could be significantly reduced by protecting the soil from the direct impact of raindrops using some form of cover. The cheapest form of cover is grass. In many regions the soil is fertile and moist enough to support indigenous grasses which naturally proliferate themselves and within a year or so provide an adequate cover without human intervention. However, on erodible soils such cover may develop too slowly to prevent serious erosion damage and the surfaces of slopes in such soils may have to be seeded, planted or turfed or in some other way protected soon after construction.

For slope protection low growing sod forming varieties of grass which spread themselves fairly rapidly by stolons above ground and/or by rhisomes from underground roots are best to prevent sheet erosion. Cynodon dactylon (Bermuda grass) is one such commonly occurring perennial grass that is recommended for slopes in warm climates. It establishes itself rapidly, is resistant to erosion and traffic wear, can be adapted to a variety of ground conditions, can persist in alkaline soils and tolerates droughts well. Digitaria decumbens (Pangola grass), though less common, is considered to offer even more protection (24). It spreads rapidly and can persist in semi-arid regions.

Another very common grass suitable for more humid climates is Axonopus (Carpet grass) (22). There are many varieties of grasses suitable for tropical areas and many of these have been listed and described in references 22, 23 and 24. Those for more temperate and cold climates are listed in 22, 25 and 26.

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Mixtures of grasses are often used particularly in temperate zones with the objects of reducing the danger of degeneration of the sod by disease or nutrient deficiency and of extending the length of the period of growth and protective efficiency. Mixtures may contain a combination of fast and slow growing grasses, and grasses whose growth periods differ (24).

Where it is essential to obtain effective surface protection very soon after construction, rapidly growing annual grasses such as barley, oats, or annual rye grasses can be included in the mixture as a temporary protective measure until the perennial grasses can take over (24, 25).

Recent experiments have shown that grasses and legumes can be successfully combined to provide lasting protection. Grasses require a continuous supply of nitrogen in soluble form. This is naturally present in organic material. On geological soils containing little or no organic matter, the nitrogen must be supplied by means of top dressing until such time as the build up of humus can supply nitrogen. The lack of nitrogen often accounts for deterioration and disappearance of grass cover three years or so after establishment. Legumes such as clovers, vetches and peas can produce nitrogen fixing nodules which convert nitrogen from the free air in the soil into a form which is soluble. Grasses growing adjacent to legumes can benefit from this nitrogen supply. Since legumes take about two or three years to provide complete cover, it is essential to sow them with grass. Experience in Virginia has proved that crown vetch (Coronilla Varia) when sown with Lovegrass (Egrarostic curvula) and Bermuda grass can produce very good protection with the legumes gradually taking over from the grass (26). Seeding and establishing legumes in deteriorating grass sods appears to be an excellent way of stopping further erosion and providing

TABLE 1 (After Richardson et al 1970)

Average Annual Rainfall, Runoff, and Erosion from Roadbanks with no cover and with vegetation, from 1965 to 1967.

Plot Description (All on Cecil Subsoil)

Plot	Exposure	Runoff area (ha)	Erodible Area (ha)	Slope	Cover	Total Rainfall (mm)	Runoff (mm)	Sediment yield t/ha
1	Northern	0.064	0.033	1 in 1.4	None	1344	293	338
2	Southern	0.109	0.070	1 in 1.25	None	1344	282	278
3	Northern	0.084	0.019	1 in 2.5	Crown Vetch & Abruzzi Rye	1353	210	9.9
4	Southern	0.121	0.009	1 in 3.3	Sericea Lespedeza & Lovegrass	1353	109	2.6
5	Northern	0.072	0.008	1 in 1	Kentucky Fescue	1353	116	6.0
6	Southern	0.093	0.012	1 in 1.1	Pensacola Bahia Grass & Bermuda Grass	1353	141	5.0

Table 2

(After Turelle 1973)

Effect of Straw Mulch Rate on Erosion Rate and Runoff Velocity

Mulch Rate of Application (t/ha)	Soil Loss (t/ha)	Runoff Velocity (m/s)
0	62.3	0.139
0.56	20.1	0.071
1.12	19.4	0.069
2.24	11.5	0.056
4.48	2.5	-
8.96	1.5	-

Table 3

(After Wischmeier & Meyer 1973)

Influence of Several Mulch Types and Rates on Soil Loss from 1 in 5 Construction Side-Slope. (Rain Intensity 63 mm/h, Total 127 mm, Slope Length 10.7 m)

Treatment	Quantity	Soil Loss
No Mulch	-	88.7 t/ha
Woodchips	4.5 t/ha	60.7 "
Stone	34 "	57.4 "
Gravel	157 "	32.9 "
Straw	5 "	27.1 "
Stone	134 "	25.5 "
Woodchips	9 "	19.0 "
Woodchips	16 "	12.3 "
Stone	302 "	7.8 "
Stone	538 & 840 t/ha	< 4.5 "
Woodchips	27 & 56 t/ha	< 4.5 "

permanent effective cover on slopes. Other perennial legumes which have been successfully tried out in the U.S.A. are flat pea (Lathyrus sylvestris L) (27) and Sericea lespedeza (Lespedeza cuneata)(26).

17. EFFECTIVENESS OF GRASS COVER

It may be difficult to predict soil losses from construction sites but what is not difficult to appreciate is the dramatic effect of grass cover in reducing erosion. Barnet et al (28) measured 62 percent runoff and soil losses of 160 m^3/ha from a single storm of 69 mm of intensive rainfall on a bare 1 in 2.5 highway cut. Richardson et al (29) reported the results of measurements of 5 year average sediment yields from bare roadside slopes and slopes having a full vegetative cover in the U.S.A. The bare slopes yielded between 174 and 524 t/ha/year. After a vegetative cover was established and ditches lined, the sediment yield was reduced to an average of less than 11 t/ha/year. Table 1 summarises some measurements which they took on 5 experimental sloping plots on the same soil over a three year period and illustrates how a fully developed cover can reduce both runoff and sediment yield.

18. PROVIDING INSTANT COVER

Mulching may be necessary for establishing vegetation on geological soil of construction sites. Not only does it protect soil, seed, and fertiliser from erosion, but affects the microclimate and moisture conditions for the benefit of germination. Considerable research has shown how effective mulches can be in reducing erosion. Table 2 (30) summarises the results of soil loss measurements on a plot of Fox loam on an unploughed 15 percent slope 10.7 m long. 111

Table 3 shows the results of a study of stone and wood-chip mulches for erosion control on construction sites. This experiment was carried out on a 20 percent slope on Wingate subsoil (3). Surface mulches of crushed rock, gravel and wood-chips showed great potential for erosion control on short denuded slopes.

In areas where either drought or a highly acid soil makes it difficult to maintain a vegetative cover on erodible soils, it may be economic to spread rock waste obtained from cuttings over batter surfaces. An example of this is on the Sydney - Newcastle Expressway in Australia where sandstone was packed on to a batter to afford protection (8). Another is the covering of steep slopes of the Tahola highway near Seattle, U.S.A. with pit-run 50 mm minus screen gravel (31).

In North America wood-chip mulches are commonly used. Woody vegetation salvaged from the road reserve during initial site clearance is converted into wood chips by a special chipping machine (16, 7). This is often mixed with nitrogen rich fertiliser together with the seed and sprayed on to the slopes using a hydroseeder which permits the mix to be applied up to about 60 m away (7, 8, 32). This technique is particularly suitable for treating steep slopes which cannot be transversed by conventional seeding equipment. Such equipment may not be available in a developing country but in Western Australia use is made of ordinary disc ploughs to chop up vegetation other than trees into mulch for mixing with topsoil prior to spreading it (8).

Hay and straw mulches are commonly and effectively used but other vegetation such as crushed corncobs, sugar-beet pulp, cocoa or peanut hulls which may be available locally can be used.

All these vegetable mulches are liable to be blown or washed away and are really only effective if tacked down to the slope in some way. The most common tacking technique is to spray the previously spread mulch with a slow breaking anionic bitumen emulsion. This technique was successfully used over large areas by the Snowy Mountains Authority in Australia, (8) and is now being used experimentally in Madagascar (33). When a mulch blower machine is used to spray on the mulch a combined mix of mulch, fertiliser, seed and bitumen emulsion can be applied in one operation. Further information on these techniques may be found in references 7, 15, 25, 34, 35 and 36.

Other chemical soil stabilisers discussed by Chittenden (36) Jaaback (15) and others (38) will not be discussed here as their use would be exceptional in developing countries.

Temporary protection of limited and critical areas of highly erodible soil may be provided by coverings (7,35) of burlap or jute matting (25), plastic fabric netting (15), glass fibre blankets (37), Excelcior mats (35) reed or straw mats or hay held down by wire or plastic netting (8).

19. DESIGN AND PROTECTION OF ROADSIDE DITCHES

On gravel roads the road foundation is often formed by cutting soil out of the side ditches and blading it by grader into the centre of the road thus raising the subgrade above the surrounding land. The ditches are formed with a slope of about 1 in 4 or 5 from the shoulder to the invert forming an asymmetrical V shape with the outer slope of the ditch cut at about 1 in 1 as shown in Figure 7. This simple shape is the easiest to maintain by grader but the ditch may be susceptible to gully erosion by high velocity flow of storm water if care is not taken to divert water from the side ditch into contour drains cut at intervals along the ditch. The permissible maximum flow velocity Vc depends on the hydraulic erodibility (as opposed to slope erodibility) of the soil. Several authorities have published empirical values for Vc relating them to soil texture (11, 18, 24) although it must be added that the original sources of their information is not clear. Kinori (24) quotes values published by Fortier and Scobey together with values tabulated by Russian investigators who more precisely attempted to relate Vc to particle size. The author has prepared Table 4 by drawing on data from both sources which do appear to be in broad agreement.

The spacing of the contour drain outlets may be determined by applying Manning's formula to the assumed cross-section of a ditch and the Rational runoff formula to calculate flow into the ditch from the catchment area which includes the plan area of half the road formation, one shoulder and cutting side slope and the ditch itself (18). One simply calculates the critical length of ditch at the end of which the flow velocity reaches the permissible value

TABLE 4

Permissible Mean Flow Velocities for High and
Infrequent Discharges of Short Duration

Type of Soil	50 Percentile size (mm)	Permissible Mean Velocity m/s
Fine Silt	-	Varies 0.25 to 0.8
Sandy Clay of density < 1.2 t/m^2	-	0.4
Coarse Silt, Fine Sand	0.05	
Fine Sand (Non Colloidal)	0.25	0.6
Sandy Loam (Non Colloidal)	-	0.7
Sandy clay of medium density Silty loam	-	0.8
Medium sand	1.0	
Dense Clay Volcanic Ash	-	1.0
Coarse Sand	2.5	
Stiff Clay Graded Loam to Cobbles Alluvial Silt (Colloidal)	-	1.5
Graded Silt to Cobbles (Colloidal)	-	1.6
Gravel (Medium to Fine)	5.0	1.1
Gravel (Coarse to Medium)	10	1.4
Coarse Gravel and Cobbles	25	1.9
Cobbles	40	2.4
Cobbles	100	3.6

TABLE 5

Permissible Velocities in Vegetated Channels

Vegetation	% Slope of Drain	Permissible Velocities m/s	
		In Stable Soils	In Erodible Soils
Bermuda Grass	0 - 5%	2.4	1.8
(Cynodon Dactylon)	5 - 10	2.1	1.5
Buffalo Grass	0 - 5	2.1	1.5
(Buchloe Dactyloides)	5 - 10	1.8	1.2

114 Note: According to Turner (18) Kikuyu Grass (Pennisetum Clandestinum) affords even more protection than Crouch but Cocksfoot (Dactylis Glomerata) can tolerate velocities only half those of Crouch.

(for the soil forming the invert). Figure 8 shows a chart which has been prepared for use in Zambia taking account of the rainfall conditions in that country.

Blet (39) also produced a design chart for rapidly determining this critical length using equations derived by Jeuffroy and Prunieras (40) who took account of the fact that because runoff is flowing into the ditch along its entire length, the quantity of water flowing in the ditch increases as the exit point is approached.

On gravel roads a proportion of the gravel forming the running course is lost annually due to ravelling by traffic. Much of it is thrown into the ditch from which it is recovered by the grader maintaining the road reserve. It is not practical therefore to encourage the growth of vegetation on the shoulders and in the ditch because it will simply be removed during maintenance.

On improved roads having a bituminous surfacing, however, it is good practice to encourage controlled growth of selected grasses in ditches and on shoulders. Vegetative cover significantly increases resistance to scour depending on its nature. Turner (18) quotes a permissible velocity for a Bermuda grass cover of 2.1 to 2.7 m. Kinori (24) however quotes lower permissible velocities which depend on the soil, the vegetation type and the channel slope. Some of these are quoted in Table 5. 115

The hydraulic characteristics of a ditch are affected by the presence of vegetation and Manning's roughness coefficient is dependent on the type of vegetation, its height and the product of mean velocity and hydraulic radius (24). Thus, design should take account of the likely standard of maintenance by mowing or herbicides, making allowance for possible impedance of flow by the vegetation.

A steep sided V-shaped ditch is prone to erosion of the sides and siltation of the invert, is hydraulically unstable and not very efficient, and is not to be recommended except where for economic reasons it may be necessary to restrict the width of the road reserve, as may be the case in deep cuttings. To reduce subsequent maintenance costs it will often be cheapest to use a fully lined rectangular ditch in a deep cutting. Where an earth ditch is used in a long cutting, one can calculate the critical length of the drain at which the permissible flow velocity is reached (as indicated above) and then allow for provision of a lined ditch beyond that.

In open rolling country, a trapezoidal ditch with a wide bottom is hydraulically stable and efficient. It permits greater infiltration of collected water in the soil and when covered with grass, it may easily be mown.

In order to avoid having to line ditches, it is often sufficient to insert simple and small drop structures such as the bolster shown in Figure 9 which is commonly used in Rhodesia. Such drop structures permit the gradients of ditches and hence the flow velocities in them to be controlled. They do however make mowing grass in the ditches more difficult.

20. PROTECTION OF SHOULDERS FROM RAIN AND TRAFFIC EROSION

It is usual to provide shoulders onto which vehicles may come to rest clear of the traffic lane. These should be capable of occasionally supporting the weight of the heaviest vehicles yet be constructed at a cost lower than that of the pavement. A common problem causing deterioration of the shoulders is gulley erosion due to runoff from the pavement as well as ravelling due to traffic running on the shoulders.

Some highway authorities apply surface dressing to the shoulders to provide protection. Unfortunately it is often difficult for the driver to distinguish between pavement and shoulder. The result is that many vehicles tend to run on the edge of the pavement or on the shoulder which quickly results in damage by edge breaking of the pavement and potholing. Examples of this are to be found on the highway between Abidjan and Buaké in the Ivory Coast where the most common repair is patching and strengthening of the pavement edge. This tendency for vehicles to run frequently onto the shoulders has been overcome to some extent in Rhodesia where as an experiment, shoulder dressing was made a contrasting colour.

On roads where the shoulders are unsurfaced perhaps the most effective way of protecting the edge of the surfaced base is to extend the base at least 500 mm beyond the edge of the surfacing and when applying a prime coat to impregnate at least 300 mm beyond the edge of the proposed surfacing. Protection of the shoulders may most often be provided by grass which can tolerate trafficking as well as water erosion. The presence of the grass also deters drivers from running their vehicles too close to the edge of the road.

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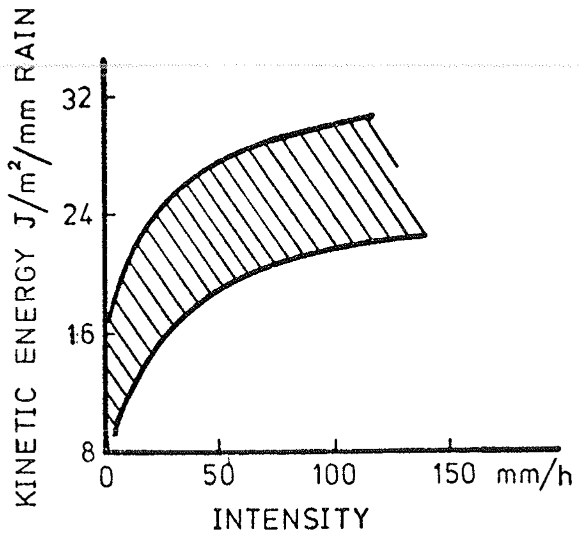

RELATION BETWEEN KINETIC ENERGY & INTENSITY

FIGURE 1

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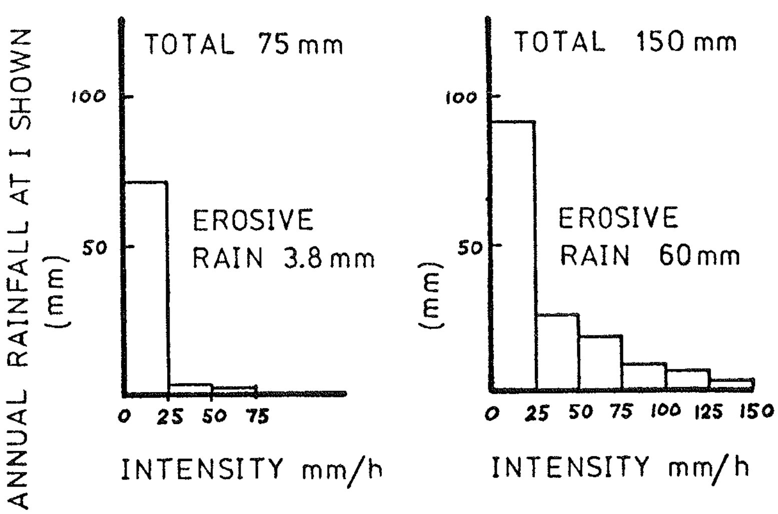
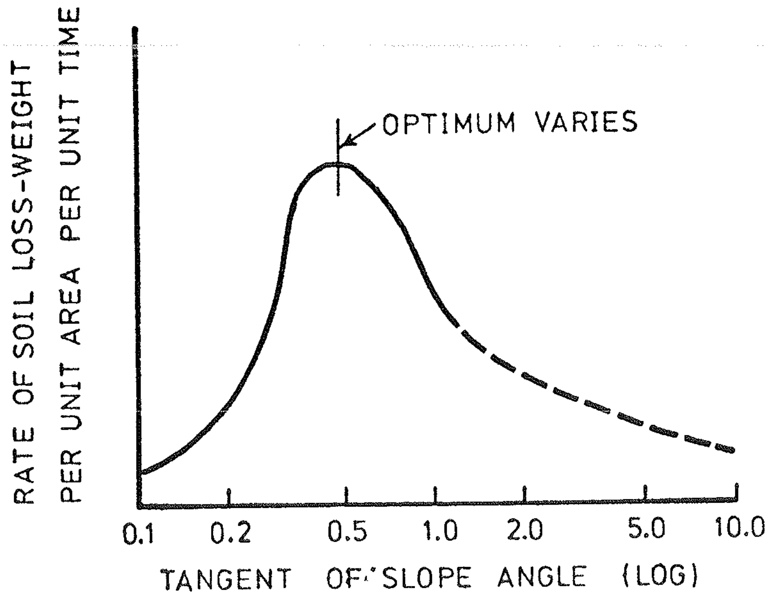


(a) TEMPERATE CLIMATE (b) TROPICAL CLIMATE

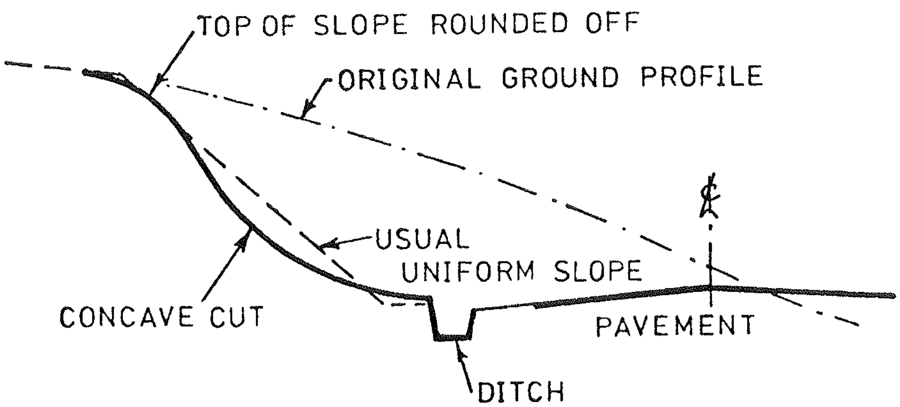
COMPARISON OF TYPICAL ANNUAL RAINFALL DISTRIBUTIONS FOR TEMPERATE & TROPICAL CLIMATES

FIGURE 2



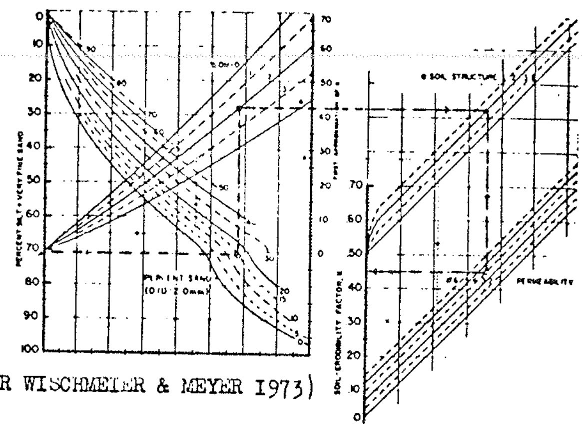
PROBABLE FORM OF VARIATION OF SOIL LOSS (DUE TO SHEET EROSION) WITH SLOPE ANGLE

FIGURE 3



SHAPING SLOPE TO REDUCE EROSION

FIGURE 4



(AFTER WISCHMEIER & MEYER 1973)

FIGURE 5 SOIL ERODIBILITY NOMOGRAPH

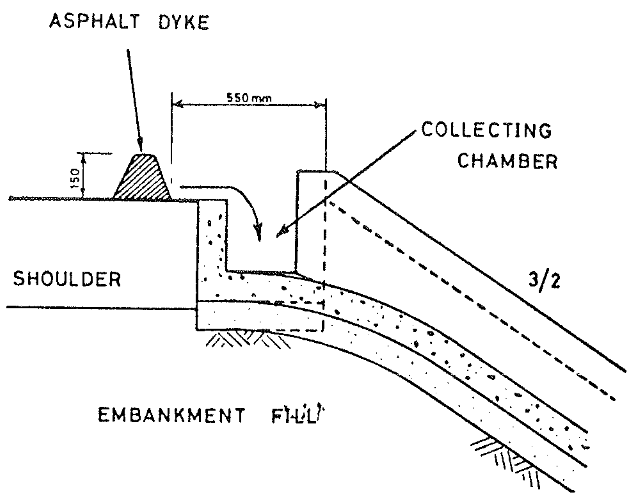


FIGURE 6

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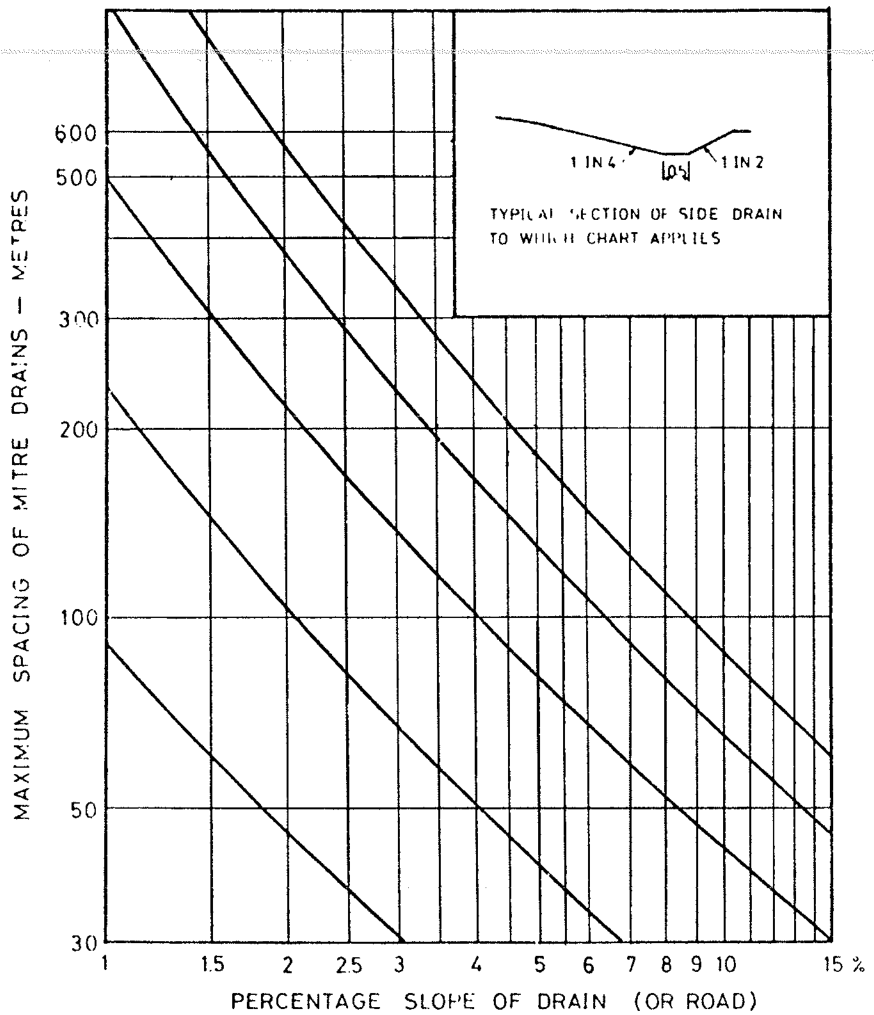
TYPICAL CROSS-SECTION OF DITCH AT SIDE OF EARTH OR GRAVEL ROAD

FIGURE 7



DESIGN CHART FOR DETERMINING SPACING OF MITRE DRAINS

FIGURE 8 (EX ZAMBIAN ROADS MANUAL)

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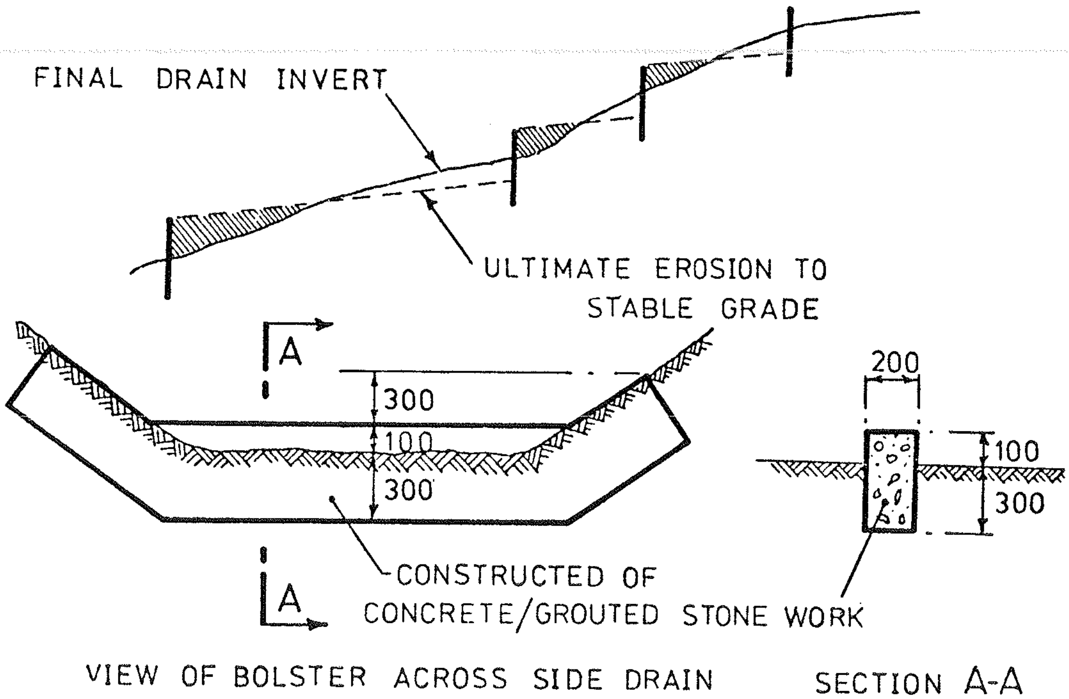

DETAIL OF BOLSTER DROP STRUCTURE

FIGURE 9

HIGHWAY RESEARCH RECORD

Number 206

Roadside Development

5 Reports

Subject Area

13 Land Acquisition
23 Highway Drainage
24 Roadside Development
40 Maintenance, General

HIGHWAY RESEARCH BOARD

DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

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Protecting Steep Construction Slopes Against Water Erosion

N. P. SWANSON, A. R. DEDRICK, and A. E. DUDECK
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Mulching practices on a roadside cut (3:1 slope) were evaluated with respect to controlling soil erosion and minimizing grass seed and fertilizer loss prior to grass establishment. A field plot rainfall simulator and a device to introduce additional surface flow over a test plot were used to evaluate the mulching practices. Measurements of soil erosion and grass seed and fertilizer losses were made from runoff samples taken through a series of simulated rainstorms. The effectiveness in protecting soil surfaces against water erosion was determined for 13 mulches. The best protection was provided by mulches of jute netting, wood excelsior mat, prairie hay (1 ton/acre) and fiberglass (1,000 lb/acre) anchored with asphalt emulsion (150 gal/acre). The least effective mulches were the latex (150 gal/acre) and a kraft paper netting. Anchoring a material with asphalt emulsion provided increased adherence to the soil surface and was generally beneficial.

•TEMPORARY stabilization of a disturbed soil surface until vegetation can become established is a continuing problem for state highway departments, the Department of Defense and other public agencies. Stabilizing the backslopes of dams and the side slopes of waterways and spillways are similar problems for soil conservationists. The advantages of holding the grass seed and soil in place until adequate cover has been established are apparent. In many instances, erosion may cause greater maintenance costs on a construction slope than the initial cost of smoothing, mulching, and seeding.

Conventional equipment can be used on slopes flatter than 4:1 for seeding, mulching and mulch anchorage. Steeper slopes pose special problems in the application of mulches and the establishment of vegetation. Research on mulching materials used to prevent water erosion on a 6-percent slope has been conducted, using simulated rainfall, since 1962 at Lincoln, Nebraska (3). During the summer of 1965, a rotating-boom rainfall simulator (2) was used to evaluate the effectiveness of 13 selected mulches for controlling the losses of soil, seed, and fertilizer on a 3:1 roadside backslope.

MATERIALS AND METHODS

This study was conducted on a Wymore silty clay loam at a site located about 3 miles south of Firth, Nebraska, along State Spur 341. A roadside cut was shaped to approximately a 3:1 slope. The surface was quite moist at the time of shaping and hardened upon drying. A mechanical analysis of a composite sample from the cut soil surface analyzed 9 percent sand, 59 percent silt and 32 percent clay.

Twenty-six plots, each 10 × 20 ft, provided test plots for two replicates of 13 mulch treatments. These treatments, along with rates and methods of application, are given in Table 1. After application of the mulch, each plot was covered with plastic for protection against natural rainfall until simulated rainstorms could be applied.

Paper sponsored by Committee on Roadside Development and presented at the 46th Annual Meeting.

TABLE 1

MULCH TREATMENTS STUDIED

Mulch Treatment	Description and Method of Application	Application Rate[a]
Wood cellulose	Wood cellulose fiber applied hydraulically as a water slurry	1000 lb
Fiberglass	Continuous filaments of fiberglass applied with compressed air	1000 lb
Asphalt emulsion	Emulsifiable asphalt diluted 1:1 with water and sprinkled on plot	1200 gal
Latex	Emulsifiable material diluted 1:6 with water and sprayed on plot	150 gal
Wood cellulose and asphalt emulsion	Wood cellulose fiber anchored with 1:5 asphalt emulsion	1000 lb with 150 gal
Fiberglass and asphalt emulsion	Fiberglass anchored with 1:5 asphalt emulsion	1000 lb with 150 gal
Prairie hay and asphalt emulsion	Prairie hay[b] anchored with 1:5 asphalt emulsion	1 ton with 150 gal
Woodchips and asphalt emulsion	Pine woodchips from a portable chipper anchored with 1:5 asphalt emulsion	6 tons with 150 gal
Corncobs and asphalt emulsion	Ground corncobs slightly larger than ¼ in. in diameter anchored with 1:5 asphalt emulsion	5 tons with 150 gal
Prairie hay and wide-weave paper netting	Prairie hay anchored with tightly twisted kraft netting with a 2 × 0.5 yarn count	1 ton
Wood excelsior mat	High-grade wood excelsior covered on both sides with a strong, large-mesh, kraft netting	
Jute netting	Heavy woven jute matting with a 1.6 × 1.1 yarn count	

[a]Per acre; undiluted volume applied in the case of liquids.
[b]Average composition of the prairie hay was 74 percent bluestem, 23 percent switchgrass and miscellaneous grasses and weeds.

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Four "storms" were applied to pairs of test plots as follows:

Storm	Duration (hr)	Intensity (in./hr)
1	1.4	2.5
2	1.0	2.5
3	0.3	5.0
4	0.8	2.5 plus introduced surface flow

The second storm was applied 18 to 20 hr after Storm 1, and Storm 3 immediately followed Storm 2. The fourth storm included three successive increases of introduced surface flow over the plots. Each increase in surface flow was held constant for 0.2 hr after the first 0.2 hr of simulated rainfall.

The surface flows were introduced across the upper edge of a plot through a pipe with holes on the upslope side. The energy of the water jets is dissipated against a curved metal shield from which the water ran onto the plot. The rate of water addition was controlled by a valve and measured through a meter.

Runoff samplers designed by Meyer and further reported by Hermsmeier (1) were used in this study. A nearly continuous sample of the runoff with its sediment load was obtained by taking successive samples over 6-min intervals throughout a test. A water-stage recorder provided a hydrograph of the runoff.

Grass seed and fertilizer were applied prior to mulching. Smooth bromegrass (Bromus inermis Leyss.) seed was applied at a rate of 120 seeds per sq ft. The seed was autoclaved to prevent germination on the plots or after collection in the runoff samples. The grass seeds in the fractional runoff samples were counted to determine the total number of seeds removed by the water runoff for a given storm.

Phosphorus was applied to each plot at the rate of 83 lb/acre in the form of treble superphosphate. The amount of phosphorus, both in the soil and in the water of each runoff sample, was determined.

RESULTS AND DISCUSSION

Soil Erosion

The mulches varied widely in the degree of erosion protection provided. A maximum soil loss of 16.5 tons/acre was measured from a 5-in./hr storm of 18 min duration on plots treated with the latex. The results from each mulch treatment, given in Table 2, are expressed in terms of a relative erosion value that indicates the effectiveness of a particular mulch in preventing erosion in comparison to the jute netting. The relative erosion values are weighted averages (weighted with respect to the amount of erosion for a particular storm) for three simulated rainstorms.

The mulch materials can be grouped into four distinct classes. Materials such as the jute netting, wood excelsior mat, and fiberglass anchored with asphalt emulsion provided excellent protection against water erosion. The amount of erosion was reduced by about 95 percent as compared to the soil loss from plots mulched with the latex. Good protection against water erosion was provided by woodchips, prairie hay or corncobs anchored with asphalt emulsion, and from asphalt emulsion alone. Soil erosion in this group was reduced by 85 to 90 percent when compared to the latex treatment. Wood cellulose, kraft paper netting, and the latex provided unsatisfactory protection.

TABLE 2

MULCH TREATMENTS RANKED ACCORDING TO RELATIVE EFFECTIVENESS AGAINST SOIL EROSION

Mulch Treatment	Relative Erosion[a] (No. of times the erosion from jute-net mulch)
Jute netting	1.0[b]
Wood excelsior mat	1.1
Fiberglass and asphalt emulsion	1.4
Woodchips and asphalt emulsion	2.3
Prairie hay and asphalt emulsion	2.5
Asphalt emulsion	2.5
Corncobs and asphalt emulsion	4.5
Prairie hay and wide-weave paper netting	7.9
Fiberglass	7.9
Wood cellulose and asphalt emulsion	8.5
Wood cellulose	12.9
Kraft paper netting	20.7
Latex	25.4

[a]Average of three simulated rainstorms replicated twice for each mulch treatment.

[b]Mulch treatment used for comparison purposes.

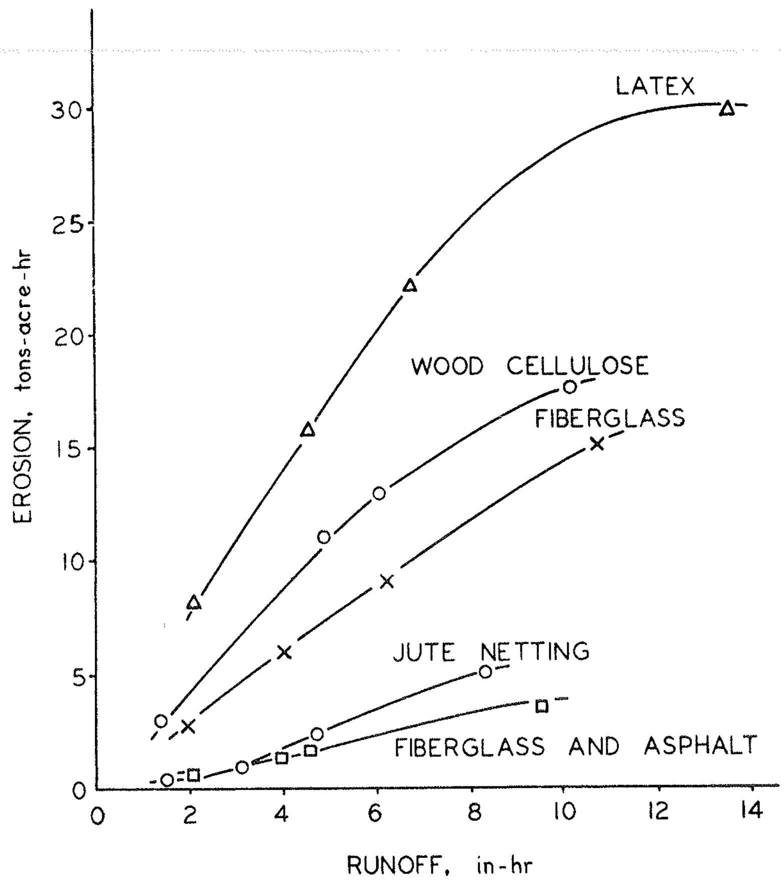

Figure 1. Rates of erosion as related to runoff for various mulch treatments.

TABLE 3

MULCH TREATMENTS RANKED ACCORDING TO SEED LOSS FROM RUNOFF PLOTS

Mulch Treatment	Number of Grass Seeds Lost[a]			
	Storm 1	Storm 2	Storm 3	Total
Jute netting	0 a	0 a	0 a	0 a
Wood excelsior mat	0 a	17 a	0 a	17 a
Prairie hay and asphalt emulsion	0 a	0 a	32 abc	32 a
Fiberglass and asphalt emulsion	17 a	0 a	38 abc	55 a
Fiberglass	72 a	0 a	0 a	72 a
Asphalt emulsion	80 a	16 a	24 ab	120 a
Woodchips and asphalt emulsion	142 a	6 a	143 abc	291 ab
Corncobs and asphalt emulsion	250 ab	127 ab	127 abc	504 abc
Wood cellulose and asphalt emulsion	394 abc	115 ab	88 abc	597 abc
Wood cellulose	355 abc	237 bc	219 c	811 bcd
Prairie hay and wide-weave paper netting	665 bc	124 ab	194 bc	983 cd
Kraft paper netting	676 bc	238 bc	202 bc	1116 cd
Latex	762 c	355 c	169 abc	1286 d

[a]Seed losses followed by same letter are not significantly different (5% level).

The use of increased surface flows in addition to the simulated rainfall provided more distinguishable differences between the mulch treatments (Fig. 1). Accelerated erosion resulted when some of the mulch treatments failed under increased surface flow (latex, kraft paper netting, wood cellulose, and fiberglass), but nearly stable conditions persisted witn others (fiberglass anchored with asphalt emulsion, wood excelsior mat, and jute netting). Some mulch materials provided relatively better protection than others as the flow rates increased. The fiberglass anchored with asphalt emulsion became relatively more effective than the jute netting with increased runoff.

Grass Seed Loss

Of the 24,000 bromegrass seeds on each plot, a maximum of 2,186 were lost from the plots treated with the latex. No observed losses occurred from a plot mulched with jute netting during a series of three simulated rainstorms (Table 3). The maximum number of grass seeds removed from the test plots accounted for only about 5 percent of the number applied, which would still permit establishment of adequate grass stands. However, grass seed need not be removed from the test plot to cause inadequate grass stands. Seeds may be washed from some areas into concentrations, causing spotted grass

TABLE 4

MULCH TREATMENTS RANKED ACCORDING TO PHOSPHORUS LOSS FROM RUNOFF PLOTS

Mulch Treatment	Storm 1	Storm 2	Storm 3	Total
(a) Phosphorus Loss in Soil Removed From Plot Surface (lb/acre)[a]				
Jute netting	0.2 a	0.1 a	0.1 a	0.4 a
Wood excelsior mat	0.2 a	0.1 a	0.2 a	0.5 a
Fiberglass and asphalt emulsion	0.1 a	0.1 a	0.3 ab	0.5 a
Woodchips and asphalt emulsion	0.3 a	0.1 a	0.2 a	0.6 a
Prairie hay and asphalt emulsion	0.3 a	0.2 a	0.2 ab	0.7 a
Asphalt emulsion	0.2 a	0.2 a	0.3 ab	0.7 a
Corncobs and asphalt emulsion	0.5 a	0.4 a	0.3 ab	1.2 a
Wood cellulose and asphalt emulsion	0.9 a	0.5 a	0.2 ab	1.6 a
Wood cellulose	1.0 a	0.6 a	0.6 ab	2.2 a
Fiberglass	0.8 a	1.0 ab	0.9 b	2.7 a
Prairie hay and wide-weave paper netting	1.7 a	1.1 ab	0.7 ab	3.5 a
Latex	4.2 b	1.9 bc	1.7 c	7.8 b
Kraft paper netting	6.9 c	2.2 c	2.2 c	11.3 c
(b) Phosphorus Loss in Runoff Water (lb/acre)[a]				
Fiberglass	0.7 a	0.6 a	0.4 ab	1.7 a
Latex	1.0 ab	0.5 a	0.2 a	1.7 a
Asphalt emulsion	1.0 ab	0.5 a	0.4 ab	1.9 ab
Wood cellulose	0.8 a	0.8 a	0.4 ab	2.0 ab
Jute netting	0.9 a	0.8 a	0.4 ab	2.1 ab
Prairie hay and asphalt emulsion	1.1 abc	0.7 a	0.3 ab	2.1 ab
Wood excelsior mat	1.0 ab	0.9 a	0.4 ab	2.3 ab
Kraft paper netting	1.2 abc	0.7 a	0.4 ab	2.3 ab
Fiberglass and asphalt emulsion	1.4 abc	0.8 a	0.3 ab	2.5 ab
Wood cellulose and asphalt emulsion	1.6 bc	0.6 a	0.3 ab	2.5 ab
Corncobs and asphalt emulsion	1.3 abc	1.0 a	0.4 ab	2.7 ab
Prairie hay and wide-weave paper netting	1.8 c	0.7 a	0.3 ab	2.8 ab
Woodchips and asphalt emulsion	1.7 c	0.8 a	0.4 ab	2.9 b

[a]Phosphorus loss followed by same letter not significantly different (5% level).

stands. Also, if the seed and soil are moved by runoff (inadequate mulch), much of the grass seed will be covered too deeply to germinate.

Few bromegrass seeds were lost in the runoff from plots mulched with jute netting, wood excelsior, prairie hay and fiberglass anchored with asphalt emulsion, fiberglass, and asphalt emulsion alone. Conversely, the latex, kraft paper netting, prairie hay anchored with wide-weave mesh netting, and wood cellulose did not control the movement and loss of grass seeds from the plot surface. Mulch materials that provided adequate protection against soil loss likewise prevented movement of the grass seed.

Phosphorus Loss

A relatively wide range of phosphorus losses was measured in the eroded soil removed from the mulch test plots (Table 4). Since these losses are dependent on the amount of soil loss under the various mulch materials, the results obtained are similar to those for soil loss. Mulches of jute netting, wood excelsior, and fiberglass anchored with asphalt emulsion permitted the least phosphorus loss in the eroded soil; however, the values are not significantly less than those for most of the other mulches. The plots covered with kraft paper netting indicated significantly greater losses than those plots mulched with latex and, in turn, these two materials permitted significantly higher phosphorus losses than all other mulch materials.

After the first storm, phosphorus losses in the runoff water were relatively constant for the various mulch materials (Table 4) with no significant differences measured. Only the losses occurring in the runoff from the first 3.5 in. of water applied appeared to be dependent on the mulch material.

The average phosphorus lost in the eroded soil for all three storms was 2.6 lb/acre, and that lost in the runoff water was 2.2 lb/acre. The total phosphorus loss ranged from 13.6 lb/acre (16.5 percent lost) for plots mulched with kraft paper netting to 2.5 lb/acre (3 percent lost) for jute netting-mulched plots. Such losses are relatively small in comparison to the total amount (83 lb/acre) applied. Adequate amounts of available phosphorus should still remain on the plots under most of these mulches. It is possible, however, that the phosphorus fertilizer was moved and concentrated in areas on the plots with more erosion.

SUMMARY

Simulated rainstorms of 2.5 and 5.0 in./hr were applied to plots located on a 3:1 roadside backslope and mulched with various materials. The plots were uniformly seeded with bromegrass and fertilized with phosphorus. The protection afforded against water erosion by each mulch was evaluated by measuring soil, grass seed and phosphorus losses. The best protection was given by materials such as jute netting, wood excelsior, and prairie hay (1 ton/acre) or fiberglass (1000 lb/acre) anchored with asphalt emulsion (150 gal/acre). The least effective mulches were latex (150 gal/acre) and kraft paper netting.

The most effective mulches were those providing both protection from raindrop impact and adherence to the soil surface. Anchoring a material with asphalt emulsion provided increased adherence to the soil surface and was generally beneficial. Adherence of the mulches to the soil surface increased surface detention of the runoff water and eliminated the undercutting of the mulch material which was a serious problem with some of the nettings.

ACKNOWLEDGMENTS

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DEPARTMENT OF
SCIENTIFIC AND INDUSTRIAL RESEARCH
ROAD RESEARCH LABORATORY

Road Research Technical Paper No. 52

The Use and Control of Vegetation on Roads and Airfields Overseas

BY
K. E. CLARE, B.Sc., A.R.I.C.

LONDON
HER MAJESTY'S STATIONERY OFFICE
1961

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The Use and Control of Vegetation on Roads and Airfields Overseas

SUMMARY

THIS PAPER gives information, supplied from 33 overseas territories, on the types of vegetation occurring at roadsides and on airfields, the useful genera and those presenting problems to the engineer being briefly indicated. Rainfall, geographical location, existing control and drainage are believed to be the major factors controlling the vegetation regime at any given site.

Vegetation is useful for preventing haunch, ditch and side-slope erosion on roads, for providing running surfaces for roads and airfields, and for improving road safety and amenities. Present practice in these fields is briefly reviewed, and reference is made to the desirability of introducing into overseas road and airfield construction improved techniques and vegetation species that become available from developments in other countries or in related fields of research.

The uncontrolled growth of vegetation can disrupt road and airfield pavements, reduce visibility and increase fire hazard on roads, and provide a reservoir for the reinfestation by weeds of adjacent clean agricultural land. Methods of controlling vegetation include cutting by hand or by machine, and burning or grazing. The costs of control in a number of overseas territories are reported. Recently, interest has developed in the increasing number of chemical treatments that are becoming available. Experiments with these in different overseas territories are briefly described.

INTRODUCTION

MANY engineers overseas are continually engaged in combating the tendency of vegetation to interfere with drainage, to encroach on road pavements or to obscure the vision of drivers. Others, in drier areas, are glad to employ vegetation to prevent erosion and as a surfacing on grass airfields. At the Round Table Conference on Overseas Highways Problems in London in 1958,[1] interest was expressed in the problems arising in the encouragement and control of vegetation on or near roads, and the Committee for Colonial Road Research subsequently recommended that the Road Research Laboratory should examine the possibilities of chemical control of roadside vegetation, in collaboration with road authorities overseas. Later in the same year, the problems of soil erosion arising in connexion with roads in Africa were noted at the C.C.T.A. Conference of Road Specialists at Lorenço Marques,[2] and methods of using vegetation to prevent it were recorded.

To collect relevant information, a circular letter was sent in August, 1958, to the Public Works organizations in all the major British overseas territories, asking for data under the following headings:

(1) The methods of roadside maintenance used, and the ranges of cost per mile per year.

(2) The types of vegetation normally encountered in ditches and on side-slopes and shoulders.

(3) The types of plant that are particularly useful in controlling soil erosion.

(4) The types of plant that present problems because of a rank habit of growth.

To obtain any information available from departments other than those dealing with public works, a savingram in similar terms was later sent by the Secretary of State for the Colonies to Officers Administering Government in British overseas territories.

Replies were received from the 55 sources in 33 territories, listed in Appendix 1. The present paper reviews the main types of vegetation reported to occur on roads and airfields overseas, and notes the use of certain genera for controlling soil erosion. Problems arising with vegetation are then listed, and the methods of control at present in use are described, and average costs are quoted. It is felt in many quarters that control by chemicals offers advantages in economy and convenience compared with manual or mechanical methods, and reference is therefore made to the experiments in this field that have already been initiated in a number of territories.

VEGETATION ENCOUNTERED ON ROADS AND AIRFIELDS

Vegetation encountered on roads and airfields is listed, by region and territory, in Table 1, which for simplicity, gives only the genera concerned. Where a genus includes species having a wide range of habit, however, the species name is also given. Appendix 2 gives the local English names of many of the different species. In Table I the genera are divided into grasses, herbs and shrubs, and woody species, a grouping that is of assistance in considering their susceptibility to chemical control.

The main factors appearing to affect the distribution of vegetation at road-sides are rainfall, geographical location, existing control and drainage.

Table 1
Vegetation genera occurring at roadsides overseas

Region	Territory	Rainfall	Location	Vegetation type	Genera
East, Central and Southern Africa	Kenya		All areas	Grasses	Cynodon, Pennisetum
			,, ,,	Herbs	Tagetes, Ricinus
			,, ,,	Trees	Acacia
		40–50	Rift Valley	Herbs	Abutilon, Conyza, Crotalaria, Cynoglossum, Erigeron, Gomphocar-
			,, ,,	,,	pus, Hibiscus, Indigofera, Leonotis, Physalis, Sonchus, Solanum,
			,, ,,	,,	Veronia, Withania
			,, ,,	Shrubs	Lantana, Solanum
	Uganda	40–55	All areas	Grasses	Cynodon, Digitaria, Pennisetum, Paspalum
			,, ,,	Herbs & shrubs	Acanthus, Lantana
	Tanganyika	20–60	,, ,,	Grasses	Cynodon, Chloris, Hyparrhenia, Panicum, Urochloa
	Zanzibar		,, ,,	Grasses	Present
	Southern Rhodesia	33	,, ,,	Grasses	Cynodon, Eleusine, Echinochloa, Eragrostis, Hyparrhenia, Hetero-
			,, ,,	Grasses	pogon, Rhynchelytrum, Sorghum, Sporobolus, Urochloa
	Nyasaland	35–100	,, ,,	Grasses	Cynodon, Hyparrhenia
	British Somaliland	10–20	,, ,,	Grasses	Present
			,, ,,	Herbs	Indigofera
			,, ,,	Trees	Acacia
	Basutoland	25–35	Lowlands	Grasses	Themada
		25–80	Highlands	Grasses	Festuca
West Africa	Northern Nigeria	35	All areas	Grasses	Annual and perennial species present
			,, ,,	Herbs & shrubs	Annual and low-growing perennial species present
			,, ,,	Trees	Present
	Eastern Nigeria	100	,, ,,	Grasses	Andropogon, Digitaria, Imperata, Panicum, Paspalum, Pennisetum, Setaria
			,, ,,	Herbs	Aspilia, Aframomum, Commelina, Costus, Caladium, Cuscuta, Cyperus
			,, ,,	,,	Dissotis, Eupatorium, Emilia, Desmodium, Gloriosa, Ipomoea,
			,, ,,	,,	Urena, Sida
			,, ,,	Shrubs	Cassia, Mimosa, Schrankia
			,, ,,	Trees	Acacia
	Sierra Leone	73–130	Orchard bush	Grasses	Present
			Savannah	Grasses	Present
			Secondary forest }	{ Grasses	Present
			Farm bush }	{ Herbs	Annual and perennial dicotyledonous weeds
West Indies	Barbados	50	All areas	Grasses	Annual—Cenchrus, Chloris, Digitaria, Eleusine
			,, ,,	Grasses	Perennial—Cynodon, Paspalum, Panicum
			,, ,,	Herbs	Amaranthus, Chamaecrista, Cyperus, Commelina, Desmodium,

Compendium 9

Table 1 (contd.)

Region	Territory	Rainfall	Location	Vegetation type	Genera
West Indies	Barbados (contd.)		All areas	Herbs	Euphorbia, Hypoxis, Leonitis, Leonurus, Phyllanthus, Portulaca,
(contd.)			,, ,,	,,	Rhynchosia, Stachytarpheta, Sida, Teramnus, Wedelia
			,, ,,	Shrubs	Cassia poladens, Croton, Lantana, Mimosa, Psidium
			,, ,,	Trees	Tecoma
	British Guiana	93	,, ,,	Grasses	Cynodon, Paspalum, Sporobolus
			,, ,,	Herbs	Borreria, Canna, Crotalaria, Heliotropium, Indigofera, Montri-
			,, ,,	,,	chardia, Solanum jamaicense
			,, ,,	Shrubs	Cassia alata, Cordia, Iatropha, Lantana
			,, ,,	Trees	Annona
	British Honduras	50–175	Coastal areas	Swamp	Mangrove
			Pine ridge areas	Grasses	Andropogon, Axonopus, Cynodon, Paspalum
			,, ,, ,,	Herbs	Sedges
			Border areas	Grasses & herbs	Hyparrhenia, Panicum (well-drained sites), Scleria (poorly-drained sites)
	Jamaica		All areas	Herbs & shrubs	Annual, biennial and perennial species
	Leeward Islands				
	Antigua	44	,, ,,	Grasses	Andropogon, Axonopus, Dicanthium
	British Virgin	49	,, ,,	Shrubs	Leucaena
	Islands		,, ,,	Trees	Acacia
			,, ,,	Herbs	Castor, Manchineel
			,, ,,	Shrubs	Cactus
	Monserrat	55	,, ,,	Trees	Acacia, Mangrove
			,, ,,	Herbs	Achyranthus, Commelina, Crotalaria, Cyperus, Indigofera, Mimosa pudica
			,, ,,	Shrubs	Leucaena, Tephrosia
	St. Kitts	54	,, ,,	Trees	Acacia
			,, ,,	Grasses	Andropogon, and other species
			,, ,,	Shrubs	Opuntia, Privet
	Trinidad	100–120	,, ,,	Trees	Acacia
			Areas trimmed	Grasses	Axonopus, Chloris, Cynodon, Sporobolus (dry sites), Axonopus,
			more than 3 times	,,	Paspalum (wet sites), Brachiaria (waterlogged sites)
			annually	Herbs	Desmodium, Hyptis, Mimosa pudica, Sida (dry sites), Bidens, Bor-
		80–100	,, ,, ,,	,,	reria, Eryngium, Peperomia (wet sites), Sedges (waterlogged sites)
			Areas trimmed 2	Grasses	Axonopus, Chloris, Cynodon, Eleusine, Paspalum, Rottboellia,
			to 3 times annually	,,	Sporobolus (dry sites), Axonopus, Brachiaria, Paspalum (wet sites)
			,, ,, ,,	Herbs	Alternanthera, Amaranthus, Bidens, Borreria, Emilia, Euphorbia,
			,, ,, ,,	,,	Jussiaca, Desmodium, Mimosa pudica, Pluchea, Pseudo-elephantopus,
			,, ,, ,,	,,	Seneciodes, Stachytarpheta, Sida (dry sites), Cyperus, Dichromena,
					Eclipta, Eryngium, Peperomia (wet sites)

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Text 5

Table 1 (contd.)

Region	Territory	Rainfall	Location	Vegetation type	Genera
West Indies (contd.)	Trinidad (contd.)	60–80	Areas trimmed less than twice annually	Grasses	Paspalum, Rottboellia, Sporobolus
				Herbs	Euphorbia, Mimosa pudica, Pluchea, Desmodium
				Shrubs	Flemingia, Ixora, Leucaena, Psidium, Urena
	Windward Islands				
	Dominica	70–250	All areas	Grasses	Cymbopogon, Vetiveria
	Grenada	30–200	,, ,,	Herbs	Commelina, Cyperus, Ipomoea
			,, ,,	Grasses	Axonopus, Bambusa, Cynodon, Panicum, Paspalum
			,, ,,	Herbs	Commelina, Crotalaria, Cuscuta, Cyperus, Malvastrum, Mimosa pudica, Priva Ruellia
			,, ,,	Shrubs	Corchorus, Pedilanthus
			,, ,,	Trees	Cocos, Anacardium, Gliricidia, Mangifera, Spondias, Swietenia, Tecoma, Yucca
	St. Vincent	100	,, ,,	Grasses	Axonopus, Panicum, Poacea, Vetiveria
			,, ,,	Herbs	Bidens, Caesalpinia, Commelina, Crotalaria, Cyperus, Desmodium,
			,, ,,	,,	Indigofera, Mimosa spp.
			,, ,,	Shrubs	Cordia, Psidium
				Trees	Tabebuia
Atlantic Ocean	Bahamas	40–60	All areas	All types	Acacia choriophylla, Ambrosia paniculata, Chloris radiata, Coccolabis laurifolia, Cynodon dactylon, Duranta repens, Leucaena glauca, Parthenium hysterophorous, Paspalum conjugatum, Pteris caudata, Sporobolus domingensis, Stylothanthes hamata, Torrubia obtusata, Tribulus cistoides
	Bermuda	58	,, ,,	Grasses	Cynodon, Panicum
			,, ,,	Herbs	Bidens, Euphorbia, Sonchus, Foeniculum
Indian Ocean	Aden	0–8	,, ,,	None	
	Mauritius	50	Shoulders	Grasses	Chloris, Eleusine, Eragrostis, Sporobolus
			,,	Herbs	Parthenium, Portulaca, Tridex
			Ditches & slopes	Grasses	Cynodon, Panicum
			,, ,,	Herbs	Ageratum, Argemone, Bidens, Euphorbia hirta, Plantago
		50–100	Shoulders	Grasses	Chloris, Paspalum
			,,	Herbs	Appium, Blumea, Cyperus, Daucus, Euphorbia spp. Lepidium, Senebiera
			Ditches & slopes	Grasses	Chloris
			,, ,,	Herbs	Anagallis, Argemone, Hydrocotyle, Oxalis, Phyllanthus tenellus,
			,, ,,	,,	Sonchus, Solanum spp., Verbena officinalis
		>100	Shoulders	Grasses	Chloris, Eleusine, Panicum, Paspalum, Sporobolus, Setaria
			,,	Herbs	Alternanthera, Kyllinga, Plantago
			Ditches & slopes	Grasses	Ischaemum, Paspalum

Table 1 (contd.)

Region	Territory	Rainfall	Location	Vegetation type	Genera
Indian Ocean (contd.)	Mauritius (contd.)	100	Ditches & slopes	Herbs	Ageratum, Bidens, Cynoglopsum, Elephantopus scaber, Kyllinga, Lobelia, Oxalis, Phyllanthus tenellus, Verbena officinalis
			,, ,,	Shrubs	Rubus
Mediterranean	Cyprus	10-12	Lowlands	Grasses	Avena, Briza, Bromus, Cynosurus, Cynodon, Hordeum, Lolium, Psilurus, Triticum, Lagurus
			,,	Herbs	Alhagi, Anthyllis, Asphodelus, Alkanna, Anagallis, Anthemis, Carthamus, Centaurea, Cistus, Convolvulus, Cynara, Echium, Erodium, Eryngium, Ferula, Galium, Hippocrepis, Helianthemum, Inula, Iris, Lactuca, Lagoecia, Leontodon, Linum, Malva, Mandragora, Mercurialis, Onopordon, Papaver, Plantago, Raphanus, Ornithogalum, Ranunculus, Sanguisorba spinosa, Salvia, Sinapis, Statice, Taraxacum, Teucrium, Thesium, Thymus, Urginea, Valerianella, Verbascum
			,,	Shrubs	Cistus, Paliurus, Prosopis
		20–40	Hills	Grasses	Brachypodium, Briza, Bromus, Hordeum, Lolium, Poa
			,,	Herbs	Astragalus, Medicago, Trifolium, Trigonella, Vicia, Ajuga, Anagallis, Anthemis, Asparagus, Bellis, Brassica, Crepis, Centaurea, Epilobium, Filago, Galium, Helichrysum, Hypericum, Lactuca, Lithosperum, Onosma, Origanum, Rubia, Salvia, Smilax, Taraxacum, Tuercium, Thymus
			,,	Shrubs	Cistus, Genista, Rhus, Rubus, Thymelaca
	Malta	17	All areas	Grasses	Poa
			,, ,,	Herbs	Chrysanthemum, Cirsium, Ecballium, Oxalis, Urtica
Far East	Singapore	95	,, ,,	Grasses	Imperata
	Sarawak	120–150	,, ,,	Grasses	Axonopus, Chrysopogon, Ischaemum, Imperata, Panicum, Paspalum
	Hong Kong	85	,, ,,	Grasses	Eleusine, Imperata, Isachne, Ischaemum, Miscanthus, Oplismenus, Panicum, Rottboellia
			,, ,,	Herbs	Ageratum, Boehmeria nivea, Kyllinga, Lespedeza, Malva, Tithonia
			,, ,,	Shrubs	Bridelia monoica, Ficus hirta, Solanum nigrum, Lantana, Leucaena
Western Pacific	Fiji	70	,, ,,	Grasses	Dicanthium annulatum, Dicanthium caricosum, Imperata, Panicum, Pennisetum, Sorghum, Sporobolus
			,, ,,	Herbs	Elephantopus mollis, Miscanthus japonicus, Stachytarpheta, Xanthium, Urena, Sida
			,, ,,	Shrubs	Triumfetta
			,, ,,	Trees	Acacia, Cassia
		120	,, ,,	Grasses	Axonopus, Brachiaria mutica, Eleusine, Ischaemum, Panicum, Paspalum
			,, ,,	Herbs	Ageratum, Cyperus, Cuphea, Desmodium, Eichornia, Elephantopus mollis, Hyptis pectinata, Mikania, Solanum, Stachytarpheta, Urena
			,, ,,	Shrubs	Lantana

Rainfall

This is by far the most important factor, and appears to influence both the quantity and type of vegetation. At the lower end of the scale, in arid territories like the Aden Protectorate and British Somaliland with average annual rainfalls below 20 in., the vegetation cover is very sparse, often leaving the road verges bare of grass and very susceptible to erosion. Acacia (thorn) occurs sporadically, however.

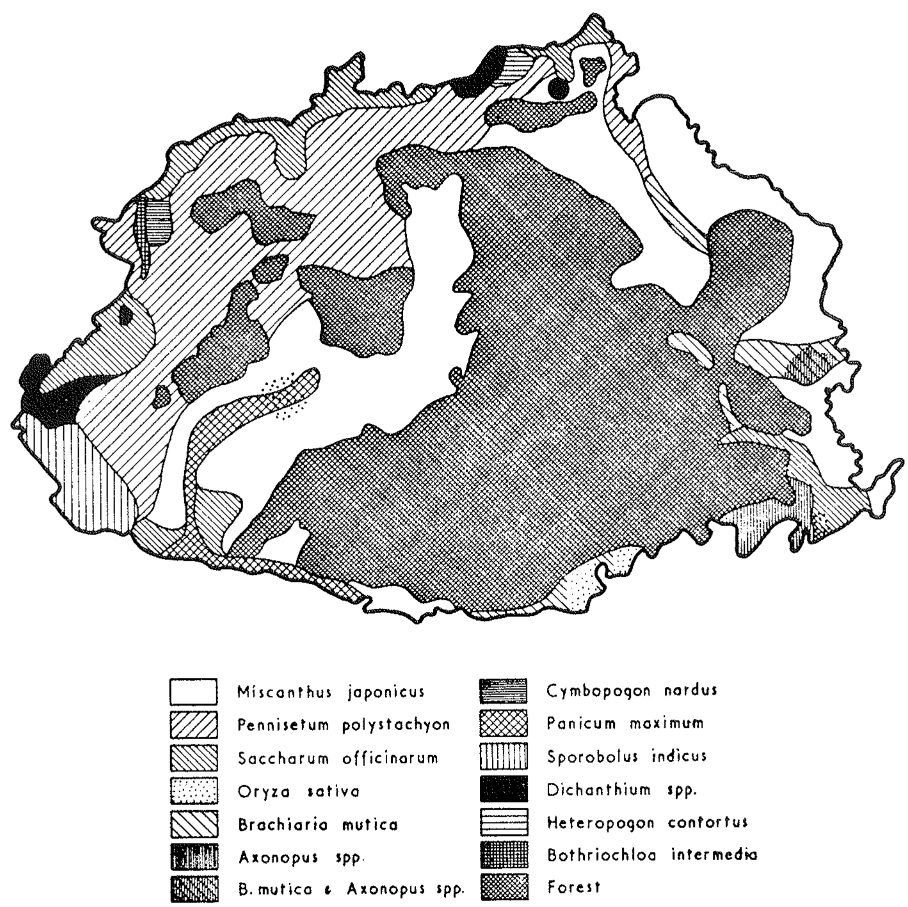

Fig. 1(a). Distribution of major grass species on Viti Levu, Fiji

In Swaziland two vegetation zones can be recognized: (i) the bushveld, with an average annual rainfall of 25 in. or less, where sweet grasses such as Brachiaria predominate, and (ii) the higher veld areas, with rainfalls between 25 and 45 in., where the Hyparrhenia species of grass predominate.

In Mauritius, three vegetation zones have been recognized, i.e. sub-humid, humid and super-humid areas, with average annual rainfalls in the ranges <50 in., 50 in. to 100 in. and >100 in. In Fiji, Parham[3] has noted that the distribution of the different individual species of grass is to a certain extent governed by rainfall (Fig. 1).

