TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

COMPENDIUM 7

Road Gravels

Gravas

Les graviers

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Notice

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

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: Application of lateritic gravel surface in Brazil.

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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 seventh 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 gravels used in road construction. 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 Society of Civil Engineers; Butterworth and Co. (Publishers) Ltd., London; Cornell University, Ithaca, N.Y.; National Association of County Engineers; Transport and Road Research Laboratory, U.K.; Virginia Department of Highways and Transportation; U.S. Federal Highway Administration; U.S. Agency for International Development.

Prefacio y agradecimientos

Este compendio es el séptimo 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 la grava utilizada en la construcción de caminos. 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 Society of Civil Engineers; Butterworth and Co. (Publishers) Ltd., London; Cornell University, Ithaca, N.Y.; National Association of County Engineers; Transport and Road Research Laboratory, U.K.; Virginia Department of Highways and Transportation; U.S. Federal Highway Administration; U.S. Agency for International Development.

Avant-propos et remerciements

Ce recueil représente le septième 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 des matériaux graveleux utilisés en construction routière. 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 Society of Civil Engineers; Butterworth and Co. (Publishers) Ltd., London; Cornell University, Ithaca, N.Y.; National Association of County Engineers; Transport and Road Research Laboratory, U.K.; Virginia Department of Highways and Transportation; U.S. Federal Highway Administration; U.S. Agency for International Development.

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 R.G. Hicks, Oregon State University, Lynne H. Irwin, Cornell University, and Wilbur J. Morin, Lyon Associates, Inc., 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 especial 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 permisión 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 R. G. Hicks, Oregon State University, Lynne H. Irwin, Cornell University, y Wilbur J. Morin, Lyon Associates, Inc., 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 Services 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 R.G. Hicks, Oregon State University, Lynne H. Irwin, Cornell University, et Wilbur J. Morin, Lyon Associates, Inc.,qui ont bien voulu prêter leur assistance à la préparation de ce récueil.

Overview

Background and Scope

Low-volume roads are constructed mostly of soils. Some are surfaced with coarse granular soils that include gravel and crushed stone. Gravel has two meanings to the engineer. In the context of soil-fraction size limits, it is the material that passes through a 3-in sieve (particle size-76 mm) and is retained on a No. 4 sieve (particle size-5 mm). In the broader context, the Unified Soil Classification System defines gravel as a coarse-grained soil in which more than half of the material is larger than a No. 200 sieve (particle size-0.08 mm) and more than half of the coarse fraction — i.e., the material larger than 0.08 mm — is larger than a No. 4 sieve. This compendium deals with gravel in the latter context of a blend of particles.

The proper blend of particle sizes produces an interlocking effect known as mechanical strength. The mechanical strength, or load-carrying capacity of gravel, is a function of several properties. Basically, the more dense the material is, the stronger it will be. Density is a function of proper gradation. When compacted properly at optimum moisture content, a

Vista General

Antecedentes y alcance

Los caminos de bajo volúmen se construyen mayormente de tierra. Algunos se revisten con suelos granulares toscas, que incluyen grava y piedra triturada. Para el ingeniero la palabra "grava" tiene dos significados. Cuando se refiere a las limitaciones de tamaños de partícula del suelo, es aquel material que pasa por un tamiz de 3 pulgadas (tamaño de partícula — 76 mm), y es retenido por un tamiz Nº 4 (tamaño de partícula — 5 mm). En el sentido más amplio, el Sistema de Clasificación de Tierras "Unified" define la grava como un suelo de grano tosco en el cual más de la mitad del material es mayor que el tamiz Nº 200 (tamaño de partícula - 0,08 mm), y más de la mitad de la porción tosca, es decir, el material más grande que 0,08 mm, es mayor que el tamiz Nº 4. Este compendio se refiere a la grava en el sentido más amplio, es decir, una mezcla de tamaños de partícula.

La mezcla correcta de tamaños de partícula desarrolla un efecto de engranaje, que se conoce como resistencia mecánica. La resistencia mecánica o capacidad de soporte de cargas de la grava es una función de varias propiedades. Se podría decir que cuanto más denso es el material, más fuerte será. La densidad es una fun-

Exposé

Historique et description

Les routes économiques sont, pour la plus grande partie, des routes de terre. Il y en a quelques unes dont la couche de surface est faite de matériau granuleux grossier qui comprend du gravier et de la pierre broyée. Pour l'ingénieur routier, le mot "gravier" peut avoir deux définitions. La première, définit le gravier comme étant un matériau qui passe l'ouverture de maille d'un tamis de 3 in (dimension des grains — 76 mm), et est retenu par un tamis no. 4 (dimension des grains — 5 mm). La seconde, celle employée par le système de "classification unifiée" des sols, dèfinit le gravier comme étant un sol grossier, dont plus de la moitié du matériau est de dimension supérieure à l'ouverture de maille du tamis no. 200 (dimension des grains 0,08 mm), et plus de la moitié de la fraction grossiére, c'est á dire le matériau dont les grains sont plus grands que 0,08 mm, est de dimension plus grande que le tamis no. 4 (dimension des grains 5 mm). Nous allons retenir et examiner cette seconde définition du gravier.

well-graded mixture has a minimum of voids. The spaces between the gravel particles are keyed with sand. The voids between the sand particles are partially filled with silt and clay. The quantity of silt and clay in a road gravel is of special importance because these materials tend to soften when wet. A certain amount of silt and clay is desirable for a gravel road surface to minimize ravelling and to seal the surface. For gravel bases that will have a bituminous surface, a smaller quantity of silt and clay is allowable. This is critical because the moisture retention characteristics of these fine materials can cause the base to soften and fail when the moisture is trapped below an impervious layer of pavement.

Well-graded gravel seldom occurs in nature. It can be manufactured by blending different materials from different sources or by screening and washing material from a single source and recombining the screenings in the proper proportions. It can also be made by using a rock crusher and properly blending the screened crushed material. Properly compacted crushed gravel normally will have more strength because the angular shapes of the crushed portions have more resistance to movement than the rounded

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ción de una graduación correcta. Cuando una mezcla bien graduada se compacta correctamente con la humedad óptima, contiene una mínima cantidad de huecos. Los espacios entre las partículas de grava se llenan de arena, y entre las partículas de arena, se llenan de sedimentos y arcilla. La cantidad de sedimentos y arcilla que se encuentra en la grava es muy importante, ya que estos materiales tienden a ablandarse cuando se mojan. Una cierta cantidad de sedimentos y arcilla es deseable en una superficie de grava para reducir la desintegración y sellar la superficie. En las bases de grava donde se colocará una superficie bituminosa, se puede permitir una menor cantidad de sedimentos y arcilla porque la característica de retención de humedad que éstas poseen puede hacer que la base se ablande y se quiebre cuando la humedad se atrapa bajo una capa impermeable de pavimento.

Es poco común encontrar una grava natural bien graduada. Se puede manufacturar mezclando distintos materiales de distintas fuentes, o tamizando y lavando el material de una sola fuente y recombinándolo en las proporciones correctas. También se puede utilizar un triturador de rocas y luego mezclar correctamente el material triturado y tamizado. Normalmente la grava triturada correctamente compactada tendrá más resistencia porque las formas angulares se mueven menos que las formas redondeadas que se encuentran en la grava de ribera. El tema de este compendio es la estabilización mecánica o granular, que significa la mezcla de varios tamaños de material para formar una mezcla densa bien graduada.

Un mélange adéquat de grains de dimensions différentes, résulte en un phénomène d'accrochage connu sous le nom de résistance mécanique. La résistance mécanique, ou la capacité portante d'un gravier, est fonction de plusieurs caractéristiques. Fondamentalement, plus le poids volumétrique, du matériau est élevé, plus ce matériau est résistant. La densité, ou poids volumétrique, est fonction de la granulométrie. Un mélange ayant une courbe granulométrique convenable, compacté à la teneur en eau optimum, aura un minimum de vides, parce que l'espace entre les grains de gravier est calé par le sable, et les vides entre les grains de sable, sont partiellement remplis d'argile et de silt. La quantité de particules fines, c'est à dire d'argile et de silt, a une très grosse importance, quand il s'agit de gravier routier, car ces matériaux ont tendance à se ramollir quand ils sont mouillés. Pour une couche de surface en gravier, une certaine quantité d'argile et de silt est désirable, pour amoindrir les chances de désintégration, et sceller la surface. Pour une couche de base en gravier, qui sera revêtue d'un tapis hydrocarboné, on doit avoir une plus petite quantité de silt et d'argile, car la teneur en eau de ces fines peut être la cause du ramollissement, et de la rupture de la base, quand l'humidité est bloquée par un revêtement imperméable.

On trouve rarement, à l'état naturel, un gravier ayant une bonne granulométrie. On peut le fabriquer en mélangeant des sols en provenance de différents gîtes, ou en passant au tamis, et en lavant, le matériau d'un gisement, et en reconstituant les proportions de ce matériau de façon ce qu'il ait une bonne granulométrie. On peut aussi améliorer la qualité de ce gravier, en le concassant, et en le remélangeant de façon adéquate, après qu'il ait été passé au tamis. Un gravier concassé, compacté de façon convenable, sera normalement plus résistant, car les arêtes vives des éléments concassés, résistent plus au déshapes found in bank gravel. The blending of various sizes of material into a well-graded dense mix is called mechanical or granular stabilization and is the subject of this compendium.

Rationale for This Compendium

The following definition of a low-volume rural road has been adopted for use throughout this compendium series:

> Two levels of traffic volume can be identified: less than 50 ADT (class 1) and 50 to 400 ADT (class 2). Class 1 roads are generally unsurfaced or are graded in situ. Class 2 roads generally have granular surfaces, such as gravel, crushed stone, laterite, or stabilized soil; they generally do not have a high type of paved surface but, at the upper traffic volumes, may be primed, have single surface treatments, or be chip sealed.

This compendium contains information about grading (shaping) in situ material, i.e., class 1 roads. Very little can be done with in situ material except to try to locate the road alignment on the more granular soils in well-drained areas, avoiding saturated and low-lying areas prone to flooding. As these roads become rutted and reshaping is needed, the material should be bladed inward from

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Exposición razonada para este compendio

Se ha adoptado la siguiente definición de un camino rural de bajo volúmen para utilizarse en esta serie de publicaciones:

> Se pueden identificar dos niveles de volúmen de tránsito: un TMDA de menos de 50 (clase 1), y un TMDA de entre 50 y 400 (clase 2). Los caminos de clase 1 generalmente tienen una superficie de tierra natural o son nivelados en situ. Los caminos de clase 2 generalmente tienen superficies granulares, tales como grava, piedra triturada, laterita, o suelo estabilizado; por lo general no tienen un tipo superior de superficie pavimentada, pero en los niveles mayores de volúmen de tránsito, pueden ser imprimados, tener un solo tratamiento superficial, o ser sellados con rezagas.

Este compendio contiene información sobre la nivelación de material en situ, es decir, caminos de clase 1. Se puede hacer muy poco con el material en situ, excepto tratar de situar la alineación del camino sobre los terrenos más granulares en las áreas bien drenadas, y evitar las áreas saturadas, propensas a inundarse. A medida que se forman roderas en el camino se puede cuchillar el material hacia el centro. De esta forma se eleva la superficie y se forma un

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placement, que les formes arrondies des éléments du gravier naturel. Le mélange intime des grains de dimensions variables, qui résulte en un matériau de bonne qualité granulometrique, et de densité correcte, est appellé stabilisation mécanique, ou granulaire. Cette stabilisation mécanique est le thème de ce recueil.

Objet de ce recueil

La définition d'une route à faible capacité que nous avons adoptée pour cette serié de publications est la suivante :

> Deux niveaux de volume de trafic peuvent être identifiés: moins de 50 ADT (classe 1) et de 50 à 400 ADT (classe 2). Les routes de la classe 1 sont généralement non-revêtues, ou sont nivelées sans apport de matériaux. Les routes de la classe 2, ont des revêtements, soit graveleux, soit roche concassée, soit latérite ou sol stabilisé ; en général, elles n'ont pas un revêtement de qualité supérieure, mais pour les limites maximales de volume de trafic, elles peuvent être imprégnées, avoir un enduit superficiel monocouche, ou être gravillonnées.

Ce recueil donne des informations, sur les opérations de nivellement in-situ, des routes de la classe 1. On ne peut pas faire grand chose sans matériaux d'apport, sauf essayer, dans la mesure du possible, de tracer la route sur des sols graveleux, dans des zones bien drainées, en évitant les terrains saturés et en contrebas, qui seraient facilement inondés. Quand il se forme des ornières, et qu'un reprofilage est nécessaire, le sol doit être nivelé en partant des bords de la route vers le centre. De cette façon le niveau de la route est relevé, le bombement de sa surface est assuré, et cela permet au drainage de se faire.

outside the road edges. This serves to raise the roadbed, provide a crowned surface, and initiate a drainage system.

Soil may be mechanically or chemically stabilized. Compendium 7 discusses mechanically stabilized granular surfaces but excludes chemically stabilized soil. The process of soil modification with cement, lime, asphalt, or other materials is a possible subject for a future compendium.

When a granular roadway surface is resurfaced with asphalt, the initial granular surface becomes a base course under the pavement. By definition this consists of only a thin surface dressing. Although the asphaltic surface treatment provides an almost waterproof surface and requires less maintenance, it adds little strength to the pavement structure itself. It does present certain problems in the selection of the granular material that is to be the load-distributing base.

The most important problem relates to the amount of fines (silts or clays) in the gravel material. Thus, the specifications presented in this compendium for road-surface gravel and road-base gravel differ. The base-course requirements call for a much cleaner gravel, i.e., a gravel with a lower percentage of fines having a lower liquid limit and a lower plasticity index.

Natural or blended gravel never retains a cons-

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bombeo que permite el desagüe superficial.

La tierra puede ser estabilizada mecánicamente o químicamente. El Compendio 7 examina la estabilización mecánica de superficies granulares, pero no el suelo químicamente estabilizado. El proceso de modificación del suelo con cemento, cal, asfalto u otros materiales está identificado como posible tema de un futuro compendio.

Cuando la superficie granular de un camino se reviste con asfalto, aquélla se convierte en la capa de base bajo el pavimento. Según la definición supracitada, éste consiste únicamente en un fino riego superficial. Aunque el tratamiento superficial asfáltico provee impermeabilidad y requiere menos mantenimiento, agrega poca resistencia a la estructura del firme misma. Además, presenta ciertos problemas en la selección del material granular que formará la base de distribución de carga.

El problema más importante es la cantidad de finos (sedimentos y arcillas) en la grava. Por esta razón las especificaciones presentadas en este compendio para la grava de superficie y la de base difieren. La capa de base requiere una grava más limpia, es decir, con un porcentaje más bajo de finos, con un límite líquido y un índice de plasticidad más bajos.

Después de manipularse, la grava, natural o mezclada, nunca mantiene una graduación constante. Por esta razón hay husos granulométricos para todas las especificaciones. Un huso granulométrico consiste en una serie de designaciones de tamaño de tamiz y un porcentaje aceptable mínimo y máximo del material que puede pasar por cada tamaño de tamiz. El huso granulométrico toma en consideración las variaciones introducidas en las operaciones de mezclado y esparcido. Normalmente el huso granulométrico de grava de capa de base y el de

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Les sols peuvent être stabilisés de façon mécanique ou chimique. Ce recueil traite de la stabilisation mécanique des matériaux granuleux, et exclut la stabilisation chimique des sols. Les procédés de modification des sols par l'addition de ciment, de chaux, de bitume, ou d'autres matériaux ont été choisis comme sujets d'un prochain recueil.

Quand on met un revêtement bitumé, sur une route dont la couche de roulement est en matériaux granuleux, cette couche de roulement devient la couche de base sous ce revêtement, qui d'après la définition que nous avons donné, consiste seulement d'une mince couche d'usure. Bien que ce revêtement hydrocarboné assure une surface à peu près imperméable, et nécessite moins d'entretien, il n'ajoute guère à la capacité portante de la route elle même, et présente des problèmes dans la sélection des matériaux granuleux appellés à répartir les charges imposées par la circulation.

Le problème le plus important est celui de la quantité d'éléments fins, (argile ou silts) contenus dans les matériaux graveleux. C'est pourquoi les spécifications, qui sont présentées dans ce recueil, sont différentes, quand il s'agit de gravier pour la surface de roulement, ou pour la couche de base. La couche de base nécessite un gravier beaucoup plus propre, c'est à dire un gravier avec un moindre pourcentage de fines, une limite de liquidité plus basse, et un indice de plasticité moins élevé.

Le gravier, soit à l'état naturel, soit quand il est mélangé, ne garde jamais une granulométrie constante, une fois qu'on commence à le manier. A cause de ceci, il y a des fuseaux de réfétant gradation after handling. Therefore, grading envelopes are given in all specifications. A grading envelope consists of a series of sieve-size designations and a range of minimum and maximum percentages of the material that can pass each sieve size and still be considered acceptable. This envelope allows for variations introduced in the mixing and spreading operations. Usually the envelopes for base-course gravel and surface gravel overlap.

One solution to the surface-course and base-course gradation problem is to use gravel that falls in the overlapping envelope area. This material is acceptable as both a surface and a base. This requires much more careful control of the mixing and spreading operations because the range of acceptable passing percentages is reduced considerably. If there is no probability that the material will be repaved with an asphaltic surface before it requires additional replacement gravel due to loss, wear, or strength considerations, it should not be attempted. If it is known that the gravel is to be surfaced in the near future (e.g., as in stage construction), it is possible to use a base-course gravel and maintain the surface (i.e., keep the moisture in to prevent the surface from ravelling) by periodic addition of calcium chloride or sodium chloride until the bituminous wearing course is added. High traffic volumes or heavy rainfall will increase the frequency of the addition of either chloride.

A second consideration in gravel used for road surfaces and for base courses under an asphaltic surface treatment is the maximum size

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grava de superficie se sobreponen un poco.

Una solución para el problema de la graduación de la superficie y la capa de base es la utilización de la grava que cae en el área de superposición de los husos granulométricos. El material así obtenido es aceptable como superficie y como base. Se requiere un control mucho más estricto en las operaciones de mezclado y esparcido porque los porcentajes aceptables de material que pasa por el tamiz son considerablemente más limitados. No debe intentarse si no hay ninguna probabilidad de repavimentación con asfalto, antes de que se requiera grava adicional debido a pérdida, desgaste, o por razones de refuerzo. Si hay intención de revestir la grava en un futuro cercano, tal como en la construcción por etapas, es posible utilizar una grava de base y mantener la superficie (retener la humedad para evitar desintegración de la superficie) con una aplicación periódica de cloruro de calcio o cloruro de sodio, hasta que se agregue la capa superficial bituminosa. Si hay gran volúmen de tránsito o una gran cantidad de lluvia se deberá aumentar las aplicaciones de cualquiera de los cloruros.

Una segunda consideración en la grava a utilizarse en las superficies de camino y en las capas de base con tratamiento superficial de asfalto, es el tamaño máximo del agregado. La superficie superior de la grava de superficie o base deberá ser lisa y nivelada para ofrecer una buena superficie de rodadura. Por esta razón el

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rence pour toutes les specifications. Un fuseau de référence consiste en une série de tamis de tailles différentes, et un pourcentage maximum et minimum du matériau qui peut passer chaque taille de tamis, et être considéré comme acceptable. Ce fuseau tient compte des variations apportées par le mélange et l'épandage. D'ordinaire, les fuseaux des graviers utilisés pour la couche de base, et de ceux utilisés pour la couche de roulement, empiètent l'un sur l'autre.

Une des solutions du problème surface de roulement/couche de base, est d'utiliser le gravier compris dans la zone chevauchante. Ce matériau est alors acceptable à la fois pour la couche de base, et pour la surface de roulement. Ceci demande un contrôle très soigné des operations de mélange et d'épandage, parce que l'éventail des pourcentages passants est considérablement réduit. S'il est improbable que le matériau soit revêtu d'une couche hydrocarbonée avant qu'il ne nécessite une addition de gravier pour pallier aux pertes et à l'usure, ou pour le renforcer, cette opération ne doit pas être entreprise. Si l'on sait que le gravier sera revêtu dans un proche avenir, comme c'est le cas dans l'aménagement progressif, on peut utiliser le gravier comme couche de base, et entretenir la surface (assurer l'humidité, de la couche inférieure pour éviter la désintegration) en ajoutant périodiquement du chlorure de calcium ou du chlorure de sodium, jusqu'a ce qu'on ajoute une couche de roulement hydrocarbonée. En cas de grosse circulation, ou de fortes pluies, il faudra augmenter la fréquence de ces traitements.

Quand on utilise du gravier pour la couche de base, et pour la surface de roulement et que ce gravier est revêtu par une couche hydrocarbonée, les dimensions maximales des agrégats, sont à prendre en considération. La surface supérieure, soit de roulement, soit de base, doit être lisse et vraie pour fournir une of the aggregate. The upper surface of either the surface or base gravel must be smooth and true to provide a good riding surface. For this reason the maximum size of aggregate used should not exceed ¾ in (20 mm).

The gravels found in temperate climates and in the tropics are sometimes different because of the conditions under which they were developed. Compendium 7 recognizes these differences. The various ways in which gravel was developed are the subjects of some of the selected texts. Sample specifications for both temperate zone gravels and tropical lateritic gravels are presented. The recommendations for gravel in both climatic zones vary slightly from text to text but are much more consistent for gravels in the temperate zone for two reasons. First, the countries in the temperate zones have had more experience building gravel roads. Second, some tropical gravels may be of inferior quality when measured by temperate criteria, but may still perform satisfactorily in the countries where they are found. Lateritic gravels present additional gradation problems due to their unique mechanical properties. Excess corrugations will form during the dry season, if a large percentage of a lateritic surface material is gravelly — i.e., is retained on a No. 10 sieve (particle size-2 mm). If, on the other hand, a large percentage of the lateritic surface material is sand and fines — i.e., is passed by the No. 10 sieve — it will show lack of stability or excessive slipperiness during the rainy season.

The problems of maintaining a gravel road are universal, however. Corrugations appear as the road surface dries out. Corrugations appear on all gravel-surfaced roads. The exact cause of corrugations has been the subject of many in-

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tamaño máximo de agregado no deberà exceder ¾ de pulgada (20 mm).

Las gravas que se encuentran en los climas templados y trópicos son a veces distintas según las condiciones en que se desarrollaron. El compendio toma nota de la diferencia. Las varias formas en que se ha desarrollado la grava son el tema de algunos de los textos seleccionados. Se presentan especificaciones de muestra para las gravas de zonas templadas y las gravas lateríticas de los trópicos. Las recomendaciones para las gravas de ambas zonas climáticas varían de texto a texto, pero son más consistentes para las de la zona templada por dos razones: (a) los países de las zonas templadas tienen más experiencia en la construcción de caminos de grava, y (b) algunas de las gravas del trópico son de calidad inferior según los criterios de la zona templada, pero son satisfactorias para los países en donde se encuentran. Las gravas lateríticas presentan problemas de graduación adicionales por sus propiedades mecánicas únicas en su género. Si un gran porcentaje del material laterítico de superficie es de grava, es decir, es retenido en un tamiz Nº 10 (tamaño de partícula: 2 mm), durante la época de sequía se formarán excesivas corrugaciones. Si por otro lado un gran porcentaje del material laterítico de superficie es de arena y finos, es decir, que pasa por el tamiz Nº 10, se notará una falta de estabilidad o un carácter excesivamente resbaladizo durante la época de lluvia.

Sin embargo, los problemas de mantenimiento de caminos de grava son universales. Las corrugaciones aparecen cuando se reseca la superficie del camino. Aparecen en todos los caminos con superficies de grava. La causa de corrugaciones ha sido el tema de muchas inves-

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bonne surface de roulement. Pour assurer ceci, les dimensions maximales des agrégats ne devraient pas excéder ¾ inch (20 mm).

Les graviers que l'on trouve dans les climats tempérés, et dans les tropiques, sont quelques fois différents, à cause des conditions sous lesquelles ils se sont formés. Nous reconnaissons cette différence dans ce recueil. Les différentes façons dont le gravier a été formé, sont traitées dans certains textes choisis. Des exemples de spécifications pour les graviers des régions tempérées, et pour les graviers latéritiques des tropiques, sont présentés. Les spécifications du gravier dans les deux zones climatiques varient quelque peu d'un texte à l'autre, mais sont beaucoup plus consistantes pour les graviers de climat tempéré, ceci pour deux raisons : d'abord, les pays de climat tempéré ont eu beaucoup plus d'expérience dans la construction des routes en terre, ensuite, quelques graviers tropicaux peuvent sembler être de qualité inférieure, si on les juge par les critères utilisés dans les pays tempérés, mais en fait, ils peuvent jouer un rôle tout à fait satisfaisant dans leurs pays d'origine. Les graviers latéritiques présentent, en outre, des problèmes de gradation, causés par leurs singulières caractéristiques mécaniques. Si un gros pourcentage d'un matériau latéritique de surface est graveleux, s'est à dire retenu par un tamis no. 10 (particules de 2 mm), on aura formation de tôle ondulée à la saison sèche. Si, par contre, il y a une grosse provestigations. Corrugations are now thought to be the result of an interaction between the vehicles using the road and the material making up the wearing surface. They are created by the rhythmical bouncing of vehicle wheels. The vehicle weight, suspension, and tire pressure affect the formation of corrugations. The rate of formation of corrugations is influenced by (a) traffic speed, (b) type of surface material, (c) road crown condition, and (d) traffic volume.

There is no known design method to eliminate corrugations from gravel road surfaces. Therefore, corrugations must be removed as they appear. This can be accomplished by (a) hand labor with brooms; (b) drags consisting of chains, tires chained together, weighted frames with blades, or mechanical brooms; and (c) road graders. The frequency of such maintenance procedures can only be determined by observation. The gravel road surface corrugations must

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tigaciones. Se ha concluído que son el resultado de una acción recíproca entre los vehículos que utilizan el camino y el material que compone la superficie de rodadura. Se forman con el rebote rítmico de las ruedas de los vehículos. El peso, suspensión, y presión del neumático del vehículo afectan la formación de estas corrugaciones. La velocidad de formación de las corrugaciones es influenciada por (a) la velocidad del tránsito, (b) el tipo de material de superficie, (c) la condición del bombeo del camino, y (d) el volúmen del tránsito.

No se conoce ningún método de diseño que elimine las corrugaciones de los caminos de grava. Por esto las corrugaciones deberán eliminarse cuando aparecen. Se puede llevar a cabo con (a) trabajo a mano con escobas, (b) dragas de arrastre que consisten en cadenas, neumáticos juntados con cadenas, armazones con cuchillas y pesos, o escobas mecánicas; y (c) niveladoras. Tales procedimientos de mantenimiento deberán repetirse cada vez que se determine necesario. Se deben eliminar estas corrugaciones antes de que se forme una capa dura. Si no, será necesario el reperfilado de la superficie del camino, una operación mucho más difícil.

Los baches aparecen donde se ha utilizado material inferior o donde la superficie no se desagua. El hinchamiento por la helada ocurre en los climas más fríos donde el material de la base o subbase es susceptible a la helada. El Compendio 7 toma nota de estos problemas y presenta prácticas de diseño, construcción o mantenimiento para resolverlos. Se da importancia a través de los textos seleccionados, a que los te-

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portion de sable et d'éléments fins (passant le tamis no. 10) dans le matériau latéritique de surface, la surface sera instable, ou excessivement glissante à la saison des pluies.

Les problèmes d'entretien d'une route en gravier sont universels. La tôle ondulée apparaît dès que la surface de roulement devient sèche. La tôle ondulée apparaît sur toutes les routes en gravier. La genèse de la tôle ondulée a été le sujet de bien des recherches. On pense maintenant qu'elle est causée, par une interaction entre les véhicules qui circulent sur la route, et le matériau dont est construite la surface de roulement. Les ondulations sont crées par le rebondissement rythmique des roues des véhicules. Le poids, la suspension, la pression des pneus d'un véhicule, sont responsables de la formation des ondulations. La vitesse de formation des ondulations est influencée par : (a) la vitesse du trafic, (b) le type de matériau de surface, (c) l'état du bombement de la route et (d) le volume du trafic.

On ne connait pas de procédé pour empêcher l'apparition, sur les routes en graviers, du phénomène de la tôle ondulée. Donc les ondulations doivent être effacées dès leur apparition. Ceci peut être accompli de façons diverses : (a) manoeuvres armés d'un balai, (b) traineaux à chaines ou à pneus, gratte-tôle à lames, tôlards, balayeuses mécaniques, et (c) niveleuses ou graders. La fréquence d'entretien sera fixée par l'observation directe. Sitôt que les ondulations prennent corps, elles doivent être effacées de façon systématique, avant qu'elles ne se durcissent, autrement, l'emploi du profileur devient indispensable, et cela résulte en une opération beaucoup plus complexe.

Les nids de poule se forment là où l'on a utilisé des matériaux de qualité inférieure, ou aux endroits où l'eau ne s'écoule pas bien de la surface de la route.Les soulèvements dûs au gel apparaissent dans les climats plus froids, où les matériaux de la couche de base ou de la couche de fondation sont susceptibles au gel.

be systematically removed before a hard crust is formed. Otherwise the road surface will have to be reshaped. This is a much more difficult operation.

Potholes occur where inferior material has been placed or where water does not run off the road surface. Frost heaves occur in colder climates where the base or subgrade material is frost susceptible. Compendium 7 recognizes and discusses design, construction, or maintenance practices to deal with them. The selected texts stress the construction of both embankments and granular pavements with layers of material that are well compacted at or near optimum moisture content.

Discussion of Selected Texts

The first text, *Low-Cost Roads*, is excerpted from a paper published in *Proceedings, Second Annual Virginia Highway Conference* (November 1948). It presents a general historical review of road construction procedures. It defines the true cost of a road as the sum of its construction and maintenance costs. Thus, there is no such thing as a low-cost road but only roads that are the least expensive. These low-volume roads are the focus of this project.

It discusses the advances made in the useful knowledge of the engineering properties of soils as applied to highway construction. This knowledge led to the development of soil classification systems based on grading, liquid limit, and plasticity index. For highway construction in general the most important properties of a soil are its size grading, plasticity, and optimum moisture content.

This text presents some of the principles that should be observed in the construction of low-volume roads. These include (a) consideration of

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rraplenes y pavimentos granulares se construyan con capas de material bien compactadas y con humedad óptima.

Presentación de los textos seleccionados

El primer texto, *Low-Cost Roads* (Caminos de bajo costo), es una porción de una disertación publicada en *Proceedings: Second Annual Virginia Conference* (Actas de la segunda conferencia vial anual de Virginia) (Noviembre de 1948). Presenta un resumen general histórico de procedimientos de construcción vial. Define el costo verdadero de un camino como la suma de los costos de construcción y mantenimiento. En este sentido no existe tal cosa como un camino de bajo costo, sino que hay caminos que son los más económicos. Estos son los caminos de bajo costo, tema de este proyecto.

Este proyecto habla sobre los adelantos en los conocimientos útiles de las propiedades ingenieriles de suelos, aplicados en la construcción vial. Estos conocimientos llevaron al desarrollo de sistemas de clasificación de suelos basados en la graduación, límite líquido e índice de plasticidad. Para la construcción vial en general las propiedades más importantes de los suelos son su granulometría, su plasticidad, y su humedad óptima.

Luego presenta algunos de los principios que se deberán observar en la construcción de caminos de bajo volúmen. Estos incluyen (a) la consideración de la resistencia de subrasante, (b) la compactación correcta de rellenos, (c) el uso correcto de los materiales excavados de los cortes, (d) el tratamiento de las subrasantes en tramos excavados, y (e) la división de la estruc-

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Dans ce recueil no. 7, nous allons identifier et discuter ces problèmes, ainsi que la façon de les traiter, lors des dimensionnement, construction et entretien de la route. Les textes choisis mettent l'emphase sur l'utilisation de couches de matériaux bien compactées, à une teneur en eau optimum (ou le plus près possible), lors de la construction soit de remblais, soit de revêtements granuleux.

Discussion des textes choisis

Le premier texte, *Low-Cost Roads* (Routes économiques) est extrait d'une communication publiée dans les *Proceedings : Second Annual Virginia Highway Conference* (Novembre 1948). Un compte rendu historique des méthodes de construction des routes est presenté. Le prix de revient d'une route est défini comme étant la somme du prix de la construction et du prix de l'entretien. Ainsi, il n'éxiste pas de routes vraiment économiques, mais plutôt des routes dont le prix de revient est moins élevé. Ces dernières sont le thème de notre projet.

Les progrès qui ont été faits dans la science des caractéristiques des sols, au point de vue de la construction routière, sont discutés. Ces connaissances ont mené au développement des systèmes de classification des sols basés sur l'analyse granulométrique, la limite de liquidité et l'indice de plasticité. Pour la construction subgrade strength, (b) proper compaction of fills, (c) proper use of material excavated from cuts, (d) treatment of subgrades in cut sections, and (e) the division of the pavement structure into a subbase, if required, a base, and a wearing surface.

The concept of granular or mechanical stabilization of pavement structures is introduced. Granular-stabilized mixtures are used as base courses for bituminous surfaces and for wearing surfaces on low-volume roads. The characteristics of the soil binder, which are determined by the liquid limit and the plasticity index, differ for surface gravel and base-course gravel.

In road surfaces exposed to the abrasive action of traffic the soil binder should have a greater cementing power than is required in base courses. In surface courses, as compared to base courses, a higher clay content and a higher liquid limit may be permitted. A higher plasticity index of the soil binder is generally desirable. If such a granular-stabilized mixture is covered with a bituminous surface, the moisture content that helped to hold it together as a surface course is increased. This occurs because evaporation losses are reduced or eliminated. The increase in moisture content frequently causes complete structural failure of this material as a base course. Therefore, specifications for granular-stabilized gravel-base courses differ from those for surface courses. They permit less fine binder material and require that this material have a lower liquid limit and a lower plastic index.

The specification requirements for granular-stabilized base courses and surface courses

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tura del firme en una subbase, si se necesita, una base, y una superficie de rodadura.

Se presenta el concepto de estabilización granular o mecánica de estructuras de firme. Las mezclas granularmente estabilizadas se utilizan como capas de base para superficies bituminosas y también para superficies de rodadura en caminos de bajo volúmen. Las características del aglutinante de suelo, determinadas por el límite líquido y el índice de plasticidad, son distintas para la grava de superficie y la grava de capa de base.

En las superficies de camino, afectadas por la acción desgastadora del tránsito, el aglutinante de suelo deberá tener más habilidad de cementación que el aglutinante en las capas de base. En las superficies se puede permitir un mayor porcentaje de arcilla y un límite líquido más alto que en las capas de base. Asimismo, es deseable un mayor índice de plasticidad en el aglutinante. Si tal mezcla con estabilización granular se tapa con una superficie bituminosa, el contenido líquido que ayudó a mantenerla como superficie de rodadura ha de aumentar. Esto ocurre porque las pérdidas por evaporación son reducidas o eliminadas. Seguidas veces hay una falla estructural total de este material como capa de base a causa del aumento del contenido de humedad. Por esta razón las especificaciones para capas de base de grava granularmente es-

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routière, les caractéristiques les plus importantes d'un sol sont sa granulométrie, sa plasticité et sa teneur en eau optimum.

Ce texte présente quelques principes qui devraient être observés dans la construction de routes à faible capacité. Ceux-ci comprennent (a) étude de la résistance du terrain de fondation, (b) compactage correct des remblais, (c) bonne utilisation des matériaux de déblai, (d) traitement du terrain de fondation dans les sections de déblai et (e) la division de la structure de la chaussée en couche de fondation si c'est nécessaire, en couche de base, et en enduit d'usure.

Le concept de la stabilisation granulaire, ou mécanique, des structures de la chaussée, est introduit. Dans la construction de routes économiques, des mélanges stabilisés mécaniquement, sont utilisés comme couche de base pour les revêtements hydrocarbonés, et aussi comme couche de surface. Les caractéristiques du liant naturel, qui sont determinées par la limite de liquidité et l'indice de plasticité, sont différentes pour les graviers utilisés comme couche de surface, et pour les graviers utilisés comme couche de base.

Pour la couche de surface, exposée à l'action abrasive de la circulation, le liant naturel devrait avoir une plus grande puissance d'agglutination que celui de la couche de base. Donc, pour cette couche de surface, à l'opposé de la couche de base, une teneur en argile plus élevée, et une plus haute limite de liquidité, peuvent être admises. Il est généralement désirable que le liant naturel ait un indice de plasticité plus èlevè. Si un mélange, stabilisé overlap. Thus, it is possible to design a base-course mixture that will also be satisfactory for a surface course. This is desirable for stage construction (when the mixture is to be used as a surface) until some later time when increased traffic warrants a bituminous surface treatment. The mixing and placing of such a material are critical. If the material lacks uniformity, it will not function properly either as a base course or as a surface course.

Granular-stabilized base courses must be compacted to maximum density at optimum moisture content. Otherwise the base course is likely to consolidate under traffic and disrupt or destroy the bituminous wearing course.

The second text, ***Chapter 4 – Roadmaking Materials and Pavement Design***, is adapted from ***Low Cost Roads: Design, Construction and Maintenance*** (UNESCO, 1971). It traces the development of a road from a simple earth track to a surfaced all-weather road. An "unimproved road" is defined as a rudimentary track with a minimum of earthwork done by hand or with bulldozers. The surface consists of the soils found on the line of the road and immediately adjacent to it. Many natural soils are poorly drained and thus are too weak to carry traffic when very wet. Unimproved roads may be closed at times during the rainy season.

An "improved road" is defined as the first

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tabilizada se distinguen de las especificaciones para las superficies de rodadura. Permiten que el aglutinante sea de un material menos fino y requieren que este material tenga un límite líquido y un índice de plasticidad más bajos.

Los requisitos para las especificaciones de superficies y de capas de base granularmente estabilizadas se sobreponen. Por esta razón se puede diseñar une mezcla para la capa de base, que también es satisfactoria para una superficie de rodadura. Esto es útil en la construcción por etapas donde la mezcla a utilizarse como superficie será cubierta por un tratamiento bituminoso cuando el aumento de tránsito lo justifica. La mezcla y colocación de tal material son muy importantes. Si el material no posee uniformidad, no funcionará correctamente como capa de base ni capa de superficie.