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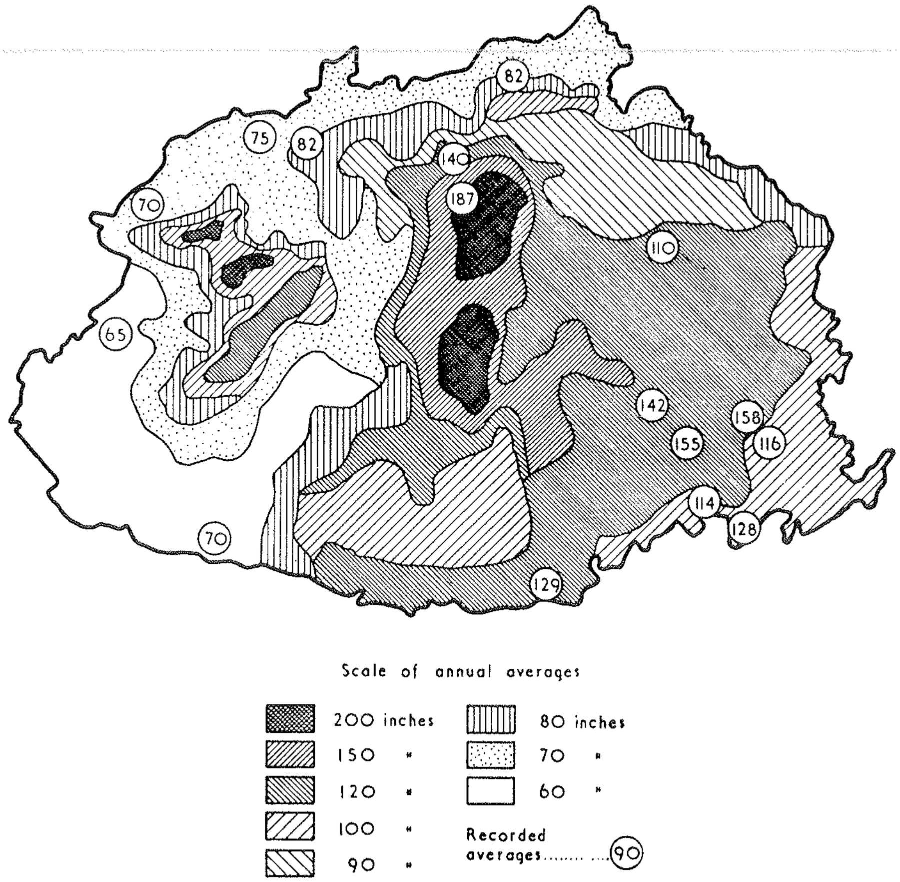


Fig. 1(b). Distribution of average annual rainfall on Viti Levu, Fiji

In Northern Nigeria, Rains [4] recognizes three zones in the grasslands, differentiated mainly by rainfall. In the Sudan zone, which includes the provinces of Sokoto, Katsina, Kano and Bornu, the annual rainfall is of the order of 25 in. to 30 in. Here the grass genera are: Cenchrus, Ctenium, Schoenefeldia, Eragrostis, Pennisetum, Andropogon, Aristida and Loudetia. The Northern Guinea zone includes the provinces of Zaria, Bauchi and Northern Niger as well as part of Ilorin, the rainfall being about 45 in., and the grasses found include Hyparrhenia, Andropogon, Cymbopogon, Imperata, Rottboellia, Thelopogon, Pennisetum, Digitaria and Setaria. In the Southern Guinea zone, with rainfall between 45 in. and 60 in., Pennisetum, Andropogon and Panicum species occur in Kabba, Niger and Benue provinces and the remainder of Ilorin.

Geographical location

Most species of grass and many shrubs and trees, such as the 14-ft high woody shrub Lantana, occur in territories all over the world. Where geographical differentiation appears, however, it is on a regional or continental scale.

Thus the Hyparrhenia (Elephant) grasses are characteristic of Africa, while Imperata (Lallang) grasses are mostly found in South-East Asia.

Existing control

Hand or mechanical cutting of roadside vegetation produces a change in the vegetation regime, and it has been observed in Mauritius and elsewhere that on the shoulders of maintained roads perennial grasses form the dominant species, whereas in ditches and side-slopes a mixed flora is more common.

Drainage

In British Honduras, vegetation species are reported to be influenced by the state of drainage, which in this connexion is taken to mean the depth to the water-table. Thus, under the swamp conditions near Belize, mangrove vegetation is reported, whereas in higher but still poorly-drained ground sour grasses of the Scleria species predominate. On higher, better-drained ground Panicum (Guinea Grass) and Hyparrhenia species predominate. In Tanganyika the sedge Cyperus is said to prefer the poorly-drained areas. Where roads in Southern Nigeria traverse undulating ground, grass cover on the haunches is noticeably more extensive in the valleys where the soil is damp than on the drier hill crests. This brings the advantage of greater protection against erosion where it is most needed.

USES OF VEGETATION NEAR HIGHWAYS

The following uses of vegetation can be recognized:

(i) Prevention of haunch and ditch erosion
  (a) Gravel roads
  (b) Bitumen-surfaced roads

(ii) Prevention of side-slope erosion

(iii) Provision of running surfaces
  (a) Airfields
  (b) Roads

(iv) Improvement of foundations

(v) Improvement of road safety
  (a) Crash barriers
  (b) Dazzle screens
  (c) Relief of monotony

(vi) Aesthetic purposes—tourism.

Prevention of haunch and ditch erosion

Certain types of low-growing grasses can usefully be planted on the haunches of earth, gravel and bitumen-surfaced roads (Plates 1(A) and (B)) to stabilize them against abrasion by wind or erosion by rain. Where funds are limited such planting is initially undertaken at points on the road where experience shows erosion to be particularly severe.

Gravel roads are frequently kept in shape with a blade grader, and this results in the periodic removal of any natural grass cover that has established itself. Because more and more gravel roads are being provided with bituminous surfacings this practice is being abandoned where appropriate, enabling advantage to be taken of the stabilizing effect of the grass. The greater run-off of rainwater over the haunches, resulting from the presence of the bituminous surfacing, makes the erosion protection of the grass of particular value (Plates 2(A) and 2(B)). Grass spreads from verge to haunch more readily in valleys than on crests, where roads traverse undulating country, no doubt due to the moister soil. This is fortunate since the longitudinal scour is more violent on the lower slopes of roads running downhill.

There is clearly scope for the selection of special strains of grass particularly suitable for this purpose. Thus, Somaliland reports that any vegetation would be welcome at the roadside, and in this case the species needed would have to be capable of flourishing under arid conditions. Most of the existing cover in this territory has been removed by overgrazing, and the species needed should therefore have a low degree of palatability to stock. In Hong Kong grass on the haunches is completely worn away during the dry season by pedestrian traffic, and strains more resistant to foot abrasion are needed there. In some of the more populated and flatter areas of Nigeria, where scour is not so severe, it is recognized that removal of grass from a strip of the haunch serves as a footpath or cycle track attracting pedestrian and cycle traffic away from the pavement particularly with narrow bituminous surfacings. A 6-in. to 1-ft width of grass is, however, left immediately adjacent to the bituminous surfacing to protect the edge. Ungrassed strips are also used immediately adjacent to single-carriageway bituminous surfacings in Nyasaland.

In Swaziland the vegetative cover on the surrounding ground is often inadequate to protect the soil from the scouring action of the discharge from the road drains, and much general erosion is said to result from the run-off. In this and in other dry territories it is felt that the first step towards improving the cover is to make the ditches with a cross-section that is flat and wide rather than narrow and deep, to reduce the speed of water flow and to permit vegetation to be readily cut by machine.

In territories with higher rainfall the more vigorous growth can produce a ridge that acts as a kerb at the edge of a bituminous surfacing. As a temporary measure, mitre drains or 'grips' may then be dug through the ridge to dispose of surface water from the road. It is more satisfactory, however, to remove the ridge with a blade grader. This operation is made easier if the shoulder has a steeper crossfall than the road surface.

Prevention of side-slope erosion

Table 2 gives the grass genera that have been reported as being useful for planting on the slopes of embankments or cuttings overseas to reduce soil erosion. Most are low-growing and many are of creeping habit, proliferating either by shoots from underground roots or by propagating stems above ground (Plate 3(A)) thus developing, fairly rapidly, root systems which bind the soil.

Table 2

Vegetation useful in controlling erosion on roadsides overseas

Region	Territory	Genera
East and Central Africa	Kenya	Cynodon, Pennisetum
	Uganda	Cynodon, Digitaria, Paspalum
	Tanganyika	Cynodon, Pennisetum
	Zanzibar	Stenotaphrum (also controls weeds)
	Somaliland	Any vegetation is regarded as helpful
	S. Rhodesia	Paspalum, Pennisetum
	N. Rhodesia	Cynodon, Star, Swazi grasses
	Nyaşaland	Paspalum
West Africa	N. Nigeria	Cynodon, Desmodium, Ipomoea
	E. Nigeria	Axonopus, Cymbopogon, Cynodon, Digitaria, Melinis
	Sierra Leone	Axonopus, Cymbopogon, Pueraria
West Indies	Barbados	Axonopus, Cynodon, Elusine, Euphorbia, Portulaca
	Br. Guiana	Cynodon
	Br. Honduras	Axonopus, Cynodon, Paspalum
	Jamaica	Bambusa, Vetiveria
	Antigua	Andropogon, Axonopus, Dicanthium
	Montserrat	Vetiveria, Sweet grass, Creeping grasses
	St. Kitts	Axonopus (wet sites), Cynodon (dry sites)
	Trinidad	Axonopus, Cynodon, Desmodium, Euphorbia, Mimosa, Sporobolus
	Dominica	Vetiveria
	Grenada	Andropogen, Axonopus, Cynodon, Cyperus, Panicum, Paspalum
	St. Vincent	Vetiveria, Panicum
Atlantic and Indian Ocean	Aden	None
	Bahamas	Cynodon, Sporobolus, Stylosanthes, Tribulus
	Bermuda	Stenotaphrum, Wedelia, Mesembryanthemum
	Mauritius	Cynodon, Stenotaphrum,* Ischaemum, Panicum†
Mediterranean	Cyprus	Most grasses and plants
Far East	Singapore	Axonopus, Digitaria, Ischaemum, Zoysia
	Sarawak	Axonopus, Chrysopogon, Ischaemum
	Hong Kong	Axonopus, Agrostis, Chrysopogon, Beuteloua, Cynodon
Western Pacific	Fiji	Dicanthium, Ischaemum

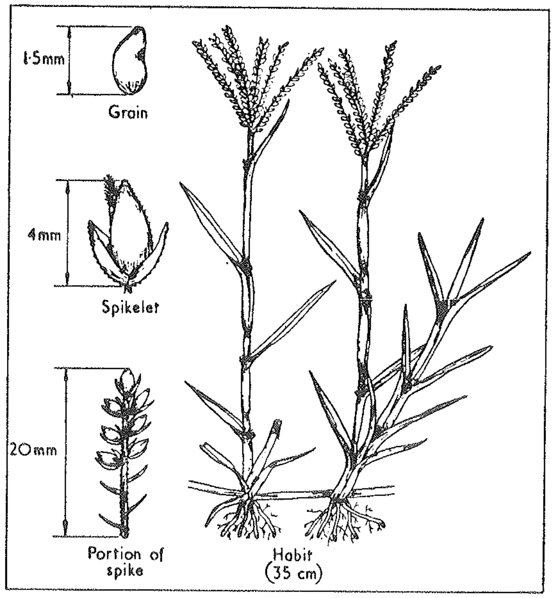
*Low- and medium-rainfall areas
†High-rainfall areas

Table 3 shows the number of territories reported as using each of the twelve most common genera of grasses; Cynodon (Fig. 2(a)) and Axonopus are easily the most favoured. From St. Kitts it is reported that these grasses prefer dry and wet sites respectively, and inspection of Table 2 suggests that this may be true to some extent on a continental scale, since Cynodon seems to be more common than Axonopus in the African territories, which are on the whole drier than the rest. In Tanganyika, however, it has been noted that in some circumstances Cynodon can be displaced by other grasses unless these are controlled.

In the Northern Nigerian province of Ilorin, Cynodon is used on road haunches and embankment slopes, and is said to have the following advantages:

(i) it provides a thick mat about 2 in. deep needing little cutting,
(ii) it chokes out taller-growing species,

(iii) it holds up seed pods fallen from trees, which are then removed by birds,
(iv) it can carry some traffic,
(v) it stops scouring.



(a) Cynodon dactylon

Fig. 2(a). Grass occurring on roadsides overseas
(*see also p.* 23)

Table 3
The twelve most common genera of grasses useful in controlling soil erosion and the number of territories using them

Genera	Number of territories using
Andropogon	2
Axonopus	11
Chrysopogon	2
Cymbopogon	2
Cynodon	15
Dicanthium	2
Digitaria	3
Ischaemum	4
Panicum	3
Paspalum	5
Stenotaphrum	3
Vetiveria	4

In the wetter climate of Malaya earth slopes on hill roads are liable to considerable erosion. Bradley[5] has described how these may be protected by planting Tebrau grass, a bamboo-like variety which roots very quickly in the poorest soil, and develops a thick matted root.

Research into the control of soil erosion is receiving considerable attention, particularly in Agriculture and Land Use Departments, and benefits undoubtedly accrue when, because of good liaison, the results of this work are immediately available to those responsible for road construction in the area. In Southern Rhodesia, for example, the Roads and Agriculture Departments have collaborated in trials of grasses for protecting the slopes of embankments on Kalahari sand. In Singapore, trials are planned with Tephrosia Candida, while in St. Kitts, Digitaria decumbens, recently introduced, is felt to be promising. In some territories, however, it would appear that the results of research, particularly that done outside the territory, could be made more readily available to road engineers, e.g. by reviewing what has already been done agriculturally to determine what is relevant to road engineering. Experiments like those made in Iowa by Davis(6) and by Peperzak, Shrader and Kempthorne(7) are of general interest. In these the most appropriate plant species and seeding mixtures were determined, and the factors leading to increased plant growth on roadside slopes were identified. Steiner,(8) reviewing development work by the U.S. Soil Conservation Service of interest to road engineers, notes the remarkable results obtained by the use of jute matting during the seeding of slopes. Experiments of this type might well be of value in those overseas territories where jute is produced locally. The research work leading to the design of the recently constructed Florida Turnpike included a special investigation by means of test plots of grass species suitable for the control of erosion on the embankment slopes.(9) Information relating to the use of grass for soil conservation is given in "Herbage Abstracts", published quarterly by the Commonwealth Bureau of Pastures and Field Crops.* 147

Astrup,(10) has described how a helicopter may be used to apply seed and fertilizer on high and steep highway slopes that are otherwise difficult of access.

Provision of running surfaces

It seems safe to predict that for some time to come grass runways have a useful purpose to serve at airports where the number of aircraft handled is low and their weights limited. Thus, in Northern Rhodesia in 1957, 19 of the 34 airfields and landing grounds maintained by the Public Works Department had grass runways.(11) In a somewhat higher grade of construction, grass is combined with gravel to obtain a higher bearing value than that obtained with the natural soil (Plate 3(B)). Even on airfields of the highest grade, with paved runways, areas equal to more than 80 per cent of the ground benefit from grass cover to improve the soil stability.

Although not specifically requested in the original circular, some information was sent to the Laboratory regarding vegetation on airfields overseas. Thus, in Fiji, Axonopus compressus is dominant on airfields in the wet zone and blue grass (Ischaemum aristatum and Dicanthium caricosum) in the dry zone. Zanzibar reports that low creeping grasses are predominant, possibly as a result of frequent mechanical cutting. In Uganda, Paspalum notatum, which is encouraged on roadsides, is considered to be too lumpy for airstrips used by light aircraft and the cover on runways generally consists of indigenous grasses of many species, the tufted ones being removed. Cynodon dactylon is sometimes planted owing to its soft and spreading characteristics. In Mauritius, the

*The address is: Commonwealth Bureau of Pastures and Field Crops, Hurley, Berkshire.

runways of the airfield are surfaced and the types of vegetation encountered along it are similar to those on the roadsides in the humid zone. On the main runway at Ibadan, Western Nigeria, Cynodon dactylon predominates, with Axonopus species in the majority elsewhere on the airfield. On Tortola airfield in the British Virgin Islands sage occurs as well as a herb known as "Fir Stick" or "Thumb Tack". In Borneo, Bassett reported[12] that Bermuda, Kentucky blue top and marram grasses were popular on airstrips although not universally suitable, and he felt that paspalum should be examined as a possible replacement. He also reported difficulties with grass mowings blowing up into retractable undercarriages, necessitating particular supervision from maintenance staff.

Between 1939 and 1945 interest increased in Great Britain, the U.S.A. and elsewhere in the methods of producing grass surfaces for airfields. Owing to climatic differences not all the information acquired is useful under tropical conditions, but some points are relevant. Thus, Paeschke[13] recommends mixtures rather than single species of seed, and irrigation where necessary in subtropical climates. Smith notes that the stability of wet clay soils is increased by turf formation, and suggests that the seed mixture used should be suited to the texture of the soil.[14] Clouston recommends soil analyses to determine whether benefit can be obtained from the use of fertilizers.[15] Sack[16] describes research carried out by South African military engineers on the production of turf for airfields. More recently Long[17] has given recommendations for the design, construction and maintenance of grass airfield surfaces for small urban airfields in South Africa. Yarrow observes that grass adjacent to paved runways is liable to grow rapidly and to rise above pavement level, owing to concentration of moisture.[18] Rolling, discing and blading have been used to correct this condition.

Guide specifications have been produced in the U.S.A. by the Corps of Engineers and by the Civil Aeronautics Administration for the operations of topsoiling, topsoil planting, seeding, sodding, sprigging,* mulching, tillage and irrigation.[19][20] The choice and use of mechanical equipment and the organization of the work of seeding airfields has been discussed by Aust.[21] The value of grassing to reduce wind erosion on airfields has been noted by Bell and Tedrow.[22] Morrish reported the grass types suitable for use in the different climatic zones of the U.S.A. He observed that in extremely dry areas annual grasses such as cereal grains may be used on unstable soils until perennial grasses can become established, and suggested that in regions with less than 10 in. of annual rainfall, straw or hay mulch may be applied, initially to control dust and erosion, but ultimately to increase the chances of obtaining established grass by retarding soil moisture evaporation.[23]

In experiments on several airfields in the United Kingdom, Sutton, Alexander and West[24] found that germination and growth could be fostered during dry periods by stabilizing the surface soil with bituminous peat compositions. Mott[25] has shown that grass can be grown successfully on granular road-making material compacted to pavement densities, and that it is helpful to mix with the aggregate plant-nutrient materials as well as a small proportion of clay to retain the nutrient and some necessary moisture.

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*Sprigging is the planting of grass cuttings and roots in parallel rows about a foot apart to encourage the early development of turf.

Table 4
Vegetation used for constructional purposes in the U.S.A.
(Cale[24])

	Species	Seeding rate (lb/acre) Minimum	Seeding rate (lb/acre) Maximum	Minimum annual rainfall (in.)	Characteristics
(a) *Warm humid region*					
Grasses	Axonopus compressus	10	30	35	Sod forming by surface runners: prefers moist sandy soil, tolerant of low fertility
	Cynodon dactylon	5	20	35	Sod forming by runners above and below ground, intolerant of shade; spread by vegetative methods
	Lolium multiflorum	10	50	30	
	Paspalum notatum	5	20	35	Bunch grass, adapted to infertile soils; high resistance to wear; needs minimum of maintenance
	Stenotaphrum secundatum	—	—	35	Spreads by surface runners
Herbs	Lespedeza striata	10	15	35	Summer annual, re-seeding naturally, planted with Cynodon dactylon
	Trifolium repens	1	5	20	Spreads by creeping stems or seeding on fertile, moist soils
(b) *Warm arid region*					
Grasses	Bouteloua hirsuta	10	15	10	Summer rainfall above 3000 ft
	Bouteloua eriopoda	10	15	10	Summer rainfall, moderate altitude
	Eragrostis spp.	1	3	8	Tufted, best seeded in mulch
	Hilaria spp.	4	8	8	Underground rhizomes, drought resistant
	Oryzopsis hymenoides	8	10	10	Medium altitudes
	Sporobolus airoides	2	4	10	Open sod, alkali soil
	Stipa pulchra	8	12	10	
Herbs	Ice plant	—	—	—	Succulent perennial using atmospheric moisture; needs no irrigation except in very dry soil or low atmospheric moisture; procumbent habit and needs no mowing

In Florida the climatic and geological conditions are closer, than in any other part of the U.S.A., to those in the less arid regions of some overseas territories. Monteith has described how grass has been used successfully on the shoulders and runways of paved ends at 27 airfields in the State. A 6-in. thick layer of soft limestone and sand was sprigged, fertilized, seeded with Cynodon dactylon and compacted to maximum density.[26] A special machine was used for the sprigging operation. This combination of stabilized soil and grassing greatly reduced maintenance costs.[27]

Cale, reviewing vegetation useful for construction in the different climatic zones of the United States, has given the data shown in Table 4 on seeding rates, minimum annual rainfall and general characteristics.[28] Table 4a relates to the warm humid region, including Florida and the Gulf Coast States and should also be applicable to some of the West Indian territories. Table 4b relates to the warm arid region, including New Mexico, Arizona and south-eastern California, and should apply to the drier African territories.

Improvement of foundations

Fascine mattresses are often used to provide improved support for soil embankments laid over swampy foundations. Coode[29] has described the use of brushwood for this purpose during the construction of the Ebute Metta Causeway in Lagos, Nigeria, and Osborne[30] has given details of the use of mangrove poles in mattresses under a dual-carriageway road in Trinidad.

VEGETATION TO IMPROVE ROAD SAFETY

In the United Kingdom and the United States of America it has been recognized for some years past that roadside vegetation can play a useful part in increasing safety on roads, and this awareness is now spreading to overseas territories. In Southern Rhodesia and the Union of South Africa, the increasing mileage of long-distance high-speed trunk roads is bringing to the fore the problem of driver hypnosis, a condition induced by long periods of fast driving on straight alignments over flat open country. Recognizing that alertness can be stimulated visually by objects at the roadside that can engage the attention of the driver for short periods, trees are now being planted at suitable intervals (see Plate 4(A)) or near places where there are changes of alignment. In Kenya, the Ministry of Works is interested in planting trees for shade, and shrubs as crash barriers or headlight screens (Plate 4(B)).

Thedié, in a statistical study of accidents on a trunk road in France, compared sections without trees with others lined with trees planted at different distances from the edge of the roadway. The trees were found to reduce the number of accidents when planted more than a metre from the road edge, but increased them if they were close to the edge of the road.[31]

In the U.S.A., interest in the use of vegetation screens as crash barriers and for reducing dazzle on dual-carriageway roads has been stimulated by the papers presented by Deakin to the Committee on Roadside Development of the Highway Research Board. In tests, a hedge of Rosa multiflora as a crash barrier, has been said to stop a car travelling at 50 mile/h in 60–75 ft without injury to the occupants.[32] Methods of combining fencing with plants of thick foliage and semi-evergreen character have been developed to provide dazzle screening for cases where the central reservation ('Median') on dual-carriageway roads is narrow. In a second paper, the conclusions from development work in the U.S.A. have been summarized,[33] and, as the majority are also applicable in overseas territories, they are (verbatim) as follows:

(i) Planting for screening headlight glare and for traffic guidance may be kept to a minimum by adopting highway design criteria that will establish a cross-section with a minimum ultimate median width of 50 ft or greater, wherever property values permit.

(ii) Properly designed median plantings will not only reduce headlight glare and serve as a guide for traffic travelling over a changing alignment, but will also allow motorists to drive with high-beam headlamps continuously in use. This will increase night driving visibility at least fifteen times over low-beam driving.

(iii) Median plantings, to be effective, must ultimately measure $4\frac{1}{2}$ to 5 ft in height and be composed of plant material that will provide a dense twig growth.

(iv) Median-zone plantings may prove to provide additional benefits, such as serving as effective crash barriers, preventing vehicles and pedestrians crossing medians, replacing guide rail, and eliminating its yearly maintenance cost and periodic replacement.

(v) Planting of trees and shrubs at the back of (existing) guide rails will help to make such fixed barriers easier to detect during night driving, as well as to aid in warning the driver of a changing alignment.

(vi) Plantings of trees and shrubs in traffic circles and grade separation ramps have proved to be helpful warnings to motorists to slow down.

(vii) Median-zone plantings will present varying maintenance problems in urban as compared with rural areas.

Vision impeded by tall trees on the inside of curves may often be improved without felling, by suitably trimming lower branches. White painting of the trunk delineates the road edge at night (Plate 5(A)). 151

AESTHETIC CONSIDERATIONS

As noted by Jellicoe in a recent Rees Jeffreys lecture[34] dealing with the landscaping of new motorways, roads can and should add to the exhilaration of daily life, and a long journey on them could be a continuous and positive delight. In striving for this objective, the modern road-landscaping architect can make considerable use of the many attractive trees and shrubs that are available for planting. In many tropical territories nature is generous in the provision of beautiful vegetation, and in particular regions such as the Mediterranean and the West Indies there is scope for the use of this natural asset in the development of roads for tourist purposes.

In Great Britain, the Roads Beautifying Association has led the way in this field, having been responsible for planting schemes along 600 miles of road in 33 counties. In a review of the Association's activities over the last 25 years, Spitta[35] has given several illustrations of what can be accomplished with ornamental shrubs and trees. Literature produced by the Association includes practical instructions for the planting of trees and shrubs with special reference to roadside conditions, advice on the pruning of roadside and street trees, and the standard specifications for trees and shrubs for roadside planting. Advice is available from the Association* to enquirers from any part of the world: in the case of some overseas territories this could usefully supplement that available from the Curators of Botanical Gardens or Herbaria.

Literature of the Aryan period (3500–2500 B.C.) shows that in India trees

*The Roads Beautifying Association, Kipling House, 43 Villiers Street, London, W.C.2.

were planted at the sides of public roads. Marco Polo recorded in 1300 that the road surveyors of Tartary planted and maintained trees giving shade as well as ornamentation.[36] Planting with similar aims is in hand with Macadi trees on the Kano to Zaria trunk road in Northern Nigeria (Plates 6(A) and 6(B)). The shade attracts the slower pedestrian and animal user to the safety of the roadside leaving the paved centre free for the faster vehicular traffic.

The principles of roadside tree planting in Nigeria are discussed in the Public Works Department's "Manual of road construction and maintenance".[37] Briefly, these are:

(i) Assuming a carriageway width of 22 ft and verges 5 ft wide, trees should not be planted nearer the centre line than 20 ft. The species used should not have branches below a height of 20 ft when mature.

(ii) One side of the road (preferably the westerly) should be reserved for tree planting while the other is used for electricity and telegraph lines. This arrangement provides shade for maintenance gangs during afternoon work and avoids the breakage of wires by falling branches.

(iii) To encourage pedestrians to leave the verges, trees should be as far from these as practicable, but not so that pedestrian or animal traffic will break down or interfere with drainage channels. A suitable distance is 25 ft from the centre line on the side where drainage works are required, unless this interferes with farming or increases fire hazards.

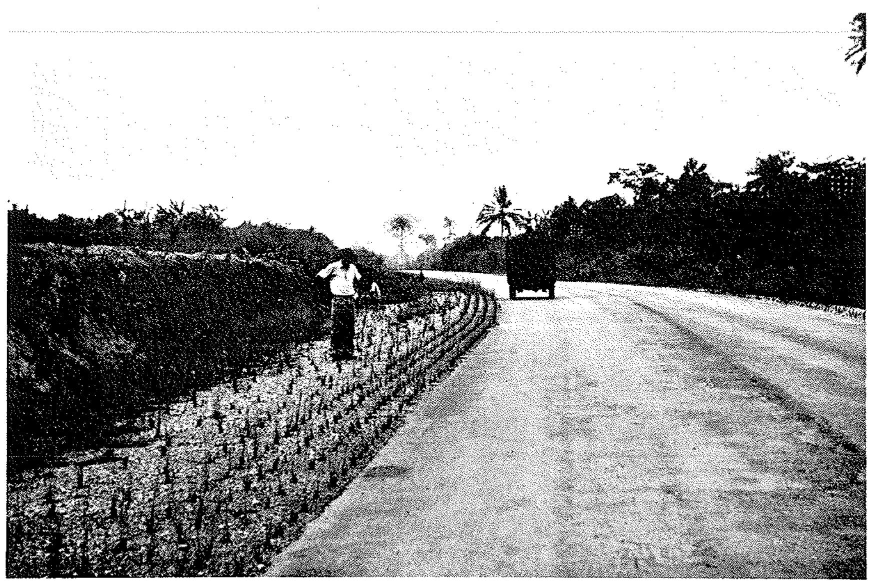
Table 5

Details of trees suitable for roadside planting in Nigeria

Annual rainfall (in.)	Species	Local name	Soil	Height (ft)	Remarks
20–35	Mangifera indica	Mango	Heavy	40	
	Tamarindus	Tsamiya	Poor	70	Slow to start
	Acacia Albida	Gawo	Dry Sandy	60	Fast growing
	Ficus Thonningii	Chediya	Medium	60	Easily propagated
	Ficus Polita	Durumi	Medium	60	From cuttings
	Parkia	Dorowa	Medium	70	Useful tree
35–55	Mangifera	Mango	Heavy	40	
	Khaya	Mahogany	Any soil	80	From seed
	Ficus	Fig	Medium	60	Easily propagated
	Jacaranda		Medium	40	High altitudes
	Azadirachta indica	Neem	Sandy	40	Does not stand tornadoes
	Afzelia Africana	Kawo	Medium	70	Popular shade tree
55 over	Pentaclethra	Apara	Any soil	60	Oil bean tree
	Peltaphorum		Any soil	50	
	Ekebergia Senegalensis	Oromu	Dry	50	Drier areas
	Pithicolobium	The Ran Tree			Plant well back
	Cassia Fistula and Nodosa	Pink Cassia	Sandy	30	

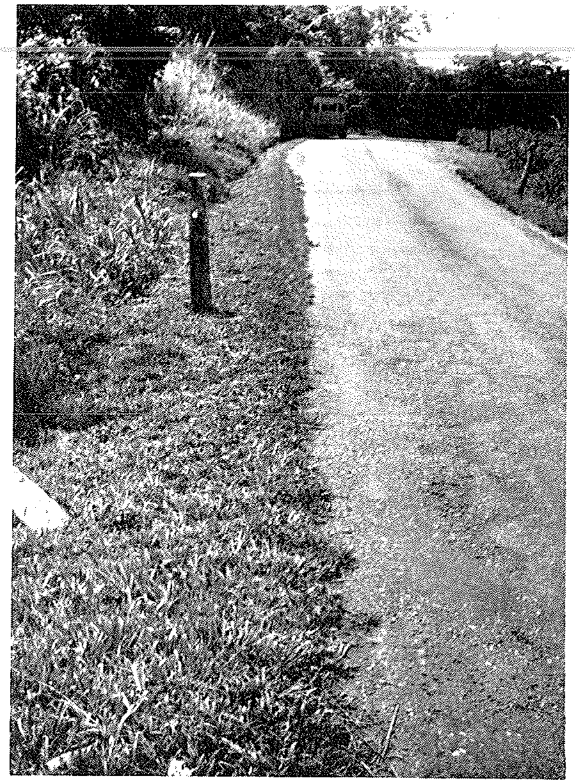
Table 5 lists trees found suitable for planting at roadsides in the various rainfall regions of Nigeria. These species would be expected to be suitable in West Africa generally.

(A) Grass establishing itself on the haunches of the sand-clay road between Ughelli and Kwale in the Eastern Region of Nigeria



(B) Planting grass on the haunches of a bituminous pavement on the road from Tarkuwa to Takoradi, Ghana

PLATE 1



(A) A length of road in Western Nigeria, where the edge of the bituminous surfacing is protected by grass

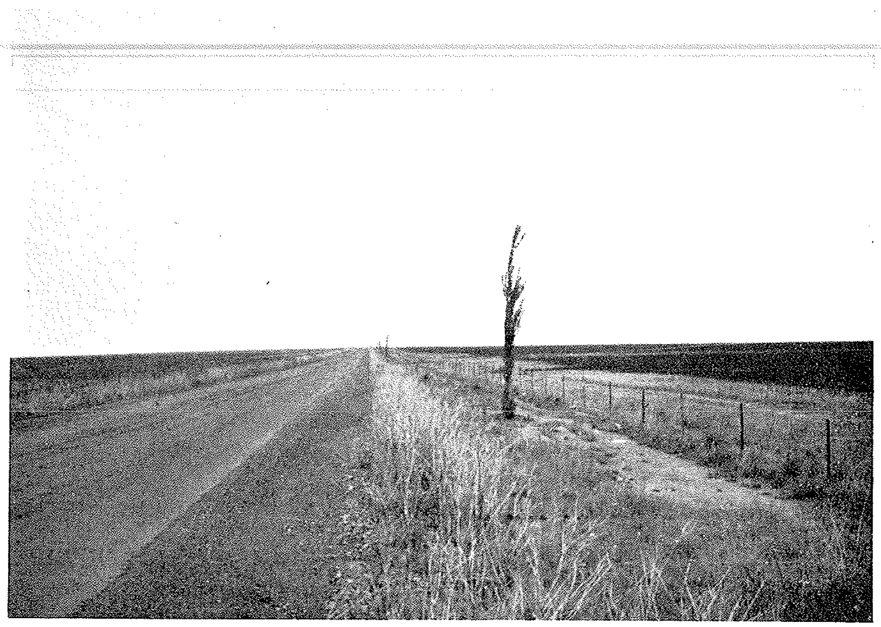
(B) 20 yards along the same road where grass is absent and fretting has occurred

PLATE 2

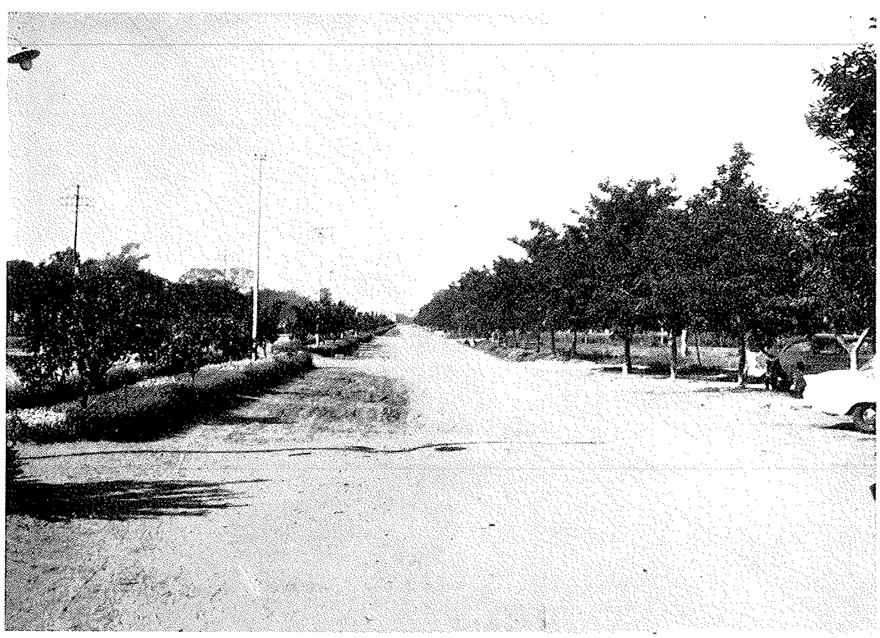
(A) Planting of grass to check erosion at a critical point—a shallow embankment on the road from Mamfe to Ikom, in the Southern Cameroons

(B) The grass-bound laterite surfacing of the runway at Fort Jameson Airfield, Northern Rhodesia, showing a particularly severe skid-mark

PLATE 3

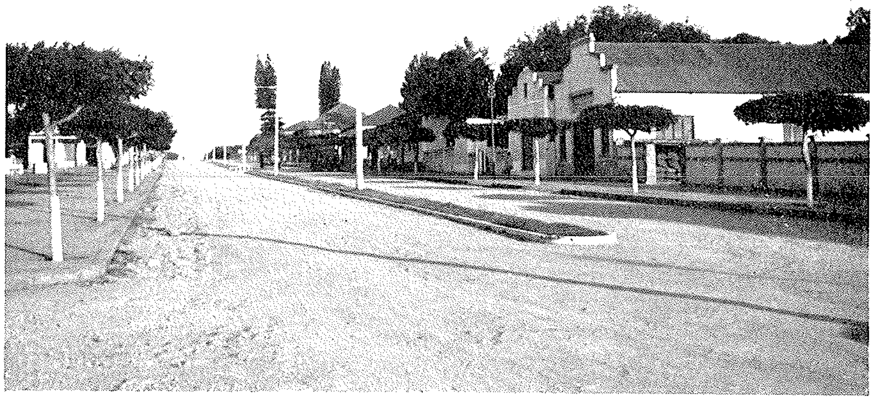


(A) Poplars planted to relieve driver monotony on a road in the Orange Free State. Union of South Africa



(B) Ornamental planting serving as a headlight screen in the central reservation of an urban road in Guija, Portuguese East Africa

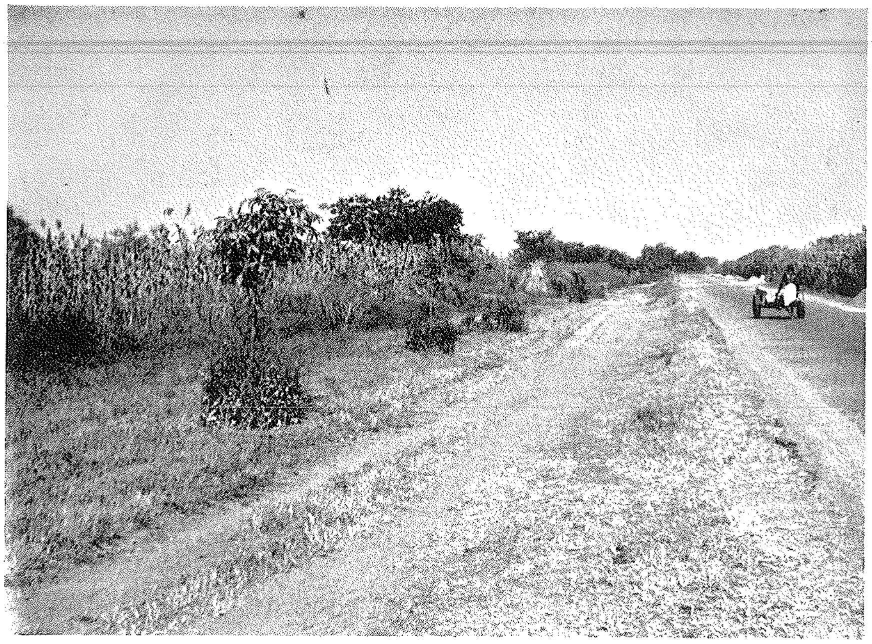
PLATE 4



(A) White paint on tree trunks to indicate the road edge at night, in Chibuto, Portuguese East Africa

(B) Couch grass (Cynodon dactylon) encroaching on bituminous surfacing, on the Essexvale to Bulawayo road, Southern Rhodesia

PLATE 5



(A) Young Macadi trees planted alongside the Zaria to Kano trunk road, Northern Nigeria

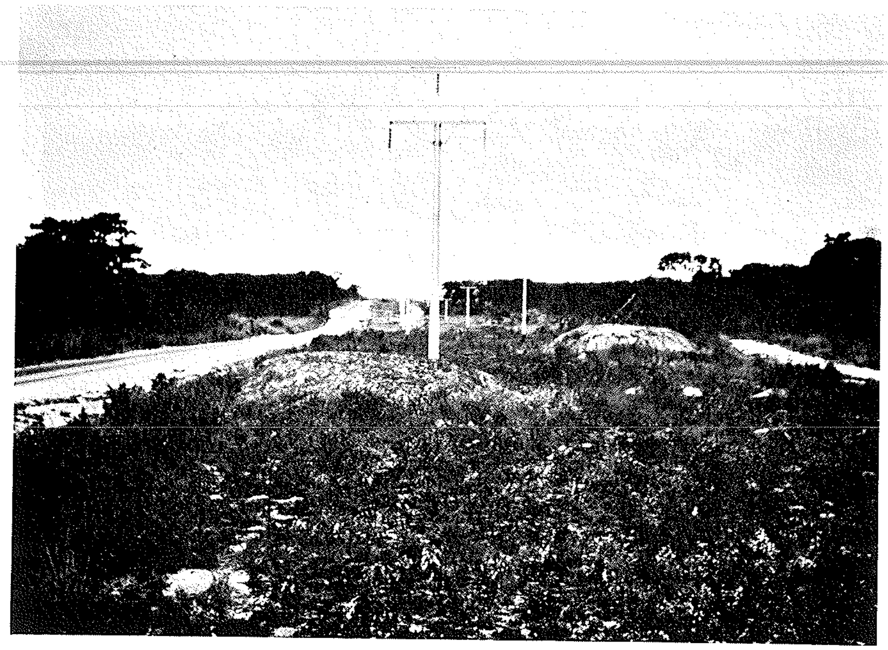
(B) Mature trees providing shade and attracting slow traffic from the road centre

PLATE 6

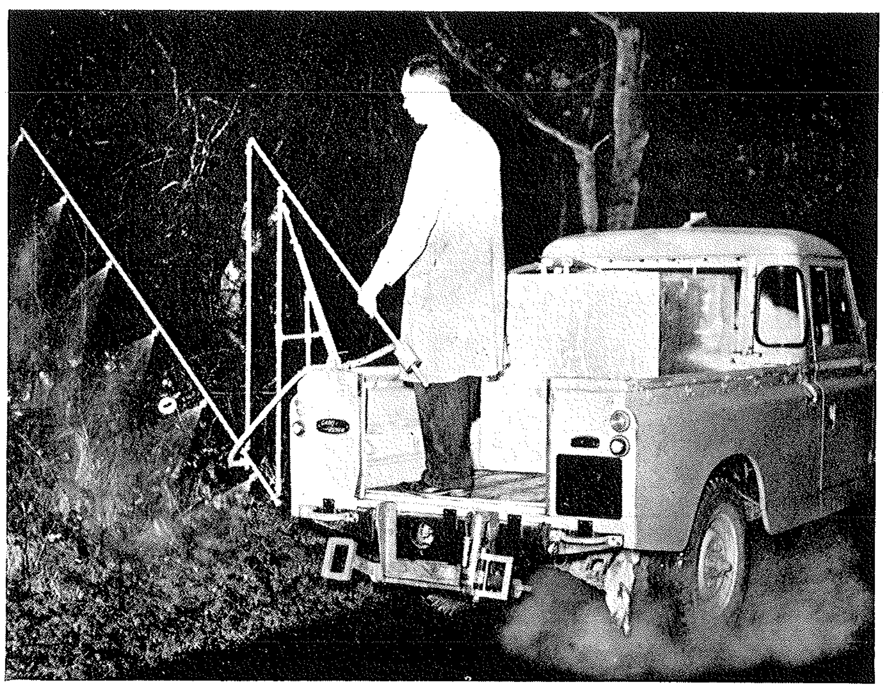
(A) Grass growing through an old, unmaintained, soil-cement pavement at Norton Airfield, Southern Rhodesia

(B) Tall-growing elephant grass (Hyparrhenia spp.) which obscures cyclists entering a road from small tracks at right-angles, and causes accidents. On this road, from Monze to Lusaka, in Northern Rhodesia, the verges have been cut to improve vision

PLATE 7



(A) The electricity line reservation on the road from Chingola to Kitwe, Northern Rhodesia. The smoke from fires on this land is a hazard on the adjacent high-speed road, and the fires can damage the power lines. Control of the vegetation eases both these problems; mechanical control is impracticable because of the ant-hills



(B) Tank and cantilevered spray bar accessories for a Land Rover, developed for the chemical control of roadside vegetation. The pump is driven from the centre P.T.O., in the cab.

(*Photograph—Evers and Wall*)

PLATE 8

Table 6
Details of trees suitable for roadside planting in South-East Asia

Species	Local names	Geographical distribution (i.e. regions where native)	Appropriate altitude (ft)	Rate of growth	Dimensions relating to nature: Height (ft)	Diameter of trunk (ft)	Minimum distance between adjacent trees (ft)
Agathis alba	Damar	Indo-China, Malaysia, Borneo, New Guinea	>750	Very slow	150	3	25
Swietenia macrophylla	Broad-leaved mahogany	Honduras	<1800	Very fast	up to 100	6	>25
Casuarina equisetifolia	Australian pine Horsetail oak Ironwood Aru	All S.E. Asia Pacific Islands	Various	Very fast	110	6	28
Lagerstroemia speciosa	Ketangi Woengoe	India Ceylon Australia Indonesia	<2400	Slow	30–110	2	25
Cinnamomum iners	Kajoe lawang	India Borneo Malaya Indonesia	450–3000	—	60	1	28
Grevillea robusta	Silver oak	Australia	1500–3000	Slow	40–100	2	25
Pterocarpus indica	Andaman redwood Burmese kino tree Kajoe merah Angsana	S.E. Asia	<1500	Fast	110	5	30–45
Tamarindus indica	Tamarind tree Asam djawa	W. Asia E. Africa	—	Slow	30–75	8	30–45

Table 6 (contd.)

Species	Local names	Geographical distribution (i.e. regions where native)	Appropriate altitude (ft)	Rate of growth	Dimensions relating to nature		
					Height (ft)	Diameter of trunk (ft)	Minimum distance between adjacent trees (ft)
Michelia champaca	Tjempaka	Burma S.E. Asia	<3600	Very slow	45–75	$1\frac{1}{2}$	30
Manilkara kauki	Kajoe saboea Saoe djawa	West Malaysia	<900	Slow	up to 40	1–3	25
Enterolobium Saman	Rain tree Kajoe ambon	Trinidad British Guiana	<3000	Fast	30–75	4–8	70
Canarium vulgare	Java almond tree Kenareh	Indonesia	<1200	Moderately fast	up to 130	2	30
Adenanthera pavonina	Red sandalwood Saga rajoe	Singapore Borneo Indonesia	<1800	Fast	up to 60	2–7	25
Cassia siamea	Djohar	Ceylon, India, Indonesia	<3000	Fast	30–60	1–2	24
Canarium indicum	Kanari ambon	Indonesia to Solomon Is.	—	—	110–120	2–4	30
Spathode campanulata	Tulip tree Angserot	Africa	—	Fast, short lived	75	6	30
Cedrela toona Cedrela odorata	Redwood tree Jamaica cedar	W. Indies	450–3600	Very fast	60–90	3	22
Calophyllum inophyllum	Alexandrian laurel Benaga	Australia Oceania Indian Ocean Is.	—	Slow	60	8	55

The species listed in the upper part of the table are those most suitable for roadside use

Table 6 lists tree species suggested by Wigman to be suitable for roadside use in Indonesia;[38] these would be expected to be of use in territories in South-East Asia generally.

PROBLEMS ARISING WITH VEGETATION

Vegetation can cause four main problems on roads, namely deformation and disruption of pavements, reduction of visibility, fire hazards, and re-infestation of clean agricultural land.

Croney and Lewis,[39] on the basis of studies in the United Kingdom, have recommended that on heavy clay soils, fast-growing tree species should be planted more than 50 feet from the carriageway to avoid settlement and cracking of the road surface due to transpiration of moisture from the foundation. In the Union of South Africa, Williams[40] associates failures on a bitumen-surfaced road on black clay with the planting of Blue Gums 60 feet from the edge. In Texas, Felt [41] reports that vegetation, including mesquite and oak trees produced non-uniform drying in the clay foundations of a projected road. He attributes deformation of an existing road to differential swelling following wetting up of the soil after construction. In such cases, removal of the above-ground parts of the vegetation prior to a rainy season should enable moisture to become more uniformly distributed in the foundation by the time the road is constructed in the subsequent dry season. Only small low-growing trees and shrubs should therefore be used within 10 feet of the carriageway at such sites.

Bituminous pavements are sometimes damaged by the root systems of plants, which penetrate the foundation in searching for moisture and in growing disrupt the structure. Cynodon dactylon is reported to be troublesome in this respect in Southern Rhodesia (Plate 5(B)), Mauritius and Bermuda, owing to the tough underground rhizomes (underground stems). In Dominica, nut grass (Cyperus spp.) is reported to behave similarly. Where traffic is relatively infrequent, such as at the edges of airfield runways, grasses tend to grow through the pavement; spear grass has given this kind of trouble at Lungi airport in Sierra Leone: Plate 7(A) shows a more advanced example on a disused airfield in Southern Rhodesia. The incidence of this kind of damage can be avoided, or at least greatly retarded, by the use of total herbicides during and subsequent to construction (see p. 26).

Overhanging trees and bushes delay evaporation. after rainfall and may unnecessarily prolong softening in roads and haunches of earth and gravel, and slipperiness of bituminous surfacings. Trimming the trees or selective felling to give sunlight and wind access to the road prevents this.

Reduction of visibility is the most serious problem presented by roadside vegetation. Rank growth obscures vision on curved alignments, and in Northern Rhodesia accidents result from the screening by Hyparrhenia grasses of cyclists entering high-speed main roads from bush tracks joining them at right angles (Plate 7(B)). During the dry season rank vegetation at the roadside also constitutes a reservoir of combustible material easily ignited by cigarettes thrown from passing cars or by the annual bush fires in scrub country. Apart from obscured vision caused by drifting smoke, these fires are a potential source of damage to any adjacent timber stands in forest country; Uganda reports that damage can also be caused to overhead power and telephone lines, which so often run in the road reservation (Plate 8(A)).

In overseas areas with intensive cultivation of cash crops, the road reservation is rightly regarded as a source from which agriculturally clean land can be continually re-infested with weeds. Complaints have been voiced from Jamaica, Dominica and Cyprus, and the circumstance probably arises in many other areas, particularly in the West Indies. The road authorities usually have no compelling reason to control vegetation to the extreme limit of the road reservation and the maintenance vote may well be sufficient only to keep the road and its immediate edges in reasonable condition. If the Departments responsible for roads and agriculture could join forces to clear weeds from both fields and roadsides in one operation, a solution to this problem might well be found that would save much more than it would cost.

Rank growth of vegetation can also reduce the effectiveness of drains at roadsides and on airfields.[42] Cyperus spp. have been particularly blamed for this in Tanganyika.

Table 7

Vegetation of rank growth habit on roadsides overseas

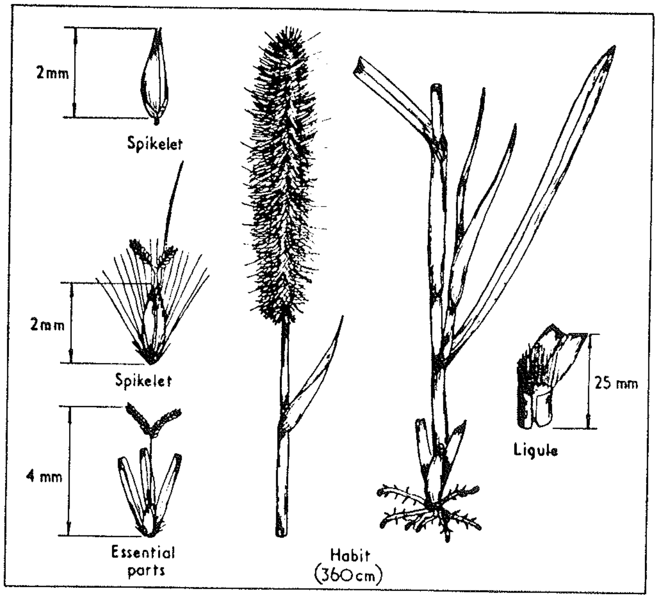
Region	Territory	Genera
East and Central Africa	Kenya	Acacia, Tagetes, Indigofera, Lantana, Solanum*
	Uganda	Acanthus, Lantana, Pennisetum
	Tanganyika	Hyparrhenia, Imperata, Panicum, Pennisetum
	Zanzibar	None
	Somaliland Prot.	None
	Southern Rhodesia	Hyparrhenia
	Swaziland	None
West Africa	Northern Nigeria	Hyparrhenia
	Eastern Nigeria	Andropogon, Eupatorum, Imperata, Panicum, Pennisetum
West Indies	Brit. Guiana	Cassia, Cordia, Indigofera, Lantana, Solanum†
	Brit. Honduras	Hyparrhenia, Panicum, Scleria, Mangrove
	Jamaica	Annual, biennial and perennial weeds
	Antigua	Acacia
	British Virgin Islands	Acacia
	Montserrat	Acacia
	St. Kitts	None
	Trinidad	Brachiaria, Paspalum
	Dominica	Cymbopogon
	Grenada	Bambusa, Spondias
	St. Vincent	Axonopus and others
Atlantic and Indian Ocean	Aden	None
	Bahamas	Acacia, Coccolobis, Leucaena, Torrubia
	Bermuda	Foeniculum
	Mauritius	Cynodon, Digitaria, Paederia
Mediterranean	Cyprus	Many species
	Gibraltar	None
	Malta	None
Far East	Singapore	Imperata
	Sarawak	Imperata
	Hong Kong	Lantana, Leucaena, Tithonia
Western Pacific	Fiji	Acacia, Brachiaria, Cassia, Lantana, Panicum, Pennisetum, Solanum†

*The first two in all areas, the last three, with many others, in the Rift Valley.
†With many other species.

Table 8
Incidence of vegetation genera having a rank habit of growth on roadsides overseas

Genera	Number of territories reporting	Classification	Maximum height (ft)
Acacia	6	Tree	–
Brachiaria	2	Grass	8
Cassia	2	Shrub	–
Hyparrhenia	4	Grass	6
Imperata	4	Grass	4
Lantana	5	Shrub	14
Panicum	4	Grass	10
Pennisetum	4	Grass	16
Solanum	3	Shrub	–
Indigofera	2	Herb	–

Table 7 shows the major genera that have been reported to give trouble owing to rank growth on overseas roadsides. Table 8 lists the numbers of territories from which difficulties have been reported with the more important genera given in Table 7. The Acacia tree and the woody shrub Lantana are the most commonly encountered of the larger species; the majority of the remainder are tall grasses. The overseas territories differ in this respect, therefore, from the United Kingdom where tall herbs and shrubs present the main problem, and the natural grasses are of low habit. Geographically, Hyparrhenia and Pennisetum spp. (Fig. 2b) offer the major problems in African territories, whereas Imperata Cylindrica (Lallang) predominates in South-East Asia. Neither of these groups appear to be very troublesome in the West Indian islands, where the difficult vegetation is more varied. 165



(b) Pennisetum purpureum

Fig. 2(b). Grass occurring on roadsides overseas

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METHODS OF VEGETATION CONTROL AND COSTS

Methods of controlling vegetation on roadsides have been borrowed from agricultural practice, a good review of which is given by Robbins, Crafts and Raynor.[43] The methods discussed of particular application to roads are:

(i) Mechanical methods
- (a) Hand-cutting or hoeing
- (b) Mechanical cutting
- (c) Burning

(ii) Biological methods
- (a) Grazing
- (b) Use of parasites

(iii) Chemical methods
- (a) Non-selective herbicides.
- (b) Selective herbicides.

Table 9 gives the methods reported for maintaining roadside verges overseas free from rank vegetation, together with approximate roadside maintenance costs in 1958.

Mechanical methods

Hand-cutting is the most widely used method, although in many territories this is being supplemented or superseded wherever practicable by mechanical cutting. A range of specialized equipment is available for cutting roadside vegetation, including one machine (the 'bush hog') capable of dealing with woody growth up to 3 in. in diameter, which is of particular value in forest areas. Mechanical-cutting offers particular advantages in dealing with airfields because it enables large areas to be dealt with in a limited time by a small labour force. In Africa, maintenance of airfields and landing grounds can absorb considerable effort during and just after the rains owing to the rapid growth of grass. In Zanzibar, however, it is reported that the presence of large stones at the roadsides makes the use of machinery difficult. Ant-hills present similar difficulties (Plate 8(A)). Hand-cutting is a seasonal occupation, as for example in the Northern Nigerian province of Ilorin where a cut is made during each of the eight months of the wet season, and none during the dry season. In those countries of South-East Asia where rainfall remains at a high level throughout the year, however, cutting may be needed once every month. By defoliation, cutting reduces the capacity of vegetation for further growth; it is therefore most useful in the earlier part of the wet season. Similarly, the amount of cutting needed by a newly constructed verge may well decrease with time.

Burning is used in some seasonally dry areas, but Uganda reports that with tall grasses, such as the Pennisetum spp., burning may damage any overhead power lines present. In Northern Nigeria it has been noted that deliberate burning encourages the rank Hyparrhenia species of grass at the expense of the more erosion-resistant species. In British Honduras, on the other hand, where there are regions of wetter climate, the use of a flame thrower is being considered to retard the damp vegetation without actually killing it.

Table 9
Methods and costs of roadside maintenance overseas

Region	Territory	Methods of maintenance	Annual cost quoted per mile (1958) (£)
East and Central Africa	Kenya	Hand-cutting, on gravel roads and reservations	3–8
		Mechanical-cutting, on bitumen-surfaced roads	8–15
	Uganda	Hand- and mechanical cutting	—
	Tanganyika	Hand-cutting	20
	Zanzibar	Hand- and mechanical cutting	—
	Somaliland	General maintenance	5–50
	S. Rhodesia	Burning and grading grass	
		Mechanical-cutting	40
	Nyasaland	Hand- or mechanical-cutting of grass	3–15
		Hoeing or burning of other vegetation	
West Africa	N. Nigeria	Burning of grasses	
		Hand-cutting of woody species	60
	E. Nigeria	Hand-cutting	10–20
	Sierra Leone	Hand-cutting	20
	Gambia	Grazing of verges	—
West Indies	Barbados	Chemical control on plantation roads	—
	Brit. Honduras	Mechanical-cutting of forest road verges	—
	Brit. Guiana	Hand-cutting	—
	Jamaica	Hand-cutting	
		Chemical control on plantation roads	—
	Grenada	Hand-cutting	8
	St. Vincent	Hand-cutting and grazing	—
	Trinidad	Hand-cutting up to several times each year	—
Mediterranean	Cyprus	Hand- and mechanical cutting	22
Far East	Singapore	Hand- and mechanical cutting	
		General maintenance	210
	Sarawak	Hand-cutting	75–80
		Mechanical-cutting	50–60
	Hong Kong	Hand-cutting, twice annually	—

The width of road reservations in different territories varies. Some are narrow because adjacent ground is already held for other purposes. Others are broader, permitting good pavement widths, adequate drainage and sight lines, and afford room for future development as the speed and intensity of traffic increases. In the latter case a road authority may well hold in trust a width of reservation that is greater than can be adequately maintained from existing annual income. In such cases vegetation control could be affected by permitting agricultural cultivation of low-growing, short-term crops on the outer edges of the reservation. The rights of the road authority to re-entry at short notice, to provide adequate drainage structures and to dispose of surface water might well need legal safeguards.

Biological methods

The practice of grazing stock on the road verges is reported from Kenya, Gambia, Cyprus, Antigua and St. Vincent, although all but two of these territories rely on some additional method for controlling grass. Unless the stock can be satisfactorily folded, grazing would appear to be undesirable from the point of view of road safety. In a small, hilly territory, however, the level grassy verges on the roads may well form a sizeable proportion of the total grazing land available; in St. Vincent, for example, the road verges carry one-quarter of all the cattle on the island.

An example of the use of parasites to control vegetation is reported from St. Kitts, where prickly pear (Opuntia spp.) is now being controlled by the predatory caterpillar of the moth Cactoblastis cactorum, which consumes the plant. This technique was first used in Queensland, Australia, where a total infestation of 60 million acres was virtually eliminated between 1925 and 1933. Introduction of the caterpillar to the drier parts of Hawaii has also met with success. Attempts have been made to control Lantana camera in Fiji by introducing insects of the Agromyza, Thecla and Teleonemia families, but it is not known whether this has met with success.

To take advantage of this method the species to be controlled should preferably not be a native of the area concerned, and have no near relatives of agricultural importance. It is necessary to collect predators in the area from which the species originated, and to introduce them into the area to be controlled, free from their own natural parasites. The predators, having then no natural enemies and access to unlimited food, rapidly reduce the host plant to a low level of survival. The method is therefore of limited but long-term use, and needs great care in application.

Chemical methods

Vegetation can be controlled by chemicals, the more important types being (a) non-selective herbicides, (b) selective herbicides, (c) arboricides, and (d) grass-stunting agents. For detailed accounts of these, and of the individual chemicals and their uses the reader is referred to the current issue of the "Weed Control Handbook" issued by the British Weed Control Council.*[44]

The non-selective weed-killers are used for the total eradication of vegetation, e.g. on paths and at pavement edges to prevent encroachment and disruption by grass and weeds. They are sub-divided into 'contact' types (mineral oils, tar oils) and 'translocated' types (borates sodium chlorate, sodium arsenite, N-(4-chlorophenyl)-N', N'-dimethylurea) ('monuron'). Thus, sodium chlorate is used to control weeds under asphalt pavements in Bermuda. Contact herbicides kill plant tissues only in the immediate vicinity of the points at which sprayed droplets of the chemical solution come to rest. Translocated herbicides, on the other hand, move within the plant away from the site of application. In general, the latter are more effective against deep-rooted perennial weeds and act more slowly than contact herbicides, the full effect of which takes place within a few days of application.

The selective weedkillers are used when one species (e.g. dicotyledenous weeds) have to be killed leaving another species, such as the common grasses, unharmed. They can also be sub-divided into 'contact' types (mineral oils, di-nitro compounds, sodium nitrate and sulphuric acid) and 'translocated'

*The British Weed Control Council, 95, Wigmore Street, London, W.1.

types (2:4-dichlorophenoxyacetic acid—'2:4:D', 4-chloro-2-methyl phenoxyacetic acid — 'MCPA', and 4-(4-chloro-2-methylphenoxy)-butyric acid — 'MCPB'.

Woody vegetation is killed by arboricides, the most important being ammonium sulphamate, sodium arsenite and 2:4:5-trichloro-phenoxyacetic acid ('2:4:5-T'). They are applied to the aerial parts of woody plants or to the roots and are believed to be translocated.

Maleic hydrazide stunts the growth of grass. Applied during early spring, in the United Kingdom, it has been found to inhibit the growth of perennial grassses for periods of up to 16 weeks.[45] The current knowledge on the mechanism of action of herbicides has been reviewed by Woodford, Holly and MacCready:[46] interference with normal cell development is believed to be responsible.

The experience reported from the overseas territories in chemical methods of controlling vegetation at roadsides is rather limited, but interest is growing. In North Borneo experiments are in hand. In Dominica, the amine salt of 2:4:D has proved satisfactory for controlling broad-leaved weeds of the Commelina and Ipomoea species. Monuron has been used successfully by the Forest Department in British Honduras for controlling tall grasses and herbaceous growth. In Singapore, Sarawak and North Borneo experiments with some types of chemicals have shown that Imperata Cylindrical (Lallang) can be retarded, but not yet eradicated. Trials by the P.W.D. in British Guiana have shown that the sodium salt of 2:4:D eradicates Paspalum and encourages the more useful Cynodon grass species.

In Mauritius, sodium chlorate, sodium arsenite, 2:4:D and trichloroacetic acid ('TCA') control weeds on paths through fields of sugar cane, and treatments have been worked out for different local vegetation regimes which investigation might well show to be suitable for roadside use. In the same territory, the Forest Department has found that a mixture of 2:4:D, TCA and pentachlorophenol will check the growth of Panicum grass species for 2 to 4 months in fire-belts. Hand-cutting was found to be cheaper in this instance, however. 169

In Uganda, trees and shrubs have been controlled in forest reserves with 2:4:5-T and 2:4:D ester formulations. In the West Indies, Acacia has been found to be resistant to the herbicides so far tested, and in Antigua and Montserrat these bushes still have to be controlled by stumping. Most of the other plants in the latter island can, however, be controlled by herbicides.

Evidence of the interest in chemical control for roadside use is shown by the trials that are planned with it, by views expressed as to its potential usefulness and by suggestions made about the characteristics desirable in suitable chemicals. Comments on all these points have been received from overseas.

In Barbados, the P.W.D. are planning to compare the costs of chemical and mechanical control of vegetation at Seawell Airport, and the cost of chemical and manual control on roadsides. It is believed there that combinations of Weedone LV4, Weedone Brushkiller 64 (butoxy ethanol esters of 2:4:D and 2:4:5:T respectively) and ACP grass killer (a proprietary brand of sodium trichloracetate) will give adequate control of all the roadside grasses and weeds in the island with the exception of Cyperus and Hypoxis spp. In Jamaica, chemical control is felt to be widely applicable to roadsides, and it is to be tried at Palisadoes and Montego Bay airports. Experiments with knapsack sprayers on the Duncans airstrip in Trelawney Parish have given good results at low cost. The long-term effects have yet to be observed, however. In British Guiana, P.W.D. experiments have shown that sodium 2:2-dichloropropionate does not control Sporobolus grass growing in joints on the concrete runway at Atkinson airfield, and further trials are planned. The need for avoiding drift was experienced here, since damage was done to adjacent kitchen gardens. In the British Virgin Islands, Brushkiller and Weedone LV4 with diesel oil and water have given effective results in trials against mangrove trees and stumps, cactus, manchineel, castor and grass weeds.

In Fiji, a 20-ft wide strip is maintained, by cutting, down each side of the road, the balance of the reservation width being occupied by rank grass and weeds, and it is felt that these two zones should be treated separately. In the first, 2:2-dichloropropionic acid is felt to offer the greatest possibility of controlling the grasses, while any weeds which may supplant them could be controlled with selective herbicides. The latter would also be used to deal with the weeds in the balance of the verge, leaving the rank grasses to assist in preventing their regrowth and in reducing soil erosion.

The Agriculture Department in Cyprus envisages the following advantages for the chemical control of roadside vegetation in the island:

(i) It may be cheaper than manual control.

(ii) The soil is not disturbed, as it is in manual control, thus reducing the extent of erosion.

(iii) Livestock can graze the improved pasture.

(iv) Re-infestation of adjacent land could be reduced.

The practice in several territories of grazing the road verges has already
170 been mentioned, and because of this any weedkillers employed must be non-toxic to livestock. From the Gambia it is pointed out that such chemicals should also be harmless to humans because pedestrians often walk barefooted on the verges to avoid vehicles. Some chemical weedkillers are poisonous, and the risks to workers and wild life when substances of this kind are used have been the subject of an investigation in the United Kingdom.[47] The Ministry of Agriculture, Fisheries and Food has prepared a code of procedure for the protection of operators[48] which should be helpful for road and airfield application overseas, supplemented by local agricultural experience with the materials in question. The Ministry also issues a dossier[49] containing the Government's current recommendations on the safe use of certain chemicals in agriculture. New and revised recommendations are issued from time to time as new chemicals and experience become available. No difficulties arising from toxicity have been experienced with chemicals used on roadsides in the United Kingdom: in fact the quality of the grass is so improved following weed removal that it is sold to farmers as fodder, the revenue offsetting some of the cost of the treatment. However, in using any new types of chemical overseas, road authorities would be well advised to seek assurance from the manufacturers on this point. In Kenya, it is noted that any chemical treatment should not affect adjacent crops such as tea or coffee, and it is suggested that efficient cantilevered spraybars are needed to minimize wind drift of the spray on to adjacent agricultural land. In this connexion, it may be noted that selective chemicals are frequently used on large estates for killing the weeds in fields without harming the main crop. If the same treatment is used on adjacent roadsides where the weeds would be expected to be of the same type, no harm to the crop would be anticipated.

In 1953, the Road Research Laboratory, in collaboration with the University of London and other interested bodies in the United Kingdom, carried out experiments on the spraying of roadside verges.[50] Three of the conclusions reached are relevant to overseas conditions:

(i) Using suitable equipment, spraying can be efficiently carried out by one lorry driver and one spray operator.

(ii) A good water supply is essential to avoid delay in filling the tanks.

(iii) Since all the plants needing control may not reach their most susceptible stage at the same time, more than one application may be needed.