Las capas de base granularmente estabilizadas deberán ser compactadas a su densidad máxima y con humedad óptima. De otra forma es probable que la capa de base se endurezca bajo el tránsito y rompa o destruya la superficie bituminosa.

El segundo texto, una porción de ***Chapter 4 — Roadmaking Materials and Pavement Design*** (Capítulo 4 — Materiales de construcción vial y diseño de pavimento) fué extraído de ***Low Cost Roads: Design, Construction and Maintenance*** (Caminos de bajo costo: diseño, construcción y mantenimiento) (UNESCO, 1971). Habla del desarrollo de un camino, desde un simple sendero de tierra hasta un camino con superficie para toda temporada. Un "Camino sin Mejora" es un sendero rudimentario con un mínimo de terraplenado, realizado a mano o con un "bulldozer", o la rasadora utilizada para el movimiento de tierras. La superficie consiste en las tierras encontradas sobre la traza del camino o inmediatamente adyacente a ella. Muchos de los suelos nativos están mal desaguados, y por esto no tienen la resistencia necesaria para soportar el

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mécaniquement de cette façon, est recouvert d'une surface hydrocarbonée, la teneur en eau qui l'a rendu cohésif en temps que couche de surface, s'accroît, parce que les pertes dûes à l'évaporation sont réduites ou même éliminées. Cette augmentation de la teneur en eau cause fréquemment la rupture complète de ce matériau, quand on l'emploit comme couche de base. Donc, les spécifications pour une couche de base en matériau graveleux stabilisé mécaniquement, diffèrent des spécifications pour le même matériau employé en couche de surface. Ces spécifications permettent moins d'éléments fins dans le liant, et éxigent une limite de liquidité plus basse et un indice de plasticité moins élevé.

Les spécifications requises pour les couches de base et de surface stabilisées mécaniquement, se chevauchent. Par conséquent, il est possible de calculer un mélange qui sera à la fois satisfaisant pour la couche de base, et pour celle de surface. Ceci est désirable dans le cadre d'une politique d'aménagement progressif, quand le mélange doit servir de couche de surface pendant un certain temps, jusqu'au moment où l'augmentation de la circulation justifie un revêtement hydrocarboné. Le mélange et la pose de ce matériau sont critiques, car si celui-ci manque d'uniformité, il ne fonctionnera correctement ni comme couche de base ni comme couche de surface.

Les couches de base stabilisées mécanique-stage in the improvement of an earth track. It generally involves (a) earthworks to provide or raise embankments in poorly drained areas, (b) the construction of permanent bridges over river crossings, (c) vertical and horizontal alignment corrections to some design standard, and (d) an attempt to provide an all-weather running surface. Normally, it is necessary to improve the stability of the running surface either by mixing imported materials with the local soil (i.e., mechanical or granular stabilization) or by superimposing a layer of more stable material. The text presents typical specifications for the gradations used in mechanical stabilization of gravel running surfaces and the plasticity characteristics preferred for gravel surfacings in three climatic ranges: moist temperate–wet tropical, seasonal wet tropical, and arid.

This text also describes roads with permanent surfaces. Although pavement design is beyond the scope of this compendium, the characteristics of gravel used as a base under flexible pavements is an important part of this topic. The principle function of the base and subbase is to distribute the stresses imposed by traffic. On low-volume roads the bituminous surfacing consists only of a thin surface dressing. The base itself must therefore be resistant to the weakening effects of water. The upper surface of the base must be sufficiently smooth and true to provide a good riding surface.

The text outlines the characteristics of natural soils and gravels commonly used in making bases and subbases. It also offers typical specifications for the mechanical stabilization of gravel base material.

The third text is excerpted from ***Location and Evaluation of Gravel Sources for Highway Use*** (Department of Agricultural Engineering, Cornell University, 1956). The first part describes the lo-

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tránsito cuando están muy mojados. Durante la época de lluvia es común clausurar los caminos no mejorados después de tormentas.

Un "Camino Mejorado" se refiere a la primera etapa en la mejora de un camino de tierra. Generalmente significa (a) el movimiento de tierras para proveer o mejorar terraplenes en áreas de desagüe insuficiente, (b) la construcción de puentes permanentes sobre vados de ríos, (c) correcciones de alineamiento vertical y horizontal de acuerdo con alguna norma de diseño y (d) un esfuerzo para proveer una superficie de rodadura para toda temporada. Normalmente es necesario mejorar la estabilidad de la superficie de rodadura por la mezcla de materiales importados con el suelo nativo (es decir, estabilización mecánica o granular) o por la superposición de una capa de un material más estable. El texto presenta las especificaciones típicas para la graduación utilizada en la estabilización mecánica de superficies de rodadura de grava y las características de plasticidad que se prefieren para los revestimientos de grava en tres variaciones climáticas: templado húmedo — tropical lluvioso, tropical lluvioso por temporada y árido.

El texto también describe los caminos con superficie permanente. Aunque el diseño de pavimento está fuera del alcance de este compendio, las características de la grava que se utiliza como base de los pavimentos flexibles es una parte importante de este tema. La función más importante de la base y subbase es la distribución de la tensión creada por el tránsito. En

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ment doivent être compactées à une teneur en eau optimum. Autrement, la couche de base est susceptible de se consolider sous la circulation, et de causer la rupture ou même la destruction de la couche de roulement hydrocarbonée.

La deuxième texte consiste en des extraits du ***Chapter 4, Roadmaking Materials and Pavement Design*** du livre ***Low Cost Roads; Design, Construction and Maintenance*** (Routes dans les pays en voie de développement ; Conception, construction, entretien) (UNESCO, 1967 ; traduction anglaise, 1971). Dans ce texte, le développement d'une route, depuis la simple piste en terre jusqu'à la route tous temps dôtée d'un revêtement, est retracé. Une route "non aménagée" est définie comme une piste rudimentaire, réalisée avec des terrassements élémentaires faits à la main ou au bulldozer. La surface de cette piste consiste en matériaux trouvés sur son tracé ou aux abords immediats. L'eau s'écoule plus ou moins bien de beaucoup de ces matériaux naturels et, de ce fait, leur portance est insuffisante pendant la saison des pluies. Par conséquent, les routes non aménagées ont des chances d'être complétement fermées à la circulation pendant cette saison.

Une route aménagée est définie comme le premier stade de l'aménagement d'une piste en terre. Ce stade comprend, en général ; (a) des terrassements pour remblayer les zones mal drainées, ou pour surélever les remblais éxistants, (b) la construction d'ouvrages permanents cation of possible gravel sources. It describes the formation of gravel deposits by glaciers and by present-day streams. It also describes the profile development of gravel deposits, i.e., the formation of overburden, and discusses the importance of that overburden. It describes methods of locating possible gravel deposits. Rounded stones are noted as a good indication that a gravel has been deposited and sorted by running water.

The second part describes the evaluation of possible gravel sources. This evaluation includes the information to be considered before a possible source is opened. This includes (a) the nearness to current and future needs, (b) access to an existing roadway, and (c) extent and depth of the deposit. It also includes the characteristics to be evaluated after an exploratory pit is dug: (a) depth of overburden, (b) character of gravel particles, (c) maximum gravel sizes ex-

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los caminos de bajo volúmen el revestimiento bituminoso consiste solamente en un fino riego superficial. Por lo tanto, la base deberá ser resistente a los efectos debilitantes del agua. La superficie superior de la base debe ser lo suficientemente lisa y nivelada para ofrecer una buena superficie de rodadura.

El texto describe las características de suelos y gravas nativas que comunmente se utilizan para las bases y subbases. Asimismo, provee especificaciones típicas para la estabilización mecánica de la grava de base.

El tercer texto fué extraído de ***Location and Evaluation of Gravel Sources for Highway Use*** (Ubicación y evaluación de fuentes de grava para uso vial) (Departamento de Ingeniería Agrícola, Cornell University, 1956). La primera parte describe la ubicación de posibles fuentes de grava. Describe la formación de depósitos de grava por la acción de glaciares y de arroyos actuales. Describe el desarrollo en perfil de los depósitos de grava, es decir, la formación de sobrecarga, y la importancia de ésta. Describe métodos de localizar posibles depósitos de grava. Explica que las piedras redondeadas son una buena indicación de que se ha formado un depósito por la acción de agua.

La segunda parte describe la evaluación de

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sur les rivières, (c) l'amélioration du tracé et du profil en long et (d) l'essai de réalisation d'une couche de surface utilisable par tous les temps. Il sera en général nécessaire d'améliorer la stabilité de la couche de surface en mélangeant des matériaux d'apport au sol naturel, (stabilisation mécanique) ou en le recouvrant d'une couche d'un matériau plus stable. Dans ce texte on trouvera un tableau de fuseaux granulométriques pour couches de roulement, et un autre tableau qui indique la plasticité recommandée pour les revêtements graveleux pour trois sortes de climat : chaud et tropical humide, tropical humide saisonnier, et aride.

Ce chapitre comprend aussi une section sur les routes revêtues. Bien que l'étude des chaussées dépasse l'envergure de notre projet, les caractéristiques des graviers utilisés comme base sous les chaussées souples, constituent, par contre, un élément très important de ce recueil. La fonction principale des couches de base et de fondation consiste à répartir les charges imposées par la circulation. Le revêtement hydrocarboné des routes économiques ne se compose que d'un mince enduit d'usure. Donc, la base elle même doit résister aux effets affaiblissants de l'eau. De plus, la surface supérieure de la couche de base doit être assez lisse et homogène pour permettre d'obtenir un bon uni de surface.

Ce texte esquisse les propriétés générales requises par les sols naturels et les graves utilisés comme couches de base et de fondation. Il donne aussi les fuseaux granulométriques typiques pour la stabilisation mécanique des matériaux graveleux utilisés pour les couches de base.

Le troisième texte est extrait de ***Location and Evaluation of Gravel Sources for Highway Use*** (Localisation et évaluation des gisements de graviers routiers) (Department of Agricultural Engineering, Cornell University, 1956). La première partie décrit la localisation des gisements éventuels de matériau graveleux. Elle décrit la formation des gisements par les glaciers et les rivières. Le développement des gisements de gravier, c'est à dire la formation de surcharge ou mort-terrain, ainsi que l'importance de cette surcharge sont discutés. Les méthodes de localisation de ces gisements sont passées en revue, et il est noté que la présence de pierres arrondies ou de galets, est souvent une bonne indication que du gravier a été deposé par l'eau courante.

La seconde partie explique comment on évalue les gisements éventueis de gravier, et énumère les informations que l'on doit rassembler pour décider de l'exploitation d'un gîte éventuel : (a) la proximité, pour les besoins immédiats et futurs ; (b) l'accès par une route existante et (c) la cubature et la profondeur de l'emprunt. Le pected, (d) gradation of granular material, (e) plasticity of the fines, (f) position of the water table, and (g) degree of cementation.

Evaluation techniques used to determine all of the characteristics listed here are described. Included in the evaluation of the gradations of a possible gravel source is a description of a quick wash test that, because of its simplicity and the wide availability of the equipment needed, is sometimes used in place of the standard sieve analysis.

This text also includes a graphical solution to the problem of combining materials from different sources into a blend with a satisfactory gradation. If the gradation of two available materials is known, this technique can be used to determine what, if any, combinations of these sources will produce a suitable gradation for surface gravel, base gravel, or both.

The fourth text is excerpted from ***Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects: FP-61***, as reprinted in March 1968 by the Bureau of Public Roads, U.S. Federal Highway Administration. Excerpted are ***Section 200 – Aggregate Base*** and ***Section 300 – Aggregate Surfacing.***

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posibles fuentes de grava. Esta evaluación incluye la información a considerarse antes de abrir una posible fuente. Esto incluye (a) su proximidad a futuras y corrientes necesidades, (b) acceso a un camino en existencia, y (c) la extensión y profundidad del depósito. Asimismo, incluye las características a evaluarse después de llevar a cabo un hoyo exploratorio, incluyendo (a) la profundidad de la sobrecarga, (b) las características de las partículas de grava, (c) el tamaño máximo de grava anticipado, (d) la graduación del material granular, (e) la plasticidad de los finos, (f) la posición del nivel freático, y (g) el grado de aglutinación.

Se describen las técnicas de evaluación que se utilizan para determinar todas las características supracitadas. Se incluye en la evaluación de las graduaciones de una posible fuente de grava una descripción de un ensayo de lavado rápido que a veces se utiliza en lugar del análisis granulométrico por tamizado porque es simple y el equipo necesario es fácil de obtener.

El texto también incluye una solución gráfica para la combinación de materiales de distintas fuentes en una mezcla con graduación satisfactoria. Si se conoce la graduación de dos materiales disponibles, esta técnica puede utilizarse para determinar qué combinaciones de estos materiales producirían una graduación satisfactoria para grava de superficie y/o base, si es que existen.

El cuarto texto fué extraído de ***Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects: FP61*** (Especificaciones generales para la construcción de caminos y puentes en proyectos federales de carreteras: FP61) de la reimprimición de marzo de 1968, por el Bureau of Public Roads, U.S. Federal Highway Administration. Las secciones extraídas son ***Section 200 — Aggregate Base*** (Sección 200 — Base de agregado) y ***Section 300 — Aggregate Surfacing*** (Sección 300 — Revestimiento con agregado).

Cada especificación incluye (a) una descrip-

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texte indique aussi les caractéristiques à évaluer aprś le sondage : l'épaisseur de la surcharge, (b) la nature du gravier, (c) les dimensions maximales des grains, (d) la gradation du matériau granulé, (e) la plasticité des fines, (f) la position de la nappe phréatique et (g) le degré de cimentation.

Les méthodes d'évaluation utilisées pour la détermination des caractéristiques que nous venons d'indiquer, sont présentées. Pour effectuer cette gradation des graviers des gîtes éventuels, on décrit un essai, le "quick wash test", qui est parfois utilisé à la place de l'analyse granulométrique, car il est très simple à conduire et on a toujours sous la main l'équipement nécessaire.

Ce texte comprend aussi une solution graphique au problème du mélange de matériaux provenant de gîtes différents. Si on connait la gradation de deux matériaux, ce procédé peut être utilisé pour determiner, s'il est possible, et dans quelles proportions, on devra les mélanger pour obtenir une granulométrie adéquate pour le gravier de surface ou celui de base, ou les deux.

Le quatrième texte choisi est extrait de ***Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects : FP 61*** (Normes pour la construction des routes et des ponts des projets routiers fédéraux) (réimpression de Mars 1968, Bureau of Public Roads, U.S. Federal Highway Administration). Les extraits comprennent la section 200, Base en aggregats et la section 200, Surface en aggrégats.

Chaque norme comprend (a) une description de l'ouvrage à exécuter, (b) les matériaux à utili-

Each specification includes (a) a description of the work, (b) the materials to be used including acceptable grading envelopes, (c) requirements for construction methods, (d) measurement methods, and (e) payment criteria. These specifications show the difference in plasticity requirements for surface and base gravels. They can be used as a basis for the development of gravel specifications in countries that do not have formal specifications.

The previous text addressed road gravels in general. Gravel is scarce in many tropical countries. Some tropical gravels, such as lateritic gravel, do not always fit into the grading envelopes that are specified for gravels found in temperate zones. These gravels have been used successfully for the construction of low-volume roads. The next three selected texts consider tropical gravels.

The fifth text is excerpted from ***Roadmaking Gravels and Soils in Central Africa*** (U.K. Department of Scientific and Industrial Research, Road Research Laboratory, 1960). It reviews the soils, and particularly the gravels, available in Central Africa. Similar soils are found throughout the tropics.

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ción del trabajo (b) los materiales a utilizarse, incluyendo husos granulométricos aceptables, (c) requisitos para métodos de construcción, (d) métodos de medición, y (e) criterios de pago. Estas especificaciones indican la diferencia entre los requisitos de plasticidad para gravas de superficie y de base. Pueden utilizarse como base para el desarrollo de especificaciones para gravas en los países donde no existen especificaciones formales.

El texto anterior habla sobre gravas para caminos en general. En muchos países tropicales la grava es escasa. Algunas gravas tropicales, como por ejemplo la laterítica, no conforman con los husos granulométricos estipulados para las de las zonas templadas, pero son adecuadas para la construcción de caminos de bajo volúmen. Los tres textos siguientes examinan las gravas tropicales.

El quinto texto fué extraído de ***Roadmaking Gravels and Soils in Central Africa*** (Gravas y suelos para la construcción de caminos en Africa Central) (Departamento de Investigación Científica e Industrial de Gran Bretaña, Road Research Laboratory, 1960). Repasa los suelos, y particularmente las gravas, disponibles en Africa Central. Se pueden encontrar suelos similares en todos los países tropicales.

El texto incluye (a) las gravas y arenas detríticas que se encuentran en las áreas de poca lluvia (menos de 30 pulgadas o 760 mm por año), (b) gravas cuarcíticas y arena-arcilla en las áreas de lluvia normal y de mucha lluvia (más de 760 mm por año) y (c) gravas nodulares lateríticas y gravas calcáreas en las áreas de mucha lluvia (más de 40 pulgadas o 1020 mm por año). El primer grupo, gravas y arenas detríticas, se divide en los siguientes sub-grupos según la petrología de la roca matriz: (a) materiales graníticos, gnéisicos y cuarcíticos, (b) gravas y arenas de piedra arenisca, (c) materiales deleríticos (término inglés) o diabásicos (término americano) y basálticos, (d) gravas micáceas y esquistosas, (e) materiales derivados de la lutita, y (f) gravas de piedra caliza.

Se describe cada material. Se definen los criterios y la conveniencia de su utilización como material de superficie o base. También se eva-

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ser ainsi que les fuseaux granulométriques admissibles, (c) les conditions requises pour les méthodes de construction, (d) les unités de mesure et (e) les critères de paiement par unité de mesure. Ces spécifications indiquent les différents taux de plasticité requis par les graviers de base et les graviers de surface. Ces spécifications peuvent servir de point de départ pour le développement de normes officielles.

Le texte précédent s'adresse aux graviers routiers en général. Dans beaucoup de pays tropicaux le gravier est plutôt rare. Certains graviers tropicaux, comme le gravier latéritique, ne concordent pas avec les fuseaux granulométriques des graviers de zones tempérées. Cependant ces graviers ont été utilisés avec succès dans la construction de routes à faible capacité. Les trois textes qui suivent examinent les graviers tropicaux.

Le cinquième texte est extrait de ***Roadmaking Gravels and Soils in Central Africa*** (Graviers et sols routiers en Afrique Centrale) (U.K. Department of Scientific and Industrial Research, Road Research Laboratory, 1960). Ce texte passe en revue les sols, et les graviers en particulier, que l'on trouve en Afrique Centrale. Les mêmes types de sols se trouvent d'ailleurs dans toutes les régions tropicales.

Ce texte considère (a) les graviers et sables détritiques que l'on trouve dans les endroits où la quantité de pluie annuelle est moins de 760 mm (30 inches), (b) les graviers quartzifères et

The text discusses (a) detrital gravels and sands found in low-rainfall areas, i.e., less than 30 in (760 mm)/year, (b) quartzitic gravels and sand-clays in intermediate and high-rainfall areas (more than 760 mm/year), and (c) nodular lateritic and calcareous gravels in high-rainfall areas, i.e., more than 40 in (1020 mm)/year. The first group, detrital gravels and sands, is further divided into the following subgroups on the basis of the petrology of the parent rock: (a) granite, gneissic, and quartzitic materials; (b) sandstone gravels and sands; (c) doleritic (U.K. term) or diabasic (U.S. term) and basaltic materials; (d) micaceous and schistose gravels; (e) materials derived from shale; and (f) limestone gravels.

Each material is described. The suitability and criteria for its use as a surface or base material are defined. The materials are also evaluated for subbase and imported subgrade usage based on evaluation of existing roads throughout the area. The possibility of economically stabilizing some of the materials is discussed. A short section on methods of locating gravel deposits is also included.

The sixth text is a paper entitled ***Lateritic Gravel Evaluation for Road Construction*** (Journal of the Soil Mechanics and Foundations Division,

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lúan los materiales para utilizarse en la subbase y subrasante importada, de acuerdo con la evaluación de caminos existentes en el área. Se habla sobre la posibilidad de estabilizar algunos de los materiales económicamente. Se incluye una breve sección sobre los métodos de localizar depósitos de grava.

El sexto texto es un artículo titulado ***Lateritic Gravel Evaluation for Road Construction*** (Evaluación de la grava laterítica para la construcción de caminos), (***Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers***) (Publicación de la División de Mecánica del Suelo y de Cimentación, Actas de la Sociedad Americana de Ingenieros Civiles) (Noviembre de 1972). Presenta los resultados de estudios hechos sobre las gravas lateríticas de Ghana. Aunque no todos los países tropicales poseen laterita en todas sus formas, el estudio evalúa la laterita de varias formaciones geológicas en cuatro regiones climáticas. Estas lateritas son típicas de casi todas las lateritas que comunmente se encuentran en el trópico.

En Ghana las formaciones geológicas más comunes asociadas con depósitos de grava fueron divididas en cuatro grupos: (a) igneo ácido — granito, gneis, cuarcita; (b) igneo básico — basalto, "gabro"; (c) metamórfico — lutita, filita, esquisto; y (d) sedimentario — piedra arenisca, piedra caliza. Las cuatro regiones climáticas incluyen (a) pradera costera con 25-30 pulgadas (635-760 mm) de lluvia por año, (2) zona arbolada de mucha lluvia, con 70-120 pul-

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les bétons d'argile des régions ou la chûte de pluie annuelle est de plus de 760 mm et (c) les graviers calcaires et latéritiques noduleux des régions où les chûtes de pluie annuelles sont de plus de 1020 mm (40 inches). Le premier groupe — graviers et sables détritiques — est subdivisé selon la lithologie de la roche-mère : (a) matériau granitique, quartzifère, gneiss, (b) graviers et sables gréseux, (c) dolérites et matériaux basaltiques, (d) graviers micacés et schisteux, (e) matériaux schisteux, et (f) les graviers calcaires.

La description de chaque matériau est données ainsi que leurs critères d'emploi pour couche de base ou couche de surface. On donne aussi une évaluation de l'emploi de ces matériaux comme couche de fondation ou couche de forme d'apport, basée sur un examen des routes de la région. La possibilité de stabiliser mécaniquement certains de ces matériaux de façon économique est discutée. Une courte section sur les méthodes de prospection des gisements de gravier est incluse.

Le sixième écrit est une communication : ***Lateritic Gravel Evaluation for Road Construction*** (Evaluation des graviers latéritiques pour la construction routière) (Journal of the Soil Mechanics and Foundations Division, Proceedings, American Society of Civil Engineers, Novembre 1972). Les résultats d'une étude des graviers latéritiques au Ghana sont donnés. Bien que dans tous les pays tropicaux on ne trouve pas la latérite sous toutes ses formes, cette étude éxamine les latérites provenant de plusieurs formations géologiques, sous quatre régimes climatiques. Ces latérites sont typiques de la plupart de celles qu'on trouve dans les tropiques.

Les formations géologiques qui sont le plus souvent associées à la formation de gravier au Ghana, sont divisées en quatre groupes : (a) granit igné à reaction acide, gneiss, quartzite ; (b) basalte basique igné, gabbro ; (c) schiste

Proceedings of the American Society of Civil Engineers, November 1972). It reports the results of studies made on lateritic gravels in Ghana. Although all tropical countries do not have laterite in all forms, this study evaluates laterite from several geological formations in four climatic regions. These laterites are typical of most laterites commonly found in the tropics.

The more common geological formations associated with gravel formations in Ghana were divided into four groups: (a) acid igneous — granite, gneiss, quartzite; (b) basic igneous — basalt, gabro; (c) metamorphic — shale, phyllite, schist; and (d) sedimentary — sandstone, limestone. The four climatic regions include (a) coastal savannah with 25-30 in/year (635-760 mm/year) rainfall, (b) rain forest zone with 70-120 in/year (1780-3050 mm/year) rainfall, (c) forest zone with 50-70 in/year (1270-1780 mm/year) rainfall, and (d) interior savannah with 40-50 in/year (1020-1270 mm/year) rainfall.

Samples of typical gravelly material from different locations were sieved to one size, passing ½-in (12.7-mm) and restrained on ⅜-in (9.5-mm) sieves, and were given various physical, chemical, mechanical strength, weathering, and durability tests, which the text describes. From earlier studies and these investigations supported by field data on road pavement performance, a relative rating of lateritic gravels is suggested.

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gadas (1780-3050 mm) de lluvia por año, (c) zona arbolada, con 50-70 pulgadas (1270-7080 mm) de lluvia por año, y (d) pradera del interior con 40-50 pulgadas (1020-1270 mm) de lluvia por año.

Se tamizaron muestras de material cascajoso típico de varias localidades, hasta quedar solamente el material que pasó por el tamiz de 1/2 pulgada (12,7 mm) y que fue retenido en el tamiz de 3/8 pulgada (9,5 mm). A éste se le hicieron varios ensayos físicos, químicos, de resistencia mecánica, de meteorización y de durabilidad, que se describen en el texto. Se recomienda una calificación relativa de las gravas lateríticas. Esta recomendación se basa en los estudios anteriores, estas investigaciones, y los datos recogidos en el campo sobre el rendimiento del pavimento. Las calificaciones fueron compiladas en el texto en la Tabla 1 — "Range of Various Properties of Four Groups on Basis of Performance". Las calificaciones del rendimiento de la grava en pavimentos son excelente, buena, regular, y pobre. Los resultados de ensayo utilizados en la tabla para calificar las varias gravas lateríticas son (a) aggregate impact value (valor de impacto sobre el agregado) (modificado de la norma británica), (b) aggregate impact value (valor de impacto sobre el agregado) (norma británica), (c) Los Angeles abrasion value (valor de abrasión), (d) absorción de agua (24 horas) y (e) peso específico.

El séptimo texto *Chapter 6 – Material and Construction Specification* (Capítulo 6 — Especificación de material y construcción) fué extraído de ***Laterite and Lateritic Soils and Other Problem Soils of the Tropics – Volume II, Instruction Manual*** (La laterita y suelos lateríticos y otros suelos problemáticos del trópico — Tomo II, Ma-

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métamorphique, phyllade, schiste ; et (d) grès sédimentaire. Les quatre régimes climatiques sont : la savane côtière avec 635-760 mm de pluie par an (25-30 inches), la forêt humide avec 1780-3050 mm de pluie (70-120 inches), (c) la forêt avec 1270-1780 mm de pluie (50-70 inches) et (d) la savane intérieure avec 1020-1270 mm de précipitation annuelle (40-50 inches).

Des échantillons typiques de matériaux graveleux provenant de différents gîtes ont été passé au tamis, passant une ouverture de maille de 12.7 mm (1/2 in) et étant retenus par une maille de 9.5 mm (3/8 in). Ces échantillons ont été ensuite soumis à des essais divers de résistance mécanique, chimique et physique, ainsi que des essais de durabilité, et de résistance aux altérations atmosphériques. Ces essais sont expliqués dans le texte. En combinant le résultat de ces essais de recherches antérieures, corroboré par des données sur la durabilité des chaussées, un classement relatif des graviers latéritiques est proposé. Ces catégories sont illustrées dans le tableau no. 1 de la communication : Range of Various Properties of Four Groups on Basis of Performance (Portée des caractéristiques de quatre groupes d'après leur performance). Les valeurs attribuées au gravier comme chaussée vont de excellent à mauvais, en passant par bon et adéquat. Les essais qui ont été faits pour en arriver ce classement des graviers latéritiques sont (a) essai de résistance mécanique des agrégats (modifié du British Standard), (b) essai de résistance mécanique des agrégats (British Standard), (c) essai Los Angeles (abrasion), (d) essai d'absorption d'eau (24 heures) et (e) essai de poids spécifique.

These ratings are compiled in the text in Table 1 — Range of Various Properties of Four Groups on Basis of Performance. The gravel's performance ratings in pavements are excellent, good, fair, and poor. The test results used in the table to rate the various lateritic gravels are (a) aggregate impact value (modified from the British standard), (b) aggregate impact value (British standard), (c) Los Angeles abrasion value, (d) water-absorption (24 hours), and (e) specific gravity.

The seventh text, ***Chapter 6 – Material and Construction Specification***, is excerpted from ***Laterite and Lateritic Soils and Other Problem Soils of the Tropics – Volume II, Instruction Manual*** (USAID, 1975). It provides information about acceptable specifications for pavement and base-course construction using lateritic gravels. These specifications allow the use of materials that would be unacceptable, if the standard specifications given in Selected Text No. 4 were enforced.

A method of determining a design California Bearing Ratio (CBR) for material taken from a specific borrow pit is illustrated. A method for modifying CBR values to reflect actual rainfall conditions is presented. Borrow-pit excavation methods are discussed. Special compaction techniques required for lateritic gravel are described. The same information is given in much more detail in Chapter 12, Volume I, of the same publication (see bibliography, Ref. 14).

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nual de instrucciones) (USAID, 1975). Provee información sobre las especificaciones aceptables para la construcción de pavimento y capa de base, utilizando gravas lateríticas. Estas especificaciones permiten la utilización de materiales que serían inaceptables según las especificaciones presentadas en el texto seleccionado Nº 4.

Se ilustra un método para determinar un CBR (California Bearing Ratio) de diseño, para el material extraído de una cantera de préstamo específica. Se presenta un método para modificar las tasas CBR para indicar las condiciones efectivas de caída de lluvia. Se habla sobre métodos de excavación de canteras de préstamo. Se describen técnicas especiales de compactación que se requieren para la grava laterítica. Se presenta la misma información en mucho más detalle en el Capítulo 12 del Tomo I de la misma publicación (ver Ref. Nº 14 de la bibliografía).

El octavo texto, ***Blading Aggregate Surfaces*** (Conformación a cuchilla de superficies de agregado), es una guía de entrenamiento publicada por la Asociación Nacional de Ingenieros de Condado (1974). Este texto también se publicó en español (USAID) (ver Ref. Nº 18 de la bibliografía).

Los agregados son suelos gruesos o partículas minerales. Todas las gravas mencionadas anteriormente en este compendio caen en esta clasificación. Se pueden utilizar distintos tipos de equipo para mantener los caminos de grava. Los caminos de muy bajo volúmen pueden ser y son mantenidos por trabajo a mano con picos,

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Le septième texte, Chapter 6, ***Material and Construction Specification*** (Spécification pour les matériaux et la construction) est extrait du livre ***Laterite and Lateritic Soils and Other Problem Soils of the Tropics – Volume II – Instruction Manual*** (Latérites, sols latéritiques, et autres sols difficiles des tropiques — Volume II — Manuel d'instruction) (USAID 1975). Ce livre donne des informations sur des spécifications acceptables pour la construction de chaussées et de couches de base en graviers latéritiques. Ces spécifications permettent d'utiliser des matériaux qui seraient inacceptables si on appliquait les normes du texte choisi no. 4.

Une méthode pour déterminer l'indice portant californien CBR d'un matériau extrait d'un lieu d'emprunt spécifique, est illustrée. Une méthode qui permet de modifier l'indice CBR pour reproduire les conditions de pluviosité réelle, est présentée. Des méthodes d'excavation de lieux d'emprunt sont discutées. Les procédés de compaction qui doivent être utilisés pour les graviers latéritiques sont representés. Cette question est d'ailleurs traitée en détail dans le chapitre 12, volume 1 du même livre (voir bibliographie, référence 14).

Le huitième texte, ***Blading Aggregate Surfaces*** (Le nivellement des chaussées en agrégats) est un livret d'instruction publié par le National Association of County Engineers en 1974. Ce même texte est traduit en espagnol par USAID (voir bibliographie, référence 18).

Les agrégats sont des sols grossiers, ou grains minéraux. Toutes les sortes de gravier dont nous avons parlé dans ce recueil tombent dans cette catégorie. Différentes sortes d'engins

The eighth text, ***Blading Aggregate Surfaces***, is a training guide published by the National Association of County Engineers (1974). This same text is also published in Spanish by USAID (see bibliography, Ref. 18)

Aggregates are coarse soils or mineral particles. All of the gravels previously discussed in this compendium fall into this classification. Different kinds of equipment can be used to maintain gravel roads. Very low-volume roads can and are being maintained by hand labor using picks, shovels, baskets, and brooms. The most common equipment used, however, is the motorized road grader.

Smoothing or reshaping activities may be required to maintain gravel road surfaces and shoulders. Smoothing the surface is done by dragging. The moldboard of the motor grader is tipped forward to produce a dragging rather than a cutting action. If the smoothing is to be done when the road is dry, care must be taken not to cut too deeply or the hard crust will be disturbed.

Reshaping involves remixing the aggregate base to get a proper blend of fines and different size aggregates and blading this blended material into a properly crowned road surface. Additional aggregates or fines may have to be added

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palas, cestones y escobas. Sin embargo, el equipo más utilizado es la motoniveladora.

Las operaciones de alisado y reperfilado pueden ser necesarias en el mantenimiento de superficies y arcenes de grava. El alisado de la superficie se realiza por arrastre. La orejera de la niveladora se inclina hacia adelante para arrastrar en vez de cortar. Si el alisado se realiza cuando el camino está seco, se debe tener cuidado de no alterar la capa dura con un corte demasiado profundo.

El reperfilado consiste en remezclar la base de agregado para obtener una combinación correcta de finos y distintos tamaños de agregados y cuchillar este material combinado para formar una superficie con un bombeo correcto. Puede resultar necesario añadir agregados o finos adicionales en los lugares fragosos y áreas erosionadas por el agua. Las áreas de capa dura que siguen intactas deberán ser quebradas durante el remezclado con la cuchilla o los dientes del escarificador de la niveladora. El reperfilado de un camino seco requiere la adición de agua.

Este texto consiste en un manual de instrucciones que incluye el trabajo con cuchilla, bajo condiciones especiales tales como (a) en la intersección de caminos con superficies de agregado, (b) en la intersección de un camino con superficie de agregado y un camino pavimentado, (c) donde el camino cruza vías de ferrocarril, (d) donde cruza puentes, (e) en la intersección de un camino y una vía de acceso, (f) en la cumbre de una colina (cresta), (g) en el fondo de valles (combas), y (h) en caminos con curvas. Se puede obtener un conocimiento

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peuvent être utilisés pour entretenir les routes en gravier. Les routes à très basse circulation peuvent être entretenues manuellement avec des pics, des pelles, des paniers et des balais. La plupart du temps on utilise des niveleuses automotrices.

L'entretien des surfaces gravelées peut demander leur aplanissement ou leur reprofilage. L'aplanissement de la surface se fait en baissant le versoir de la niveleuse en avant, pour produire une action de balayage plutot que d'entaille. Si l'aplanissement est fait quand la route est sèche, il faut faire très attention de ne pas racler trop profondément pour ne pas endommager la croûte dure.

Le reprofilage consiste à remélanger la base d'agrégats, pour obtenir un mélange satisfaisant de fines et d'agrégats de tailles différentes, et ensuite à répandre ce mélange en prenant soin de rétablir un bombement précis. Il se peut que l'on ait à ajouter soit des agrégats, soit des fines, aux endroits où la chaussée est raboteuse ou a été érodée par l'eau. La croûte qui reste devra être écrasée pendant les opérations de mélange, soit avec la lame de la niveleuse, soit avec le scarificateur. Quand la route de terre est sèche, le travail de reprofilage doit se faire avec addition d'eau.

Ce texte est un manuel qui explique comment se servir de la niveleuse pour exécuter des manoeuvres spécialisées : (a) au croisement de deux routes en agrégats, (b) au croisement d'une route en agrégats et une route pavée, (c) à un passage à niveau, (d) au croisement d'une route et d'un pont, (e) au croisement d'une route et d'une voie d'accès, (f) sur les crêtes, (g) au fond des vallées, et (h) dans les routes à virages. En lisant ce manuel en même temps que le to the road surface in rough spots or washed-out areas. The crust that still remains must be broken up during remixing, either with the grader blade or the scarifier teeth on the grader. A dry road cannot be reshaped without adding water.

This text is a how-to-do-it manual that includes blading under special road conditions, such as (a) the intersection of aggregate surface roads, (b) the intersection of aggregate surfaced and paved roads, (c) roads crossing railroad tracks, (d) roads crossing bridges, (e) at driveways, (f) on hilltops (crests), (g) at the bottom of valleys (sags), and (h) curved roads. A comprehensive knowledge of motor-grader operation can be gained by reading this manual in conjunction with Selected Text No. 4, *Grading Illustrated*, in Compendium 5, *Roadside Drainage*.

The ninth text, *Crown on Soil-Aggregate Roads*, is a report that was published in *Highway Research Record 91* (Highway Research Board, 1965). It discusses the problem of potholes on gravel roads.

Potholes are more likely to appear on gravel roads with flatter crown slopes than on those with steeper cross slopes. They are usually more severe on flat, longitudinal grades. This study explored the relationships between (a) the severity of potholing and crown slope and (b) potholing severity and the resultant of the crown slope and longitudinal grade. It concludes that potholing is a function of the resultant of the crown slope and the longitudinal grade. The maximum resultant slope, though less than an ideal design characteristic, may be useful as a guide in selecting the minimum tolerable crown. Figures are presented that provide a guide to (a) the selection of the lowest maximum resultant slope for an acceptable risk of potholing and (b) the determination of the minimum crown to produce this resultant slope for various longitudinal grades.

This study also indicates that grader operators shaping roads by eye in sidehill terrain tend to tilt the crown in a downhill direction. This

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completo de la operación de motonivelación leyendo este manual junto con el texto seleccionado Nº 4. *Grading Illustrated* (Nivelación, Ilustrada), del Compendio 5, *Roadside Drainage* (Drenaje del borde de la carretera).

El noveno texto, *Crown on Soil-Aggregate Roads* (El bombeo en caminos de suelo-agregado), es un informe que fué publicado en *Highway Research Record 91* (Archivo de Investigaciones Viales 91, HRB, 1965). Habla sobre el problema de baches en los caminos de grava.

Es más probable que los baches aparezcan en los caminos de grava con poca pendiente en el bombeo, que en aquellos con pendientes transversales más empinadas. Generalmente son peores en las pendientes longitudinales chatas o casi chatas. Este estudio explora la relación entre (a) la formación de baches y la pendiente del bombeo y (b) la formación de baches y el resultante de la pendiente del bombeo y la pendiente longitudinal. Se llega a la conclusión de que la formación de baches es una función del resultante de la pendiente del bombeo y la pendiente longitudinal. La "pendiente resultante máxima" puede ser útil como guía en la selección del bombeo mínimo aceptable aún cuando no es una característica ideal de diseño. Se presentan figuras que proporcionan una guía para (a) la selección de la "pendiente resultante máxima" más baja para un riesgo aceptable de

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texte choisi no. 4, *Grading Illustrated,* Recueil no. 5, on obtiendra une solide connaissance de la manoeuvre de la niveleuse automotrice.