More recent experiments in the United Kingdom have shown that the grass-stunting agent, maleic hydrazide, is compatible with the 2:4-D type of selective weedkiller, and that the two materials are complementary in effect.[45] It was observed that although the maleic hydrazide stunted the grass it did not prevent it from spreading into and filling the gaps left by dead weeds. Such combined treatment offers advantages in overseas areas where tall-growing grasses such as Imperata and Hyparrhenia are as much of a nuisance as rank dicotyledonous weeds.

Research into herbicides for overseas agricultural use is sponsored by the Colonial Pesticides Research Committee with the technical advice and assistance of the Agricultural Research Council Unit of Experimental Agronomy. The Colonial Pesticides Research Unit (C.P.R.U.) conducts field work at Arusha, in Tanganyika. Reviewing tree- and scrub-control problems in East Africa, Ivens has suggested that chemical control of the Acacia spp., also troublesome on roads, should be economic.[51] A list of proprietary herbicides available in East Africa has been prepared by the Colonial Pesticides Information Service, in London.[52] A testing unit for spraying equipment has been established by the Tropical Products Institute at Silwood Park, near London. 171

The results of three of the investigations made by the C.P.R.U. are recorded below, since the vegetation species concerned also occur at roadsides, as indicated by the present survey:

(i) Sodium 2:2-dichloropropionate and amino-triazole have been found to be promising for the control of the couch grasses Cynodon dactylon and Digitaria scalarum in East Africa; the second chemical is also promising for the control of Bidens pilosa.[53]

(ii) Ester formulations of 2:4-D applied to the base of the trunk, with frilling (the circumferential notching of the bark), have been found suitable for the eradication of both Avicenna and Rhoziphora mangroves in Sierra Leone.[54]

(iii) The above-ground parts of a number of Acacia species can be killed by the arboricide 2:4:5-T, preferably applied during a period of active growth.[55]

A recent development has been the introduction of 2:chloro-4:6:bisethylamino-s-triazine ('simazin') as a comparatively non-selective herbicide. In tests on a road site in the United Kingdom, reported by Hughes,[56] this chemical has given results as good as those obtained with sodium chlorate/borate preparations and is said to be effective at rates of application of 5–10 lb/acre. Tests in Tanganyika maize fields (this crop is resistant to the herbicide), reported by Ivens,[57] showed that weeds and annual grasses are almost completely eliminated for 12 weeks using a rate of application of

1 lb/acre. Trials are planned in which 'simazin' will be incorporated in the base material to reduce disruption by vegetation of a reconstructed runway at Calabar, Eastern Nigeria.

Tall Lallang grass (Imperata cylindrica) is a continuous problem on roadsides in Malaya, where it grows quickly and kills the adjacent carpet grass (Axonopus compressus) which forms a dense mat useful in protecting against erosion. Lallang, having deep tap roots, offers little protection, and is cut at approximately monthly intervals with scythes, bill hooks or, on a large scale in recent years, with motor mowers. The carpet grass then flourishes.

Recent experiments carried out by the Rubber Research Institute of Malaya indicate that sodium 2:2-dichloropropionate, applied at a rate of 15–20 lb per acre dissolved in water, may be an ideal material for controlling Lallang. The chemical is safe to animals, and is completely effective within a period of 4–6 weeks, after which it is important that a good low-growing cover grass should be planted to counter erosion.[58]

Duthie[46] has comprehensively reviewed the possibilities of chemical control of vegetation in East Africa, in a summary of the papers and discussion at the first East African Herbicide Conference.[59] The materials are dealt with on the basis of the crops with which they are used, e.g. sorghum, coffee, pyrethrum, sisal, etc., and the experience quoted would be expected to be applicable to roads running through the areas where these crops are grown.

In the early experiments with chemical weed control home-made spraying equipment was employed, usually mounted on the back of a lorry. More recently, accessory equipment has been developed for the Land Rover (Plate 8(B)); it includes an adjustable spray boom and a pump operated from the power take-off. For use when access to water is limited, a sprayer has been developed which produces a steam-like vapour from highly concentrated solutions of chemicals. Worked from the exhaust pressure of a Land Rover, it has no pump or moving parts. The vapour produced is more liable to drift than are the sprays normally used, and this type of distribution is best suited to Savannah, forest or scrub country where there are no adjacent crops of value.

In some areas, such as the cocoa belt in Western Nigeria, thousands of private farmers own and use portable 'knapsack' sprayers for applying fluid insecticides. Provided that these and herbicides can be applied satisfactorily at different times of the year, manpower and equipment are potentially available in such areas for roadside weed control. Thorough removal of herbicides from the sprayers subsequently would, however, be essential.

Cost of controlling roadside vegetation

The information from twelve territories on the annual cost of controlling roadside vegetation per mile by hand or machine (given in Table 7) shows that the cost varies both as between territories and within any one territory. A major factor influencing the cost must be the number of times per year that it is deemed necessary to cut the vegetation, which can vary from one to three or more, as noted from Trinidad. This in turn would be expected to be influenced by the average annual rainfall, control costing more in the wetter than in the drier territories.

The average value of cost for all twelve territories is about £26 per mile per annum. Assuming a total mileage of maintained roads in overseas territories of approximately 100 000[60] it follows that the cost of controlling roadside vegetation on public roads alone is now running at over 2½ million pounds.

Figures given by Taylor for four roads in Nigeria suggest that vegetation control is responsible for about 10 per cent of the overall cost of maintaining the roads there.[61]

In the United Kingdom, experiments made by the Road Research Laboratory in collaboration with the Ministry of Transport and the Gloucestershire County Council, compared the costs of combined hand- and machine-cutting with those of a combination of spraying and cutting. Over a period of two years the average annual cost was found to be the same, £8 per mile for each type of treatment, although the chemical treatment reduced the labour component of the cost by about 40 per cent.[62]

Later experience in Gloucestershire indicates that the costs of treatment with a combination of selective weedkiller and grass-stunting agent are constant over an initial period of two or three years, but subsequently fall owing to alterations in the vegetation regime.[63] The treatment needed then becomes less, and its effect greater. In one division the cost of roadside maintenance is said to have been reduced by 50 per cent, but part of this is due to revenue obtained from the sale of hay from the verges, which becomes possible owing to the absence of weeds in the grass.

Cost of controlling vegetation on airfields

The annual reports from a number of overseas Public Works Departments give information about the costs of maintaining grass airfields and landing grounds, the major element of which is the cost of controlling vegetation.

The cost in 1956 of maintaining the grassed area and scrub land on the international airport at Piarco in Trinidad is given as £6416.[64] Assuming that there are about 40 international airports in Commonwealth countries in the tropical and sub-tropical belts,[65] and that at each the annual maintenance cost is on average half that at Piarco, then the annual bill for vegetation control at these airports is about £120 000.

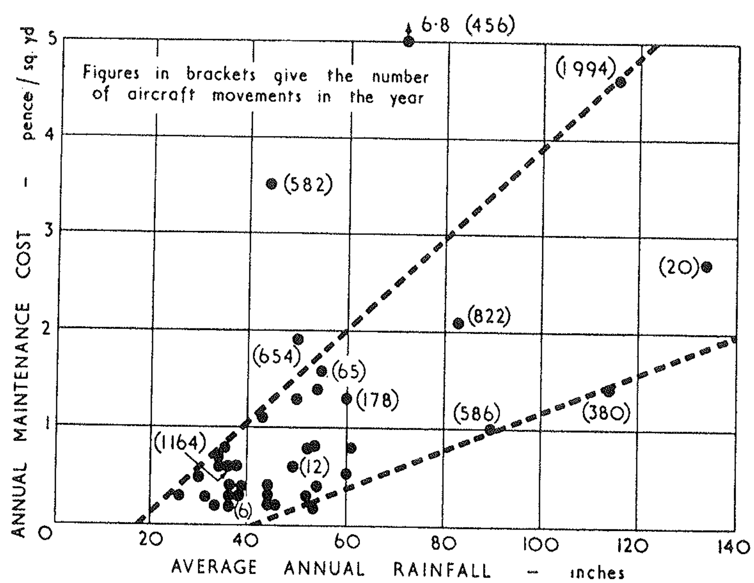

Fig. 3. Maintenance costs for grass airfields in tropical territories during the period 1954–57

For grass airfields, which carry the lighter types of aircraft, the average annual cost of maintenance for 42 fields for which published data are available is of the order of 1*d* per square yard. Assuming that in Africa there are about 100 such airfields each with a single runway 100 000 sq. yd in area then the annual maintenance cost in the continent is of the order of £40 000. It would be expected that the cost of controlling vegetation on grass airfields would bear some relation to the average annual rainfall, and Fig. 3 shows the unit annual costs for 38 airfields, mostly in Africa, for which rainfall figures are also available.[66] A general tendency for cost to rise with increase in rainfall is seen, but there is no marked correlation. One reason for this may be because the cost is also associated with the volume of traffic handled: within a given rainfall range there is a noticeable trend for cost to increase with the number of aircraft movements. Fig. 3 also shows that grass runways are commonest in areas having rainfalls between 25 and 60 inches per annum. In areas with less than 25 in. existing strains of grass are presumably of negligible value as surfacings. When the rainfall exceeds 60 in. on the other hand, the bearing strength of many turfed soils is presumably so low that some form of pavement is needed. In this connexion it is of interest that four of the points to the right of the 60-in. ordinate relate to fields in Fiji having gravel-and-grass pavements, when some proportion of the cost must be due to re-gravelling. In some of the instances shown in Fig. 3 the installation of paved runways is almost certainly under consideration, suggesting that the maximum number of light aircraft movements that can be reasonably carried by grass runways is of the order of 1000 annually.

174 With regard to grass landing grounds, the only information so far available comes from Kenya, where in 1955–6 the sum of £2500 was spent on the general maintenance of 18 airfields.[67] The proportion of this sum spent on vegetation control is not known, but it is presumed to be high.

DISCUSSION

The information given in this paper shows that the use and control of vegetation are matters of wide interest to the road and airfield engineer. The economic data suggest, however, that the expenditure involved is not very large by civil engineering standards, placing the subject on the fringe of road and airfield technology.

On the other hand, it is equally clear that this is a field in which small but useful developments are continually taking place, often within the agricultural industry, which have the effect of making the engineer's work somewhat easier and more efficient. The interest displayed by many Departments of Public Works in the possibilities of chemical weed control indicates that many engineers are alive to such developments and wish to exploit them where possible and this is encouraging, bearing in mind the limited amount of his time that the average practising engineer can afford to devote to fields other than his own. In such work, the prime objectives are to accelerate the flow of information from the agricultural to the engineering fields and where necessary to assist in devising modifications that engineering use may require. This applies particularly to the development of methods for the control of soil erosion and of chemical vegetation.

In matters such as the mechanical control of roadside vegetation, the provision of grass running-surfaces, and road safety, the initiative comes from the road engineer rather than the agriculturalist. The dissemination of knowledge regarding good practice and the results of experimental work by individual road authorities is particularly valuable here, and it is felt that it would be useful if more engineers could be persuaded to set down their experiences in print.

Finally, a most important aid to future development will be the continued and increasing co-operation between the Departments of Public Works and of Agriculture in the individual territories. Good liaison on matters affecting the roadside is already in evidence in many places, both at the formal and informal levels. The conscious fostering of this liaison will undoubtedly bring mutual benefit.

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This paper has been prepared from information kindly supplied, at the Laboratory's request, by many people overseas. In a number of cases research investigations involving a considerable expenditure of time and effort were made and the results were reported to the Laboratory. The co-operation from overseas is gratefully acknowledged. Thanks are also due to the Director of the Royal Botanical Gardens, Kew, and his colleagues for dealing with some of the botanical facts.

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APPENDIX 1

SOURCES OF INFORMATION

East and Central Africa		
Kenya	—	Ministry of Works
	—	Ministry of Agriculture
Uganda	—	Department of Agriculture
	—	Forest Department
Tanganyika	—	Public Works Department
	—	Department of Agriculture
Zanzibar	—	Department of Agriculture
Somaliland Protectorate	—	Acting Governor
	—	Public Works Department
	—	Department of Natural Resources
Southern Rhodesia	—	Commissioner for Roads and Road Traffic
Nyasaland	—	Public Works Department
Central African	—	Department of Agriculture
Federation	—	Department of Research and Specialist Services
Basutoland	—	Director of Public Works
Swaziland	—	Director of Land Utilization
West Africa		
Northern Nigeria	—	Acting Governor
	—	Ministry of Works and Transport
Eastern Nigeria	—	Ministry of Transport
Sierra Leone	—	Public Works Department
	—	Department of Agriculture
The Gambia	—	Director of Agriculture
West Indies		
Barbados	—	Department of Highways and Transport
	—	Messrs. Plantations Ltd.
British Guiana	—	Department of Agriculture
British Honduras	—	Department of Agriculture
	—	Forest Department
Jamaica	—	Ministry of Agriculture and Lands
Leeward Islands	—	Acting Administrator, Antigua
	—	Administrator, British Virgin Islands
	—	Agricultural Department, Montserrat
	—	Administrator, St. Christopher
Trinidad and Tobago	—	Ministry of Agriculture
Windward Islands	—	Department of Agriculture and Forestry, Dominica
	—	Administrator, Grenada
	—	Public Works Department, Grenada
	—	Administrator, St. Vincent
	—	Public Works Department, St. Vincent
Atlantic and Indian Ocean		
Bahamas	—	Governor
Bermuda	—	Governor
	—	Department of Agriculture
Aden	—	Public Works Department
Mauritius	—	Mauritius Sugar Industry Research Institute
	—	Department of Agriculture
	—	Conservator of Forests

Mediterranean

Cyprus	—	Department of Agriculture
Gibraltar	—	Governor
Malta	—	Governor

Far East

North Borneo	—	Governor
Singapore	—	Department of Public Works
Sarawak	—	Governor
	—	Public Works Department
	—	Department of Agriculture
Hong Kong	—	Public Works Department
	—	Forestry Department

Western Pacific

Fiji	—	Department of Agriculture

APPENDIX 2

LOCAL NAMES OF VEGETATION SPECIES OCCURRING ON OVERSEAS ROADWAYS

Species	*Territory reporting*	*Local name*
Acacia farneseana	Fiji	Ellington curse
Achyranthus indica	Montserrat	Devil's horse whip
Ageratum conyzoides	Fiji	Goat weed
Alternanthera ficcides	Trinidad	Rabbit meat
Amaranthus spp.	Barbados	Pigweed
Anacardium occidentale	Grenada	Cashew
Andropogon caircosus	Antigua	Antigua hay grass
,, ,,	St. Kitts	,, ,, ,,
,, muricatus	Grenada	Khus-khus
,, pertusus	St. Kitts	Barbados sour grass
Anona glabra	Brit. Guiana	Monkey apple
Axonopus affinis	Fiji	Narrow leaf carpet grass
,, compressus	East. Nigeria	Carpet grass
,, ,,	West. Nigeria	,, ,,
,, ,,	Fiji	,, ,,
,, ,,	Grenada	,, ,,
,, ,,	Trinidad	Savannah grass
Bambusa vulgaris	Grenada	Bamboo
Bidens pilosa	St. Vincent	Railway daisy
,, ,,	Trinidad	,, ,,
Brachiaria mutica	Fiji	Para grass
,, ,,	Trinidad	,, ,,
Canna glauca	Brit. Guiana	Wild canna
Cascuta spp.	Grenada	Love vine
Cassia alata	Brit. Guiana	Carrion crow bush
,, mimosoides	Fiji	Kaumoce
,, occidentalis	Fiji	,,
,, polandena	Barbados	Wild tamarind
,, tora	Fiji	Kaumoce
Cenchrus echinatus	Barbados	Burr grass
Chamaecrista aeschynome	Barbados	Shame bush
Chloris inflata	Barbados	Plush grass, bed grass
,, radiata	Barbados	,, ,, ,, ,,
,, ,,	Fiji	Plush grass
Cocus nucifera	Grenada	Coconut
Commelina spp.	Barbados	Pondgrass, French weed
,, nudiflora	Grenada	Watergrass
,, eligans	Montserrat	Watergrass, French weed
Corchorus siliquosus	Grenada	Broom weed
Cordia spp.	St. Vincent	Black sage
,, curassavica	Brit. Guiana	,, ,,
Crotalaria verrucosa	Grenada	Crotalaria
,, striata	Brit. Guiana	Shack-shack
Croton flavens	Barbados	Sage
Cuphea carthagineusis	Fiji	Tar weed
Cymbopogon citratus	Dominica	Lemon grass
,, ,,	East. Nigeria	,, ,,

Species	*Territory reporting*	*Local name*
Cynodon spp.	Kenya	Maadi river grass
„ „	St. Kitts	Bermuda, Bahama grass
„ dactylon	Barbados	Bermuda, Devil's grass
„ „	Brit. Guiana	Bahama grass
„ „	Grenada	Devil's grass
„ „	Kenya	Star grass
„ „	Mauritius	Chien-dent
„ „	North. Nigeria	Bermuda, Dhub grass, Bhama grass
„ „	West. Nigeria	Bahama, Dhub grass
„ „	South. Rhodesia	Couch grass
„ „	Trinidad	Devil grass
„ plectostachyon	North. Nigeria	Star grass
Cyperus melanospermus	Fiji	Navua sedge
„ rotundus	Barbados	Nut grass
„ „	Dominica	„ „
„ „	Grenada	„ „
„ „	Montserrat	„ „
„ „	Tanganyika	Sedge
Desmodium spp.	Fiji	Desmodium
„ „	Barbados	Sweetheart
Dicanthium aristatum	Antigua	Antigua hay grass
„ annulatum	Fiji	Blue grass
„ caricosum	Fiji	„ „
Digitaria decumbens	St. Kitts	Pangola grass
„ gayana	East. Nigeria	Finger grass
„ saguinalis	Barbados	Crab grass
„ scalarum	Uganda	Couch grass
Eclipta alba	Trinidad	Congo-la-la
Elephantopus mollis	Fiji	Tobacco weed
Eleusine indica	Barbados	Dutch, goose grass
„ „	Fiji	Crowi foot
„ „	Trinidad	Flow foot grass
Eichornia crassipes	Fiji	Water hyacinth
Eryngium foetidum	Trinidad	Chadonne beni
Euphorbia spp.	Barbados	Milk-, red-, poverty-weed
Flemingia strobilifera	Trinidad	Wild hops
Festuca caprina	Basutoland	Letsiri grass
Gliricidia maculata	Grenada	Gliricidia
Heliotropum indicum	Brit. Guiana	White clary
Hyparrhenia spp.	Nyasaland	Elephant grass
„ rufa	Brit. Honduras	Jaragua grass
„ „	Kenya	Thatching grass
Hypoxis decumbens	Barbados	Yellow, Barbados crocus
Hyptis pectinata	Fiji	Mint weed
Imperata cylindrica	Sarawak	Lallang grass
„ „	Singapore	„ „
Ischaemum aristatum	Fiji	Batiki blue grass
„ timorense	Fiji	Waidoi grass
Lantana spp.	Barbados	Sage
Lantana camara	Fiji	Lantana
Leonatus nepetacfolia	Barbados	Ball bush
Leonurus sibiricus	Barbados	Motherwort
Leucaena glauca	Montserrat	Wild tamarind

Species	*Territory reporting*	*Local name*
Leucaena glauca	Trinidad	Wild tamarind
Malvastrum spicatum	Grenada	Monkey bush
Mangifera indica	Grenada	Mango
Melinis minutiflora	East. Nigeria	Molasses grass
Mikania micrantha	Fiji	Mile-a-minute
Mimosa pudica	Fiji	Sensitive plant
" "	Grenada	" "
" "	Montserrat	" "
" "	Trinidad	" "
Miscanthus japonicus	Fiji	Reeds
Montrichardia aculeata	Brit. Guiana	Moka-moka
Panicum maximum	Brit. Honduras	Guinea grass
" "	Fiji	" "
" "	Grenada	" "
" muticum	Grenada	Para grass
" "	St. Vincent	" "
Paspalum conjugatum	Fiji	Paspalum
" "	Grenada	Savannah grass
" fasciculatum	Trinidad	Bamboo grass
" notatum	Nyasaland	Kapinga grass
" "	South. Rhodesia	Tanner grass
" Virgatum	Brit. Guiana	Razor grass
" "	Trinidad	" "
Pedilanthus tithymaloides	Grenada	Milk bush
Pennisetum clandestinum	Kenya	Kikuyu grass
" "	South. Rhodesia	" "
" polystachyon	Fiji	Mission grass
" purpureum	Tanganyika	Elephant grass
" "	Kenya	" "
Phyllanthus niuri	Barbados	Seed-under-leaf
Piper aduncum	Fiji	Wild yaquona
Piperomia pellucida	Trinidad	Shining bush
Portulaca oleracea	Barbados	Purslane, pussley
Priva echinata	Grenada	Velvet burr
Psidium guajava	Barbados	Wild guava
" "	Fiji	Guava
" "	Trinidad	"
Rhynchosia minima	Barbados	Burnmouth vine
Ricinus communis	Kenya	Castor oil plant
Rottboellia exalta	Trinidad	Corn grass
Ruellia tuberosa	Grenada	Many roots
Scleria spp.	Brit. Honduras	Sour grass
Sida acuta	Fiji	Broom week
Sida rhombifolia	Barbados	Broomwood
" "	Fiji	Paddy's lucerne
" "	Trinidad	Broom weed
Solanum demerarense	Brit. Guiana	Bura-bura
" torvum	Fiji	Prickly solanum
Sorghum halepense	Fiji	Johnson grass
Spondias lutea	Grenada	Hog plum
Sporobolus indicus	Brit. Guiana	Iron grass
" "	Fiji	Wire grass
" "	Trinidad	Tapia grass
Stachytarpheta indica	Barbados	Vervain

Species	*Territory reporting*	*Local name*
Stachytarpheta urticaefolia	Fiji	Blue rat tail
Stenotaphrum dimidiatum	Zanzibar	Pemba grass
Swietenia mahagoni	Grenada	Mahogany
Tagetes minuta	Kenya	Mexican marigold
Tecoma Leucoxylon	Barbados	White wood, white cedar
„ „	Grenada	White cedar
Teramnus spp.	Barbados	Rabbit vine
Themeda triandra	Basutoland	Seboku grass
Triumfetta bartramia	Fiji	Chinese burr
Urena lobata	Fiji	Hibiscus burr
„ „	Trinidad	Cousin mahoe
Vetiveria spp.	St. Vincent	Khus-khus
„ zizanoides	Dominica	Vetiver grass
„ „	Jamaica	Khus-khus grass
Wedelia trilobata	Barbados	Carpet weed
Xantium pungens	Fiji	Noogoora burr
Yucca aloifolia	Grenada	Spanish needle

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COVER: Conservation on the land. Soil Conservation Service photo by Erwin Cole.

Erosion-proofing drainage channels

CHESLEY J. POSEY

A large portion of the four billion tons of soil eroded from our land annually is scoured from the beds and banks of natural channels that are dry much of the time (6). Gullies and arroyos grow whenever there is appreciable runoff. Constructed drainage channels customarily are designed with non-eroding velocities or provided with some sort of erosion-resistant lining. However, runoff from rainstorms and snowmelt sometimes thwarts the designer. Protective vegetation is ripped out. Concrete and asphalt linings are destroyed by overtopping and undermining. Erosion then proceeds with every rain until repairs are made.

Much has been accomplished over the years through public programs to minimize erosion on agricultural land. But overall we may be actually and figuratively losing ground in the fight against erosion. For example, erosion along highways has been an increasing problem in recent years as superhighways and primary roads, built to modern standards of line and grade, intercept many natural drainage channels. New channels are required to carry runoff from impervious paved areas. As urbanization spreads, storm runoff peaks exceed the capacities of natural channels more frequently. Cross sections and alignments must be improved hydraulically, aesthetically, and economically. How are old channels to be improved and new ones built so that storm waters can be accommodated without causing excessive erosion?

Lining with Grass

Where soil and moisture conditions permit, grass can thrive and protect the channel, which can be made wide with flat side slopes, presenting a pleasing appearance and minimum hazard (5). Flat slopes and the absence of obstacles simplify mowing. If a dense cover can be established before rills form, erosion can be minimized. Already widely used, this method is superior from almost every viewpoint. Research projects now underway can be expected to extend its range of application. Maximum velocities of flow must be limited, depending on soil erodibility and the kind and quality of vegetation. If low flows persist long enough to kill grass, other means of protecting the channel bottom must be provided.

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Drop Structures

Where conditions are otherwise favorable for grass, but average slopes are too great, concrete drop structures can be used at necessary intervals to minimize slope in the grassed channel from one structure to the next, thereby assuring safe velocities. A design perfected at the St. Anthony Falls Hydraulic Laboratory has been widely used (2). Disadvantages of the structures include high cost, obstruction to mowing, unpleasant aesthetics, and danger to vehicles.

Lining with Asphalt or Concrete

The cost of asphalt or concrete linings may dictate a comparatively narrow, deep ditch that presents a serious hazard and complicates mowing. Minor repairs are comparatively easy with asphalt, but if either concrete or asphalt linings are overtopped or undermined, destruction is apt to be complete. Neither is particularly attractive. Since they are relatively smooth, water velocities are high. The lining must continue downstream beyond the potentially erodible channel, otherwise a scour hole will form at the lower end, possibly undermining the lining and starting progressive failure.

Rock Linings

Since beds of steep natural streams often appear to be rocky, the use of rock linings in newly formed channels seems to be logical. Where rock is not available, concrete blocks or even bricks can be used. Experience reveals two problems, however. First, the rocks may not remain in place. In fact, they may be removed completely during high flows. Second, finer material under the rocks may be gradually washed out so the rocks are not really serving their intended purpose. Recent laboratory experimentation has shown how both problems can be solved, the second with more certainty than the first.

Keeping Rocks in Place

Early efforts to keep rocks in place included careful hand-placement of the stone, perhaps with the aid of asphalt or mortar, to preserve alignment and minimize exposure to the force of the current. While this increased stability, it was found that more could be accomplished if something were provided to hold the stones together. Since ancient times, the Chinese have bound rocks in bamboo or willow cages of trumpet, snake, or sausage-like shapes. These are still used in some localities, but more often wire is used as the binding material. Large-scale projects, including closure of breaks in Yellow River levees, have been accomplished by skillful use of these devices. The Romans used rectangular rock-filled wooden cribs. Wood has now been mostly replaced by wire, and box-like gabions find increasing use. The mechanized manufacture of wire or plastic mesh rock sausages offers further economies.

Obviously, having to bind rocks into containers increases the cost. Knowing under what conditions this could be avoided would be helpful indeed. A recent report from the St. Anthony Falls Laboratory provides tentative answers in terms of the main variables: discharge, channel shape and slope, size and specific gravity of stones available (1). Stones large enough to resist being moved by the flow may not be available in some locations. Use of rock sausages or gabions is then required. The diameter of a sausage need only be half that of loose stones having equivalent resistance and the rocks to fill it smaller yet by a factor of three or more. With their upstream ends anchored, rock sausages can be used where channel slope is as great as 50 percent. For slopes less than 10 percent, a loose rock lining can be used unless the size required is too large. As in the case of concrete and asphalt linings, rock linings must be extended downstream to a zone of low velocity where they are no longer necessary (3).

Preventing Fine-Material Wash

Failure to stop the washing of fine material from beneath rocks is a source of continuing maintenance expense. Loose rocks, rock sausages, or gabions placed directly on the soil to be protected settle and must ultimately be replaced. More serious from the standpoint of preventing erosion and avoiding sediment pollution, however, is the loss of material from the channel bed and banks that has permitted the rocks to settle. This process, referred to as "leaching," is commonly slowed by placing a layer of gravel under the stones. Study of the protective action of such layers shows that leaching can be stopped completely (3).

The leaching of soil from the bed and banks of a channel lined with rock is caused by a "reverse-flow" mechanism. Water pressures on the channel boundary vary with time and from point to point because of disturbances in the flow that are induced by the roughness and geometry of the channel itself. When the pressure momentarily drops at a point, water flows immediately from the channel bed upward and outward through the rock—a reverse flow. Soil particles may move with this flow through the rock layer to be carried away by the main stream. A means for preventing this soil movement is found in the work of Terzaghi, who studied the prevention of soil movement from dams by seepage.

Terzaghi conceived the idea of preventing this type of failure by covering the danger zone with a filter layer incorporating material many times as pervious as the soil that might be washed away, but with interstices small enough to keep the soil particles from penetrating it. He formulated criteria for the necessary grain size relationships and patented and successfully used the system in Austria 50 years ago. It has since been universally accepted among dam designers.

Experience and research indicate that only slight modifications of his original quantitative relationships are necessary for channels. As determined by the U. S. Waterways Experiment Station at Vicksburg, Mississippi, the grain-size distribution in the filter should be related to that of the material to be protected according to the following inequalities:

$$D_{15}\text{ Filter} < 5D_{85}\text{ Base} \quad (1)$$

$$4D_{15}\text{ Base} < D_{15}\text{ Filter} < 20D_{15}\text{ Base} \quad (2)$$

$$D_{50}\text{ Filter} < 25D_{50}\text{ Base} \quad (3)$$

with the additional suggestion that the grain-size distribution of the filter not have any large deficiency or excess of any particular intermediate size (7). Fifteen percent, by weight, of the filter material is finer than the size indicated by D_{15} Filter; 85 percent by weight of the base material, the material to be protected, is finer than the size denoted by D_{85} Base; etc.

Only recently has the importance of these criteria in the technology of erosion prevention become evident. Tests in laboratory flumes show that underlayers that come close to meeting the reverse-filter criteria of the equations allow a rate of leaching that is extremely difficult to measure (1). A more sensitive test uses an inclined, high-velocity jet impinging on the bottom at a fixed location that can be observed through a glass side wall (4). Comparisons like the following are typical: Fine, extremely erodible material protected by a thick layer of rocks large enough to resist being directly displaced by the jet—rapid leaching starts immediately; same material protected by layers almost meeting the criteria—slow leaching reaches moderate depths in hours; same material protected by layers meeting the criteria—no sign of leaching when test was stopped after more than 300 hours (Figures 1, 2, and 3). Of course, no material, not even a continuous covering of stainless steel, could prevent erosion forever, but the comparison shows the improvement that can be obtained with a well-graded reverse-filter layer.

Recent research shows that 200-mesh nylon can serve as a filter to prevent leaching, but only where the seepage velocities are not affected by the pulsations of turbulent flow. The screen won't stop leaching below gabions or rock sausages, but it does permit French drains to be installed with greater reliability than when sand filters are used, since coverage is more easily made complete. 187

Cost of Reverse Filters

Sand and gravel suppliers are likely to view reverse-filter specifications with trepidation, fearing they will be more difficult to meet than specifica-

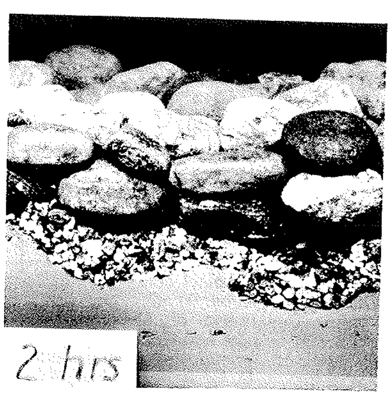

Figure 1. Inclined high-velocity jet attacks erodible soil protected by loose rock layers. Lack of correct grading permits slow leaching.

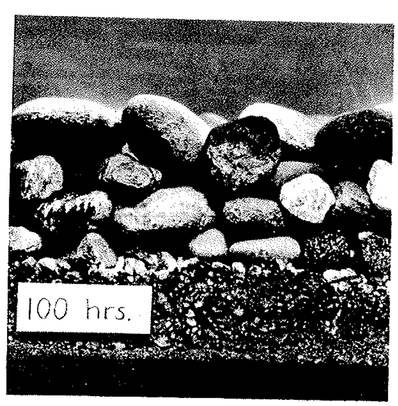

Figure 2. With loose rock layers meeting Terzaghi-Vicksburg specifications, the same jet is unable to initiate leaching in 100 hours.

Figure 3. With the top layer of rocks bound in mesh tubes, thinner Terzaghi-Vicksburg layers suffice for long-lasting protection.

tions for concrete aggregates. Actually, they need not be. It is usually possible to find deposits that require neither sieving nor washing.

A reverse-filter installation with rock sausages on Interstate 91 in Connecticut showed slight evidence of leaching after a year's service (Figure 4). Investigation revealed that sifted sand that did not meet the Terzaghi-Vicksburg criteria had been used. The supplier could not understand the need for anything as cheap as unwashed sand dug right out of the pit. As relaid, using correctly graded sand, the installation shows no sign of leaching after four years (Figure 5).

In parts of the country where soils are comparatively uniform the amount of work entailed in first getting samples and then specifying satisfactory sources of protective materials is not great, but it would be prohibitive in regions where subsoil conditions change markedly within short distances. An alternative approach then becomes necessary.

Instead of starting with a grain-size analysis of the soil to be protected, first determine the size of rock necessary for the topmost layer, according to the maximum flow exposure. Then find an available material that this rock size will protect, according to the Terzaghi criteria, and continue the process down through one, two, or three layers of finer material.

Tests show there is a lower limit. A filter layer that will protect a soil with a D_{50} of about 0.045 millimeter will protect any finer material.

The number of layers used in a specific location is determined as the installation is made. Where not enough layers are used, failure will be slow. When it becomes evident that leaching has caused the lining to settle, layers should be rebuilt from the bottom up, not simply by adding coarse material on top. This is done most easily where a rock sausage lining has been used, since the sausages can be lifted out and set aside. Laboratory tests show that layers of properly graded aggregates need be no thicker than three or four times the diameter of the largest particle. Placing layers of finer materials this thin in the field, however, is impractical, and a minimum thickness of 3 to 6 inches is generally used.

Stopping Gully Growth

Measures taken to stop gullies from ruining good land generally range from simply dumping rock or other material into small gullies to reshaping medium-sized gullies, lining them with grass, and providing drop structures if needed. Gullies too large for this treatment are planted with grass to slow erosion and with bushes and trees to hide the scar. In any case, effective erosion-proofing of actual water channels is essential if gully growth is to be stopped. Early detection of small gullies is important. Their treatment can probably be satisfactorily handled by farmers if, as anticipated, rock sausages are carried in stock by local rock and gravel suppliers who should be prepared to advise on the appropriate underlayers.

Figure 4. Asphalt lining of steep ditch along I-91 failed during first season.

Figure 5. Rock sausage replacement of I-91 ditch lining after four years.

Benefits of Pervious Linings

Reverse-filter linings, of course, are pervious and permit water to seep into the soil. Since they are rough, the velocity is low, water flows deep, and the channel has more wetted perimeter, all factors favoring a greater rate of groundwater recharge. Moreover, the water velocity keeps the bottom from becoming clogged with fine material, which can happen if the water contains even a little particulate matter, but is quiescent. Rock-lined channels, whether bound rock or loose, provide living space for small forms of plant and animal life and are thus preferable to asphalt or concrete linings, perhaps even to gullies.

Long-Range Effects

Although it is unlikely that preventing erosion by effective reverse-filter protection will ever become so prevalent that erosion on intermittent streams will be stopped over any sizable watershed, the consequences of achieving such a goal should be considered. With the water delivered to permanently flowing streams always clear, the rate at which they would erode bed and banks of alluvial material would be greatly increased. This could be stopped, perhaps at great cost, but other uncertainties remain. Changes brought about by the great reservoirs on the upper Missouri River have already made its popular name, "Big Muddy," inappropriate. Egyptian experience with the Nile may also provide valuable data in this regard.

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SUGGESTIONS FOR TEMPORARY EROSION AND SILTATION CONTROL MEASURES

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Region One

SUGGESTIONS FOR TEMPORARY EROSION AND SILTATION CONTROL MEASURES

Introduction

This booklet has been prepared to assist highway designers, construction field personnel, and contractors by providing some ideas and suggestions for controlling erosion and sediment pollution during highway construction. Many of the control measures are considered temporary, intended to serve during construction or until permanent controls are installed and become effective.

Most of the features discussed and shown have been successfully employed on highway construction projects. In some States, they have been incorporated into design plans and specifications. State highway departments are encouraged to incorporate these temporary features, along with other erosion and siltation control measures, into their designs. Necessary pay items should be established for the installation and adequate maintenance of temporary controls during construction.

Where temporary erosion control features are not included in the plans, it is expected that construction field personnel and contractors will anticipate possible problems and provide timely and adequato controls to prevent or at least minimize adverse effects.

These ideas and suggestions should also be of value to contractors in developing erosion control schedules as required on all Federal-aid projects.

Discussion

The most effective erosion and siltation control that can be exercised on any highway construction project is early treatment of the slopes - both cut and fill. Early treatment means treating cut slopes as excavation progresses and fill slopes as embankment construction proceeds. Slope treatment varies from State to State but generally consists of mulch-seeding, and in some instances topsoil application. Stone blankets and other special treatments may be needed in problem areas. The temporary control measures discussed and shown in this booklet should not be considered in lieu of early slope treatment, but rather for use in conjunction with early slope treatment.

It is also presumed that proper excavation and embankment construction operations will be performed including items such as: early installation of interceptor and toe of slope ditches, adequate roadway crowning to allow lateral drainage in both cuts and fills, maintaining side ditches in cut areas at a lower elevation than the main body of the cut, and proper embankment compaction. In general, control measures should not be constructed in existing watercourses. If at all possible, erosion and siltation control should be accomplished before runoff reaches the main watercourse.

Sedimentation Pools

A major siltation control feature which is being included in many highway designs is the sedimentation pool. Figures 1, 2 and 3 show the general layouts of these pools. Large sedimentation pools, such as shown in figures 1 and 3a, should be considered during the design stages and incorporated into the construction plans. They may be added to a project during construction but must be subjected to a formal design procedure based on site conditions. These pools should be located at critical areas to provide protection for major streams, rivers, ponds and lakes. This type of sedimentation pool can be permanent, to remain in place after project completion. These pools should be constructed early in grading operations and all runoff from the contributing construction area controlled to enter the pool before reaching a stream or adjacent watercourse. Periodic cleaning is necessary in order to maintain their effectiveness.

There are also many locations on a highway construction project where smaller sedimentation pools or basins can be constructed as a temporary measure. Figures 2, 3b and others in this booklet show the various types of pools and basins that can be used to effectively control pollution until permanent controls are installed.

Special care must be exercised in building and maintaining all sediment traps and basins. If these dikes pond much water, a failure could result in extensive damage.

Berms and Slope Drains

Temporary berms serve as an effective measure in controlling runoff and preventing

erosion. Figure 4 shows the use of temporary berms along the top of a fill slope. The berms should be large enough to control heavy runoff and prevent washout. The earth berms shown in Figure 4 are approximately 2 feet wide by 1 ft. high and should be compacted by the wheel or track of construction equipment. Earth berms can easily be constructed at the end of each day's embankment operations to provide positive erosion control during construction stages. Another type of temporary berm which has been used successfully is a long burlap sleeve filled with sand. This type is effective when installed on essentially completed embankments. The sand filled burlap sleeve remains in place to allow grass to become established before the burlap rots and the sand disperses. Temporary berms can also be placed along the top of cut slopes where runoff might cause erosion along the cut face.

In using temporary berms, it is important to recognize that the runoff collected must be periodically outleted to prevent severe erosion. Figure 4 shows a temporary slope drain installed for this purpose. An end section should be placed on the inlet of the pipe and a cresent shaped earth berm constructed to channel runoff into the slope drain. Dumped stone protection may be necessary to prevent erosion at the drain outlet.

Figure 5 shows the installation of a flexible downdrain. The collapsible pipe is about 20 inches in diameter and can be connected to an 18 inch pipe end section. It is held in place by pinning or staking. Flaps with grommets are provided every twenty feet for this purpose. This type of temporary downdrain system can be easily removed while additional embankment is being placed and reinstalled at the end of each embankment operation. Also, the location of the outlet can be easily changed when desired. Outlet protection is needed and the pipe should be inspected for clogging after each storm.

Toe of Slopes

Another problem area where some form of temporary erosion control should be provided is along the toe of embankment slopes. Where plans call for toe of slope ditches, they should be constructed early in the grading operations. However, ditches in themselves may not offer the type of protection needed and additional controls should be installed.

Figures 6a through 6d show the plan details for brush barriers and silt and check dams. These devices are useful where brush is plentiful and can be allowed to remain in place.

Figures 7, 8 and 9 show the use of hay bales along the toe of slope. Hay bales can be effectively used in many locations as a temporary measure to control erosion and prevent siltation. For long lengths of this type of barrier and at low points where runoff will accumulate, overflow outlets should be provided as shown in Figure 7. Bales should be embedded in the ground 4 to 6 inches to prevent water from flowing under them. Figures 8 and 9 show the manner in which bales are to be placed depending on whether the existing ground slopes toward or away from the embankment. Bales can remain in place until they rot, or be removed after they have served their purpose. Replacement of damaged or silted bales may be necessary.

Figure 10 is a composite picture indicating various temporary control measures that can be employed during embankment construction.

Cut-to-Fill Slope

Generally, a major problem area is created when grading operations begin. The problem area starts at the cut to fill transition and extends along the toe of the embankment slope. Figure 11 shows this area and suggests some possible temporary controls that should be installed. Controls in this area should be provided at an early stage of grading and maintained throughout excavation-embankment operations and until permanent controls are installed.

Ditches

Newly excavated ditches may be highly susceptible to erosion and often contribute to the siltation of waterways. Although desirable, it is not always practical to provide necessary ditch lining immediately after excavation. Consequently, timely installation of temporary erosion and siltation control measures is important.

Figure 12 shows a typical situation involving side and median ditches or swales. Dumped stone, jute mesh, or sod can be used to effectively minimize erosion of ditch bottoms and sides. Hay bales can be used

as temporary check dams to assist in controlling erosion and minimizing siltation. In providing the protection shown in this figure, the width of the lining or dam should extend far enough up the ditch slopes to effectively contain the runoff and prevent erosion and washout at the edges.

Figure 13 expands on the use of temporary dams for use in wider ditches or small streams. These types of dams are generally used where flow must be maintained by providing a spillway opening. As a word of caution, careful consideration should be given to temporary dams constructed of graded stone to assure that the size of the stone selected is large enough to withstand the force of the flowing water. A number of temporary stone dams have been constructed utilizing 2 inch stone and, while they have been quite effective during periods of low flow, they have failed during periods of heavy rain. As a rule of thumb, about 50% of the stone should be 6 inches or larger for dams in small streams.

Waterway Crossings

Most highway construction projects cross some form of a waterway--a stream, river, pond, etc. These are highly critical areas that must be protected from siltation.

For smaller streams, where temporary dams can be provided without causing upstream damage, a log and hay erosion check dam can be used. Figures 14a and b show the general plan details of this type of dam. These dams can be constructed from readily available native material and should be placed on the downstream side of the construction area.

Figure 15 shows a method of installing a temporary board dam at the inlet of a culvert. This method can be used in those locations where space is not available at the outlet end to install adequate temporary measures. Also, many locations are usually available where this method can be used to temporarily pond runoff in medians and ramp loop areas. The basin created by this dam should be periodically cleaned. Hay bales may be used in conjunction with the boards if adequate measures (such as staking) are taken to prevent them from clogging the culvert.

At larger stream or river crossings, temporary dams in the channel are generally not

feasible or practical, except under special conditions. In these instances, eroded materials should be intercepted before they reach the waterway. Figure 16 shows three types of protection that can be installed to trap sediment. Dumped stone or riprap protection is also needed between the outlet and the waterway.

Ditch Junctions

Most highway plans show the location of ditches and include a typical cross-section detail. However, no special details are generally included for those locations where ditches join and in many cases the junctions are indicated as 90 degree intersections. At junctions, heavy concentrations of flow may result in the water leaving the ditch and eroding the adjacent earth. Ditch junctions should therefore, be designed and constructed to accommodate the runoff and side slope at junctions should be steepened to more effectively direct the flow.

Drainage Inlets

Unprotected drainage inlets, catchbasins, and other minor structures oftentimes empty silt laden runoff directly into waterways or ditches leading to waterways. Runoff should be intercepted before it reaches these drainage structures and the silt and other materials removed. Figures 17 and 18 suggest three methods that can be used to minimize the amount of sediment entering these structures. Periodic cleaning is necessary to maintain their effectiveness and all accumulated silt must be removed before constructing the pavement structure.

Pipe Outlets

When water is discharged from a pipe, erosion often results. While permanent splash pads, energy dissipators, or other special treatment may be required, oftentimes they are not constructed until some time after the pipe is installed. In these situations, dumped stone should be used as shown in Figure 19 for temporary or permanent erosion control. The quantities of stone required should be determined depending on conditions such as the anticipated discharge and velocity.

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Consideration should be given to including provisions in the contract requiring stockpiling of stone during the early stages of construction for use at pipe outlets, ditches and other locations where erosion problems may develop.

Diversions Channels

Temporary diversion channels are used when it is necessary to divert water around an area where a culvert is to be constructed. Oftentimes the raw erodible slopes of these channels contribute to siltation. Figure 20 suggests using stone linings with gravel foundations for erosion control in large diversion channels and gravel lining for smaller channels. On those projects where rock excavation is encountered, ledge fragments should be stockpiled for use in lining channels, ditches, pipe outlets, and for constructing haul roads across streams. Temporary stone or hay bales check dams placed in the diversion channel can also effectively minimize siltation.

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Haul Roads

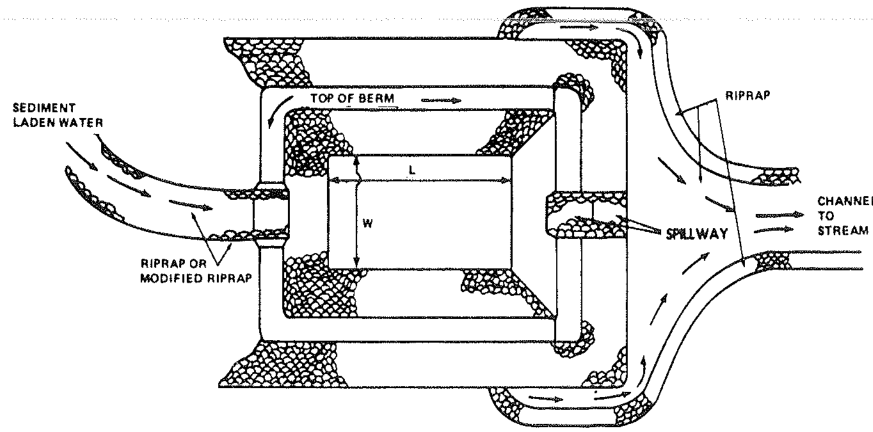
Hazardous conditions can be created not only by the hauling activities but also from the silt-laden runoff that is discharged from the haul road onto the local street. Quite often sediment is deposited in street drainage systems and ultimately carried to a nearby waterway.

Temporary erosion and siltation controls should be included at these locations. One method that can be employed is to construct a sag in the haul road profile, install a temporary pipe under the road and direct runoff to a temporary sediment pool. A similar arrangement can be used at stream and river crossings.

Summary

The ideas and suggestions presented in this booklet depict many of the temporary measures that have been used successfully in minimizing soil erosion and water siltation related to highway construction activities. In some instances, these temporary controls are being included in the project plans.

The features shown in this booklet will apply to other conditions besides those discussed. There are many situations which occur on a typical highway construction project where erosion and pollution problems become evident and some type of temporary control should be provided. The features discussed in this booklet are just some of the items that have been successful and should be considered. Bridge construction, borrow pits, waste areas and haul roads off the right-of-way are some other areas where the features discussed in this booklet could be used effectively.



SEDIMENTATION POOL

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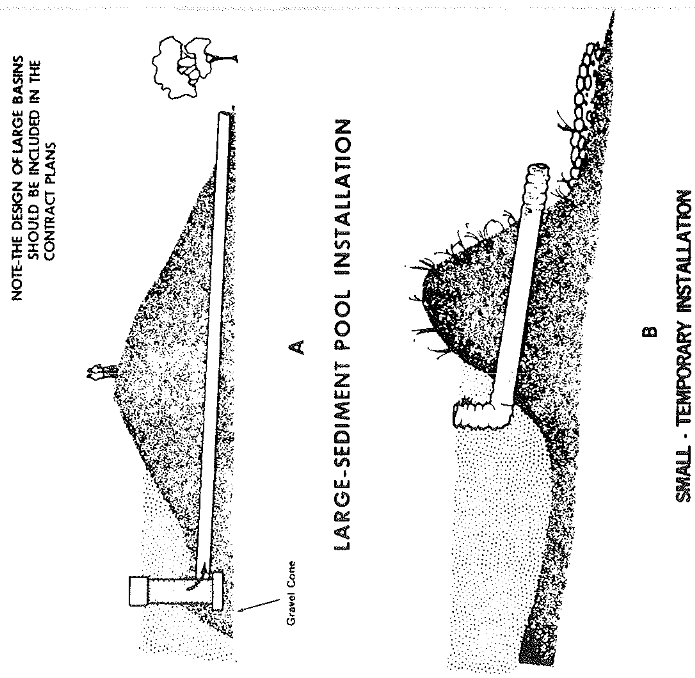
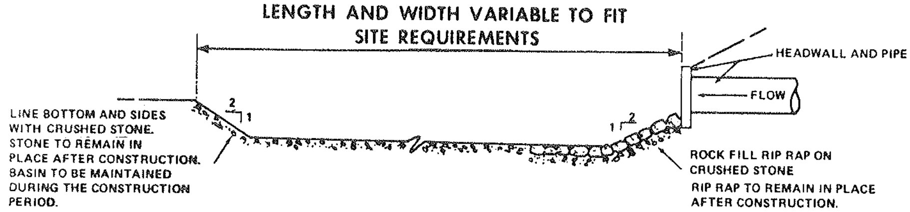
FIGURE 1



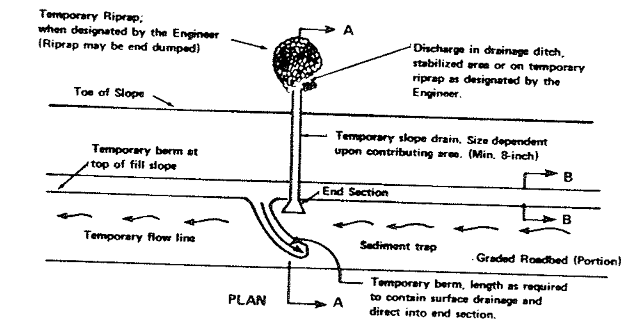
SEDIMENT DAMS

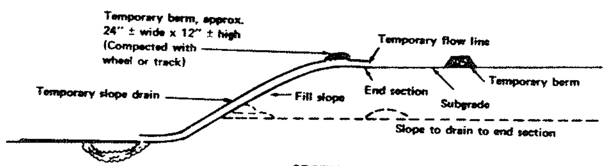
FIGURE 3



TEMPORARY
EROSION CONTROL STILLING BASIN

FIGURE 2



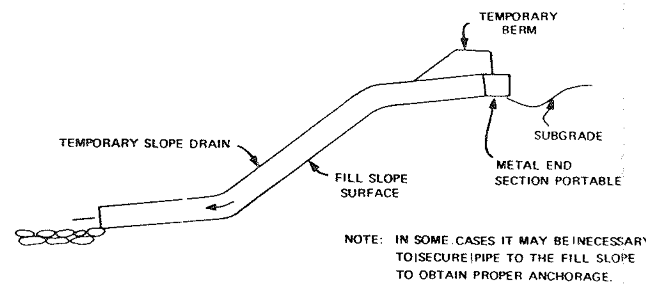


SECTION A–A
TEMPORARY SLOPE DRAIN, BERM AND RIPRAP
(FOR FILL SLOPES)

SECTION B–B

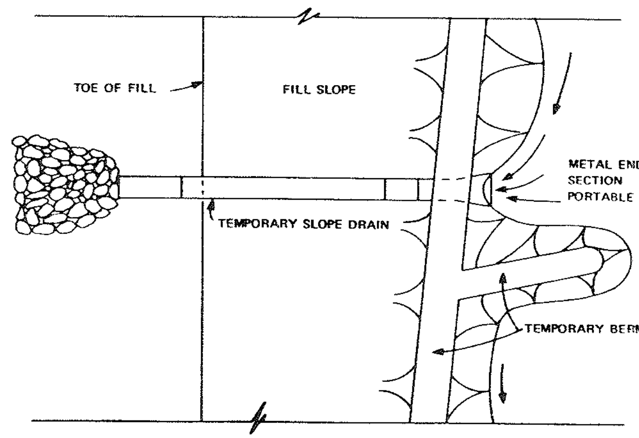
TEMPORARY BERMS & SLOPE DRAIN

FIGURE 4



NOTE: IN SOME CASES IT MAY BE NECESSARY TO SECURE PIPE TO THE FILL SLOPE TO OBTAIN PROPER ANCHORAGE.

END VIEW

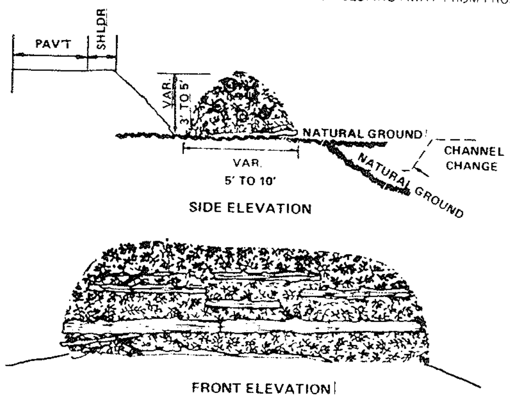


PLAN VIEW

TEMPORARY SLOPE DRAIN (FLEXIBLE)

Figure 5

NOTE: BRUSH BARRIER TO BE USED WHEN NATURAL GROUND IS LEVEL OR SLOPING AWAY FROM PROJECT



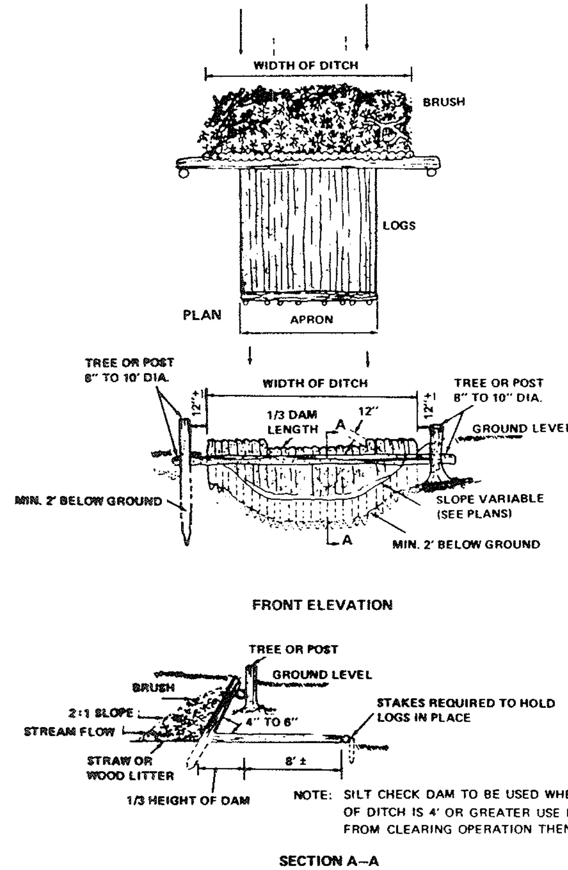
PLACE BRUSH, LOGS AND TREE LAPS APPROXIMATELY PARALLEL TO TOE OF FILL SLOPE WITH SOME OF THE HEAVIER MATERIALS BEING PLACED ON TOP TO PROPERLY SECURE THE BARRIER AS DETAILED ABOVE AT LOCATIONS SHOWN ON PLANS OR AS DIRECTED BY THE ENGINEER.

TO ALLOW WATER TO FILTER THROUGH BRUSH BARRIER, INTERMINGLE THE BRUSH LOGS AND TREE LAPS SO AS NOT TO FORM A SOLID DAM.

THE BRUSH BARRIERS MAY BE CONSTRUCTED WITH MECHANICAL EQUIPMENT.

DETAIL OF BRUSH BARRIER

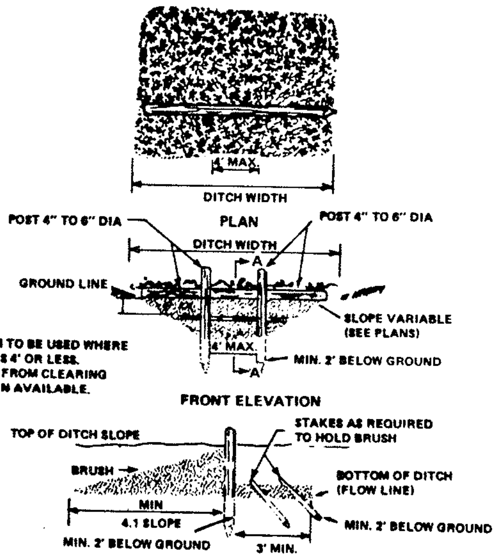
FIGURE 6-A



NOTE: SILT CHECK DAM TO BE USED WHERE BASE OF DITCH IS 4' OR GREATER USE MATERIALS FROM CLEARING OPERATION THEN AVAILABLE.

DETAIL OF SILT CHECK DAM TYPE A

FIGURE 6-B



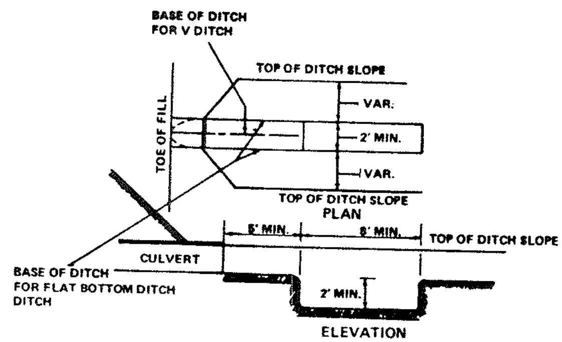
NOTE:
SILT CHECK DAM TO BE USED WHERE BASE OF DITCH IS 4' OR LESS.
USE MATERIALS FROM CLEARING OPERATION WHEN AVAILABLE.

SECTION A–A

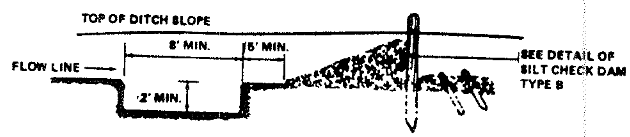
WHERE LOGS ARE NOT AVAILABLE, WOVEN WIRE FENCE MAY BE USED TO RETAIN WOODS LITTER FOR BRANCH FILTER. IF WOVEN WIRE FENCE IS USED, THE WIRE SHALL BE ANCHORED SECURELY AND TO THE SATISFICATION OF THE ENGINEER PRIOR TO PLACING THE LITTER AND FOLIAGE FILTER MATERIALS.

DETAIL OF SILT CHECK DAM TYPE B

FIGURE 6-C



DETAIL OF SILT BASIN TYPE B



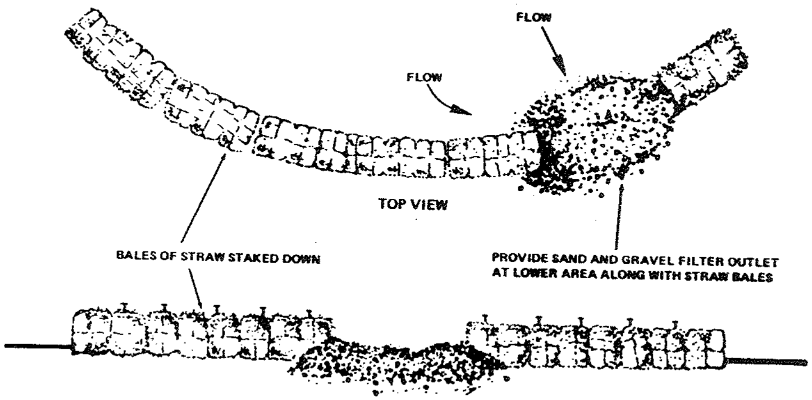
NOTE:

SMALL SILT BASIN TO BE USED AS NEEDED AT PIPE INLET AND OUTLETS PARALLEL ROADWAY DITCHES AND AT OTHER LOCATIONS AS DIRECTED BY THE ENGINEER.

LENGTH, WIDTH AND DEPTH AS REQUIRED TO CONTROL SILT IN FLOW LINE'

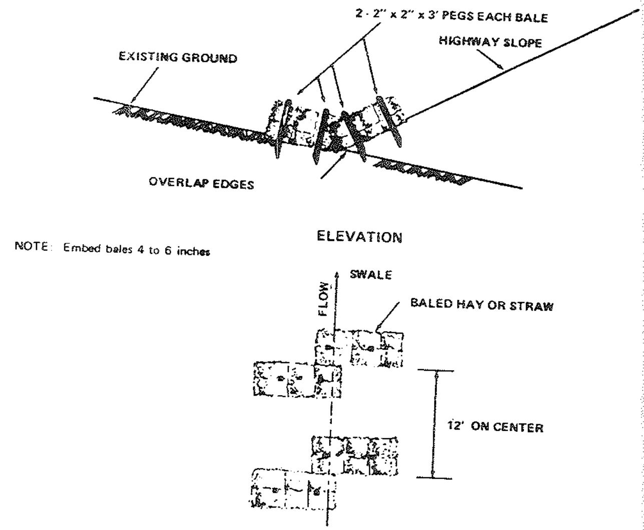
DETAIL SHOWING COMBINATION OF SILT CHECK DAM TYPE B AND SILT BASIN TYPE B

FIGURE 6-D



HAY BALE DAMS USED ALONG TOE OF SLOPE

FIGURE. 7



PLAN

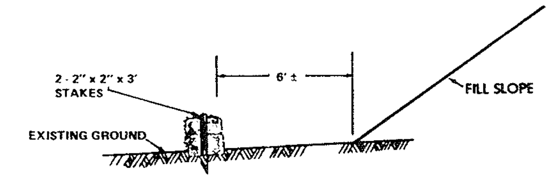
TO BE USED WHERE THE EXISTING GROUND SLOPES TOWARDS THE HIGHWAY EMBANKMENT AS CALLED FOR ON PLANS.

MEASUREMENT AND PAYMENT WILL BE BY THE BALE IN PLACE. BALES WILL BE ALLOWED TO ROT IN PLACE SO THERE WILL BE NO REMOVAL ITEM. THERE WILL BE NO PROVISIONS FOR MAINTENANCE OTHER THAN REPLACEMENT OF A BALE IF REQUIRED.

TYPE "A"

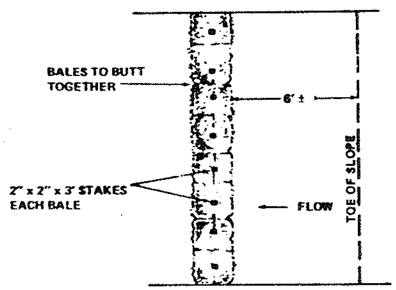
BALED HAY OR STRAW EROSION CHECKS

FIGURE 8



ELEVATION

NOTE: Embed bales 4 to 6 inches



PLAN

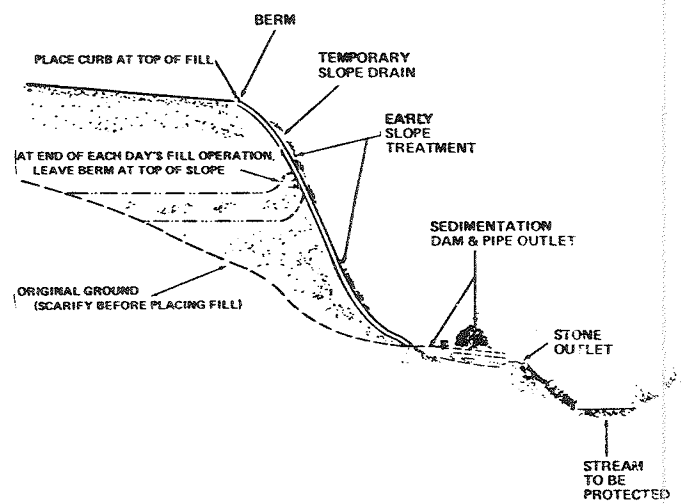
TO BE USED WHERE THE EXISTING GROUND SLOPES AWAY FROM THE HIGHWAY EMBANKMENT AS CALLED FOR ON PLANS.

MEASUREMENT AND PAYMENT WILL BE BY THE BALE IN PLACE. BALES WILL BE ALLOWED TO ROT IN PLACE SO THERE WILL BE NO REMOVAL ITEM. THERE WILL BE NO PROVISIONS FOR MAINTENANCE OTHER THAN REPLACEMENT OF A BALE IF REQUIRED.

TYPE B

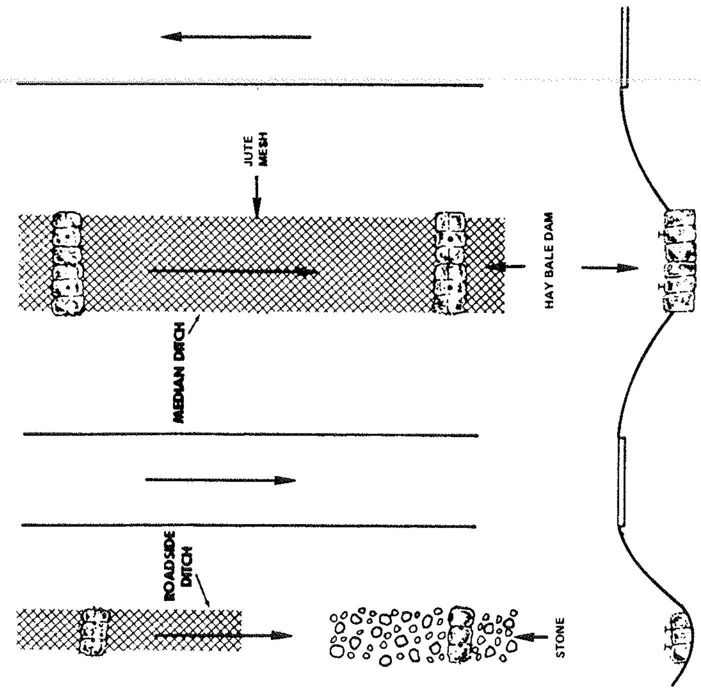
BALED HAY OR STRAW EROSION CHECKS

FIGURE 9



EMBANKMENT CONSTRUCTION
UTILIZING SILTATION CONTROLS

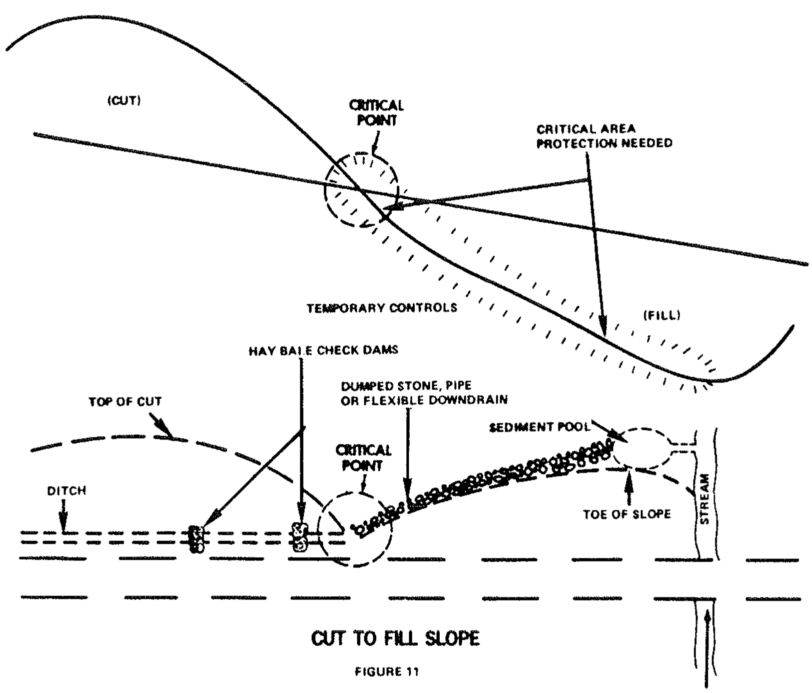
FIGURE - 10



HAY BALE DAMS USED IN DITCHES

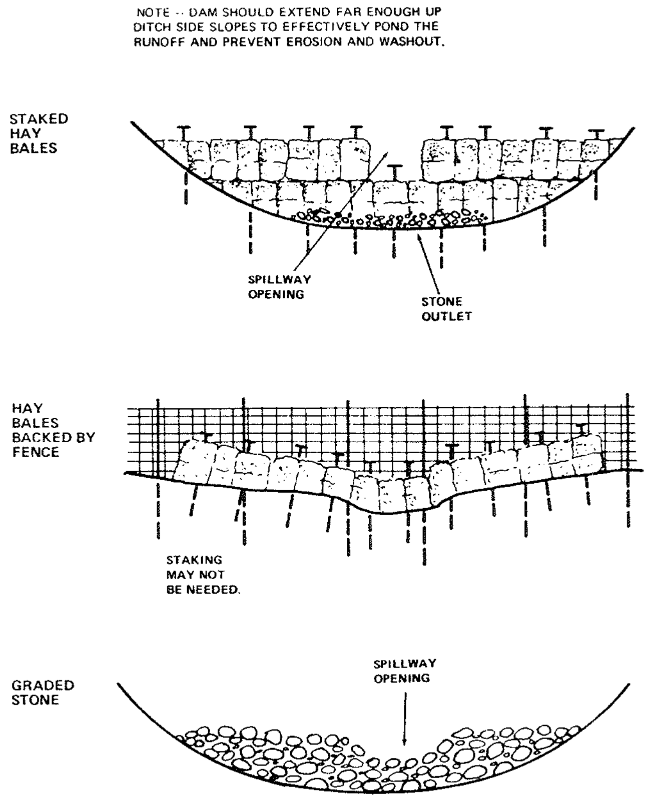
FIGURE 12

204



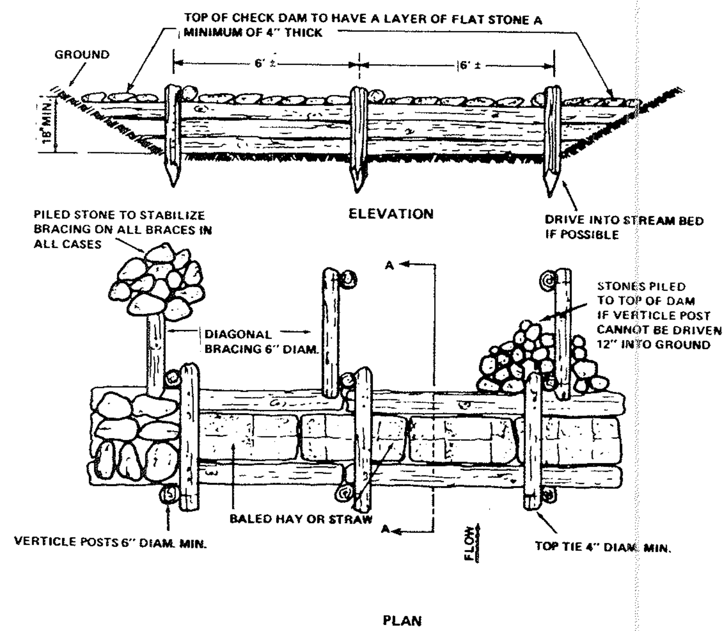
CUT TO FILL SLOPE

FIGURE 11



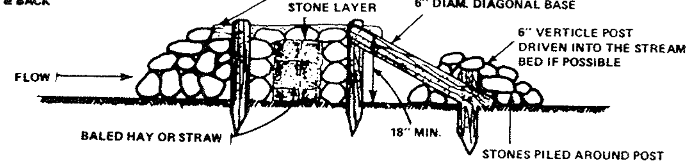
TYPES OF TEMPORARY DAMS

FIGURE 13



LOG AND HAY EROSION CHECK DAM

FIGURE 14a

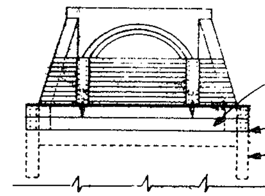


SECTION A-A

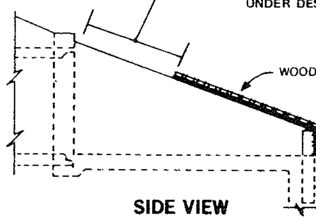
DAM TO BE CONSTRUCTED OF NATIVE LOGS OBTAINED FROM CLEARING OPERATION. ALL LOGS TO BE SPIKED WITH BOAT & DOCK OR WIRE SPIKES OR BOLTED TOGETHER. EXISTING TREES, BOULDERS OR LEDGE MAY BE USED IN PLACE OF THE VERTICLE POSTS AT THE DISCRETION OF THE ENGINEER. WHEN VERTICLE POSTS CANNOT BE DRIVEN INTO THE STREAM BED, STONES SHALL BE USED TO BRACE THE STRUCTURE. DAM TO BE PAID FOR BY THE LINEAR FOOT IN PLACE. REMOVAL OF DAM TO BE PAID FOR BY THE UNIT "EACH" FOR EACH TIME THE POOL IS CLEANED. INCLUDING ALL LABOR AND SMALL SIZE EQUIPMENT. NO LARGE EQUIPMENT WILL BE ALLOWED IN THE AREA. ALL EQUIPMENT AND METHODS OF OPERATIONS SHALL HAVE THE WRITTEN APPROVAL OF THE ENGINEER BEFORE ANY WORK IS DONE ON EITHER THE CONSTRUCTION OR MAINTENANCE

LOG AND HAY EROSION CHECK DAM

FIGURE 14b



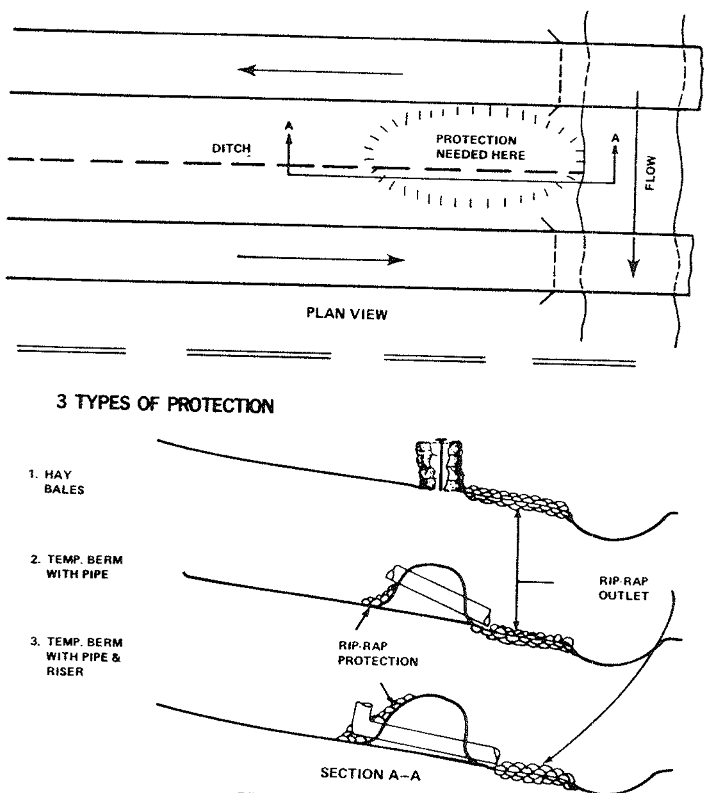
FRONT VIEW



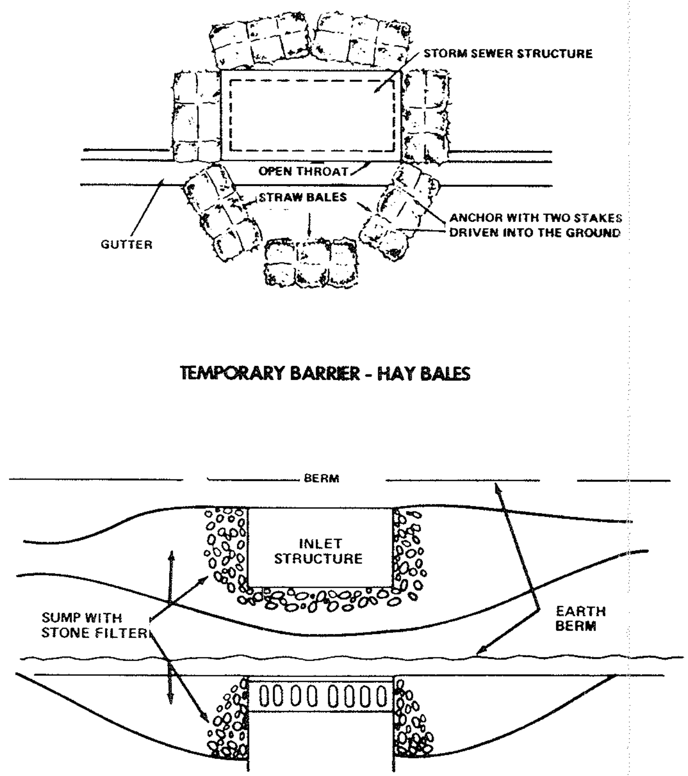
SIDE VIEW

CULVERT SEDIMENT TRAP

Figure 15

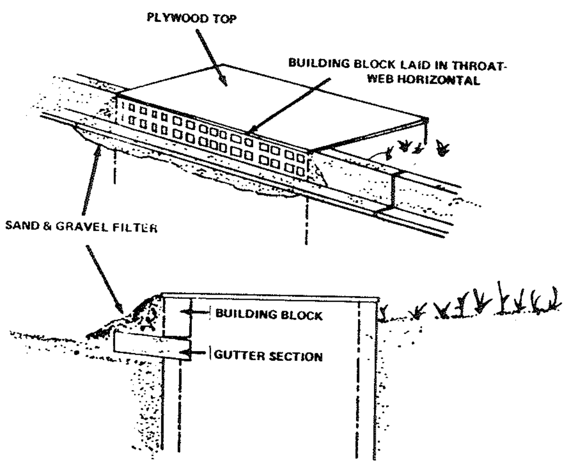


PROTECTION AT STREAM CROSSING
MEDIAN & SIDE DITCHES
FIGURE 16



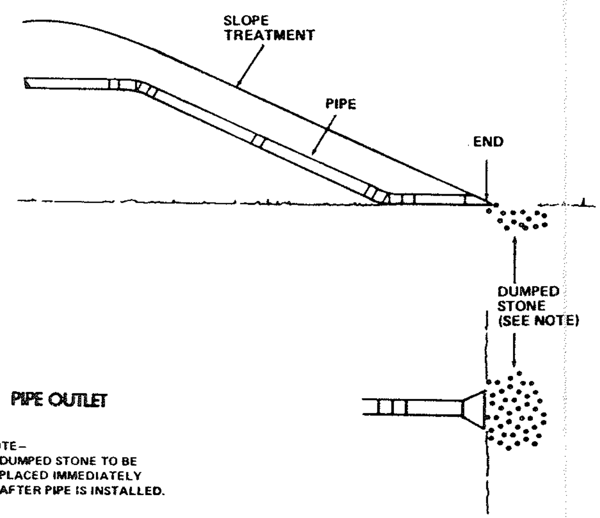
TEMPORARY SUMP - STONE FILTER
INLET SEDIMENT TRAPS

FIGURE 17



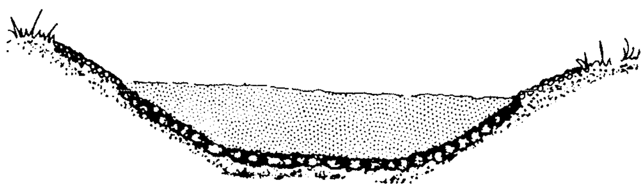
SAND AND GRAVEL FILTER INLET SEDIMENT TRAP

FIGURE 18



EROSION PROTECTION AT PIPE OUTLET

FIGURE 19

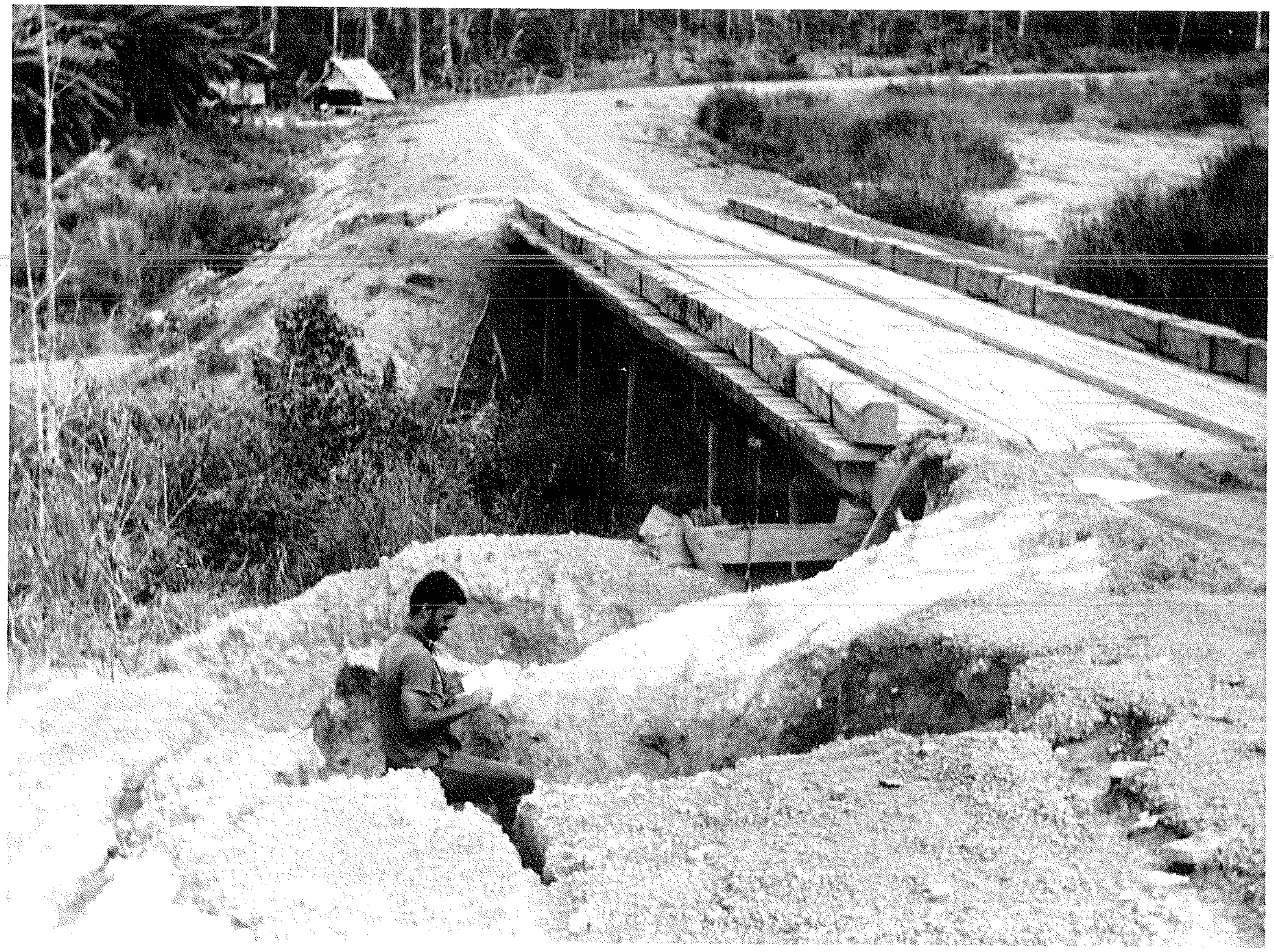


LARGE CHANNELS – USE STONE LINING WITH GRAVEL FOUNDATION

SMALL CHANNELS – USE GRAVEL.

DIVERSION CHANNELS

Figure 20



Erosion at approaches to newly constructed bridge (Brazil).

LOW-VOLUME ROADS

Proceedings of a workshop held June 16-19, 1975, in Boise, Idaho, by the Transportation Research Board and cosponsored by the Agency for International Development, American Association of State Highway and Transportation Officials, Federal Highway Administration, Idaho Transportation Department, International Bank for Reconstruction and Development, International Road Federation, National Association of County Engineers, National Science Foundation, U.S. Army Engineer Waterways Experiment Station, U.S. Forest Service, and University of Idaho

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Transportation Research Board
National Research Council
National Academy of Sciences
Washington, D.C.
1975

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IMPACTS OF HIGH-INTENSITY RAINSTORMS ON LOW-VOLUME ROADS AND ADJACENT LAND

Melvin Dittmer and Allan A. Johnson, U.S. Forest Service, Medford, Oregon

One of the most severe tests a road receives is a high-intensity rainstorm. The Siskiyou mountain range of the Rogue River National Forest has received several such storms in the past decade. The most recent of these storms occurred during January 1974, resulting in over $8 million of damage to low-volume, mostly single-lane roads. This paper describes the kinds of road failures that occurred through narrative, sketches, and photographs. The interrelationship between the road and the adjacent land is often not fully considered by the land manager or the road engineer. Poor land management practices, especially in mountainous terrain, place extreme burdens on the road's drainage facilities. Roads, on the other hand, tend to concentrate water, cause surface erosion, and upset slope stability. Land and road failures on the upper portions of a watershed often cause damage to the land, roads, and other facilities located in the lower basin. There are numerous commonly used techniques in road construction to minimize storm damage to roads and the land. This paper describes some of the least expensive methods that should be used more frequently on low-volume roads.

The true test of an engineered product consists of exposing that product to the most stringent natural conditions it was designed to endure. A good test then of the drainage facilities of a road is exposure to a high-intensity rainstorm. On January 15 and 16, 1974, a high-intensity storm occurred on the Siskiyou mountain range of the Rogue River National Forest in southwestern Oregon and northern California. That storm caused the greatest flood ever recorded in this area and was estimated by the Army Corps of Engineers as a 56-year flood. The forest suffered damage in excess of $8 million at 1,000 locations on low-volume roads carrying traffic volumes from near 0 to about 200 vehicles per day.

Many traditional road design and construction features result in extensive road and land damage during severe rainstorms. Through the use of simple and generally inexpensive design and construction features that are mostly commonplace, soil erosion, mass soil flows, and road damage can be greatly reduced. The road is thoroughly interrelated with the land it serves. Soil, geologic, vegetative, and drainage changes that occur on one affect the other, often with devastating results during floods.

DEBRIS-PLUGGED CULVERTS (IN DRAINAGES)

Problem

One of the most frequent and severe forms of road damage caused by the 1974 storm was culverts in drainages plugged with debris. In most cases, the entire road fill was taken out once the water overtopped the road. Examination of these culverts after the storm showed that the major cause of failure was debris plugging the inlet. The debris either completely plugged the culvert or reduced its effective size and capacity such that failure occurred.

Types of debris in the culvert included logging slash, native soils, rocks, and natural forest litter. A high-intensity storm on steep terrain can move much debris downhill. Only an overdesigned culvert can be expected to carry its maximum design flow when it is plugged with waterborne debris. The design size of most drainage culverts that fail would have been adequate had the debris problem not developed.

Prevention or Minimization

This problem is a difficult one to prevent or minimize. This is partially because the road agency may not have control of the land practices that generate the debris. If this is the case, the only alternative is to design for the debris flow, which leads to high construction costs.

Construction of elaborate and costly drainage facilities is not justifiable on very low-use roads. In this case, either temporary or minimal facilities might be used. Such a facility might be a temporary bridge, culvert, or ford. This would mean the road could be used in low stream flow periods. Except for a permanent ford, the facility would have to be removed during periods of nonuse to prevent land resource damage.

For county roads or major forest access roads, the facilities just described are inadequate. Permanent and uninterrupted access is necessary or at least is the goal. Some ways to prevent debris from plugging culverts are as follows.

Trash racks installed upstream from the culvert stop debris before it reaches the culvert. There are many variations of trash racks; they all need to be firmly anchored and not act as a dam. They should not be located too far upstream or they become difficult to maintain. It is doubtful that trash racks will work effectively under all or even most conditions. They are one alternative, especially where trash and not soil or rock debris is the principal cause of culvert blockage.

A safety overflow of some type can be provided. The Ashland watershed on the Rogue River National Forest has had high-intensity storms four times in the last 10 years. Some of the same stream crossings have been wiped out each time. Large amounts of soil, rock, and logging debris plug the culverts and cause road fills to be washed out after overtopping (Figure 1). A high water ford is planned for the overflow at these locations (Figure 2). A culvert will handle ordinary storms. In the case of severe storms, the culvert is expected to fail because of debris flow. For this situation, an armored grade sag will be built in the fill to provide for storm runoff. The fill armor can be provided by cast-in-place concrete, grouted riprap, large riprap for the entire fill, or a combination of reinforced earth with an armor cover. This solution should greatly reduce the

Figure 1. Washed out stream crossing caused by plugging of culverts during high-intensity storm.

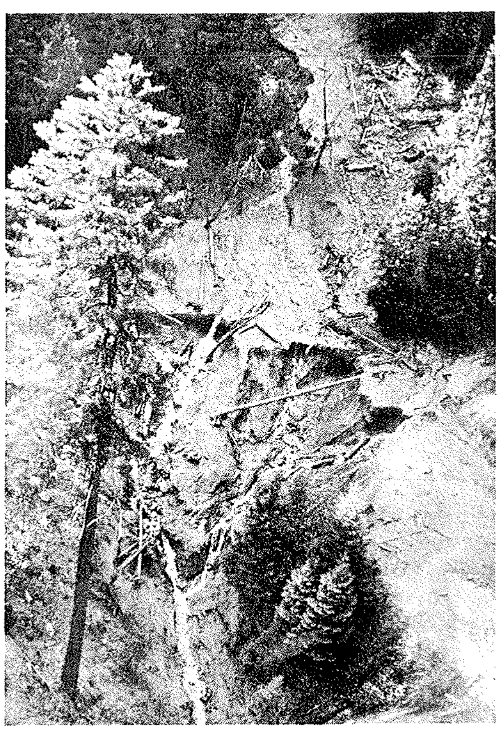
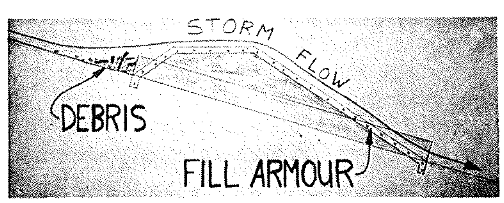


Figure 2. High water ford to prevent washing out of road when debris plugs culvert.



amount of soil flushed down the streams because road fills at stream crossings will not be added to the debris and soil already moving down the drainage and scouring it out.

A takeoff on this concept for very small drainages is the use of a rocked drainage dip at the culvert site. Again, normal or moderate storm flows would pass through the culvert. In severe storms the water would flow over the rocked drainage dip if the pipe became plugged.

For larger drainages with severe debris problems, a bridge may be the best solution. A large waterway opening would allow the debris to pass under the bridge. The bridge foundation would have to be designed to withstand scouring. This is a more costly option and would have to be evaluated. For higher use roads a bridge can often be justified.

DITCH RELIEF CULVERTS

Problem

Ditch relief culverts are those installed to periodically drain ditch line flows across the road. On flatter road grades common to gentle terrain, these culverts are less troublesome. Steep mountainous terrain subject to high-intensity storms is another matter. During these storms, severe road and land damages can occur when these culverts fail.

Because of economics and a desire to remove the least amount of land from production, grades are often very steep on low-volume roads, 8 to 12 percent or even more. This greatly increases the ditch scour potential. Failure occurs when the relief culverts can no longer handle the flows. Severe scouring of the ditch line occurs, sometimes to depths of 10 ft (3 m) or more. Eventually, the ditch line flow breaks across the road at a sharp horizontal curve or a sag in the road grade. Once this occurs, extensive washing out of the fill slope and road surface results.

Debris plugging culverts again is a main culprit leading to failure. Also common is a domino effect when soil and debris begin to build up in one culvert until eventually it becomes plugged. Water, soil, and debris then move on to the next relief culvert. This added amount of water and debris causes this culvert to fail also, and so on down the road.

Besides the damage to the road, these failures have a detrimental effect on the land below the road. Siltation in streams is increased, degradation of water quality is increased, and fish habitat may be totally destroyed. Concentration of the runoff increases erosion. Roads and other facilities can be damaged.

Prevention or Minimization

To prevent or minimize this problem requires that proper culvert spacings be designed. Spacing should be close enough so that excessive ditch scour does not result. The spacing depends on the grade of the road and the erodibility of the ditch soils. Design guides are often used for determining spacing. Because of the cost, the tendency is to place ditch relief pipes too far apart. This is usually false economy because the cost to repair a severely damaged road is more than the cost of adequate ditch relief culverts. Too frequently relief culvert spacing is determined only by ditch erosion criteria. In highly erosive and unstable soils, maximum spacing should be determined by conditions at the culvert outlet. Water concentrated at relief culvert outlets can undermine road fills or supersaturate the soil, creating slides and subsequent road and land damage.

Proper installation of ditch relief culverts is also very important. They should be placed at skew angles of 30 deg or more. If they are not skewed, the ditch flows tend to run past the relief pipes. Chances of culvert entrances plugging are increased when ditch flows must turn 90 deg to enter the channel. Where sharp turns are required for water entering a culvert, deposit of water bed load material may occur. Also sticks carried by the water frequently fail to make the sharp turn, thus setting up conditions for complete culvert inlet blockage.

The grade of relief pipes is also important. The grade of the ditch relief culvert should be at least 2 or 3 percent greater than the ditch grade to avoid a decrease in the velocity of the ditch flow at the culvert entrance. A decrease in velocity will greatly increase the chance of the culvert plugging.

A well-constructed catch basin helps to direct ditch water into the culvert. The ditch should be blocked off with a berm of earth and rock, and the inlet should not be too deep in the ditch line. Deep inlets tend to plug easier because of material sloughing into the catch basin. They are also difficult to clean out when plugged. Improving the inlet conditions of ditch relief culverts is very effective in preventing failures under storm conditions.

One way to do this is to use a drop inlet. A design proven effective is installing a 36-in. (0.9-m) corrugated metal pipe vertically with a cover to keep bank slough out. A notch is cut for the entrance of the ditch water. This provides a vertical fall into the crossdrain and avoids a slowdown in velocity.

Another possibility is a flared inlet and elbow installed in the ditch line. The flared inlet is placed in the ditch line facing the flow. The elbow connects the flared inlet and crossdrain. Because the ditch flow runs directly into the flared inlet and is guided into the crossdrain by the elbow, a slowdown in velocity is minimized or eliminated. These installations are somewhat costly, but elimination of road washouts and resulting adjacent land damage justifies the cost in most cases. These have been found to be quite effective on raveling back slopes such as those made of decomposed granite soil types.

The measures discussed are not a panacea for prevention of ditch relief culvert failures. High-intensity storms causing debris flows, soil movement, and large runoff can still cause failure of relief culverts. In this case, some type of safety overflow can be used. One type is a dipout (Figure 3). This is a depression constructed in the road to drain ditch flows across the road in the event that ditch relief culverts fail. The dipout is constructed in the road subgrade. Some type of armor or waterproofing is provided to prevent scouring. The dipout should also be skewed to be most effective. The location of the dipout is normally just downgrade from culverts. Because of the rather abrupt effect on the profile grade, dipouts can normally be used only on low-speed roads.

Another design alternate is periodic use of an oversized ditch relief culvert. Ditch relief culverts are usually 18 in. (460 mm) in diameter. Using a 24- or 30-in. (610- or 760-mm) ditch relief culvert every third installation or so can stop the domino effect discussed earlier (Figures 4 and 5). Larger culverts are less apt to plug up from small waterborne debris. The road will probably still suffer ditch scour, but complete road washout is prevented.

OUTSLOPED ROADS

All of these alternatives assume a ditched road is necessary. In some cases, a ditch can be eliminated by designing an outsloped road. For very low-volume roads, an outsloped road can often be substituted for a ditched road. These roads are constructed with a 4 to 10 percent outslope to provide drainage across the road. The outslope allows all water falling on the road as well as runoff coming down cut banks to drain off the road. Where live streams are crossed, a culvert or ford is provided. This type of road is appropriate for ADTs of 0 to 50 vpd, although outsloping occasionally is satisfactory for roads with higher traffic volumes.

This type of road has many advantages. Because the ditch is eliminated, the road width and cut bank heights are greatly reduced. The constant outslope disperses runoff along the entire length of the road, instead of concentrating water as ditch relief culverts do. The cost of the road is reduced because ditch relief culverts are not used and excavation quantities are greatly reduced. The outsloped road can be surfaced or unsurfaced depending on the season of use and erodibility of the soil.

Drainage dips (Figure 6) are recommended as a safety drainage feature, especially on unsurfaced outsloped roads. This is because water may follow wheel ruts instead of

Figure 3. Dipout provides safety overflow.

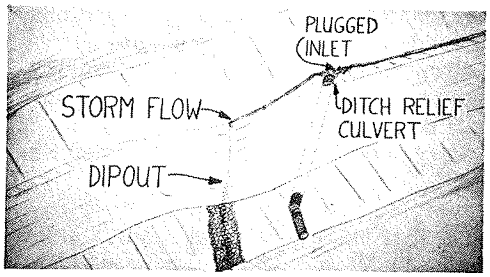


Figure 4. Deeply scoured ditch caused by failure of ditch relief culverts.

Figure 5. Oversized ditch relief culvert.

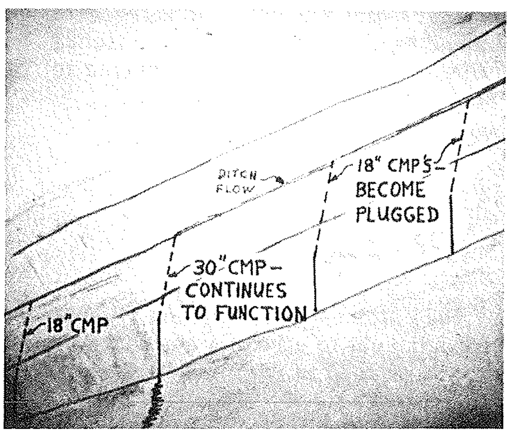


Figure 6. Typical drainage dip constructed on an outsloped road.

Figure 7. Paved outsloped road catching soil and debris.

running off the outslope. If enough water flows in the wheel ruts, it can erode deep channels in the road during storm conditions. Drainage dips ensure drainage across the road. They can be formed through a grade sag in the profile or cut into the subgrade in a constant grade line. For maximum efficiency, dips should be skewed. They should be well defined and built in the subgrade so that future maintenance operations do not negate their effectiveness. On unsurfaced roads the drainage dip should be armored with rock material across the road and down the fill slope to natural ground. On surfaced roads, armoring the fill slope down to natural ground is adequate. Sometimes an overside drain is installed to carry runoff down the fill.

Outsloped roads cannot be used everywhere. They should normally not be used when

1. Substantial subsurface water flows are intercepted by the cut slope,
2. Roads are used during snowy and icy seasons that make outsloped roads a safety hazard,
3. Roads have high traffic volumes and travel speeds that make outsloping unacceptable for safety reasons, and
4. Roads have grades of more than 10 percent, again for safety reasons.

Several roads in the Rogue River National Forest that experienced the January 1974 storms were outsloped. We found much less damage on these roads than on ditched roads. Damages were mainly a few cut bank sluffs or small slides. This seems to indicate that outsloped roads offer a relatively stormproof design alternate.

SCOUR ON RIVER GRADE ROADS

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Problem

Another major type of damage due to the January 1974 storms was scour on river grade roads. River grade roads are roads that are built adjacent to streams and that follow the grade and the alignment of the stream. This type of road is common in steep mountainous terrain on both high-standard and low-volume roads. On low-volume roads, it is difficult to finance expensive and elaborate design features to protect the road. Often all that the road owner can afford is to replace washed-out roads with an unprotected road similar to the one that was washed out. Yet, because of its impacts and effects on the environment, this alternative will not always be desirable or even allowable.

Prevention or Minimization

Some of the ways to protect low-volume river grade roads are given below.

1. Transportation planning in the preliminary stages should avoid the river grade road where possible. Unfortunately, this is not a viable alternative for the many miles of river grade road already in existence. Large costs, right-of-way problems, land development, and a host of other problems usually do not allow changing the location of a river grade road once it is built. However, on roads extensively damaged by river scour with little investment value, a new higher elevation location should be considered.
2. Heavy riprap can be used to repair some scour-damaged roads. A source of very large riprap at a short haul distance is necessary for this method to be economically feasible. To be effective, riprap with 50 percent 12-ft^3 (0.34-m^3) material is needed. This would have to be placed by a derrick. A good key trench is also needed to prevent failure. Where large riprap is unavailable, a tamped riprap using smaller sizes is a possibility. The riprap must be mechanically tamped to tightly bind the stones and make a smoother riprap face to withstand the forces of fast-moving streams. A large heavy plate on a crane can be used to tamp the riprap. The Federal Highway

Administration has used tamped riprap successfully in Vancouver, Washington.

3. Gabions are another alternative for protection against river scour. These are galvanized wire baskets filled with stones. Manufacturers' brochures adequately describe applications of gabions for protection against river scour, so they need not be discussed here.

4. Metal bin walls are being used to repair some of the scour-damaged roads in the Rogue River Forest. They will be used on sharp stream bends where earlier riprapping has failed. A rock stratum will be excavated to provide the foundation for the bins.

CUT BANK AND FILL FAILURES

Problem

Extensive damage to roads from cut bank and fill failures occurred during the January 1974 storms. Large blocks of material slid into the roads from the cut banks and completely blocked the roads. Fills slid out, allowing extensive amounts of soil to enter streams. Some fills failed because of saturation; others were washed out by failures of culverts. Cut bank failures and slides usually result from saturation of the soil, excessively steep cut banks, or undermining of the slope by ditch erosion.

Prevention or Minimization

Ways to minimize the damage are generally not new but need to be considered and emphasized more on low-volume roads. The time is past where the cheapest possible roads are an acceptable alternative. The effects on the resources and the environment need to be fully considered.

Building roads to the minimum width possible is effective in reducing cut bank and fill slope failures. Narrower roads can be built with substantially lower cut and fill bank heights. Both the probability and extent of failure are greatly reduced with lower slope heights. Of course, the road must be wide enough to safely handle the types and volume of traffic for which it was intended. This type of minimum impact road is being emphasized more and more in national forests. In addition to outsloped roads, which have no ditch and can therefore be narrower, insloped roads and roads with shallow, narrow ditches can also meet the objective of low cut bank heights. Insloped roads and shallow ditched roads have their limitations and disadvantages in certain soils and saturated subgrade situations. They also still require ditch relief culverts. However, they are safer under icy conditions than outsloped roads. Shallow ditches can be used by passing vehicles on narrow low-volume roads.

Care in the location of roads can often prevent or minimize future problems. Slump or slide areas, poor soils, excessively steep terrain, and poorly drained areas are all examples of where roads should not be located. Only experienced road locators who can recognize potential problems should be responsible for the location work. In addition, geologic and soils investigation is necessary to avoid or minimize future problems. For low-volume roads, large amounts of funds and manpower can seldom be justified for full geologic and soils investigation. Often visual observation by an experienced engineering geologist or soils engineer is adequate. In other cases, soils and geology should be investigated to the extent justified by environmental protection and the road investment and maintenance costs. On low-volume roads, soils and geologic investigation to the point of zero failure would seldom be warranted.

Another method of reducing cut bank and fill failure is rolling the profile grade to reduce cut and fill heights. Likewise, alignment should follow the ground curvature. This can be done because design speed and traffic volumes are seldom critical on very low-volume roads. Besides high cut and fill slopes, straight alignments and long grades tend to concentrate runoff. This increases chances of culvert failures. A rolling grade and curvature following natural contours will provide more opportunities for runoff to leave the road.

Cut bank slope ratios should be flattened when possible to reduce failure. Cut slope ratios of 1½:1, 2:1, or even 3:1, where the terrain allows, are nearly always desirable. Use of variable slope ratios on the same road should be encouraged to take advantage of the added stability of flatter slopes. Where a surface stratum of soil with a shallow natural angle of repose overlays a material with a much steeper angle of repose, a variable cut slope ratio can be effective. The harder material can be cut at perhaps 1:1 and the surface layer at 2:1. Without extensive soil borings, the variable slope ratio would normally require extensive field adjustments during construction.

The use of perforated pipe underdrains can reduce fill failures. Installation of the perforated pipe prevents saturation of the fill. Locations for perforated pipes can sometimes be spotted during design reviews but more often are selected during construction operations. Installation of underdrains during initial construction is much less costly than replacing lost fills or correcting the problem after the road is built.

The use of horizontal drains to prevent both cut and fill bank failures is becoming common. Horizontal drains work by draining out excess water from the cut or fill bank. The beauty of horizontal drains is that they can be placed in existing roads about as easily as in initial construction. When the drains stabilize large potential failures, great savings in the excavation and haul costs are realized and adjacent land and aesthetics are protected.

Simple rock buttresses can be used to stabilize cut banks on low-volume roads, usually at low cost. These can be built during initial construction or as a repair measure on an existing road. The buttress acts as a heavy stable mass to hold back further sliding of material above the road.

Revegetation of cut slopes and fill slopes helps to prevent and minimize damages from high-intensity storms. The vegetation holds the soil particles together, slows the runoff, and prevents surface erosion. Application of seed, mulch, and fertilizer soon after construction will normally get vegetation started. However, on slopes steeper than 1½:1, the chances of establishing vegetation are frequently poor. Normally deep-rooted native vegetation is the most effective in the long run for stabilizing road cut and fill slopes. For extreme conditions, more exotic revegetation methods can be tried. Some of these are jute netting, turf blankets, soil binding agents, asphalt-coated mulch, planting of native plants and shrubs, and many others. For low-volume roads, many of the more expensive revegetation methods are not justifiable.

During construction, trees and shrubs should be removed only when necessary. The clearing limits should be kept close to the cut and fill slopes. Removing larger trees close to the cut slope and leaving small trees and shrubs are also helpful. Besides disrupting the aesthetics and taking additional land out of production, removal of trees and shrubs makes the soil more erosive and less stable. The roots of trees and shrubs help to hold the soil in a compact mass and provide resistance to erosion. The tree crowns intercept precipitation so that, through evaporation, less moisture is available to saturate the soil.

Daylighting should be avoided on roads where a through cut can be left. Daylighting causes movement of more soil than necessary and exposes more area to erosion. In addition, more land is at least temporarily removed from production.

A paved 2 percent outsloped road with curbs and berm relief culverts was constructed in the Ashland district of the Rogue River National Forest several years ago. This road is in an area subjected to very intense rainstorms. Soils are highly erosive, decomposed granite. The previously insloped, unsurfaced road was paved and outsloped to prevent the periodic severe damages the road was receiving.

This road experienced the January 1974 storms. Damage to the road was much less severe than on the unpaved portion of the road. The pavement tended to catch soil and debris from back slope erosion and slumps (Figure 7). This material was held on the road and prevented from entering streams. Some of the fills failed because they were undermined by water carried off the road to the toe of the fill by berm relief culverts. This occurred even though energy dissipators were installed on the outlets of the culverts. More complete dispersal of the water is needed in these erosive granitic soils.

All in all, the performance of the paved outsloped road seems to justify the cost, especially when the reduced land damage is considered in the analysis.

LAND MANAGEMENT PRACTICES

Problem

As noted earlier, the type of land management adjacent to roads has a significant effect on the road. Often damage occurring to roads is blamed on the design and construction of the road, but the failure was brought about by land management activities occurring after the road was constructed. Some of the ways land uses can adversely affect roads are discussed below.

Construction of temporary or log skid roads on timbered lands concentrates runoff and changes drainage patterns. Runoff and drainage are especially severe in steep mountainous terrain. When these changes occur, drainage facilities that were once adequate fail. Culverts cannot carry the increased flows caused by the concentration. Drainage channels change, and water flows to the road where no culverts were installed.

Removal of a large percentage of trees or other vegetation causes an increase in the rate and amount of runoff. This increase can cause once adequate drainage facilities to fail.

Debris generated by land use moves downhill in storms, resulting in plugged drainage facilities and severe road damage.

Poor land management practices visible to travelers are aesthetically unpleasing. On low-volume roads, the visual resource may not be a primary consideration. However, if a road is intended as a scenic route, these unsightly disturbances can be considered a road failure.

Prevention or Minimization

Land Use Planning

Where the road agency is also responsible for management of the adjacent lands, land use planning can be implemented. This helps to blend the land management and road management into one coordinated plan. Activities on the land that cause damage to the road could be modified to avoid or minimize the road damages. Likewise, the design of the road can be adjusted to prevent adverse impacts on the land.

Concern in Land Practices

Land use activities should exercise concern for the land and resources. Examples are water barring and revegetation of temporary and skid roads, removal of temporary drainage structures, reduction in the volume of timber removed, and, in extremely critical areas, no land use activities at all. Frequently, good land management can be done at little or no increase in cost to the land owner. Even if costs of land management are increased (or profits reduced), it is probably a necessary step. Can we forever allow a landowner high up in a drainage to exercise land management activities that result in severe damage to streams and other lands below him? Probably not.

Design to Withstand Poor Land Management Practices

As noted earlier, the road agency may not have control over lands adjacent to the road. In this case, it may be necessary to design the road to withstand expected or existing poor land management activities. This can be very difficult and costly but may be the only option available.

CONCLUSION

The impacts on low-volume roads of high-intensity storms and the resulting floods have been discussed. The interrelationship between the road and the adjacent land is such that each has an effect on the other. Ways to design and build roads to withstand or minimize damages from storms and floods were discussed. Many old ideas and some newer ones were put forth. Using these methods may prevent much damage to roads and the land resources.

Engineers and road building agencies need to do a better job in designing and maintaining roads to withstand severe conditions. The tendency on low-volume roads to build the cheapest first-cost facility possible needs to be avoided. The damage to resources and the environment needs to be adequately recognized. In analysis of alternatives, proper values must be assigned to damage to the environment. When the costs of stream siltation and loss of fish habitat are assigned, perhaps an unprotected river grade road is not the cheapest alternative after all. Building reasonably maintenance-free roads must not impact the adjacent land and create maintenance costs on it.

Low-volume roads are constructed to serve an identified transportation need. Part of the analysis for that need must include the interrelationship of a road to the surrounding environment. A principal requirement for low-volume roads is that they fit lightly on the land before and after a high-intensity rainstorm.

THE HIGHWAY ENGINEER

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FRONT COVER STORY

After the long droughty summers of 1975 and 1976 pictures of "Beware Camels", cars up to their mudguards in sand and endless sun-parched desert panoramas conjur up Aldershot as readily as they do Arabia.

Fortunately, however, it is the latter, and the photographs illustrate Dr. Fookes' Paper on "Road Geotechnics in Hot Deserts", which he will give to a joint meeting of this Institution and the Civils in January, 1977.

As engineers you would be well-advised to read the Paper carefully and to attend the meeting if possible. A third hot summer in 1977 and, who knows, his (at the moment) specialised problems might well be your everyday ones

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Road Geotechnics in Hot Deserts

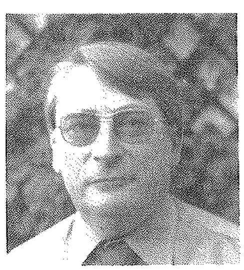
P.G. Fookes, PhD, BSc, MIMM, FGS

INTRODUCTION

In recent years there has been a rapidly expanding road construction programme in many of the world's hot deserts, particularly in the Middle East. Extensive construction programmes are being undertaken both on major projects crossing vast areas of desert and on local feeder roads serving small centres of population. Furthermore a considerable amount of bitumen pavement overlays are being laid on existing surface dressed roads. Many roads are performing satisfactorily but there are many examples of rapid deterioration and even complete failures over a short period of time that cannot simply be attributed to poor construction practice.

This Paper reviews some of the specific problems of road building in hot desert terrains in relation to the particular desert terrain type and the natural processes and surface materials occurring in that terrain. This approach has been adopted to help categorise the engineering problems by desert terrain type (or zone) which enables generalisations to be made about potential problems, their location, occurrence and frequency, and methods of evaluation and design. This approach also makes reconnaissance studies and follow up site investigations more technically efficient and generally easier in terms of cost and time. A working knowledge of desert geomorphological forms and processes is invaluable in helping diagnose design and construction problems.

For the purposes of this Paper a hot arid climate is one where evaporation exceeds precipitation (rain, snow and dewfall) and in many areas of the near and Middle East, especially the Red Sea and the Arabian Gulf and their adjoining regions, large parts of Saudi Arabia, parts of Iraq, Iran, Egypt, Algeria and Libya, it is the normal situation. This climatic regime produces hot desert terrains. Average annual rainfall may only be a few centimetres (even only a few millimetres in some parts) which usually only occurs seasonally, and sometimes only from a single cloudburst. Summer shade temperatures are frequently in excess of 40°C and humidities may be around 100 per cent near the coast. The contrast between maximum night and day temperatures and between night and day humidities is often great and in winter night-time frost can occur. Strong and persistent winds are normal in many areas.



P.G. Fookes

BIOGRAPHY

Dr Fookes is a consultant engineering geologist in private practice and is also retained part-time by Rendel, Palmer and Tritton, and Engineering Geology Ltd. He has wide experience in many ground engineering and construction materials fields both overseas and in the United Kingdom. He specialises in investigating problems in various terrain and environmental types. Formerly on the staff of Imperial College, and Binnie and Partners he has published over 50 Papers.

SUMMARY

Hot deserts provide a variety of design and construction problems for engineers which stem from the nature of the dry climatic regime and the desert landforms. Engineering solutions to these problems which are usually based on good practice in other regions, may not necessarily be successful. The problems include: **unstable terrain** *— e.g. wind blown silt (loess) and sand (drifts and dunes);* **aggressive salty ground** *— e.g. sabkhas, salinas, salt playas and some duricrusts;* **unsuitable construction materials** *— e.g. some silts, sands and soft carbonate sediments,* **rapid erosion** *— by wind and floods, especially flash floods.*

In coastal areas, causeways and reclaimed land may also present special problems due to evaporite salts and the leaching and piping of fills.

These problems are discussed in the context of a simple model based on mountain and plain desert terrain and natural desert processes, in which four zones are recognised each with different desert characteristics and different engineering behaviour. Particular reference is made to the near and Middle East.

This Paper will be presented at a joint meeting of the Institution and the Civils to be held in London on January 12th, 1977.

THE DESERT SURFACE

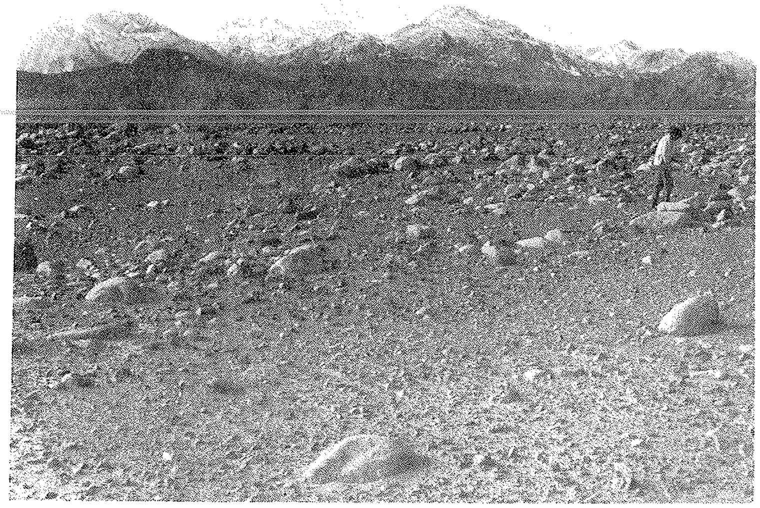
Surface sediments found in the hot arid climates are generally granular and with or without the presence of evaporite salts. They are generally formed by physical weathering of local hills or mountains; the disintegration of bedrock results largely from thermal weathering and to a lesser extent from salt weathering, wind abrasion and other local processes. The products of this type of weathering are generally coarse grained materials. Parent rocks of high silica content (e.g. granites) produce detrital sands and gravels which when sorted and transported by wind give loess (silt sizes grains) or dunes (sand sized) or when transported by flood water give alluvial sands and gravels. Breakdown of calcareous rocks (e.g. limestones or dolomites) result in calcareous sands and gravels and sometimes marls. Therefore, although the size ranges of material in different deserts are broadly similar as they are the product of similar transporting agencies — gravity, wind or water, the composition of desert surface is largely determined by the local bedrock types. Unfortunately for the civil engineer in many near and Middle East locations the local bedrock is of Tertiary limestones, marls, chalks or dolomites and often contains evaporite rock horizons. These latter release salts into the groundwater which, on evaporation, deposit the salts into the desert surface. Hence many near and Middle East deserts are potentially salty.

Commonly the world's hot deserts comprise intermontane basins ranging in size from a few hundred metres to tens and even hundreds of kilometres across. They are often centrally draining without outlet to the sea. The basic cross sectional profile comprises a **mountain** and a **piedmont plain**. Although such a profile characterises most deserts it may vary greatly in detail in different locations. For example, in "basin and range" country the ratio of mountain to piedmont plain area may approach one, whereas in the huge expanses of the Sahara or South Australia it is much smaller. A piedmont plain can be composed of various landforms. The basic contrast is between **bedrock pediment** (a bedrock plain) and an **alluvial plain**. In parts of Arizona for example the mountains form 10 per cent of the landform area, the whole piedmont is the remaining 90 per cent of which 50 per cent is alluvial plain, 30 per cent rock pediment and 10 per cent thin alluvial veneer to rock pediment. In the western Mojave desert 30 per cent is mountain, 70 per cent piedmont of which only 7 per cent is rock pediment and the remainder alluvial plain (Cooke & Warren 1973).

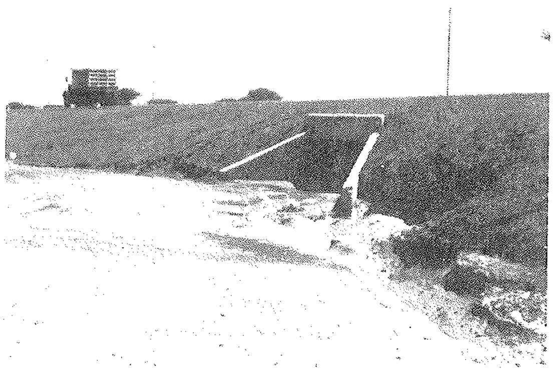
For engineering purposes Fookes & Knill (1969), with much idealisation developed a geomorphological division of the mountain and piedmont plain into four sediment deposition zones (Figure 1) which can each be correlated with different degrees of disintegration of the parent bedrock. The sorting of the different sizes of granular material characteristic of each zone being done by the dominant transporting agent in that zone. Rock pediments would occur in zone II of the Fookes & Knill classification. As they are not a granular material they are not the prime concern of this Paper and will not be discussed further. However, their engineering significance in controlling water courses and as foundations to structures and areas for provision of borrow material is important. The Paper principally considers the alluvial piedmont plain which comprises zones II to IV.

Boundaries of the zones run approximately parallel to the mountain ranges and the zones tend to be gradational into one another. The mountains undergo slow erosion and the resulting debris spreads out in colluvial and alluvial fans extending from the mountain slopes into the centrally draining basins of the desert. Coarse-grained material is found near the mountain flanks and buries the underlying rock, while the finer material accumulates some distance away and forms the alluvial plains. In general terms, the greater the distance from the mountains the finer the sediment forming the surface. Drainage patterns develop on the mountain slopes and fans, but generally lose themselves in the central desert areas. Stream flow is intermittent and the watercourses may be dry for long periods even for years.

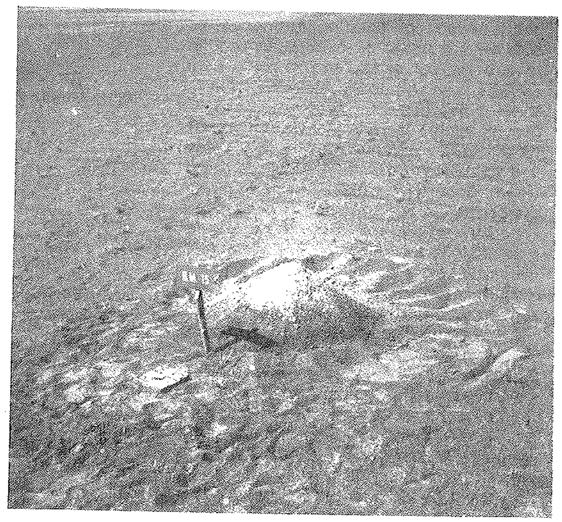
In semi-desert regions, with rainfalls greater than say 150mm per annum, more clay fraction material and clayey pedological soils tend to occur. Vegetation is



Apron fan slopes. Zone II with Zone I mountains in the background. Iran



Erosion in granular fill behind unprotected culvert headwall due to streamflood conditions. Zone III Trucial Coast



Above: Survey cairn. Zone III. Iran

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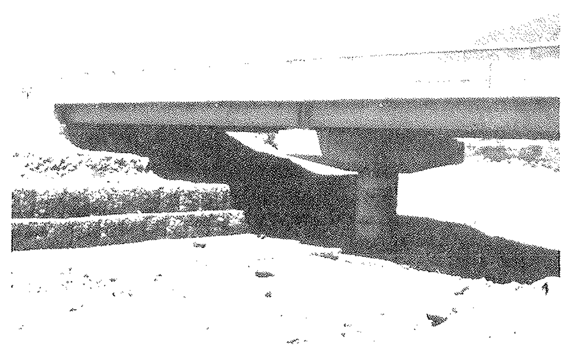
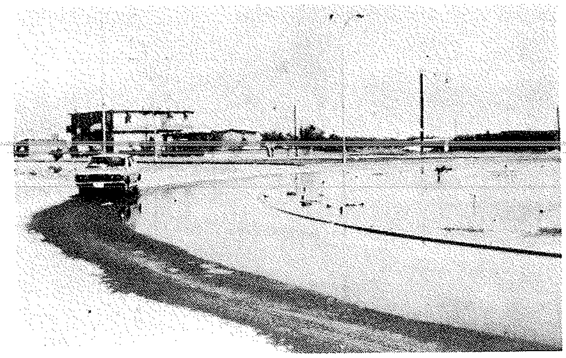
Wide culverts and training bunds. Zone II/III. Trucial Coast



Right: Gabion protection against scour of bridge abutments. Zone II/III. Trucial Coast



Sheetflooding on a roundabout with no designed drainage arrangements. Zone III/IV. Gulf of Oman

Erosion of shoulder by rain runoff from the road, with damage to pavement by headward erosion. Zone III/IV. Trucial Coast

also more abundant.

Within zone I (the mountains) grading sizes range from poorly sorted medium angular gravel to very large boulders and in this zone and zone II, gravity and water flow provide the main force of movement. In zone II deposition may take place from intermittent sheet and stream flow during short periods of flooding and here the soils are composed of mixtures of angular to sub-angular sands and gravels, with cobbles and boulders included. These sheet flows provide the principal transporting agents to zone III, where two soil types may be differentiated — silty stony and sandy stony desert. Aeolian (i.e. wind blown) deposits are mainly to be found in the central parts of the desert designated zone IV, where the material is poorly graded. It is principally in this zone that evaporite salts may be found.

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Figure 2 shows an idealised cross section across one half of a desert basin — the zones would repeat themselves across the other half *or* meet the coast as a beach or as sabkha. The relative sizes of the zones vary depending on the age of the desert, its overall size, drainage arrangements and so on. Often, however, zone IV or sometimes zone III is the biggest within the basin. As a generalisation, the ground water table is nearest the surface in zone IV. Its closeness to the surface is often of particular importance to the engineering situation especially when the ground water table is within capillary moisture movement reach of the ground surface.

Figure 3 shows typical ranges of grain size within each zone and some plasticity characteristics of the clays (sometimes only rock flour) found occasionally in the zones.

ENGINEERING CHARACTERISTICS OF THE ZONES

Generalised summaries of the engineering characteristics are given in Figures 2 and 3.

Zone I — the mountain slopes

Weathering is active with daily and seasonal temperature changes dominating in the rock shattering process. Gravitational effects together with the ephemeral mountain streams are responsible for removing the rock fragments from the immediate vicinity of the mountain to form large rock scree and talus slopes and small alluvial fans. These rock debris slopes within the mountains consist exclusively of material derived from the adjacent mountain slope and grading sizes range from ill-sorted medium angular gravel to that of a large sized house. Such slopes are generally free of stratification but some imbrication of individual particles may be present; slope angles of up to 38° may be developed.

In some areas, free standing single mountain peaks or a cluster of several peaks, are separated from the mountain range and are surrounded by stony desert or a pediment. These peaks each have their own debris slopes of rock fragments around them and are themselves being slowly eroded by the desert processes.

The engineering characteristics of the coarse deposits are consistent with the grading and type and are not essentially different from steep rock debris slopes in

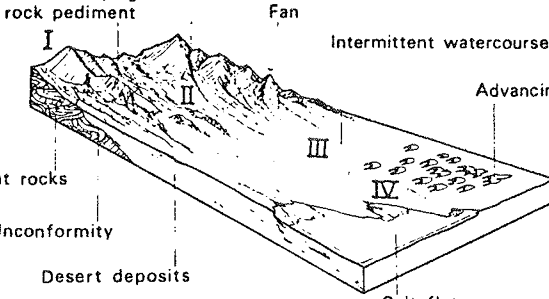
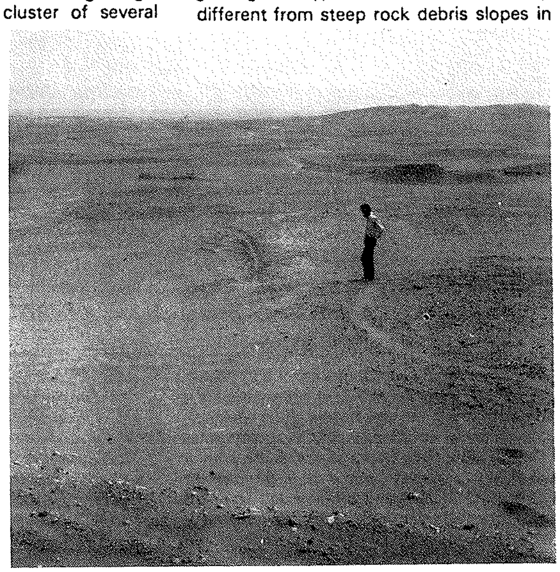
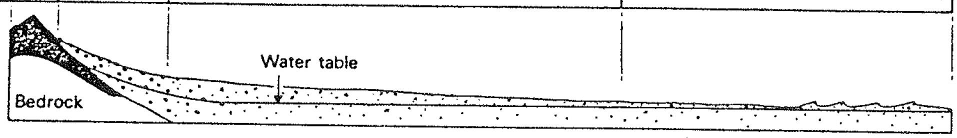


Fig.1 Block diagram of hot desert mountain and plain terrain showing the four engineering zones discussed in the Paper (see also Figure 2)



Windblown sand terrain. Zone IV Near East

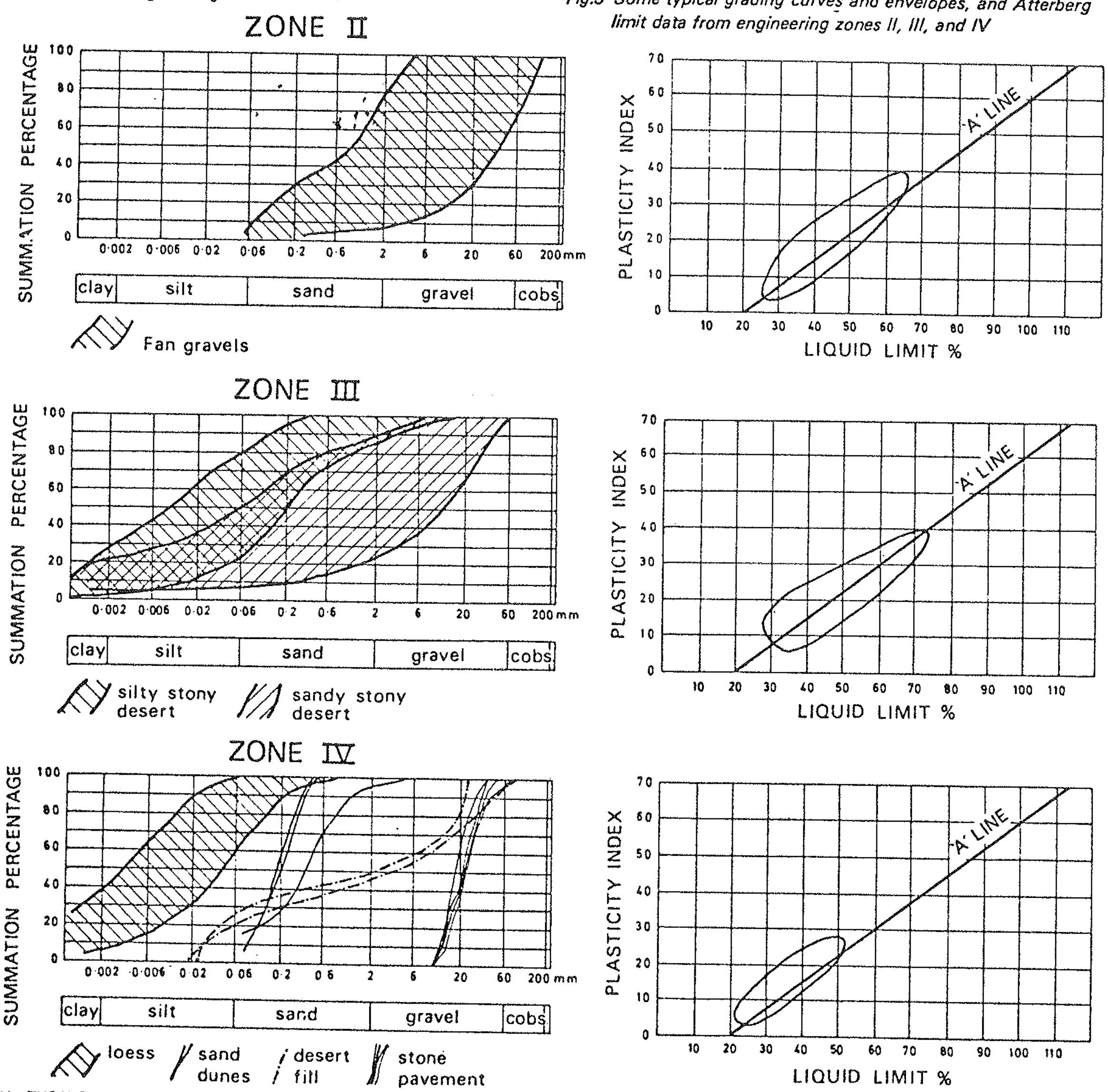
ZONE	I	II	III	IV
PRINCIPAL ENGINEERING SOIL TYPES		Rock fans Boulder gravels	Silty stony desert and sandy stony desert. Some evaporites. (Could thinly cover a rock pediment)	Sand dunes, loess and evaporites.
SLOPE ANGLE OF DESERT SURFACE		2–12°	1/2–2°	0–1/2°
PRINCIPAL TRANSPORTING AGENT OF THE ENVIRONMENT		Gravity and as III Wadis	Intermittent stream flow and sheet floods. Shallow anastomosing channels. Mudflows. Mudfloods.	Wind and evaporation. Sheetflow. Some wadis
GEOTECHNICAL FEATURES		Good for foundation and fill	Generally very good foundation and fill material. Saline. May be pervious in foundations.	Erratic behaviour to load bearing. Migrating dunes. Mestable loess. Saline. Absence of coarse material.



(After Fookes & Knill 1969)

Fig.2 Idealised cross-sections of mountain and plain terrain showing the four engineering zones with brief notes on some of their engineering characteristics

Fig.3 Some typical grading curves and envelopes, and Atterberg limit data from engineering zones II, III, and IV



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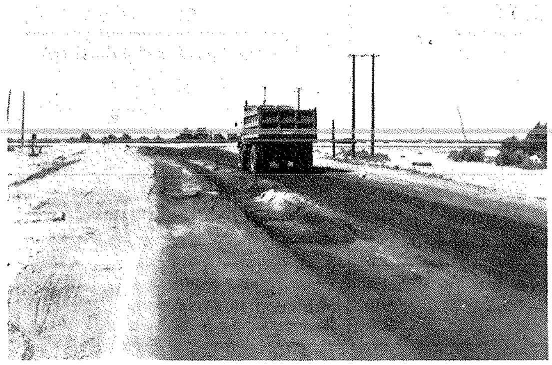
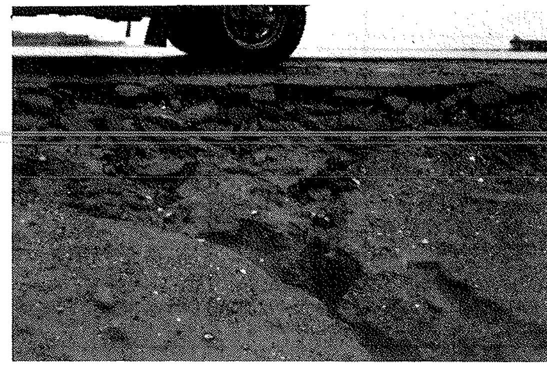


Foundation failure in soft sands. Zone IV. North Arabian Gulf



Breakup of bitumen stabilised road verge by traffic and rainwater erosion. Sand fill embankment. Zone IV. Trucial Coast

temperate climates and therefore do not require any particular discussion. The bedrock is undergoing fairly active physical erosion and thus deep chemical weathering mantels are not generally developed (as in hot wet climates) though case hardening of some rock types may occur. Discussion of this and related processes is left to zone IV.

This zone may well provide rock borrow material either from conventional quarries in the rock or in pits in the rock debris deposits.

Zone II — the apron fan (or "bajada")

Aprons are formed by the interfingering of rock and alluvial fans that extend more or less continuously around all mountains. Their extent depends on the height of the mountain range, and erodability of the rock types, the larger mountains having apron fans extending for several kilometres. Rock pediments can also occur.