Le neuvième texte s'intitule : *Crown on Soil-Aggregate Roads* (Le bombement des routes en agrégats) et a été publié dans le *Highway Research Record 91,* (Highway Research Board 1965). Le problème des nids de poules dans les routes de graveleux en forme le thème.

Les nids de poule ont tendance à apparaître plus souvent sur les routes de graveleux dont le bombement est moins accentué, que sur celles dont la pente transversale est de forte inclinaison. Ils sont d'ordinaire, beaucoup plus importants, quand la pente longitudinale est plate, ou presque plate. Ce texte de recherches explore le rapport entre (a) l'importance des nids de poule et le profil en travers et (b) la sévérité des nids de poule et la résultante du profil en travers et de la pente longitudinale. En conclusion, il est déterminé que le phénomène de la formation des nids de poule est fonction de la résultante du profil en travers et de la pente longitudinale. Le calcul de la pente maximale résultante, bien que n'étant pas l'outil idéal, peut être utile quand on doit décider le bombement minimum tolérable. Des figures, qui indiquent (a) le choix de la plus basse pente maximale résultante par rapphenomenon is probably due to the driver's misconception of the true vertical plane. A practical implication of this misconception is a less-than-desired crown slope on the uphill side of the road that increases the chances of potholing on that side. Sidehill locations should be checked for proper crown slope during grading and shaping operations.

Bibliography

The selected texts are followed by a brief bibliography containing reference data and abstracts for 19 publications. The first nine describe the selected texts. The other 10 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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formación de baches, y (b) la determinación del bombeo mínimo para producir esta pendiente resultante para varias pendientes longitudinales.

El estudio también indica que los operadores de niveladoras que hacen la conformación de los caminos a ojo en las laderas de colinas tienden a inclinar el bombeo cuesta abajo. Este fenómeno se debe probablemente a un concepto erróneo del plano vertical verdadero por parte del que maneja. Un resultado de este concepto erróneo es una pendiente de bombeo más empinada de la deseada sobre el costado ascendente del camino, que aumenta las posibilidades de baches sobre ese lado. El trabajo en las laderas de colinas deberá revisarse para producir una pendiente de bombeo correcta durante las operaciones de nivelación y conformación.

Bibliografía

Se sigue a los textos seleccionados con una breve bibliografía que contiene datos de referencia y abstractos para 19 publicaciones. Los primeros nueve describen los textos seleccionados. Los otros diez 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 referencias que se relacionen con el tema de este compendio. La bibliografía contiene únicamente aquellas publicaciones básicas que hubieran sido seleccionadas si no hubiera un límite al número de páginas en este compendio.

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port à un risque acceptable de formation de nids de poule et (b) la détermination du bombement minimum qui produira cette pente résultante pour des pentes longitudinales variées, sont incluses.

Il est aussi remarqué que les conducteurs de niveleuses, quand ils font le reprofilage "à l'oeil", sur un terrain à flanc de colline, ont tendance à bomber la route vers le bas. Ce phénomène est probablement causé par le fait que la topographie influence la conception de la verticale et de l'horizontale du conducteur. Le résultat pratique de cette conception erronée, est un bombement moins que désirable du côté colline, qui entraine à sa suite le risque de formation de nids de poule. Dans ce cas particulier, on devra donc vérifier le profil en travers durant les opérations de nivelage et de reprofilage.

Bibliographie

Les textes choisis sont suivis d'une brève bibliographie, contenant des données de références et des analyses de 19 publications. Les neuf premières décrivent les textes choisis. Les autres dix 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'objectifs 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.

Selected Texts

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:

*Some pages (or parts of pages) in this part of the original document appear in the

Textos seleccionados

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Proceedings

Second Annual

Virginia Highway Conference

November 11, 12, 13, 1948

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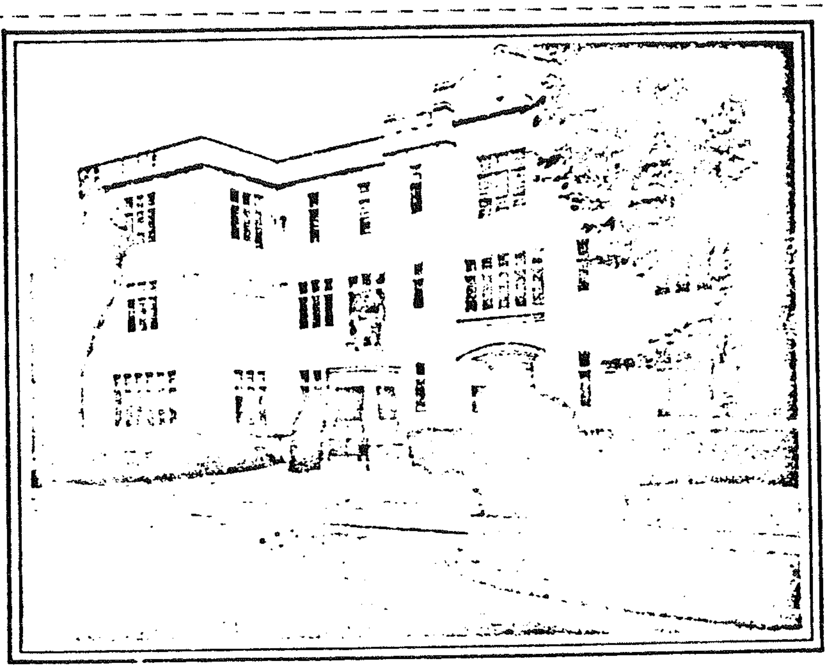

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LEXINGTON, VIRGINIA

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LOW-COST ROADS

By E. F. Kelley1/

For presentation at Second Annual Highway Conference
Virginia Military Institute
November 13, 1948

Low-cost roads have been discussed so exhaustively during recent years that it is difficult to approach the subject from a new angle and to say anything that is essentially different from what already has been said repeatedly. So much has been said, and so convincingly, that many people interested in highway construction believe that there actually are such things as low-cost roads.

The cost of a road includes more than the mere cost of con- 5
struction. It includes also the cost of maintenance. When we add the two together we get the true cost of the road. Costs are relative and no one has given any adequate idea of the maximum number of dollars which can be spent for a road which is in the low-cost class. We have high-type expensive roads; we have intermediate-type roads which are less expensive; and we have low-type roads which are the least expensive. But, in terms of the dollars which must be spent for the construction and maintenance of roads which will serve the traffic adequately under all weather conditions, we have no low-cost roads.

1/ Chief, Division of Physical Research, Public Roads Adm.

Excluded from this discussion are the roads which cost little to build but which are very expensive to maintain in a satisfactory condition if, in fact, it is even possible to give them satisfactory maintenance. Such roads frequently are impassable in the early spring, especially if the winter has been severe, and the annual maintenance may involve what amounts almost to annual reconstruction. Such roads are cheap roads in terms of initial cost but they are not low-cost roads in terms of total cost, which includes maintenance.

If, in fact, there are no low-cost roads, what do we mean when we use that term. Most of us are guilty, at one time or another, of using a loose terminology which conveys our ideas to
6 those who think in the same terms but which is not clear, or may even be unintelligible, to those who are not so familiar with the subject. Every trade and every profession has its jargon which is understood perfectly by the initiate but which is meaningless, or conveys the wrong meaning, to others. Highway engineers are no exception and when they speak of low-cost roads most of them are really thinking of roads for light traffic. Roads for light traffic, sometimes called secondary roads or farm-to-market roads, are the subject of this discussion.

These roads are of great importance in our transportation system and they may be expected to increase in importance in the future. Greater service will be demanded of them as the consolidation of rural schools continues and a further load will be placed on them by the decentralized industrialization of rural areas which will require the worker to use them for his daily travel to and from the mill or factory.

It has been said repeatedly, but it cannot be said too often, that soil is the foundation of the road and as such is the most important constituent of the road structure. If the foundation fails the road fails. Also soil is the most commonly used of road-building materials. Soil materials such as gravel, sand and the fine-grained silts and clays are used in embankments, in base courses and, in the lowest-type roads, in surface courses. Therefore, a knowledge of soil characteristics, and the application of this knowledge in highway construction, is essential.

The development of our knowledge of soils to the point where it has a practical value in its application to highway construction is of comparatively recent date. It is interesting to re-
call that only twenty years ago highway engineers knew practically 7
nothing of the engineering properties of soils and, moreover, very few evidenced any great concern about this most important road-building material. The general attitude at that time was that we must take what nature has given us, whether good or bad, and that any effort to improve bad conditions was hopeless. Now it should be recognized that the situation has changed completely. Highway engineers have available a fund of information concerning soils which, if utilized, will greatly improve the quality of highway construction and lower the ultimate cost. There are still those in the highway engineering profession who refuse to concern themselves seriously with the most effective utilization of soils and who appear to be indifferent to the advantages to be gained by

putting into practice the knowledge which has been developed. These engineers are now in the minority and their numbers are dwindling rapidly as the knowledge of soils becomes more widely disseminated. It is not too much to say that today the highway engineer who attempts to build roads without putting into practice the existing knowledge of soils is inviting failures which could be avoided. Such failures increase ultimate costs by increasing the expenditures required for maintenance or reconstruction.

In this connection it is interesting to recall an experimental road which was constructed about 20 years ago by one of the State highway departments in cooperation with the Public Roads Administration. Two types of base-course material were obtained
8 from local deposits and were placed on the existing road bed. One of them proved to be good and the other one poor. At the time of this construction we knew practically nothing about soils and how their characteristics affect their performance in road bases. However, during the next few years a great deal of information on this subject was developed. Before the experiment was concluded it had been determined that the imported base-course material which gave poor service was actually inferior to the material which existed in the original road bed. Because of ignorance of the facts that we have now, the expenditure for this base-course material had been a waste of money.

As has been said, a useful knowledge of the engineering properties of soils as applied to highway construction has been developed during the past twenty years. The Public Roads Administration takes pride in having been a pioneer in this development work. When it was started there were many who were critical or contemptuous of such research work on the ground that it was a waste of time and money to engage in an undertaking from which it was hopeless to expect useful results. As the work progressed and it became apparent that there was something in this new idea, it was taken up, first by one State highway department, and then by another and another in rapid succession. And every State which undertook to apply the principles of soil science to highway construction added to our store of information because, after all, soils engineering is not an exact science any more than is any other branch of engineering. It is an art in which certain scientific principles are applied to practical engineering problems and the limits of application are determined by experience. The more there is of experience, the more information we have regarding the practical application of the scientific principles and the limits within which they may be applied.

Today every State highway department in the United States, to a greater or lesser degree, is making some use of soils engineering in its construction work and is observing the results. Every road that is built to embody certain principles of design is, in effect, an experimental road if the facts are observed and recorded for future use.

From this viewpoint, the United States has become a vast laboratory in which research work on soils is constantly in progress.

The combined and cooperative effort of the State highway departments and the Public Roads Administration has developed our present knowledge of soils. As compared with the situation which existed only a few years ago, a great advancement has been made but it should not be inferred from what has been said that we have reached or even approached the ultimate goal. Fifty years from now our successors, from the vantage point of their superior knowledge, may look back with wonder at our gropings in the dark. The research work which has resulted in such phenomenal progress must be continued and extended if we are to make the most effective use of the money expended for road construction. The Virginia Department of Highways is to be congratulated on its forward-looking attitude in making provision for the continution of this research.

Soil materials include, in the descending order of particle size, gravel, sand, silt and clay. All materials which will pass the No. 200 sieve (with sieve openings of approximately 0.003 inch) may be classed as silt and clay. Materials retained on the No. 200 sieve are classed as sand and gravel. Soils range in character from granular materials, in which gravel and sand predominate, to the fine-grained plastic soils in which silt and clay predominate. The granular materials are the best for road-building purposes. The fine-grained silt-clay soils are less desirable and some of the heavy clays are so poor that their use should be avoided if possible. Frequently their use cannot be avoided and dependence must be placed on the results of past research to insure that the best results possible will be obtained.

Early in its research work on soils the Public Roads Administration developed a classification of soils which has been widely used by the State highway departments. In this classification the soils were divided, on the basis of their physical properties, into the more important groups. More recently the Highway Research Board has adopted a simplified and improved classification which, essentially, is a revision of the original Public Roads classification. In the new classification the soils are divided up into a number of groups entirely on the basis of grading, liquid limit and plasticity index. The classification of a soil by this or any other method does not give the final answer by any means but it is a very useful tool for the highway engineer.

For highway construction in general the most important properties of a soil are its size grading, its plasticity and its optimum moisture content.

The complete size grading of a soil may be determined by sieve analysis of the coarser fraction and hydrometer analysis of the finer fraction. The hydrometer analysis is a sedimentation test by means of which it is possible to determine the grain size of the soil particles down to those of microscopic size. Its value lies in the fact that by its use it is possible to extend the grading analysis through the fine sizes and determine the percentage of silt and the percentage of clay. There are times when this information is important. When the separation of the silt and clay fractions is not important, the grading may be determined entirely by sieve analysis. In this case the character of the fine fraction is judged by the results of the plasticity tests.

The plastic properties of a soil are measured by the liquid limit, the plastic limit and the plastic index. Without becoming too technical we may define the liquid limit as that moisture content at which the soil is on the dividing line between the liquid and the semi-solid state. When it is in the semi-solid state it is plastic. The plastic limit is the moisture content at which the soil is on the dividing line between the

semi-solid and the solid state. The plastic index is the difference between these two moisture contents and defines the moisture range within which the soil is in the semi-solid state and is in a plastic condition.

A knowledge of the optimum moisture content is important in all types of construction which involve the consolidation or densification of soil materials. This is because the stability of a soil mass, or its ability to support loads, is dependent in a great degree on its density. For a given amount of compactive effort the density of a consolidated soil is dependent on its moisture content. As the moisture content is increased the density increases to a maximum and then decreases with further increases in moisture. The moisture content at maximum density is called the optimum moisture and it is highly important to compact enbankments and base courses at a moisture content which is at or near this optimum. A soil mass of high density is much more resistant to the action of water than is one of low density and failure to obtain the maximum density that is practicable with the type of compacting equipment used may mean the difference between success or failure of the construction. The optimum moisture of a given soil is dependent on the amount of compactive effort expended in its consolidation. A high compactive effort results in a higher density and a lower optimum moisture content than does a lesser compactive effort. Therefore, on a given job the optimum moisture and maximum density are dependent on the soil itself and on the type of compacting equipment and the manner or amount of its use.

The performance of the rather simple tests that have been described is not spectacular and the soils engineers who conduct them are sometimes accused, facetiously or otherwise, of playing with mudpies. Nevertheless, they are important since the success of the work may be dependent on them.

The foregoing discussion has been preliminary to a consideration of some of the principles which should be observed in the construction of roads for light traffic. Except as they pertain particularly to low-type surfaces, these principles are equally applicable to the construction of roads for heavy traffic. However, they are specially important in the case of light-traffic roads since the lower types of construction, such as surface-treated gravel roads, do not have as great an ability to resist the detrimental and destructive effects of poor

subgrade or foundation conditions as do concrete pavements.
concrete pavement with its high beam strength, may function
in a reasonably satisfactory manner on an unstable subgrade
whereas on the same subgrade a gravel surface which is lacking
in beam strength, would fail completely.

The natural undisturbed soils upon which fills are con-
structed require some consideration although this is a fact
which is sometimes overlooked. If the foundation soil under
the fill is too weak to support the load it will be displaced
by the superimposed weight and the embankment will fail by sub-
sidence. With ordinary soils and fills that are not excessively
high this is not generally a problem of great importance. How-
14 ever, when fills are to be built across peat bogs or through
swampy areas or when the fill is to be of unusual height it does
present a problem which should be given careful study. A de-
tailed consideration of this subject is beyound the scope of
this discussion. It is sufficient here to point out that under
certain rather special conditions fills should not be built
without a careful preliminary investigation of the foundation upon
which the fill will rest.

In the construction of the fill itself the importance of
compacting the soil to maximum density at optimum moisture con-
tent has already been mentioned. Adequate compaction is impor-
tant in all fills but it is more important in high fills than
in low ones because the failures which may otherwise result are
likely to be more severe and more costly to repair. The proce-
dure, once prevalent, of building fills by end dumping is no

longer considered good practice. Instead of this the soil should be spread in relatively thin layers which will give a compacted thickness of the general order of 6 inches and each layer should be thoroughly compacted before the succeeding layer is placed. The type of roller used for compaction is not important if the desired density is obtained. Depending on circumstances, sheepsfoot tamping rollers, rubber-tired wobble-wheel rollers, or smooth-face steel rollers may be used. Satisfactory densities may also be obtained with the earth-hauling equipment used on the job. However, it is difficult to control the uniformity of operation of such equipment over the area to be compacted and the result may be a lack of uniformity in the density of the finished embankment.

In addition to the improved embankment structure which results from the compaction of fills, there is an immediate practical benefit to the contractor. Compacted soils are resistant to the absorption of water with the result that there is less delay in construction operations because of muddy conditions following rains.

The grading of a highway usually involves the construction of a succession of cuts and fills. If it were not for the cuts through hills or along hillsides many of our troubles with soils would not develop. However, in a cut of any depth the grade line may intersect a number of layers of the soil profile and the lower layers of soil, being less weathered than the upper layers, are frequently less suitable as road-building materials. Sometimes the soil taken from the bottom of a cut is so poor that it should be wasted. In other cases the poorer material from the bottom of the cut is suitable for use in the lower portion of a fill but not in the top portion. In still other cases all of the material taken from a cut is of good quality and may be used in fill construction without any special precautions. When fills are constructed of the materials taken from cuts which vary in quality from top to bottom, normal construction operations may result in the placement of the best material in the bottom of the fill and the poorest material on top, which is the reverse of the order of placement which is desirable. This should be avoided to the extent necessary and practicable and the better materials taken from the top of the cut stored in stockpiles for subsequent placement in the upper portion of the fill. The extent to which this is necessary is, of course, dependent on the character of the soil.

The natural soil in its undisturbed state in a cut may have less density than the similar soil which has been compacted in the adjacent fill. When this condition occurs the undisturbed soil in the cut will have less ability to support loads than does the compacted soil in the fill. This deficiency is frequently corrected by loosening the subgrade soil in the cut to a depth of a foot or more and recompacting it by rolling to maximum density at optimum moisture.

In climates where freezing temperatures are prevalent during the winter season, the so-called frost boils are a constantly recurring source of trouble and expense unless positive means are taken to correct the conditions which produce them. Depending upon soil and climatic conditions, detrimental frost action may result in a differential heaving of the pavement, sometimes as much as a foot, or it may result in little noticeable change in elevation of the pavement. The differential heaving may be so severe as to damage the pavement or result in a hazard to traffic. Whether there is heaving or not, the end result of detrimental frost action is the frost boil and this does not develop until the weather moderates and the ground thaws. Then the soil becomes saturated with free water which cannot escape rapidly and the result is a soft mud which cannot support traffic. Frequently the road surface breaks up and the road becomes impassable. It is a matter of common observation that these frost boils are most likely to develop in cut sections although fill sections are not necessarily immune to them. The impassable sections of road which develop may be short but they may be sufficient to render the entire highway unsuitable for traffic for a period of several weeks during the spring.

Detrimental frost action is usually associated with fine sand and silt, although it may occur in the coarser sands if these are not drained. The heavy clays, otherwise the poorest materials for road construction, are not a cource of this type of trouble.

In a road under construction, the danger of future frost boils may be avoided by proper attention to the results of the soil survey. The recurrence of frost boils that develop in roads in service may be prevented by reconstruction of the offending section. For undrained sand pockets which would otherwise be saturated the remedy may be drainage. However, this condition is the exception rather than the rule and drainage is generally ineffective in the very fine sands and silty materials. Here the remedy is to remove the questionable material and replace it with selected granular material or sandy soil or to blanket it with such material to a depth of at least two feet. Merely to repair the surface of a road which has been damaged by frost boils is a waste of money since the same trouble is likely to recur the next year. The cause of the frost boils should be eliminated. The Virginia Department of Highways is alive to the importance of this problem and is engaged in an intensive study of frost damage and means for its prevention.

The subgrade of a highway may be defined as the soil mater-
18 ial in the cut or fill that is below the level of the bottom of the pavement structure. The pavement on a light-traffic road is usually of the nonrigid type as, for example, a gravel base course with a low-type bituminous wearing course such as a surface treatment. For a pavement of this character the pavement structure may be considered to include the subbase, if one is used, the base course and the wearing course. The preceding discussion has been concerned with subgrades. Attention will now be given to the pavement structure.

The subbase is a foundation course placed on the subgrade to support the base course. The need for this foundation and its thickness are dependent on the magnitude of the traffic loads to be carried and on the character of the subgrade. Frequently a subbase is not required. When required, it is composed of selected soil material, preferably granular, which is superior in supporting strength to the underlying subgrade soil. It serves to distribute the weight of traffic to the weaker soil which supports it.

As has been said, the pavement on a low-traffic road usually consists of a nonrigid base course and a bituminous wearing course. The base course for such a pavement is built almost invariably of soil materials. On secondary roads of the least importance the bituminous surfacing may be omitted, in which case the base course does duty also as a surface or wearing course. In some areas, notably in the southeastern States, some of the natural top soils are suitable for use in road bases or surfaces without any change in their composition but this situation is the exception rather than the rule. Generally speaking, even the best materials that are available, such as sands and gravels, are lacking in certain characteristics which will insure their stability when used in the road structure. Frequently such materials may be made suitable for use by blending other soil materials with them. The process of producing a stable mixture by combining in the proper proportions coarse and fine soil fractions of suitable quality, without the admixture of any foreign materials, such as cement, asphalt or tar, is known as granular stabilization.

The pioneer investigations of the effect of the grading of soil materials on the performance of gravel, sand-clay and topsoil roads were made many years ago by Dr. C. M. Strahan of the University of Georgia. The term "stabilization" was not applied to road construction at that time but the roads studied by Dr. Strahan were actually of the granular-stabilized type and as early as 1917 he recommended a size grading of soil materials for the best roads of this class. Of necessity, Dr. Strahan's studies were confined to the effect of grading because other significant tests had not been developed. In 1922, he called attention to the need for additional tests that would indicate the physical properties of the fine-grained binder material. Now these tests are available and play an important part in the selection of materials for use in granular stabilization.

The years of research and practical experience that have followed Dr. Strahan's pioneer investigations have given us the additional information that is needed to insure success with granular stabilization. To the requirements for mechanical grading have been added those which control the characteristics of the binder material. The quality of the soil binder is now determined by the tests for liquid limit and plasticity index. As a result we may now write specifications for granular-stabilized mixtures with assurance that they will function in the desired manner.

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Granular-stabilized mixtures are used as base courses for bituminous surfaces and also they are used as road surfaces. When they are used as road surfaces it is frequently with the intention of covering them with a bituminous surface at a later date and thus converting them to base courses. It is important to recognize that the requirements of granular stabilization are not the same for a base course as they are for a surface course. In road surfaces exposed to the abrasive action of traffic the soil binder should have a greater cementing power than is required in base courses. And so in surface courses, as compared with base courses, a higher clay content and a higher liquid limit may be permitted and a higher plasticity index of the soil binder is generally desirable. The deleterious effect of moisture on the stability of this more active soil binder is minimized or overcome in a road surface by evaporation which tends to maintain the moisture content at a safe level. But if the stabilized mixture that has functioned satisfactorily as a wearing course is covered with a bituminous surface, evaporation losses are reduced or eliminated, the moisture content increases and complete failure may, and frequently does, result. Therefore the specifications for granular-stabilized gravel base courses differ from those for surface courses in that they permit less fine binder material and require that this material have a lower liquid limit and a lower plastic index. These facts are well known but it seems desirable to give them emphasis because they are sometimes ignored. The specification requirements for granular-stabilized base courses and surface courses overlap sufficiently so that, with care, it is possible to design a base-course mixture which will also be satisfactory for a surface course. It is desirable to do this if it is the intention to use the material initially in a surface course and ultimately as a base course for a bituminous surface. Base-course mixtures used for surfacing frequently lack resistance to the abrasive action of traffic and tend to dust and ravel. If the mixture has been properly designed this defect may be overcome by maintaining the surface with calcium chloride until the bituminous wearing course is added.

The requirements of a granular-stabilized base course are two; a properly designed mixture and its adequate compaction during construction. The mixture should consist of granular materials ranging in size from coarse to fine, so graded as to produce a high degree of density and strength, and fine-grained soil binder having the binding properties and volume-change characteristics required to prevent displacement or separation of the coarser particles. The binder material must be of such character and in such amount that it will perform its function through a wide range in moisture content. It must not lose its binding properties within this range of moisture content and it must not swell sufficiently when wet to unseat the granular materials and destroy the structure. The importance of fill consolidation has already been discussed. It is equally important to compact granular-stabilized base courses to maximum density at optimum moisture content. Otherwise the base course is likely to consolidate under traffic and disrupt or destroy the bituminous wearing course.

Given granular materials of satisfactory grading and soil binder of suitable quality it is possible to construct satisfactory base courses of the granular-stabilized type. On account of cost considerations the granular materials most commonly used are the natural sands and gravels but crushed stone or slag or stone screenings are equally suitable. When these materials are economically available this type of construction is the least expensive that can be used for light-traffic roads.

NOTE: The rest of this paper deals with other types of soils stabilization.

LOW COST ROADS

DESIGN, CONSTRUCTION
AND MAINTENANCE

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CONTENTS

4

ROADMAKING MATERIALS AND PAVEMENT DESIGN

4.1 SCOPE

There is an enormous range in design requirements between the simple earth track and the multi-lane main highway. In most developing countries many of the roads consist of simple tracks on which the main work done is the clearing of vegetation. At this stage there is no call for quantitative structural design, but there are principles of design which, if followed, will produce a reasonable return for the small investment that these roads justify; the first part of this chapter contains an outline of these principles. These roads, designated as 'unimproved roads', are generally suitable solely for light traffic, up to a dozen or so vehicles per day, and they usually become impassable in rainy weather.

As traffic increases the road layout is improved, permanent river crossings are provided and the roads are given an all-weather running surface, usually of natural gravel or other stable material dug from deposits near the line of the road, or a mixture of such materials. Section 4.3 outlines the design of these 'improved' roads.

Finally, with further increases in traffic it becomes worthwhile to provide a permanent road with a surfacing of bituminous material or concrete. It is at this stage that the surfacing and road base are first designed as a structure adequate to carry traffic loads without deforming or breaking. Section 4.4 contains a description of the different components of the road structure, their properties and functions are indicated and the factors influencing the choice of materials and thickness of construction are discussed.

In this chapter, the only aspects of drainage considered are those concerning the removal of surface water from the road. However, road drainage is of such importance that Chapter 5 has been devoted to this subject.

4.2 UNIMPROVED ROADS

At its inception the unimproved road is a rudimentary track formed by clearing vegetation from the natural soil surface and subsequent improvement depends on the volume of traffic attracted. The funds of such low-cost roads permit only of rudimentary earthworks such as can be done by hand and by the bulldozers used in clearing vegetation; generally the only surfacing materials that can be afforded are the soils found on the line of the road and immediately adjacent to it. The traffic-bearing capacity of these roads depends on the type of soil forming the running surface and on prevailing moisture conditions. In all but arid areas, the aim at every stage of development is to keep the road and its environs as dry as possible. When saturated, most soils are too weak to carry traffic and often the roads are closed during the rainy season at least for periods after rain has fallen. However, correct location and attention to detail can greatly assist in extending the periods of the year during which these roads can carry traffic.

Where possible, roads should be located on the more sandy and granular soils in well-drained situations, avoiding waterlogged and low-lying areas prone to flooding. Where it is not possible to avoid such areas, low embankments must be built at this stage. Trees and scrub should be cleared well back from the running surface so that the drying effects of wind and sun can have full play in drying the road surface. In heavily-wooded country it is desirable for trees to be cleared for a distance from the road equal to the average height of the tree cover. In the tropics, on roads with a north-south orientation, it is an advantage to increase the clearance distance up to 1½ times the height of the trees.

Under traffic the roads become rutted and reshaping is needed. This should consist of blading soil inwards from outside the road edges and serves to raise the road bed, provide a cambered surface and initiate a drainage system (Fig. 4.1). The simpler expedient of digging out the rutted soil and throwing it to the road edges to expose a fresh soil surface will result in a sunken road prone to waterlogging and impassable to traffic in the rainy season. The establishment of grass up to the road edges assists in preventing

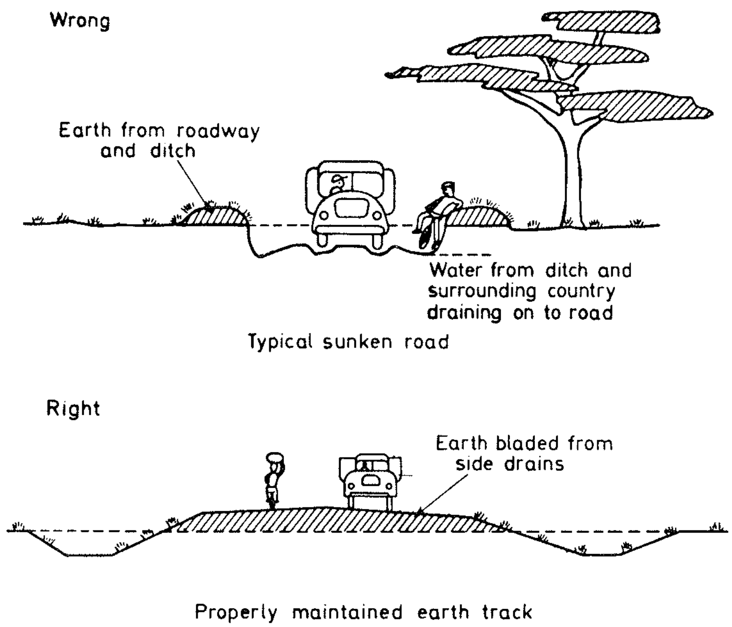

FIG. 4.1. *Correctly and incorrectly maintained earth track.*

erosion. Simple turnout drains should be opened to discharge water collected from the roadway.

4.3 IMPROVED ROADS

The first stage in improvement from the earth track generally involves earthworks to provide or raise embankments in poorly-drained areas and the construction of permanent bridges over the river crossings. At the same time the vertical and horizontal alignment will be generally improved. Desirable standards of alignment and cross-section have been indicated in Chapter 3 and the aim will be to work towards these.

At the same time attempts should be made to provide an all-weather running surface. Many soils can be compacted to form a running surface that will carry light traffic and even a limited number of fairly heavy vehicles in dry weather. Soils of clay and silt rapidly lose strength when they become wet and are quite unsuitable as running surfaces in wet weather. In general, it will be necessary to improve the stability of the running surface either by mixing imported materials with the *in-situ* soil, a process known as 'mechanical stabilisation', or by superimposing a layer of 15–20 cm (6–8 in) of more stable material.

4.3.1 MECHANICAL STABILISATION

Natural soils consisting mainly of gravel or coarse sand, with finer particles to fill the voids and a small proportion of clay to function as a binder, may be compacted to form quite strong running surfaces. These soils may be as-dug or mixtures from different sources to provide a stable material.

In dry weather a fairly high proportion of clay binder is desirable to prevent the surface from ravelling and becoming corrugated. In wet weather the presence of clay in the mixture is a disadvantage since it makes the surface slippery and prone to soften and to rut under traffic. Thus specifications for mechanical stabilisation usually reflect a compromise between the ideal requirements for wet and dry weather. These trends are illustrated in the typical specifications given in Tables 4.1 and 4.2.

To obtain a reasonable finish and for ease in working or reshaping with motor graders, it is desirable to restrict the maximum size

Table 4.1 LIMITS OF PARTICLE-SIZE DISTRIBUTION FOR SURFACINGS[1]

BS. sieve size	*Percentage passing**		
	Nominal maximum size		
	19 mm (3/4 in)	*9·5* mm (3/8 in)†	*4·75* mm (3/16 in)†
19 mm (3/4 in)	100	—	—
9·5 mm (3/8 in)	80–100	100	—
4·75 mm (3/16 in)	60 – 85	80–100	100
2·36 mm (No. 7)	45 – 70	50 – 80	80–100
425 μm (No. 36)	25 – 45	25 – 45	30 – 60
75 μm (No. 200)	10 – 25	10 – 25	10 – 25

* Not less than 10% should be retained between each pair of such successive sieves specified for use, excepting the largest pair.

† These may have up to 35% of stones not larger than 38 mm (1½ in), provided that the material passing the 4·75 mm (3/16 in) sieve is within the limits specified.

Table 4.2 PLASTICITY CHARACTERISTICS PREFERRED FOR GRAVEL SURFACINGS

Climate	*Liquid limit not to exceed* (%)*	*Plasticity index range* (%)*	*Linear[2] shrinkage* (%)†
Moist temperate and wet tropical	35	4–9	2–4
Seasonal wet tropical	40	6–15	3–7
Arid	55	15–30	7–14

* There are some soils that possess a structure which is not easily broken down by traffic, e.g. some lateritic and concretionary soils. With these, higher limits may be acceptable. There are other soils with a structure that is broken down by traffic. Thus any variations from the limits should be based only on carefully collated local experience.
† The linear shrinkage test has the advantage of requiring only very simple equipment. Another simple test requiring very little skill and equipment is the Sand Equivalent Test[3]. Experience is not available to prescribe limits in the three climates listed and it is suggested that test criteria be developed from local experience.

of aggregate to 19 mm (¾ in). In practice, choice is limited by what is available. Those regions of the world in which lateritic gravels are available, are fortunate in having this material which can generally provide a surfacing of good mechanical stability. Other regions often have suitable deposits of alluvial gravels or decomposing rocks. In India a special form of mechanically stable surfacing has been developed in which broken brick is mixed with soil of medium plasticity.[4] Elsewhere, although natural materials of ideal characteristics may not be available, the stability of the *in-situ* soil may often be improved by the incorporation of imported material. In dry desert areas, much can be done to improve the running surface of sand roads if deposits of clay soil can be found to mix with the sand. In wet areas where clayey soils predominate, it may be possible to obtain suitable surfacing material by seeking deposits of decomposing rock or other material which contains a substantial proportion of angular particles.

The material used for the running surface may be used throughout the whole depth of the road pavement. Alternatively, material of lower plasticity, conforming to the requirements for road bases given in the section dealing with natural soils and gravels, can be used in the lower layers. This is particularly desirable if further improvement to provide a bituminous surfacing is foreseen.

4.3.2 DRAINAGE

The running surface must be sufficiently cambered to shed surface water quickly but not so steeply cambered as to cause vehicles to slide off the road in wet weather or to encourage erosion (see Table 5.1).

4.4 ROADS WITH PERMANENT SURFACES

4.4.1 TERMINOLOGY

Broadly, there are two types of construction, 'flexible' pavements in which the running surface is made of bituminous materials and 'rigid' pavements where the running surface is of concrete. There may be intermediate types, as for instance where lean concrete bases are used with bituminous surfacings on heavily-trafficked roads in some developed countries. It may be thought that stabilised-soil bases with bituminous surfaces represent an intermediate type, but cement- and lime-stabilised soils in the tropics are designed on the presumption that they will crack; their load-distributing properties are then little, if any, better than other granular materials in present use, and they are thus best regarded as flexible for design purposes.

Flexible pavements comprise the bituminous surfacing, the base and the sub-base, supported on the subgrade (Fig. 4.2). The subgrade is the term used to describe the upper layers of natural soil,

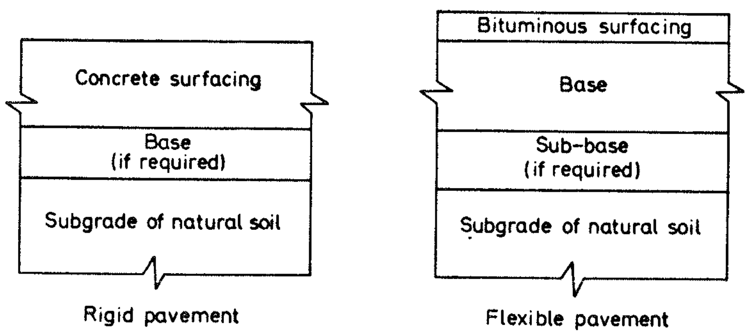

FIG. 4.2. *Structural elements of flexible and rigid pavements.*

either *in-situ* or in fill, which is compacted to give it added stability. The base and sub-base may be made from a variety of materials including natural gravels, partially disintegrated rocks, sand-clays, crushed rock and soils stabilised with small proportions of cement, lime or bitumen. Similar terminology is used for rigid pavements.

Bitumen (known as asphalt in American terminology) is usually derived from the distillation of crude mineral oil. Another bituminous binder, tar, is derived from the destructive distillation of coal. Bitumen may be rendered more fluid and convenient to use either by blending it with lighter oils to produce cut-back bitumens or by emulsifying it in water.

4.4.2 BASES AND SUB-BASES FOR FLEXIBLE PAVEMENTS

The principal function of the base and sub-base is to distribute the stresses imposed by traffic. A guiding principle in pavement design is that their total thickness should be sufficient to reduce the stresses on the subgrade below the limit that the soil will accept repeatedly without excessive deformation deriving either from shear failure or from compaction under traffic. It follows that on strong soils a sub-base may not be necessary whereas on very weak soils two or even more layers of sub-base may be needed. On such soils the sub-base also provides a working platform on which construction can proceed in wet weather.

To prevent surface water from entering and reducing the bearing capacity it is desirable that the base be effectively impermeable and itself resistant to the weakening effects of water. Since, in most developing countries, the bituminous surfacing consists only of a thin surface dressing, the upper surface of the base must be sufficiently smooth and true to provide a good riding surface. With most of the materials used it is possible to produce a surface with depressions of less than 10 mm ($\frac{3}{8}$ in) under a 3 m (10 ft) straight-edge[5] and with this criterion, roads of quite good riding quality are obtained. Some difficulty may be experienced in obtaining a smooth surface when the maximum size of aggregate used exceeds 19 mm ($\frac{3}{4}$ in).

Thus the general properties required in base and sub-base materials are as follows:

(a) they should possess sufficient strength to sustain without failure the imposed traffic stresses, and

(b) they should be of uniform and consistent quality so that they can be spread and compacted without difficulty, to provide a road surface that will not be impaired by the compacting effects of traffic.