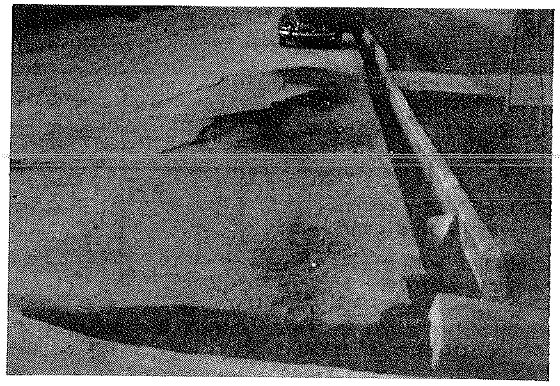
The "soils" are all composed of mixtures of angular to sub-angular clastic debris of sand to gravel grade with associated material that may be as large as cobbles and boulders. Locally clay or silt sized material may be derived directly from fine grained bedrock (e.g. a marl). The coarse deposits have poor to good stratification and in general become finer further away from the mountains, but isolated boulders or groups of boulders in huge trains, may be present. Deposition takes place from intermittent sheet and stream-flow of high velocity occurring during flash floods from storm rains. The accumulation of flood waters in the mountain area may first give rise to a sheet-flood spreading out over the desert floor and as infiltration takes place there is a progressive restriction of the flow to stream beds. The duration of sheet floods is measured in terms of minutes, stream floods in hours and the flow of streams in hours and occasionally days. Snowmelt in high terrains subject to winter snow may give local flood conditions. Mud flows may occur in fine gravels and mud-flow deposits can be common in some areas. The stability of such materials may need to be investigated before construction.

Borrow areas for construction materials of the required grading can usually easily be found in the apron fan. A typical grading curve for zone II material would lie in the envelope for sandy stony desert shown as Figure 3 and a typical set of geotechnical properties from Iran is given in Table 1. Where Atterberg limits are given in this and other Tables and Figures they refer only to material passing the BS 200 sieve, i.e. the silt and clay fraction. For roads, the apron fan deposits generally provide good base and sub-base materials although screening *or* crushing and screening may be required. This material can also be used for coarse aggregates in grave-bitumen and base

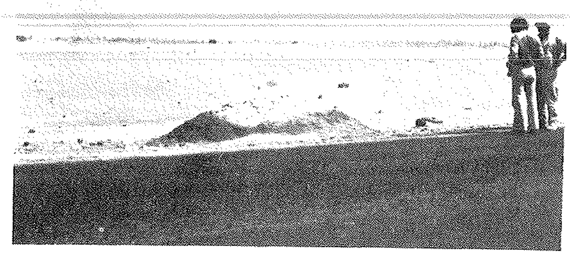
Table 1

Granular soils - Classification test results

Zone	Sample Type	Particle Size (per cent passing)				Atterberg limits			Density/moisture relationship		California bearing ratio(%)		Water Soluble Matter
		20 mm	2 mm	0.06 mm	0.002 mm	Plastic limit	Liquid limit	Plasticity Index	Max. dry Density Mg/m^3	Optimum Moisture Content	Unsoaked	Soaked	
II	Fan	87	38	-	-	-	-	-	2.12	8.4	53.2	38.7	10.8
II	Fan	63	27	-	-	22	27	6	2.24	7.0	46.3	39.3	0.1
III	Sandy desert	93	54	21	8	18	36	18	-	-	-	-	2.25
III	Sandy desert	83	30	-	-	-	-	-	2.11	9.5	59.2	67.10	1.63
III	Silty desert	97	77	31	-	58	112	50	1.60	20.3	15.7	2.8	41.90
III	Silty desert	-	99	76	35	19	39	18	1.75	18.2	21.8	4.8	1.00
III	Silty desert	-	96	63	20	15	29	17	1.94	12.0	24.0	14.0	0.70
IV	Silty desert	-	100	57	15	26	39	23.5	1.93	13.0	29.8	14.4	0.50
IV	Loess	-	-	83	21	26	64	38	1.57	22.80	11.1	6.5	0.50
IV	Loess	-	-	89	18	17	33	6	1.81	11.59	9.8	4.3	0.60
IV	Loess	-	-	90	20	19	36	17	1.57	23.0	5.1	6.7	0.45
IV	Sandy desert	-	96	14	-	-	-	-	1.96	12.00	15.0	16.5	0.65
IV	Dune sand	-	99	83	9	22	39	17	1.74	18.3	3.9	3.2	1.75



Foundation failure after winter floods. Loess silts. Zone IV. Iran



Capillary moisture rise in fresh sand tipped onto sabkha. Zone IV. Bahrain

courses. The *in-situ* material is a sound foundation with a safe bearing pressure usually in excess of 4kg/cm^2.

The permeability of alluvial fan deposits depends on their grading and porosity, and is a function of the size and continuity of the interstitial voids. For practical purposes, deposits are effectively uncemented within depths of engineering interest and the water tends to move along the partings between successive deposits. However, in the locations where mudflow deposits occur there tends to be a restriction of ground-water flow as such deposits have a compact structure with small interstitial openings. Thus mudflow deposits may form aquicludes in contrast to the streamflow deposits, which are relatively good aquifers. Alluvial fans built up by streams and mudflows may result in confined conditions that, together with the original dip of the fan, tends to make such an alluvial fan an ideal site for recovery of artesian water. However, the recharge of these aquifers is limited, and the tubewells successfully developed in these fans could have relatively limited long-term yields, but may be the only source of water for construction use.

Road location in this zone should be done with the flood potential in mind. There are two areas which can help minimise potential flood danger. Either by locating the road at the mouth of the mountain wadi (boundary of zones I and II) supplying the flood water and debris to

TABLE 2

Outline Summary of Runoff and Soil Characteristics of Desert Zones.

Desert Zone	Typical Soils (Casagrande symbol)	Runoff Hazard	Notes on Road Design.
I	Scarce GP GU GW	Stormflow down hillsides and in mountain canyons. High runoff coefficients say >0.55	Conventional road design for mountain areas. Do not under estimate potential flood conditions because of the 'arid' nature of the terrain. Generally good subgrade conditions.
II	Boulder gravels GP GU GW	Storm wadi flow, possibly some sheetflow. Low to moderate runoff coefficients, say 0.3 to 0.55	Volume of dumped water-transported debris during storm flow may be large. For roads parallel to stream flows, low embankments with strengthened stream crossing areas may suffice. For roads transverse to stream flow, high embankments, numerous wide culverts and bridges. Scour protection for abutments by gabions or similar. Generally good subgrade conditions.
III	GF SW SP	Storm sheetflow and deep wadi flow. Low to moderate runoff coefficients, say 0.2 to 0.5	Scour may be a major hazard. For roads parallel to streamflow, low embankments with strengthened stream crossing areas. For roads transverse to stream flow moderate embankments, numerous wide culverts and bridges, and training bunds, and scour protection. Upstream sides of embankment may require armouring or the whole construction by rockfill. Generally poor to moderately good subgrade conditions.
IV	SU SF ML	Storm sheetflow and shallow wadi flow. Moderate to high runoff coefficients - ground may quickly get saturated (especially ground with high water table), say 0.25 to 0.7	Scour may be a hazard. Generally low embankments, armoured in potential stream flow areas. Training bunds and many small culverts may be necessary in some areas. Generally poor to moderate subgrade conditions especially where groundwater table is high.

Above: *Salt blisters. Jet efflux layer to a runway. Sabkha, Zone IV. Arabian Gulf*

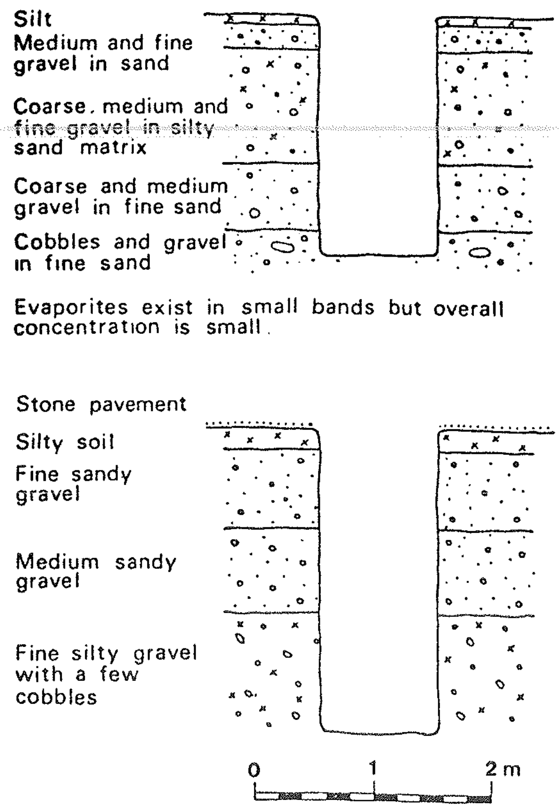


Fig.4 Typical explanatory pit logs from Zone III, Iran

the apron fan *or* by running the road at the lower end of the fan (at the boundary between zones II and III) far away from the mountain slopes. Air photographs are usually valuable in helping interpret the terrain and for locating an alignment. Assessing quantities of water during time of flood is a difficult and little researched art as yet and caution should be exercised in design. Run-off coefficients are quite variable and may typically be quite high ranging from say 0.2-0.8. The analysis of floods in deserts is fairly-fully discussed by Cooke & Warren (1973) in relation to geographical studies. If possible an alignment, away from zone II is probably the best solution with the road raised on embankment when it has to cross stream beds in zone III with wide culverts located opposite visible shallow channel mouths

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coming off the zone II fans. Training bunds of gravel with rock protection or gabions may be needed if strongly erosive conditions are expected (these conditions can be "read" off the ground by the presence of erratic boulders and deep cuts in otherwise generally shallow channels). The embankment itself may also require rock protection or even be locally made of rockfill. Upstream ditching may need to be considered but well away from the embankment so that it cannot be undercut by erosion of the ditch sides. Culvert walls and bridge piers may have to be protected from scour. Table 2 gives in outline a summary of observations and comments on surface water flows in this and the other zones which may help in road design. It is emphasised, because of the general lack of records and understanding of desert catchment characteristics, that careful observations be made of the local ground conditions. The run-off co-efficients in the Table are a guide only.

Zone III – the alluvial plain

This zone is generally quite widespread and may, in places, extend completely across the intermontane plateau to zone II on the opposite side. The soils of this zone are dominantly of silt, sand and gravel grading. Such soils may contain varying but generally small amounts of clay and/or evaporite minerals. In addition, the zone may contain local areas of stationary or mobile sand dunes and loess but discussion of these windblown soils and of evaporite salts is left to zone IV where they are more common.

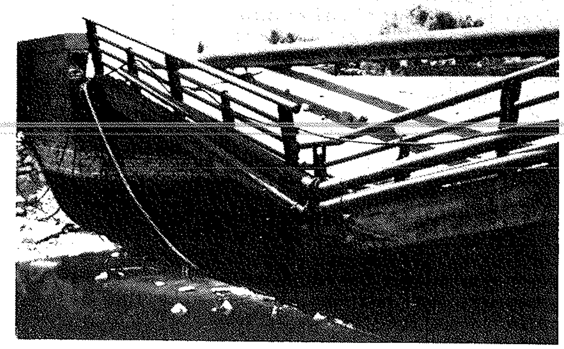
Slopes in zone III are a maximum of say 2° at the margin decreasing to ½-1° towards zone IV. Watercourses are shallow, typically less than 0.5m deep and several tens of metres in width; the drainage channels extend in a distributory fashion towards the central areas where they become topographically indistinct. Transport of sediments is principally by sheet-flow but some stream-flow occurs where shallow channels exist. Flow reaches zone III only at times of heavy cloudbursts. Occasional remnants of Quaternary terraces and lake deposits may be present and these conditions are relics of periods when the water level was at higher elevations.

As a gross simplification engineering soils can be sub-divided into two main types; "silty stony desert" and "sandy stony desert". Grading envelopes produced from several hundred grading curves are given in Figure 3; in addition some typical geotechnical properties are given in Table 1. The percentage of soluble matter reflects the varying amounts of salts present near the desert surface, the other properties being consistent with the grading of the material. In general, the fragments are angular to subangular with minor proportions of more rounded shape; ventifacts (wind shaped stones) are common. Over long distances, the two soil types may be observed to be sheet-like and interdigitate with each other. In addition, minor lenses or sheets of either the more silty or more gravelly material may interfinger throughout the main soil type. If the lenses are uniform silt or silty sand grade, or are uncemented openwork gravel, then engineering problems can arise below the water table. The silty and sandy stony desert soils, however, in general are quite satisfactory for road construction and provide good foundations because the water table is too deep to influence most engineering operations. In areas where lines of qanats cross the road a specific investigation should be carried out as collapse of a near surface tunnel could cause settlement of the road or structures.

Results of laboratory CBR tests indicate that, for typical desert soils, a minimum thickness of about 15cm of sub-base material would be generally sufficient to provide the necessary bearing capacity for a road pavement. Usually soils are of low plasticity, with acceptable shrinkage and compaction characteristics. Exploratory pits may stand with vertical walls for many months or even years until infilled with blown sand or channel wash material. Figure 4 shows logs of typical exploratory pits from Iran and indicates the distribution and thickness of material types, which are the usual products of sheet-flood and stream-flood environments. Every possible gradation between these types of deposit can occur. The deposits of sheet floods and less violent stream-floods tend to have a high percentage of silt-sized particles and, therefore, in general form the silty stony desert. Whereas deposits of stream floods tend to have a high percentage of sand-sized particles and, therefore, in general form sandy stony desert.

Evaporite salts may occur and could be fairly evenly dispersed (in any one area) throughout the soil profile, with a

Salt weathering on stone pitching to bridge abutment. Salina, Zone IV. Trucial Coast



Collapse of road bridge due to sulphate attack on mass concrete centre pier. Near East

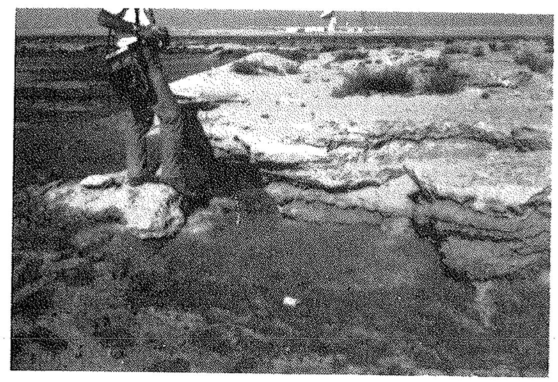
tendency to be concentrated a few centimetres below the surface, where for example layers of fibrous gypsum can accumulate.

Zone IV – the base plain

Perhaps generally the most widespread of all the zones and also probably the one with the most engineering problems. The zone tends to be irregular in shape and its margins may be constantly changing. Inland it occupies the central areas of the piedmont plain and centrally draining basins and is surfaced by the finest materials, clays, silts and sands, winnowed out by the transporting agencies, principally the wind. It often margins coastal areas where marine agencies help sort the wind blown materials and may additionally provide marine clays, silts and sands. Salty coastal areas are sabkhas.

Average ground slope is from 0° to ½°, but locally, as little hills of bedrock or small cemented cliffs or sanddunes, slopes of limited extent may be much steeper.

Although windblown material tends to predominate and great quantities of dust (silt) and sand are moved during periods of high wind, water plays an important part. Flash floods are relatively rare and any meandering stream actually reaching zone IV is usually short-lived after the downpour, but the standing water table, which may be quite near ground surface can dominate the desert processes, as this zone usually represents the local base level down to which wind erosion can take place. Wind erosion more or less stops when sand and silts are damp; capillary moisture movement from the water table to ground surface readily occurs if the water table is high and if continual evaporation takes place. In these conditions a thick salt crust can build up from continual precipitation of salts dissolved in the groundwater even if they are in very weak dilutions. Crystals of these salts are also blown by the wind and can contaminate dunes and other parts of the desert surface. Capillary moisture movement depends on many factors but it can be up to 3m above the water table in fine soils.

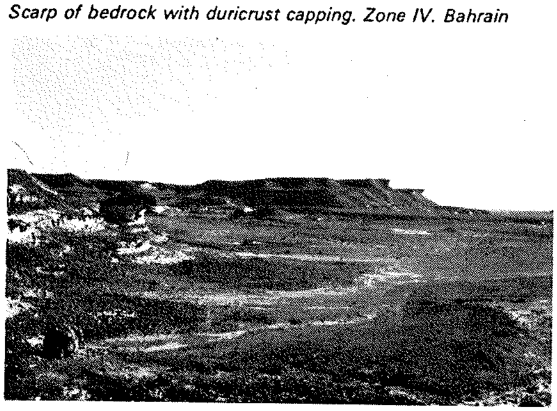


Duricrust being eroded. Sabkha. Zone IV. Bahrain

Moisture and chemical movements over long periods of time give rise to numerous forms of case hardening of rock surfaces and the development of various forms of "duricrust". The latter is often, but not always, a precipitation of calcium carbonate (chalk or "limestone") as calcrete. Duricrusts have a large variety of local names (Goudie 1973). Moisture movement in clays and clayey silts can cause considerable swelling or shrinkage (e.g. gilgai topography). Effects due to different moisture conditions on desert surfaces create easily identifiable patterns readily interpretable from walkover surveys or air photographs (e.g. Neale 1973).

For ease of description it is best to discuss separately, from a road engineering viewpoint, the more common and important desert features. In practice combinations of features often occur.

Scarp of bedrock with duricrust capping. Zone IV. Bahrain



Clayey pumped fill in newly reclaimed land showing drying cracks. Granular dozed fill in background. Arabian Gulf

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Clayey Soils. These soils are usually formed by deposition of clay minerals *or* even very fine particles of rock *or* chalky precipitates, in water. Near coasts they may be former shallow sea deposits, now forming land (as in parts of the Arabian Gulf); inland they may be from temporary lakes (playas) or rivers. They are often contaminated with silts, sands and salts. Perhaps most commonly they are calcareous.

They can frequently be classed in the CI to CH range on the Casagrande classification. When dry they usually have high shear strengths but this drops to low values when wet and they may have marked swelling and shrinkage characteristics on wetting and drying, which can give pavement difficulties unless they are kept at a reasonably constant moisture content. Tomlinson (1957) gives a good discussion of their performance in airfield construction. Table 3.

Table 3

Cohesive soils - Classification Test Results

Location of Sample	Atterberg Limits: Liquid Limit %	Plastic Limit %	Plasticity Index	Shrinkage Limit %	B.S. Compaction Tests: Max. dry Density Mg/m³	Optimum Moisture Content %	Modified AAHSO Density test: Max. dry Density Mg/m³	Optimum Moisture Content %	Casagrande Classification.
Baghdad Civil Airport, Iraq *	51	25	26	-	1.61	22	1.81	17	CH
Amara-Basra Road, Iraq *	44	21	23	-	1.62	23	-	-	CI
Braim, Abadan Island, SW. Iran**	59	24	35	-	1.63	21	1.83	16	CH

* Tomlinson (1957)

** Road Research Laboratory Note No. RN/942/FR.

Silty Soils. Windblown silts, the loesses, sometimes occur in deserts and if they have not been redeposited by water may be metastable, that is in this context they can quickly collapse on wetting (especially if under load) but in the dry state can have good strength and bearing characteristics. Loess plains may have underground drainage channels which may not be easily visible from the ground surface, and loess can readily pipe by internal erosion from percolating groundwater. A general solution to geotechnical problems provided by metastable loess is to consolidate by flooding and rolling prior to construction or to admix with coarser material to make more suitable

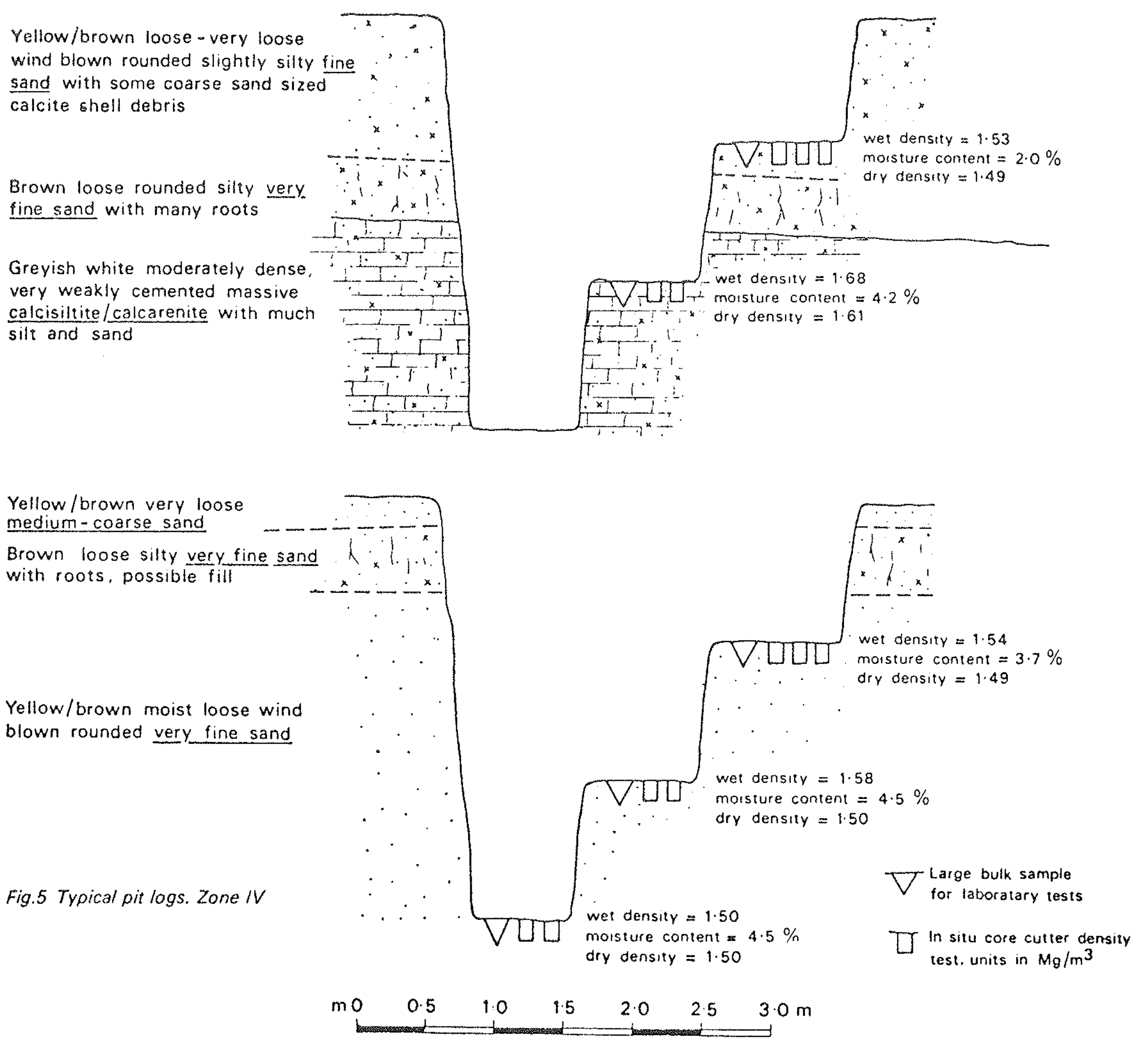


Fig.5 Typical pit logs. Zone IV

grading, especially if it is to be used as embankment. For geotechnical discussion on loess see Holtz and Gibbs (1951) and on desert loess in Iran see Fookes and Best (1969).

Sandy Soils. Most sands in deserts are the direct or indirect result of wind transport even if they are no longer in the form of dunes. They are perhaps the most extensive of all the soil types. They have typically a single sized grading curve (Figure 3) and this characteristic often makes them difficult to drive a light vehicle over and gives difficulties during compaction. They occur frequently in a loose state with low *in-situ* densities due to the poor packing of the uniformly graded materials deposited in a subaerial environment. They therefore also have a low allowable bearing capacity because of the potentially large settlement due to their low density and also if weak cementation is present the possible collapse of the material under load. Therefore, density characteristics in the sub-grade and under structures is important, especially in depth. Figure 5 is of test pits in typical zone IV sands from Libya and illustrates some of the common characteristics. The sands are uniformly graded in the fine sand range with silt contents from 0-10 per cent by weight and medium sand 0-15 per cent. Uniformity coefficients of these sands ranged from 1.25 per cent to 1.88 per cent indicating their uniform grade. Their effective size (size of the smallest 10 per cent in millimetres) was from 0.08-0.10mm, again giving only a small range. Comparative wet and dry sieving of the *loose* sands showed only small differences indicating little cementation was available from breakdown by the wet sieving. Lightly cemented sands and silts can also be present as indicated on Figure 5. Heavy Proctor tests gave a big range of maximum dry densities from 1.65 to 1.95 mg/m³ at moisture contents ranging from 7.5 to 11 per cent. Unsoaked CBR values not surprisingly were also widely ranging from 3-30 per cent but with most results in the 7-20 per cent range. Soaked CBR's gave consistently low values and were always less than 10 per cent with most in the range 2-4 per cent. Table 4 gives a selection of results.

The moderately dense fine sands which may be lightly cemented can show differential settlements under load and even metastable settlements similar to the

TABLE 4

Desert Zone IV Sands - Classification Test Results

Brief Description	Depth m.	Optimum moisture content	Maximum Dry Density Mg/m³	CBR% Unsoaked		CBR Soaked		Total water Soluble Salts %	pH value
				Top	Bottom	Top	Bottom		
Fine sand	0.1	9.5	1.720	12	15	5	8	0.05	9.2
Fine sand	0.1	9.0	1.682	11	13	2	2	0.03	8.5
Slightly silty fine sand	1.0	9.5	1.979	8	11	2	2	0.04	8.7
Slightly cemented silty sand with nodules of calcrete	1.9	6.7	2.076	29	37	9	21	0.04	8.5
Calcarenite*	2.0	9.5	2.013	74	87	24	39	0.05	8.7

* For terminology see Fookes, P.G. & Higginbottom I., 1975. 'The classification and description of near-shore carbonate sediments for engineering purposes'. Geotechnique. Vol. 25 No. 2. pp. 406-411.

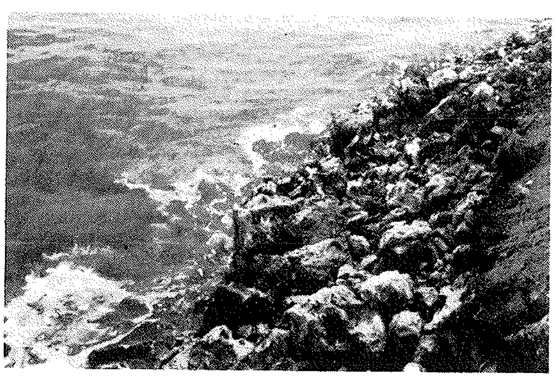
loesses. *In-situ* dry densities of these sands ranged from 1.45 to 1.65 mg/m³ Shear box tests on disturbed samples gave an angle of internal friction of 31° for a maximum density of 1.62 mg/m³ and 26° for the loosest state of 1.2 mg/m³ Oedometer tests carried out on undisturbed samples at natural moisture contents gave coefficients of volume compressibility (m_v) in the range 0.006 to 0.014cm²/kg at a loading of 1 kg/cm². Settlements at this loading were in the range 0.4 to 1.5 per cent but at 2 kg/cm² overall settlement during testing increased between 1.2 to 2.2 per cent. Wetting of the samples at this load caused approximately another 2 per cent metastable settlement. Metastable settlement was observed even on loadings less than 0.75 kg/cm².

Dry sands may compact reasonably well with vibrating equipment but careful field trials to get optimum conditions will be necessary. When the sands are used as fill even slight adjustments to the grading curve of true windblown sand, as the adding of silt or gravel, can give significant improvement to the compaction performance of the material. Laying and rolling in thin controlled lifts helps produce stable fills, and sand fill embankments can be constructed with the shoulder zones of a more stable material. Again field and laboratory trials are strongly recommended. For structures on low bearing capacity sands piling may be necessary and recently vibro flotation and dynamic compaction techniques are reported to have been used with success. Small plate bearing tests can be a valuable guide to settlement characteristics in certain situations.

Active Windblown Sands. Problems due to wind erosion of embankments and the migration of dunes and sand drifts can be common. Sand is generally moved by saltation and to a lesser extent by suspension, creep and gravity. The study of sand movements, dune patterns and so on is too big a subject to compress adequately here but Cooke and Warren (1973) give a most readable and comprehensive account. Dune movements can be largely predictable and therefore avoidance of mobile dune fields (viz. families of barchans or sief dunes which may move say, one metre a month downwind) by choice of alignment, if possible, may be the best solution. Reconnaissance investigations including study of satellite imagery and conventional air photo interpretation are therefore most useful to delineate sand source areas, mobile and dead dune complexes, rates and directions of advance. If crossing small dunes is unavoidable, they can be successfully immobilized by a variety of ways depending on circumstances. Table 5 modified after Kerr and Nigra (1952) summarises some possibilities.

A level road will receive a layer of sand over the leeward side during normal wind conditions. The layer will be thin and will probably not impede vehicles even if they are equipped with high pressure tyres. When wind of the opposite direction occurs, the thin layer of sand will shift to the other side of the road. A crown to the road will aggravate the down-wind side accumulations and for this reason the crown should be kept to a minimum.

Leaching of fines from desert fill by wave action on a recently placed causeway, Arabian Gulf



Loss of fines from end tipped desert fill reclaimed land by wave action, Arabian Gulf

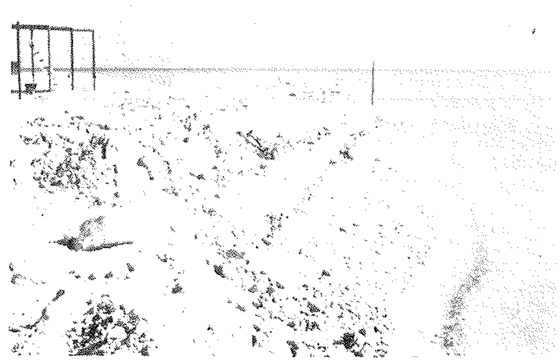


Table 5 - Objectives and Methods of Dune and Drift Sand Control

	OBJECTIVES
1.	The destruction or stabilisation of wind blown sand accumulations in order to prevent further migration and enroachment.
2.	The diversion of wind blown sand around works requiring protection.
3.	Stopping sand movement in front of the works to be protected
4.	Aiding sand movement in order to avoid desposition over a specific location, especially by surface smoothing and obstacle removal

	METHODS
	The above objectives are achieved by the use of one or more types of surface modification. Potentially more attractive methods first.
1.	Align route upwind of sand source to avoid major dune fields.
2.	Oiling involves the covering of wind blown materials with a suitable oil product (e.g. high gravity penetrating oil) which stabilises the treated surface and may destroy dune forms. Often a quick, cheap and effective method.
3.	Fencing the use of relatively porous barriers to stop or divert sand movement or destroy or stabilise dunes. Cheap, portable and expendable structures are suitable (using, for example. palm fronds, chicken wire or snow fencing).
4.	Planting of appropriate vegetation designed to stop or reduce sand movement, bind surface sand and provide surface protection. Early stages of control may require planting or sand stilling plants (e.g. Ammophila arenaria (beach grass), protection of surface (e.g. by mulching), seeding, and systematic creation of surface organic matter. Planting is permanent and attractive, but expensive to install and maintain.
5.	Paving is designed to increase the saltation coefficient of wind transported material by smoothing or hard-surface a relatively level area, thus promoting sand migration and preventing its accumulating at undesirable sites. Often used downwind of fencing where wind is unladen of sediment, and paving prevents its re-charge. Paving may be with concrete, asphalt or wind-stable aggregates (e.g. crushed rock or gravel).
6.	Panelling by erection of solid barriers to the windward areas to be protected, designed either to stop or to deflect sand movement (depending largely on the angle of the barrier to wind direction). In general, this method is unsatisfactory and expensive, although it may be suitable for short-term emergency action.
7.	Trenching cutting of transverse longitudinal trenches across dunes destroys their symmetry and may lead to dune destruction. Excavation of pits on the lee of sand moulds or on the windward side of the works to be protected will provide temporary loci accumulation.
8.	Removal of material - rarely successful and not normally long term.

Ideally for dune areas flat roads are to be preferred but the embankment should be gently rounded at the shoulder break point.

Unbanked, single-line roads on elevated grades are generally self-cleaning and do not usually present a serious problem by drifting sand. They are, however, vulnerable to migrating dune masses. Banked horizontal curves are troublesome and vulnerable to drifting sand, if the wind first impinges on the high side of the bank. The high windward side will remain exposed but the lower leeward side will receive a deposit of sand, the depth of which depends on the amount of super-elevation of the windward side. Curves should, therefore, have as long a radius as possible and banking should be held to a minimum.

Cuts can be serious problems and probably the best remedy is to build impounding fences up-wind from the cut, stabilise the sand between the cut and the fence (Table 5) and then increase the height of the fence whenever it loses its trapping efficiency.

It is important to remove all obstructions up-wind from the road. Any obstruction will cause a drift stream to develop downwind. It is not uncommon for these drifts to be 20 times the height of the obstruction. A large bush a metre high may send out a streamer 35 metres long. A hummock of earth or a rock a few centimetres high at the edge of the road can send a drift across the entire road. The up-wind side of the road should therefore be cleaned off and smoothed with a drag for a width of at least 20 metres or even wider if large bushes or hummocks are present.

Oil stabilisation adjacent to the road is not necessary unless it is desired to prevent scouring of the up-wind side of the embankment. Scouring of the up-wind side of the embankment can be completely prevented by an application of a high gravity penetrating oil. Crushed rock, or gravel of medium to coarse grading, marl, or a liberal application of heavy asphaltic oil will also serve, though they are more expensive than the penetrating oil treatment.

Migrating dunes that are approaching the road are another serious hazard. Destruction or immobilisation of the dunes can be accomplished if it is carried out while the dune is over 20 times its height away from the road. If the dune is allowed to approach closer than this distance, it will probably have to be immobilised by oil stabilisation and then restricted against further growth by building an impounding fence up-wind from it. This would cut off new supplies of sand that would otherwise cause it to become elongated down-wind.

To prevent erosion of embankments built with dune sand choose low slope angles (1:4) and protect the slope with a stabilising material.

During construction vehicles should be discouraged from running wild over the existing desert surface upwind of the road as it could destroy any existing natural thin crust or sparse binding vegetation which in turn could lead to sand near the road being mobilised by the wind.

Salty Soils. Salts from local bedrocks go into solution in the groundwater and these salts and salts in seawater in near coast locations can then be precipitated by evaporation in any drying situation above the water table. Of the many different salts perhaps the commonest aggressive ones are calcium sulphate, magnesium sulphate, sodium sulphate and sodium chloride and these can be found in amounts varying from a trace to virtually 100 per cent, in most of the world's deserts. Therefore it is always advisable to test for salts in soils and in groundwaters — not by single samples but by a profile of samples taken down an exploratory pit face and then repeated for other pits as the terrain changes.

Certain natural conditions produce exceptionally high salt concentrations in zone IV (and sometimes zone III). Local names for these conditions are many and bewildering; at the risk of gross over-simplification these have been reduced to **playa, salt playa** and **salina** in Figure 6 and Table 6 to show the relation of these conditions to the water table. To these must be added the **sabkha**, the coastal approximation to the salina.

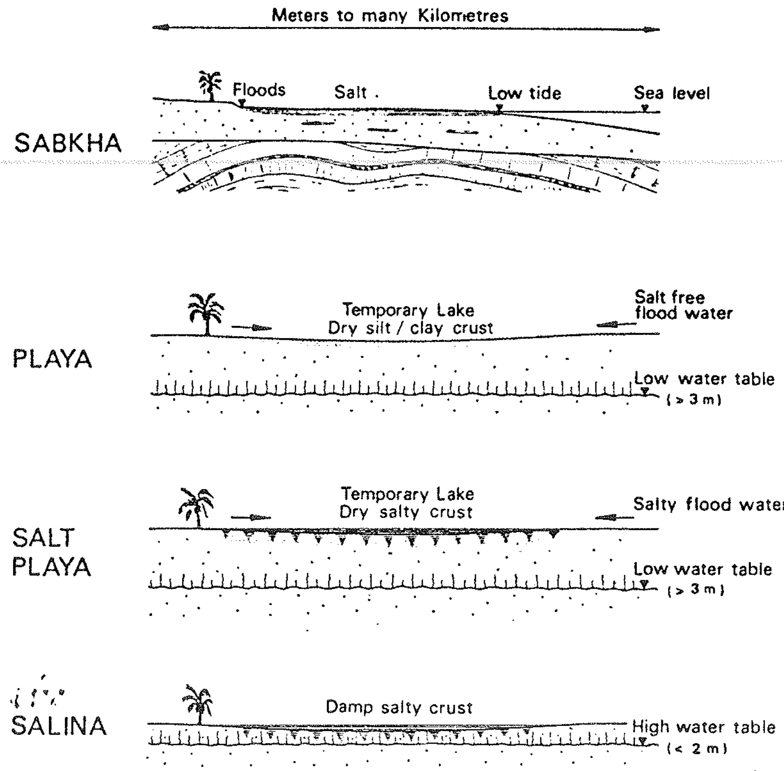
Salts, especially the sulphates, can physically disintegrate rocks (and aggregates, blacktop and concrete), especially those with high porosities, by a variety of methods. This attack occurs commonly and is a natural form of weathering which occurs little in Britain (except for coastal cliffs) and is the result of salts crystallising out in the pores of the rock (or concrete etc.). Expansive forces are quickly set up by the growth of crystals *or* by differential volume changes in the crystals due to day/night temperature fluctuations *or* by hydration/dehydration cycles with climatic moisture changes. Therefore, depending on circumstances, rock fill, coarsely granular bases and sub-bases and even porous bitumen road surfaces can be severely disintegrated by salt movements within them and distress and failure can result. It is important to note that inert unbound rocks and finely granular materials do not suffer as in a sense they are already disintegrated. In many circumstances salt may act as a satisfactory binder in low cost unsurfaced roads (e.g. Fumet (1960), Fenzy (1966), Ellis & Russell (1973)).

Potentially dangerous conditions for surfaced roads are therefore in salina and sabkha terrains, i.e. high water tables and high salt contents, especially where the local aggregates are friable and porous (e.g. some sandstones, some limestones, chalks, weathered igneous rocks). Engineering solutions to these conditions are by the avoidance of those areas by route alignment, raising the road on fine fill embankments of low permeability (i.e. for a low capillary rise), use of inert aggregates for the base (i.e. stone of low percentage loss to the ASTM weathering test C-88, high SG, low porosity) and with a dense, thick asphalt or bituminous wearing course. In critical situations use of an impermeable membrane to act as a positive cut off at, say, the top of the formation, can be considered to reduce moisture movement *or* use of a bitumen/ sand mix as a low permeability carpet *or* by bituminous soil stabilisation. In thin constructions, for example jet efflux areas round runways, or pedestrian pavements, surfaces can heave up by salt blisters forming under the blacktop which quite quickly (within months) can rupture and disintegrate. Salty soils (salina or sabkha material) as fill for surfaced roads should therefore only be used after careful laboratory and field examination and preferably after long term trials. Acid soils and salt concentrations of greater than 0.05 per cent sulphates and 0.5 per cent chlorides are reported to be harmful. For discussion see Weinert and Clause (1967) and Weinert (1964).

Concrete is also attacked by physical salt weathering mechanisms as well as by classical "sulphate" chemical attack. Therefore serious consideration must be given to protection of concrete structures in salty areas. For discussion of concreting in desert areas see Fookes and Collis (1975(a)&(b)) and (1976).

Land reclaimed by fill of sandy material may quickly turn into a salina, i.e. develop a salty crust, if it has a high water table. The new land will, therefore, suffer from the same disadvantages as natural salinas. For further discussion see Fookes and Collis (1976). Duricrusts. A general term for a variety of surface materials which for engineering purposes can be simplified to two principal forms.

Crusts, a weak layer up to tens of centimetres thick overlying a desert soil, e.g. a gypcrust is formed of gypsum crystals and cretes, a natural concrete, a hardening of rock surfaces, can be hundreds of centimetres thick, e.g. calcrete is formed by precipitation of



(After Fookes & Collis 1975a)

Fig.6 Idealised cross-sections of sabkha, playa, salt playa and salina terrain. Zone IV. (see also Table 6)

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Table 6 - Some specific salty soil types in zone IV and their engineering significance.

Name	Terrain	Ground water table	Salts	Special significance	Construction technique
SABKHA	Coastal flat, inundated by sea water either tidally or during exceptional floods.	Very near the surface	Thick surface salt crusts from evaporating sea brines. Salts usually include carbonates, sulphates, chlorides and others.	Generally aggressive to all types of foundations by salt weathering of stone and concrete and/or sulphate attack on cement bound materials. Evaluate bearing capability.	Carefully investigate. Consider tanking concrete foundations; using SR cement. For surfaced roads consider using inert aggregate, capillary break layer or positive cut-off below sub-bases. Use as fill suspect. May not be deleterious to unsurfaced roads.
PLAYA	Inland, shallow, centrally draining basin - of any size.	Too deep for the capillary moisture zone to reach the ground surface but area will be a temporary lake during floods.	None if temporary lake is of salt free water.	Non-special. Ground surface may be silt/ clay or covered by windblown sands. Evaluate bearing capability.	Non-special.
SALT PLAYA	As Playa but often smaller than a playa.	As Above but lake of salty water	Surface salt deposits from evaporating temporary salty lake water. Salts usually include chlorides and sometimes nitrates, sulphates and carbonates.	Can be slightly to moderately aggresive to all types of foundations by salt weathering and sulphate attack. More severe near water table.	As Sabkha.
SALINA	As Playa	Near surface; capillary moisture zone from salty groundwater can reach the surface.	Surface crusts from evaporating salty groundwater. Salts include carbonates and many others.	Can be slightly to exceptionally aggressive to all types of foundations by salt weathering and sulphate attack.	As Sabkha.

(After Fookes & Collis 1975(a))

calcium carbonate; silicrete from precipitation of silica, ferrocrete of iron and so on. These duricrusts are quite common in zone IV and in wadis and on rock outcrops in other zones. There are many variations on this general theme and each situation requires its own investigation. However, a few generalisations can be made for highway engineering purposes.

Friable, soft or damp crusts may indicate the presence of a fairly high water table, they may be made of salts particularly aggressive to rocks and concrete. Their use as fill, and their bearing characteristics are quite variable depending on the local circumstances and, therefore, they should always be investigated. Some crusts are advantageous both as fill and in bearing capacity. Some are the opposite. Many are salty.

Cretes are much harder and often make good borrow materials for aggregate but, and this is especially true for concrete aggregates, they must be carefully evaluated first from both a mechanical and chemical standpoint. Underneath its case-hardened surface the rock tends to be more porous and friable and therefore a simple visual examination of the surface is often quite misleading and is not adequate to make judgements on whether to open as a quarry, rip out a cutting or use as a load bearing strata. A drilling investigation is required.

Some hard duricrust surfaces are dissected or nodular in character and intermixed with the hard material are sands and silts deposited from wind or from rare rainwater flows. Winning this surface can present an attractive proposition as it is often easily rippable. The as-loaded material is thus a mix of silt/sand and ripped nodular rock, which can be quite gap graded (see 'desert fill' grading Figure 3). Care, therefore, has to be taken, when placing this mixed material as fill, to ensure good compaction. If it is used for causeway construction especial care has to be taken over its grading otherwise the fines are removed by water action and differential settlement can then occur. This can be overcome by adjusting the poor grading of the material *or* protecting the as-placed poorly graded material with suitably designed side filters. Rockfill construction, if suitable rock is available, is an attractive alternative.

ENVOIE

In order to get the relative proportions of the various desert surfaces in perspective, Table 7 gives a comparison of desert surface types in the world's major deserts. It has been modified from Clements *et. al.* (1957) to suit the terminology used in this Paper. The extensive dune areas of the near and Middle East are worth drawing attention to — these are the really arid areas where wind transport dominates. In slightly wetter areas as south-western United States, Iraq and Iran, sand dune areas are less and alluvial fans greater in extent.

Table 7 - Comparison of Desert Surface Types by Plan Area

Geographical Zone	Likely occurrence commonest in engineering zone.	Sahara	Libyan Desert	Arabia	South Western U.S.
Desert mountains	I	43%	39%	47%	38.1%
Volcanic cones and fields	I	3	1	2	0.2
Badlands and subdued badlands	I/II	2	8	1	2.6
Wadis	I/II/III	1	1	1	3.6
Fans	II	1	1	4	31.4.
Bedrock pavements	II/III	10	6	1	0.7.
Regions bordering throughflowing rivers	II/III/IV	1	3	1	1.2
Desert flats	III/IV	10	18	16	20.5
Playas and salinas	IV	1	1	1	1.1
Sand dunes	IV	28	22	26	0.6
		100.0	100.0	100.0	100.0

ACKNOWLEDGEMENTS.

The author gratefully acknowledges help given in the preparation of this Paper, in the field with Mr K. Cross over many years, and in discussions with Messrs. J.M.H. Kelly and E.B. Kelbie, all of Rendel, Palmer & Tritton, Consulting Engineers, London and Dr. D. Brunsden of Kings College, London University.

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OBSERVATIONS ON THE CAUSES OF BRIDGE DAMAGE IN PENNSYLVANIA AND NEW YORK DUE TO HURRICANE AGNES

Charles L. O'Donnell, Office of Engineering and Traffic Operations, Federal Highway Administration

This paper evaluates the performance of bridges subjected to a major flood, determines the adequacy of design standards based on bridge performance, and recommends revisions to design standards where inadequacies are apparent. Hurricane Agnes caused severe flooding in Pennsylvania and New York, and several bridges and highways that were damaged by the floods in those states are discussed. The two major causes of bridge damage were scour at abutments and piers and impacting debris.

•HURRICANE AGNES spawned the floods of June 1972, which have been called the greatest natural disaster in the history of the United States. Its impact on certain areas of the Northeast may require several years to eradicate. Although many of the bridges in Pennsylvania and New York were damaged extensively or destroyed, most survived and soon were reopened to traffic after undergoing necessary repairs and maintenance.

A few structures were less fortunate, particularly those struck by large amounts of current-driven debris and others that were subjected to extensive scour behind and beneath their abutments and at their piers. The bridge damage, however, seems remarkably slight in relation to the total number of bridges involved and the unprecedented flows. In those situations involving large streams in northeastern Pennsylvania and the southern tier area of New York, flows exceeded the largest previously experienced floods by a wide margin. For example, the June 1972 flood discharge of the Susquehanna River at Wilkes Barre, Pennsylvania, was approximately 1.5 times the magnitude of previous historic floods, which occurred in March 1865 and March 1936. Although the flood frequency of the Susquehanna's peak discharge during this record-breaking flood has not been definitely established, all of the experts seem to agree that the recurrence interval is substantially greater than 100 years. In New York, the recurrence intervals of the flooding also are much greater than 100 years at many sites. 241

Although the June 1972 flood was a maximum of record, many bridges survived the flood with little if any damage. These bridges were of particular interest because they obviously have features that enabled the structures to survive a severe test. The outstanding performance of these structures is a positive indication of features that constitute desirable design standards. The case history approach is used to discuss a few of the most revealing situations that were encountered as they relate to the causes of bridge damage.

DEBRIS

The most obvious cause of damage was waterborne debris that struck the bridges and collected on the superstructures and piers, as shown in Figure 1. Even in the absence of structural damage, debris removal alone was costly. At one location involving a major structure more than 1,400 ft long on the Susquehanna River in Pennsylvania, personnel of the Pennsylvania Department of Transportation and the Federal Highway Administration estimated that the cost of debris removal from the bridge deck, piers, and superstructure would approach $80,000.

Inspection of several steel bridge spans that had been carried away by the floodwaters indicated that the force of the impacting debris, in addition to, or in combination with, the pressure of the flowing water on the lodged debris, was largely responsible for this type of damage. In several instances, large portions of the piers were ripped away when the spans were dislodged from their supports. Stone piers or combination stone and concrete piers supporting multispan structures seemed to be particularly vulnerable. Considerable cracking of the pier caps also was noted, as the example shown in Figure 2 indicates.

Simply supported spans seemed to be most vulnerable to the dynamic forces produced by floodwaters and impacting debris. Bearing devices at the piers apparently did not resist the lateral forces that developed. In contrast, multispan stone and concrete arch bridges (Fig. 3) seemed to withstand these forces best, probably because of the continuity at the piers afforded by this type of construction.

In some cases it appeared that debris completely blocked the bridge openings and caused the already swollen river to increase further and inundate upstream areas. As the floodwaters progressively increased in depth, they eventually were able to overtop the bridge or its approaches. This resulted in many highway washouts and large amounts of damage to highway pavement that might not have occurred if the full capacity of the bridge opening and the river channels had been used. Adequate provision for highway-embankment overflow prevented the destruction of many bridges.

In several instances, overflow sections provided an effective means of reducing the high potential for debris damage at structures where heavy deposits of drift accumulated, clogged the bridge opening, and prevented the full hydraulic capacity of the waterway area from being used effectively. The relief provided by overflow reduced the pressure of the flowing water on the debris lodged in the bridge openings, which resulted in less structural damage than would have occurred otherwise. Some of the drift was conveyed over the roadway at the overflow sections, bypassing the bridges entirely, without being forced to enter the bridge openings. It was apparent that a judicious provision for overflow can appreciably reduce the structural damage caused by the impact of debris.

Reinforced concrete piers at the newer bridges developed a greater resistance to cracking than the unreinforced concrete, stone, or combination stone and concrete piers of the older bridges. The only exception, in this regard, was the old multispan stone arch bridges, which proved to be extremely damage-resistant. The superiority of reinforced concrete over unreinforced concrete as a construction material for piers was clearly evident.

One victim of debris was the James Street bridge at North Towanda, Pennsylvania. It was reported that the steel bracing of the trusses that supported the roadway deck was struck by at least one house trailer, possibly several buildings, a large amount of debris, and a variety of flood trash that collected on the vertical members and chords. Figure 4a shows conditions near the east abutment during the height of the flood. Note the large deflections of the vertical members of the upstream truss under the combined forces exerted by the flowing water and debris. Figure 4b shows the deflection of some of the members of the downstream truss under similar conditions. Both photographs were taken just before failure. A close examination of Figure 4b seems to indicate that at least two vertical members had been sheared from the lower chord of the truss under the action of the dynamic forces. Also note the deflection of the guardrail on the deck, which further indicates the forces on the bridge.

SCOUR

Scour at bridge abutments and piers was the second most obvious cause of damage. In many cases, the scour that occurred around bridge piers was amplified by the debris that collected on the piers. The debris increased the turbulence of the floodwater, which further increased the tendency to scour.

North Street Bridge at Wilkes Barre, Pennsylvania

With the exception of its end spans, the North Street bridge at Wilkes Barre, Pennsylvania, was totally destroyed. The piers tipped because of scour and, in some cases,

Figure 1. Debris deposited on bridge by floodwaters.

Figure 2. Cracked pier cap on Towanda Creek bridge in Powell, Penn.

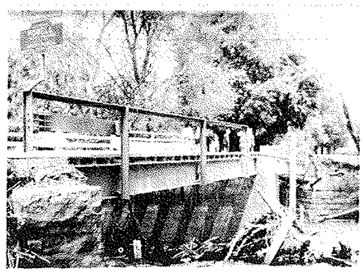
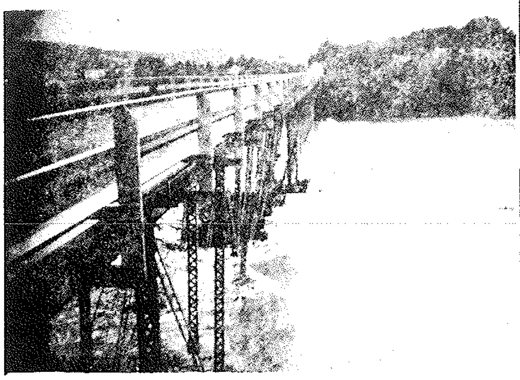


Figure 3. Arch bridges, such as the Market Street bridge in Wilkes Barre, Penn., were most damage-resistant.

Figure 4. Large deflection of (a) the upstream truss and (b) the downstream truss of the James Street bridge in North Towanda, Penn.



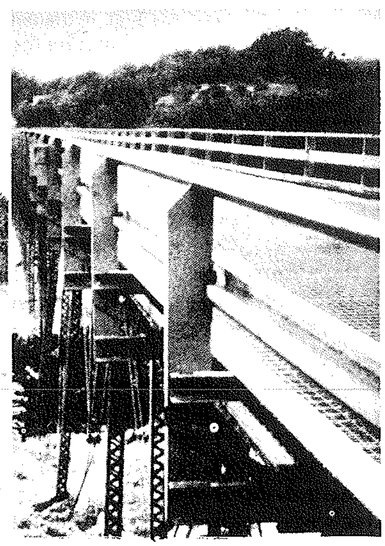


Figure 5. Post-flood remnants of the James Street bridge.

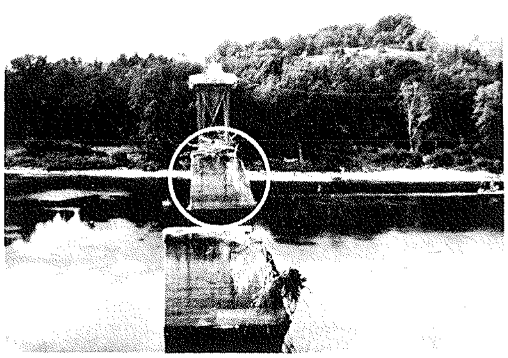
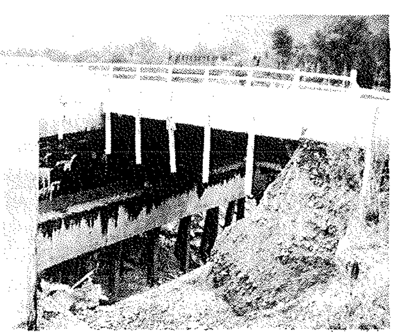


Figure 6. Exposed piling and undermined abutment of Chemung River bridge.



completely fell over. This bridge was constructed many years ago, and the details of its substructure design are unknown. It was reported that some of the piers, but not all, had been supported by timber piling. The City of Wilkes Barre is underlain by numerous coal mines that reportedly have undergone subsidence in recent years. Mines are known to be located under the river at the bridge site.

James Street Bridge at North Towanda, Pennsylvania

The James Street bridge at North Towanda, Pennsylvania, which fell victim to debris also, was adversely affected by scour. After the Susquehanna's flow had subsided sufficiently, the Pennsylvania Department of Transportation wisely arranged for an underwater inspection of this structure. The following remarks are excerpted from the diver's report:

> Pier No. 7 can best be described as being supported by its own inertia. With the exception of a small area of not over 20 sq ft at the downstream left corner [downstream is toward the left in Figure 5], there is no ground support for the pier. The undercut at the upstream end is 40 in. high. The pilings, which in 1969 were measured at 10 to 12 in. in diameter, are now eroded to 3 in. in diameter. At least 2 piles under the upstream nose of the pier have been eroded completely in two. I was able to pass completely under the pier at a point directly below the upstream bridge truss. In this area the thickest pile measured was 5 in. in diameter. Toward the downstream end a pile 8 in. in diameter was found. I was unable to measure the piles on the interior rows downstream of the point I passed under the pier, but they felt as if the radius was larger, and the piles were definitely less spongy. The sand and gravel carried in the bed load of the river is effectively eroding away the wood in the piles.

Bridges on the Chemung River, New York

244 Many bridges in New York State survived the flood principally because their abutments were founded on piles. Three excellent examples of abutment scour were observed at bridges on the Chemung River. At the bridge near Lowman, although the abutment footing and a considerable length of piling beneath the footing were exposed (Fig. 6), the piling retained its load-carrying capability, and the structure remained in place in spite of the large amount of scour that occurred. With the exception of one of the abutments of the bridge near Lowman, which will be discussed subsequently in more detail, none of these structures was protected by spur dikes at the time of the flood. A careful examination of the concrete abutments failed to reveal any indication of cracking damage or other evidence of structural distress due to differential settlement or abutment rotation. After the abutments were underpinned and the washed-out sections of the approach embankments were reconstructed, the bridges were reopened.

Tioga River Bridge at Presho, New York

Another interesting situation involved a breaching of the approach embankment behind one of the abutments at a county bridge on the Tioga River at Presho. Although the footing and approximately 7 ft of piling were exposed (Fig. 7), the underlying pile foundation retained its supportive capacity and the abutment remained intact.

A short distance landward from the breach along the approach embankment, a section of the highway in a sag vertical curve was overtopped, several hundred feet of pavement were displaced, and the downward slope of the embankment was severely eroded. Water, cascading over the embankment, fell several feet to the toe of the fill and eroded the unprotected downstream slope. Although the pavement shown in Figure 8 was completely destroyed, the underlying embankment sustained surprisingly little damage. Field reconnaissance indicated that the floodplain upstream from the damaged highway carried a large quantity of overbank flow. A section of railroad track owned by Penn Central crosses the floodplain parallel to the river channel and intersects the highway within the sag. The trackage also sustained considerable damage (Fig. 8). Extensive repairs and maintenance were required before either rail or highway service could be restored.

Canisteo River Bridge at Erwins Junction, New York

Another noteworthy example of the effects of scour was provided at a site on the Canisteo River at Erwins Junction. Figure 9 shows the location of the dual bridges (indicated by the circle) and the alignment of US-15. The Canisteo River channel is located at the extreme south side of a wide valley, at the toe of steeply sloping hills. When sufficiently high flood stages are experienced, the bridge opening becomes fully eccentric in relation to the area occupied by the river and a large quantity of flow is carried by the floodplain, which is located entirely on the north bank. As shown in Figure 9, the Tioga and Canisteo Rivers meet to form the Chemung River, a few thousand feet downstream. When the Tioga discharges a large flow at this confluence, it is capable of creating backwater at the Canisteo River bridge.

At this location, US-17 borders the north side of the floodplain, paralleling the Canisteo River. US-17 is spanned by a grade separation structure about 1,700 ft north of the Canisteo River bridge at the Erwins Junction interchange. Extensive hydrologic and hydraulic design studies were made at the time this project was designed. These studies were used to design the Canisteo River bridge, which survived the flood with only minor damage to the north abutment of the upstream structure. During the June 1972 flood, the approach embankment at the north abutment was slightly scoured, and some material was eroded beneath the abutment footing, exposing about 2 ft of piling (Fig. 10). In view of the fully eccentric condition that developed and the large quantity of overbank flow that reentered the main channel at the bridge opening, it was surprising and perhaps fortuitous that the north abutment did not sustain far greater damage than the nominal amount described. The transverse movement of a large overbank flow along a highway embankment toward a bridge opening causes substantial embankment scour in the vicinity of the abutment.

Some relief for the Canisteo River bridge was provided by the grade separation structure at the interchange of US-15 and US-17 at Erwins Junction. The overflow at this interchange apparently helped to prevent more serious damage at the north abutment of the Canisteo River bridge. Perhaps the most significant factor in limiting the scour damage at the abutment and in the bridge opening was the presence of a row of large trees at the edge of the floodplain, parallel to the main channel. This line of trees extends upstream from the abutment, along the top of the riverbank, for a considerable distance. This natural feature apparently was extremely effective in preventing excessive scour damage at the abutment and in the vicinity of the bridge opening.

In contrast to the minimal damage sustained by the bridge opening, the channel downstream was extensively scoured. The north bank of the channel was lined with a dense growth of heavy trees, whereas the south bank was treeless. Both banks were subjected to large quantities of overflow. The treeless bank was severely scoured and required considerable maintenance. In comparison, the bank with trees sustained only slight scour damage because of the stabilizing influence of the heavy overgrowth.

Although the Canisteo River bridge was not overtopped, it was evident from the high-water marks on the upstream and downstream sides of the approach embankment at the bridge that its entire waterway must have been utilized. This structure survived the flooding with little damage and was never closed for repairs.

The situation at the interchange of US-15 and US-17, just north of the Canisteo River bridge, was somewhat less satisfactory. Its abutments were constructed on spread footings. Piles were not used because it was considered extremely unlikely that the river would ever flow through this interchange, and, in addition, an adequate bearing capacity for abutment support was available. It appeared that the high stages in the Canisteo were increased by backwater caused by the Tioga, and, as a consequence, US-17 at Erwins Junction interchange was inundated and the interchange structures were forced to convey a substantial flow. This flow caused a large amount of scour at the interchange abutments and resulted in substantial damage as shown in Figures 11 and 12. Both abutments were extensively undermined with the scour approximating 3 ft at some points beneath the footing and extending laterally 10 ft or more from the breast wall of the left abutment. The maximum depth of scour at the abutment shown in Figure 12 was $4\frac{1}{2}$ to 5 ft. The state department of transportation felt that the structure

Figure 7. Approximately 7 ft of exposed piling beneath abutment of Tioga River bridge.

Figure 8. Approach damaged by overflow on Tioga River bridge.

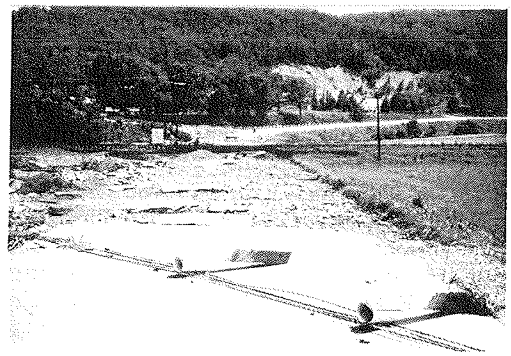


Figure 9. Location and alignment of highways at bridge site. Canisteo River bridge is indicated by circle.

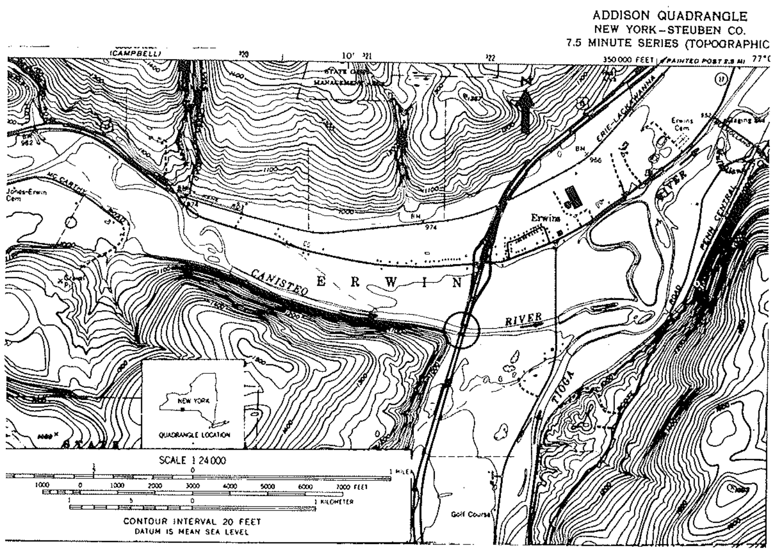


Figure 10. Upstream view of scoured bridge abutment and approximately 2 ft of exposed piling on Canisteo River bridge.

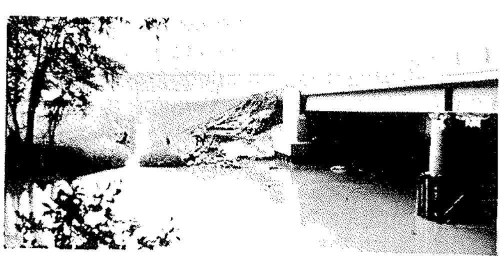


Figure 11. Timber cribbing supporting US-17 interchange bridge until abutments could be underpinned.

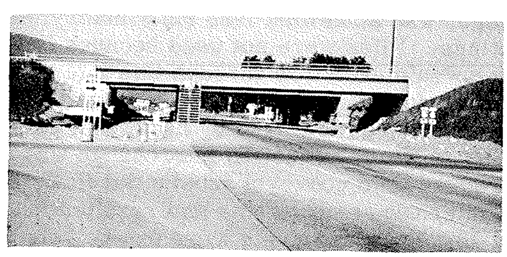


Figure 12. Scour beneath and behind abutments on US-15 interchange bridge.

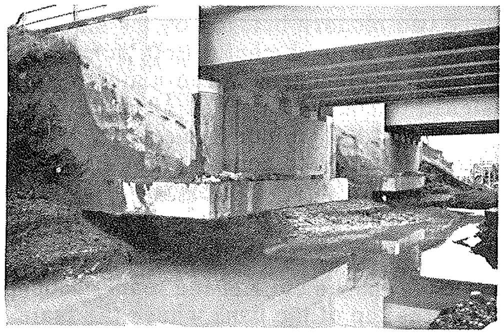


Figure 13. Settlement due to scour on Chemung River bridge in Elmira, N.Y.

Figure 14. Rockfill spur dike near Susquehanna River bridge in Nanticoke, Penn., during 1964 flood.

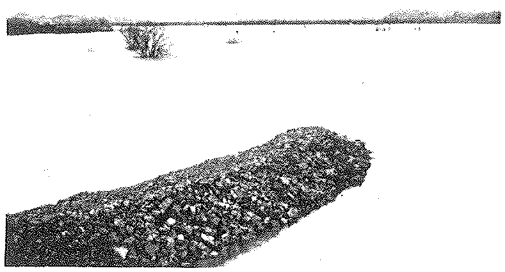


Figure 15. Post-flood condition of floodplain between abutment and adjacent pier of Susquehanna bridge.

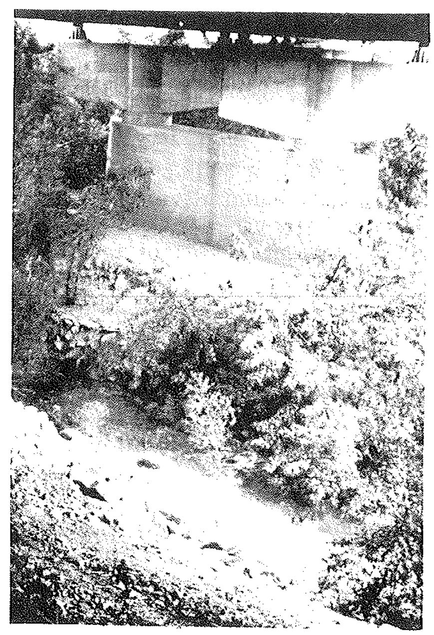


Figure 16. Remnants of earthfill spur dike near Chemung River bridge near Lowman, N.Y.

Figure 17. Enlarged scour hole upstream from Chemung River bridge in Waverly, N.Y.

survived because the steel superstructure prevented collapse. The structure was closed to traffic and braced by timber cribbing until the footings could be underpinned.

The situation provided a striking example of the importance of hydraulic and hydrologic considerations in highway design. Here were two modern bridges on the same highway separated by only a few hundred feet of roadway embankment. Both structures were designed to the same high structural and geometric standards. The major difference was that the Canisteo River bridge was designed to convey "hydraulic traffic" as well as vehicular traffic. It performed well and suffered only minor damage. In contrast the Erwins Junction interchange bridge was not designed to convey river flow; its function was to carry vehicular traffic only.

Chemung River Bridge at Elmira, New York

In those cases where the abutments were set back from the edge of the main channel, it was noted that a pier often was located near or at the top of the bank where the main channel and floodplain merge. Unfortunately a pier in this location appeared to be the most vulnerable of all to scour. Figure 13 shows a pier located near the edge of a river channel. The structure spans the Chemung River at Elmira, New York. As shown in the figure, the pier plunged into the riverbed as a result of scour and subsequent settlement. The pier apparently collected a large amount of debris, which may have increased the amount of scour. It is significant that the structure is continuous at the pier. In the author's opinion this feature was largely responsible for supporting the bridge until it could be adequately braced, thereby preventing collapse or serious damage to the superstructure due to the loss of support and settlement of the pier. The benefits of continuity in bridge structures were clearly demonstrated here.

Susquehanna River Bridge at Nanticoke, Pennsylvania

In the early 1960s, a 300-ft rockfill spur dike was constructed at an abutment of a bridge on the Susquehanna River at Nanticoke, Pennsylvania, after scour undermined an abutment and adjacent piers. Figure 14 shows the spur dike during the March 1964 flood and the turbulent conditions that existed near the dike's upstream tip where the overbank flow reentered the main channel. A comparison of the scour after two floods, both before and after the dike's construction but prior to the June 1972 flood, indicated that the dike had been effective in arresting the scour. During the flood of June 1972, the dike was overtopped by about 3 ft of water, and its effectiveness in controlling scour under such adverse conditions was severely tested. The dike remained intact and was remarkably effective during the June 1972 flood.

When the dike was examined after the flood, there was little evidence of scour other than a small, slightly eroded area near the upstream tip of the dike where a minor amount of vegetation was removed by the floodwater. There was no apparent damage along the streamward face of the dike. Figure 15 shows the area directly under the bridge near the abutment. Note the small trees growing in the area between the pier and the abutment. Because these trees were not uprooted by the floodwaters it is concluded that little if any scour occurred in this area. Prior to the spur dike's installation, the amount of scour was so extensive here that the abutment and adjacent piers were in grave danger due to undermining.

Another significant factor in the dike's excellent performance, in view of the overtopping that occurred, was the size and weight of the rock that had been used in its construction. The rock appeared to be sufficiently massive, which permitted the fill to resist the destructive effects of overtopping and to withstand the potentially damaging currents that flowed around the dike, especially near its upstream tip.

The trees and heavy brush that have grown up around the spur dike also helped in preventing the development of erosive velocities in the overbank area adjacent to the spur dike. This example illustrates that clearing and grubbing operations should be limited to that part of the right-of-way actually necessary for the construction, especially at river crossings. Full advantage should be taken of the available flow retardance of the existing vegetation. If possible, the trees and ground cover in the vicinity of the tip of a proposed spur dike should not be cleared.

Chemung River Bridge Near Lowman, New York

At a site on the Chemung River near Lowman, New York, a spur dike was constructed at an abutment to provide scour protection. A small branching channel of the Chemung rejoins the main channel near the upstream tip of the dike. The floodplain upstream from the bridge carried a large quantity of flow during the June 1972 flood. Although this earthfill spur dike was overtopped and largely washed away as shown in Figure 16, the upstream side of the approach embankment remained intact and survived the flood with no apparent damage to itself or to the vegetation growing on its slopes. Only minor amounts of erosion occurred at this abutment. In contrast, the abutment on the opposite riverbank did not have the benefit of spur-dike protection and was extensively scoured. Of the four Chemung River bridges discussed in this report, the bridge near Lowman was the only one with a spur dike at the time of the flood. (Since that time, New York has constructed spur dikes at the abutments of three of the four Chemung River bridges referred to.) The damaged spur dike was replaced at a fraction of the cost of a new structure, and reconstruction was accomplished with a minimum of traffic interruption. A new spur dike also was installed at the abutment that had been severely scoured (5).

Chemung River Bridge at Waverly, New York

At another location on the Chemung River at Waverly, New York, the floodplain on the west bank upstream from the bridge is several thousand feet wide and was inundated to a depth in excess of 6 ft. A spur dike would have provided an extra measure of safety against the possibility of scour damage, but its absence did not result in damage to the west abutment in this instance. According to the New York DOT, there was less debris at this site than at the other Chemung sites, and the west abutment was afforded some protection by its location, which is on the inside of a gentle bend in the river. Note the extensive scour hole, shown in Figure 17, at the riverbank where the floodplain and river channel join, upstream from the abutment. The embankment was intact and undamaged in the vicinity of the abutment. Because of the topography of the floodplain, a large portion of the overbank flow apparently reentered the main channel at a depression some distance upstream. A scour hole of much smaller dimensions had existed at this depression for several years. The June 1972 flood simply enlarged the existing scour hole. The most extensive damage to the bridge occurred at the abutment on the opposite bank where more than 5 ft of scour occurred beneath the footing and exposed the piling. Because the floodplain is practically nonexistent on the east side of the river, a spur dike would not have helped here.

It should not be inferred from this example that a preformed scour hole upstream from a bridge abutment is suggested as a means of protecting the abutment from scour due to overbank flow or that it is recommended in lieu of a spur dike. Floodplain topography played a major role in determining that a large portion of overbank flow would enter the main channel well upstream from the structure. In fact, the location of the scour hole may have been determined by the topography of the floodplain. But, as mentioned previously, extreme floods tend to generate complex conditions that are all but impossible to anticipate. Unfortified natural features, by themselves, cannot be relied on to always provide sufficient protection when rare and unusual conditions are experienced.

Chemung River Bridge at Chemung, New York

The quantity of scour at this site was unusual inasmuch as there was much scour and no structural damage at the west abutment and its adjacent piers. A large quantity of material was deposited in this area. The deposit extended downstream from the bridge for a considerable distance.

The east abutment was extensively scoured: Approximately 7 or 8 ft of scour occurred beneath the abutment footing. Also the highway approach embankment was breached behind the abutment. The highway bridge abutment had been connected by a levee to the abutment of a nearby upstream railroad bridge to provide scour protection. During the flood, this levee was overtopped and severely eroded, thereby enabling the floodwaters to scour the highway bridge abutment. The levee was rebuilt to a substantially higher elevation and riprapped to provide protection against a reoccurrence. At the highway bridge abutment, concrete slabs were placed in conjunction with stone riprap to provide stouter protection than could be afforded by stone riprap alone.

Lehigh Valley Railroad Bridge at Athens, Pennsylvania

Further downstream on the Chemung at the Lehigh Valley Railroad bridge in Athens, Pennsylvania, another excellent example of abutment scour occurred. It provides further corroboration of a previous statement that scour at bridge abutments largely depends on the degree of flow constriction imposed by the bridge opening. The location of the bridge and the embankment alignment are indicated by circle No. 1 in Figure 18. The east abutment of this bridge is located at the edge of the riverbank. The railway embankment traverses the floodplain diagonally, which causes a large amount of overbank flow to funnel into the bridge opening at the east abutment. Turbulence in the eddy zone, which resulted from the mixing of the overbank flow with the flow in the main channel, caused a large scour hole to form upstream. Resulting scour damage is shown in Figure 19. A spur dike would have helped to prevent scour at this abutment.

This bridge had a number of aspects that are worthy of comment. It consists of five simply supported through trusses on stone piers and abutments. The structure was obviously built many years ago. To ensure that the structure would stay in place and survive the effects of the flood in a structurally sound and usable condition required that a fully loaded freight train be driven onto the bridge to provide extra weight, or ballast, and parked on the deck until the rampaging waters of the Chemung receded. This probably saved the bridge. Nevertheless, the first pier streamward from the west abutment experienced substantial settlement during the flood and was reported to have settled 5 ft, sinking virtually straight down. Near the height of the flood, a standing wave, heavy turbulence, and a strong concentration of flow were observed in the vicinity of the pier that experienced the 5-ft settlement. This adverse flow condition may have been due in part to the large quantity of overbank flow that entered the river at the left abutment, which caused the flow in the channel to deflect toward this pier and concentrate in its vicinity.

After the flood, steel cribbing was placed around the pier for support. It was reported that an attempt was made to underpin this pier, but foundation conditions made it impossible to drive piles. The bridge is still in use although its track profile (Fig. 20) is deflected vertically in the vicinity of the sunken pier. The west abutment did not appear to have been damaged.

Another interesting aspect of the Lehigh Railroad bridge problem is concerned with the historic flood profile at the site. Figure 21 shows the water-surface profiles for several historic floods of the Chemung River in the reach where the bridge is located. The sharp break in the slope of the water-surface profile at the bridge for the 1946 flood indicates that this structure was at least a partial high-water control during the 1946 flood for a substantial reach of the river upstream from the bridge. The sharp break in slope is indicative of a large increase in flood flow velocity at the bridge. A similar condition possibly existed at the site during the recent flood and would, in that event, have been a significant factor in the amount of scour that occurred.

The location of Tozier's Bridge, indicated by circle No. 2 in Figure 18, is also shown in Figure 21. Figure 21 shows that this structure was extensively inundated by the 1946 flood; however, it was totally destroyed by the June 1972 flood. Debris, scour, and the extensive inundation combined to cause the failure in this case. The flood profiles were used in designing the bridge openings of the Chemung River bridges at Waverly and near Chemung. Their respective locations are indicated in Figure 21 by the designations D.L.&W. R.R. Bridge and proposed bridge site. The damage due to the June 1972 flood might have been much greater at both of these structures if the information provided by the 1936 and 1946 flood profiles had not been taken into account when the bridge openings were designed. It is noteworthy that the county highway bridge located immediately upstream from the structure designated on the flood profile as the D.L.&W. R.R. Bridge, the Waverly bridge, was totally destroyed by the June 1972

Figure 18. Athens, Penn.: Circle No. 1 shows Lehigh Valley Railroad bridge and approaching track alignment; circle No. 2 shows location of Tozier's Bridge.

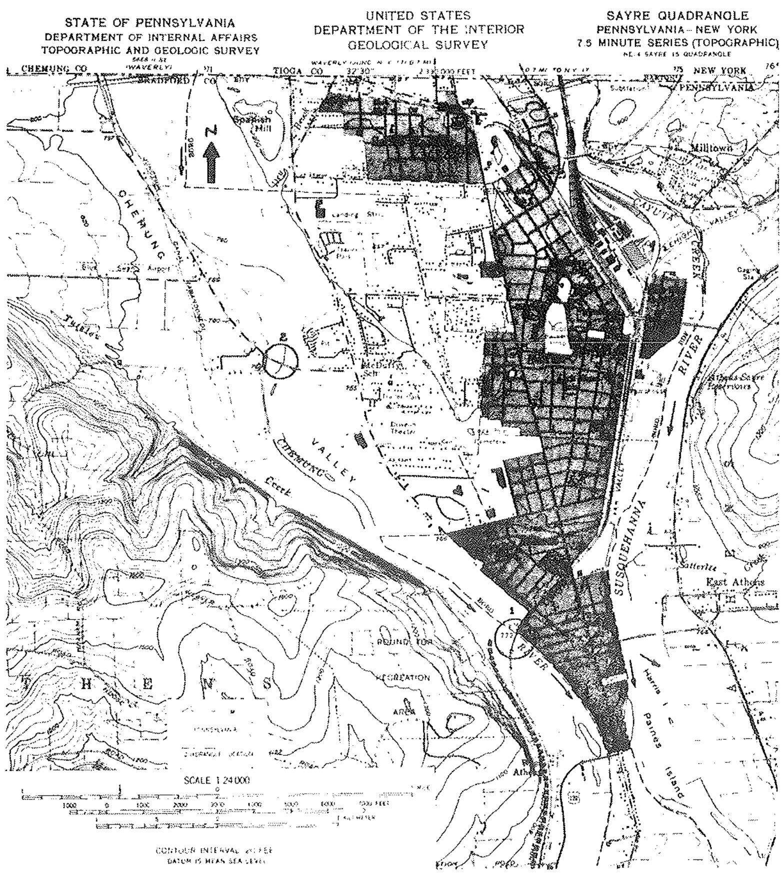
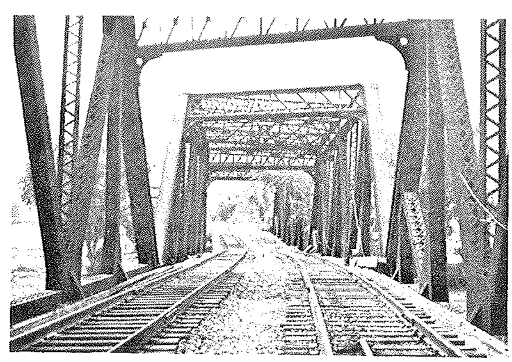


Figure 19. Upstream scour hole, eroded approach embankment, and damaged abutment of Lehigh Valley Railroad bridge.

Figure 20. Downstream view of Lehigh Valley Railroad bridge showing pier settlement.



flood. Historic flood profiles are very useful in the design of replacement and new structures.

County Highway Paralleling the Tioga River at Presho, New York

Highways that parallel streams along the top of a riverbank are vulnerable to undermining. One segment of roadway that parallels the Tioga River along the top of the riverbank at Presho, New York, was badly damaged by overflow during the June 1972 flood. The streamward side of the highway, shown in Figure 22, was extensively undermined, but the damage would almost certainly have been far greater if the embankment slope had not been heavily riprapped. The pavement consisted of 8-in. reinforced concrete with a 5-in. asphalt overlay. In one segment, the asphalt overlay was badly scoured and exposed the concrete, which in turn was extensively undermined. The damage to the pavement appeared to have been caused by trees and other debris that were carried by the stream as well as by the erosive action of the floodwaters. In situations such as these, it probably would be neither possible nor desirable to completely eliminate all damage, but a well-protected riverbank bordering the edge of the roadway in the overtopped area can help to substantially reduce inundation damages.

Susquehanna River Bridge at Dewart, Pennsylvania

Many of the Susquehanna River bridges in Pennsylvania had obviously been designed with overflow in mind. In checking bridge abutments for scour damage, many situations were encountered where overflow had occurred at some point along the approach roadway embankment. In each instance no damage was sustained by the bridge abutments. The embankment approaches seemed to have been intentionally constructed with a slight dip in their longitudinal profiles to permit overtopping when the anticipated floodwaters exceeded some predetermined elevation.

Evidently the concept of using highway embankment overflow as a means of effectively conveying flood flow was understood and successfully employed by the bridge builders of yesteryear. The wisdom of this thinking and the effectiveness of this method in preventing scour damage at bridge abutments were proved many times during this flood.

The overflow concept apparently was used in the design of the Susquehanna River crossing at Dewart, Pennsylvania. At this site the highway embankment traverses the east bank floodplain on a low profile, which gradually rises to the bridge. The downstream edge of the embankment had been paved with a concrete apron that was effective in preventing scour damage, even though the roadway had been overtopped by 7 or 8 ft of fast-flowing floodwater. An additional factor was the difference in elevation, several feet in some sections, between the crest of the pavement at the shoulder's edge and the downstream toe of the embankment. The overflow section was several hundred feet long and obviously provided considerable relief for the bridge during the flood. It appeared that the total absence of damage to the structure and its abutments was directly related to the availability of an adequate overflow section, which conveyed drift as well as floodwater. Although it was clear that drift had struck the bridge, there was no evidence of damage or structural distress. It also was apparent that the downstream slopes of highway embankments that are designed for overflow, or that are subject to overtopping, may require protection from debris and scour by paving, riprap, or some comparable type of ballasting if the expected debris is heavy and the anticipated drop between the upstream and downstream water-surface elevations is large.

The pattern of reduced damage, due to drift and scour, where overflow occurred was repeated so often at the bridge sites in Pennsylvania and New York that some consideration should be given to incorporating an overflow provision in the design criteria.

OTHER CAUSES

Bridges that were located in the proximity of bends in river channels also sustained damage. In some cases, several spans of multispan, simply supported bridges were washed away because of flow concentration in the channel near the outside of the bend. The nonuniform flow distribution contributed to the failure of the Susquehanna River bridge at Lacyville, Pennsylvania. The bend is located upstream from the structure. In traversing the bend, the flow tended to concentrate on the east side (outside) of the channel, and, as a result, the east abutment was badly scoured. The bend also contributed to a severe debris problem at this site. The two spans that were destroyed probably were lost because of the combined effects of the bend, scour, and debris.

When the performance of the bridges that had been subjected to the severe conditions was compared, it was evident that those that had been designed and built in accordance with high structural and geometric design standards generally survived the flood in better condition than those that had been designed to a lower standard. However, the June 1972 floods clearly demonstrated that designing to these high standards alone is not sufficient if essential hydrologic and hydraulic considerations are overlooked or if inadequate provisions are made to accommodate those considerations.

One bridge designed to low standards is the bridge on Schrader Branch of Towanda Creek at Powell, Pennsylvania. At this site, a concrete pier was found to be completely cracked from top to bottom over its entire cross section in the direction of its width (Fig. 23). In addition the spread footing was completely broken away from the pier shaft (Fig. 24), which gave it a wedge-shaped appearance. Investigation revealed that the pier footing apparently had been poured on the riverbed, which is composed of loose, granular material. It appeared that the weight of the bridge was primarily responsible for preventing the pier from toppling over. There was no evidence of a pile foundation beneath the footing. Lacking the support of an adequate foundation and the strength provided by steel reinforcement, the pier subsequently cracked under the applied forces and loads. Although it was impossible to determine the extent of the pier damage attributable solely to the June flood, it is likely that the pier was in a weakened condition before the flood occurred. It was evident that a previous attempt had been made to seal and grout the crack. This pier was struck by a large amount of debris, which apparently was traveling at a high velocity at impact.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

It was concluded from the examples cited that a pile foundation of sufficient length or footings founded at a sufficient depth are needed to avoid abutment or pier failure in erodible soils. Specifications in design standards giving arbitrary depths of piles for protection against scour should be avoided. Pile length or depth of spread footings should be based on the anticipated depth of scour as well as bearing capacity. In this regard, a designer should not become overly concerned that stub abutments are unduly scour-prone. A stub abutment is as acceptable as a full-height abutment if the depth of the foundation is sufficient to provide adequate structural support where extensive scour occurs. If the depth of the foundation is insufficient, the choice of abutment obviously is immaterial.

Another factor that contributed to damage was the location of abutments and piers in relation to the main river channel. During the field investigation, it was noted repeatedly that the amount of scour at bridge abutments and piers within the bridge opening depended primarily on the amount of constriction that the bridge opening imposed on the flood flow. Abutments and piers positioned near the edges of the main channel generally suffered extensive scour damage regardless of geometric shape or construction material unless they were protected by spur dikes or the approach embankments were constructed on a sufficiently low profile to provide relief as a result of overtopping.

The practice of locating an unprotected pier at the top of a riverbank should be avoided because a pier at this location is highly vulnerable to scour. If a pier must be constructed in this location, the pier shaft should extend well below the anticipated depth of scour. The outstanding performance of spur dikes during the June 1972 floods clearly demonstrated that they are one of the most effective means now available for preventing scour damage to bridge approaches, abutments, and adjacent piers in situations involving large quantities of overbank flow.

All 45 major bridges in Pennsylvania on the Susquehanna River and its major tributaries upstream from Harrisburg were checked to determine the cause of damage. Of this number only four were washed out or damaged to the extent that they had to be

Figure 21. Water-surface profiles of Chemung River for 1935, 1936, and 1946 floods.

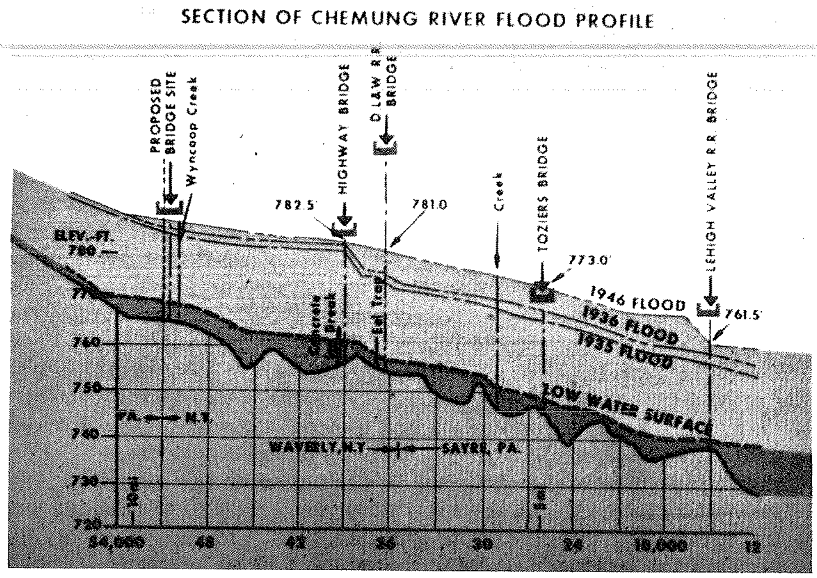


Figure 22. Undermined roadway slab and scoured embankment fill adjacent to Tioga River.

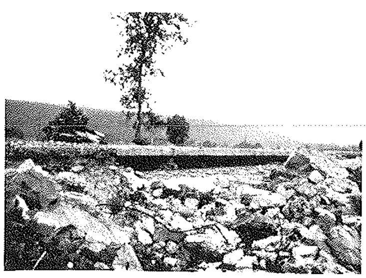


Figure 23. Cracked pier shaft supporting a county bridge on Schrader Branch of Towanda Creek.

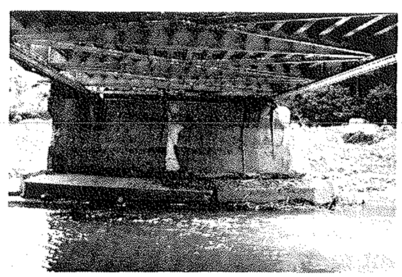
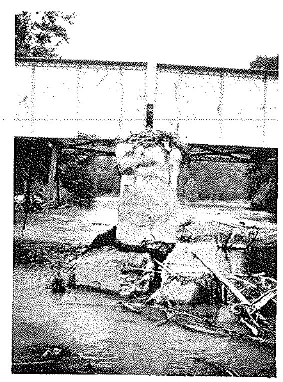


Figure 24. Front view of cracked pier shaft and broken pier footing.



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closed to traffic; however, many others were extensively damaged. (A total of 694 bridges and culverts were reported damaged or destroyed.) In virtually every case of reported damage, debris was either the primary cause or a significant contributing factor. Scour at abutments and piers was the other major cause of damage. Somewhat surprisingly, perhaps, damage due to superstructure inundation was not a significant factor unless the inundation was accompanied by debris.

Although the greatest emphasis in this study was placed on Pennsylvania's Susquehanna River bridges, several bridges in New York State were also included because they illustrated a number of noteworthy aspects of hydraulic and structural performance. In conjunction with the Pennsylvania structures they provided valuable insight into the nature of flood-induced bridge damage.

Only three bridges on the New York State highway system were reported completely washed out, but many others were severely damaged and required extensive repairs before they could be returned to full operation. [A total of 182 bridges were reported damaged or destroyed in New York State (1).] In addition, many county bridges were destroyed or badly damaged. Most of the damage was concentrated in the Genesee and Chemung River basins although other areas suffered major damage also. Debris and scour were the primary factors causing the damage—the same factors that caused the major damage in Pennsylvania.

If there was a common thread to the cause of the scour damage sustained by the bridges in Pennsylvania and New York, it could be characterized as follows: Any bridge site having an abrupt change in its cross-sectional waterway geometry, which forced floodwater to suddenly change its depth, distribution, or direction of flow, was potentially vulnerable to scour. This sudden but predictable change in a river's flood flow characteristics occurs naturally at the riverbank where the main channel joins the floodplain. Frequently, the abutments that frame the bridge opening are located there too. Often the worst scour conditions exist not at the peak of a flood but at an intermediate stage as the waters recede and the overbank flow returns to the main channel. Although scour frequently occurs in a random and unpredictable manner, a waterway constriction caused by a bridge opening in an embankment is usually most susceptible to damage in the vicinity of its abutments and piers, unless adequate scour protection is provided.

The location of the abutments and piers in relation to the main channel was an important factor in the damage that the bridges sustained. During the field investigations of the Susquehanna and Chemung River bridges it was noted repeatedly that the amount of scour at the abutments and in the bridge opening primarily depended on the amount of constriction that the bridge opening imposed on the flood flow. In general, abutments and piers that had been constructed at the tops of the riverbanks near the edges of the main channel sustained the greatest damage. This repetition of the damage pattern was prevalent, regardless of the shape of the abutments or piers and the material used in their construction. Exceptions were noted at sites where (a) spur dikes had been constructed at the abutments, (b) approach embankments had been constructed on a sufficiently low profile to provide adequate relief by means of overflow, and (c) a physical feature of the upstream floodplain had provided natural scour protection that was at least adequate for the conditions that had been experienced.

The following conclusions and recommendations were reached as a result of this study:

1. The primary causes of damage to bridges during the June 1972 flood were debris and scour.
2. In some instances, freeboard can help in reducing the damage inflicted by waterborne debris, but freeboard alone probably will not be effective in controlling debris damage when rare and unusual floods occur. Freeboard alone cannot guarantee the complete elimination of damage because the degree of protection is limited by the ever-present chance that a flood will occur that exceeds the level of protection provided by the freeboard, as well as by other engineering and economic considerations.
3. Bearing devices at piers of simply supported structures should be designed to resist dynamic flood forces, such as the horizontal forces due to impacting debris.

4. Structural continuity at bridge piers is a desirable structural feature because of the extra strength that this type of construction can provide.

5. Embankment or roadway overflow sections are recommended as a means of reducing potential debris damage at structures where heavy deposits of drift may accumulate, clog the bridge opening, and prevent use of the full capacity of the bridge waterway area. The relief provided by overflow reduces the pressure of the flowing water on the lodged debris, which in turn reduces the damage to the structure and the bridge opening. The risk of damage due to debris impacting a structure and clogging its waterway opening may be appreciably reduced because some of the drift can be conveyed through the overflow section and bypass the bridge.

6. Pile foundations for piers and abutments prevented many failures that would have occurred otherwise. According to the New York State DOT, spread footings constructed with adequate allowance for the depth of scour retained their supportive capacity also. Economic considerations might well be the deciding factor in determining which type of foundation to select in any given situation, but depth of foundation appeared to lessen the risk of failure from scour.

7. Scour at bridge abutments and within bridge openings primarily depends on the amount of constriction that the bridge opening imposes on the flood flow.

8. Piers located at the junction of the main channel and the floodplain are highly susceptible to scour. The practice of placing a pier in this location should be avoided, or more substantial provisions should be made for adequate scour protection.

9. Reliable water-surface profiles of rare floods are among the most relevant and useful items of hydrologic and hydraulic design information that can be obtained; their importance cannot be overemphasized. Bridge designers can use water-surface profiles to good advantage in a number of ways, and their use is recommended whenever possible. Although agencies such as the U.S. Geological Survey and the U.S. Army Corps of Engineers collect hydrologic and hydraulic data, state highway departments and railroads also record high-water marks from extreme floods.

10. Spur dikes were effective in controlling and preventing embankment scour behind and beneath bridge abutments and at adjacent piers even when the dikes were overtopped or partially destroyed. Their use is recommended wherever the transverse movement of a large overbank flow along a highway embankment toward a bridge opening is anticipated.

11. Highways that were designed for embankment overflow were effective in controlling scour at bridge abutments. Overflow sections might be a feasible alternative to spur dikes at some locations. Properly designed relief structures also can be used to maintain flow distribution and to reduce scour.

12. Downstream slopes of highway embankments that are designed for overflow may require protection from scour by paving, riprap, or some comparable type of ballasting if the anticipated drop between upstream and downstream water-surface elevations is large.

13. It is suggested that appropriate design committees, recommending design procedures and standards, consider incorporating provisions for accommodating highway-embankment overflow resulting from rare and unusual floods.

14. Bridges that had been designed and constructed in accordance with high structural and geometric design standards generally survived the flood in better condition than those that had been designed to a lower standard. However, the June 1972 floods clearly demonstrated that designing to such high standards alone will not be sufficient if essential hydrologic and hydraulic considerations are overlooked or if inadequate provisions are made to accommodate those considerations.

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Although it would be impossible to list all of the organizations and individuals who so generously contributed their information and time, I would be remiss if I failed to acknowledge the assistance provided by the departments of transportation in Pennsylvania and New York, the regional and division offices of the Federal Highway Administration for those two states, and my associates in the FHWA Washington office.

I especially appreciate the opportunity to discuss the causes of bridge damage with those federal and state highway personnel who worked to restore transportation facilities in Pennsylvania and New York immediately after the flood.

Appreciation also is expressed to the Daily Review of Towanda, Pennsylvania, for cooperation and permission to use several outstanding photographs of bridge damage that appeared in the special flood edition of that newspaper. Also, acknowledgment is made to Richard R. Church of the New York State Department of Transportation and Gerald E. Schroeder, Jack Justice, Stanley Davis, and Robert Burk of the Federal Highway Administration for furnishing several photographs.

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Start of erosion in side ditch where flow of water exceeds scouring velocity (Brazil).

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4 Design of waterway opening for scour and backwater

4.1 Types of bridge scour and their causes

Terminology

'Scour' is used here to mean a lowering by erosion of the channel bed below an assumed natural level or other appropriate datum, tending to expose or undermine foundations that would otherwise remain buried. 'Depth of scour' refers to the depth of material removed below the stated datum. 'Scoured depth' refers to the depth of water above a scoured bed under stated flow conditions. Figure 4.1 illustrates these terms.

A bridge crossing is referred to here as 'uncontrolled' where no significant constriction or realignment of natural flows is imposed by the bridge approaches or training works. All other cases are referred to as 'controlled waterway openings.' Account must be taken of the possibility that an initially uncontrolled crossing may later become controlled as a result of shifting of the channel.

Principal categories of bridge scour

Scour at bridges may be divided into four main categories as follows.

1

General scour across a controlled waterway opening associated with constriction of flood flows through the opening (Figure 4.2).

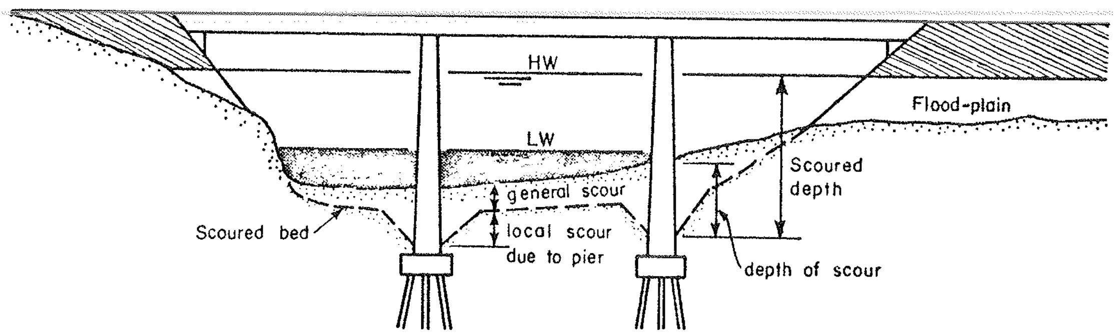

Figure 4.1 Cross-section at a bridge waterway opening, illustrating scour terminology.

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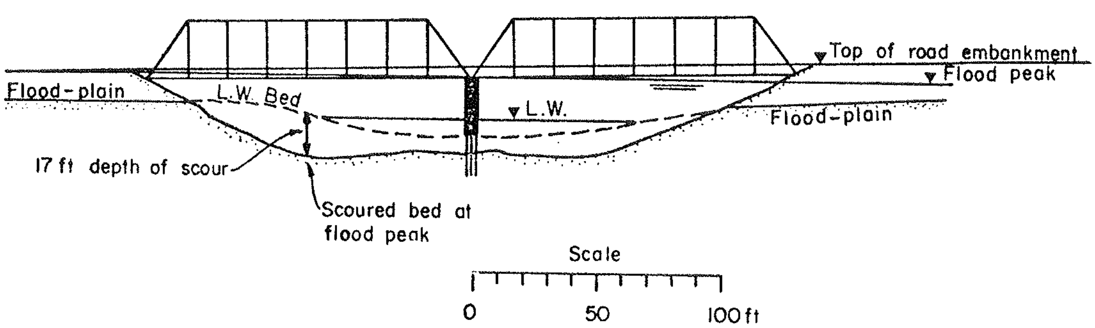
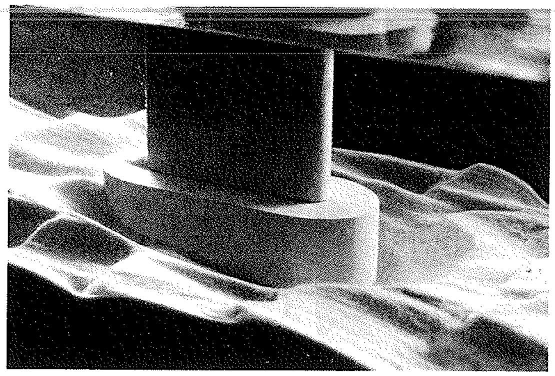


Figure 4.2 Soundings at a bridge, showing an example of general scour across a waterway opening resulting from the constriction of a flood through the opening.



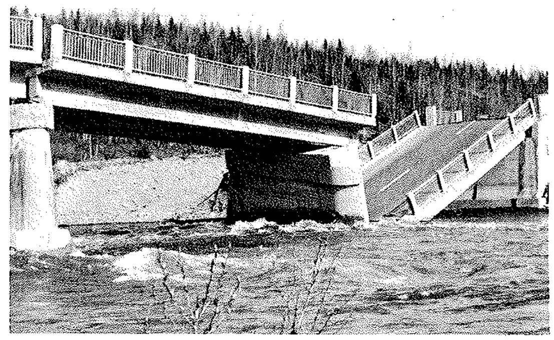


Figure 4.3 Local scour at piers as illustrated by a model experiment and by a bridge failure. The flow is from right to left in both photographs.

2
Local scour around piers, abutments, and noses of guide banks and embankments, associated with vortex systems induced by obstructions to the flow (Figure 4.3).
3
Natural scour in alluvial and tidal channels associated with variations in flow conditions and associated channel processes including bed-material transport, bed-form migration, and channel shifting (Figure 4.4).
4
Progressive channel profile degradation associated with geological processes or with man-made regime changes upstream or downstream (Figure 4.5).

The scour observed or to be expected at a given bridge may represent a combination of these categories, as well as other less common effects. For more details on various scour phenomena and their causes, reference may be made to previous publications (refs. 4.1, 4.2, and 4.3), and to references contained therein.

Methods of scour estimation
Sections 4.4, 4.5, and 4.6 following give suggested methods of estimating the first three of the four principal categories of scour listed above, and Section 4.7 discusses their combined effects. Progressive channel profile degradation, the fourth category, is not usually susceptible to computation, and should, where appropriate, be estimated on the basis of past trends or future project plans, as indicated in Chapter 2.

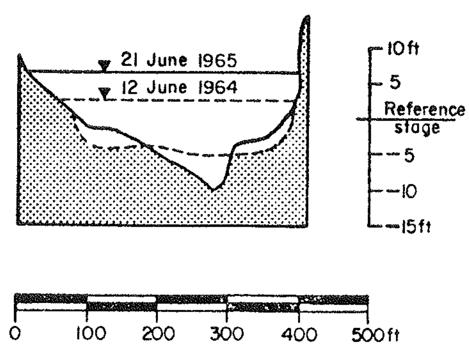


Figure 4.4 Cross-section of an alluvial river showing the bed profiles observed under different flow conditions. (Vertical scale exaggeration 10 X)

Figure 4.5 Bridge foundations repeatedly undermined as a result of progressive channel profile degradation.

Refs. 4.1 to 4.4 discuss various previous formulas and charts for scour. An example of scour estimation by the methods proposed here is given in Appendix III.

Factors affecting scour
The depth and area of scour at a given bridge at a given time may be affected by any or all of the following factors:

- slope, natural alignment, and shifting of the channel;
- type and amount of bed-material in transport;
- history of former and recent floods;
- accumulations of ice, logs, or other debris;
- constriction and/or realignment of flow due to the bridge and its approaches;
- layout and geometry of training works;
- geometry and alignment of piers;
- classification, stratification, and consolidation of bed and sub-bed materials;
- placement or loss of rip-rap and other protective materials;
- natural or man-made changes in flow or sediment regimes;
- accidents, such as collapse of a near-by structure.

The order in which the factors are listed above is not intended to indicate their relative importance, which varies from case to case.

4.2 Influence of various physical factors on scour

The purpose of this section is to outline some physical considerations that should be kept in mind when estimating scour for design or when analysing observed cases.

Principal factors influencing erosion of materials
The erosive power of flowing water on a channel boundary is determined primarily by the local shear stress or drag exerted by the flow on the boundary, and by the associated velocities and turbulent fluctuations of velocity near the boundary. The relationship of local velocities to cross-sectional average velocities is complex and depends on depth of flow, boundary roughness, and channel geometry. Macroturbulent flow phenomena such as eddies, helicoidal flow, rollers, and surges may also be important factors influencing scour. Average velocities and depths therefore give at best a very rough indication of erosive power, but calculations based on more refined measures are impracticable for the bridge engineer in many cases. Figure 4.6 illustrates the relationships between velocities at different depths in a wide stream of fairly regular depth.

The resistance to erosion of cohesionless materials depends primarily on grain size, size distribution, and grain density, and to a lesser extent on grain shape, orientation, and packing arrangement. Practical criteria for sand and gravel are often based on grain size only, assuming a standard specific gravity of approximately 2.6 for natural rocks. It is often assumed that a mixture

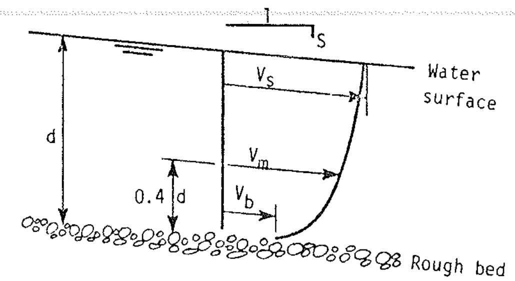


Figure 4.6 The vertical velocity profile and approximate velocity ratios in a wide, straight channel with a rough bed. The time-average bed shear stress = γdS, where γ is the unit weight of water. The surface velocity V_s is about 1.1–1.2 times the mean velocity V_m. The bottom velocity V_b is usually in the range 0.3–0.7 times V_m. The bottom velocity (time-average value) is somewhat ill-defined because of the steep velocity gradient and the strong turbulent fluctuations. Particles on the bed experience fluctuating lift and drag forces even when the surface velocity is fairly steady.

can be represented by a single size such as the median size by weight (D_{50}), but this assumption is not necessarily justified for certain types of mixture, as noted subsequently.

The resistance to erosion of fine-grained cohesive materials depends on a number of physicochemical and environmental factors, since the bonding between particles must break down before erosion can occur. Standard soil mechanics tests and index properties have not proved very satisfactory as a basis for erosion resistance criteria (ref. 4.5), and some form of direct scouring test appears to be desirable, but as of 1971 no standard guidelines for such a test are available.

For weak sandstones and weakly cemented sands and gravels, it is important to investigate whether the cementing medium will be dissolved during the life of the structure to the point where the material acts as if it is cohesionless. Laminated materials such as hard shales may appear capable of withstanding high velocities, but in practice may tend to peel off during major floods.

Rates of scour

Rates of scour in different materials and situations vary widely. The rate depends not only on the relationship of erosive power to erosional resistance, but also on the balance between material eroded and material deposited. Under conditions of steady flow most scour situations eventually reach a final or equilibrium condition. Under natural unsteady flow conditions a final scour topography is not necessarily attained in a single flood event, but it may develop progressively over a series of events. Methods of scour estimation proposed here are therefore based on the

assumption that design flows persist long enough or occur often enough to produce a final scour condition in the material under attack.

During a typical flood rise and recession, scour tends to lag behind discharge, so that maximum scour occurs after the flood peak has passed.

Heterogeneous materials and geological limitations

A channel bed may be underlain by a succession of strata of varying resistance to scour. Where a comparatively resistant layer overlies more easily erodible material, it may be advisable to prevent scour penetration of the resistant layer by careful design or by adopting special protective measures.

When scour occurs in a widely graded granular mixture or a cohesive material containing stones, paving of the depression by the coarser fraction of the mixture can be expected, provided the general rates of scour and of bed-material transport are relatively low. If the channel bed is generally in vigorous movement, however, paving does not necessarily occur.

When applying methods of scour estimation subsequently suggested here, it should be remembered that the presence of more resistant strata may impose a limit on the possible depth of scour. Careful evaluation of sub-bed stratigraphy, as indicated by test boring and geophysical investigations, is of primary value.

Pier design and foundation type

The depth of local scour at a pier may be greatly affected by the geometry of the pier and its foundation, also by construction procedures and temporary works. These points are discussed further in subsequent sections of this Guide.

Pile foundations are often assumed to give more security against scour than spread footings, but they are not necessarily immune to its consequences, as recorded failures testify (ref. 4.6). It is essential to investigate the possible effects of scour on the stability of piles, taking ice and flow forces into account where appropriate.

Bed-load transport

As the discharge rises in a stream, so does the tendency to transport bed load and to produce scour at bends, constrictions, and obstructions. In streams carrying bed load, scour for a given discharge tends to reach a limit after a certain time, because bed load is supplied as fast as the local scouring currents can remove it. Experiments indicate that the worst scour may not necessarily occur in the highest flows.

4.3 Suggested procedures for design of waterway opening

Flow chart
Figure 4.7 outlines a tentative procedure for design or checking of the waterway opening. This chart in effect constitutes an expansion of the middle part of Figure 2.2.

Trial waterway opening width
Where no other guidance regarding a suitable width of waterway opening is available (see Section 2.7), a first trial width may be selected from Figure 4.8. This is based on an empirical 'regime' formula for stable alluvial channels:

$$W_s = CQ^{1/2}, \qquad (4.1)$$

where W_s is the net waterway surface width at design discharge, Q is the design discharge, and C is a coefficient. This formula was originally proposed by Lacey (ref. 4.7) for sand-bed canals and rivers, with $C = 2.67$ when W_s and Q are in foot-second units. The suggested range indicated on the chart is from $C = 1.8$ to $C = 2.7$. The upper end of the range should be used for shifting channels in sandy materials, but for relatively stable channels in more scour-resistant materials the lower end may be used, subject to confirmation from local experience. Further adjustment of the waterway opening width should be made on economic grounds after consideration of scour and other factors, as indicated in Section 2.7 and Figure 4.7. The final adopted width may well fall below the range indicated by Figure 4.8.

Waterway opening widths and cross-sectional areas should always be calculated normal to the principal direction of flow as it enters the bridge in major floods.

Hydraulic models
Where the results of design proposals are difficult to predict because of the complexity of the hydraulic situation, or where the structure is particularly important or expensive, a hydraulic model study may achieve considerable economies in total project costs. Models may be valuable for visualizing design problems and for obtaining approvals from regulatory authorities, even when their behaviour cannot be interpreted reliably in a quantitative sense. Mobile-bed models of proposed crossings will generally give useful indications of scour patterns and tendencies, but in many cases the scaling difficulties are formidable and the models cannot be relied upon for accurate prediction of scoured depths.

Some principles of model testing are discussed in more detail in Chapter 6.

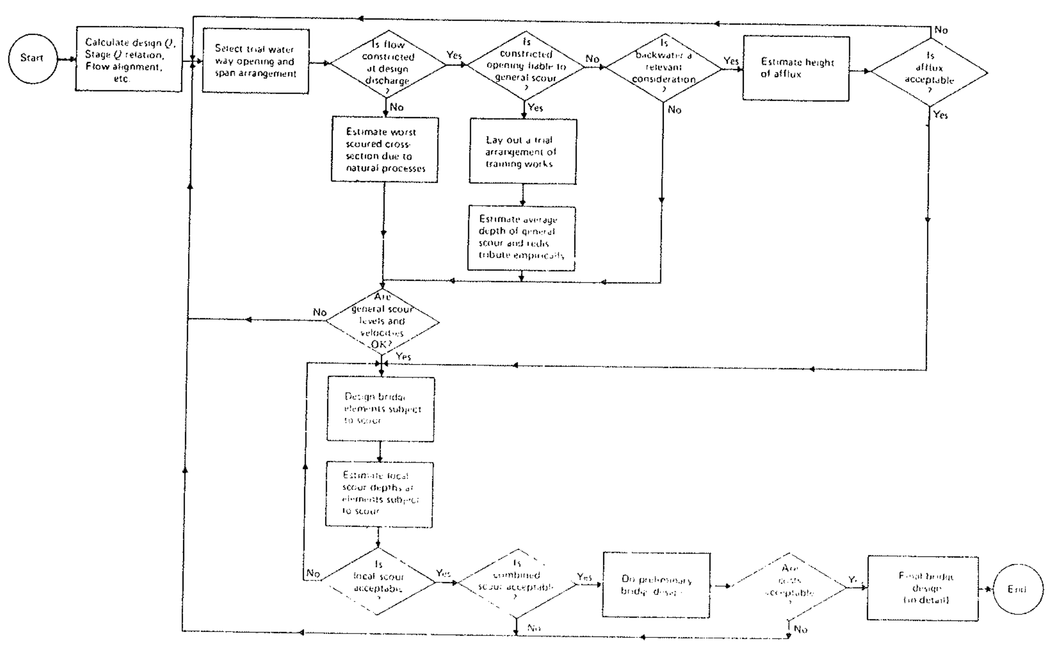


Figure 4.7 Flow chart for the design or checking of a waterway opening (may be supplemented by model tests – see Section 6.2).

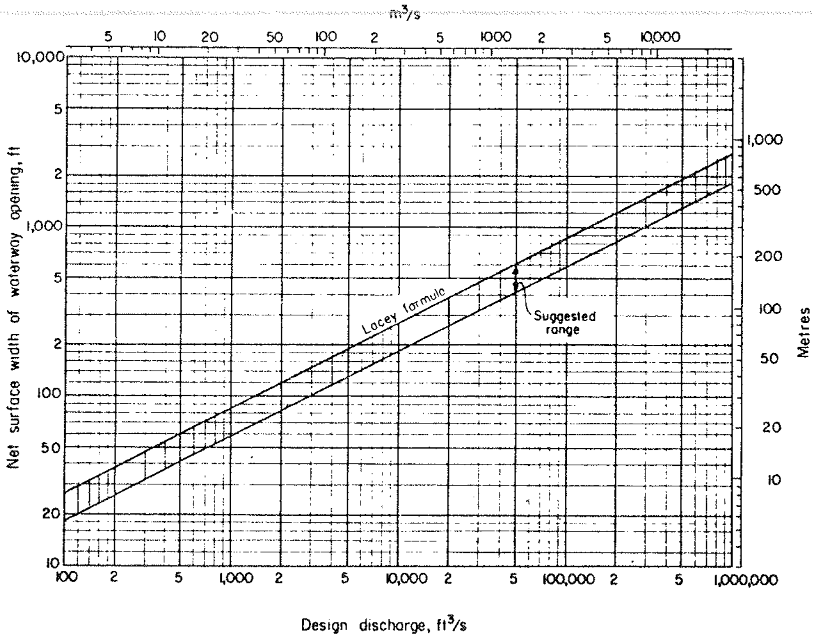


Figure 4.8 Chart for selecting a trial waterway opening width based on Lacey's regime formula for alluvial channels.

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4.4 General scour in controlled waterway openings

Applicable circumstances

The methods of estimation given below are intended to apply where the bridge and its associated training works so constrict or realign natural flows that an artificial waterway opening is in effect created, bounded on each side by road approach embankments or guide banks. The problem is then to estimate scoured depths due to the design flow passing through the controlled waterway opening. Wherever practicable, two or more of the four methods suggested should be tried and the results compared. When large differences in estimated scour are obtained, every effort should be made to find reasons for the discrepancy. In case of doubt the more conservative estimate should be accepted, or specialist advice should be sought.

Appendix III provides an example of the calculations involved in selecting a waterway opening and estimating general scour.

Method 1: Direct inference from field measurements of scour

This method involves the measurement by sounding of depths and bed levels at existing bridge sites, sharp bends, constrictions, or other locations where the natural channel configuration is comparable to that proposed or expected at the future crossing site. The sounding should ideally be done under flow conditions comparable with design flood conditions, but this is seldom practicable in inland rivers. The measured maximum depths are used as a guide to estimating scoured depths in the proposed waterway opening. The method has its limitations, however, because the geological and bed-material conditions at the different sites may not be similar, the flow concentration in the proposed waterway opening may be more severe than at the measured location, and it may be impossible to obtain soundings under high flow conditions. Despite these reservations, however, every effort should be made to obtain and assess actual soundings.

The significance that can be attached to soundings obtained at flows considerably lower than design flood varies greatly according to the type of stream and the preceding flood history. In many sand-bed streams deep scour holes formed during a severe flood tend to refill quite quickly during the flood recession, whereas on some gravel-bed and hard-bed streams deep holes at certain locations appear to persist from year to year. Documentation and analysis of this problem is scarce.

Method 2: Regime method utilizing limited field measurements

The following method of estimating general scour is based primarily on recommendations made by Blench (refs. 4.8 and 4.9).

1

Obtain field measurements of the average geometry of the channel cross-section in a relatively straight 'incised' reach, by surveying and sounding a number of cross-sections, preferably during a flood event (by 'incised' is meant a reach that does not spill except in very high flows – see Figure 4.9). Then determine the bankfull discharge, or the highest non-spilling discharge Q_i, and the corresponding stage and average depth d_i (Figure 4.10a).

Compute the average incised discharge intensity under bankfull or highest non-spilling conditions:

$$q_i = \frac{Q_i}{b_i}, \qquad (4.2)$$

where b_i is the average channel width at half of the depth d_i corresponding to Q_i (Figure 4.10a).

2

Compute the average design discharge intensity in the proposed waterway opening

$$q_f = \frac{Q_f}{b_w}, \qquad (4.3)$$

where Q_f is the design flood discharge and b_w is the net width of the proposed waterway opening normal to flow, at half of the estimated scoured depth d_f (Figure 4.10b). In order to determine b_w, d_f should first be estimated by trial, and later adjusted if necessary after step 3.

3

Compute the average 'flood depth' in the controlled waterway opening

$$d_f = d_i \left(\frac{q_f}{q_i}\right)^m, \qquad (4.4)$$

where d_i is the average depth in the incised reach (Figure 4.10a), q_i is as in Eq. (4.2), q_f is as in Eq. (4.3), and m is an exponent dependent on the bed-material, ranging from 0.67 for sand to 0.85 for coarse gravel. Since q_f is dependent on d_f through b_w (Eq. 4.3), successive approximation may be required. d_f is visualized as the average scoured depth to be expected in a long, straight reach of the same net width as the proposed waterway opening.

4

Estimate the maximum general scoured depths in the waterway opening (not including local pier scour – see Section 4.5) by considering the approach conditions and layout of training works (see discussion following method 4 below). The references recommend that in general d_f should be multiplied by a factor not less than 1.4, and not more than 1.7 when guide banks (Chapter 5) are provided. Reliance must be placed on one's judgment to decide at which piers this maximum general scour might occur (see Figure 4.11).

In applying the above method it is essential to check that the incised reach surveyed has an erodible bed and is not bedrock-controlled as to depth, also that its bed material is similar to that at the bridge site. In unstable alluvial streams of braided channel pattern it may be impossible to find a suitable incised reach.

Method 3: Mean-velocity method utilizing limited field measurements

This method is somewhat similar to method 2 but uses the more easily visualized concept of cross-sectional mean velocity as a rough criterion of general scour.

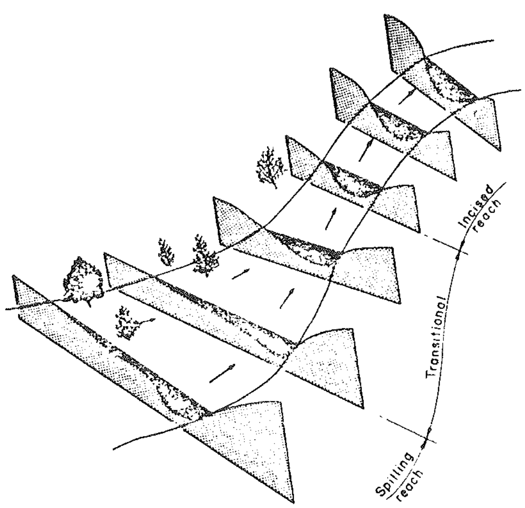


Figure 4.9 Sketch of a river at flood stage, illustrating the concept of 'incised reach.'

1

Obtain field measurements of the average geometry of the channel in the vicinity of the bridge site, if possible in incised reaches, at one or more relatively high known discharges. Compute the average cross-sectional mean velocity and extrapolate to design flow conditions, using a known or estimated stage-discharge relation and the Manning formula. If possible, check computed velocities against measured velocities.

2

Measure the net water area of the proposed waterway opening under design discharge, before scour, and compute the cross-sectional mean velocity through the opening. If this is significantly greater than the extrapolated average channel velocity at design discharge, general scour should be allowed for.

3

Determine by trial the average general scour level, assuming a trapezoidal cross-sectional shape, that will make the mean velocity through the waterway opening equal to the estimated average channel velocity at design discharge, as estimated by step 1.

4

Redistribute the trapezoidal cross-sectional area to give the worst expected cross-sectional shape and lowest elevation of general scour, as subsequently described in this section.

This method will tend to give somewhat greater estimates of average general scour than method 2, since it corresponds approximately to an exponent m of 1.0 in Eq. (4.4).

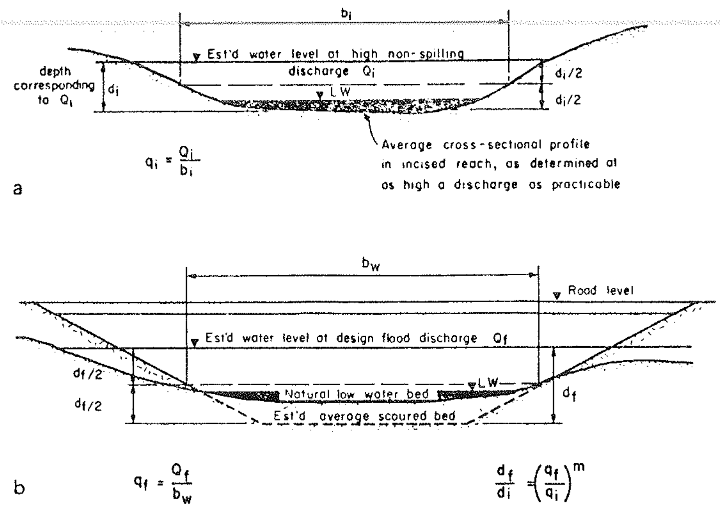


Figure 4.10 Sketches illustrating the determination of quantities for method 2 of estimating general scour in controlled waterway openings: (a) average cross-section of surveyed incised reach; (b) proposed bridge waterway section.

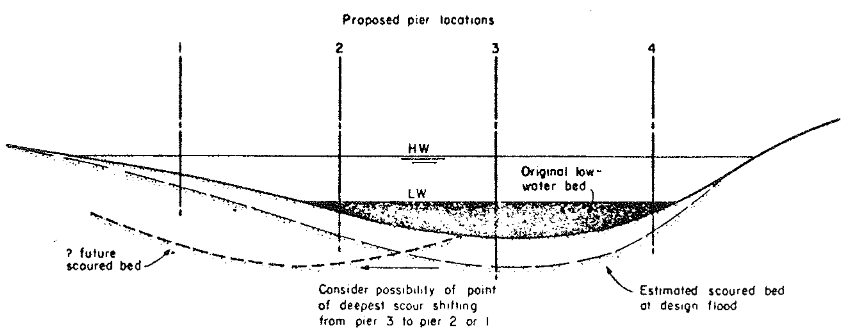


Figure 4.11 A hypothetical river cross-section, illustrating the problem of allowing for a shift in the position of deepest scour.

Method 4: Competent-velocity chart and table
This method can be used if the field measurements required for methods 2 and 3 are not available, and may be used in any case as a rough check on other methods. It depends on the hypothesis that general scour will proceed in the waterway opening until the mean velocity is reduced to a value just competent to move the bed material exposed at the scoured depth. In channels carrying substantial bed loads this principle is excessively conservative (see Section 4.2), but it can still be applied to estimate a maximum limit to scour, on the grounds that in certain circumstances the normal inflow of bed material might fail. The method is applied as follows.

1
Compute the mean velocity through the waterway opening at design discharge, assuming no scour. Determine the corresponding depth of flow and median diameter (D_{50}) of bed material based on a bulk sieve curve or equivalent (see Appendix IV).
2
For cohesionless materials, compare the computed mean velocity with the competent velocity indicated by Figure 4.12,* using the appropriate flow depth and D_{50} by weight. For cohesive materials, compare with Table 4.1.* If the computed mean velocity significantly exceeds the competent velocity, general scour should be allowed for.
3
Determine by trial the average general scour level, assuming an appropriate cross-sectional shape, that will make the mean velocity through the waterway opening equal to the competent mean velocity for the material exposed at that level, as given by Figure 4.12 or Table 4.1. The appropriate average depth of flow after scour should be used in selecting the competent velocity. For widely graded granular mixtures where some degree of paving might be expected as scour proceeds, it may be appropriate to select the competent velocity corresponding to a grain size larger than D_{50}, but the size selected should not be greater than D_{80}.
4
Estimate the maximum general scour as in step 4 of method 3.

Possible discrepancy between results of methods described
For alluvial channels carrying a considerable bed load, the mean waterway velocities (after scour) implied by methods 2 and 3 may be considerably greater than the competent mean velocity used for method 4. Where methods 2 and 3 imply or use a mean velocity more than 50 per cent greater than the competent value indicated by Figure 4.12, a special check of possible reasons for the difference should be made, and some caution should be observed before accepting scour levels based on the greater velocity.

* The bases of development of these data are explained in Appendix V. The data apply, strictly speaking, to straight, uniform channel flow, and their application to non-uniform flow as normally found in bridge waterway openings is not fully justified. They should therefore be treated with reservations.

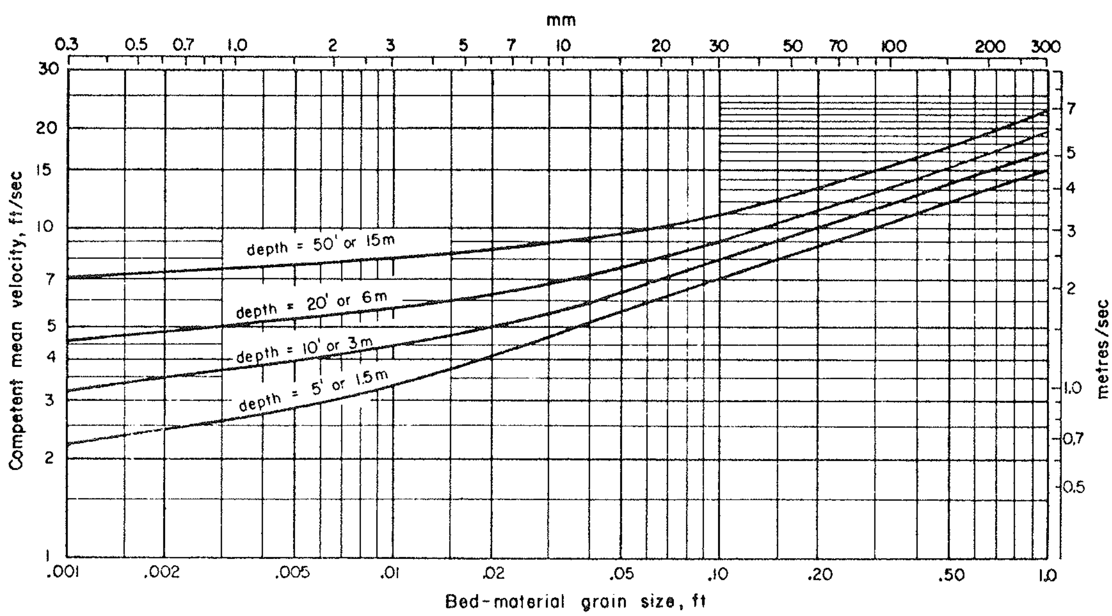


Figure 4.12 Suggested competent mean velocities for significant bed movement of cohesionless materials, in terms of grain size and depth of flow.

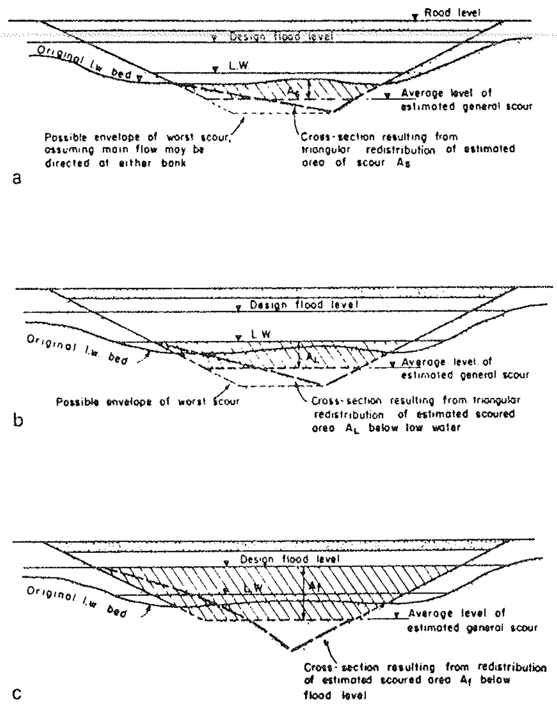


Table 4.1 Tentative guide to competent velocities for erosion of cohesive materials*

Depth of flow		Competent mean velocity					
		Low values – easily erodible material		Average values		High values – resistant material	
ft	m	ft/s	m/s	ft/s	m/s	ft/s	m/s
5	1.5	1.9	0.6	3.4	1.0	5.9	1.8
10	3	2.1	0.65	3.9	1.2	6.6	2.0
20	6	2.3	0.7	4.3	1.3	7.4	2.3
50	15	2.7	0.8	5.0	1.5	8.6	2.6

* Notes: (1) This table is to be regarded as a rough guide only, in the absence of data based on local experience. Account must be taken of the expected condition of the material after exposure to weathering and saturation. (2) It is not considered advisable to relate the suggested low, average, and high values to soil shear strength or other conventional indices, because of the predominating effects of weathering and saturation on the erodibility of many cohesive soils.

Figure 4.13 Various alternatives in graphically redistributing the cross-sectional area of a scoured waterway opening: (a) redistribution of net area of scour only (non-alluvial streams with erodible beds); (b) redistribution of scoured area below the low-water level (semi-alluvial streams with limited bed movement); (c) redistribution of scoured area below the design flood level (alluvial streams with highly mobile channels).

Estimation of maximum general scour from a computed average level

Step 4 of methods 2, 3, and 4 above requires that the computed cross-sectional area of the waterway opening, after scour, be redistributed in some manner to yield the lowest estimated level of general scour. This step probably introduces more uncertainty than any other into the scour estimates. In general the redistribution should be done graphically with reference to Figure 4.13, Figure 4.11, and the following points.

1

The procedure given under step 4 of method 2 above, i.e., multiplying the average scoured depth below flood level by a factor of 1.4 or more, appears warranted only for rather wide alluvial rivers where the surface and bed widths are not greatly different, and where shoaling and other bed-level changes can occur over the whole depth up to flood level. (The latter point is illustrated by Figure 4.13c.) In other circumstances the procedure is probably excessively conservative.

2

In non-alluvial streams with cohesive or semi-cohesive beds that are expected to scour to only a limited degree as a result of flow constriction, it is probably sufficient to redistribute the estimated net area of scour below natural bed, as illustrated in Figure 4.13a. The redistribution need not take the triangular form shown.

3

In intermediate types of stream with limited bed transport, the area to be redistributed may extend up to low water level or any higher level that may appear appropriate, depending on an assessment of the level to which the channel bed is likely to shoal (Figure 4.13b).

4

In figure 4.13 it is assumed that side slopes of the scoured area are maintained at a 1 upon 2 angle of repose. This should normally be ensured by providing rip-rap aprons where necessary (see Chapter 5).

5

The cross-sectional shape will depend on the approach alignment and on the layout of training works. A section on a sharp bend will tend to adopt a more or less triangular form below the highest level of shoaling. A straight alignment with parallel guide banks will favour retention of a more trapezoidal section. Triangular or irregular sections may, however, develop in alluvial channels with straight alignments, as bars pass through the opening.

6

On a bend the deepest point often tends to remain near the outer bank. In other cases it may be necessary to allow for an envelope of worst scour (Figure 4.13a and b), assuming that the deepest point can shift from side to side (see also Figure 4.11).

In view of a general lack of data on this question, little further guidance can be given. Considerable weight should be given to local experience where it has been suitably recorded.

Special circumstances affecting general scour
Consideration should be given to special circumstances that might increase the general scour over and above estimates made by the methods suggested. These include the following:

- jams and accumulations of ice and drift;
- lowering of normal downstream water levels, for example as a result of control wòrks, change of regime on a parent stream, etc.;
- beds of silt or organic material;
- obstruction of the waterway opening by mounds of stone rip-rap piled around piers;
- arrest of normal bed-load transport by upstream obstruction (not relevant to method 4).

Allowance for such circumstances should be based on experience and judgment.

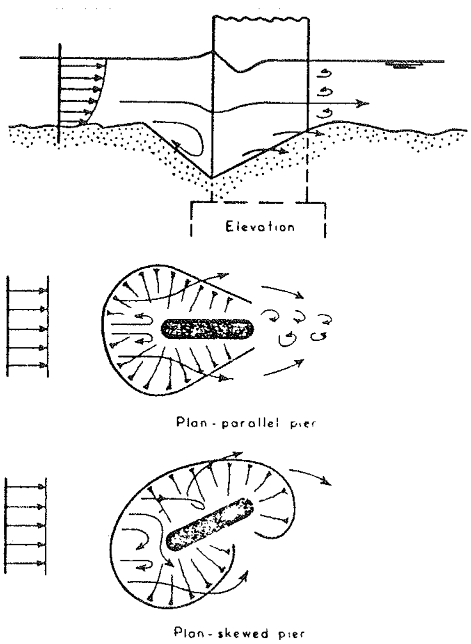


Figure 4.14 Usual form of local scour holes at piers, as demonstrated by model experiments.

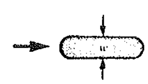
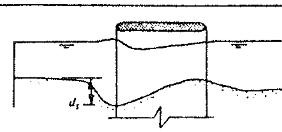
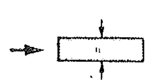
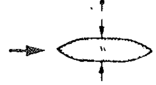
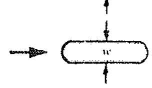
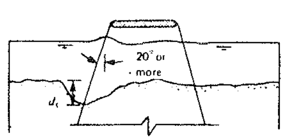
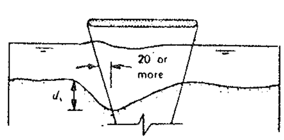
4.5 Local scour due to piers and abutments

Occurrence of local in addition to general scour
The scour as estimated in Section 4.4 should be visualized as occurring under a single-span bridge without piers in the channel. Piers placed in the waterway opening tend to produce additional local scour (Figures 4.3 and 4.14) even where they do not produce any significant reduction in the net waterway width.

Considerable detail on experimental findings concerning local pier scour is given in ref. 4.2, and in earlier publications referred to there. In general the local depth of scour depends on the pier width, length, shape, and alignment, on footing details, on velocities and depths of flow, on the type and size of bed-material, on the rate of bed transport, and on ice or drift accumulations. In practice these factors cannot all be taken into account, and it is necessary to use simplified relationships derived from model tests, which give an indication of the worst scour that might occur. Because local scour might be substantially increased by ice or debris accumulations around a pier, refined estimates of local scour are not warranted in many Canadian situations.