The characteristics of materials commonly used in making bases and sub-bases are outlined below.

4.4.2.1 *Natural soils and gravels*

This group comprises a wide range of naturally occurring materials such as lateritic and quartzitic gravels, partially decomposed rock, river gravels, sand-clays, coral, etc. For use as bases under bituminous surfacings they should have a grading that is mechanically stable and contain sufficient fines to provide a dense material of low permeability.

The materials may be 'as-dug' or may be prepared by blending soils from different sources. The gradings are similar to those specified for mechanically stable surfacings but the limits of plasticity are more stringent.

The clay, necessary as a binder in gravels used as a running surface, is most undesirable in a road base as it is a source of weakness should water enter the material. The plasticity index, linear shrinkage and liquid limit of the material passing the 425 μm (BS. 36) sieve should not exceed 6%, 4% and 25% respectively and the material should preferably be non-plastic.

Table 4.3 LIMITS OF PARTICLE-SIZE DISTRIBUTION FOR BASE MATERIALS[1]

BS. sieve size	*Percentage passing*				
	Nominal maximum size				
	75 mm (*3* in)	*38* mm (*1½* in)	*19* mm (¾ in)	*9·5* mm (⅜ in)	*4·75* mm (3/16 in)
75 mm (3 in)	100	—	—	—	—
38 mm (1½ in)	80–100	100	—	—	—
19 mm (¾ in)	60–80	80–100	100	—	—
9·5 mm (⅜ in)	30–65	40–75	80–100	100	—
4·75 mm (3/16 in)	25–55	30–60	50–85	80–100	100
2·36 mm (No. 7)	20–45	25–50	35–70	50–80	80–100
425 μm (No. 36)	10–30	15–30	15–35	25–50	25–55
75 μm (No. 200)	5–15	5–15	5–15	10–25	10–25

Grading and stability may be improved by crushing material which contains large particles. Even with this expedient it is not easy to find naturally occurring materials that consistently meet the requirements of a base for use under bituminous surfacings.

This difficulty can sometimes be overcome by judicious blending of different soils. Most commonly the material found in natural deposits is too variable and has too high a clay content. Where supervision is strict, it may be possible by suitable working to eliminate undesirable material, to secure a material within the specified limits. Thus the practice of using untreated natural materials as bases is decreasing except in very dry areas where the clayey soil they contain is not a source of weakness.

Particular care is needed in using gravels derived from decomposing igneous rocks; large fragments though superficially sound, may contain minerals that are already decomposed. Such particles will rapidly break down to clay when used in the road. Gravels from the more basic rocks of the basalt type are particularly prone to this weakness.[7]

The grading and plasticity requirements for sub-bases are not so stringent as for bases and some widening of the limits for the base materials shown in Table 4.3 can be allowed. Limitations on the plasticity index may be relaxed in the light of local experience, particularly under impervious base materials (see Chapter 5). Natural gravels or even finer textured soils of low plasticity may be used to make satisfactory sub-bases.

A useful additional criterion for sub-bases is that they should have a California bearing ratio (C.B.R.) of not less than 25% when tested at the critical density and moisture content that will occur in the field[8]. A common and useful way of employing natural gravels in road building is to build up the total thickness of base and sub-base with layers of the compacted material and then stabilise the top 150 mm (6 in) with Portland cement or hydrated lime to provide a strong base that is both impervious and resistant to the weakening effect of water.

NOTE: The remainder of the chapter is beyond the scope of this compendium.

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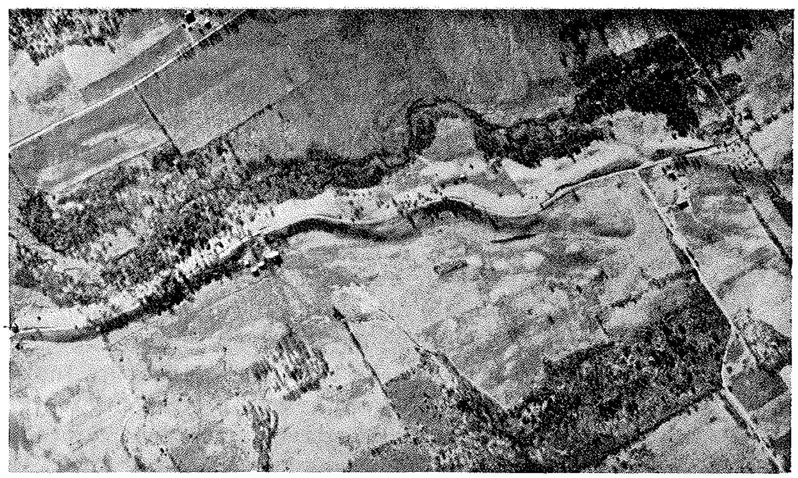

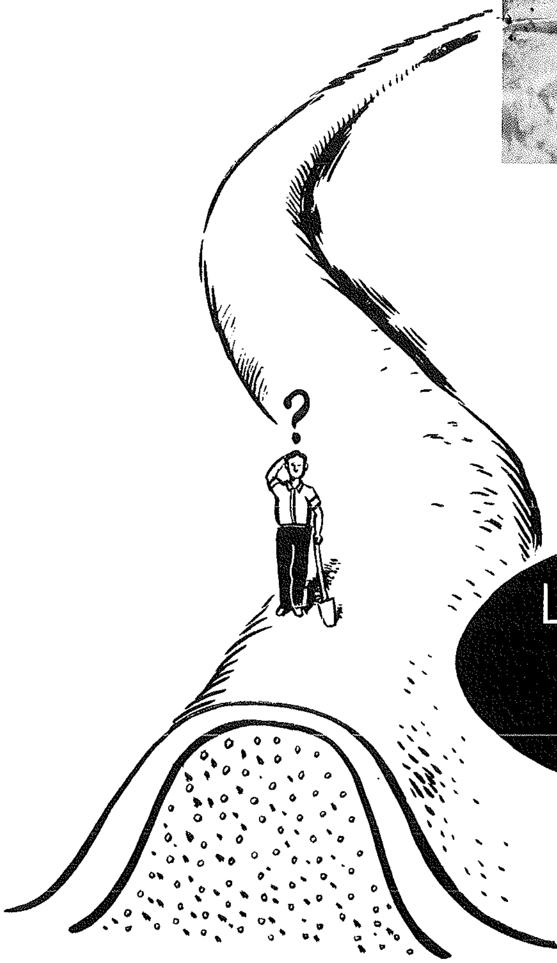

Short Course

LOCATION AND EVALUATION OF GRAVEL SOURCES FOR HIGHWAY USE

James W. Spencer
and Olin K. Dart, Jr.

FOREWORD

This short course has been prepared as a practical guide for town and county highway superintendents in New York State. Although these notes were designed to supplement oral presentation and discussion in groups of 10-20 persons, we hope that they are sufficiently complete to serve as a lasting reference on this important subject of gravel sources.

These notes may be criticized by experts because of an apparently hasty treatment of such broad subjects as glacial geology, pedology, airphoto interpretation and soils engineering. This course is not intended to produce a geologist, pedologist, airphoto interpreter or soils engineer. Instead, it hopes to skim from these areas of knowledge only those basic concepts which will help a practical road man to locate and evaluate the gravel sources so important to the economical constructtion and maintenance of local rural roads.

ACKNOWLEDGMENTS

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36 The following individuals assisted in the planning of the short course and the preparation of this publication.

Professors D. J. Belcher and T. A. Cheney assisted in the selection of suitable photographic illustrations.

Professor E. H. Muller generally reviewed the manuscript and offered suggestions concerning the formation of glacial gravel deposits.

Carl S. Pearson and other staff members of Cornell's Agronomy Department suggested the locations of some of the gravel landforms which are used as examples in this short course.

John G. Broughton, State Geologist, provided helpful advice on available geologic information pertaining to gravel landforms in the State. He also furnished the photographic copy of a portion of a new geologic map of the St. Lawrence Valley (Figure 20).

Charles D. Ditmars helped prepare the visual aids and suggested the technique for evaluating the plasticity of the binder soil fraction.

Mrs. Josephine Wilson typed these notes and assisted with the layout. James K. Estes prepared the cover. Frank P. Deane assisted with the illustrative sketches.

March 1956

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PHOTO CREDITS

Bradford Washburn furnished the photograph of Woodworth Glacier in Alaska (Figure 1).

The Cornell Air Photo Center furnished the ground photographs of a beach ridge and an outwash plain (Figures 13 and 15).

Richard A. Maurer photographed the gravel evaluation procedures shown in Part II of this publication and prepared the slides for the short course.

The Canadian Department of National Defense Photographic Library furnished the stereo pair for Figure 25. All other aerial photograph illustrations were furnished by the United States Department of Agriculture.

The generalized bedrock map (Figure 37) is from Cornell Extension Bulletin No. 930, Soils and Soil Associations of New York.

INTRODUCTION

Gravel deposits should be considered as valuable natural resources and, as with most natural resouces, we are faced with a depleting supply. Our Erwin roads built in the years 1952 through 1955 have consumed an estimated 12 1/2 million cubic yards of gravel. If this graveliing had been confined to an area the size of a football field, the compacted gravel would reach upward about 1.3 miles. By the time we've completed our proposed Erwin construction, we will have used the equivalent of the football field piled 4.1 miles high.

As our supply diminishes, it seems that we're going to have to do some prospecting or detective work to "uncover" all of the possible sources of granular material in our area. Just as geiger counters are used in prospecting for uranium, there are some simple tools that we can use in becoming good gravel prospectors. Of course, we could forget the prospecting techniques and scatter the countryside with 50 foot drill holes but this would be a pretty expensive endeavor.

Don't forget one important detail. If Mother Nature didn't leave any gravel in your area, even the best prospecting tools are not going to locate gravel. Yet, if "she" did leave any gravel deposits, we should consider it our responsibility to find them.

This short course is divided into two parts. In Part I, we will consider the various techniques for the location of potential gravel sources; and in Part II, we will briefly consider how we should evaluate the suitability of these sources for highway use.

PART I LOCATION OF POSSIBLE GRAVEL SOURCES

A. Formation Of Gravel Deposits

Before we talk about finding possible gravel sources, we'll have to study what they look like. (You have to know what a man looks like before you can recognize him in a crowded hotel lobby.) But even before we talk about the recognition of gravel sources, we should develop a general idea of how gravel deposits were formed.

We can generally classify our gravel deposits as those left from glacial times and those formed by present-day streams. Let's consider these two types of deposits separately.

1. Glacial Gravel Deposits

Living in Canada 12,000 years ago would not have been an enjoyable experience. In 10,000 B.C., the climate was much different than today. Because of much colder temperatures, snow did not melt even during the summer months and accumulated into a great mass of ice. The weight of this great mass of ice, thousands of feet thick, caused the edges to flow southward over New York State.

Geologists call this great mass of moving ice a glacier. The result of the advance and retreat of a glacier (reshaping the land) is called glaciation. Visualize how a glacier was able to "bulldoze" the soil and hard rock - pushing and dragging these materials across New York State. Realize, also, that millions of gallons of glacial melt water formed many temporary lakes and rivers in New York. This glaciation is estimated to have taken place about 14,000 years ago in the southern part of the state, about 10,000 years ago in the central portion of the state, and somewhat more recently in the North country.

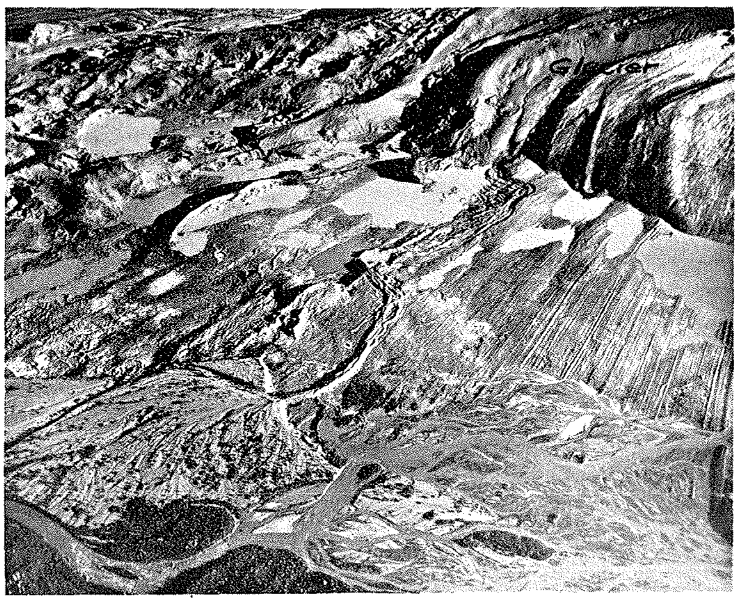

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Fig. 1 "Present-day" Woodworth Glacier in Alaska (Photograph courtesy of Bradford Washburn).

Recognizing the danger of oversimplifying the very complex process of glaciation, let's look briefly at how the various gravel landforms were built. The action of a glacier formed many types of deposits, but we will consider only those deposits which are likely to contain sands and gravels. As we discuss the process of glaciation, remember that a glacier was not pure ice; but in its formation and during its travels, it had picked up and retained large quantities of rock, cobbles, soils, trees, stumps, etc.

The glacial landforms which will interest us most are eskers, kames, beach ridges, deltas, outwash, and terraces. Each of these six landforms are likely to contain sands and gravels and we shou'd understand how they were built.

a. Eskers. During extremely cold weather, very little melt water flowed from the glacier. But, during periods of thawing temperatures, the ice at the surface melted and, like any water, flowed downhill. This flowing water tended to concentrate into streams at the top, within, and beneath the ice. Remember that the flowing water was not clear but "muddy", carrying or dragging soil materials ranging in size from clay to cobbles. When temperatures dropped and the quantity of melt water decreased, the speed of the flowing water was reduced. As the speed of the flowing water was reduced but slightly, the larger cobbles were dropped and the smaller particles remained in suspension. As temperatures dropped further, the speed of the flowing water decreased more yet and gravel and sand particles began to settle out. As long as these "streams" continued to flow at all, however, the smaller silt and clay particles remained in suspension and flowed on as muddy water. (In order for silt and clay particles to settle out, the water must be nearly still as in a pond or lake.)

So, in a period of time, melt waters flowing on top of, within, or beneath the glacier dropped sand, gravel and cobbles in stream beds. As this process continued, deep beds of stratified or layered materials were built up. These layers or stratifications in many of our gravel deposits are the result of variations in the speed of the flowing water.

As the front of the glacier moved backward, the gravelly stream bed was left as a remnant - a long, stream-like ridge of sand and gravel which the geologists call an <u>esker</u>. Figure 1 illustrates a recently formed esker in front of a retreating glacier. The eskers in New York State range from a few hundred feet to several miles in length. The height of the eskers is variable but about 20-40 feet may be average. 41

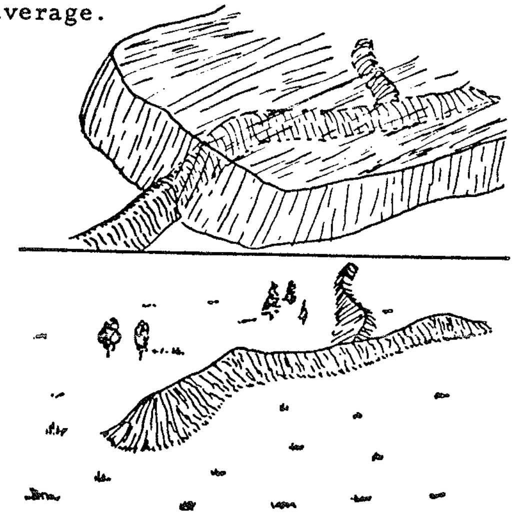


Fig. 2 Formation of an esker.

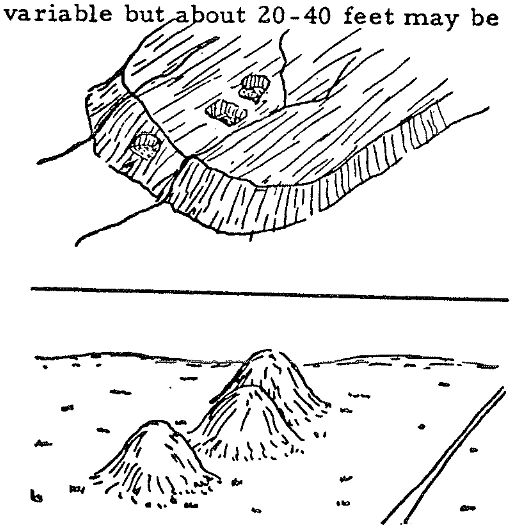
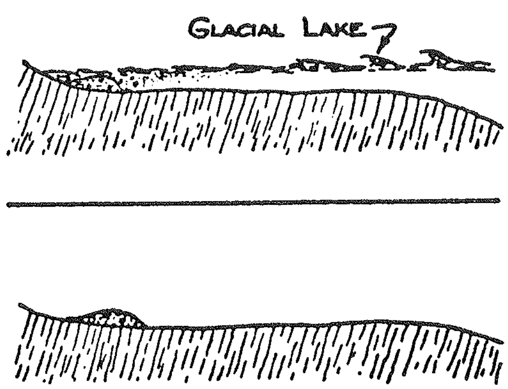


Fig. 3 Formation of kames.

b. <u>Kames.</u> The top and front surfaces of the glacier were not smooth; there were often large depressions or plunge basins in the ice. As melt water flowed into or over one of these depressions, its speed was reduced and the coarser sand, gravel and cobbles settled out. Over a period of time, these depressions became filled with granular materials and when the glacier melted, these materials were left as gravel hills. These rounded hills, containing sand and gravel, are called <u>kames</u>.

c. Beach ridges. We have all noticed that the beaches of most present-day lakes are covered with sand and gravel. Wave action deposits these granular materials along the shoreline.

Thousands of years ago, portions of the state were covered by lakes of glacial melt water. These glacial lakes, in most cases, were enlargements of present-day lakes. Although large areas of these old lakes may be "dry" today, we find beach ridges marking the receding shorelines.



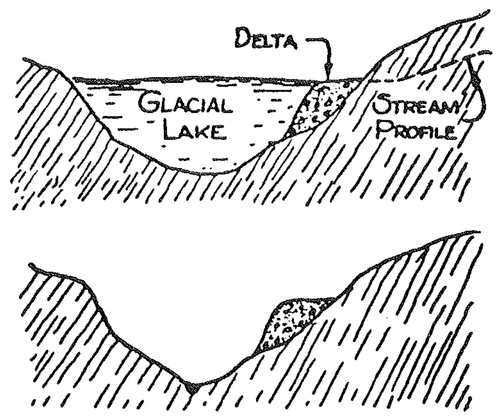


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Fig. 4 Formation of a beach ridge.

Fig. 5 Formation of a delta.

d. Deltas. Granular deltas are deposits of sand and gravel formed when a rapidly flowing stream, carrying or dragging coarse materials, suddenly enters a body of still water. The speed of the flowing water is immediately reduced and the coarse materials are dropped. We see many deltas being built today where rapidly flowing streams enter a body of relatively still water.

In discussing the formation of beach ridges, we pointed out that in glacial times, many areas of the state were covered with lakes of glacial melt water. Some of these were relatively small lakes, "trapped" in valleys by the glacier. Deltas formed at the edge of these lakes; today, the melt water is gone and these old deltas are left high and dry.

Deltas are slightly sloping to steep deposits - usually, but not always, found adjacent to present-day streams. The underlying topography is usually sloping.

e. Outwash. Keep in mind that the glacier was not clear ice but contained much debris, including gravel and sand. As the glacier melted, large volumes of melt water flowed from the glacier, carrying and dragging the debris along with it. As this rushing melt water emerged from the face of the glacier, its speed was reduced and the coarser sand and gravel particles were deposited. The silt and clay particles remained in suspension and flowed away with the melt water, leaving relatively clean deposits of sand and gravel.

As this process continued, "overloaded" streams of glacial melt water conributed more and more to the deposit of sand and gravel. Geologists define such granular deposits as outwash. As might be expected, outwash deposits are usually quite flat and cover a relatively large area in contrast to eskers, kames, beach ridges or deltas. There are usually remnants of old streams which contributed to the deposit.

A good example of recently formed outwash can be seen in the lower left of Figure 1.

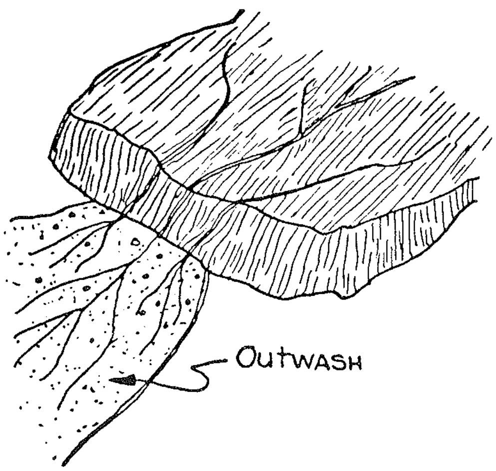

Fig. 6 Formation of outwash.

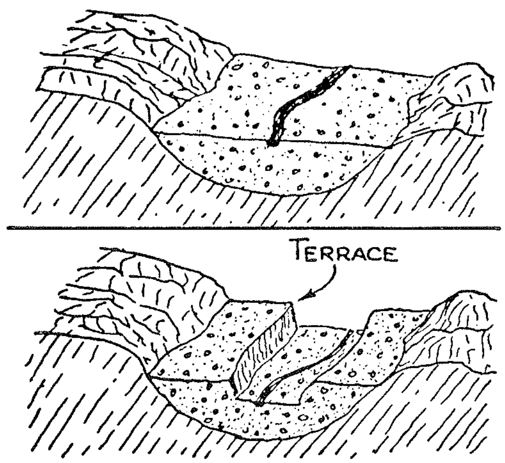

Fig. 7 Formation of terraces. 43

f. Terraces. Terraces are similar to outwash except that they were formed between valley walls and, subsequently, have been modified by stream action. The top sketch in Figure 7 illustrates the deposit of sands and gravels between valley walls. At some later time (lower sketch), more water "poured" down the valley and cut a trench in the surface of the granular outwash. Subsequent erosive flows of water cut the trench deeper and several steps or terraces were left in the original outwash. These flat terraces, containing sand and gravel are found "high and dry" near many of our larger present-day streams.

2. Gravel Deposits From Present-Day Streams

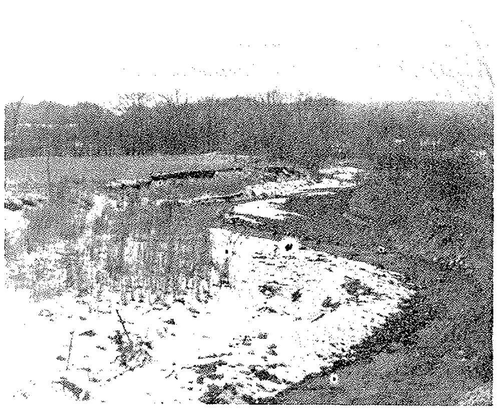

Fig. 8 Gravel in a present-day stream.

From our discussion of gravel deposits left by the glaciers, we have seen that deposits of sand and gravel have resulted from the slowing down of rapidly flowing water. Don't some of our present-day streams follow this same pattern? Of course. Many highway departments are making good use of what they call "creek gravel".

Some of our faster flowing present-day streams leave their bottoms covered with cobbles, gravel and sand. Build-ups of these granular materials are usually concentrated wherever particular obstructions or "slow downs" are present. The four most likely areas to find sand and gravel, in and near present-day streams, are pointed out in the following sketches. Remember, though, if any stream is to deposit sand and gravel it must, during some season of the year, flow with sufficient speed to erode and then carry or drag sand and gravel particles. In short, if a stream can't pick up or roll these larger particles, it surely can't transport them. If you expect to find gravel, then, you first choose a stream that flows rapidly (at least occasionally) and then look for conditions which might cause an immediate decrease in the speed of the rapidly flowing stream.

Conditions causing a "slow down" of flowing water are:

a.
b.
c.
d.

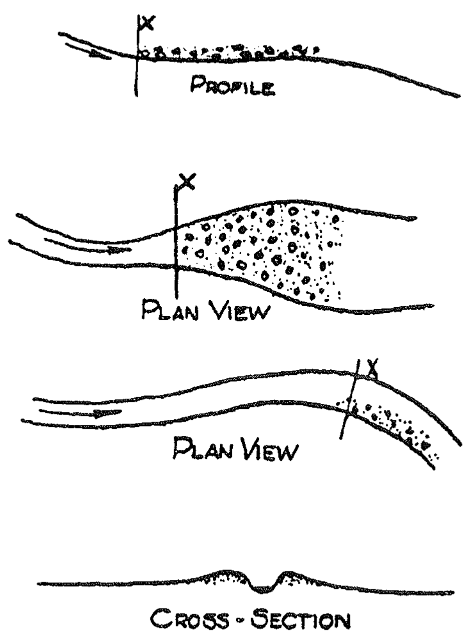

Fig. 9 Favorable conditions for deposition of granular materials in streams.

a. When a rushing stream levels out (point x in sketch), its speed is decreased and coarser materials are likely to settle out. Such changes in grade are likely places to find sand and gravel.

b. When a fast moving stream in relatively narrow confines suddenly spreads out (point x), its speed is decreased and coarser particles are dopped. Any widening in a stream channel is a likely spot for gravel deposition.

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c. The inside of stream bends is a likely spot to look for granular materials. The movement of water around a bend in a stream is similar to the movement of a car around a bend in a road. Cars have a differential because the "inside" wheels travel more slowly than the "outside" wheels. By the same reasoning, it is quite obvious that flowing water tends to slow down on the inside of a bend and may deposit sand and gravel in this area. Figure 8 illustrates this condition.

d. In areas where a stream is known to overflow its banks, deposits of granular material are likely to occur. As the fast flowing stream spills over its bank, the speed of the overflow is immediately reduced and the deposition may form a natural levee. In these overflow areas, the coarsest materials are usually found closest to the stream banks although such deposits often consist largely of sands and silts.

3. Summary - Formation Of Gravel Deposits

We have seen that the formation of gravel deposits, either thousands of years ago or today, has depended on flowing water. Flowing water is capable of transporting gravel, sand, silt and clay particles. As the speed of flow is decreased, the gravel and sand particles are dropped. Fortunately, the finer silt and clay particles are held in suspension until flow is almost still.

Potential gravel deposits laid down by glacial melt waters can be generally classed as eskers, kames, beach ridges, deltas, outwash, and terraces. Present-day streams are possible sources of gravel, though the volume of such deposits is usually relatively small.

B. Profile Development On Gravel Landforms

When glacial gravel deposits were originally formed, they consisted of relatively clean sand and gravel throughout their depth. Yet today, they are covered with a variable thickness of topsoil or overburden. How did this overburden get there? Why is the thickness of overburden important?

1. Profile Development (formation of overburden)

a. When the gravel deposit was originally laid down, granular material extended all the way to the ground surface.

b. Under the influence of time, climate, topography and other factors, things began to happen in the upper profile. As water soaked into the ground, silt and clay particles were carried down- 45
ward. Of course, climate and topography influenced the amount of water available for infiltration. Weathering caused some breakdown of gravel particles and these finer materials were leached downward. So, in the upper area of the profile we have an "A" horizon, which has been generally leached of fines. We also have a "B" horizon where these fine-textured particles have accumulated. The underlying "C" horizon, the original parent material, has been little affected by the weathering process. Although somewhat leached of clayey materials, the "A" horizon has usually developed some organic matter from the decay of vegetation.

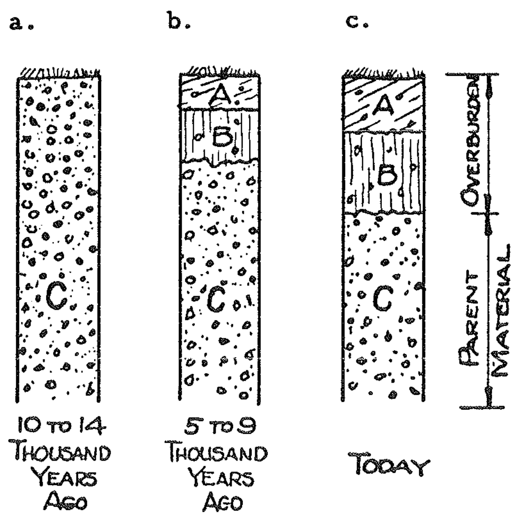

Fig. 10 Stages in soil profile development.

c. Over the years, this profile development has continued. Both the "A" and "B" horizons are deeper and more fully developed. The "A" and "B" horizons, considered together, are the overburden which usually should be removed before a gravel deposit is developed. In some instances, when higher amounts of binder soil are desired in a gravel mixture, the overburden may be used.

On some gravel deposits, especially deltas, a relatively deep overburden may be due to an overwash of finer sands and silts. In such cases, stripping must extend deeper than the zone of profile development.

2. Importance Of Thickness Of Overburden

The thickness of overburden to be stripped influences the cost of development and operation of any gravel deposit. In sampling a gravel deposit, we are obviously interested in digging where the overburden is likely to be thinnest.

The average thickness of overburden on a gravel deposit depends largely on:

a. how long weathering has been taking place. Older deposits generally have thicker overburden.

b. topography, or slope. Steeper slopes are likely to have thinner overburden since runoff has reduced the amount of water infiltration. Perhaps more important, erosion on slopes has slowly, but definitely, reduced the thickness of the surface soil.

On the more hilly deposits, it will be easiest to sample a possible source near the top or crest. At this point, minimum leaching coupled with maximum erosion will have resulted in a minimum depth to the parent material.

C. Methods Of Locating Possible Gravel Deposits

So far, we've discussed how gravel deposits have been formed by Nature. Now, how are we going to locate all of the deposits that Mother Nature decided to leave in our particular town or county? Let's keep in mind that some deposits may be good ones but others may be of poor quality and unsuitable for highway use. Nevertheless, it's to our interest to locate all of the possible deposits so that we can later evaluate their suitability for road use.

How should we go about it? How can we spot these eskers, kames, deltas, etc.? There are four general rules we should follow in locating possible gravel deposits. These rules, and a discussion of their use and limitations are summarized here.

1. Keep Your Eyes And Ears Open

Now that we generally understand how the gravel landforms were built, we should be on the lookout to see if we can recognize them as we travel around our town or county. Since our view from the ground is always limited in scope, we can quite easily be fooled. Nevertheless, it should be worthwhile to study a ground photograph of each of these gravel landforms and point out several of the distinguishing characteristics. Understandably, not all of these distinguishing characteristics are visible in the one photograph.

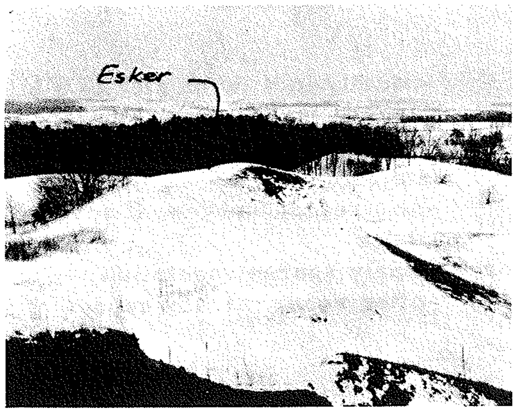

Fig. 11 Esker near Malloryville, N.Y.

- -ridge with fairly steep side slopes
- -both side slopes have about equal steepness
- -not straight but zig-zag like a stream (that's what it used to be!)
- -usually not uniform in height; average height 20-40 feet
- -no streams and few, if any, gullies on ridge
- -sparse vegetation, especially near top
- -often wet or marshy at base of ridge

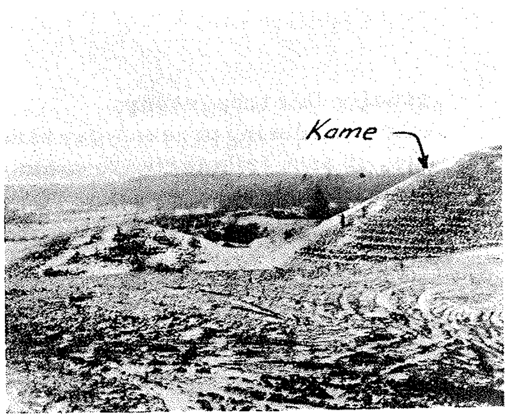

Fig. 12 Kame near Freeville, N.Y.

- -rounded, conical hill, or knob, either isolated or in groups
- -fairly steep side slopes
- -average height 50 feet
- -no streams and few, if any, gullies on knob
- -sparse vegetation, especially near top
- -often wet or marshy at base of knob

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Fig. 13 Beach ridge in Monroe County, N.Y.

- -isolated ridge or series of parallel ridges
- -top of ridge approximately level
- -slope toward "lake" is steeper
- -sharp break in slope at base of ridge

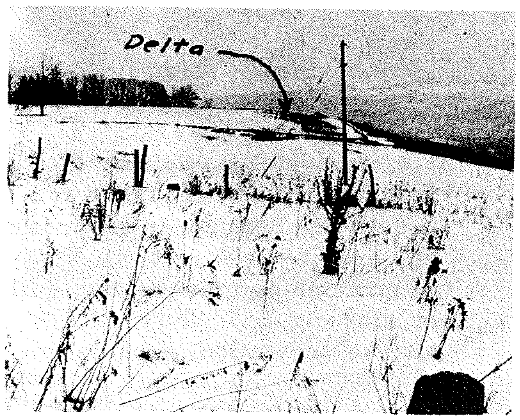

Fig. 14 Delta near Ithaca, N.Y.

- usually located on side of a hill
- usually fairly steep slope (outer slope), bench on top - may be bisected by glen or gully
- no streams and few, if any, gullies on delta
- fairly sparse vegetation
- often wet or marshy at base of delta

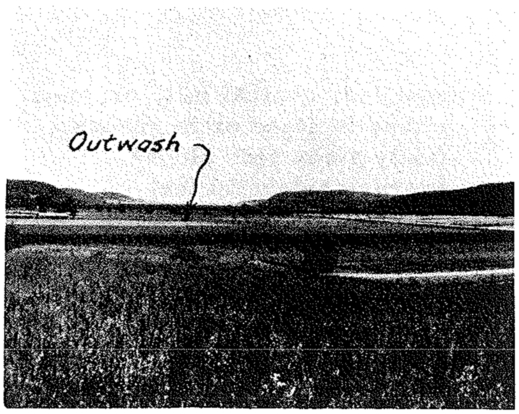

Fig. 15 Outwash near Cortland, N.Y.

- usually flat topography
- often bordering present-day stream
- few, if any, tributaries to main stream
- many rounded stones in cultivated fields
- may be abandoned muck filled channels in outwash
- hillsides rise abruptly from plain

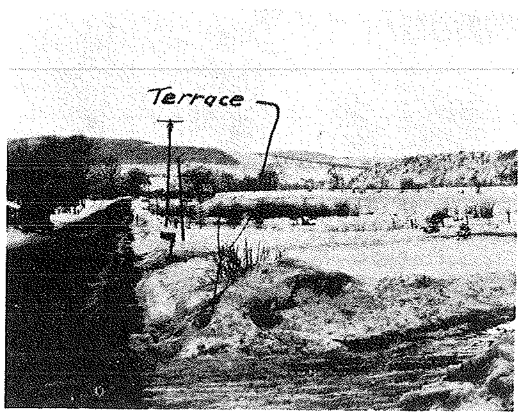

Fig. 16 Terrace near Harford, N.Y.

- usually associated with present-day stream
- steep slopes at edge of terraces
- gullies, if any, are short and V-shaped at edge of terraces
- few, if any, tributaries across terrace to main stream
- bounded by high land on one side, low on the other

While we're practicing the recognition of gravel landforms, here are some other practical pointers which may be of some value:

a. If a landowner tells you about some gravel on his property, find out how much he knows about it and then indicate this information on your map as a possibility to be investigated.

b. If in riding or walking around your area, you notice a cultivated field containing a predominance of rocks or stones, note it as a possiblity if the stones are rounded. If there are many stones and the stones are well-rounded or waterworn, it is likely that the deposit has been placed and assorted by running water. Water assortment is less likely if the stones are predominantly flat.

c. Some superintendents are enthused when they find a woodchuck hole bordered by a pile of gravelly material. This enthusiasm must be tempered by the realization that much of the finer soil that may have been brought out of the hole has been washed away by rain. The evidence of a pile of gravel near woodchuck holes should be considered in light of the shape of the gravel particles; round gravel usually indicates water assortment.

NOTE: Rule 2 - Check Available Agricultural Soil Maps
Rule 3 - Check Available Geologic Information
Rule 4 - Rely On Aerial Photographs As The Most Complete Inventory Of Possible Gravel Deposits

The text concerning the above rules has been deleted since it deals specifically with New York State.

PART II EVALUATION OF POSSIBLE GRAVEL SOURCES

A. What Should We Know About A Gravel Deposit?

The evaluation of an already opened and partially used gravel deposit is a relatively simple task. Sometimes we need only to ask ourselves how it worked out on the road we built last year. Evaluating an unopened but possible source, before spending the money to develop a pit, is more of a challenge. As we plan to evaluate a likely gravel source, let's resolve not to classify it arbitrarily as "good" or "bad"; instead, we should look quite specifically at several important characteristics.

Before opening a possible source for evaluation, we should consider:

- -nearness to current and future needs
- -access to public highway
- -extent and depth of deposit

Once a pit or test hole has been opened, we are interested in these characteristics:

1. Depth of overburden - This is an important characteristic which may affect methods of development as well as the economic feasibility of development.

2. Character of gravel particles - We should know if a gravel source is shaley or consists of harder particles of limestone, sandstone, etc.

3. Maximum gravel sizes expected - The presence of many large cobbles may necessitate crushing or screening at the bank or raking and cleanup on the roadway.

4. Gradation of granular material - The performance of any gravel mixture depends largely on the relative proportion of gravel, sand, silt and clay. The amount of silt and clay (dirt) is an especially critical factor.

5. Plasticity of fines - To evaluate the suitability of a gravel mixture for highway use, we should know how it will act when it is wet. Two gravel mixtures, having identical gradation, may behave quite differently in the presence of water.

6. Position of water table - Methods of development, loading, and access depend on whether a gravel source is dry or saturated.

7. Degree of cementation - Working a gravel deposit may be very difficult if individual sand and gravel particles are cemented together in a rock-like mass.