Local scour at circular or elongated piers
The local depth of scour (below the surrounding bed) at the nose of a circular pier or of an elongated pier *aligned parallel to the flow* should normally be taken as equal to the effective pier diameter or width near the general bed level multiplied by a factor as given in Table 4.2. These factors are intended as design values for non-cohesive materials that are expected to be mobile

Table 4.2 Local scour allowances for piers aligned parallel to flow

Pier shape in plan	Pier shape in profile	Suggested allowance for local scour*
		$d_s = 1.5\,w$
	Ditto	Ditto
	Ditto	$d_s = 2.0\,w$
	Ditto	$d_s = 1.2\,w$
		$d_s = 1.0\,w$
Ditto		$d_s = 2.0\,w$

* Note that if the depth of flow exceeds 5 w, the allowances should be increased by 50 per cent.

under design flow conditions, where no special protection is provided. Smaller allowances may be appropriate in more scour-resistant materials.

In special cases where piers of large dimensions or unusual shape are contemplated, and where it is important to estimate local scour fairly closely, it may be advisable to have flume tests conducted on a model pier using a mobile bed (Figure 4.3). The results of such model tests should be given due weight in arriving at estimates of local scour, but they should not be regarded as infallible. Principles on which model tests may be conducted are discussed briefly in Section 6.2. The most important requirement is that under design flow conditions the model bed-material should be in a comparable state of motion to the bed-material in the prototype.

Effect of pier skew

Experimental data and full-scale experience both demonstrate that if an elongated pier is substantially skewed to the direction of flow, local depths of scour may be very much greater than given by Table 4.2. Angles of attack greater than 5° to 10° should therefore be avoided wherever practicable. If flow directions are so variable or uncertain that large angles of attack must be allowed for, special model tests should be considered. Consideration may also be given to the use of circular piers or of open piers consisting of a row of circular columns, or to provision of scour protection as discussed later in Section 5.9.

Table 4.3, based approximately on data given by Laursen (ref. 4.10) and other experiments, is intended to indicate the approximate range of increase in local scour due to pier skew. The figures should be treated with caution, because there are substantial discrepancies between the results of different experimenters.

Table 4.3 Multiplying factors for local scour at skewed piers* (to be applied to local scour allowances of Table 4.2)

Angle of attack	Length-to-width ratio of pier in plan		
	4	8	12
0°	1.0	1.0	1.0
15°	1.5	2.0	2.5
30°	2.0	2.5	3.5
45°	2.5	3.5	4.5

* The table is intended to indicate the approximate range only. Design depths for severely skewed piers, where the use of these is unavoidable, should preferably be determined by means of special model tests. The values quoted are based approximately on graphs by Laursen (ref. 4.10).

As the angle of attack increases, the point of maximum scour tends to shift downstream of the pier nose along the exposed side. In cases of severe skew it may even occur downstream of the pier tail.

Effect of footings

Table 4.2 applies basically to piers without exposed footings. A footing, caisson, or other enlargement (Figure 4.15) tends to reduce the local depth of scour provided the enlargement remains below the general scoured bed level under design flow conditions (Figure 4.15b) and is of sufficient horizontal extent to cover the area of local vortex action. Under such conditions the factors of Table 4.2 may be reduced at the discretion of the designer, provided the horizontal projection of the enlargement is at least equal to the diameter or width of the pier shaft. If, however, the enlargement is liable to be exposed to the main current (Figure 4.15c) its effect is similar to that of a larger pier, and the factors of Table 4.2 should then be applied to the footing width. A conical transition between the pier shaft and footing (Figure 4.15d) may be effective for minimizing local scour where the general scoured bed level is uncertain.

Where footings or caissons are not required for other purposes, a similar effect in counteracting local scour may sometimes be achieved by attaching a thin horizontal plate or slab structurally to the pier (Figure 4.15e). The exact effects of unusual pier geometries are difficult to estimate without making special model tests.

Effect of ice or drift accumulations

Accumulations of ice or drift may substantially increase local pier scour, especially if they are allowed to grow down to near the channel bed. For scour-susceptible piers, appropriate maintenance procedures should be adopted to forestall excessive accumulations. General experience is that a pier nose semicircular in plan, and vertical or only slightly raked in profile, is best for discouraging drift accumulations.

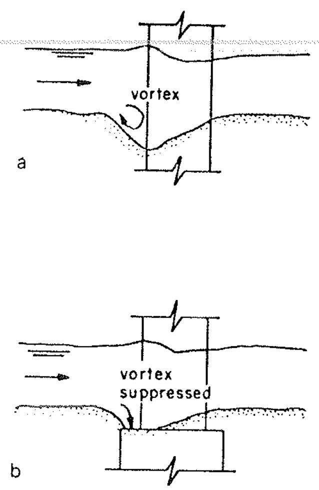
For relatively slender piers, where the expected local scour would otherwise be small, some allowance should normally be made for an increase in effective width due to accumulations.

Local scour at abutments

It is difficult to give reliable guidance on the estimation of local scour at abutments, because of the wide variation in geometry and approach flow conditions that can occur in practice, and because of a comparative lack of experimental data. Where it appears advisable to allow for local scour resulting from the obstructive effects of closed abutments projecting into the flow, it is recommended that reliance be placed on previous local experience, on special model tests, or on specialist advice. Scour near open abutments should be regarded in the context of general scour in controlled waterway openings, as discussed in Section 4.4. Section 5.7 also touches on this problem.

Rip-rap protection against local scour

Local scour at piers and abutments can often be reduced or eliminated at minor expense by backfilling foundation excavations with rip-rap or by providing aprons. Details are discussed in Chapter 5.



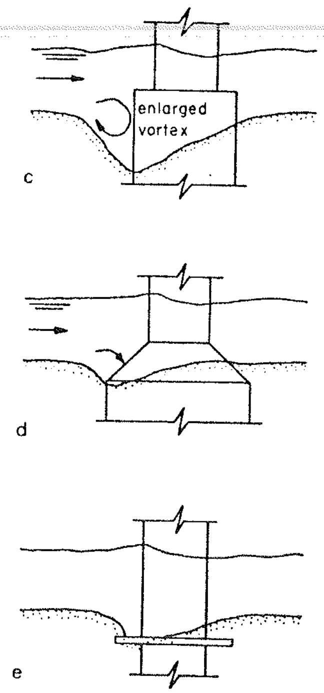


Figure 4.15 Effect of pier footings on local scour: (a) pier without footing; (b) pier with footing below the general bed level; (c) pier with footing or caisson projecting above the general bed level; (d) pier with conical transition between shaft and footing; (e) collar instead of footing.

4.6 Natural scour at uncontrolled bridge crossings

Applicable circumstances

It is sometimes necessary to estimate scour for cases where the proposed waterway opening is so wide that it is not appropriate to estimate general scour as suggested in Section 4.4. In such cases it is, however, necessary to allow for natural scour of the channel as well as local scour induced by the piers. This is especially relevant where an uncontrolled crossing is located on a channel bend (see Section 2.5), because bends on alluvial streams are usually subject to significant scour during flood periods (see ref. 4.2). Even on straight reaches, however, allowance should be made for natural scour associated with migration of bed forms and shifting of the thalweg.

Inference from field measurements

Wherever possible, estimates of maximum natural scour should be based on soundings of maximum scoured depths at the site or at comparable sites on the same stream, made under flow conditions comparable with the design flow conditions. Appropriate soundings can be obtained more easily in tidal channels, where flows comparable with design conditions may occur fairly frequently, than in rivers where design flows are normally of rare occurrence. Although in some rivers deep scour holes at sharp bends appear to persist relatively unchanged for years, in others they appear to fill in quite quickly after major floods. Therefore scour observations made under low-flow conditions should be used with caution unless the characteristics of the river are well known.

Table 4.4 Values of the Lacey 'silt' factor f (adapted from Indian Roads Congress Bridge Code, 1966, ref. 1.2)

Mean grain size of cohesionless bed material, mm	Value of f
0.08	0.5
0.16	0.7
0.23	0.85
0.32	1.0
0.50	1.25
0.72	1.5
1.00	1.75
1.30	2.0

A suggested method of inferring past scour levels is to investigate the sub-bed stratigraphy by boring, density logging, and other geotechnical methods (ref. 4.11). It has been claimed that the lowest level of recent scouring can often be detected by differences in subsoil density and other properties, but interpretation of the data is necessarily subject to considerable uncertainty.

Estimation by Lacey's regime formula (sandy alluvial channels)

A recent Indian bridge code (ref. 1.2) recommends that, where appropriate field measurements are not available, scoured depths in unconstricted alluvial rivers may be estimated with the aid of an empirical regime formula due to Lacey (ref. 4.7):

$$d_m = 0.47 \left(\frac{Q}{f}\right)^{1/3} \qquad (4.5)$$

where d_m is the mean depth at design discharge, in ft or m (defined as the wetted area divided by the surface width); Q is the design discharge, in ft^3/s or m^3/s; and f is Lacey's 'silt factor' (values according to Table 4.4). The water surface level corresponding to Q must be known in order to determine scour levels from the equation. The equation implies that the channel width follows Eq. (4.1), with $C = 2.67$.

Eq. (4.5) is plotted in Figure 4.16 for three values of f. Unless experience indicates otherwise, f should normally be taken as 1.0 for sandy materials. The formula should be equally applicable to alluvial rivers and to tidal channels if the beds are sandy, but it may tend to give excessive depths in more resistant materials.

Eq. (4.5) gives only an estimated mean depth across the channel section. To estimate the maximum natural scoured depth a multiplying factor must be applied. Table 4.5 gives coefficients recommended by the Indian code (after Lacey), based mainly upon considerations of cross-sectional shape. The coefficient for 'noses of piers,' which derives from early Indian experience with relatively large circular piers, does not take into account the important factors of pier width and alignment. For relatively slender piers it is probably better to ignore it and to estimate the local pier scour separately as indicated in Section 4.5. The terms 'moderate' and 'severe' for bends presumably take into account both the deflection angle and the ratio of channel width to radius of curvature, but more precise guidance is not available. Judgment must be used to determine whether the maximum depth might shift to any pier in the course of time (see Figure 4.11). Careful evaluation of channel trends and processes is advisable.

Table 4.5 Empirical multiplying factors for maximum scoured depth (to be applied to the Lacey mean depth, Eq. 4.5)

Nature of location	Factor
Straight reach of channel	1.25
Moderate bend	1.5
Severe bend	1.75
Right-angled abrupt turn	2.0
Noses of piers*	2.0
Alongside cliffs and walls	2.25
Noses of guide banks	2.75

* See Section 4.6 of text for comments.

Allowance for migration of bed forms

The height of migrating dunes and bars in natural alluvial streams can be as much as half the depth of flow. In channels subject to bed forms (Figures 4.17 and 4.18) allowance should therefore be made for a possible depth of scour below general bed levels of up to 25 per cent of the average depth of flow at flood stage. Judgment must be used to decide whether this figure should be added to the estimated natural scour at bends. The factor of 1.25 for straight reaches given in Table 4.4 does not allow for bed forms, but only for the roughly trapezoidal or elliptical shape of straight cross-sections: allowance for bed forms as indicated above would increase the factor to approximately 1.5.

An allowance for scour due to bed-form migration should, in theory, be made also for certain controlled waterway openings, but in most cases the procedures recommended in Section 4.4, combined with adequate safety margins, probably make sufficient allowance.

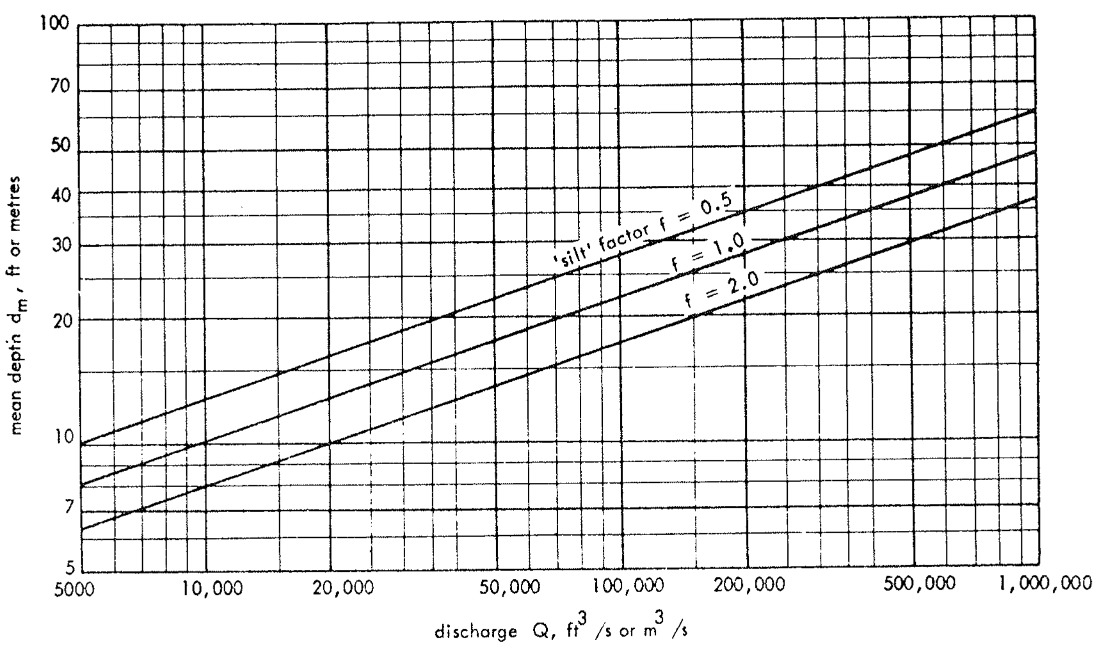


Figure 4.16 Plot of Eq. (4.5) for mean depth in unconstricted sandy alluvial channels.

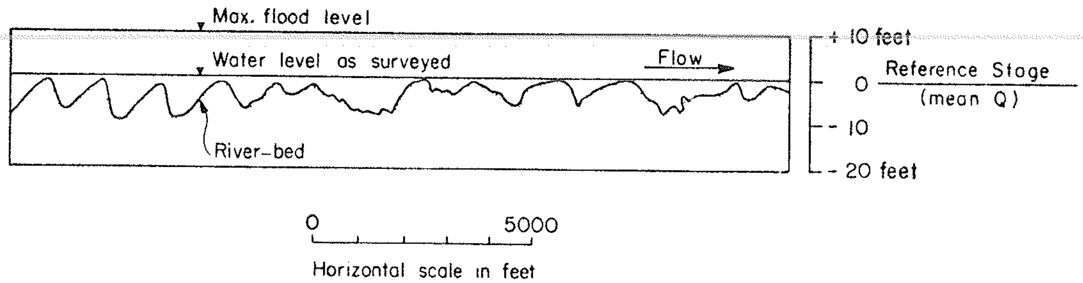


Figure 4.17 Longitudinal profile of migrating bed-forms in a river with a sandy bed.

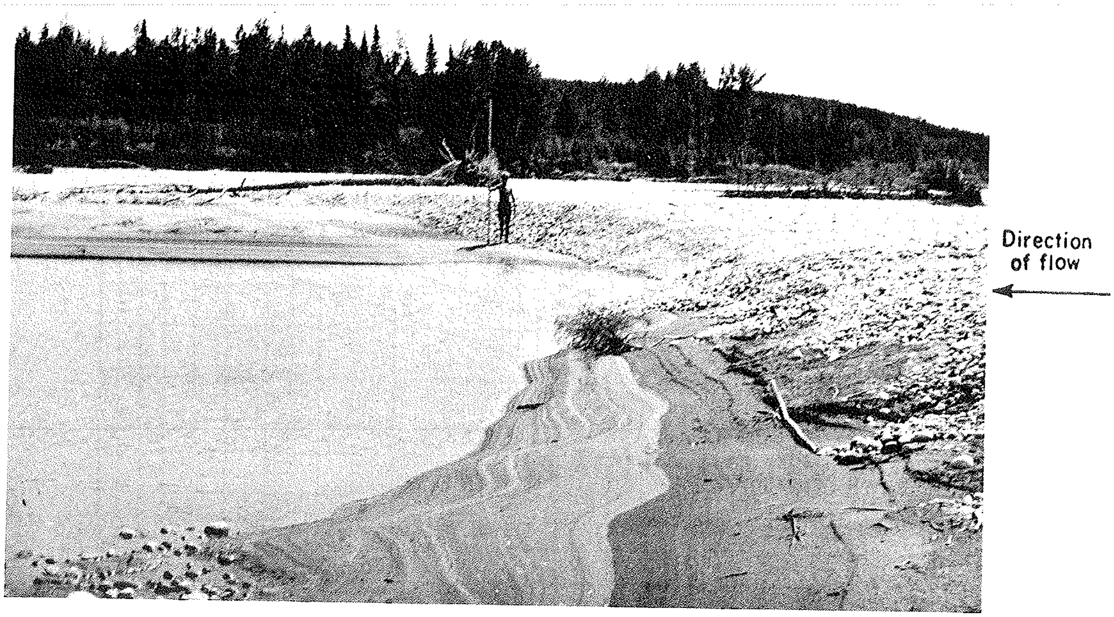


Figure 4.18 Front of a migrating bed-form in a river with a gravel bed, as seen in low flow conditions shortly after a period of high flow.

4.7 Combination of scour effects and selection of safety margins

Combination of scour

Scour as estimated according to Sections 4.4, 4.5, and 4.6 should normally be combined as follows.

1
Estimate the average level of general scour in a controlled waterway opening according to Section 4.4, or of natural scour at an uncontrolled crossing according to Section 4.6.

2
Draw the estimated scoured cross-section or the envelope of worst scour, with reference to Figures 4.11 and 4.13, Table 4.5, and preceding recommendations.

3
Estimate the local depths of scour at piers according to Section 4.5 and draw these below the general scour levels to obtain minimum levels at pier locations (Figure 4.1).

4
Consider the advisability of allowing for progressive channel profile degradation or migration of bed forms, and modify the levels accordingly.

Safety margins against scour

Because of the inherent uncertainty of scour estimates and the complex considerations involved, it is difficult to give general guidance on safety margins against scour. The following factors should be taken into account in the final analysis:

- reliability of basic data, especially hydrologic and geotechnical;
- probability that extreme flows might exceed limits selected for design estimates;
- foundation type and liability to failure in event of actual scour exceeding estimated scour;
- seriousness of consequences of total or partial pier failure;
- experience of the designer in comparable situations;
- additional cost of providing more security.

4.8 Common backwater effects and their relation to the waterway opening

Types of backwater effects

Backwater refers to the raising of natural (flood) water levels as a result of the constricting or obstructing effects of bridges and associated road approaches. The height by which the natural level is raised at any point is referred to as 'afflux.'

It is necessary to distinguish between the following types of backwater effects.

1
Backwater on a flood-plain resulting from construction of a long, skewed or curved road embankment, where the bridge opening is in effect located up-valley from one end of the embankment (Figure 4.19a). The backwater effect along the embankment arises from ponding of water along a line running obliquely down-valley. In the case of steep rivers with wide flood-plains the effect can be very large, since a large pond is created. This type of effect can be prevented by choosing a suitable location and alignment, or by providing dikes to close off the affected part of the flood-plain from flood waters (see Section 5.5), or possibly by providing a relief span.

2
Backwater in an incised river channel without substantial overspill, resulting in part from constriction of flow through an opening somewhat smaller than the natural cross-section, and in part from obstructive effects of piers (Figure 4.19b). The afflux arising from this type is seldom large, but may be significant in occupied areas.

3
Backwater in a river with flood-plain, where the road crossing is more or less square to the valley but the road approaches block off overbank flow (Figure 4.19c). In these cases the afflux may be significantly greater than in type 2.

The effect of guide banks (see Section 5.3) appears to be generally to reduce type 3 backwater effects by improving the hydraulic efficiency of the opening (ref. 4.12), but there is some doubt as to whether this is necessarily true for steep streams.

In some cases considerations of allowable afflux rather than scour may control the waterway opening size. In other cases estimation of afflux is important where damage is alleged to have resulted from enhanced flooding due to road and bridge construction.

Effects of scour and other factors on backwater

The effect of general scour in the waterway opening is to reduce the afflux that might otherwise occur as a result of type 2 or 3 backwater effects. The reduction can be allowed for in the method of estimating afflux mentioned in Section 4.9 below. If the consequences of backwater are important it may be advisable to estimate afflux on the assumption that scour will not necessarily occur. Artificial enlargement of bridge waterways by excavation, to reduce afflux, is discussed in ref. 4.14.

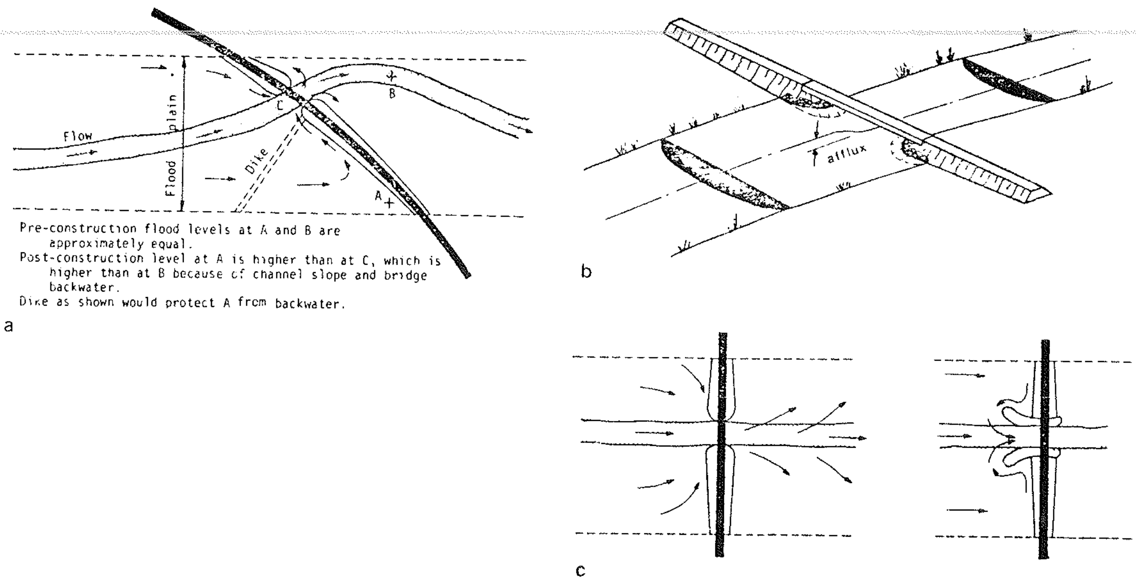


Figure 4.19 Three types of backwater effect associated with bridge crossings: (a) effect of a skewed embankment across a flood-plain; (b) effect due to constriction of the channel flow; (c) effect due to constriction of the overbank flow, both without and with guide banks.

In many Canadian rivers the stage-discharge relation (see Chapter 3) is unstable and poorly defined, or is subject to erratic deviations as a result of ice or drift accumulations. In such circumstances refined calculations of bridge backwater effects are scarcely warranted.

4.9 Calculation of backwater effects due to bridge constrictions

Several detailed methods for calculating type 2 and 3 backwater effects due to bridge constrictions are available in the published literature. Only a brief discussion of their principal features will be given here. The basic theory of flow through rigid-boundary, open-channel constrictions is outlined by Chow (ref. 4.13), pp. 475–93.

A somewhat indirect method of calculating backwater effects using charts and coefficients based on laboratory experiments is outlined in ref. 4.13. It was developed as an offshoot of a method for estimating flood discharges at channel contractions, and is sometimes referred to as the U.S. Geological Survey method.

BPR method

A more direct method of calculating backwater effects is that of the U.S. Bureau of Public Roads (ref. 4.14). It is based on the same theory of short constrictions (neglecting channel friction), and introduces charts based on further laboratory experiments and field measurements for selection of appropriate coefficients. A computer program for solution is available from the Bureau of Public Roads, and variants are available from other agencies.

For reasonable validity of the BPR method the following restrictions should be noted (see ref. 4.14):

- channel essentially straight and of uniform cross-section;
- approximately constant bed slope;
- no appreciable general scour;
- subcritical (tranquil) flow;
- relatively narrow flood-plain with no strong concentrations of flow along upstream side of approach embankments.

A procedure for adjusting calculated afflux to allow for scour is included in ref. 4.14.

4.10 Uncommon backwater effects

It is advisable to be aware of unusual backwater effects that might occur in special circumstances, although they might never arise in ordinary bridge design practice.

Effects of a submerged superstructure
If insufficient clearance is provided above the design high-water level and as a result the flow reaches the bottom of the superstructure, the bridge will act as a short culvert. If the leading edge of the bridge's underside is sharp-cornered, the height of afflux may rise rapidly after the opening is closed.

For bridges which are designed to be submersible under certain conditions, it is advisable to provide a rounded nosing on the leading edge of the deck, in order to improve the hydraulic efficiency and to reduce the liability to catch driftwood and ice. The height of afflux can be estimated by the method given in ref. 4.14.

Effects of supercritical flow
In contrast to the usual drop at a constriction in subcritical flow, in supercritical flow water-levels may rise suddenly at the contracted section. The phenomenon of 'choking' is particularly likely if the Froude number only slightly exceeds 1.0. 'Choking' may occur even in subcritical flow if the constriction is severe enough. For details see ref. 4.15, pp. 248-9 and 116-18. Ref. 4.14 discusses the case of flow passing through critical depth at a bridge.

Supercritical flow is not common in natural rivers, but occurs in certain mountain streams and artificial channels.

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5
Scour protection and channel training works

5.1 Protection of foundations against scour

General principles of design

The need for scour protection can be minimized by locating bridges on stable tangential reaches of channels and by placing foundations on inerodible materials. However, as indicated in Sections 1.1 and 2.5, such a solution is not always practicable, economical, or desirable from a road alignment standpoint.

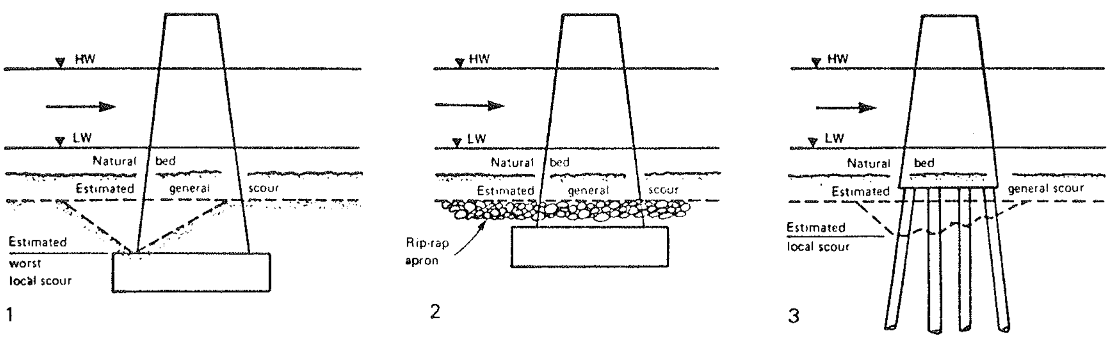
Having estimated the probable lowest scour levels as indicated in Chapter 4, several choices are open to the designer in selecting the type and elevation of the foundation (Figure 5.1).

1
Place the bottom of the pier footing below estimated lowest scour levels, making allowance for local scour caused by the pier shaft and footing, and including an appropriate margin of safety. (See Section 4.5 for effects of footings on local scour.)

2
Place the bottom of the pier shaft below estimated lowest general scour, and provide protection against local scour effects as indicated below. (See Section 4.5.)

3
Support the pier shaft or footing on piles or columns sunk well below lowest scour levels, and designed to be secure when their upper parts are exposed by scour.

4
Construct the pier in the form of a row of piles or columns without a footing or solid shaft, sinking these well below esti-



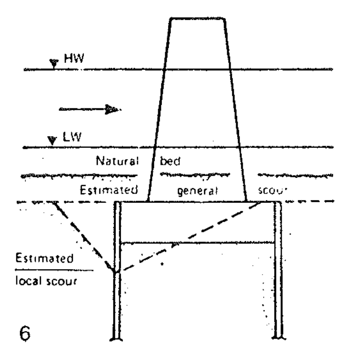


Figure 5.1 Various ways of catering for scour in the design of pier foundations (see also Figure 4.15): 1, bottom of footing placed well below the estimated lowest scour level; 2, footing placed below the general scour level and protected by a rip-rap apron against local scour; 3, pier supported on piles designed to withstand the exposure of their upper parts, with alternatives 4, piles continued upwards to form a multi-column pier, and 5, rip-rap apron placed as in 2; 6, footing protected by a sheet-pile skirting.

mated scour levels and designing them to be secure when their upper parts are exposed by scour.

5

As in 3 above, but protect the upper parts of piles or columns against exposure by local scour.

6

Protect the spread footing or piles against undermining by means of a sheet-pile skirting tied to the foundation. The skirting must itself be designed against scour and loss of support.

The choice among these and other possible alternatives depends on a great many factors including load-bearing requirements, subsoil conditions actually encountered, economics, feasible construction methods and schedules, inspection procedures, etc. The following points may be relevant in making a choice.

1

Since the worst local scour at a pier or other obstruction is very directly related to the width of the obstruction (see Section 4.5), it is important that pier shafts and footings liable to be exposed to strong currents should be as narrow as is consistent with structural requirements. Noses should be streamlined and long axes should be aligned parallel to the principal local current direction. In shifting channels where current directions are difficult to predict, it may be advisable to control them by means of training works, or to employ a pier consisting of a row of separate circular columns. (The last solution may not be attractive where the stream carries heavy ice or floating debris.)

2

Footings or caissons should, if possible, be kept well below estimated general scour levels.

3

Protecting shallow foundations by heaping stone around them (a practice often adopted with existing bridges) is often an unsatisfactory solution because the stone tends to require continual replacement and the heaps reduce the available waterway area, thereby increasing average velocity and scour between the piers.

4

Placing a spread footing directly on a non-cohesive material not far below the estimated scour level necessarily entails a certain amount of risk, because of the present uncertainty of scour estimates, and of possible accidents and unforeseen regime changes that might produce worse scour. The advisability of using piles driven well below the estimated scour level should always receive consideration, because the expense of sinking a caisson or footing in non-cohesive material to levels easily reached by piles is usually prohibitive.

5

Where there is a history of log or ice jams, the possibility that severe scour may occur as a result of massive blockage of the waterway opening should be considered.

6

Use of a sheet-pile cofferdam to protect footings and piles may be detrimental if the cofferdam is much wider than the pier itself, since its effect may be to greatly increase local depth of scour.

Protective aprons around piers and footings

Where it is economical to prevent the development of local scour holes immediately around piers, aprons consisting of stone riprap, flexible mattress, or other suitable materials may be provided. The apron should preferably be laid so that its surface is below the expected general scour level. Where this is not practicable it should be designed as a launching apron, as discussed subsequently in Section 5.8, and the reduction in waterway area caused by its presence after launching should be taken into account. The apron should project around the nose of the pier by a distance equal to 1.5 times the pier width, and should be equal in thickness to twice the D_{50} size of the stone. The stone size may be selected from Figure 5.4, taking the local velocity as approximately 1.5 times the mean velocity through the waterway opening. Where the cost of aprons is appreciable, it may be advisable to conduct model tests as an aid to estimating the required stone size and apron extent.

Maintenance and construction procedures

Debris caught on piers should be removed as soon as possible. Surveys should be made after floods and jams, using divers where warranted.

Foundation excavations in granular beds may usually be backfilled with the natural river-bed material. During winter construction it may be necessary to backfill using dry, imported granular material. For this purpose pit-run sands and gravels with grain size reasonably representative of the bed material may be used. Clay should not be used for backfilling pier excavations in sand beds, since the clay plug will become an obstruction to flow, increasing local scour beyond expectations and losing the advantage of an otherwise slender and hydraulically efficient pier shaft. Excavations for spread footings in cohesive materials should be poured neat where possible. The backfill material may either be clay, a suitable coarse pit-run gravel, or stones, placed up to the top of the cohesive stratum or other selected elevation.

Temporary sheet-pile cofferdams used for construction purposes should preferably be removed unless this is liable to cause deterioration of the foundation material. If left in place, they should be cut off at or below bed level, and any projection above expected general scour levels should be taken into account when estimating local scour.

Berms used for cofferdams and for construction causeways should be removed and the river-bed restored to its original natural condition immediately upon completion of the work or prior to the flood season. The use of earth berms in lieu of sheet pile cofferdams and work bridges should be viewed with caution, and consideration must be given to the adverse effects on pier scour and channel regime that may result from temporarily constricting the river. Work causeways should be designed to wash out in the event of an unusual flood emergency.

Natural vegetation which serves as protection against erosion should as far as possible be preserved during construction, and due weight should be given to the effects of alternative construction procedures on the natural regime of the stream and on the biological habitat.

5.2 Applications of bank protection and training works

Reasons for use
Many bridge sites require the use of some type of bank protection or training works to protect the bridge and its approaches from damage by flood water. Modern standards of road alignment are leading to increasing use of training works to make naturally unfavourable sites usable. Such use should always be considered as an alternative to routing the roadway to a more favourable bridge site. A good appreciation of river behaviour is required for optimum use of training works.

Specific functions of bank protection and training works in relation to bridges and their approaches include:

- to stabilize eroding river-banks and channel location in the case of shifting streams;
- to economize on bridge lengths by constricting the natural waterway;
- to direct flow parallel to piers and thereby to minimize local scour;
- to improve the hydraulic efficiency of a waterway opening, thereby reducing afflux and scour and facilitating passage of ice and drift;
- to protect road approaches from stream attack and to prevent meanders from folding on to the approaches;
- to permit construction of a square bridge crossing by diverting the channel from a skewed alignment;
- to reduce the over-all cost of a road project by diverting the channel away from the base of a valley slope, thereby allowing a reduction in bridge length and height;
- to secure existing works, or to repair damage and improve initial designs.

Types
The principal types of bank protection and training works recommended for use at bridges are as follows:

- bank and slope revetment: rip-rap, paving, or other covering placed on a stream bank, embankment, or headslope to prevent erosion;
- guide banks (sometimes referred to as 'spur dikes'): embankments constructed more or less parallel to the stream to direct the flow smoothly through the waterway opening;
- spurs (sometimes referred to as 'groins'): embankments or walls constructed more or less square to a stream bank or shore;
- dikes: embankments or walls constructed to prevent flooding of lands adjacent to roads and bridges;
- channel diversions: artificial cuts made in order to improve flow alignment through the bridge opening, or to facilitate layout and construction of adequate training works of other types.

Other devices sometimes used, such as wire fences, steel jacks, willow mattresses, pile rows, are not discussed in detail here. Many of these are limited in their application because of their ugly appearance or their inability to withstand ice and drift.

Figure 5.2 Aerial oblique photograph showing various types of training works on a braided gravel river: 1, dike, 2, spurs; 3, guide bank; 4, protected embankment end slope. (Constructed 1962)

It is difficult to give general guidance regarding the particular type of works to be used in individual cases: much depends on feasible construction methods. Their design is to a large extent an art, and many questions concerning the relative merits of various types have not been definitively answered. Extensive information on applications of bank protection training works in river engineering can be found in refs. 5.1 to 5.4 inclusive. Figures 5.2 and 5.3 show several types of works in use in highway practice.

General principles of design and construction
The following principles should be followed in designing and constructing bank protection and training works.

1
The cost should not exceed the benefits to be derived. Permanent works should be used for important bridges on main roads and where the results of failure would be intolerable. Expendable works may be used where traffic volumes are light, alternative routes are available, and the risk of failure is acceptable.

2
Designs should be based on studies of channel trends and processes and on experience with comparable situations. The ultimate effects of the works on the natural channel both downstream and upstream should be considered.

3
Site reconnaissance by the designer is highly desirable. If circumstances prevent on site inspection, aerial reconnaissance or air-photo study are possible substitutes.

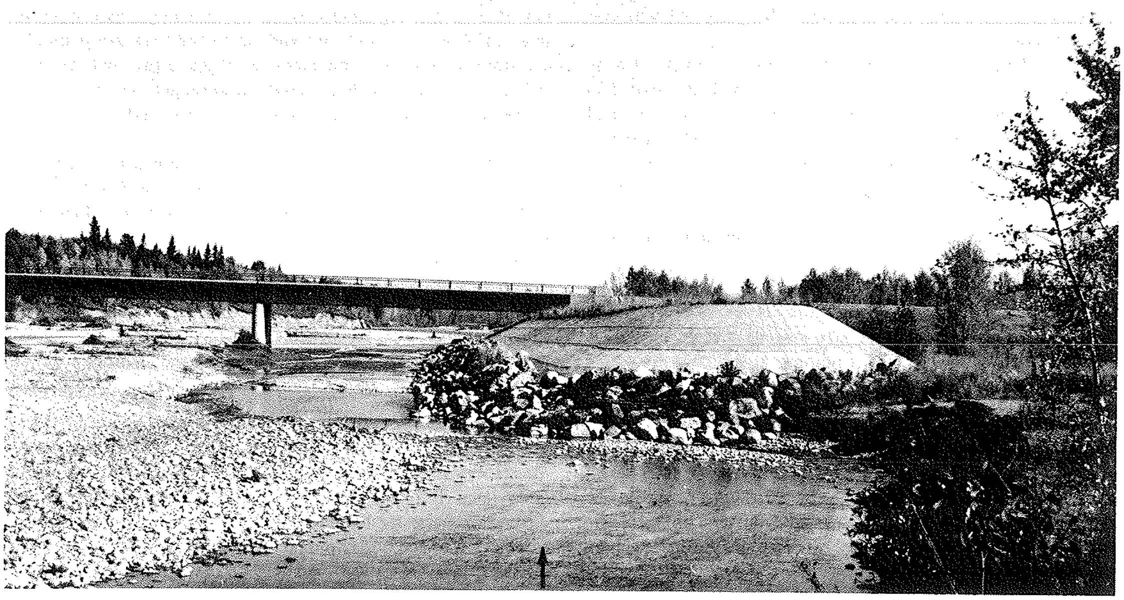


Figure 5.3 View of a guide bank from upstream, showing concrete slope revetment and rip-rap launching apron.

4
The possibility of using model studies as a design aid should receive consideration at an early stage.
5
The works should be inspected periodically after construction with the aid of surveys, to check results and modify the design if necessary. The first design may require modification. Continuity in treatment, as opposed to sporadic attention, is advisable.
6
In lieu of maintaining an existing road or bridge, consideration should be given to relocating it away from the river hazard.

Reference should also be made to Section 2.5 regarding basic design criteria for bridge crossings, and to Section 4.3 regarding procedures for design of waterway opening.

5.3 Bank and slope revetment

Selection of revetment type

The type of revetment to be used will depend upon the cost of materials and upon considerations of durability, safety, and appearance. Commonly used types of flexible revetment include stone rip-rap, stone-filled wire baskets (gabions), wire mesh over a layer of stones, bagged concrete, and articulated concrete slabs. Rigid types include poured concrete slabs, soil-cement, asphaltic concrete, and log cribs.

Attention is concentrated here on stone rip-rap because of its considerable advantages over other types in many circumstances. To quote ref. 5.1 in abridged form:

- it is flexible and is not impaired by slight movement of the embankment resulting from settlement;
- local damage is easily repaired;
- no special equipment or construction practices are necessary;
- appearance is natural;
- vegetation will often grow through the rocks;
- additional thickness can be provided at the toe to offset possible scour;
- wave run-up is less than with smooth types.

An additional advantage is that, for pedestrians, it presents less danger of slipping than concrete slabs or other smooth types of revetment.

The other types of flexible protection mentioned above have all been applied successfully in road and bridge practice, but some of them are more susceptible to ice damage than rip-rap. The use of vegetation consisting of willows and dense bush should be considered. Natural bush cover should be preserved wherever practicable during construction.

The most common type of rigid revetment consists of a reinforced concrete slab, usually 4 to 6 inches thick, poured in place on the embankment. It is used where a permanent type of protection able to withstand ice and debris is required. The design should include a granular backing and/or weep holes to reduce hydrostatic pressures during falling stages. The slabs should be terminated in such a way that they cannot be 'peeled off' by the current, either by turning them into the bank or by placing a rip-rap transition.

Determination of rip-rap stone size against stream flow

Methods of selecting the stone size may be divided into three categories – local experience, empirical rules, and hydraulic charts or formulas.

1

Local experience may be relied upon where sufficient installations have been tested in service under floods approximating to design conditions. On the basis of such experience some organizations have developed empirical data on required stone sizes for the various types of situation they encounter. Such an approach was used extensively in the past and still finds application.

2

Empirical rules that may be mentioned include that of Blench (ref. 5.5), which reads as follows: 'A rough guide is that a large sand bed river will normally need stone about 150 lb if it does not have a very large bed-load; a small one might have stone as small as 50 lbs. A gravel river with small bed-load charge should use stone at least twice the diameter of the largest material that rolls on the bed, if moderate attack is expected; for very violent attack, as at a major spur nose, three times size is safer.'

3

The required size of stone for stability depends theoretically on the local flow velocity adjacent to the slope, stone density, depth of flow, degree of turbulence or eddying, curvature of flow, and slope angle. Practical formulas and charts published by different agencies vary considerably in their predictions, however (refs. 5.1, 5.6, 5.7, 5.8). A general difficulty in using hydraulic criteria is that the size obtained is quite sensitive to the assumed flow velocity, which may be difficult to estimate in practice. A systematic method of allowing for curvature and large-scale turbulence is also lacking.

Figure 5.4, adapted from ref. 5.7, compares graphs of stone size vs. local flow velocity against the slope, based on the recommendations of four agencies in the United States. The spread is quite large, but it should be noted that different agencies use different criteria for determining the representative size of mixtures. Adjustment to a common basis, say D_{50}, would reduce the discrepancies. A suggested compromise curve, assuming a specific gravity of 2.65, is shown on the figure.

In the absence of data from the field or from model tests, the

local velocity against the slope of an embankment more or less parallel to the flow may be taken as approximately two-thirds of the cross-sectional mean, where the channel is straight. For flow around a severe bend, the velocity near the outer bank may be up to four-thirds of the cross-sectional mean (ref. 5.1). Local velocities at the noses of guide banks and spurs may exceed cross-sectional means by considerably larger factors.

Where rock is quarried for use as rip-rap, the average size specified generally affects the cost to a relatively minor degree, so that refinement in size selection is seldom warranted. Where use is made of boulder deposits, however, estimation of the minimum stable size may be more critical. In view of the uncertainties in the data quoted, adequate factors of safety should be allowed where failure would have serious consequences, especially in locations such as the entry to a contraction where the bank may be subject to severe angles of attack.

Ref. 5.9 may be consulted for a theoretical discussion of the resistance of stones and precast shapes to flowing water.

Rip-rap grading specifications

There seems to be fairly general agreement that the exact size distribution of a rip-rap mixture is not critical, but that it should form a smooth grading curve without a large spread between

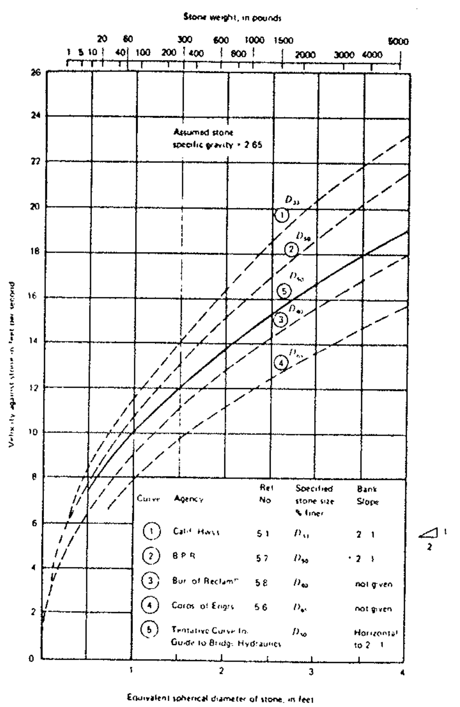


Figure 5.4 Graph of rip-rap size vs. local flow velocity, comparing the recommendations of four agencies in the United States. It is suggested that curve 5 be used as a guide.

Table 5.1 Suggested stone rip-rap gradings for stream bank revetment*

Class I
Nominal 12 inch diameter or 80 lb weight
Allowable local velocity up to 10 ft/sec
Grading specification:

	100%	smaller than 18 inches or	300 lb
at least	20%	larger than 14 inches or	150 lb
at least	50%	larger than 12 inches or	80 lb
at least	80%	larger than 8 inches or	25 lb

Class II
Nominal 20 inch diameter or 400 lb weight
Allowable local velocity up to 13 ft/sec
Grading specification:

	100%	smaller than 30 inches or	1500 lb
at least	20%	larger than 24 inches or	700 lb
at least	50%	larger than 20 inches or	400 lb
at least	80%	larger than 12 inches or	70 lb

Class III
Nominal 30 inch diameter or 1500 lb weight
Allowable local velocity up to 15 ft/sec
Grading specification:

	100%	smaller than 48 inches or	5000 lb
at least	20%	larger than 36 inches or	2500 lb
at least	50%	larger than 30 inches or	1500 lb
at least	80%	larger than 20 inches or	400 lb

* Note the percentages quoted are by weight; the sizes quoted are equivalent spherical diameters, $= 1.24\sqrt[3]{\text{volume}}$; the relative density is assumed to be in the range 2.4 to 2.9 (for a size-weight conversion chart see Figure 5.5).

median and maximum sizes. The size obtained from Figure 5.4 should be taken as the median diameter (D_{50}), which means that 50 per cent by weight of the mixture should be larger. Stone shape should be as near to cubical as practicable: in particular, thin slab shapes should be avoided. Stone should be subjected to soundness and durability tests.

Table 5.1 gives suggested grading specifications for three classes of rip-rap which should be suitable for a fairly wide range of streamflow situations. The table indicates approximate local velocities for which each class is suitable when used on side slopes of 1 upon 2. On steeper slopes the allowable velocities should be reduced somewhat, and on flatter slopes they may be slightly increased. Flow is assumed to be parallel to the bank.

Rip-rap thickness and placing
The thickness of the stone layer measured normal to the slope should be at least as great as the long dimension of the largest stones in the specified grading. Ref. 5.1 recommends at least two layers of overlapping stone so that slight loss of material does not cause massive failure. Unless the embankment consists of coarse gravel, a granular reverse filter blanket should be laid under the rip-rap to prevent the embankment from washing out between the stones. For narrow channels, the reduction in cross-sectional area caused by a thick layer of rip-rap may be significant, and a thinner form of revetment, such as a concrete slab, might be preferable.

The method of placing rip-rap is important in order to obtain the desired benefit. Individual placing of rocks is not often justi-

fied economically, but strict construction control of dumping is necessary to ensure proper meshing of stones, a reasonably even thickness and surface texture, and an even distribution of sizes without protrusion of isolated large stones. Isolated projections may provoke severe eddies leading to failure.

Stone size to weight conversion
Figure 5.5 shows the relationship between the stone weight and equivalent spherical diameter for specific gravities of between 2.4 and 2.9. The equivalent spherical diameter D_e is defined by

$$D_e = 1.24\sqrt[3]{\text{volume}}. \qquad (5.1)$$

Ref. 5.1 gives data relating the volume to the principal dimensions for various geometrical shapes.

5.4 Guide banks*

Uses
Guide banks (Figure 5.3 and 5.6) may be used to confine the flow to a single channel, to improve the distribution of discharge across the waterway opening, to control the angle of attack on piers, to break up meander patterns, and to prevent erosion of approach roads. Two guide banks are generally required when the waterway opening is located in the middle of a wide flood-plain or braided stream where the direction of the main flow can shift from side to side. A single guide bank may be sufficient when the stream is confined to one side of a valley, or where advantage can be taken of a natural inerodible bank on one side (Figure 5.7).

Width between guide banks
The minimum width between guide banks should be selected to provide the required waterway opening area through the bridge, as discussed in Chapter 4. In addition to limitations imposed by allowable scour, backwater, etc., the degree of constriction may also be limited by construction procedures: it is difficult and expensive to place an earth embankment in flowing water, and preferable to construct it on dry land or in still water. When choosing the location of guide banks, and before proceeding with a final design, it is essential to check that the subsoil is capable of carrying their weight.

* In some publications these are referred to as 'spur dikes.'

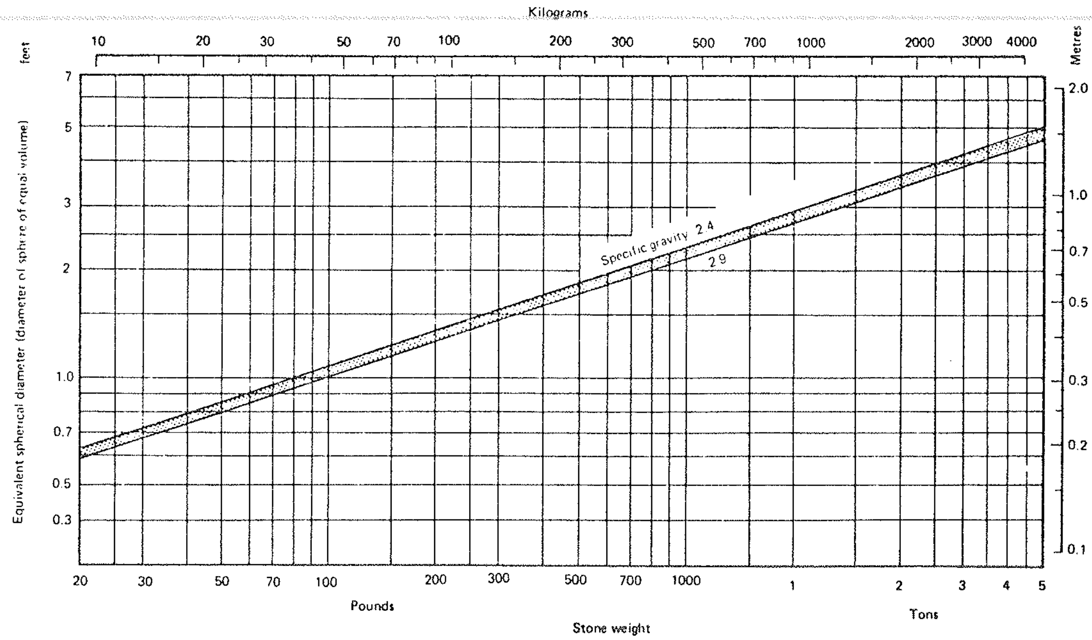


Figure 5.5 Stone size-weight conversion chart.

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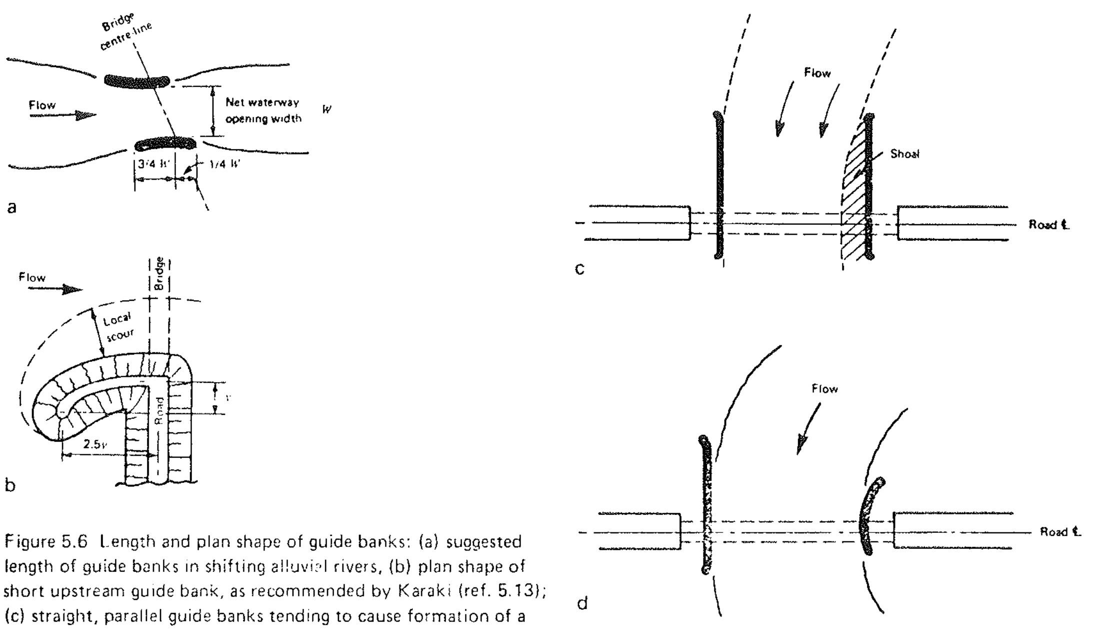


Figure 5.6 Length and plan shape of guide banks: (a) suggested length of guide banks in shifting alluvial rivers, (b) plan shape of short upstream guide bank, as recommended by Karaki (ref. 5.13); (c) straight, parallel guide banks tending to cause formation of a shoal on one side (an elliptical shape is preferable on the inner bank here); (d) combination of straight and curved banks on a channel bend.

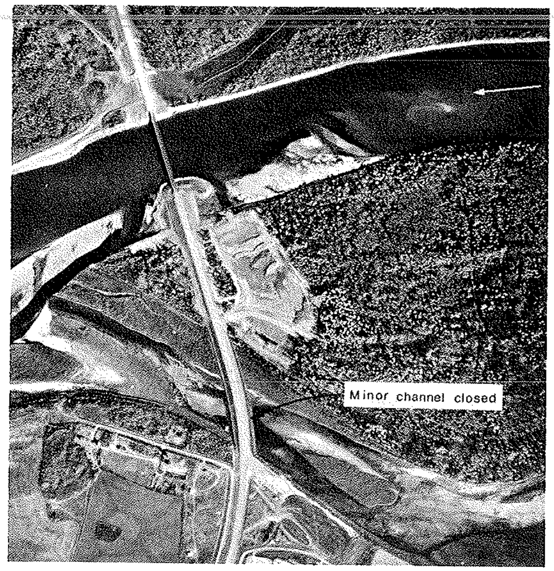


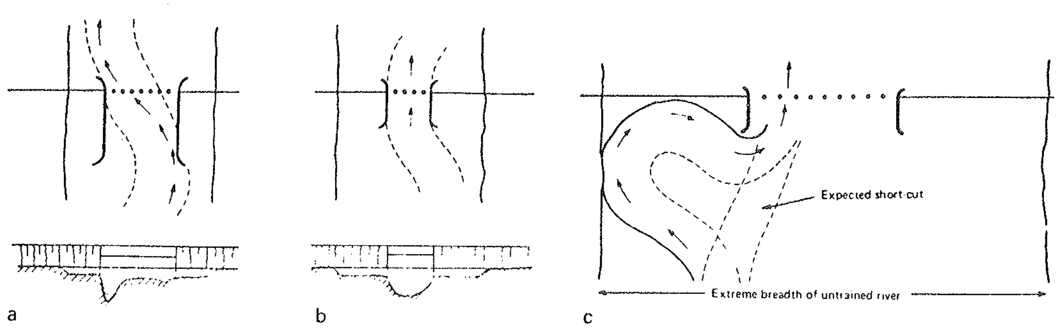
Figure 5.7 Airphoto illustrating the use of a short guide bank on one side only. Note that the construction of a large storage reservoir upstream justified the substantial degree of channel constriction in this case. Note also the sand bars visible through the shallow water.

Length

Various authors (refs. 5.5, 5.10, 5.11, 5.12) give rules of thumb for determining the length of guide banks on spilling rivers, which relate their length to the width of the waterway opening. It is suggested that in unstable shifting rivers guide banks should extend upstream of the bridge centreline by approximately three-quarters of the waterway opening width, and downstream by one-quarter width (Figure 5.6a). This guideline can, however, be modified to suit natural features and observed channel behaviour. For example, when the stream's erosive tendency is known to be biased to one side, a shorter length may be used on the other (Figure 5.6d). In other cases, short lengths may be built initially with a view to extension later, should subsequent channel behaviour so require.

Spring (ref. 5.10) stated, with reference to the shifting alluvial rivers of the Indian subcontinent, that 'the length appears to be dependent upon two considerations: first, the distance necessary to secure a straight run for the river to the bridge; and second, the length necessary to prevent the formation of a bend of the river above and behind the guide bank circuitous enough to breach the main railway approach embankment.' Figure 5.8 illustrates his reasoning.

Andreev (ref. 5.12) related the recommended length of the guide bank to the relative proportions of flood discharge in channel and flood-plain respectively. Figure 5.9 summarizes his recommendations, which appear to be intended for cases of relatively well-defined channels within flood-plains. The resulting lengths are considerably shorter than those given by the other authors quoted. 287



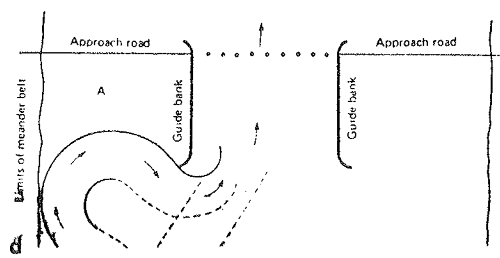


Figure 5.8 Considerations in selecting the length of guide banks in large alluvial rivers, according to Spring (ref. 5.10): (a) bridge and guide banks unnecessarily long (note the skewed flow and irregular cross-section); (b) shorter length of bridge, permitting a more efficient cross-section and shorter guide banks; (c) excessively short guide bank, permitting the breaching of the approach road after development of a large meander bend; (d) longer guide bank, preventing situation (c) and providing dead water protection to the approach road in area A.

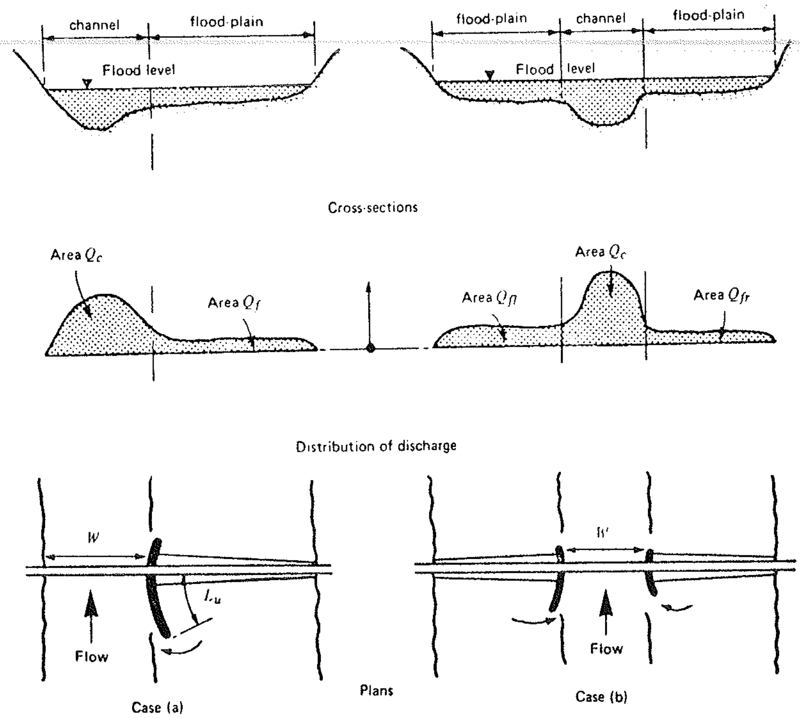


Figure 5.9

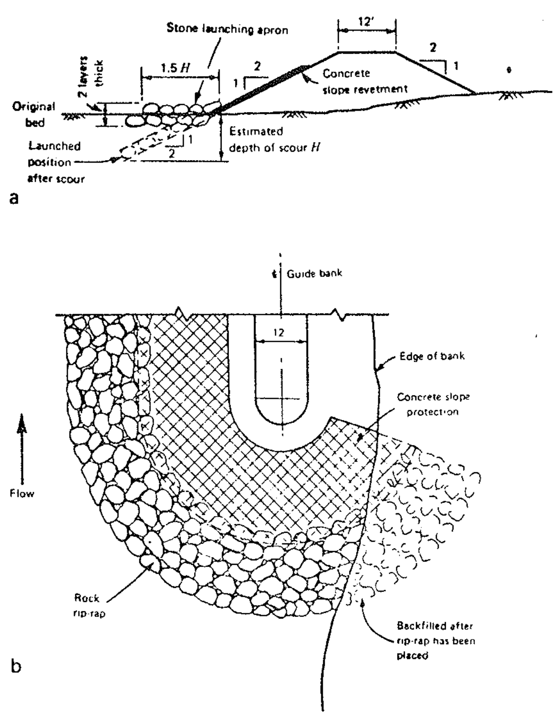


Figure 5.9 Andreev's recommendations (ref. 5.12) concerning length of guide banks in flood-plain rivers. The procedure is as follows:

1 Determine the ratio Q/Q_c, where Q is the total design discharge and Q_c is the channel portion of Q.

2 Determine the upstream guide bank length L_u for case (a) using the following figures:

Q/Q_c	1.0-1.2	1.25	1.5	1.75	2.0	2.5
L_u/W	0	0.15	0.3	0.45	0.6	0.75

3 In case (b) divide the length L_u between the two banks in the proportions of the flood-plain discharge ratio Q_{fl}/Q_{fr}.

4 Make the downstream length about one-third the upstream length.

5 Adjust to suit local features.

Figure 5.10 Typical guide bank cross-section (a) and nose detail (b).

Plan shape
Conflicting recommendations on the plan shape of guide banks occur in the literature, but majority opinion favours converging curved banks forming a bell-mouth entry to the waterway opening. Karaki (ref. 5.13) recommends a quarter section of an ellipse with a ratio of major to minor axes of 2.5 to 1 (Figure 5.6b), the major axis being arranged parallel to the principal direction of flood flow through the opening. This shape appears particularly suitable where the direction of flow can vary.

Straight, parallel guide banks can be used successfully in certain situations, but in general they tend to cause formation of a bar alongside one bank, thereby concentrating the flow on the other side of the waterway opening (Figure 5.6c). In some situations a straight bank on the outside of a bend, combined with a curved bank on the inside, may be a convenient solution (Figure 5.6d).

Cross-section and height
Figure 5.10a shows a typical embankment section for a guide bank (see also Figure 5.3). The angle of slope should be selected to suit subsoil conditions, the angle of repose of the embankment material, and the type of slope revetment provided. The steeper the slope, the smaller will be the area requiring protection, but the heavier will be the required revetment. The top should be wide enough to accommodate vehicles for construction, maintenance, and surveys. The ends of the guide banks should be rounded (Figure 5.10b). Protection against undermining is discussed in Section 5.7.

Guide banks should normally extend above the design high-water level, with an appropriate freeboard allowance. The elevation of the dead-water pond trapped behind the guide banks (see Figure 5.8d and Section 4.8) will be higher than the flood stage at the bridge by an amount approximately equal to the normal fall along the channel inside the guide banks, plus the velocity head in the contracted waterway.

Lower guide banks that can be overtopped under high flood conditions may be preferable in some instances, especially where the backwater induced by a higher bank would be unacceptable. The top must then be protected against erosion.

5.5 Spurs*

Uses and construction
Spurs may be used singly or in groups to prevent the erosion of road embankments, dikes, or natural river-banks, or in lieu of guide banks to direct the flow into a constricted bridge waterway opening. They can consist of embankments similar in cross-section and height to a guide bank, or of timber, steel, or concrete walls, or of permeable structures such as a double row of piles filled with cut trees. Suitably protected embankments are recommended as the first choice. Figure 5.11 illustrates three types.

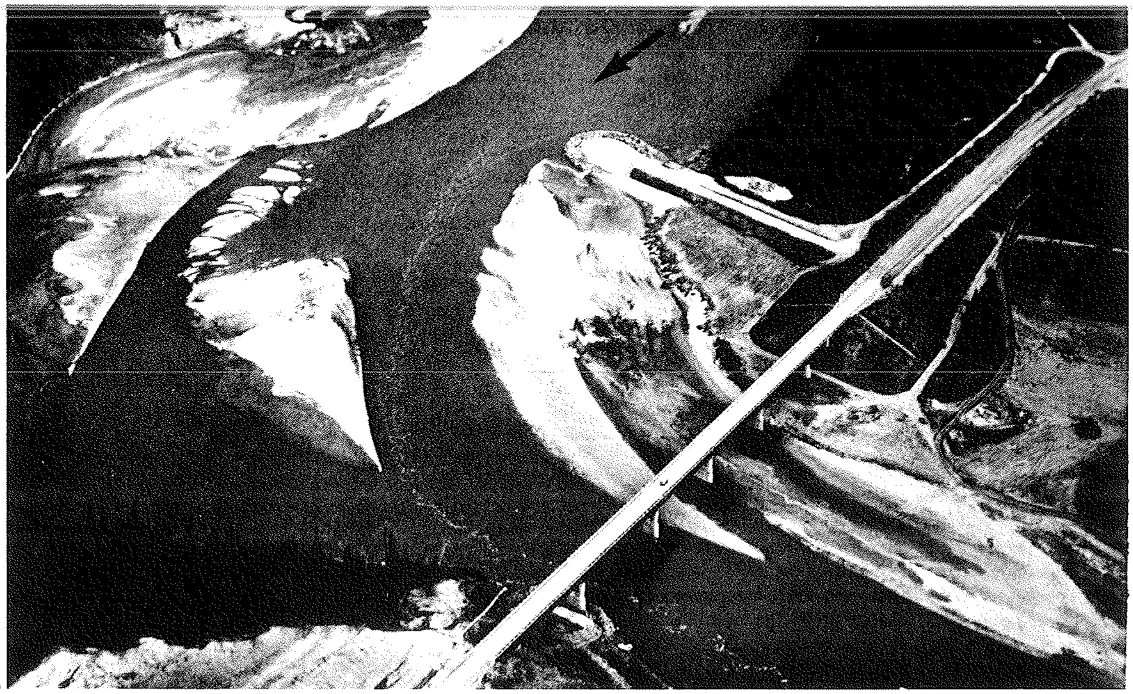
A single spur tends to cause severe flow disturbance and deep scour at its outer end. Spurs should normally be used in groups, and a single spur should in general be avoided where the main current would impinge against it. Exceptions to this recommendation can be admitted in certain circumstances (Figure 5.11a). Possible adverse effects of spurs on navigation, ice passage, and log transport should receive consideration where appropriate.

Orientation
When constructed in the form of earth embankments, spurs should generally be pointed upstream so as to create a dead water pond which provides a 'cushion' to prevent erosion of the upstream face (Figure 5.12a): it is then necessary to place protection on the spur nose only. If pointed downstream to act as flow deflectors (Figure 5.12b) the upstream faces may require protection against erosion along their full length.

Spacing and length
The length of bank protected by each spur appears to be at least twice its projected length perpendicular to the current, equally spaced about the projection of its outer end (Figure 5.12c). Therefore spurs need not be spaced closer than twice their projected length. For a group of four or more, the spacing may be up to four times their projected length (ref. 5.3).

Whether to choose fewer long spurs or a greater number of short ones depends upon their disturbing effects upon the opposite bank and upon the channel upstream and downstream. For earthwork types, the longest spur that will not produce excessive erosion and disturbance should be used, since the major cost of this type is in the slope revetment and the apron on its outer end. In lieu of a series of short spurs, consideration should be given to placing slope revetment directly along the bank or dike under attack: this is usually a cheaper and neater solution.

* In some publications these are described as 'groins.'