B. Before Opening The Deposit

At this point, we have circled and "question marked", on a map or the aerial photographs, some landforms likely to contain water assorted sands and gravels. (We hope!)

Now our job is to see if the possible sources are real sources of granular materials suitable for highway use. Before we open the source we should ask ourselves these questions:

1. Is It Near Enough To Current And Future Needs To Warrant Further Evaluation?

Our philosophy in evaluating possible gravel deposits should be "first things first". We're interested in the quality of every possible source but we are primarily concerned with the adequate sources nearest our work. A grade "A" source one mile from the job may be a better bet than a grade "A+" source five miles from the job. In short, start your evaluation in areas where gravel is most needed.

2. Is Access To A Public Highway Economically Feasible?

Other things being equal, it is obvious that we are most interested in sources requiring a minimum length of access road. If there is a worthy alternative, we don't want to build a half-mile of access road to get the gravel for a half-mile of public road. In selecting likely sources for evaluation and possible development, keep in mind the importance of access. As well as minimum length of access road, minimum grades are desirable.

3. Is There Likely To Be Enough Gravel To Warrant Evaluation And Possible Development?

The cost of evaluating a possible gravel deposit, building an access road, and opening a face is more or less fixed - regardless of the size of the deposit. It is reasonable, then, that if two or more possible sources are within reasonable hauling distance to our jobs, we should first consider the largest source. Other things being equal, we should select first the source having the least "overhead cost" per cubic yard of material removed.

Fig. 33 Estimating depth of hilly deposits.

The extent of a possible gravel source can be quite easily estimated from the aerial photographs. If we can outline an esker on the photograph and if we know the scale of the photograph, we can closely estimate its length and width. The depth of a deposit may best be estimated in the field. Of course, a few deep drill holes can give us a definite answer. In the "flat" deposits a drill hole may provide the only specific answer. General information on depth to bedrock may be available from the Ground Water Resources reports and maps described on page 22. In the "hilly" deposits, we can, for estimating purposes, assume that the depth of the gravel extends to the elevation of the adjacent terrain. Having estimated the approximate dimensions of a gravel source, we can calculate the likely yield.

C. Opening The Deposit - Where And How?

One way to open a possible gravel source for evaluation is to move in a power shovel or bulldozer and clear an open face for inspection. This is a fairly expensive operation which, considering the slight chances of success in some areas, may not be justified. Before a face is opened, it seems advisable to do some preliminary prospecting in order to (1) see if the landform contains any water assorted sand and gravel and (2) evaluate its probable suitability for highway use.

1. Where Should A Possible Source Be Opened?

From a practical standpoint, we'd like to open a source where the overburden is thinnest. On the hilly deposits, it is usually advisable to make an opening at the top (point a). In contrast to a location down the slope (point b), the top is likely to present the thinnest overburden and, once through the overburden, a greater depth of parent material should a deep inspection be desirable.

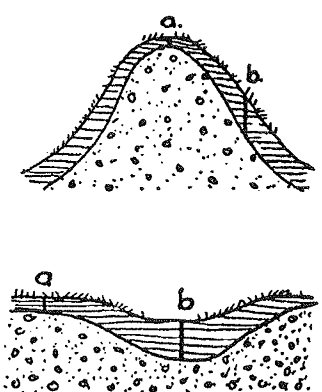

Fig. 34 Open a likely gravel source where overburden is thinnest.

On the relatively flat landforms, it is best to make an opening on the upland (a) rather than in slight depressions (b). Although the depressions may seem "closer to the gravel", actually the overburden is likely to be thicker at these points. Such depressions serve as collectors of surface runoff and the concentration of water is likely to have caused deeper profile development as well as a wash of surface soils into the lower areas.

The question might well be raised, "Is one test hole enough?". The answer depends on how much you want to know about a source before you develop it for use. One test hole will tell you if a particular landform contains water assorted sand and gravel; it can also tell you the characteristics of the granular material at one particular spot. Remember though, that gravel sources are, by nature, changeable. We may find changes in the quality of material if we dig deeper in a particular spot or if we move over 50 feet and dig another test hole. To detect changes with depth (a clay layer for example), deeper test holes are needed. The only way to detect possible changes in the material if we were to move over 50 feet is to dig another hole and find out.

Developing a gravel source is a "calculated risk" and deciding on the number and depth of test holes to be made prior to development depends on the risk we are willing to take.

2. <u>How Should A Possible Source Be Opened?</u>

a. <u>Hand labor.</u> The only advantage of the hand labor technique for opening a gravel deposit is the availability of required tools. The technique is slow and unless there is nothing else for the men to do, the operation is expensive. Hand digging might be used to strip the overburden in order to see if the materials just below appear water assorted. Hand digging to greater depths is usually impractical.

b. <u>Rotary drilling.</u> If equipment is available, a screw type rotary drill may be used to probe gravel landforms. The greatest advantages of this technique are speed of drilling and the depth to which sampling may be achieved. Disadvantages include the lack of mobility of larger drill rigs and the difficulty in drilling when large cobbles are present. In addition, materials brought up by a screw auger are sufficiently mixed so that it is difficult to determine the presence and, especially, the depth of clay seams, fine sands, etc.

c. <u>Bulldozer or power shovel.</u> This type of equipment, once at the site, may rapidly dig a trench through the overburden into the parent material. The depth of the trench is limited although a person may quite carefully inspect the parent material that is exposed. Moving such equipment to several possible sources is a relatively slow process.

d. <u>Tractor-mounted backhoe.</u> A small tractor-mounted backhoe is an excellent tool for opening a possible gravel source for 53
preliminary evaluation. Its main disadvantage or limitation is that the depth of trench is limited to about 8 feet. Among its advantages are:

1) quite widely available at moderate rental rate
2) easily and quickly moved from place to place
3) fast digging of inspection trench
4) trench wide enough for inspection of face
5) if tractor is equipped with blade, trench may be rapidly backfilled

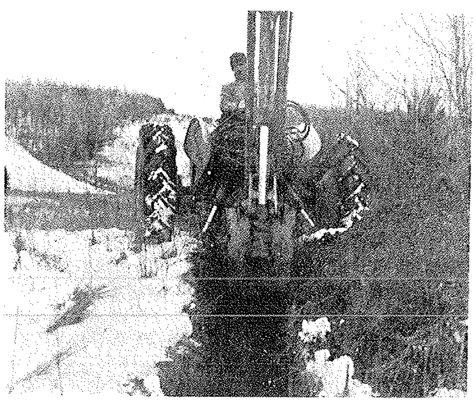

Fig. 35 Opening possible gravel source with tractor-mounted backhoe.

D. <u>Evaluation Techniques</u>

Our evaluation of a possible gravel source will not be a final answer. Instead, we should consider it as a good estimate at minimum cost. For the purposes of this discussion, we will assume that a tractor-mounted backhoe has been used to open a trench.

<u>Note:</u> Care and judgement must be exercised in entering the trench and disturbing its sides. Don't take chances since cave-ins are always a possibility.

1. Depth Of Overburden

Fig. 36 On hilly deposits, overburden is usually thinnest at the crest.

We should observe and note the thickness of overburden above the parent material. Remember that this thickness is variable and, if the location of our trench has been properly selected, the overburden here is likely to be at a minimum. It may be desirable to strip one or more additional small areas in order to better evaluate the average overburden thickness.

2. Character Of Gravel Particles

As we examine the parent material in the trench or, even before, the pile of material that was removed from the trench, we have to ask ourselves a very practical question. <u>Is this material a relatively clean, water assorted sand and gravel?</u> If it looks very clayey and has but a few, if any, rock fragments (most of them flat), we might as well backfill the trench and move someplace else. If it does appear to be predominantly sand and gravel, quite clean and with rounded, well-worn gravel particles, we can continue our evaluation.

We are obviously very interested as to whether the gravel particles are predominately limestone, sandstone, shale, crystalline rocks, etc. More practically, we are interested in whether the gravel particles are hard and durable or soft and likely to be easily crushed beneath a roller or traffic loads.

We can get a preliminary estimate of the type of gravels likely to be encountered by studying the bedrock map in Figure 37. The map is most helpful when considering relatively small deposits of local origin. Gravel particles in some of the larger deposits, placed by glacial melt waters, originated far to the north and the bedrock map is of less value. The agricultural Soil Survey report, in describing a particular soil series in a particular county, usually describes the composition of the gravel particles.

With a little experience, we can quite easily identify the composition of the gravel particles. The first step in identifying a piece of gravel is to crack it open in order to expose a fresh face.

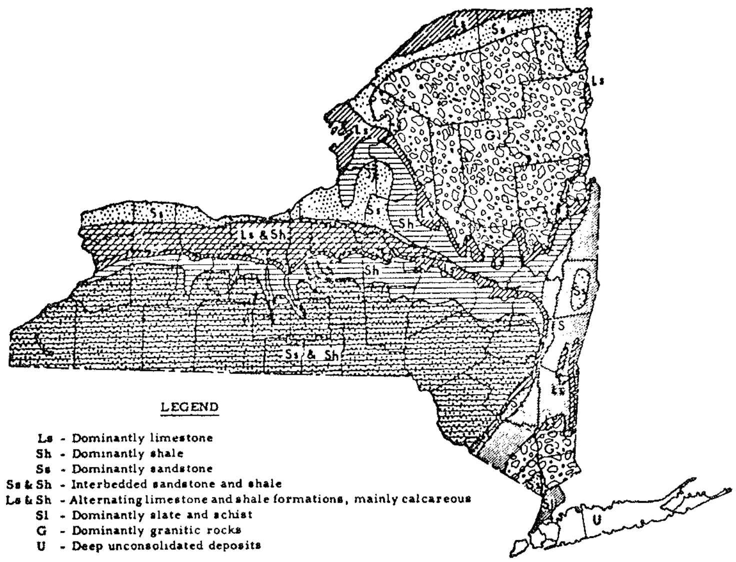

Fig. 37 Generalized bedrock map of New York. (from Cornell Extension Bulletin No. 930) 55

Limestone breaks into angular pieces. Usually gray color. Fizzes when touched with a dilute acid. (Muriatic acid is available in drug stores.) Good aggregate.

Sandstone breaks quite sharply when struck with a hammer. Color variable. Fresh face shows definite sand particles cemented together. Suitability as aggregate depends on quality of cementation.

Crystalline rocks break sharply when struck with a hammer. Fresh face shows definite particles of various sizes and usually various colors. Suitability as aggregate is indicated by soundness when struck with a hammer.

Shale breaks into flat, flaky pieces when struck with a hammer. Individual particles in shale are too small to be seen with the naked eye. A broken face usually shows some color banding. Shale is usually a poor aggregate. If it is very easily broken with a hammer, it is definitely unsuitable. The harder shales may be suitable for gravel roads.

Whether we can or cannot identify a piece of gravel, a blow with a hammer remains our best practical index of quality. Always whack a few pieces to see how easy they crack. A piece of gravel, resistant to the impact of a hammer, is likely to be suitable for highway use.

3. Maximum Gravel Sizes Expected

When building gravel bases, it is desirable that the maximum size of gravel be no larger than one-half the thickness of a compacted lift. If we compact our bases in six-inch lifts, the maximum size of gravel is about 3 inches, etc. For gravel surfaces, smooth ridability and easy maintenance dictate that the top size be limited to about 1 inch.

With these points in mind, we should inspect the material in order to evaluate the amount of processing which might be required. If large cobbles occur in distinct seams or layers, it may be possible to maneuver around them - stockpiling them for other possible uses. When well distributed through the deposit, screening or, more desirably, crushing may be necessary.

4. Gradation Of Granular Material

a. Desirable specifications. The term gradation, as applied to gravel mixtures, refers to the relative amounts of gravel, sand, silt and clay. A well-graded mixture has a minimum of air spaces to trap and hold water and, when compacted, achieves a high density and good load supporting characteristic. In Figure 38, the contents of the two tubes are identical. In the left tube, the materials are not mixed but separated by grain size. In the right tube, the well-graded mixture is mixed. Note the lesser volume in this right tube (increased density) resulting from the voids between the gravel particles being chinked with sand and the voids between sand particles being partially filled with silt and clay.

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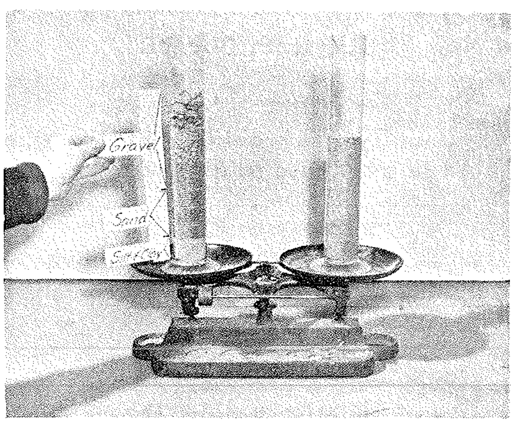


Fig. 38 The contents of these cylinders are identical. The mixture of gravel, sand, silt and clay (right tube) has a greater density than any of its components.

Of special importance is the quantity of the very fine materials, silt and clay, which tend to soften when wet. For gravel road work, a certain amount of silt and clay is desirable in order to minimize ravelling and seal the surface. For gravel bases which will receive a bituminous surfacing, a lower quantity of silt and clay is necessary. First of all, the surfacing seals the base and prevents ravelling; more important, though, an excessive amount of silt and clay may cause softening of the base when water is trapped beneath the mat.

A definition of gravel, sand, silt and clay is based on the size of the individual particles. Gravel is that part of the total sample that is retained on a No. 10 sieve (10 squares to the inch). Sand passes the No. 10 sieve but is retained on a No. 200 sieve (200 squares to the inch). The silt and clay particles are sufficiently fine to pass through a No. 200 sieve.

Assuming good gradation through the gravel and sand ranges, a suitable gravel mixture for use in gravel roads should contain:

Gravel	- 50-70%
Sand	- 25-40%
Silt and clay	- 8-15%

This is important. If a gravel mixture is to be used as a base for a bituminous surfacing the silt and clay content should not exceed 10%. Material used in the top few inches of the base ideally should contain even less silt and clay - perhaps less than 5%.

b. Sampling and preparation of sample for testing. One key word, representative, should describe any sample taken for testing. Test results refer only to the sample tested and, if the test results are to be valid, the sample must adequately represent the material in the gravel source. Many sources like that shown in Figure 39 are layered or stratified. Don't take material out of a seam of sand or a seam of gravel. Sample a mixture similar to that which would be taken in an upward sweep of a power shovel. Remember that your test results represent only the sample, and the more closely your sample represents the material that will be hauled to the road, the more valid will be your test results. 57

Fig. 39 Stratified gravel deposit.

When you have taken a representative sample (about 40 pounds), place it on a piece of canvas and mix it well. Remove any stray cobbles larger than about 2-3 inches. With a shovel handle you can quarter the large sample in order to get a smaller, yet representative sample for testing purposes. This technique is illustrated in Figure 40. After quartering, discard quarters b and d and thoroughly mix quarters a and c. This is a representative sample

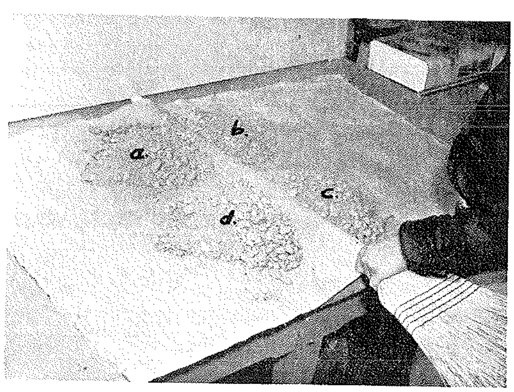


Fig. 40 Quartering the sample.

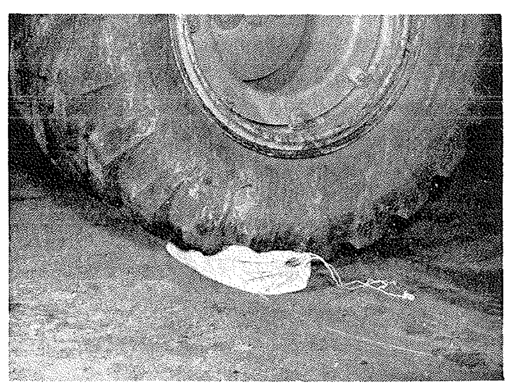


Fig. 41 "Rolling" the quartered sample.

reduced to about 20 pounds. Repeat the quartering process, place quarters a and c (about 10 pounds total) in a bag and save this sample for testing the gradation. Either quarter b or d should be saved if a plasticity estimate is desired. (See page 48)

The next step is to place the bag(s) of material on a firm surface and drive over them several times with either a loaded truck (Figure 41) or a roller to simulate conditions during construction. If any breakdown is to occur, it should be accounted for in the test.

c. Testing the sample for gradation.

1) Sieve analysis. Most highway and soils laboratories are equipped with a set of sieves and a sieve shaker (see Figure 42). If you have access to such a laboratory, the gradation can be determined quite readily. Generally speaking, the dry material is placed in the top sieve and then agitated until the smaller sizes sift on down through the nest of sieves. Then the material retained on each of the sieves is weighed and expressed as a percentage of the weight of the total sample.

Fig. 42 Using an automatic shaker for sieve analysis.

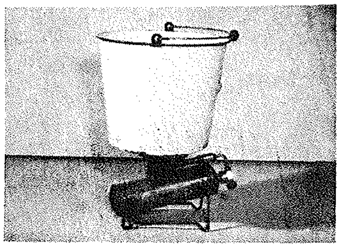
If you do this test yourself or have it done by laboratory personnel, get the total sample weight and then make sure that the total sample is washed through the No. 200 sieve before re-drying and sieving. If the material is merely sieved dry, the percent silt and clay will be too low since much of the finer material will adhere to the larger sand and gravel particles. A recommended test procedure is available from Highway Research and Extension, Department of Agricultural Engineering, Cornell University, Ithaca, New York.

2) Quick-wash test. This test is recommended in preference to the standard sieve analysis because of its simplicity and the wide availability of the equipment needed. The test method is not as precise as a sieve analysis but, from a practical standpoint, it is entirely adequate.

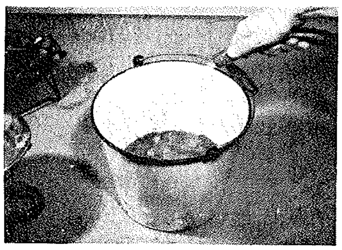
Here's the total list of equipment and supplies:

- a clean pail
- a flat pan or large cake tin
- a piece of hardware cloth with 8 squares to the inch
- a kitchen stove or a blowtorch
- a kitchen scale
- a source of water
- a sturdy stick or stirring rod

The test method is explained as follows:



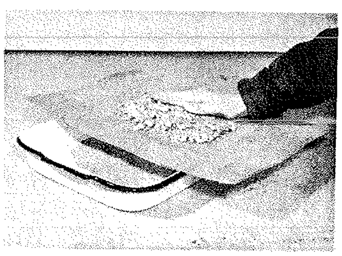
a) After getting the empty weights of the pail and flat pan, place the gravel sample in the pail and dry it out completely. A stove, oven, or blowtorch may be used for drying the sample. Do not overheat the sample; just dry it. Weigh the pail of dry material and subtract the empty weight of the pail. This is the dry weight of the total sample.



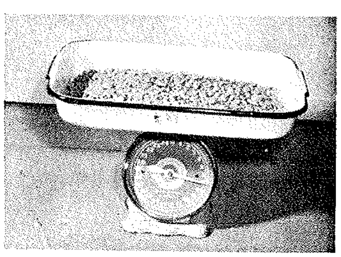
b) Cover the sample with about 6 inches of water. Stir the sample vigorously until the water becomes muddy.

c) After waiting about 15 seconds for the sand particles to settle, carefully pour off the muddy water. Don't lose any of the sand. Repeat this washing procedure until the wash water is no longer muddy.

d) The material left in the pail is wet sand and gravel. Dry the material thoroughly and get its dry weight. This weight, subtracted from the dry weight of the total sample gives the weight of the silt and clay.



e) Pour the dry sand and gravel on the piece of hardware cloth. Although the openings are somewhat larger than a No. 10 laboratory sieve, the hardware cloth will roughly separate the sand and the gravel. Material which can be worked through the hardware cloth is sand; the material retained is gravel.



f) Weigh the sand and weigh the gravel, remembering to subtract the weight of the pan. We can now compute the percentage of gravel, sand, and silt and clay in the total sample. The computation is illustrated in the following example.

Fig. 43 Quick-wash test.

Example:

Assume we have learned from the quick-wash test that:

- total weight of dry sample (not including pail)	= 9 lbs. 8 oz.
- weight of dry sand and gravel (subtracting these we learn that:)	= 8 lbs. 6 oz.
- weight of silt and clay (weighing the material that was retained on the screen and that which passed the screen, we learn that:)	= 1 lb. 2 oz.
- weight of gravel	= 5 lbs. 3 oz.
- weight of sand	= 3 lbs. 3 oz.

Notice that the sum of the weights of the gravel, sand, and silt and clay equals the weight of the total sample.

Unfortunately most kitchen scales are graduated in ounces. For computing percentages, it is necessary to convert the ounces to tenths of pounds. The following conversion table may be helpful:

60

1 oz. = 0.1 lbs.	9 oz. = 0.6 lbs.
2 oz. = 0.1 lbs.	10 oz. = 0.6 lbs.
3 oz. = 0.2 lbs.	11 oz. = 0.7 lbs.
4 oz. = 0.25 lbs.	12 oz. = 0.75 lbs.
5 oz. = 0.3 lbs.	13 oz. = 0.8 lbs.
6 oz. = 0.4 lbs.	14 oz. = 0.9 lbs.
7 oz. = 0.4 lbs.	15 oz. = 0.9 lbs.
8 oz. = 0.5 lbs.	16 oz. = 1.0 lbs.

From this table we can convert our weights as follows:

Weight of gravel	= 5.2 lbs.
sand	= 3.2 lbs.
silt and clay	= 1.1 lbs.
Total weight	9.5 lbs.

The percentage of gravel, sand, and silt and clay in the total sample may now be computed.

Gravel (5.2 lbs. of the total 9.5 lbs.) $\frac{5.2}{9.5} \times 100 = 55\%$

Sand (3.2 lbs. of the total 9.5 lbs.) $\frac{3.2}{9.5} \times 100 = 33\%$

Silt and Clay (1.1 lb. of the total 9.5 lbs.) $\frac{1.1}{9.5} \times 100 = 12\%$

Total 100%

On the basis of our general specification, the gradation of this material is suited for use as a gravel surface course but is somewhat too dirty (too much silt and clay) for a base beneath a bituminous surfacing.

3) Hand-feel evaluation. With experience, a highway superintendent may estimate the general suitability of a gravel mixture by "feel". A suitable technique is as follows. Pick up two or three handfuls of the material and discard stones larger than about 1/4 inch. Add enough water so that you can pack the material into a ball but not so much as to make it mushy.

Pick up a handful of the moist material and squeeze it into a ball. It should contain enough sand to look and feel gritty. Look at your hand. For use in gravel roads, the mixture should contain enough silt and clay to have stained your hand slightly but not enough to leave it muddy. For use in base courses, the moist material should not stain your hand. If suitable for gravel roads, the ball should hold its shape while moist. If dried, the ball will still retain its shape. Material with small quantities of silt and clay (suitable for base courses) react somewhat differently. A moist ball of the material is somewhat fragile and tends to fall apart quite easily. When dried, the ball may be broken with very slight force.

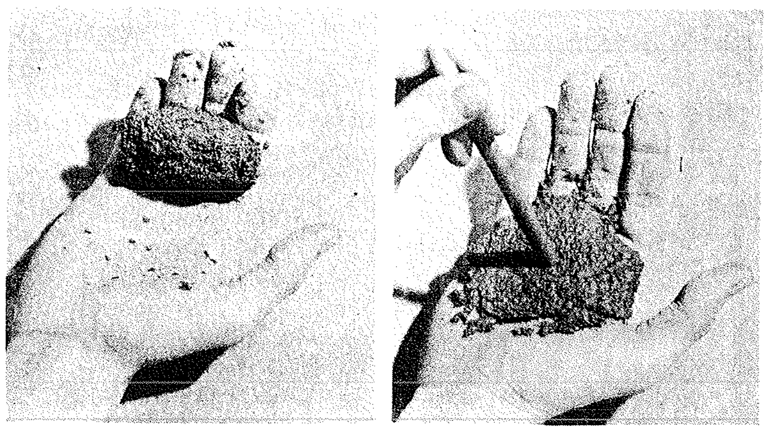


Fig. 44 This mixture is suitable for gravel roads.

Another check is to compress a handful of the material into a flat cake. Try pushing the blunt end of a pencil into it. If the pencil does not penetrate easily, there is enough sand and gravel, as well as enough binder soil for a gravel road. If the pencil tends to split the cake, it may still be suitable as base course material if it is evident that the splitting is due to too little silt and clay rather than too much.

The value of the hand-feel evaluation increases with experience but, at best, the test gives only a general idea as to gradation. It certainly does not give as clear a picture of gradation as the quick-wash test but, if time is short, it is better than nothing.

5. Plasticity Of Fines

Suppose that we have run a quick-wash test on two samples and find them to have identical percentages of silt and clay. Does this mean that these two samples will behave in the same manner when wet? Not necessarily. In the laboratory, the sieve analysis is usually accompanied by two other tests to determine the plasticity characteristics of the binder soil. These two tests, the liquid limit and the plastic limit, are run on that part of the sample which passes a No. 40 sieve (40 squares to the inch).

We won't discuss these detailed tests, but there is a simple way to roughly estimate if the plasticity characteristics of a material are likely to be troublesome. Let's assume that the quick-wash test indicates that our material is of satisfactory gradation, having 10% silt and clay. Based on gradation alone, we would say that this material could be used either for a gravel surface or base course. A simple hand test can tell us something about the plasticity characteristics of the binder soil and indicate the advisability of using the material for either or both purposes.

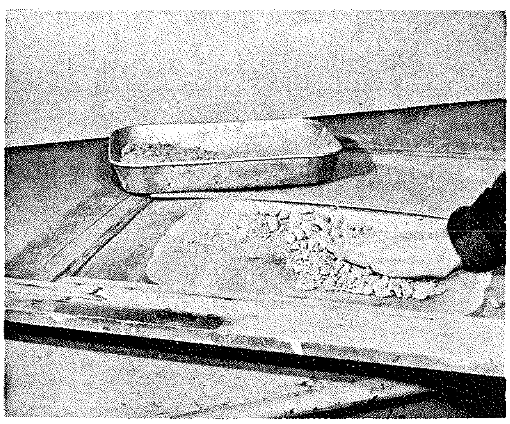


Fig. 45 Separating fine material by use of window screen.

Place some of the gravel mixture (dried) on a piece of window screen and rub the material thoroughly so that no dirt adheres to the gravel particles. On the material that passes the window screen, we can perform the following test:

a. Place about a handful of the material in a small bowl. Add water two or three drops at a time, mixing and kneading thoroughly with your fingers. Don't add too much water so that it is sloppy wet. Do add the minimum amount of water that will permit you to easily mold the material into a "golf ball". If the wet material clings to your hands, it is too wet.

b. Form the material in your hands until you have a snake-like shape about 1 inch in diameter. If you cannot readily shape the material, it may be necessary to add slightly more water, a drop at a time.

c. Lay the material on a flat surface (a cardboard or concrete surface is good) and with very slight finger pressure, begin to roll the material back and forth. The snake-like shape will gradually become thinner and thinner under its own weight. If the cardboard or concrete surface becomes muddy or very wet, you have too much water in the material.

d. Continue this rolling (at the proper moisture content) until the smallest possible "snake" is obtained. You will reach an end point where the soil will crumble rather than roll thinner.

e. Measure the diameter of the thinnest "snake".

If the material is suitable for gravel roads, the thinnest snake should be thinner than 3/8 inch; about 1/4 inch is perhaps optimum. If the diameter of the snake is 1/8 inch or less, it is probably too plastic and the roadway is likely to soften when wet. If the material is suitable for base courses, the snake should not be thinner than about 1/4 inch. You will find that materials with very little silt and clay will be difficult to roll out without crumbling. These materials, if well graded, are suitable for base courses.

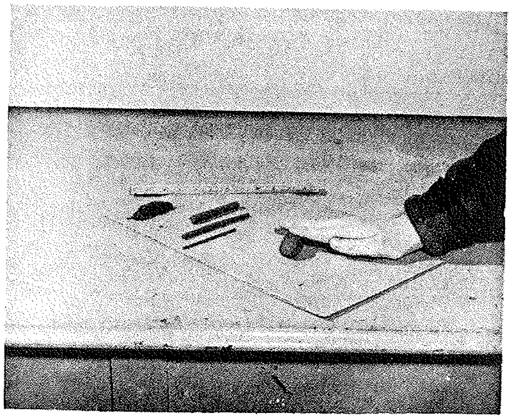


Fig. 46 Estimating plasticity.

Figure 46 illustrates the rolling procedure and shows the results of rolling materials of different plasticity. This plasticity evaluation supplements but does not replace an estimate of gradation using the quick-wash test.

6. Position Of Water Table

When evaluating a hilly gravel deposit, the water table is not often of much concern. It's a good idea though to inspect the base of the hill to see if the area is wet or marshy. If so, drainage of the floor of a gravel pit may be difficult. 63

In the flat gravel deposits, a high water table may present a problem. If the water table is at considerable depth, the gravel may be removed with a power shovel. If the water table is quite close to the ground surface, a dragline may be necessary. Quite often, the depth to the water table may be inferred from a nearby stream. In some instances, nearby farmers can provide information base on the water level in their wells.

7. Degree Of Cementation

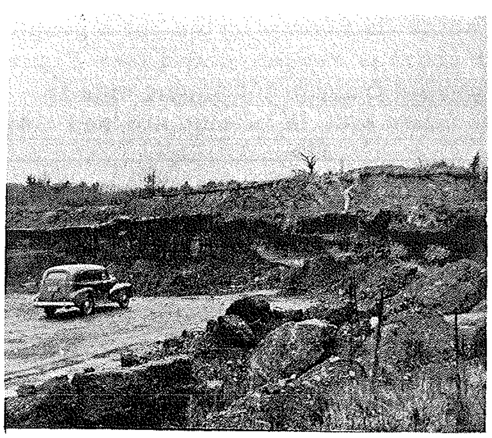


Fig. 47 Cemented gravel.

In some gravel deposits, especially those containing considerable limestone, we will find cementation of the sand and gravel particles. This is especially true at lower depths. Limestone, consisting of calcium carbonate, is slightly soluble and rainwater moving downward through the gravel mass has, over the years, dissolved some of the calcium carbonate. This solution is carried downward and, as the water evaporates, the calcium carbonate re-hardens into a white crust surrounding the sand and gravel particles. This cementation can make removal with a power shovel difficult. In some instances, removal is impossible without blasting.

The presence of cementation may not be evident in a shallow trench. If there is considerable limestone gravel, though, it might be assumed that cemented materials may be found at lower depths. Cementations are most likely to be encountered in deltas and terraces. These landforms usually collect runoff from a large watershed. Eskers and kames, because of their relatively small watershed, are not likely to be cemented.

Some superintendents have felt that once on the road, this white crusted material tends to re-cement. This is possible, although no real benefits have, to our knowledge, been definitely established.

E. Combining Materials For Satisfactory Gradation

We pointed out that gradation specifications for gravel surfaces are different than for gravel bases. We said, in summary:

For gravel surfaces		For gravel bases	
% gravel	50-70%	% gravel	50-70%
% sand	25-40%	% sand	25-40%
% silt and clay	8-15%	% silt and clay - absolute max.	10%
		desirable max.	5%

64

Suppose a particular source has too little silt and clay (is too clean) for gravel surfaces. If a binder soil is readily available, it is possible to blend a satisfactory gradation. Suppose a particular gravel source has too much silt and clay (is too dirty) for use in gravel bases. It is often possible to tap a local source of sand in order to decrease the silt and clay content in a blended mixture.

It is possible to take two materials, either one or both of them unsuitable alone for highway use, and combine them to produce a granular material of satisfactory gradation. If we know the gradation of two available materials, we can readily determine what, if any, combinations of these sources will produce a suitable gradation.

The mathematics of this calculation can be somewhat complicated but a graphical solution is simple. The following triangular chart is recommended (see Figure 48). Each of the three sides of the triangle is divided from 0-100%, one side is labeled gravel, one side is labeled sand, and the other side is labeled silt and clay.

As indicated in the legned of Figure 48, the dotted area contains all possible combinations of gradations that satisfy the requirements for gravel surface courses. It was made by drawing two lines representing the allowable range of 50-70% for gravels; two lines representing the 25-40% allowable range for sand, etc. The dotted area is enclosed by these lines. The cross-hatched area represents gradations containing less silt and clay and, hence, suitable for gravel bases.

After a quick-wash test on a particular source, suppose we find a gradation of

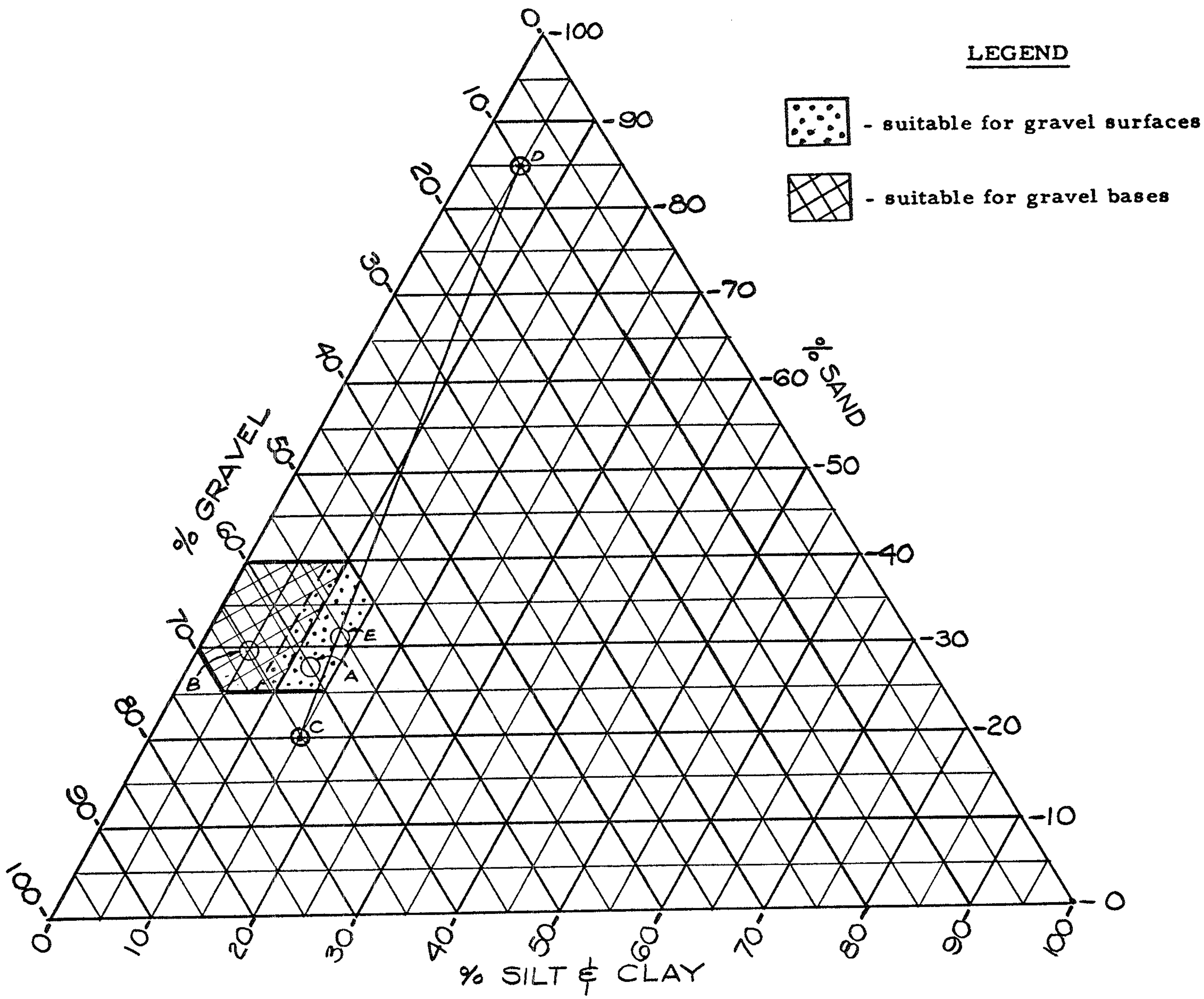


Fig. 48 Triangular chart for combining materials.

60% gravel, 28% sand and 12% silt and clay. Plotting this on the chart (point A), we see that the point falls within the dotted area and is suitable, as is, for gravel surface courses. A mixture consisting of 65% gravel, 30% sand and 5% silt and clay (point B) would be suitable for base courses.

Let's assume, though, that we have a source that tests 65% gravel 20% sand, and 15% silt and clay. Plotting this on the chart (point C) we see that it does not meet the requirements for either a base course or surface course. Let's assume, though, that about a mile from this source, we have a sand deposit that tests 10% gravel, 85% sand, and 5% silt and clay (point D). Alone, neither C nor D is suitable. Can they be combined to produce a satisfactory gradation? Here's how we can find out:

Step 1. Plot points C and D (neither falls within the areas of satisfactory gradation).

Step 2. Connect C and D with a straight line. If this line passes through an area of satisfactory gradation, these two materials may be successfully combined. In this case, we can produce a material suitable for a surface course but, by no means, can these two materials produce a blend suitable for a base course.

66 Step 3. If we want to produce a gradation suitable for a surface course, choose a point on the line near the middle of the dotted area. (point E)

Step 4. With a ruler or scale, measure the total length of line CD. In this example the length is 4.52 inches. Also measure the length of:
ED. Length 3.73 inches
EC. Length 0.79 inches

Step 5. The percentage of source D to get gradation E is computed as follows:

$$\frac{\text{length EC}}{\text{length CD}} \times 100 \text{ or } \frac{0.79}{4.52} \times 100 = 17.5\%$$

We could say that the needed percentage of material C to obtain gradation E would be: 100.0 - 17.5 = 82.5%

We can check, though, as follows:

$$\%C = \frac{\text{length ED}}{\text{length CD}} \times 100 \text{ or } \frac{3.73}{4.52} \times 100 = 82.5\%$$

Step 6. We can generalize by saying that a mixture consisting of about 83% source C and 17% source D will produce a gradation satisfactory for a gravel surface course.