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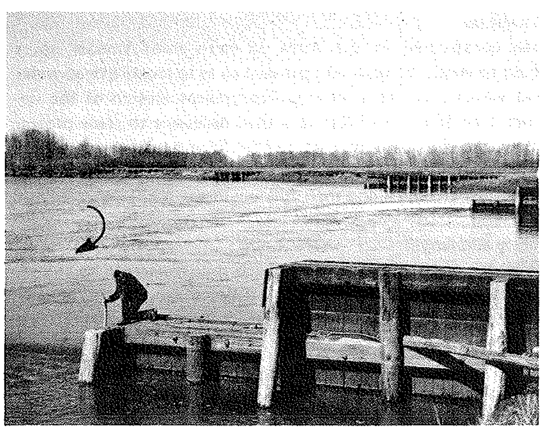

b

c

Figure 5.11 Three types of spur construction: (a) revetted earth embankment (note that part of the bridge waterway opening on the left bank is not effectively utilized and might have been dispensed with); (b) buttressed timber walls; (c) piling and cut trees.

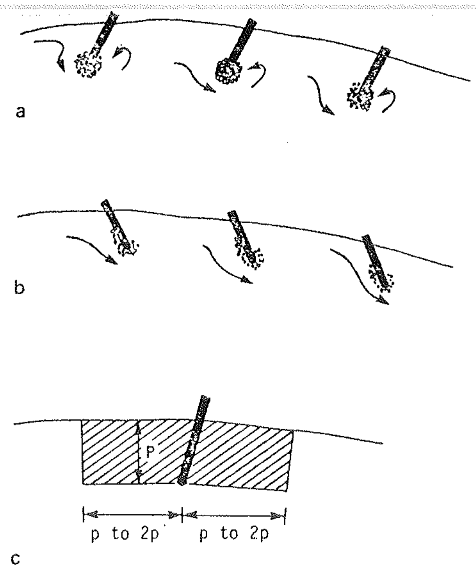

Figure 5.12 Orientation and spacing of spurs: (a) spurs pointed upstream; (b) spurs pointed downstream; (c) approximate area protected by a spur.

5.6 Dikes

Dikes are normally constructed on a flood-plain to prevent flood waters from bypassing the bridge waterway opening (Figure 5.2), or to prevent undesired backwater effects, especially where property might be adversely affected (see Section 4.8). In some cases they may serve two functions: to prevent problems arising from the road and bridge works, and to alleviate pre-existing problems. One of the most common applications is where a road crosses a wide flood-plain valley at a substantial angle of skew, and where the river gradient is such that a significant raising of flood levels would occur at one side of the valley (see Section 4.8 and Figure 4.19). Another application is to control drastic channel shifts on alluvial fans.

The essential requirements for a dike are that it should be impermeable, high enough to prevent overtopping, and secure against erosion. Generally the top should be wide enough to serve as a roadway for maintenance purposes.

In constructing dikes, care should be taken to disturb natural vegetation as little as possible, and to avoid ditches alongside that might develop into erosion channels.

5.7 Protection of banks and training works against undermining

Methods

Lack of protection against undermining is a frequent cause of revetment failure (Figure 5.13). Basically four methods may be used to prevent undermining (Figure 5.14).

1

Excavate and continue the slope revetment down to an inerodible material or to below the expected scour level. This method is the most permanent, but it may be impractical or uneconomical if deep scour is expected.

2

Drive a 'cut-off wall' of sheet piling from the toe of the revetment down to an inerodible material or to below the expected scour level. Such walls are subject to risk of failure from earth pressure on the bank side after scour occurs on the channel side, and tend to cause deeper scour than paved slopes. The risk of failure resulting from unforeseen scour can be reduced by tying back the piling to deadmen or similar anchors.

3

Lay a flexible 'launching apron' horizontally on the bed at the foot of the revetment, so that when scour occurs the materials will settle and cover the side of the scour hole on a natural slope. This method is recommended for cohesionless channel beds where deep scour is expected, as being generally the most economical. Details are discussed subsequently.

4

Pave the entire bed across the bridge waterway opening. This method is economical only for relatively small streams. Scour tends to occur at the downstream edge of the paving unless this is tied into a natural inerodible formation or unless an artificial stilling basin is formed. Stone sizes for rip-rap paving may be estimated with the aid of Figure 5.4. Paving may be used in cases where a launching apron is unacceptable because the scour associated with it could result in a sliding bank failure. The specified elevation of the paving must be such that velocities through the waterway opening will be acceptable.

Launching aprons

Materials used for launching aprons include stone rip-rap, articulated concrete matting, concrete blocks, gabions, and wire mesh mattresses filled with stone. Stone rip-rap is most commonly used (Figure 5.3).

In cohesionless channel beds the design of stone aprons should be based on the stone launching to a slope of 1 upon 2. Model tests (ref. 5.11) have indicated that such a slope is realistic for sand beds, but little definite field confirmation seems to have been reported.

Stone sizes should be determined as for slope revetment (see Section 5.3). The volume of stone should be sufficient to cover the final scoured slope to a thickness of 1¼ times the size of the largest stones in the specified grading (Table 5.1). At the nose of a guide bank or spur, there should be sufficient stone to cover the final conical surface of the scoured slope. Piers should not be

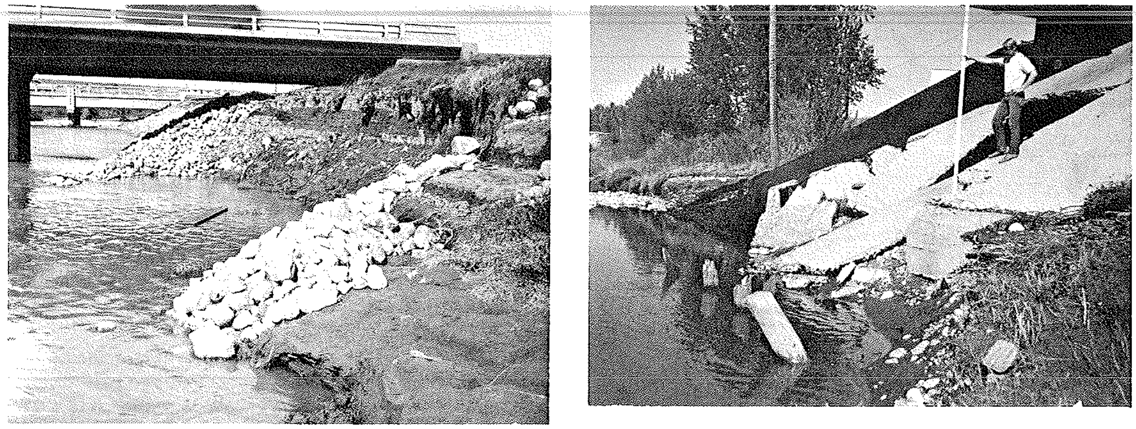

Figure 5.13 Results of inadequate protection of bank revetment against undermining.

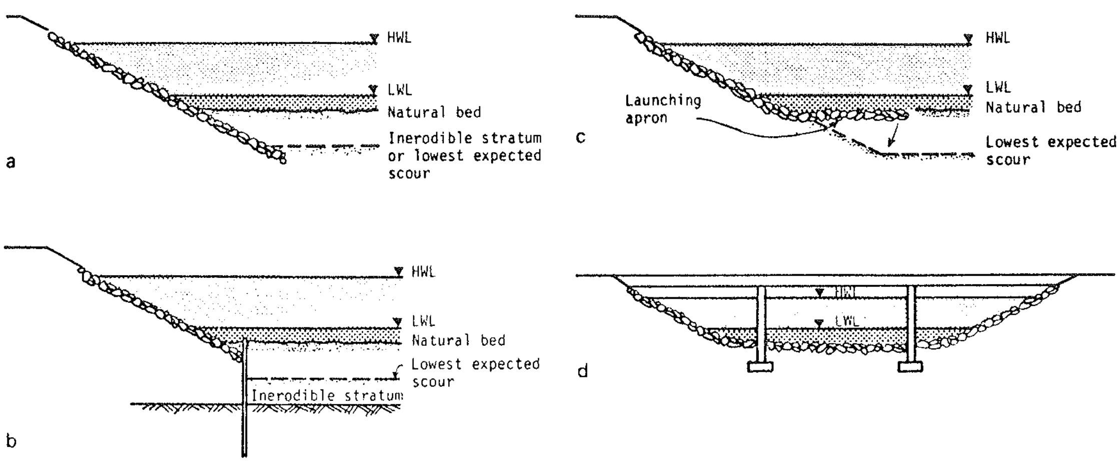

Figure 5.14 Methods of protecting bank revetment against undermining: (a) continue revetment down to inerodible stratum or to below lowest expected scour; (b) drive sheet-pile cut-off wall into inerodible stratum; (c) lay horizontal launching apron at or below the natural bed level (rip-rap settles on the slope as scour proceeds); (d) pave the entire bed of the bridge waterway opening (elevation of paving must be low enough to ensure acceptable velocities).

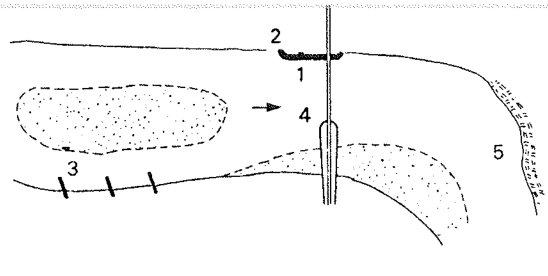

Figure 5.15 Sketch plan showing scour-susceptible locations alongside banks and training works: 1, parallel flow along bank; 2, nose of guide bank; 3, nose of spur; 4, projecting embankment end slope; 5, below a bank subject to direct impingement.

located within the launching apron slope unless it is unavoidable.

Launching aprons do not perform well on cohesive channel beds where scour occurs in the form of slumps with steep slip faces. In such cases bank revetment should be continued down to the expected worst scour level, and the excavation then refilled.

Limits of protection
Aprons must extend in plan around the noses of embankments beyond the limits of the expected scour under worst attack conditions (Figure 5.10). The limits of scour should, where possible, be determined on the basis of model tests or previous experience.

Scour depths alongside banks and training works
Scour alongside banks and training works is liable to occur at the following locations (Figure 5.15):

- alongside channel banks and guide banks, in parallel flow;
- around noses of guide banks: flow in part parallel to the bank, but with strong spiral currents around the nose;
- around noses of spurs: main flow impinging more or less at right angles on the end of the spur;
- around approach embankment end slopes without guide banks;
- under a bank, dike, or guide bank subject to direct impingement of flow.

With the exception of some data from large alluvial rivers in India and Pakistan, as in refs. 5.5, 5.10, and 5.11, there appears to be a shortage of documented information on scour depths in the above situations that can be used as a basis for generalized

design recommendations. It is therefore strongly recommended that, wherever possible, scour depths should be estimated and protection designed on the basis of experience with similar situations in the river in question. Failing that, mobile-bed models may give an indication of relative depths. In the absence of any guidance from the field or from models, the following method due to Blench (ref. 5.5) can be used to give a rough indication of scoured depth.

1
Estimate the flood discharge intensity q_f (equal to velocity X depth) immediately adjacent to the bank or structure, in cfs/ft.

2.
Calculate the corresponding regime depth in feet (assuming no bed-sediment supply):

$$d_{f_0} = \sqrt[3]{q_f^2 / F_{b_0}}, \qquad (5.2)$$

where F_{b_0} = Blench's 'zero bed factor,' by Figure 5.16.

3
Estimate the maximum scoured depth as $z \times d_{f_0}$, where z is as follows:

nose of spur or guide bank	2.0 to 2.75
flow impinging at right angles on bank	2.25
flow parallel to bank	1.5 to 2.0

Further discussion on this problem may be found in ref. 5.10 (p. 48 and following) and ref. 5.14.

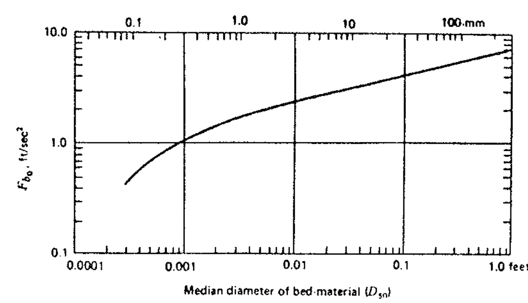

Figure 5.16 Relation of Blench's 'zero bed factor' to the size of bed material (adapted from ref. 5.5).

5.8 Channel diversions

Uses
Reasons for the use of permanent channel diversions at bridges include the following.

1
To divert the channel away from approach embankments.
2
To eliminate or reduce a skew angle of the bridge.
3
To provide a more stable channel alignment (in lieu of expensive training works).
4
To remove the crossing from the base of a steep hill, thereby allowing a lower grade-line for the structure.
5
To allow a single structure instead of a series of structures separated by embankments.
6
To reduce flood levels or prevent them from being raised by road and bridge works.

Figure 5.17 illustrates a diversion covering points 2, 3, and 6 above.

Difficulties
Before designing a channel diversion careful consideration should be given to possible adverse environmental effects, and appropriate river and wildlife authorities should be consulted. Adverse effects are liable to occur when a winding natural channel is replaced by a shorter and straighter diversion of less hydraulic resistance. The consequences may include the following:

- bed degradation and bank slumping upstream of the diversion;
- bed aggradation and an increased rate of meandering or channel shifting downstream of the diversion;
- replacement of a favourable fish and wildlife habitat associated with pools and shoals by a straight, regular cross-section with higher velocity and sediment transport;
- dumping of excess fine sediment into the downstream reach, causing damage to fish spawning and hatching grounds;
- more severe ice action during break-up.

These adverse effects can be countered to some degree by the use of drop structures or rock rapids to take up excess slope, or by designing diversions to a winding alignment with roughness similar to that of the natural channel. Care should be taken in the construction of diversions to avoid erosion and sedimentation: choice of the proper time of year for construction may be important, for example where fish hatching requires consideration.

Spectacular degradation and erosion can occur in long, straight diversions of formerly winding streams, designed without adequate slope or velocity control. When planning long diversions a careful study should be made of literature on river regime and channel stability (refs. 5.5, 5.15, 5.16, 5.17), or specialist assistance should be obtained.

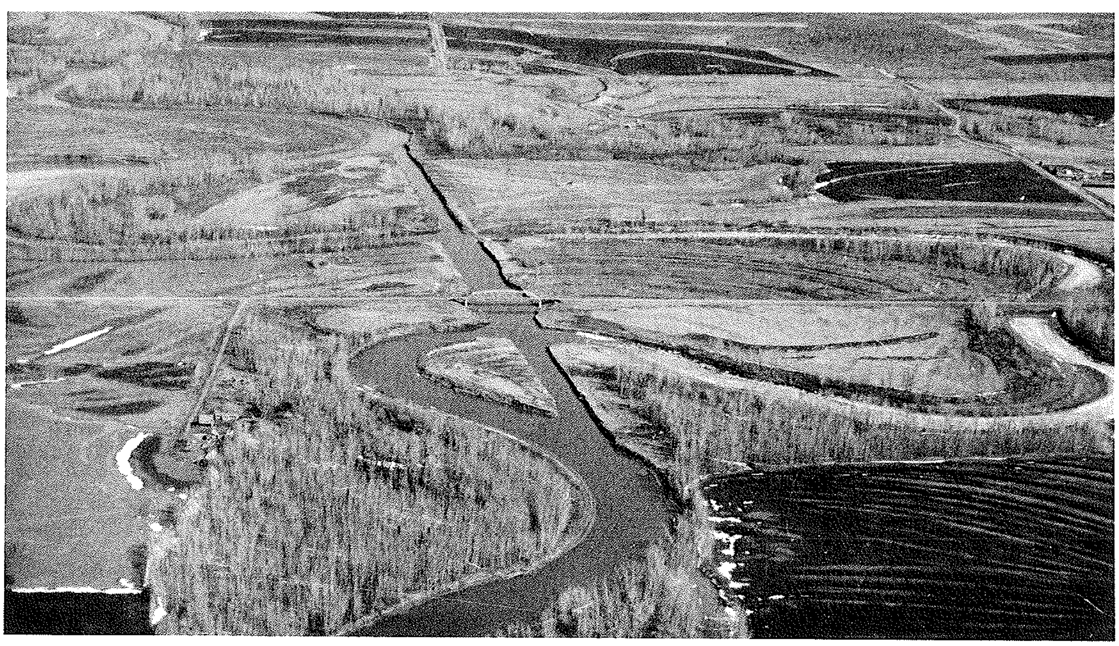

Figure 5.17 View of a bridge crossing a straight diversion of a meandering alluvial river.

Design principles

The bankfull discharge capacity of the diversion should be at least as great as that of the natural channel. The cross-section and slope for unlined channels should be so selected that mean velocities are no greater than in the natural channel at corresponding discharges. Where smaller cross-sections are desirable for economic reasons, some form of lining or erosion protection is necessary, and drops should be incorporated so that velocities in the natural channel up- and down-stream are not increased.

It is essential that the hydraulics of the designed diversion be fully evaluated, giving special attention to the actual slope provided, to the probable actual roughness after construction, and to the non-uniform flow profile that will probably occur. It is generally erroneous to assume that uniform flow will occur in a relatively short diversion.

Inlet and outlet alignments of the diversion should generally be designed tangential to the natural channel where the latter is erodible, but in some cases directing the outlet against an inerodible bank may assist in energy dissipation. Consideration should be given to designing the diversion to a gently sinuous alignment comparable with that of the more stable reaches of the natural stream, so as to maintain a closer approximation to natural slope and roughness.

Pilot cuts

A short length of diversion immediately adjacent to a bridge should normally be excavated to its full designed cross-section. For longer diversions – for example, a series of cuts through a succession of meander loops – the more distant cuts may be built as 'pilot cuts,' or 'assisted cut-offs,' i.e. they are excavated initially to a smaller section large enough to erode, and the river is allowed to complete the excavation. Principles governing the design of pilot cuts are discussed in refs. 5.3, 5.5, and 5.17. If river-excavated material is liable to settle out in the downstream reach and adversely affect the zoological habitat, it is preferable to excavate initially to full channel dimensions.

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III

Example of partial design of waterway opening

The following calculations are intended to illustrate some of the procedures for selecting the width of waterway opening and estimating general scour set out in Sections 4.3 and 4.4. They do not cover a complete hydraulic design.

1 Given information

Design discharge = 150,000 cfs
Corresponding high-water elevation = 93 ft above datum
Corresponding surface width of natural channel at crossing site = 1500 ft
Low-water elevation = 72 ft
Average river-bed elevation at low water = 70 ft

The river-bed material is sand, D_{50} = 0.4 mm, to a depth well below expected scour levels.

From a consideration of pier costs and probable local scour effects, the lowest permissible level of general scour is selected initially as elevation 55 ft above datum.

Field measurements of the average channel geometry in a nearby incised reach, at a discharge of 30,000 cfs, give the composite cross-section shown in Figure A.1. The corresponding mean water surface and mean bed levels, transferred to the crossing site, are at elevations 76 and 66 ft respectively.

2 Selection of a trial waterway opening width according to Section 4.3 and Figure 4.8

For Q = 150,000 cfs, the suggested range is approximately 700 ft to 1050 ft. Use 1000 ft for a first trial.

3 Estimates of general scour by regime method 2 of Section 4.4

First trial, taking W_s = 1000 ft at Q = 150,000 cfs.
Step 1
See Figure A.1 for the incised channel cross-section at Q = 30,000. Then

$$q_i = \frac{Q_i}{b_i} = \frac{30{,}000}{775} = 38.7 \text{ ft}^2\text{/sec.}$$

Step 2
In order to estimate the flood discharge intensity, guess the total scoured depth to be 30 ft at design discharge. See Figure A.2. Then

$$q_f = \frac{Q_f}{b_w} = \frac{150{,}000}{925} = 162 \text{ ft}^2\text{/sec.}$$

Step 3
By Eq. (4.4), $d_f = d_i\left(\frac{q_f}{q_i}\right)^m$, where m = 0.67 for a sand bed,

$$= 10\left(\frac{162}{38.7}\right)^{0.67} = 26 \text{ ft.}$$

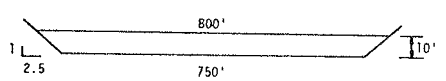

Figure A.1 Composite average cross-section in an incised reach of the river, with Q = 30,000 cfs.

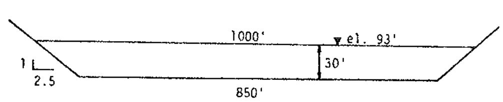

Figure A.2 Estimated average scoured cross-section at the waterway opening, with Q = 150,000 (step 2 of first trial).

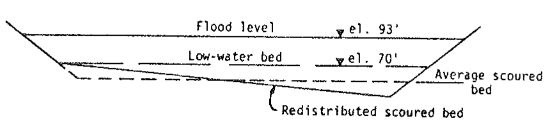

Figure A.3 Redistribution of the area of scour (step 4 of first trial, second method). This gives a *minimal* estimate of worst general scour. See Section 4.4 for a full discussion of the redistribution of scour area.

Therefore the average elevation of general scour is 93 − 26 = 67 ft above the datum.
Step 4
Estimate the lowest elevation of general scour by considering a possible redistribution of the average scoured cross-section. See Figure 4.13 and Figure A.3. Previous experience with this river, together with a consideration of the straight alignment of the approach flow and the intention to provide training works to maintain the alignment, indicates that only a modest allowance need be made for irregularities in the bed level.

First estimate: multiply the average scoured depth by 1.4 to get the maximum = 1.4 X 26 = 36 ft. Then the lowest elevation of general scour = 93 − 36 = 57 ft.
Second estimate: try the method of Figure 4.13(a). The low-water bed elevation is 70 ft and the average scoured bed elevation is 67 ft. Then redistributing the 3 ft thick rectangle as a triangle gives a lowest scoured bed elevation of 64 ft.

Second trial
On the basis of the first trial, it appears that a somewhat smaller waterway opening might meet the initially selected criterion of lowest permissible general scour at elevation 55 ft.

A similar calculation for W_s = 800 ft yields estimates of the lowest general scour elevation of 50 ft and 54 ft respectively by the two distribution methods of step 4 above; 800 ft therefore appears to be too small.

It is decided to perform a third calculation by another method, for W_s = 900 ft.

4 Estimate of general scour by competent-velocity method 4 of Section 4.4

Step 1
Taking W_s = 900 ft, and assuming no scour, the trapezoidal cross-sectional area at Q = 150,000 cfs is
½(900 + 785) X 23 = 19,400 ft^2.

Mean velocity = 150,000/19,400 = 7.7 ft/sec.
Depth of flow = 93 − 70 = 23 ft.
Step 2
Enter Figure 4.12 at D_{50} = 0.4 mm, interpolate a depth of 23 ft between the curves for 20 ft and 50 ft, and read the competent mean velocity as 5 ft/sec. Significant general scour can therefore be expected.
Step 3
Guess an average scoured depth at 35 ft. Then enter Figure 4.12 at D_{50} = 0.4 mm, interpolate, and read the competent mean velocity as 5.7 ft/sec.
Required cross-sectional area = 150,000/5.7 = 26,300 ft^2.
Corresponding average scoured depth, by the geometry of the trapezoidal section, works out at 30 ft.
Corresponding average general scoured elevation = 93 − 30 = 63 ft.
Step 4
Redistribution of the scoured cross-section by the methods used in estimate 3 above gives estimates of the lowest scoured elevations of 51 ft and 56 ft respectively. On this basis a slightly larger waterway opening might be adopted, or the initial design requirement might be revised.

5 Further procedures

The above calculations are probably sufficient for preliminary design purposes. They should be reviewed after the adoption of span lengths and pier dimensions and after a preliminary selection of foundation type. Appropriate allowance should then be made for local scour at piers (Section 4.5), and safety margins should receive consideration (Section 4.7). If the design flood has been estimated on a frequency basis (say 50-year or 100-year), scour calculations should also be performed to check the security of the structure at a higher discharge.

IV
Sampling and analysis of channel bed materials

When conducting field investigations at erodible-bed sites, samples of channel bed materials liable to scour should be obtained and analysed. It is important that the samples should give a representative picture of the material in the scour zone; therefore they should be located with regard to boring information and to surface indications. Samples are most easily obtained from bars at a low stage of flow.

In beds of fine-grained alluvial materials there is no particular difficulty in sampling. Samples are simply dug out in bulk and analysed for grain-size distribution by weight. Distributions should normally be plotted cumulatively as 'percentage by weight finer than' (arithmetic ordinate scale) against grain diameter (logarithmic abscissa scale), to produce the familiar S-shaped curve on semi-log paper. Median (D_{50}) and other percentile values may then be read from the curve.

The sampling and analysis of widely graded gravel beds may present the following difficulties:

- wide differences in the nature of the surface material from point to point;
- differences in the nature of the surface material at different times, depending on preceding flow conditions;
- presence of a thin surface layer or paving that is not representative of the immediately underlying material (Figure A.4);

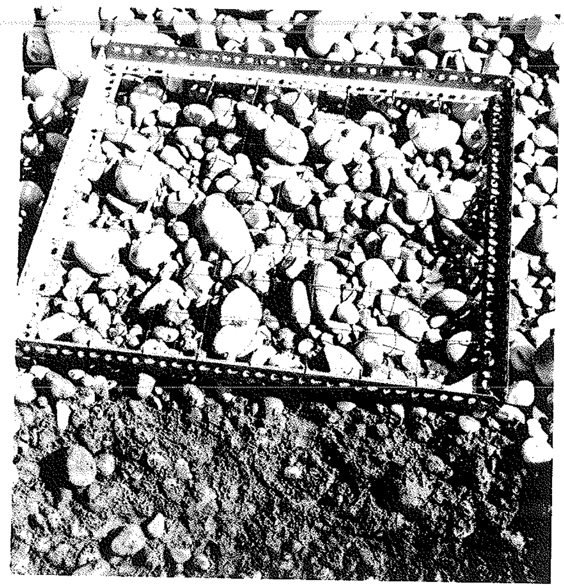

Figure A.4 Oblique photograph of river-bed gravel on a bar, showing the use of a wire grid to record the surface distribution. Note the marked difference between the composition of the underlying material (in cut) and its surface aspect.

- practical difficulties in collecting and analysing a sample large enough to be representative.

Where practicable, a representative bulk sample or samples should be obtained and analysed in the same way as for fine-grained materials. The bulk sample should be supplemented by photographing small areas of the surface through a wire grid (Figure A.4).

Where bulk sampling is not practicable, grid sampling of the surface may be substituted. In this method a grid or tape is laid out over a representative area of bar, and single stones are picked at the intersection points or at even intervals along the tape. The resulting sample should be analysed by plotting 'percentage *by number* smaller than' (arithmetic ordinate scale) against grain diameter (logarithmic abscissa scale). The resulting distribution curve is roughly equivalent to a bulk weight distribution curve of a *surface sample*, but because of paving effects it does not necessarily give a correct picture of the bulk of the material liable to scour. It is therefore important to supplement it by borings or inspection of the underlying material.

For further discussion on sampling of coarse alluvial materials, reference may be made to the paper by R. Kellerhals and D.I. Bray, 'Sampling procedures for coarse fluvial sediments,' *J. Hydraulics Div., ASCE*, August, 1971.

The statistics of grain-size analysis are clearly explained in R.L. Folk, *Petrology of sedimentary rocks*, Lecture notes, University of Texas (Austin, Texas: Hemphill's, 1965).

V
Theoretical basis for competent velocity data, figure 4.12 and table 4.1

Figure 4.12

The curves of competent mean velocity were derived by accepting 'regime' criteria for stable channels in sand, at the left side of the graph, and shear stress criteria for low rates of movement of gravel and cobbles, at the right. Empirical transition curves were drawn to join the straight lines given by the gravel criteria with those given by the regime criteria.

For 0.3 mm sand we adopt the regime criterion for negligible sand 'charge':

$$\frac{V_m{}^2}{d} = 1.0,$$

where V_m is the mean velocity in ft/sec and d is the depth of flow in ft. This produces the intercepts on the left-hand axis.

For gravel we adopt the Shields criterion:

$$\frac{\tau_0}{\gamma_s{}'D} = 0.06,$$

where τ_0 is the bed shear stress at so-called beginning of movement, $\gamma_s{}'$ is the submerged specific weight of bed material, and D is the grain size of bed material.

We further assume the mean velocity formula

$$\frac{V_m}{V_*} = 8.45 \left(\frac{d}{k_s}\right)^{1/6}$$

where V_m is the mean velocity, V_* is the shear velocity ($= \sqrt{\tau_0/\rho}$), d is the depth of flow, and k_s is the equivalent uniform-grain roughness.

These equations may be combined and transformed algebraically to give

$$\frac{V_m{}^2}{g(s-1)D} = 4.3 \left(\frac{d}{k_s}\right)^{1/3}$$

where s is the dry specific gravity of bed material. Adopting $s = 2.65$, and assuming $k_s = 4D$, gives

$$V_m{}^2 = 143\, d^{1/3} D^{2/3} \text{ in ft-sec units.}$$

This produces the straight lines with a slope of 1/3 at the right side of Figure 4.12.

The transition curves were sketched in by eye and are not based on experimental data.

The theoretical parts of the curves apply, strictly speaking, only to straight, uniform flow in a wide channel, and the entire diagram requires extensive testing in practice. The assumption $k_s = 4D$ is made to allow for form roughness and irregularities in gravel beds, as well as for the projection of large stones.

Table 4.1

On the basis of a number of studies in the USSR and USA on scouring velocities and shear stresses for cohesive soils, the suggested competent mean velocities in the table were derived from the following values of bed shear stress:

Left-hand column	0.035 lb/ft^2
Middle column	0.12 lb/ft^2
Right-hand column	0.35 lb/ft^2

For converting shear stresses to mean velocities, the Manning formula was used, assuming $n = 0.025$ in all cases. The formula then transforms to

$$V_m = 7.5\, d^{1/6}\, \tau_0{}^{1/2},$$

where d is the depth of flow and τ_0 is the bed shear stress.

Note: Due weight should be attached to cautionary notes regarding these data given in Section 4.4 of the text.

300

Erosion on downgrade that resulted from water running in wheel rut (Brazil).

Bibliography

The following bibliography contains two sets of references. The first set consists of a reference for each selected text that appeared in the preceding part of this compendium. The second set consists of references to additional publications that either were cited in the selected texts or are closely associated with material that was presented in the overview and selected texts. Each reference has five parts that are explained and illustrated below.

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(e) Analyse : ce paragraphe est une analyse du texte dont le titre est cité dans la partie (b).

Illustration (from Comp. 1) **Ilustración** (del Comp. 1) **Illustration** (du Recueil 1)

(a) Reference number
(a) Número de referencia
(a) Numéro de la référence

Reference 5
A REVIEW OF HIGHWAY DESIGN PRACTICES IN DEVELOPING COUNTRIES

(b) Title
(b) Título
(b) Titre

Cron, Frederick W. Washington, DC: International Bank for Reconstruction and Development; 1975 May. 57 p.

(c) Bibliographic data
(c) Datos bibliográficos
(c) Données bibliographiques

Order from: International Bank for Reconstruction and Development, 1818 H Street, N.W., Washington, DC 20433.

(d) Availability information
(d) Disponibilidad de la información
(d) Disponibilité des documents

The design standards of some 150 highway projects financed by the International Bank for Reconstruction and Development between 1960 and 1970 are reviewed, and areas of agreement between the standards of the 63 countries studied are identified; practical highway standards based on these areas of agreement are sketched for the guidance of planners in developing countries. The roads discussed here, fall into three functional categories: a small group of expressways, freeways and toll roads carrying large volumes of traffic; a very large group of 2-lane highways carrying a wide range of traffic volumes serving both local and long distance traffic; and a smaller group of low-traffic tertiary or special purpose roads existing primarily for land service. Comments are made on the problem of classifying highway standards, and on the comparison of standards. Conclusions regarding standards for the capacity- related elements of design and standards for the velocity-related elements of design (radius of curvature, stopping sight distance, passing sight distance) are discussed, as well as the horizontal and vertical clearances for bridges. The standard live loadings for bridges, the structural capacity of pavements and legal load limits are covered, and conclusions relating to pavement design, design standards for 2-lane highways, incremental development of highways, and levels of service are presented.

(e) Abstract
(e) Resumen
(e) Analyse

The order should include all information given in parts (b) and (c) above.

El pedido deberá incluir toda la información dada en las partes (b) y (c).

L'ordre de commande doit inclure toutes les informations données dans les parties (b) et (c).

SELECTED TEXT REFERENCES

Reference 1
HIGHWAY DRAINAGE GUIDELINES; VOLUME III: GUIDELINES FOR EROSION AND SEDIMENT CONTROL IN HIGHWAY CONSTRUCTION

American Association of State Highway Officials, Operating Subcommittee on Roadway Design, Task Force on Hydrology and Hydraulics. Washington, DC: American Association of State Highway Officials; 1973. 31 p.

Order from: American Association of State Highway and Transportation Officials, 444 North Capitol Street, N.W., Suite 225, Washington, DC 20001.

The erosion process is explained, and it is shown how effective planning and location of a highway can aid in erosion control. Such planning would take into consideration aspects such as natural drainage patterns, stream crossings, encroachments, waste supplies and catchment areas, geology and soils, and coordination with other agencies. Many erosion problems can be avoided by correct design and adequate specifications relating to geometrics, alignment and grade, cross section, drainage (channels, chutes, channel linings, culverts, bridges, underdrains, detention and sedimentation basins, grade-control structures), and construction practices. The scheduling of construction operations (avoid rainy season), the control of work areas (minimize bare soil areas, provide temporary protection, streams, borrow pits, waste areas, haul roads, channel work), and grading operations should seek to minimize erosion. Preventive maintenance and expert assistance in maintenance inspections will help save on maintenance costs. Maintenance records, training of maintenance personnel, surveillance of embankments and cut slopes, inspection of channels, disposal of waste material, maintenance of vegetation, the repair of storm damage, sedimentation and detention basins, and remedial work are important.

Reference 2
PRINCIPLES OF HIGHWAY DRAINAGE AND EROSION CONTROL

Purdue University, Engineering Experiment Station; 1962 August. 65 p. (Highway Extension and Research Project for Indiana Counties, Engineering Bulletin; County Highway Series - No. 4).

Order from: Director, Highway Extension and Research Project for Indiana Counties, School of Civil Engineering, Purdue University, West Lafayette, Indiana 47907.

This manual stresses the need for minimum interference with the natural drainage. This may be achieved by stabilizing earth surfaces with vegetal cover, providing a place for water to run freely over the surface in ditches or underground culverts and subdrains, or conducting the collected water safely to a natural watercourse. The fundamental principles of sound slope protection are described, as well as the design, construction, and maintenance of roadside ditches, culverts, and subdrains.

Reference 3
CONTROL OF EROSION ON HIGHWAYS

Dunn, C. S. Highway Design in Developing Countries. Proceedings of Seminar V. London, England: Planning and Transport Research and Computation (International) Company Limited; 1975 July; pp. 118-141. (PTRC P129).

Order from: PTRC Education and Research Services Ltd. 110 Strand, London W.C.2, England.

The objectives of erosion control are stated, and the mechanism of erosion control and the effect of the principal factors that affect the rate of erosion and soil loss are explained. The measurement of the rate of soil loss per unit area of site as a way of quantifying erodibility of a site is discussed, and the U.S. Agricultural Research Service Soil Loss Equation is given. The influence of slope shape on the rate of erosion and the soil erodibility factor are also explained. Soil conservation practices outlined in the article include contour ridging, light scarification, serrations or stepping, strip sodding, slope fascines, riprap, soil-cement benches, crest interceptor ditches, asphalt dikes, chutes and vegetative cover. The design and protection of roadside ditches and the protection of shoulders from rain and traffic erosion are also outlined.

Reference 4
PROTECTING STEEP CONSTRUCTION SLOPES AGAINST WATER EROSION

Swanson, N. P.; Dedrick, A. R.; Dudeck, A. E.; Roadside Development. 5 Reports. Highway Research Board, Washington, DC; 1967; pp. 46-52. (Highway Research Record Number 206).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

Mulching practices on a roadside cut (3:1 slope) were evaluated with respect to controlling soil erosion and minimizing grass seed and fertilizer loss prior to grass establishment. A field plot rainfall simulator and a device to introduce additional surface flow over a test plot were used to evaluate the mulching practices. Measurements of soil erosion and grass seed and fertilizer losses were made from run-off samples taken through a series of simulated rainstorms. The effectiveness in protecting soil surfaces against water erosion was determined for 13 mulches. The best protection was provided by mulches of jute netting, wood excelsior mat, prairie hay (1 ton/acre) and fiberglass (1,000 lb/acre) anchored with asphalt emulsion (150 gal/acre). The least effective mulches were the latex (150 gal/acre) and a kraft paper netting. Anchoring a material with asphalt emulsion provided increased adherence to the soil surface and was generally beneficial.

Reference 5
THE USE AND CONTROL OF VEGETATION ON ROADS AND AIRFIELDS OVERSEAS

Clare, K. E. Harmondsworth, U. K.: Great Britain Road Research Laboratory, Department of Scientific and Industrial Research. London. Her Majesty's Stationery Office; 1961. 42 p. (Road Research Technical Paper No. 52).

Order from: Her Majesty's Stationery Office, P.O. Box 569, London SE1 9NH, England.

This paper gives information, from 33 overseas countries, on the types of vegetation occurring at roadsides and on airfields, the useful genera, and those presenting problems to the engineer. Rainfall, geographical location, existing control, and drainage are believed to be the major factors controlling the vegetation regime at any given site. Vegetation is useful for preventing haunch, ditch, and side-slope erosion on roads, for providing running surfaces for roads and airfields, and for improving road safety and amenities. Present practice in these fields is briefly reviewed, and reference is made to the desirability of introducing to overseas road and airfield construction improved techniques and vegetation species that become available from developments in other countries or in related fields of research. The uncontrolled growth of vegetation can disrupt road and airfield pavements, reduce visibility, increase fire hazard on roads, and provide a reservoir for the reinfestation by weeds of adjacent clean agricultural land. Methods of controlling vegetation include cutting by hand or by machine and burning or grazing. The costs of control in a number of overseas countries are reported. Recently, interest has developed in the increasing number of chemical treatments that are becoming available. Experiments with these in different overseas territories are briefly described.

Reference 7
SUGGESTIONS FOR TEMPORARY EROSION AND SILTATION CONTROL MEASURES

Dunkley, C. L. Washington, DC: U.S. Department of Transportation, Federal Highway Administration, Hydraulics Branch, Bridge Division; 1973 February. 40 p.

Order from: U.S. Department of Transportation, Federal Highway Administration, Hydraulics Branch, Bridge Division, 400 Seventh Street, S.W., Washington, DC 20590.

This booklet which is intended to assist highway designers, construction personnel, and contractors, discusses methods for controlling erosion and sediment pollution that have been successfully employed on highway construction projects. The temporary erosion control features described include sedimentation pools used to trap eroded material before it reaches a natural waterway, temporary berms and slope drains used during the construction of full slopes, toe-of-slope protection to intercept siltation before it enters a ditch or waterway, temporary check dams to protect new ditches from siltation, temporary runoff barriers to protect drainage inlets, temporary erosion protection for pipe outlets, and linings for temporary diversion channels. For the Spanish translation of this manual see Reference 20.

Reference 6
EROSION-PROOFING DRAINAGE CHANNELS

Posey, Chesley J. Journal of Soil and Water Conservation, Volume 28, Number 2, 1973 March-April; pp. 93-95.

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

The problem of erosion of three types of lined channels is discussed. Vegetative channel erosion control is limited to channels with flows of relatively low velocity. Vegetation must not be subjected to constant flow or the moisture will kill the lining in most cases. Asphalt or concrete lining used for channel erosion control introduces high velocity flow for relatively low qualities of water due to the smoothness of the lining material. High velocities may introduce scour at the downstream limit of the channel lining, which in turn may undermine the lining and start progressive failure. If these linings are overtopped or undermined, they are apt to be completely destroyed. Rock lining used for channel erosion control reduces the velocity of the channel flow but is subject to two types of failure: The rocks may not remain in place, and the finer material under the rocks may be gradually washed out. The solution to the problem of rock movement and failure of rock-lined channels is to use bigger rocks. However, if larger stones are not available or when the slope is more than 10 percent, containers with smaller rocks (rock sausages, gabions) are recommended. The leaching of the finer material from underneath the rocks can be prevented by use of a filter layer or layers between the rock and the parent soil, i.e., reverse flow filter.

Reference 8
IMPACTS OF HIGH-INTENSITY RAINSTORMS ON LOW-VOLUME ROADS AND ADJACENT LAND

Dittmer, Melvin; Johnson, Allan A. Low Volume Roads. Transportation Research Board. Washington, DC; 1975; pp. 82-91. (Proceedings of a Workshop held June 16-19, 1975; Special Report 160).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

One of the most severe tests a road receives is a high-intensity rainstorm. The Siskiyou mountain range of the Rouge River National Forest has received several such storms in the past decade. The most recent of these storms occurred during January 1974, resulting in over $8 million of damage to low-volume, mostly single-lane roads. This paper describes the kinds of road failures that occurred through narrative, sketches, and photographs. The interrelationship between the road and the adjacent land is often not fully considered by the land manager or the road engineer. Poor land management practices, especially in mountainous terrain, place extreme burdens on the road's drainage facilities. Roads, on the other hand, tend to concentrate water, cause surface erosion, and upset slope stability. Land and road failures on the upper portions of a watershed often cause damage to the land, roads, and other facilities located in the lower basin. There are numerous commonly used techniques in road construction to minimize storm damage to roads and the land. This paper describes some of the least expensive methods that should be used more frequently on low-volume roads.

Reference 9
ROAD GEOTECHNICS IN HOT DESERTS

Fookes, P. G. Institution of Highway Engineers Journal, Vol. 23, Number 10, 1976 October; pp. 11-23.

Order from: Institution of Highway Engineers, 3 Lygon Place, Ebury Street, London SW1W OJS, U.K.

Hot deserts provide a variety of design and construction problems that stem from the nature of the dry climatic regime and the desert landforms. Engineering solutions to these problems, which are usually based on good practice in other regions, may not necessarily be successful. The problems include unstable terrain e.g. wind-blown silt (loess) and sand (drifts and dunes); aggressive salty ground, e.g. sabkhas, salinas, salt playas, and some duricrusts; unsuitable construction materials, e.g., some silts, sands, and soft carbonate sediments; and rapid erosion, by wind and floods, especially flash floods. In coastal areas, causeways and reclaimed land may also present special problems due to evaporite salts and the leaching and piping of fills. These problems are discussed in the context of a simple model based on mountain and plain desert terrain and natural desert processes in which four zones are recognized, each with different desert characteristics and different engineering behavior. Particular reference is made to the Near and Middle East.

Reference 10
OBSERVATIONS ON THE CAUSES OF BRIDGE DAMAGE IN PENNSYLVANIA AND NEW YORK DUE TO HURRICANE AGNES

O'Donnell, Charles L. Highways and Catastrophic Floods of 1972. 11 Reports. Highway Research Board. Washington, DC; 1973; pp. 22-36. (Highway Research Record Number 479).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

This report is one of 11 reports on the catastrophic floods that occurred in the United States in 1972. It evaluates the performance of bridges subjected to a major flood, determines the adequacy of design standards based on bridge performance, and recommends revisions to design standards where inadequacies are apparent. Hurricane Agnes caused severe flooding in Pennsylvania and New York, and several bridges and highways that were damaged by the floods in those states are discussed. The two major causes of bridge damage were scour at abutments and piers and impacting debris. The other 10 reports discuss the hydrometeorological conditions associated with these floods and the part played by state and federal agencies in such emergencies. Debris was found to be a primary cause or a significant contributing factor to bridge damage, and scour at the substructure was found to be the other major cause. The reports discuss recording, evaluating, and predicting extreme floods and include the following: Floods of 1972; Weather Situations Associated with Floods During 1972; Hurricane Agnes-Damage in Pennsylvania; Flood Damage in South Dakota; Floods in Minnesota; Role of the Federal Highway Administration in Restoring Highways Damaged by Disasters; Recording Floods and Flood Damage; Probability Distribution of Extreme Floods; The Worth of Data in Hydrologic Design; and Design Criteria and Research Needs.

Reference 11
GUIDE TO BRIDGE HYDRAULICS

Roads and Transportation Association of Canada, Project Committee on Bridge Hydraulics; Neill, C. R., ed. Toronto: University of Toronto Press; 1973. 191 p.

Order from: University of Toronto Press, 33 East Tupper Street, Buffalo, New York 14208.

This guide outlines hydraulic factors to be considered in the layout and design of the bridges and suggests tentative criteria and procedures to assist the bridge designer. General comments are made on economic aspects, the use of culverts as alternatives to bridges, and on some organizational aspects. Details are given of flood frequency analysis for gauging stations, extensions of such analysis, flood envelope curves, run-off formulas, and unit hydrographs, as well as hydraulic methods of estimating flood discharges, estimation of high water levels and the special consideration of very rare floods. The design of waterway openings for scour and backwater is described and scour protection and channel training works are discussed. The guide also reviews special problems such as tidal crossings, inland basin crossings, waves and wave protection, and the application of hydraulic models to bridge problems.

ADDITIONAL REFERENCES

Reference 12
SEDIMENTATION ENGINEERING

American Society of Civil Engineers Task Committee for the Preparation of the Manual on Sedimentation of the Hydraulics Division. New York, New York. Vanoni, Vito A., ed. 1975. 745 p. (ASCE Manuals and Reports on Engineering Practice - No. 54).

Order from: American Society of Civil Engineers, 345 East 47th Street, New York, New York 10017.

This book is concerned mainly with sediment problems involved in the development, use, control and conservation of water and land resources. It explains the nature and scope of sedimentation problems, the methods for their investigation, and the practical approaches to their solution. The book treats sedimentation in broad perspective, considering the interrelated processes of erosion, sediment transportation by water and air, and sediment deposition where it creates problems of practical importance. The problems of erosion, and sediment transport and deposition, as well as their solution are considered in the first chapter. The chapter on sediment transportation mechanics covers sediment properties, erosion of sediment and local scour, suspension of sediment, initiation of movement, hydraulic relations for alluvial streams, sediment discharge formulas, wind erosion and transportation, transportation of sediment in pipes, density currents, and genetic classification of valley sediment deposits. The review of sediment measurement techniques (Chapter 3) includes fluvial sediment, reservoir deposits, accelerated valley deposits, airborne sediment, and laboratory procedures. Chapter 4 reviews sediment sources and fields. Chapter 5 considers sediment control methods related to the watershed area, stream channels, canals, and reservoirs. The economic and legal aspects of sedimentation are considered in Chapters 6 and 7.

Reference 13
SOIL EROSION: PREDICTION AND CONTROL

Proceedings of a National Conference on Soil Erosion May 24-26, 1976; Purdue University, West Lafayette, Indiana. Ankeny Iowa: Soil Conservation Society of America; 1977. 393 p. (special publication no. 21).

Order from: Soil Conservation Society of America, 7515 Northeast Ankeny Road, Ankeny, Iowa 50021.

Forty-four presentations are included in this report. The papers note the merits of the universal soil loss equation (USLE) as a working tool for soil conservation and erosion control planning, and recognize that existing data limitations become important when attempting to extend the use of the equation to new physiographic areas or to larger heterogeneous watersheds. The conference included reports of USLE use in Hawaii, the Northwest (U.S.A.), the semiarid Southwest (U.S.A.), and the Ivory Coast and Nigeria in Africa. Descriptions are also included of USLE application to urban sediment control, highway erosion control systems, reclaimed coal mine lands, wildlands, small watersheds, a river basin, nonpoint-source pollution controls, and economic analyses. The deposition of sediment by overland flow, legal controls applicable to soil erosion, research needs, and other allied topics are also discussed. The 44 papers are placed in one of the following categories: applications of the universal soil loss equation; erosion research; erosion and sediment field modeling; use of the USLE in planning; soil erosion control; and conservation needs.

Reference 14
EROSION CONTROL ON HIGHWAY CONSTRUCTION

Transportation Research Board; 1973. 52 p. (National Cooperative Highway Research Program Synthesis of Highway Practice 18).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Highway construction operations that may contribute to erosion are clearing and grubbing, construction of haul roads, earthmoving and grading, ditch construction, and foundation excavation and channel changes at stream crossings. Curtailment of construction for the winter months without adequate provision for controlling erosion can result in severe erosion and sedimentation damage. This report provides information on design procedures to minimize erosion, construction practices to control erosion, beneficial landscaping procedures, and maintenance practices to sustain erosion control installations. More specifically, the report provides information on (a) seeding, planting, and mulching; (b) design of sediment basins and traps; (c) slope protection; and (d) berms. To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Transportation Research Board study analyzed available information (e.g., current practices, manuals, and research recommendations) assembled from many highway departments and agencies responsible for highway planning, design, construction, and maintenance.

Reference 15
SOIL EROSION AND WATER POLLUTION PREVENTION

Foote, Lawrence. Washington, DC: National Association of Counties, Research Foundation; 1972 July. 60 p. (National Association of County Engineers Action Guide Series, Volume XII).

Order from: National Association of Counties, 1735 New York Avenue, N.W., Washington, DC 20006.

This manual which is designed to alert the county engineer to the various ways of minimizing soil erosion and attendant water pollution problems, discusses proper design as a prime consideration in alleviating those problems. Actions that should be taken during the preconstruction and construction phases of highway programs are specifically emphasized, as well as maintenance procedures to be used to minimize soil eroison problems. The problem of winter salting and its impact upon the roadside environment are also discussed. This guide emphasizes the uses of cover soil stabilization. Information on land surface covers that can be used, various seeding mixtures, and data that will aid in developing specifications for effective erosion control in contractual work are included in appendices.

Reference 16
SOIL EROSION: CAUSES AND MECHANISMS; PREVENTION AND CONTROL

Highway Research Board, Proceedings of a Conference-Workshop Held January 26, 1973, Washington, DC: Highway Research Board; 1973; 141 p. (Special Report 135).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This two-part special report presents 14 papers. Six papers deal with the causes and mechanisms of soil erosion. These papers include a state-of-the-art report, an experimental study of the attack of water on dry cohesive soil systems, a discussion of soil erodibility on construction areas, a study of the erodibility of a cement-stabilized sandy soil, and a laboratory study of the application of chemical and electrical parameters to prediction of erodibility. Eight papers report on methods of preventing and controlling erosion. These papers include a state-of-the-art report and an inventory of roadside erosion in Wisconsin, as well as papers on erosion control structures, factors involved in the use of herbaceous plants for erosion control on roadways, promising materials and methods for erosion control, chemical soil stabilizers for surface mine reclamation, and Pennsylvania's response to erosion control.

Reference 17
ENGINEERING FIELD MANUAL FOR CONSERVATION PRACTICES

U.S. Department of Agriculture, Soil Conservation Service. Washington, DC; 1975. Variable paging. (Second printing. Report # PB 244 668/OSL).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

This manual provides guidance in the use of basic engineering principles, techniques, and procedures for the planning, design, installation, and maintenance of soil and water conservation practices. Tables, charts, curves, and forms are used to illustrate the solving of planning and design problems. The 17 chapters of this manual detail all relevant aspects of engineering surveys, estimating runoff, hydraulics, elementary soils engineering, preparation of engineering plans, structures, grassed waterways and outlets, terraces, diversions, gully treatment, ponds and reservoirs, springs and wells, dikes and levees (wildlife wetland development), drainage, irrigation, streambank protection, construction and construction materials.

Reference 18
STANDARDS AND SPECIFICATIONS FOR SOIL EROSION AND SEDIMENT CONTROL IN DEVELOPING AREAS

U.S. Department of Agriculture, Soil Conservation Service: Washington, DC; 1975 July. 300 p. (PB-281 278).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Standards and specifications (based on work in developing areas in the State of Maryland) are presented to help promote uniformly high technical quality in the selection, design, installation, and maintenance of erosion and sediment control measures. The temporary structural practices considered in this publication include dikes (diversion, interceptor, perimeter, straw bale), swales (interceptor, perimeter), stabilized construction entrances, stone outlet structures, grade stabilization structures, sediment basins, and sediment traps. The permanent structural practices include diversion, grassed waterway, level spreader, storm drain outlet protection, riprap, subsurface drain, and land grading. Vegetative practices for critical area stabilization with temporary or permanent seeding, mulching, bermuda grass, sod, ground covers, vines, etc., are reviewed. Standards and specifications are also provided for vegetative tidal bank stabilization, topsoiling, protection of trees in urbanized areas, seeding stripmine areas, dune stabilization, toxic salt reduction, dust control, and protective materials for channels and steep slopes. Appendices provide information on grasses and legumes, seeds, and turfgrass sod.

Reference 19
DESIGN OF CULVERTS, ENERGY DISSIPATORS, AND FILTER SYSTEMS. 8 REPORTS.

Highway Research Board. Washington, DC; 1971. 112 p. (Highway Research Record Number 373).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

Eight papers discuss energy dissipators at culvert outlets, the use of roughness elements within circular pipe to dissipate energy in free surface flow, the use of plastic filter cloths, and the testing of buried corrugated steel pipes. The paper on the hydraulics of rigid boundary basins describes the mechanics of flow in a rectangular basin with artificial roughness elements to induce a hydraulic jump. The second paper gives a method for the analysis and design of energy-dissipator basins at culvert outlets where high tailwater prevails. A method for the design of rock-riprapped, energy-dissipator basins at culvert outfalls is described in the third paper. Criteria for the design of rock-basin energy dissipators with or without transverse sill are described in the fourth paper. Three energy dissipators (stilling well, the Bureau of Reclamation impact dissipator, St. Anthony Falls dissipator) are evaluated in the fifth paper. The other papers describe the testing of peripheral roughness elements in a smooth circular pipe to dissipate energy in free surface flow, the performance of filter cloths used to replace granular filter materials under riprap and similar applications, and the full-scale external load testing of buried corrugated steel pipe.

Reference 20
EROSION Y SEDIMENTACION: MEDIDAS TEMPORARIAS DE CONTROL

U.S. Department of Transportation, Office of International Programs, Technical Assistance Division. Washington, DC: U.S. Government Printing Office; 1975. 44 p. (Report # PB-245 004 7SL).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

The manual, which is in Spanish, was prepared as an aid to field personnel engaged in the construction of highways in Latin America. It provides suggestions on the most efficient ways of providing emergency care against erosion and sedimentation by prompt treatment of the slopes. The booklet contains 24 pages of diagrams of various types of problems and methods of controlling them. The report was designed for distribution to the governments of Latin American countries through the cooperation of the U.S. Agency for International Development. This manual is a Spanish translation of Reference 7.

Reference 21
TENTATIVE DESIGN PROCEDURE FOR RIPRAP-LINED CHANNELS

Anderson, Alvin G.; Paintal, Amreek S.; Davenport, John T. Washington, DC: Highway Research Board; 1970. 75 p. (National Cooperative Highway Research Program Report 108).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

The erosion-resistant riprap lining has protective qualities that fall between those of a grassed drainage channel and a concrete-lined drainage channel. It consists of a layer of discrete fragments of rock of sufficient size to resist the erosive forces of the flow. The design of such riprap-lined drainage channels involves the interrelationship among the discharge, the longitudinal slope, the size and shape of the channel, and the size distribution of the riprap lining. This report describes these interrelationships and develops design criteria by which a riprap-lined drainage channel can be proportioned and the riprap lining can be specified for a given discharge and longitudinal slope. The relationships so developed have been reduced to design charts, the use of which permit rapid and simple establishment of channel shape and size, as well as of the properties of the riprap lining. Highway drainage channels are divided into two groups. In the first group are those that serve as median or side ditches for the drainage of the roadways. These are relatively small and often approach a triangular cross section because of the relatively flat side slopes and generally small bottom width. In the second group are large drainage channels that convey a larger discharge and are usually trapezoidal in cross section. A set of design charts for each type has been prepared. Limited experimental data are presented that verify the design procedure, test the efficacy of channels designed according to this procedure, and examine somewhat more closely the phenomenon of leaching of base material through the riprap interstices. These experiments, although preliminary in character, indicate that the design procedures are suitable and incorporate sufficiently large factors of safety to provide stable channels.

Reference 22
LITERATURE SURVEY AND PRELIMINARY EVALUATION OF STREAMBANK PROTECTION METHODS

Keown, Malcolm P.; Oswalt, Noel R.; Perry, Edward B.; Dardeau, Elba A. Jr.; U.S. Army, Waterways Experiment Station, Hydraulics Laboratory, Mobility and Environmental Systems Laboratory, Soils and Pavements Laboratory. Washington, DC: U.S. Army, Office, Chief of Engineers; 1977. 262 p. (Report #AD-AO42052/1St).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

This document contains the results of the literature survey and two preliminary studies of streambank erosion control. Preliminary investigations were conducted to identify the mechanisms that contribute to streambank erosion and to evaluate the effectiveness of the most widely used streambank protection methods. Appendices include (1) the text of the "Streambank Erosion Control Evaluation and Demonstration Act of 1974"; (2) a list of commercial concerns that market streambank protection products; (3) a glossary of streambank protection terminology; (4) a detailed bibliography resulting from the literature survey; and (5) a listing of selected bibliographies related to streambank protection.

Reference 23
SCOUR AT BRIDGE WATERWAYS

Highway Research Board. Washington, DC; 1970. 37 p. (National Cooperative Highway Research Program Synthesis of Highway Practice 5).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This synthesis is concerned with the prediction of and design for scour in the material supporting the foundations of the bridge. The nature of scour is defined and two types of scour (the clear water case where material is removed from the scour hole and not replaced and the sediment-transporting case where the scour hole is continuously supplied with material from the sediment load carried on the stream bed) are distinguished. The type of scour and the possibility of either degradation or aggradation should be taken into consideration in the design, construction, and maintenance of bridge structures. When estimating scour potential, practicing engineers give consideration to hydraulic and hydrologic information, engineering geology, and historic data, with emphasis on the performance of adjacent structures. The estimation of scour requires three predictions: the magnitude of the flood, the pattern of the flow, and the depth of the scour. Several methods are used for computing maximum flood flow. Current design techniques to provide scour protection at bridge waterways are discussed. Routine inspection and inspection after major floods are also discussed. Corrective measures that have been used for scour damage are reviewed. Specific recommendations for preliminary investigation, hydrologic investigation, and geologic investigation in the planning of a waterway crossing are listed.

Reference 24
HYDRAULICS OF BRIDGE WATERWAYS

2nd ed. Revised. Bradley, Joseph N.; U.S. Federal Highway Administration, Office of Engineering, Bridge Division, Hydraulics Branch. Washington, DC: U.S. Federal Highway Administration; 1978 March. 111 p. (Hydraulic Design Series Number 1; stock number 050-001-00133-1).

Order from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

This publication is based principally on the results of hydraulic model tests that have been evaluated on the basis of field data. These field data have been used to determine the actual limits of application and to complete the design curves. The computation of backwater, difference in water level across approach embankments and the configuration of backwater are discussed, as well as aspects relating to dual bridges and the abnormal stage-discharge condition. The effects of scour on backwater, the partially inundated superstructure, spur dikes at bridge abutments, and supercritical flow under a bridge are also covered. Preliminary field and design procedures and illustrative examples are presented. The development of expressions for bridge backwater and the development of charts for determining the length of spur dikes are described in appendices.

Index

The following index is an alphabetical list of subject terms, names of people, and names of organizations that appear in one or another of the previous parts of this compendium, i.e., in the overview, selected texts, or bibliography. The subject terms listed are those that are most basic to the understanding of the topic of the compendium.

Subject terms that are not proper nouns are shown in lower case. Personal names that are listed generally represent the authors of selected texts and other references given in the bibliography, but they also represent people who are otherwise identified with the compendium subjects. Personal names are listed as surname followed by initials. Organizations listed are those that have produced information on the topic of the compendium and that continue to be a source of information on the topic. For this reason, postal addresses are given for each organization listed.

Numbers that follow a subject term, personal name, or organization name are the page numbers of this compendium on which the term

Indice

El siguiente índice es una lista alfabética del vocablo del tema, nombres de personas, y nombres de organizaciones que aparecen en una u otra de las partes previas de este compendio, es decir, en la vista general, textos seleccionados, o bibliografía. Los vocablos del tema que aparecen en el índice son aquellos que son necesarios para el entendimiento de la materia del compendio.

Los vocablos del tema que no son nombres propios aparecen en letras minúsculas. Los nombres personales que aparecen representan los autores de los textos seleccionados y otras referencias dadas en la bibliografía, pero también pueden representar a personas que de otra manera están conectadas a los temas del compendio. Los nombres personales aparecen con el apellido seguido por las iniciales. Las organizaciones nombradas son las que han producido información sobre la materia del compendio y que siguen siendo fuentes de información sobre la materia. Por esta razón se dan las direcciones postales de cada organización que aparece en el índice.

Los números que siguen a un vocablo del tema, nombre personal, o nombre de organización son los números de página del compendio donde el vocablo o nombre aparecen. Los números romanos se refieren a las páginas en la vista general, los números arábigos se refieren a páginas en los textos seleccionados, y los números de referencia (por ejemplo, Ref. 5) indican referencias en la bibliografía.

Algunos vocablos del tema y nombres de organizaciones están seguidos por la palabra *see.* En tales casos los números de página del com-

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Cet index se compose d'une liste alphabétique de mots-clés, noms d'auteurs, et noms d'organisations qui paraissent dans une section ou une autre de ce recueil, c'est à dire dans l'exposé, les textes choisis, ou la bibliographie. Les mots-clés sont ceux qui sont le plus élémentaires à la compréhension de ce recueil.

Les mots-clés qui ne sont pas des noms propres sont imprimés en minuscules. Les noms propres cités sont les noms des auteurs des textes choisis ou de textes de référence cités dans la bibliographie, ou alors les noms d'experts en la matière de ce recueil. Le nom de famille est suivi des initiales des prénoms. Les organisations citées sont celles qui ont fait des recherches sur le sujet de ce recueil et qui continueront à être une source de documentation. Les adresses de toutes ces organisations sont incluses.

Le numéro qui suit chaque mot-clé, nom d'auteur, ou nom d'organisation est le numéro de la page où ce nom ou mot-clé parait. Les numéros or name appears. Roman numerals refer to pages in the overview, Arabic numerals refer to pages in the selected texts, and reference numbers (e.g., Ref. 5) refer to references in the bibliography.

Some subject terms and organization names are followed by the word *see.* In such cases, the compendium page numbers should be sought under the alternative term or name that follows the word *see.* Some subject terms and organization names are followed by the words *see also.* In such cases, relevant references should be sought among the page numbers listed under the terms that follow the words *see also.*

The foregoing explanation is illustrated below.

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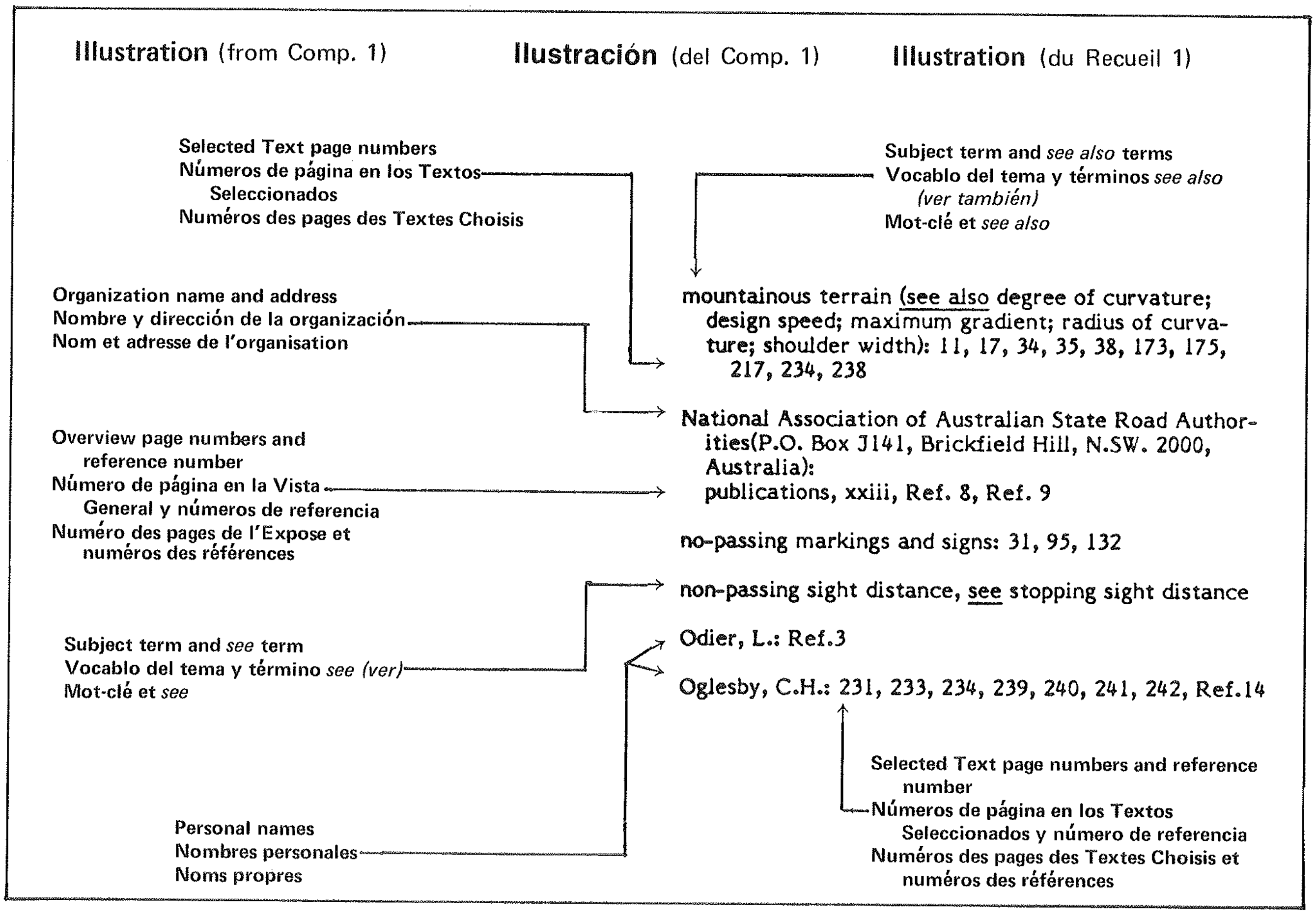
pendio se encontrarán bajo el término o nombre alternativo que sigue a la palabra *see.* Algunos vocablos del tema y nombres de organizaciones están seguidos por las palabras *see also.* En tales casos las referencias pertinentes se encontrarán entre los números de página indicados bajo los términos que siguen a las palabras *see also.*

La explicación anterior está subsiguientemente ilustrada.

écrits en chiffres romains se rapportent aux pages de l'exposé et les numéros écrits en chiffres arabes se rapportent aux pages des textes choisis. Les numéros de référence (par exemple, Ref. 5) indiquent les numéros des références de la bibliographie.

Certains mots-clés et noms d'organisations sont suivis du terme *see.* Dans ces cas, le numéro des pages du recueil se trouvera après le mot-clé ou le nom d'organisation qui suit le terme *see.* D'autres mots-clés ou noms d'organisations sont suivis des mots *see also.* Dans ce cas, leurs références se trouveront citées après les mots-clés qui suivent la notation *see also.*

Ces explications sont illustrées ci-dessous.



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