This technique is equally well suited to "cleaning up" a too-dirty gravel source or, conversely, adding binder soil to a too-clean gravel source. The materials may be thoroughly mixed on the roadway with a grader or, preferably, a rotary mixer.

Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects

FP–61

January 1961

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The original printing of this publication was done when the Bureau of Public Roads was in the Department of Commerce. The Bureau is now in the Federal Highway Administration of the Department of Transportation. This reprint of March 1968 has made no change in the text.

U.S. DEPARTMENT OF TRANSPORTATION
Federal Highway Administration
Bureau of Public Roads

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PREFACE

This book, Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects, is issued primarily for use in the construction of roads and bridges on Federal highway projects under the direct supervision of the Bureau of Public Roads. When so designated in the contract of a project, it becomes a contract document, binding upon the parties signatory to the contract. For simplification in reference, this book may be cited as "FP–61," indicating Federal projects specifications issued in 1961.

Division I of this book does not include some of those provisions whose counterparts are customarily found in the corresponding divisions of highway construction specification books. All construction contracts of the Bureau of Public Roads are awarded under Federal Procurement Regulations promulgated by the Geenral Services Administration. Labor standards and general provisions that apply to highway construction contracts are incorporated in standard forms which are made a part of each contract and which are included in each project assembly issued to prospective bidders. In order to avoid possible future conflicting requirements due to changes in these forms, their requirements are not reproduced herein.

This book contains specifications for those items of work, materials, and construction methods that are generally applicable to direct Federal highway contracts, but it is adaptable for use by other highway agencies.

CONTENTS

Division II, Part 2

CONSTRUCTION DETAILS: BASES

Section 200.—AGGREGATE BASE

Description

Article 200–1.1 This work shall consist of a course composed of gravel or crushed aggregate, whichever is called for in the bid schedule, placed and compacted on a prepared roadbed in accordance with these specifications and in conformity with the lines, grades, thickness, and typical cross section shown on the plans.

Materials

200–2.1 Gravel. Gravel shall consist of hard, durable particles or fragments of stone or gravel, and a filler of sand or other finely divided mineral matter. Oversize material encountered in deposits from which gravel is produced shall be removed by screening or shall be crushed to the required size, whichever the contractor may elect.

200–2.2 Crushed Aggregate. Crushed aggregate shall consist of hard, durable particles or fragments of stone, slag, or gravel crushed to the required size, and a filler of sand or other finely divided mineral matter. When produced from gravel, not less than 50 percent by weight of the coarse aggregate shall be particles having at least one fractured face and, if necessary to meet this requirement or to eliminate an excess of filler, the gravel shall be screened before crushing. All suitable oversize material less than 10 inches in diameter shall be crushed.

Crushed slag shall be blast-furnace slag, reasonably uniform in density and quality, and shall have a rodded weight of at least 70 pounds per cubic foot when tested in accordance with AASHO T 19.

200–2.3 General Requirements for Gravel and Crushed Aggregate. In addition to the requirements in articles 200–2.1 and 200–2.2, gravel and crushed aggregate shall be uniformly graded from coarse to fine and shall conform to the requirements given in table 200–1 for the grading called for in the bid schedule.

The portion of the material retained on a No. 4 sieve shall be known as coarse aggregate, and that portion passing a No. 4 sieve shall be known as filler.

The material shall be free from vegetable matter and clay balls.

Coarse aggregate shall have a percentage of wear of not more than 50 at 500 revolutions as determined by AASHO T 96.

For all gradings, that portion passing a No. 40 sieve, including blending filler, shall be nonplastic or shall have a liquid limit of not more than 25 and a plasticity index of not more than 6 as determined by AASHO T 89 and T 91, respectively.

The grading percentages specified in table 200–1 shall apply to the material after it has been processed on the road as well as when tested at the pit or other source of supply.

Table 200–1.—Grading requirements for aggregate: Percentage by weight passing square mesh sieves, AASHO T 11 and T 27

Sieve designation	Grading								
	A	B	B-1	C	C-1	D	D-1	E	E-1
3 inch	100								
2 inch		100	100						
1½ inch			70–100	100	100				
1 inch			55–85		70–100	100	100		
¾ inch			50–80		60–90		70–100	100	100
⅜ inch			40–70		45–75		50–80		
No. 4	15–45	20–50	30–60	25–55	30–60	30–60	35–65	35–65	45–80
No. 10			20–50		20–50		25–50		30–60
No. 40			10–30		10–30		15–30		20–35
No. 200	0–10	0–10	[1] 5–15	0–10	[1] 5–15	0–10	[1] 5–15	0–10	[1] 5–15

[1] For gradings B–1, C–1, D–1, and E–1, the fractions passing the No. 200 sieve shall not be greater than two-thirds of the fractions passing the No. 40 sieve.

200–2.4 Blending Materials. If fine aggregate or filler in addition to that naturally present in the base-course material, is necessary in order to meet the grading requirements, or for satisfactory bonding of the material, it shall be uniformly blended with the base-course material at the screening and crushing plant or on the road. The material for such purpose shall be obtained from sources approved by the engineer and shall be free from hard lumps.

200–2.5 Calcium Chloride. Calcium chloride shall conform to the requirements of AASHO M 144.

Construction

200–3.1 Pits and Quarries. Borrow pits and quarries shall be cleared and grubbed in accordance with the requirements of section 100. Cleanup shall be performed as provided in article 8.3(f).

200–3.2 Preparation of Roadbed. Roadbed, including shoulders, shall be constructed, prepared, and finished as provided under section 107.

200–3.3 Placing. The base shall be placed on the prepared roadbed and compacted in layers of the thickness shown on the plans. When more than one layer is required, each layer shall be shaped and compacted before the succeeding layer is placed.

The placing of material shall begin at the point designated by the engineer. Placing shall be from spreader boxes or from vehicles especially equipped to distribute the material in a uniform layer or windrow. The layer or windrow shall be of such size that when spread and compacted, making due allowance for any blending material that is to be added on the road, the layer shall have the required thickness.

When hauling is done over previously placed material, hauling equipment shall be routed as uniformly as possible over the entire area of previously constructed layers.

200–3.4 Adding Blending Material. When additional fine aggregate or filler is required and it is to be blended with the material on the road, the blending material shall be uniformly placed with spreader boxes or other approved devices.

200–3.5 Mixing and Spreading. After each layer of base-course material has been placed, and blending material added when required, it shall be thoroughly mixed to its full depth by means of power graders, traveling mixers, or other mixing equipment. During the mixing, water shall be added in the amount necessary to provide the optimum moisture content for compacting as specified in article 200–3.6. When uniformly mixed, the mixture shall be spread smoothly to a uniform thickness or, in case of the top layer, to the cross section shown on the plans.

The contractor shall so schedule his operations as to assure completion of spreading within 48 hours after processing.

200–3.6 Compacting. Immediately following final spreading and smoothing, each layer shall be compacted to the full width by means of smooth-wheel power rollers or pneumatic-tired rollers meeting the requirements of section 109. Each 100 cubic yards, compacted measurement, of material placed shall receive at least 1 hour of continuous rolling. Rolling shall progress gradually from the sides to the center, parallel with the centerline of the road, and shall continue until all the surface has been rolled. Any irregularities or depressions that develop shall be corrected by loosening the material at these places and adding or removing material until the surface is smooth and uniform. Along curbs, headers, and walls, and at all places not accessible to the roller, the base material shall be tamped thoroughly with mechanical tampers. The material shall be

both bladed and rolled until a smooth, even surface has been obtained.

The amount of rolling and tamping as required above is estimated as the minimum necessary for adequate compaction. During the progress of the work, the engineer may make density tests in accordance with AASHO T 147, modified to include only materials passing a ¾-inch sieve, and if he finds the density is less than 100 percent of the maximum density as determined by AASHO T 99, Method C, the contractor shall perform additional rolling or tamping as may be necessary to obtain that density. Other types of field density tests may be used for control purposes after density values corresponding to those obtained by AASHO T 147 have been established.

The engineer may permit compaction with types of equipment other than those specified above, provided he determines that use of the alternative equipment will consistently produce densities of not less than 100 percent, determined as provided above. The engineer's permission for use of alternative compaction equipment shall be given in writing and shall set forth the conditions under which the equipment is to be used.

200–3.7 Thickness Requirements. The thickness of the completed base shall not vary more than ½ inch from the thickness shown on the plans.

Immediately after final compaction of the base, the thickness shall be measured at one or more points in each 300 linear feet of base. Measurements shall be made by means of test holes or other approved methods. The points for measurement shall be selected by the engineer at random locations within each 300-foot section in such manner as to avoid any regular pattern. Various points on the cross section shall be covered. As the work proceeds without deviation in thickness beyond the allowable tolerances, the interval between tests may be increased at the discretion of the engineer to a maximum of 1,000 feet with occasional tests at closer intervals. Whenever a measurement indicates a variation from the thickness shown on the plans of more than the allowable tolerance, additional measurements shall be taken at intervals of approximately 25 feet until the measurements indicate the thickness is within the allowable tolerance. Any area not within the allowable tolerance shall be corrected by removing or adding material as necessary and shaping and compacting as specified.

The cutting of test holes and refilling with materials properly compacted shall be done by the contractor under the supervision of the engineer.

200–3.8 Surface Requirements. When tested by a crown template, conforming to the typical cross section shown on the plans, and a 10-foot straightedge applied at right angles and parallel, respectively, to the centerline of the roadbed, the variation of the surface from each testing edge between any two contacts with the surface shall at no point exceed ½ inch for the crown template and ⅜ inch for the straightedge.

200-3.9 Calcium Chloride. When called for in the bid schedule, calcium chloride, in the amount specified in the special provisions or designated by the engineer, shall be spread uniformly over the surface of the finished base course.

200-3.10 Stockpiling. When indicated on the plans, base-course material shall be stockpiled in the amounts and at the locations so indicated. Stockpiling shall be performed in accordance with the requirements of section 305. Prior to stockpiling the material, the sites shall be cleared, cleaned, and leveled.

If the contractor elects to produce and stockpile aggregates prior to placement on the roadbed, the aggregates shall be stockpiled in accordance with the requirements of section 305.

Measurement

200-4.1 The yardage or tonnage to be paid for shall be the number of cubic yards measured in the vehicles, or tons of material, including all filler, placed, bonded, and accepted in the completed course or placed in authorized stockpiles.

When slag is economically available, the bid schedule will contain alternate pay items for crushed aggregate and for slag. The estimated tonnage shown under each pay item will be based on an assumed average bulk specific gravity of available aggregates and no further adjustment in payment will be made due to variation in the specific gravity of the aggregate used.

The quantity of calcium chloride to be paid for shall be the number of tons furnished, whether or not applied to the base, and the number of tons actually applied.

Payment

200-5.1 The quantities, determined as provided above, shall be paid for at the contract price per unit of measurement, respectively, for each of the particular pay items listed below that is shown in the bid schedule, which prices and payment shall be full compensation for furnishing and placing all materials, including all labor, equipment, tools, and incidentals necessary to complete the work prescribed in this section, except that when the bid schedule contains an estimated quantity for "Watering," any watering required shall be paid for as provided under section 108.

Pay item No. and name		*Unit of measurement*
200(1)	Gravel base, grading	Cubic yard.
200(2)	Gravel base, grading	Ton.
200(3)	Crushed aggregate base, grading	Cubic yard.
200(4)	Crushed aggregate base, grading	Ton.
200(5)	Furnishing calcium chloride	Ton.
200(6)	Applying calcium chloride	Ton.

Division II, Part 3

CONSTRUCTION DETAILS: SURFACING AND PAVEMENTS

Section 300.—AGGREGATE SURFACING

Description

Article 300–1.1 This work shall consist of a course composed of gravel or crushed aggregate, whichever is called for in the bid schedule, constructed on a prepared roadbed in accordance with these specifications and in conformity with the lines, grades, and typical cross sections on the plans.

Materials

300–2.1 Materials shall conform to the requirements of section 200, except as to grading and plasticity of aggregate.

Gravel and crushed aggregate shall meet the requirements given in table 300–1 for the grading called for in the bid schedule.

For all gradings, that portion passing a No. 40 sieve, including blending filler, shall have a liquid limit of not more than 35 and a plasticity index of not less than 4 nor more than 9 as determined by AASHO T 89 and T 91 respectively.

Construction

300–3.1 Construction methods shall conform to all the requirements for construction methods under section 200.

Table 300.1.—Grading requirements for aggregate surfacing

Sieve designation	Percentage by weight passing square mesh sieves AASHO T 11 and T 27 for Grading—				
	A	B	C	D	E
1½ inch	100				
1 inch		100			100
¾ inch			100		85-100
½ inch	40-75			100	
⅜ inch					65-100
No. 4	30-60	40-75	45-80		55-85
No. 10		25-60	25-60	25-60	40-70
No. 40					25-45
No. 200	5-12	5-12	5-12	5-12	10-25

Measurement

300–4.1 The yardage or tonnage of surface-course material to be paid for shall be the number of cubic yards, measured in vehicles, or tons, including all filler, placed, bonded, and accepted in the completed course or placed in authorized stockpiles.

When slag is economically available and measurement is by weight, the bid schedule will contain alternate pay items for stone (or gravel) and for slag. The estimated tonnage shown under each pay item will be based on an assumed average bulk specific gravity of available aggregates and no further adjustment in payment will be made due to variation in the specific gravity of the aggregate used.

The tonnages of calcium chloride to be paid for shall be the number of tons furnished, whether or not applied to the surface, and the number of tons actually applied.

Payment

300–5.1 The quantities, determined as provided above, shall be paid for at the contract price per unit of measurement, respectively, for each of the particular pay items listed below that is shown in the bid schedule, which prices and payment shall be full compensation for furnishing and placing all materials, including the labor, equipment, tools, and incidentals necessary to complete the work prescribed in this section, except that when the bid schedule contains an estimated quantity for "Watering," any watering required shall be paid for as provided under section 108.

Pay item No. and name		*Unit of measurement*
300(1)	Gravel surface course, grading ______	Cubic yard.
300(2)	Gravel surface course grading ______	Ton.
300(3)	Crushed aggregate surface course, grading ______	Cubic yard.
300(4)	Crushed aggregate surface course, grading ______	Ton.
300(5)	Furnishing calcium chloride ______	Ton.
300(6)	Applying calcium chloride ______	Ton.

ROAD RESEARCH

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ROADMAKING GRAVELS AND SOILS IN CENTRAL AFRICA

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CONTENTS

ROADMAKING GRAVELS AND SOILS IN CENTRAL AFRICA

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INTRODUCTION

IN PLANNING the road system of a developing territory it is essential to systematize knowledge of the roadmaking materials that are available. The present Bulletin reviews the soils, and particularly the gravels, available in Central Africa, the nucleus of the information being that obtained during a visit to the Federation in May and June, 1958, undertaken at the invitation of the road authorities there.

After a brief discussion of some of the factors influencing soil-formation in Central Africa, this Bulletin groups the gravels and soils encountered there into three categories depending on the rainfall under which they occur. In the low rainfall area the petrological characteristics of the underlying rock have a great influence on the properties of the soils derived from it, and sub-categories can be recognized on this basis. In areas of intermediate or high rainfall, although the parent rock is still important, the large-scale geological structure of the land affects soil formation to a greater degree by influencing drainage. Sub-categories have yet to be distinguished here, but it is thought that the catena concept - that of a series of soils formed on the same parent rock but under different drainage conditions - may be useful.

Effort in locating gravel deposits can be greatly reduced by examination of geological, agricultural and forestry maps, and of landforms revealed by aerial photographs. The occurrence of mine waste materials useful for building roads in economically important areas is noted.

FORMATION OF CENTRAL AFRICAN SOILS

Soils are formed by natural forces acting on rocks over long periods of time and, like other products of evolution, their appearance and behaviour are much influenced by their history. The recognition of this in agricultural research has led to a new branch of soil science - pedology - in which the processes of soil formation are studied. This has permitted the more fundamental classification of soil and has facilitated the application in the field of the results of laboratory research and of better methods of land utilization. Pedological techniques enable large areas of soils to be examined systematically with a limited effort and, since the road engineer is also concerned with the properties of large, albeit elongated, areas of ground, these techniques would also be expected to be useful to him. This has already been found to be the case in preliminary work in the United Kingdom, which has shown that soils in similar pedological groupings behave similarly when subjected to soil-cement stabilization.(1)

During the author's visit in 1958 it was found possible to classify gravels occurring in Central Africa on a pedological basis in broad terms having relevance to road engineering. To illustrate this classification it is first necessary to discuss briefly the major physical and chemical factors affecting soil formation.

Fissures occur in rocks both between adjacent mineral crystals, and on a larger scale due to stratification, cooling or earth movements. Cracks also arise by exfoliation, due to solar heating (Plate 1), and by relief of overburden load following denudation. Rainwater percolating through these fissures breaks up the rock still further by leaching out the more soluble constituents. This water drains down to lower-lying parts of the topography where the dissolved material is deposited, following evaporation during dry periods. Water also erodes material from the surface of the ground and deposits it in lower-lying areas. The amount of annual rainfall has therefore a fundamental influence on soil formation, and in Central Africa it is probably the most important single factor. Williams has drawn similar conclusions for the soils in the Union of South Africa.(2)

Where rainfall is low, massive rock formations weather to discrete, interlocking particles or aggregates. Although sometimes stained with red iron oxide on the surfaces, individual mineral crystals or crystal clusters remain intact, as do structural patterns or stratification. The petrological characteristics of the parent rock therefore play a significant part in determining the nature of the soil formed on it.(3)

In higher rainfall areas, the more intensive disintegration produces gravels and soils rich in the more insoluble minerals - quartz and, to a lesser extent, mica. Staining of the particles by red iron oxide becomes more marked, and increasing proportions of clay are formed from the decomposition products of the rock.

In the areas of highest rainfall considerable quantities of dissolved compounds of iron, aluminium and calcium move in the ground-water to lower strata, and where drainage is impeded these compounds accumulate as a result of evaporation, forming deposits of nodular lateritic and calcareous gravels.

Clay also accumulates in areas of poor drainage, which together with evaporation, is an additional soil-forming factor. Relict soils are formed when material accumulated under a climate of high rainfall is preserved into a succeeding low-rainfall period.

The effect of these factors can be seen on the vertical profile exposed on the side of a trial pit dug in the gravel or soil. In pedological surveying, profiles are described verbally, and those with similar characteristics are grouped together (morphological classification).

DETRITAL GRAVELS AND SANDS
(low rainfall area)

The best examples of detrital gravels are found in areas of the Federation where the annual rainfall is below about 30 in. (Fig. 1) and weathering of the rock is light. These include the major portion of Southern Rhodesia, with the exception of areas around Salisbury and the mountains on the Portuguese East Africa border. They also include a strip of Northern Rhodesia running parallel to the Zambesi river.

Six sub-groups can be differentiated on the basis of the petrology of the parent rock, and a more detailed examination of the country might well reveal more. The sub-groups are:

1. Granite, gneissic and quartzitic materials
2. Sandstone gravels and sands
3. Doleritic and basaltic materials
4. Micaceous and schistose gravels
5. Materials derived from shale
6. Limestone gravels

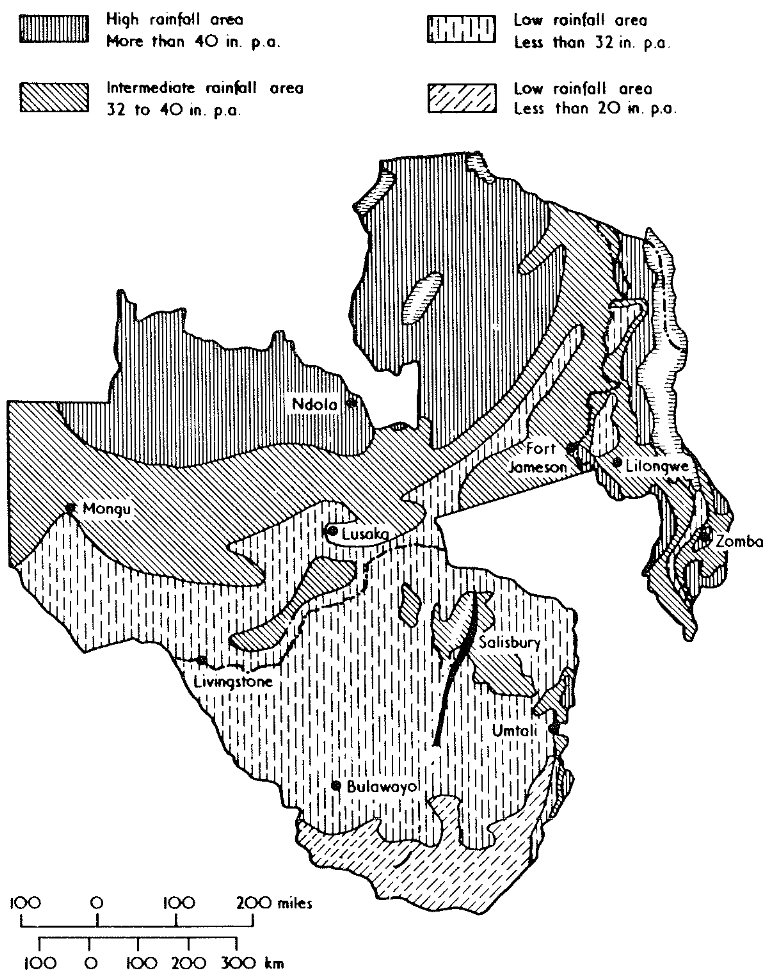

Fig. 1. Rainfall areas in Central African Federation.

Granitic, gneissic and quartzitic materials

Gravels. These usually retain the colour and texture of the original rock but cohesion is often slight. The largest particles, which may be up to several inches in size, consist either of quartz lu ps or crystal clusters of quartz, felspar and, to a lesser extent, mica in which weathering has not destroyed the bonding. Both individual lumps and crystal clusters are often stained red by iron oxide, but in the mass the predominant colours are white, cream, buff or light brown. Clay is either absent or is present in only limited proportions. The larger quartzitic particles are often cubical or rhombohedral, with sharp edges, giving a harsh gritty feel.

The gravels are easily worked with bulldozers or diggers, although the rate of wear of cutting edges may be high owing to the abrasiveness and dryness of the material. A number of cutting slopes were observed to be stable with angles in the neighbourhood of 90^{0}, suggesting high internal friction probably supplemented by cohesion due to dry clay. These steep slopes occur in areas where the total rainfall is low and the intensity is high. Cut-off drains reduce penetration of water into the adjacent formation, and the steepness of the slopes reduces erosion. Locally, areas of rock occur that are more resistant to disintegration than those surrounding them and these have to be avoided in working the pit. Gneiss is said to weather more extensively than granite, yielding deeper deposits.

The volume of gravel available in a pit is related to the depth of disintegration of the parent material, which is influenced by the land form, the sub-surface water regime and the susceptibility of the rock to weathering. The latter depends on the spacing and distribution of joints and the connexions between them. Close and vertical fissuring allows deeper weathering than widely spaced and horizontal joints. Weathering is also influenced by porosity, which can reflect the granularity of the rock.

Gravels developed on granitic, gneissic or quartzitic parent rocks are common in the Federation and provide excellent material for subgrades, sub-bases and bases, provided that the proportion of clay is limited. This is evaluated by the plasticity index(4) which, in Southern Rhodesia, is limited for different applications, i.e.

For bases in bitumen-surfaced roads	- P.I. not more than 4 per cent
For unsurfaced gravel roads	- P.I. not more than 10 per cent
For sub-bases	- P.I. not more than 12 per cent
For imported subgrade	- P.I. not more than 20 per cent

With a similar type of material ('disintegrated granite') the South Carolina State Highway Department requires a plasticity index of not more than 8 when it is used in unsurfaced gravel roads.(5)

A granitic gravel has been used successfully in the flexible base of the main runway at Kentucky Airport, Salisbury, and a quartzitic gravel in the base of runway pavements at the new Woodvale Airport at Bulawayo. At the latter site the material contained large boulders which were removed by screening and crushed to a more convenient maximum size, and then returned to the gravel to augment the proportion of coarse sizes.

Mica is a common constituent of granite and gneiss and is resistant to weathering, so that it occurs in gravels formed on these rocks. It has been estimated that mica occurs as a significant impurity in half the granitic and gneissic gravels of Southern Rhodesia, and to an objectionable extent in about 10 per cent of them. The properties of micaceous and schistose gravels will be discussed in more detail subsequently. The gneissic gravels are said to be more contaminated with mica than are the granitic materials.

Sands. 'Granitic sandveld' is the name given to a coarse-grained sandy soil derived from granites and gneisses and covering about 60 per cent of the area of Southern Rhodesia, including the economically important tobacco-growing areas. Mitchell[6] has reviewed its formation, distribution and characteristics, one of which is the presence, at a shallow depth below the surface, of a stratum of clay formed by the weathering of the overlying disintegrated rock. It is suitable for fill, but not for base construction in its natural state, but tests at the Road Research Laboratory have shown that it should be quite suitable for stabilization with cement,[7] and this has been confirmed by Holden at the Central Road Laboratory in Southern Rhodesia.[8] During the 1939-45 war the pavements at the Royal Air Force stations at Guinea Fowl and Norton, in Southern Rhodesia, were laid with cement-stabilized granitic sandveld. When these were inspected in 1958, neither airfield had been used or maintained for some time; some surface flaking and grass penetration had occurred owing to the lack of surface protection, but the body of the soil-cement layers in each case was in a satisfactory condition. Similar hardstandings were laid at the airfields at Heany, Thornhill, Cranbourne, Belvedere and Kumalo. The state of these 16-year old pavements supports the indication from laboratory work that this material should be sufficiently durable for use in road bases covered with bituminous surfacings. In the granitic areas, supplies of gravel with a low clay content, suitable as-dug for base construction, are becoming scarcer and more expensive to obtain. Cement-stabilized granitic sandveld should provide a satisfactory alternative, and the use of hydrated lime as stabilizer would also be worthwhile investigating in view of the abundant sources of limestone in Southern Rhodesia. The successful stabilization of decomposed granite with hydrated lime has been reported from Natal in the Union of South Africa.[9]

Experiments at the Road Research Laboratory[7] and by Van de Merwe in Southern Rhodesia[10] have shown that the granitic sandveld should be suitable for certain types of bituminous surfacing. Such surfacings could well be used in conjunction with stabilized bases of the type described, in which case there would be scope for the use of travelling mixing-and-laying plant capable of mixing either type of material with resulting economy in the cost.

Soils. Thompson, reviewing the granitic soils in Southern Rhodesia from the agricultural point of view, classifies them into five 'categories'.[11]

TABLE I

Categories of granitic soils (Thompson)

Category	Colour	Texture	Depth	Variation with depth	Drainage	Typical topography	Parent material
I	Yellowish-red Red	Clays Sandy-clays	Deep Moderately deep	Clay content and red colour increased with depth	Well-drained	Near 'castle-kopjes', or through uplands with slight slope	Rich in felspathic and ferro-magnesian minerals
II	Red-brown	Clayey-sands	Moderately deep				Variable content of felspathic and ferro-magnesian minerals
III	Light brown	Sand	-	Uniform or very gradual increase in clay content			Rich in silica
IV	Grey and white	Sand over-lying clays. Occasional ferruginous nodules	-	Abrupt change from sand to underlying clay	Poorly-drained. Seasonally fluctuating water-table	Flat areas and edges of 'vleis'	Poorly-jointed granite in 'whaleback' topography
V	Black	Clays	-	Accumulation of sodium salts in lower strata	Poorly-drained. High run-off. Impermeable	'Mopani' vetetation	-

Table 1 has been drawn up on the basis of this classification and indicates characteristics relevant to road engineering. It should be noted that Thompson's classification relates to the whole of Southern Rhodesia, and is not limited to the areas with rainfall lower than 30 in. per annum. As a rule granitic soils tend to be deeper as the annual rainfall increases.

The black clay of Category V, being sodium-saturated, is of interest since it would be expected to differ somewhat in its properties from the other black clays of the tropics ('black cotton soil') which tend to be calcium-saturated. For a given texture, a 'Mopani' clay of this category would be expected to be more cohesive and less permeable than the corresponding cotton soil, and to be more subject to volume changes. However, practical experience suggests that such clays are not difficult to deal with.(6)

Sandstone gravels and sands

Gravels. Near Chipinga, Southern Rhodesia, gravelly material is being won from decomposing sandstone. The material is light red-brown in colour, with the rough surface texture of sandstone, and the larger lumps are rectangular and up to several inches in size. The sandy overburden is thin, presumably because it has been removed by erosion of the steeply sloping ground. Clay is noticeably absent, and sand is the main constituent of the fines. It has been used successfully in an unsurfaced gravel road on the main route to Umtali, where, at the end of the wet season, it provided a surface which was dense, hard and free from corrugations.

Sandstone gravels would be expected to provide, without further treatment, very satisfactory materials for the bases of bitumen-surfaced roads since the absence of clay should much reduce the liability to soften under wet conditions. The lack of clay may also make for increased liability to dusting and corrugation on unsurfaced gravel roads, in dry weather. Experience in Southern Rhodesia suggests that some sandstone gravels can have a high fines content, however, and these may be stabilized with cement to provide suitable base materials.

Sands. A material of major importance in the Federation is the Kalahari sand (Gusu sand) which occurs in Barotseland in Northern Rhodesia, and to some extent in the west of Southern Rhodesia. It is aeolian, the particles being of a much more limited size range than those of the granitic sandveld (Fig. 2).

Two varieties were noted, a red and a white. The white sand lacks cohesion when dry and provides a poor running surface on an earth road. The red variety, on the other hand, is much more stable, for example giving a steep slope to a cutting seven miles south of Victoria Falls on the road to Wankie, in Southern Rhodesia. In Livingstone, Northern Rhodesia, the

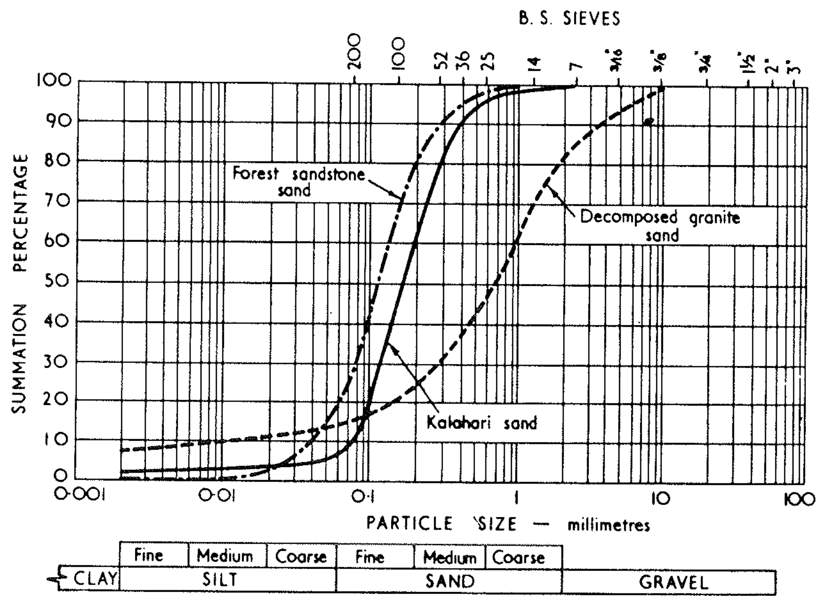

Fig. 2. Grading of sands found in Southern Rhodesia.

construction of a new municipal road at a bridge approach was seen at which the compacted subgrade of red Kalahari sand was carrying urban traffic very satisfactorily. The stability was not regarded as being sufficiently high for the sand to be used as a base, however, and the Municipality are planning experiments at this site at which cement-stabilized sand will be compared with gravel and crushed stone. Several earth roads in the adjacent Katombora area were observed to have good running surfaces when the red sand was traversed, but ruts and instability were encountered when the sand was white. The lower stability of the white material relative to the red is believed to be due to the cementing effect of a small proportion of iron oxide present in the latter. Clay is also present, however, and Mitchell(12) has shown that the California bearing ratio of sand compacted to the British Standard maximum density and soaked falls from 25 to 5 when the plasticity index rises from 0 to 20 per cent.

Millard(13) has reviewed road construction methods in Kalahari sand areas and other possible base material encountered there. These include sand-clays suitable for earth roads and nodular laterite (see p.17) as well as sheet laterite ('bog-iron'), concretionary limestone ('chebi-chebi') (see p. 24) and broken brick, all of which should be suitable for gravel roads, or for bitumen-surfaced roads after suitable treatment.

Work at the Road Research Laboratory(7) has shown that Kalahari sand should be suitable for the bases of bitumen-surfaced roads after stabilization with cement, and for the wet sand-mix process using 5 per cent of cutback bitumen and 2 per cent of hydrated lime. Other tests also indicated that it might be useful for making sand-asphalt.

In 1955 and 1957 the Southern Rhodesia Roads Department laid two series of experimental pavements on the road from Bulawayo to Victoria Falls using cement, bitumen and tar for stabilizing Kalahari sand.(14) At the time of the visit the lengths stabilized with bitumen were in the best condition, and it is felt that this additive is the most promising of those available. In this connexion it may be of interest that full-scale trials are in hand with sand-bitumen mixes in Northern Nigeria. These are being undertaken by the Road Research Laboratory in collaboration with the Federal Government and consulting engineers, and their object is to determine the minimum bitumen content and thickness necessary for bitumen-stabilized sand road bases.

84 Another sand of interest, developed on the forest sandstone formation, occurs in the northern and north-western parts of Southern Rhodesia, particularly in the Zambesi basin. A sample examined at the Road Research Laboratory was rather finer than the Kalahari sand (Fig. 2), and non-plastic. Tests also indicated that it should be suitable for stabilization with cement.(15) The grading suggests that, like the Kalahari sand, it should be suitable for some form of bituminous stabilization.

Basaltic and doleritic gravels

Gravels developed on basic rocks such as basalt and dolerite were seen in the western part of the Federation in the area of Victoria Falls and Livingstone. The basaltic gravels are grey or brown in profile and occur in flattish country, whereas the doleritic dykes are encountered in cuttings. Both tend to be overlain by a black, highly plastic clay containing rounded boulders of rock more resistant to weathering than that originally surrounding it. These boulders are often brought to the surface by some mechanism that is possibly associated with the pronounced swelling and shrinkage of the clay.

Weathered basaltic gravels, irrespective of their grading, are regarded as suspect in Northern Rhodesia, because it is believed that further decomposition may take place on the road.[16] A similar view was expressed in Southern Rhodesia. Failures are known to have occurred at the following sites:

(i) Bulawayo to Victoria Falls road, experimental length of cement-stabilized basalt gravel base, bituminous surfacing.

(ii) Victoria Falls to Livingstone road, lime-stabilized basalt gravel base, bitumen surfaced.

On the other hand, good results have so far been obtained with basaltic material at the following two airfields, which were inspected:

(i) Runway at Victoria Falls airfield, tar-stabilized basalt base, bituminous surfacing.

(ii) Runway at Livingstone airfield, crushed basalt slurried with clay on top, bituminous surfacing.

Failures have also occurred on roads in the Union of South Africa where certain doleritic gravels have been used, and Williams[2] has noted that unsound materials occur in regions where the annual rainfall exceeds 20 in., and sound materials where the rainfall is less. Weinert[17] notes that good performance may be due either to a low secondary mineral content of the dolerite or to low rainfall. If the South African experience can be applied, the basalt in the major formation running parallel to the south-eastern border in Southern Rhodesia might well be usable for road construction, since the rainfall in this area is below 20 in. per year. At the two sites in Southern Rhodesia where failure was observed the annual rainfall exceeded this value; in this connexion it is interesting that the successful stabilization of decomposed dolerite with hydrated lime is claimed in Natal[9] where the rainfall is also high, although the durability of the treatment is not yet known.

Basalts and dolerites are known to be prone to rapid chemical weathering. Secondary minerals such as zeolites and flaky chlorite are often present in the porous parts of the groundmass ('amygdales'). Some types of basalt and dolerite are believed to be unstable because they contain relatively large proportions of clay and limonite produced hydrothermally in the interstices of the rock after geological formation. These materials are locked in the spaces between crystals of more stable primary minerals, and are liberated when a large area of rock surface is exposed to moisture as, for example, when crusher-run material or weathered rock gravel is incorporated in the base of a bitumen-surfaced pavement. One possible explanation for the satisfactory performance noted in the two Rhodesian airfields may be that, by comparison with roads, runways are subjected to less mechanical pounding.

In the Union of South Africa satisfactory stone is distinguished from material liable to disintegrate by the sodium sulphate crystallization test.[18] Another method, based on the coefficient of restitution, has been developed for separating, on a larger scale, sound stones in gravel from those contaminated by clay but the view in South Africa is that this technique cannot be applied to the dolerites since with them, the clay is contained inside the stones rather than surrounding them.[19]

Failures have been recorded on roads in areas of the State of Victoria in Australia, where gravel derived from weathered basalt has been used.[20] In this case external contamination by clay seems to occur, e.g. from the over-burden. The material is believed to be suitable for sub-base construction, however, when the proportion of clay is limited by controlling the extraction of the gravel.

Basalt rock, associated with road failures in the State of Oregon in the U.S.A., when examined petrologically has been found by Scott to contain secondary minerals, such as clay and limonite, in proportions of 35 per cent or more.[21] Rock containing less than 20 per cent of such minerals gives little trouble. Methods used in Oregon for recognizing good rock and improving poor material are given in the Appendix.

Micaceous and schistose materials

Gravels. Mica is a common constituent of the gravels in Central Africa derived from granite and gneiss. Gravels and soils derived from schistose rocks also occur. Individual particles have a flaky shape, a smooth soapy feeling when handled and a variable texture. When excavated for use on the road, the orientation of the flakes that has been imposed by nature is lost and they assume a random arrangement with a high voids content. Such soils cannot easily be compacted with normal rollers. It is possible that vibratory rollers would be more effective but even so the compacted strength of the soils is not likely to be very high. They are generally permeable and when the moisture content increases, a very large and rapid fall in strength occurs, e.g. when rain falls on earth or gravel roads. Further, hydration during weathering is known to cause biotite mica to swell, an undesirable characteristic in a potential base material.

Schist and mica can also contaminate other, apparently more satisfactory, materials. In one instance recorded in the Copperbelt of Northern Rhodesia, a slightly micaceous quartz gravel was used in which the content of flaky material was visually insignificant. In service as a road surface, the gravel became smooth and slippery when wet, and finally rutted and failed completely.

In Southern Rhodesia the plasticity indices required with visibly micaceous gravels and soils are much lower than for granitic materials. The upper limits are:

For bases in bitumen-surfaced roads - P.I. not more than 2 per cent

For sub-bases - P.I. not more than 6 per cent

For imported subgrade - P.I. not more than 10 per cent.

Soils. Soils containing mica are poor foundations for roads, and in Northern Rhodesia the thickness of base indicated by the C.B.R. test is multiplied by a factor of 2, as a rule-of-thumb. The andesite schists of Southern Rhodesia are said to be potential sources of expansive clay, and as such are undesirable in roads even as fill material.

Micaceous soils tend to give rather higher results in the liquid- and plastic-limit tests than would be expected from the amount of clay present as indicated by a particle-size analysis. The presence of mica in such a soil can be confirmed by the linear shrinkage test since mica does not increase the susceptibility to volume change, as clay does.

Carbonaceous shale

In the Wankie area of Southern Rhodesia, carbonaceous shale occurs next to the coal measures worked by the mine, and is the source of 'fire-clay', a material produced by spontaneous combustion of the shale. This is similar in nature to the burnt colliery shale often used in roads in the coalfield areas of England and Scotland, the properties of which have been examined at the Road Research Laboratory.(22)

The fire-clay at Wankie, which is a red or white flaky material of gravelly texture, has been used successfully on the runway as a base protected by a surface dressing. This pavement was inspected and found to be in very good condition, apart from one or two very small areas of softening of the base. This is thought to be due to the presence of insufficiently-burnt shale. The material has also been used as a base in urban roads.

It is regarded locally as being too variable for use on main roads. This is a difficulty also encountered in the United Kingdom, and it is avoided by testing, in the laboratory, samples of material from the various potential sources, and by visual selection when working the source chosen. In Southern Rhodesia, as in the United Kingdom, swelling tests are made on fire-clay using the apparatus and technique developed in California for use with the bearing ratio test.

Visual selection at the pit is useful and a high degree of discrimination can be reached by a trained plant operator, but it is not always possible to prevent unsound material being used. To improve the quality of the material, stabilization with bitumen emulsion and with 13°-15° e.v.t.

tar has been used by Ingle in road construction in the Midlands coalfields.[23] A 5°-15° e.v.t. tar is produced at the Wankie Colliery and experiments are now in hand at the Central Road Laboratory, Salisbury, to develop methods for emulsifying tar for use in roadmaking. Experience in the United Kingdom suggests that either of these two binders could be potentially useful additives for improving the performance of the Wankie fire-clay in road bases.

In view of the importance of the Wankie area as a centre in which industries based on coal and coal chemicals will develop with the consequent need for more roads, there would appear to be scope for an investigation into the fire-clays on the lines of those made in the United Kingdom. The objects would be to select material that gives the best service when laid in roads, and to develop simple visual or other methods for identifying such material during extraction.

Limestone gravels

Limestone, mainly dolomitic, outcrops at numerous places in the Federation, but detrital gravel formed on it was only encountered on the unsurfaced road from Birchenough to Chipinga in Southern Rhodesia. Although used to only a limited extent in the territory, experience with the material is good, and it is said to be more resistant to corrugation than granitic gravel, possibly because of cementation due to solution and redeposition of calcite. More clay can be tolerated in limestone gravels for unsurfaced roads, and the maximum plasticity index allowed in Southern Rhodesia is 20 per cent.

QUARTZITIC GRAVELS AND SAND-CLAYS (intermediate and high rainfall areas)

In areas of the Federation where the annual rainfall exceeds 30 in., weathering of the rock is more intense than in the low-rainfall area, and the more soluble constituents are removed. The gravelly and sandy soils are richer in the most resistant primary mineral, quartz, than their detrital counterparts, and poorer in the less resistant, clay-forming minerals, such as felspar. These quartzitic gravels and sand-clays occur over the greater parts of Northern Rhodesia and Nyasaland, and constitute the most abundant group of gravels in the areas where the annual rainfall lies between 30 and 40 in. (Fig. 1).

Gravels. A typical residual quartz gravel contains discrete angular lumps of whole or shattered quartz which are opaque, sometimes white, but more often red due to iron oxide staining. Silty and clayey fines are present; the clay content is usually higher than with the detrital gravels. There is often little or no systematic variation in the material with its depth in the pit and the better examples of the group, developed on quartz-rich parent rocks, are among the best materials in the Federation for making bases for bitumen-surfaced roads.

Where major seams or veins of quartz have run through an otherwise fairly fine-grained rock, boulders of quartz may be encountered in the residual gravel (Plate 2) and unless removed these may present difficulties in grading or stabilizing the material for use in a road base. In the construction of the new Woodvale Airport near Bulawayo, the expedient has been adopted of screening out the boulders and crushing them to a maximum size convenient for use in concrete pavements.

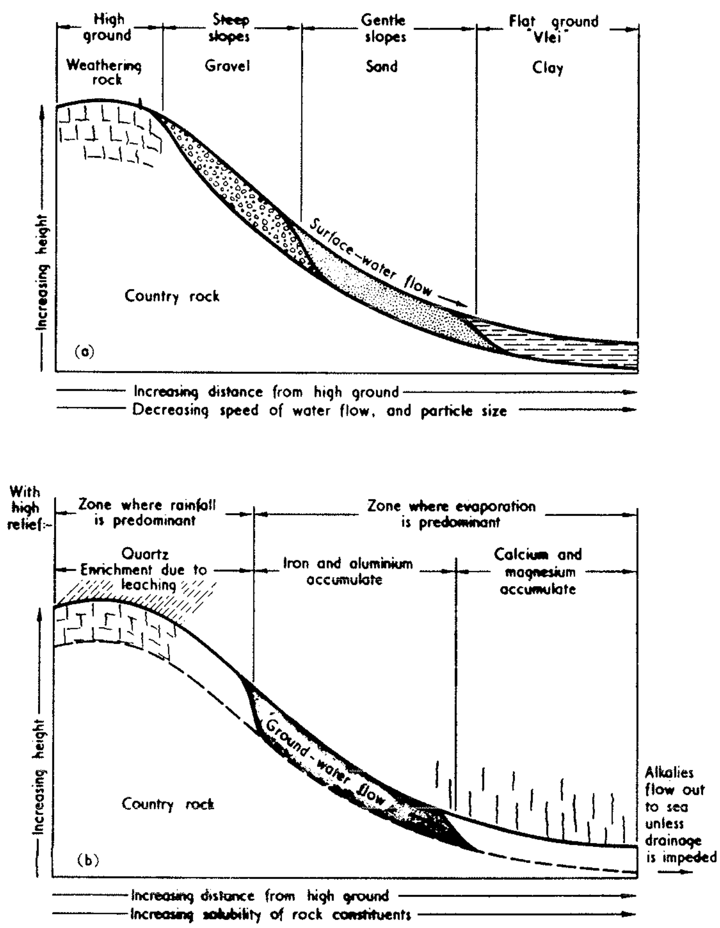

Fig. 3. (a) Physical and (b) chemical re-distribution of the constituents of weathering rock due to hydrological factors.

Residual quartz gravels form on quartz-rich reefs, which, because of their resistance to weathering, stand out as hills in undulating country. Alluvial quartz gravels are formed by the movement and deposition at lower levels of residual quartzitic material. Characteristically, the particles are more rounded than in the residual gravels and large boulders are absent, making them more convenient to handle. Some stratification can also be expected. Redistribution follows the catenary pattern shown in Fig. 3(a) in which a textural range of soil types are found with, successively, gravel, sand and clay predominating. These are formed by the weathering of rock on high ground, and are sorted as a result of the gradual reduction in the speed of flow of surface water. Pedologically-recent gravels occur near the surface on terraces in the higher reaches of rivers, while older deposits occur deep in the ancient channels of the more mature rivers, where water currents have been faster in the past.

The residual quartzitic gravels are a good deal more widespread than their alluvial counterparts in Central Africa, and the commonest variety appears to be developed on rocks containing a significant proportion of clay-forming constituents. The clay content is therefore often sufficient to provide a well-bound surface on a gravel road. When the growth of traffic requires a bitumen-surfaced road, however, the clay tends to soften, due to accumulation of moisture, and failure of the pavement may result. In Northern Rhodesia it has been found that the addition of about 3 per cent of hydrated lime to the gravel overcomes this difficulty, and provides a strong and durable base material for road construction. (16)

In Southern Rhodesia, probably owing to the lower intensity of chemical weathering, the depth of quartz gravel formations is seldom more than 2 feet, and often variable over a short distance. The plasticity index is said to vary both vertically and horizontally, necessitating close control and mixing by bulldozer on the quarry floor.

Sand-clays. Much of the igneous rock in Nyasaland is fine-grained syenite, which contains much less quartz and more clay-forming constituents than the igneous rocks found elsewhere in the Federation.

For this reason quartz gravels are less common than in the other territories, their place being taken by residual sand-clays, generally of a deep red colour and a medium texture. These soils provide earth roads that have good running surfaces in the dry season but are rather weak when wet. With good drainage, they provide fair foundations for gravel and bitumen-surfaced roads. In areas of Nyasaland where good base materials are scarce the stabilization of these residual sand-clays has interesting economic possibilities and the Public Works Department has begun to experiment with the process. For reasons of financial stringency, some stabilized bases have been made too thin to support the traffic loads that they had to carry. In some instances these bases were only 3 in. thick on cohesive soil and such failures as have occurred cannot be any condemnation of soil stabilization. With bases of adequate thickness, soil stabilization should be able to contribute much to road construction in Nyasaland, particularly as there is now an active Materials Laboratory within the Department capable of evaluating the soils available.

In one pit in Northern Rhodesia, a quartzitic gravel was seen containing what appeared to be boulders of 6 to 8 in. in size. Close inspection showed, however, that these boulders were minutely fissured and could easily be broken down into a pure white sand.

NODULAR LATERITIC AND CALCAREOUS GRAVELS (high rainfall area)

Lateritic gravels. In many areas, and particularly where the annual rainfall is greater than 40 in. per annum, a nodular ferruginous gravel occurs, known locally as 'laterite', which is widely used in roadmaking. The regions concerned are principally the two areas of Northern Rhodesia flanking the Congo Pedicle, and including the economically important Copperbelt. They also include a proportion of the higher ground in Nyasaland, and a small area near the Portuguese East African border in Southern Rhodesia.

In Northern Rhodesia and Nyasaland the gravel consists of spherical nodules of iron oxide or hydroxide with a comparatively uniform range of particle sizes in the neighbourhood of $\frac{3}{8}$ in. in diameter, embedded in a matrix of sand and clay. The nodules vary in hardness, some requiring a hammer-blow to break them while others may be crumbled in the hand. There is often a noticeable reduction in the hardness as the depth below ground surface increases. When broken open a nodule is sometimes found to be harder on the outside, progressing inwards to a softer core. The nodules may constitute the whole of the coarse fraction of the gravel, but often there is an admixture of quartz pebbles, which may predominate locally in some areas of a pit as the remnants of a former quartz intrusion. In pits containing mixtures of quartz gravel and nodular laterite, the nodules sometimes overlie the quartz pebbles and sometimes vice versa.

The colour of the gravel is regarded as a good indicator of its quality, particularly in respect of the hardness of the nodules. Thus, a profile of good gravel when wet is usually dark brown or red while a yellow colour indicates poor material. Differing colour in residual soils has been attributed by White[24] to variable spacing of the joints in underlying igneous rock. Close jointing encourages deep weathering, low water-table, penetration of air and oxidation of iron salts to the redder ferric state, while wider spacing of joints results in less oxidized, yellow material. The content of clay also influences the quality; in general the nodular lateritic gravels contain more than the quartzitic gravels (Fig. 4), and have higher liquid limits and plasticity indices. The variability of the clay content is high and in a series of tests made by the laboratory of the Public Works Department on the gravel from one pit used in the construction of the new lime-stabilized road, from Kafulafuta to Fisenge in Northern Rhodesia,

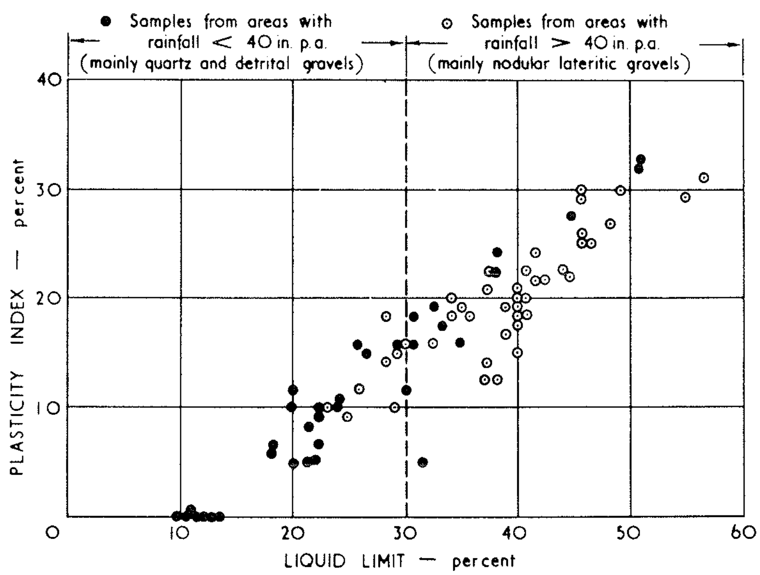

Fig. 4. Liquid limit and plasticity index values for the soil mortar of roadmaking gravels in Northern Rhodesia (tests by the Public Works Department Laboratory).

the plasticity index varied between 10 and 30 per cent. Some of this variability may be associated with vertical variations in the clay content in the profile, and to reduce it in practice pits are either worked vertically with face-shovels, or material is blended on the floor of the pit with a bull-dozer. Scrapers are not often used.

In Northern Rhodesia, the plasticity index requirements for unstabilized nodular lateritic gravels are:

For bases in bitumen-surfaced roads - P.I. not more than 10 per cent

For sub-bases - P.I. not more than 25 per cent

In addition, the proportion of the gravel passing the B.S. No. 200 sieve is required to be not more than 20 per cent.

In Southern Rhodesia nodular laterites tend to have colours in the range brown-purple-black and occur in beds of irregular thickness varying from 1 to 6 ft, with an average of 2 ft. They are particularly useful when they occur over basic parent rocks since alternative higher quality base materials are then seldom available. They can be difficult to rip and blast, and may even be cemented strongly enough to require crushing. The plasticity index of the fines varies from 0 to 30, and they are said to possess the property of re-cementation when laid on the road. This cementation is said to be associated with the presence of sparingly soluble aluminium hydroxides. Laterite developed on parent materials like the Kalahari sand, which is deficient in aluminium compounds, do not exhibit self-cementation.

In many parts of Southern Rhodesia long, level ridges of schist occur, capped with several feet of ironstone having characteristically rounded edges. These are probably nodular lateritic gravels, formed under an older, wetter climate, and which have resisted erosion better than the overlying and surrounding material. These caps weather to give a rubble, which flows down the slopes, and an alluvial red silt found on adjacent flat ground. The plasticity index of these materials varies from 6 to 30 and they can provide good sub-bases or stabilized bases, although transport is said to be expensive. No cementation is exhibited.

The plasticity index requirements in Southern Rhodesia for soils that are visibly lateritic are:

For bases in bitumen-surfaced roads	- P.I. not more than 6 per cent
For sub-bases	- P.I. not more than 18 per cent
For imported subgrade	- P.I. not more than 30 per cent

Concretionary laterite. This is a ferruginous rock-like deposit related to the nodular lateritic gravels, occurring in some instances with them. Thus in some profiles, the numbers of nodules increase with depth until they coalesce to produce a vesiculated mass containing soil in the voids, or with the soil leached away. When this material is exposed by erosion and subsequently desiccated, it has a dark brown or black appearance, is hard and durable, and has to be excavated with explosives and heavy rippers. This form is sometimes known as 'caprock'. When concretionary laterite occurs under damp conditions, however, it is a good deal softer and can be readily excavated by hand. It hardens on exposure to the atmosphere and is properly known as 'Buchanan's laterite' after its discoverer. Material of the caprock variety has been noted in Nyasaland by Schofield(25) as reefs marking the line of emergence of ground-water on the slopes of hills. The surrounding soil is believed to have been eroded away exposing a hard, black lateritic crust which overlies yellow and red laterite of the softer concretionary type. When lumps of the crust break away, they are said to harden further, yielding black honeycombed blocks. Of thirty such deposits examined by Schofield, all were small and isolated, and about one-half contained workable quantities of pavement material, between 5000 and 15 000 cubic yards covering one or two acres.

Soil associations. The ways in which nodular and concretionary lateritic materials are formed is not yet fully understood so that it is impossible to classify them completely. However, certain of the major factors underlying their formation are beginning to be known, and some of these are described briefly below.

One basic idea is that of a catenary association of soils, first developed by Milne(26) in Tanganyika and later applied to tropical soils in many other countries. It consists of a sequence of soils formed on the same parent rock, the vertical section of which has the form of a geometrical catena (Fig. 3). The sequence develops as the result of the physical and chemical redistribution of the products of weathering of rock on high ground. Physically, rock particles which are mainly of quartzitic material or residual clay are washed down the slopes of hills and deposited at distances from the crest inversely proportional to their sizes, gravel being laid on the higher and clay on the lower slopes. Chemically, the more soluble rock constituents

Exfoliation of an exposed rock surface due to solar heating, in the P.W.D. quarry at Lilongwe, Nyasaland

PLATE 1

(77625)

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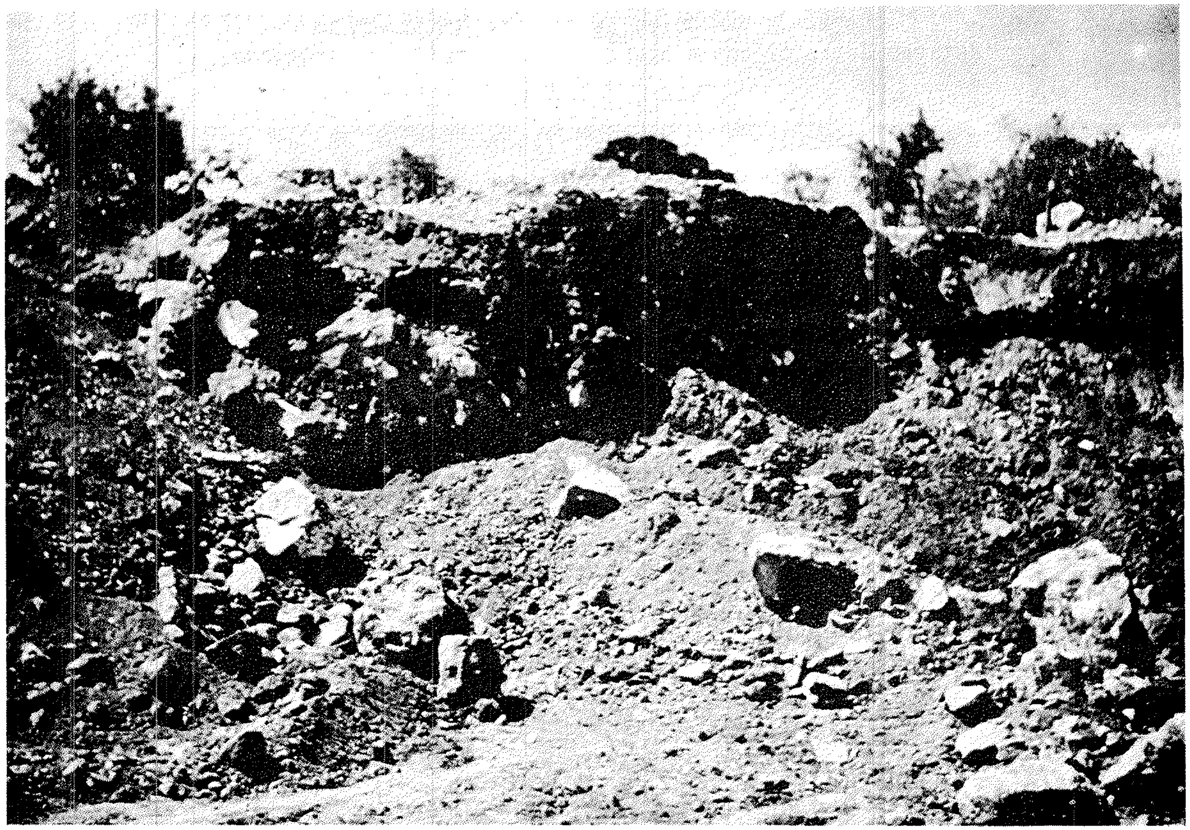

Large quartz boulders in a gravel pit near Kitwe,
Northern Rhodesia

PLATE 2

such as the alkalies, calcium and magnesium, iron and aluminium move (in the order given) from the higher to the lower levels dissolved in the ground-water. Following evaporation of water from the surface of the ground they are deposited at the lower levels, the least soluble compounds - those of iron and aluminium - being deposited first.

Thus, Haine notes that laterites useable in road construction often occur at the edges of "vleis" or low-lying, level ground.(27) Calcium and magnesium, and to some extent the alkalies, accumulate at the lowest levels: being extremely soluble, most of the alkali finds its way through the rivers to the sea.

These physical and chemical effects probably operate together, and local differences in the redistribution of sand and gravel offer one explanation for the occurrence of quartz pebbles and/or quartz sand in deposits of nodular lateritic gravel. As it appears that the amounts of rainfall and evaporation, and their variation in time and over the different scales of relief, are important factors in gravel formation, their examination in detail in future work might be rewarding. This might reveal local or regional correlations between the occurrence of lateritic materials and climatological indices that would be of service to engineers in locating gravel.

Quartz pebbles are also believed to move down from high ground when the residual red clay formed round them slides slowly down slopes. Schofield(28) has noted that such 'creep gravels' occur in Nyasaland, and can provide useful pavement material. He also finds that the best-developed catenary sequences occurred in areas with over 45 inches of rainfall per year.

Where ferruginous material accumulates, first in nodular and later in concretionary form, the resistance of the ground to erosion increases. As the rock profile weathers down, concretionary material is exposed as a reef and hardens on exposure to air giving the caprock described earlier (Fig. 5); this can therefore be regarded as the most mature of the gravels considered.

Ballantyne, in the recent reconnaissance soil survey of the Copperbelt in Northern Rhodesia,(29) has noted that there are two characteristic topographical forms associated with lateritic outcrops. He regards the

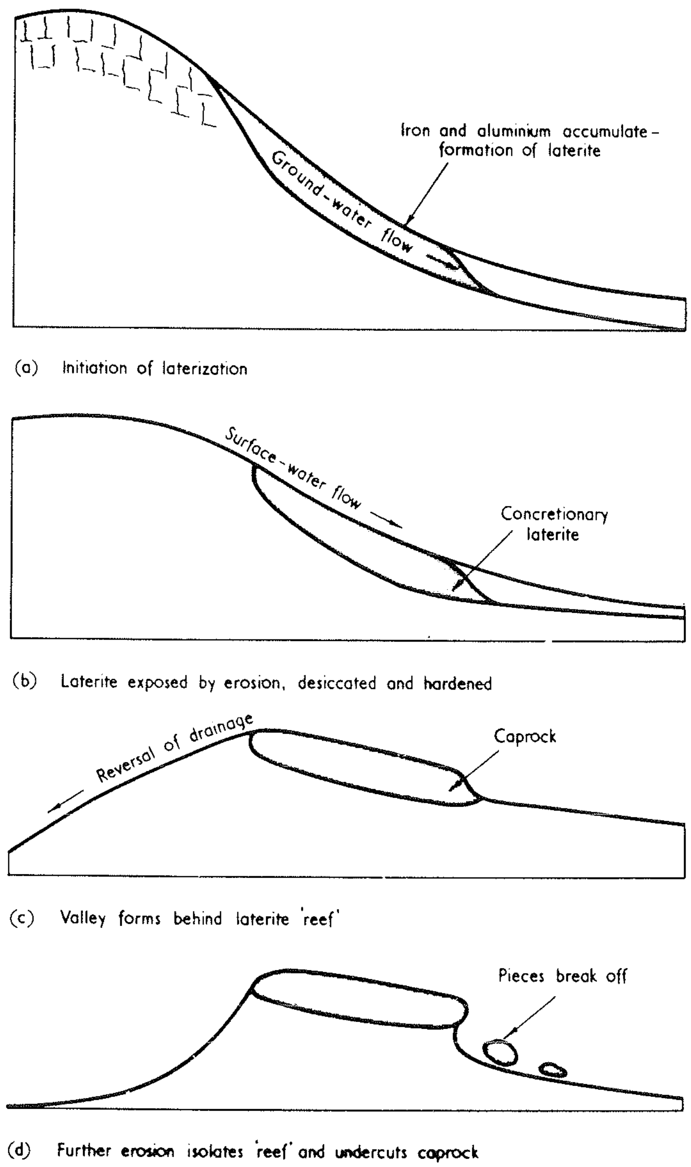

Fig. 5. Laterite Reef Development from a Catenary Soil Association

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laterite as occurring in a zone following the surface contours of the ground at a greater or lesser depth. Figure 6(a) shows a gentle slope down to a stream, with the laterite occurring at the stream edge and at the top of the slope with a pocket of soil preserved in between. Such an association is found on the Basement igneous rocks, which are predominantly of the granitic type. On the younger, metamorphic group of rocks of the Katanga series, the association is shown (Fig. 6(b)), where a flatter-topped hill slopes steeply down to the stream, and the soil cover is preserved over all except the edge of the laterite.

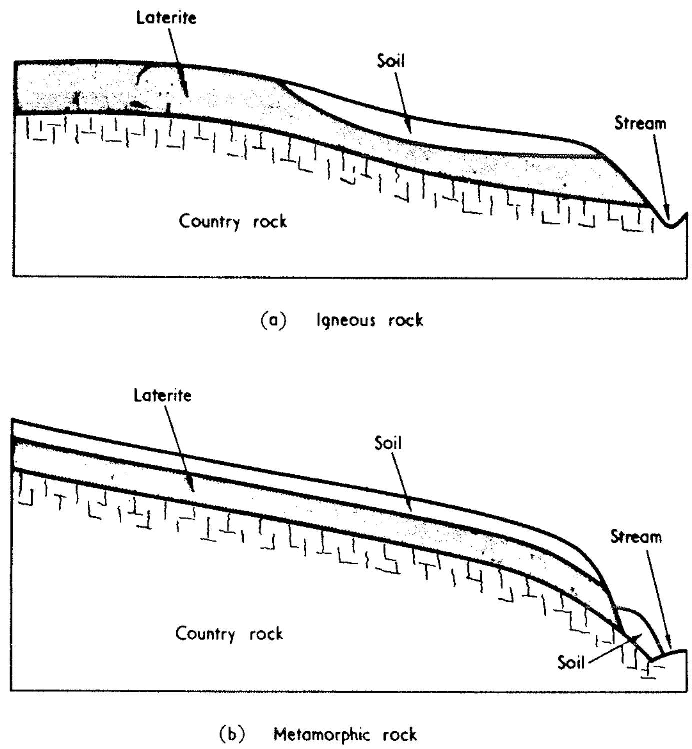

Fig. 6. Topographical forms associated with laterite outcrops in Northern Rhodesia (Ballantyne).

Road performance. Nodular lateritic gravels are widely used in Central Africa, as elsewhere, for gravel roads. In this application they are superior to the quartzitic and detrital gravels in that, having more clay, the surfaces are better bound in the dry season and hence more free from dust. The absence of large boulders makes them easier to handle and to shape with blade graders and one may suspect that the roundness of the nodules gives less tyre wear than do the gravels with sharper stones. The nodular gravels are also used successfully for surfacing runways on airfields carrying scheduled services. An example of this was seen at Fort Jameson in Northern Rhodesia, where grass was being encouraged to grow through a relatively coarse-graded gravel to bind it and resist erosion.

In the wet season, however, the nodular gravels soften more readily than their detrital counterparts and, when all-weather service is needed, practice is to provide a bituminous surfacing which offers protection against rain. In such circumstances, the best of the nodular gravels, i.e. those with the lowest clay contents, can provide satisfactory base materials. Thus three-quarters of the length of the base for the main runway at Lusaka Airport in Northern Rhodesia was constructed in 1951 with nodular lateritic gravel and is still in excellent condition. However, as has been noted, the clay content in some pits can be variable, and this can result in failure of local areas of base, since drying of the gravel is prevented by the bituminous surfacing. In view of the proportion of the cost of a road that is invested in the bituminous surfacing, it has been found to be well worthwhile adding some form of stabilizer to the gravel to raise the lower limit of the strength of the material and insure against base failure. In Northern Rhodesia this has been done very successfully with hydrated lime, as described in Overseas Bulletin No. 9,(16) about 4 per cent being needed with the nodular lateritic gravels. More than 300 miles of bitumen-surfaced main road have been constructed in this way since 1950. Cement has been used, but only on a restricted scale, the only instance known being that of the base for the main runway at Ndola Airport constructed in 1953.

Experiments in Nyasaland have indicated that the technique of lime stabilization can be applied successfully to the nodular laterites encountered there.(30)

Occurring as they do in areas of comparatively high rainfall, the site conditions under which nodular lateritic gravels are used are less advantageous than those under which the other types of gravel are employed. Williams (31) has noted three circumstances in which the advantages of stabilization are particularly applicable to the nodular materials. First, bituminous surfacings are seldom completely impervious so that water can, in practice, penetrate to the base, an observation that is supported by experience in Northern Rhodesia. Secondly, water tends to erode the material at the edge of the bituminous surfacing and enter the base from the side and, thirdly, roads over undulating country may intersect seasonally high perched water-tables, which can lead to wetting of the base material from below. The satisfactory performance of the lime-stabilized nodular laterite roads in Northern Rhodesia suggests that the lime helps on all three scores.

Calcareous gravels. Calcareous analogues of the nodular lateritic gravels were encountered at one point in the Shire Valley in Nyasaland. According to Muir and Stephen(32) these are derived from seepage water flowing from calcareous rocks on the Lupata Hills on the south side of the valley. The gravel appeared to give satisfactory results on a gravel road in the district, and to have most of the advantages of lateritic material, but the nodules did not appear to have such a high mechanical strength.

CRUSHED GRAVELS

It has recently been suggested, particularly from the U.S.A., that crushing offers a means of improving the quality of roadmaking gravels. The materials to which this idea particularly applies are those with larger proportions (say more than 20 per cent) of boulders and stones retained on the 1 - or 1½-in. sieves. Some of the quartz gravels of the Federation are of this type. The principal advantages of crushing are:

(i) By limiting the maximum size of stone, handling and spreading, e.g. by mechanical means, are made easier.

(ii) The grading is made to approach more closely to the "Fuller" curve, desirable in mechanical stabilization, because it increases the stability of the mixture.

(iii) The ratio of the volume of any clay present to the volume of the voids in the sand and silt fraction is reduced, which should reduce the lubricating effect of the clay.

(iv) The angularity of the larger particles is increased, (particularly of alluvial materials) thereby increasing the strength.

There is no doubt that such crushing will improve the quartzitic gravels, making them easier to handle and lay without serious segregation and improving their strength when compacted. The amount of improvement will vary considerably. With some it may be sufficient to convert a marginally suitable gravel into an adequate base material for bitumen-surfaced roads. With others it may not, and the only trial of this must be in field experience.

Stabilization of these gravels with cement or lime involves chemical processes which bind the soil particles together to produce a new material with inherently greater strength and resistance to the weakening effect of water.

Crushing produces no such radical changes in the material. Its effects are entirely physical and their value in terms of increased strength is likely to vary considerably from one sample to another. Where, therefore, the costs of stabilization are similar to those of crushing, the added advantages of stabilization make it the more attractive.

METHODS OF LOCATING GRAVEL DEPOSITS

Most gravel deposits in Central Africa are at present located by teams, which include experienced surveyors who have developed by practice remarkable skill in finding good roadmaking material. Once the general line of a road has been decided, such gravel-prospecting teams take to the field for periods up to several months, living in temporary housing or caravans in the area and using simple testing equipment.

The experience of these surveyors is based on their personal and unrecorded knowledge of three major factors, i.e. (i) the petrology of the rocks they encounter, (ii) the geomorphology (landform) of the countryside, and (iii) vegetation associations with soil. In all three territories, guidance is available from the large-scale maps prepared by the geological surveys and, as might be expected, these give most information about the areas where economic minerals occur. Pedological information is also becoming available through the soil-survey activities of the Federal Department of Agriculture. Thus, a pedological map of Southern Rhodesia is in the press; it recognizes thirty (agriculturally significant) categories of soil, differentiated on the basis of the parent rocks. In Northern Rhodesia, a preliminary soil map of the Copperbelt area has been prepared and has been used by the Roads Department for gravel prospecting. The classification used is based on soil associations. In Nyasaland the small amount of soil-survey work has been limited to the examination of specific problems, for example in the tea- and tung-growing areas of the Shire Highlands and in the Shire Valley.(33)

Surveyors whom the author met during the visit observed that gravel deposits often carried a particular type of vegetation. Thus, in Matabeleland in Southern Rhodesia a small un-named bush is sought, while in Northern Rhodesia the Muzuku tree is used as a gravel indicator. Trapnell and his collaborators(34) have prepared a map of Northern Rhodesia showing areas carrying similar types of vegetation, and the descriptions of the broad textural types of soil associated with them enables the simple engineering map, shown in Fig. 7, to be drawn. More detailed mapping of soil type on the basis of vegetation association may be possible with further research, although it must be recorded that Ballantyne found no such correlation possible in the Copperbelt area, owing possibly to the annual bush fires and shifting cultivation. These limitations would not be expected to apply in more sparsely vegetated and populated areas.

Aerial photography has been used successfully in the location of gravel and concretionary laterite in Nyasaland,(28) and more recently, before the reconstruction of the Great East Road, in Northern Rhodesia. A start has also been made in Southern Rhodesia.(27) The further utilization of this technique will undoubtedly pay considerable dividends, since large areas can be examined with limited effort, yielding information of value in road location, and the design of earthworks, bridges and culverts, as well as gravel location.

To sum up, it appears that information about the location of gravel supplies is available from several sources, but that in any one case all are not exploited to their fullest extent or used in a co-ordinated fashion. At present this is compensated to some extent by the very wide personal experience of the personnel concerned. With the expansion of the country, which will undoubtedly continue, the sparsity of recorded knowledge is likely to restrict the rate of discovery of new resources of road materials. The time would therefore appear to be ripe for the experience of the gravel surveyors to be recorded in manual form, and for studies to be made to extend the usefulness of geomorphological, pedological and botanical observations in gravel location.

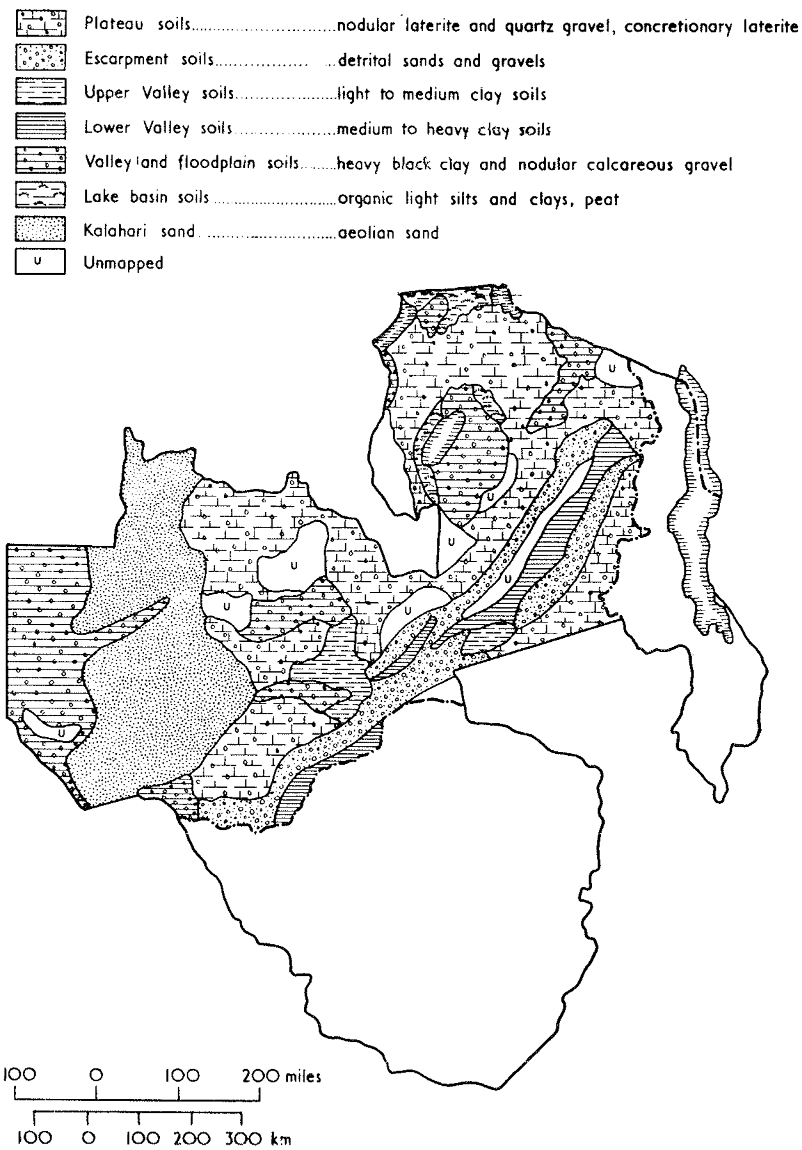

Fig. 7. Distribution in Northern Rhodesia of textural soil types having associations with specific types of vegetation (Trapnell et al).

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DISCUSSION

Proc. Paper 9306

TECHNICAL NOTES

Proc. Paper 9312

[a]Discussion period closed for this paper. Any other discussion received during this discussion period will be published in subsequent Journals.

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Lateritic Gravel Evaluation for Road Construction

By J. W. S. de Graft-Johnson,[1] Harbhajan S. Bhatia,[2] Members, ASCE, and A. A. Hammond[3]

INTRODUCTION

Laterites and lateritic soils are extensively used for road and airfield construction in many countries in Asia and Africa. The presence of such soils over vast areas in the tropics make their use very convenient and economical. Lateritic soils are a product of tropical weathering and they vary in their properties from very soft to extremely hard varieties. The hardness of these materials changes with the continuous cycles of wetting and drying in the profiles. In order to appreciate fully the factors contributing to the hardness of lateritic gravels, some studies in the past had been conducted by Akroyd (2), Novais Ferreira (1), de Graft-Johnson, et al. (8), Vallerga, et al. (21) and Hammond (12). These studies provide some useful data on the mechanical strength of lateritic aggregates and the factors likely to affect their strength. On durability, very little work has so far been done to underline the influence of chemical, thermal, and mechanical factors affecting the disintegration processes in the aggregates. The present investigation is an attempt to study systematically the pedologic and geologic factors responsible for the formation of lateritic gravels in Ghana and to investigate the physical and chemical characteristics likely to affect the durability and mechanical strength of such materials. Field observations are made to study the performance of lateritic gravels in the road pavements, and a simple grouping system,

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based on the physical and mechanical properties in relation to the field performance, is suggested. This grouping will assist the field engineers in selecting materials of appropriate quality, likely to be durable and mechanically stable in the field, ensuring a better performance of the road pavements under traffic.

FORMATION OF LATERITIC GRAVELS

Soils and gravels are the weathering product of rocks, the weathering being influenced by a number of complex factors such as, climate, geology, topography, age, relief etc. Pedology, which is the study of the combined effect of these factors on the process of soil and gravel formations, is being used more and more for the general classification of soils in the tropics. It has now been established by many researchers that soil belonging to the same pedological grouping have generally similar engineering properties.

The more common geological formations associated with gravel formations in Ghana can be divided into the following four groups: (1) Acid Igneous (AI)—Granite, Gneiss, Quartizite; (2) Basic Igneous (BI)—Basalt, Gabro; (3) Metamorphic (Met)—Shale, Phyllite, Schist; and (4) Sedimentary (Sed)—Sand Stone, Lime Stone. The distribution of these formations in Ghana is shown in Fig. 1.

Next to geology, the most important factor in the formation of lateritic soil and gravel is rainfall. West Africa, generally, and Ghana, in particular, can be divided into four climatic regions:

Region	Rainfall
Coastal Savannah	25-30 in./yr
Rain Forest Zone	70-120 in./yr
Forest Zone	50-70 in./yr
Interior Savannah	40-50 in./yr

It has been observed that in areas of high rainfall the weathering of rocks is deep seated and the soils produced are rich in more insoluble minerals such as quartz, mica, sesquioxide of iron and alumina. The properties of such gravels are therefore dictated by the accumulative proportion of these minerals and their state of dehydration in the profile. The effect of parent rock on the nature of the soil formations in such cases is of a secondary nature.

In areas of low rainfall, the rocks weather to relatively shallow depths. The gravel formations in such cases are of detrital nature, maintaining the basic mineral contents and sometimes the structure of the parent rocks. Such gravel, though stained red due to the presence of iron in the profile, have all the basic characteristics of the parent rock. Clare (7) explained the effect of physiographic features on the redistribution of chemical constituents of the weathering rocks due to hydrological factors. The work of Junner and James (15) and Hamilton (11) on Ghana lateritic profiles is also of a considerable interest. Studies recently conducted in Ghana on typical lateritic soils profiles by Gidigasu (10), Bhatia, Gidigasu and Hornsby-Odoi (5), help to appreciate better the factors influencing such formations. As a result of these studies it was possible to propose a Pedogenic-Textural Classification of Ghana Lateritic Soils (10). The present study is concerned only with materials falling in the two main groups of the pedogenic-textural classification namely, laterite rock and boulders and lateritic gravelly materials. The materials belonging to these groups were either residual primary laterities or nonresidual secondary laterites.

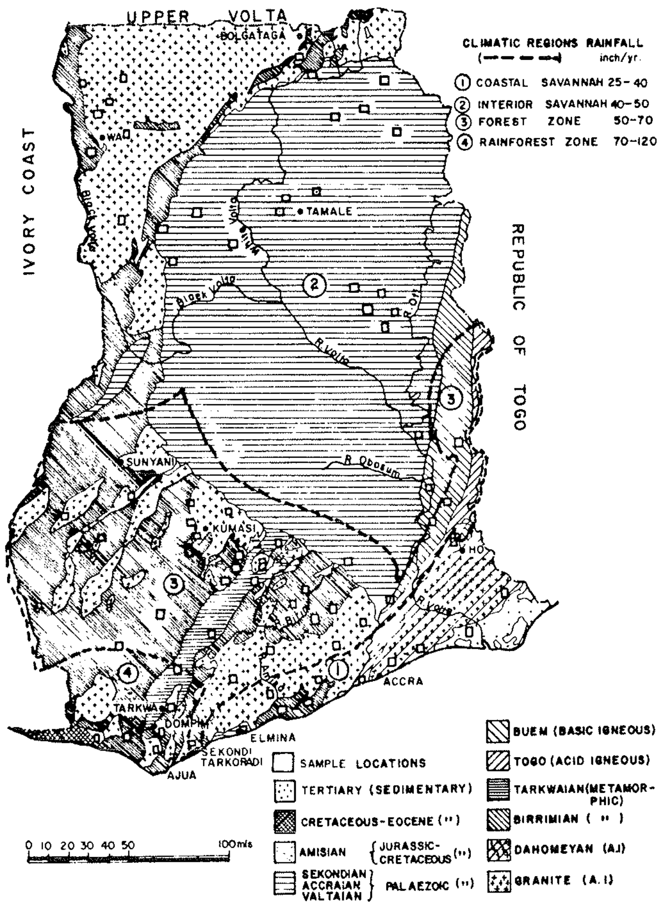

Fig. 1.—Geological Map of Ghana Showing Locations of Samples

The present profile studies in Ghana by the B.R.R.I., indicated the various stages of weathering and formation of lateritic gravels. The two typical profiles in the forest zone of Ghana and their various stages of formation, one over granite and the other over phyllite are shown in Figs. 2 and 3. The first stage in the development of such profiles is the mechanical weathering of rocks, causing cracks in the rocks and producing detrital material. Rainwater together with near-surface agents of weathering (oxygen, carbondioxide and organic acids) use joints and fissures to effect chemical weathering. The major minerals weathering in granite rock are felspar, quartz and mica. Since quartz and mica are very resistant to weathering, they remain virtually unchanged except for the leaching of iron from biotite (mica). During the process of hydrolysis of felspar, silica is dissociated from potash and alumina bases in the presence of water, removed in solution and finally leached away. In addition part of the iron oxide from weathering rock minerals is dissolved in solution at favorable pH values, and deposited at lower slopes in the

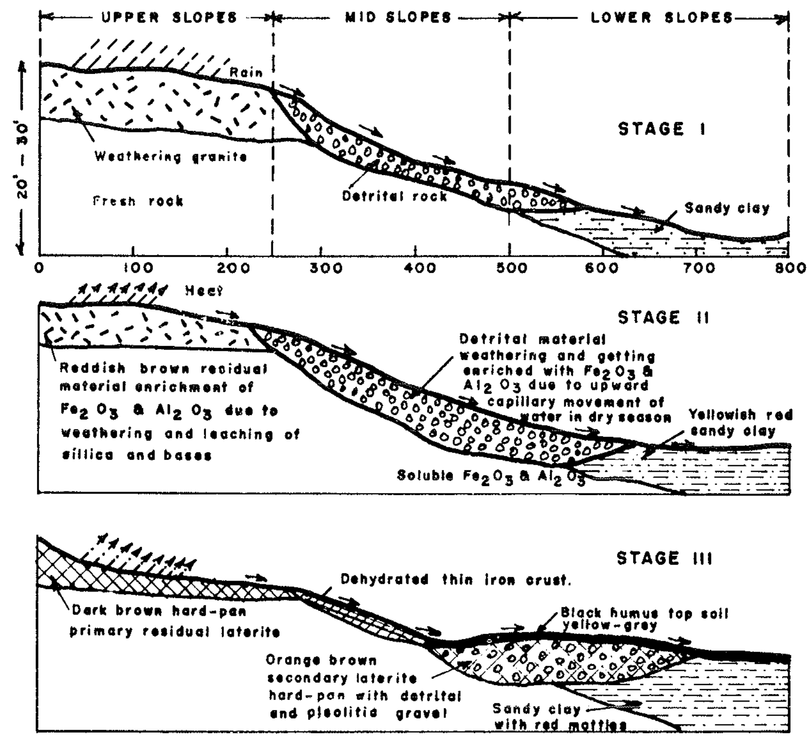

Fig. 2.—Various Stages of Typical Lateritic Soil Profile Formation over Granite, in Rain Forest Zone of Ghana

profile. In the case of phyllite, which is formed initially from clay and silt deposits with secondary minerals such as mica and quartz, the weathering produces fine textured materials with secondary minerals unaffected.

During the second stage of weathering, as a result of dry season, the evaporation from the profile exceeds precipitation. As a result, the dissolved oxides of iron and aluminium in water from the weathering minerals is brought into the upper layers by means of upward capillary movement. These are left behind in the profile as hydrated ferric oxides and alumina, due to the presence of sufficient quantity of oxygen in the upper layers of the soils.

In the third stage, due to dehydration as a result of exposure and continuous dry weather, the residual materials on upper slopes and high grounds turn into iron stone or what is known as cuirasse. Such formations are also termed primary laterites. If the mid and lower slopes are enriched with iron, they turn into hardpans after dehydration. The hardpan layers generally are cemented detrital iron stone and rock particles or highly resistant unweathered minerals like quartz and mica or pisolitic gravels, which have been formed due to the deposition of iron and aluminium oxides over the nucleus of quartz particles. The hardpans and iron stones tend to break down due to mechanical weathering

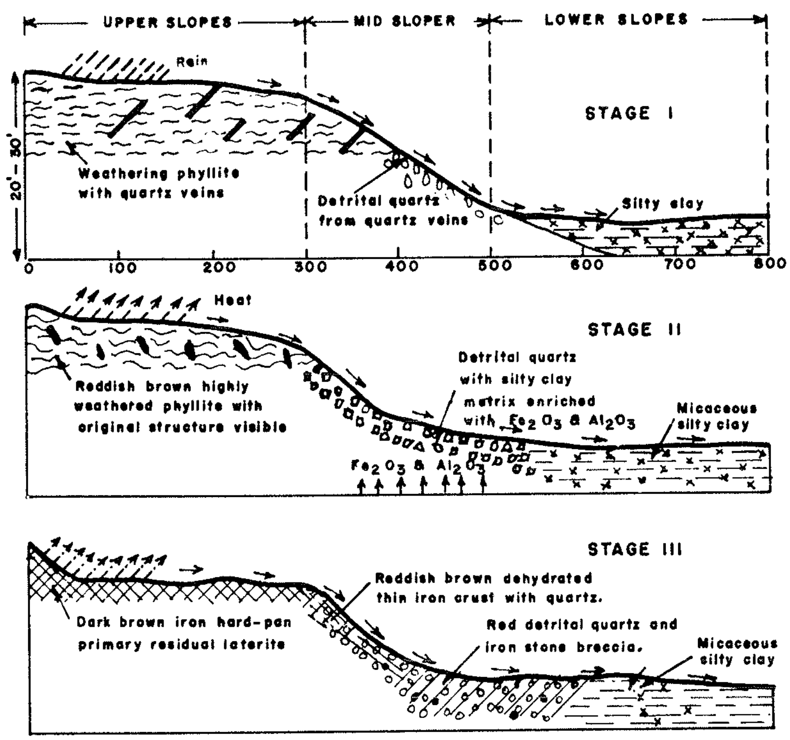

Fig. 3.—Various Stages of Typical Lateritic Soil Profile Formation over Phyllite in Rain Forest Zone of Ghana

with time. With changed drainage pattern and hydrological factors on a site, the weathered materials are deposited on lower slopes.

In the case of interior and coastal savannah zones in Ghana, the same stages of laterization in a profile take place, except that the effect of topography and rainfall is less marked, and the weathering is not very deep-seated, as is the case in forest zone soils. Generally the laterite profiles are relatively shallow in the interior and coastal savannah.

In the interior savannah, a number of lateritic profiles are developed in sedimentary materials deposited recently, such as quartz river gravels and boulders, sands, sandy clays, etc. The iron in such materials is concentrated by the capillary movement of iron rich water from the geological formations below. Such laterized deposits are usually very suitable materials of construction and are abundantly met in the inner savannah. The gravels in such profiles are generally rounded quartz particles stained red due to the presence of iron rich environments in the profile.

The field studies revealed that a large number of factors such as geology, rainfall, topography, relief, etc., were jointly responsible for the formation and mechanical strength of lateritic gravels. It was, however, difficult to assess the degree of influence of each factor in producing certain mechanical properties in the gravels, though the predominant factors influencing the formation of profiles could be clearly identified.

SCOPE OF WORK

About 50 samples of typical gravelly material from four geomorphological regions of Ghana representing various parent rocks were selected for the study. The location of various samples is shown on the Geological Map of Ghana, Fig. 1. The samples selected for the study were sieved to one size, passing 1/2 in. and retained on 3/8-in. sieves. The sieved gravels were washed to get rid of the adhering fine materials before subjecting them to detailed testing. The samples were subjected to the following tests:

1. Physical Tests—Color; specific gravity; water-absorption; flakiness and elongation indices; and angularity number.
2. Chemical Tests (Short silicate analysis)—Loss of moisture 105° C and 900° C; Silica Oxide SiO_2; Ferric Oxide Fe_2O_3; Alumina Al_2O_3.
3. Mechanical Strength Tests—Aggregate Impact Test (Standard) (B.S. 812—1960); and Los Angeles Abrasion Value (ASTM, C 131-64T).
4. Weathering and Durability Tests—Heat treatment; wetting and drying cycles in different pH media; and soundness (AASHO T 10-65).

All the physical tests were performed according to BS. 812-1960 specifications. The test results obtained for the samples were analyzed to examine the predominant factors contributing to the mechanical strength and durability of lateritic aggregates. These are considered later.

PHYSICAL TESTS

Color.—The samples ranged in color, from dark brown through brown, reddish brown to yellowish brown. Generally the hard and matured aggregates were predominantly dark in color while the softer varieties were light in color. The topography of a site had a definite influence on the color of the soil and gravels, at various levels. Generally under humus top soil at the upper slops, the color of the materials was dark brown to deep red. The color changes from orange brown to redish brown at mid slopes and yellowish brown to light red on lower slopes and valleys. The colors tend to reflect the degree of hydration of iron and alumina in the profile, as a result of hydrological factors.

Flakiness, Elongation Indexes and Angularity Number.—The shape of the lateritic gravels studied were rounded, subrounded, angular, elongated and flaky as shown in Fig. 4. Generally the flakiness index (6) was very low in lateritic gravels, except for detrital material, produced from rocks having high mica content, such as phyllites, schists, muscovite granite, etc. There were some samples of lateritic gravels which had high elongation index (6) and these were only pseudo-lateritic gravels, the detrital product of rocks. Such materials were not included in the present study.

Most of the typical lateritic gravel samples studied were either rounded or subrounded, depending on the effect of hydrological factors on the material. There was a small proportion of gravels which tended to be angular and these seeemed to have been produced as detrital material from laterite hardpans. Generally, the angularity number (6) of rock aggregates ranges from zero for very highly rounded aggregates to more than one for freshly crushed angular stones. The angularity number of most of the typical lateritic gravels varied between five and ten.

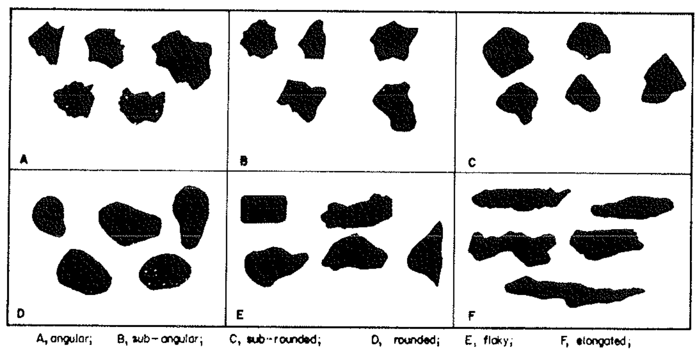

Fig. 4.—Diagram Showing Shape of Laterite Aggregates

Specific Gravity and Water Absorption.—The specific gravity values of lateritic gravels ranged between 2.6 and 3.10, though about 70 % of the samples in the present study showed specific gravities above 2.75. It may be remarked that all samples obtained from high grounds had specific gravity values not less than 2.70, whereas the gravels from mid and lower slopes had wide variation of these values, 2.6-3.0. The samples collected from rain forest zone of Ghana (rainfall above 60 in.) generally showed specific gravity values above 2.70, whereas samples from other regions had the values between 2.6 and 2.9. No clear conclusions could be drawn on the effect of parent rock on the specific gravity of gravels, as the weathered products of any single rock had specific gravity values varying between wide limits.

Twenty-four hour water absorption test was conducted on samples, at room temperature. It was observed that the higher the specific gravity, the lower was the absorption. This is shown in Fig. 5. The maximum absorption in most porous gravel was about 8 %, whereas the minimum values were as low as 1.2 %.

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MECHANICAL PROPERTIES

Aggregate Impact Value and Los Angeles Abrasion Test.—The mechanical strength of aggregates can be assessed by means of several standard tests such as: the Aggregate Impact test, the Aggregate Crushing test, the Ten Per Cent Fines Test, (all BS-812) and the Los Angeles Abrasion Test ASTM-C 131-64T). As the procedure for the Aggregate Impact test is fairly simple

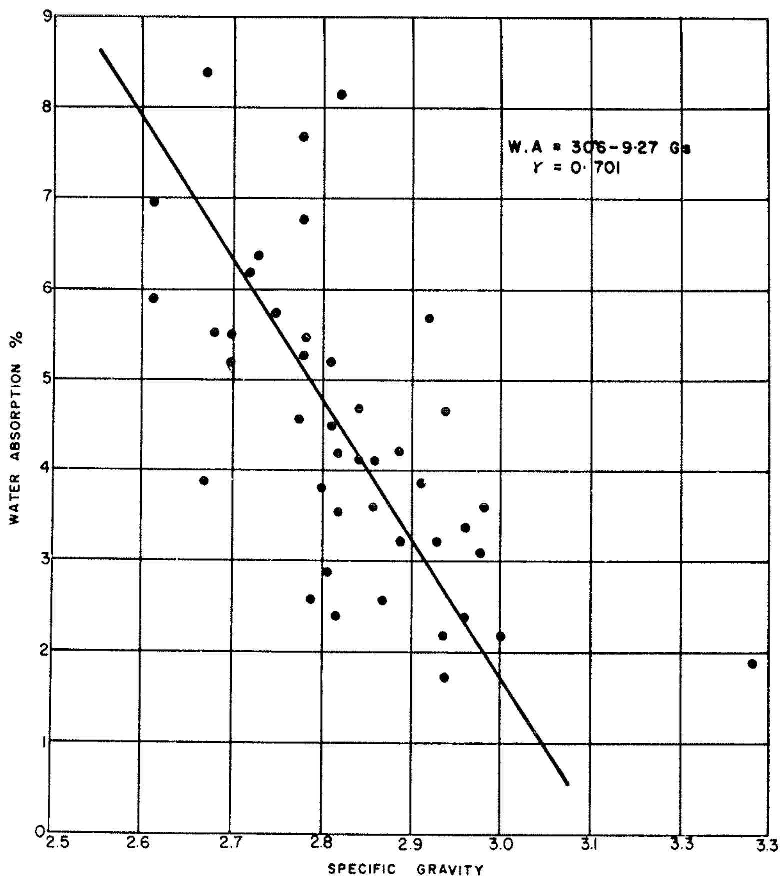

Fig. 5.—Relationship Between Water Absorption and Specific Gravity

and the quantity of sample required is small, the test was preferred over the other tests. However in addition, the Los Angeles Abrasion test was performed on some selected samples for the purpose of comparison. The values of the Aggregate Impact test for the gravels tested ranged between 16.0 % to 60.5 %, though generally matured samples from high elevations gave AIV's well below 40 %.

The Los Angeles Abrasion test was carried out according to standard test procedures. Most of the matured gravels tested in the present study gave LAA values below 50 %. There was significant correlation btween aggregate impact values and Los Angeles Abrasion values. This made it easy to interpret the results of the Aggregate Impact values in terms of the Los Angeles Abrasion test.

CHEMICAL ANALYSES

Chemical analysis on crushed samples of the aggregates were carried out to determine the proportion of iron, alumina and silica contents in the material. Loss in weight at 105° C and loss on ignition at 900° C were also determined.

The chemical analysis of most of the gravels indicated that in fully matured samples from high grounds the silica sesquioxide ratios were low, confirming the concentration of iron and alumina in the profile. In the case of samples obtained from mid slopes and lower slopes, the ratios were relatively higher.

In order to study the effect of geological formations on the chemical nature of lateritic soils, a number of samples from various formations were studied. It was seen that samples of gravel formed over sandstone, quartzite, and in rare cases over phyllites and granite, showed relatively higher concentration of silica (above 60 %) and this indicated that the proportion of various minerals in the parent rock had some influence on the chemical nature of the residual lateritic materials.

As a result of this study it could be remarked that matured gravels with dark brown or reddish brown color on very well drained sites (generally high grounds) had silica sesquioxide ratios less than 2.5. In the case of mid slope gravels, from reasonably drained sites, having reddish brown or yellowish brown colors, the silica sesquioxide ratios were between 2.5 and 6.0. The other gravels partially matured, and obtained from poorly drained areas, had sesquioxide ratio's above 6.0. It was, however, difficult to draw any definite conclusions on the range of ratios of silica to iron and silica to alumina for gravels obtained from various elevations.

It may be pointed out that, due to the presence of free quartz as nucleus in many hard nodular gravels, high silica sesquioxide ratios were recorded. This was due to the crushing of quartz nuclei during the preparation of the samples. Many such gravels were very matured and showed very high mechanical strengths. The silica sesquioxide ratio in such samples gave a false impression of lack of maturity.

WEATHERING AND DURABILITY

Effect of Heating on Strength.—As the process of dehydration of iron in the profile plays a significant role in developing strength in lateritic gravels, it was considered interesting to heat typical samples of gravel in the laboratory to temperatures of 105° C to 110° C, for periods varying between 2 days to 60 days. After each period of heating the samples were tested for Aggregate Impact values. The typical samples selected for the study were those which were not very matured. The results of the study are shown in Fig. 6. It would be seen in the figure that most of the samples from interior savannah showed a tendency to improve in strength as a result of heating. The improvement in mechanical strength of such samples ranged between 14 % to 21 %.

Effect of Environment Conditions.—To understand the effect of environmental conditions on the strength of lateritic gravels, five typical samples from two regions of Ghana were selected. These samples were subjected to three cycles of wetting in solutions of varying pH media, and to drying in an oven at 105° C to 110° C. The pH media selected were 5.5, 7.0 and 9.5, and the soaking period in each cycle was for 16 hr.

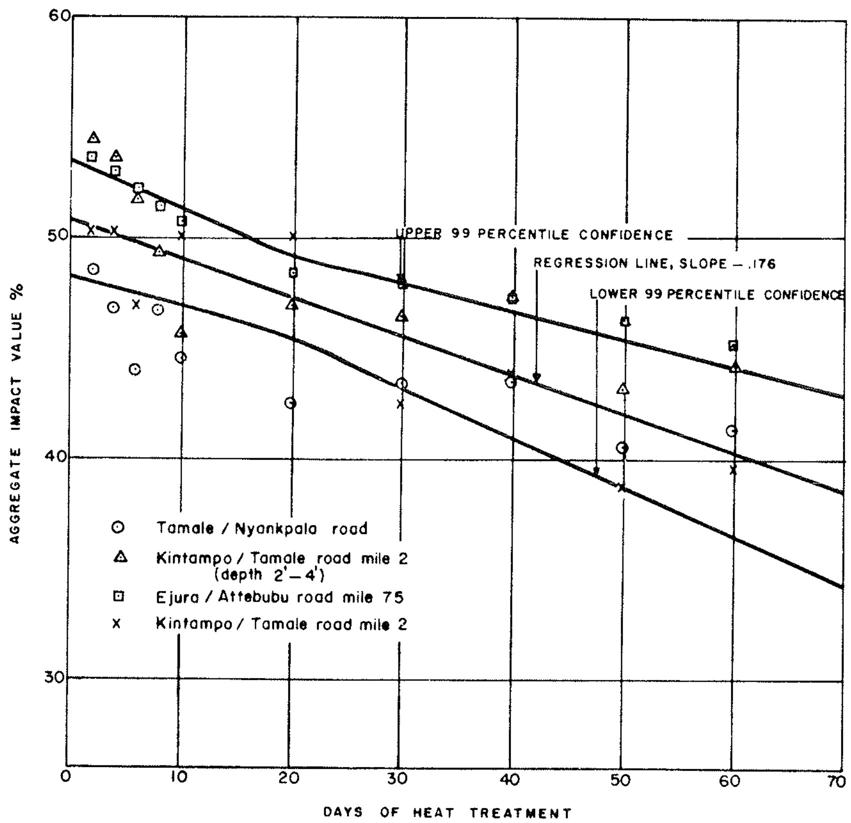

Fig. 6.—Relationship Between Aggregate Impact Values and Cycles of Heat Treatment

The samples after the soaking period were dried to constant weight in an oven, before subjecting them to Aggregate Impact test. No conclusive results were obtained in the study. Detailed work is in progress on the effect of environments on the chemical weathering of laterites.

Soundness.—In studying the durability of aggregates, the soundness test was carried out according to AASHO T 10-65 standards. The samples were immersed in a saturated solution of sodium sulphate for 16 hr and dried at temperature of 105° C to 110° C to constant weight.

As the test was carried out on single sized aggregates the results were assessed only qualitatively by inspecting each aggragate piece to find out the extent of damage done on individual particle. The number of samples which showed cracked surface or chipped material on the surface, were separated and considered affected by the test. The results were expressed as the percentage of the affected pieces to the total number of aggregates in each test. It was noted that sodium sulphate solution had relatively very little effect on matured samples from the forest zone of Ghana as compared to less matured samples from inland savannah. The inland savannah samples had generally 16 % to 21 % gravel pieces, not meeting the requirements of soundness test.

STATISTICAL ANALYSIS OF RESULTS

In order to appreciate what factors are responsible for giving the lateritic gravels certain physical and mechanical properties, statistical analysis was carried out, using IBM Computer 1620-II, to correlate the various physical and chemical properties with the mechanical strength. Very significant correlations were established between these properties and some of the correlations tend to show the close interdependence of these properties on each other.

Physical Properties and Mechanical Strength.—There was significant correlation between the water absorption and the specific gravity of laterite gravels. In addition, correlations existed between Aggregate Impact and Los Angeles Abrasion values with specific gravity and water absorption. The plotted values are shown in Figs. 7 to 9. Some of the statistical correlations between the various properties can be represented by the following equations:

WA = 10.60 − 9.27 Gs with correlation coefficient value r of 0.701 . . . . . (1)

AIV = 315 − 100 Gs with r value of 0.727 . . . . (2)

LAA = 327 − 100 Gs with r value of 0.716 . . . . (3)

AIV = 6.25 WA + 4.38 with r value of 0.849 . . . . (4)

LAA = 6.25 WA + 15.15 with r value of 0.830 . . . . (5)

LAA = 0.95 AIV + 11.6 with r value of 0.810 . . . . (6)

In the preceding statistical correlations WA = the water absorption; Gs = the specific gravity; AIV = the Aggregate Impact Value; and LAA = the Los Angeles Abrasion value.

In order to compare the results of this study with some of the results reported in an investigation on Indian lateritic gravels by Nanda and Krishnamachari (19), the results of specific gravity values of Indian laterites were plotted against their Aggregate Impact Values and Los Angeles Abrasion values. The plotted data are also shown in Figs. 7 and 8, along with the values obtained on gravels in the present study. The results of the two studies were fairly comparable. This tends to suggest that the basic statistical correlations developed in Ghana are likely to be applicable in a general way to laterites from other parts of the world.

These statistical correlations also suggest that higher the specific gravity the lesser the water-absorption and better the mechanical strength of aggregates.

The highest specific gravity value of 3.10 recorded in this study, had correspondingly the lowest values of AIV and LAA, 16.0 and 28.81, respectively. From these relationships, it is possible to predict with some degree of accuracy the mechanical strength of gravels using simple physical tests, such as specific gravity and water absorption.

Significant correlations also existed between Aggregate Impact Values and Los Angeles Abrasion values, for laterite gravels of Ghana. The test results of Ghana samples along with the results obtained by Nanda and Krishnamachari

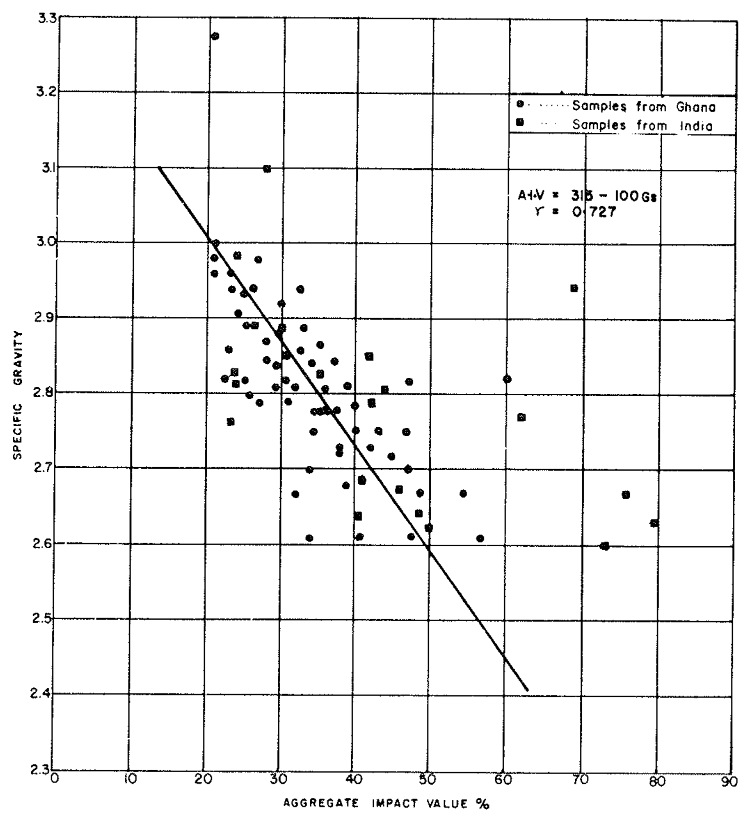

Fig. 7.—Relationship Between Specific Gravity and Aggregate Impact Values

(19) on Indian lateritic soils are plotted in Fig. 10. In Fig. 10 the regression curve for samples from India was different from that of Ghana, and the correlation coefficient for Indian samples was rather poor. As the specific gravity values of some of the Indian samples were as high as 4-5, it could be assumed that all the samples included in the Indian study were not typical lateritic gravels, but only pseudo-lateritic materials or iron rock.

Chemical Nature and Mechanical Strength.—Statistical relations were also established between various chemical properties and the mechanical strength,

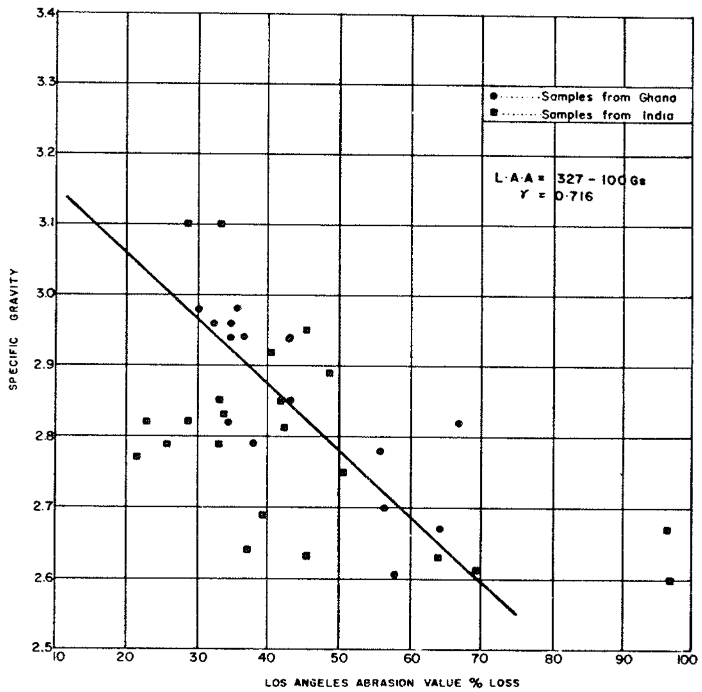

Fig. 8.—Relationship Between Specific Gravity and Los Angeles Abrasion Value

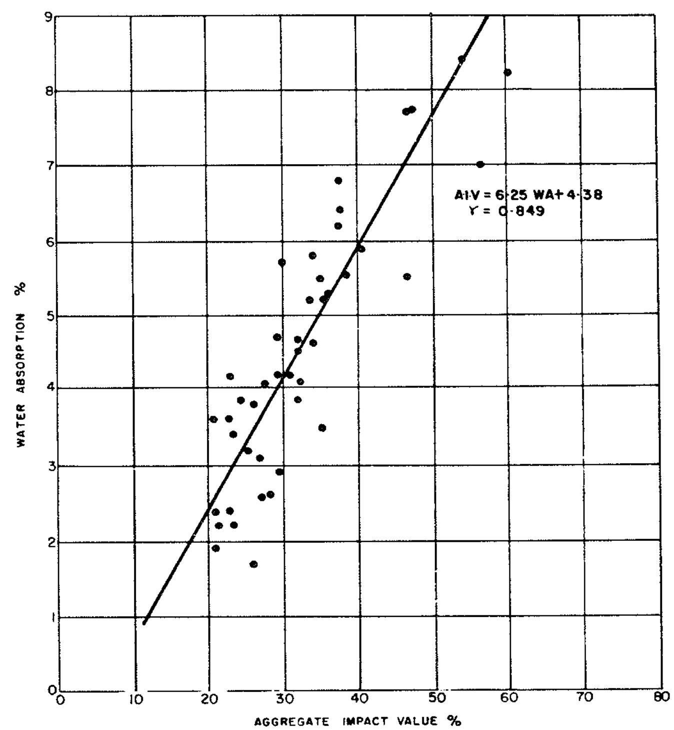

Fig. 9.—Relationship Between Water Absorption and Aggregate Impact Value

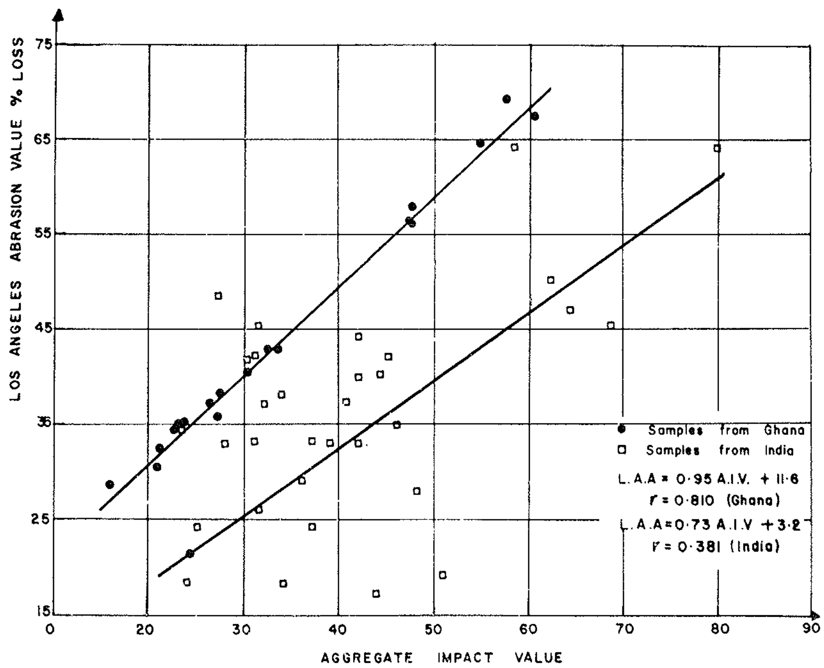

Fig. 10.—Relationship Between Aggregate Impact Value and Los Angeles Abrasion Values

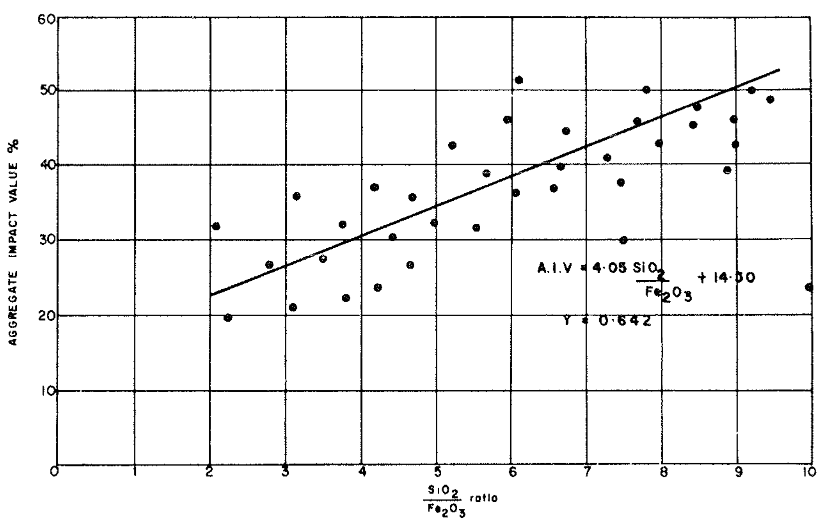

Fig. 11.—Relationship Between Aggregate Impact Value and SIO_2/Fe_2O_3

such as the Aggregate Impact values. These are plotted in Fig. 11. There was significant correlation between the ratio of oxides of silica to iron and the mechanical strength of the aggregates, and this is represented by

$$AIV = 4.05\frac{SiO_2}{Fe_2O_3} + 14.50 \text{ with } r \text{ value of } 0.642 \quad (7)$$

No correlations were found to exist between the ratios of silica to alumina

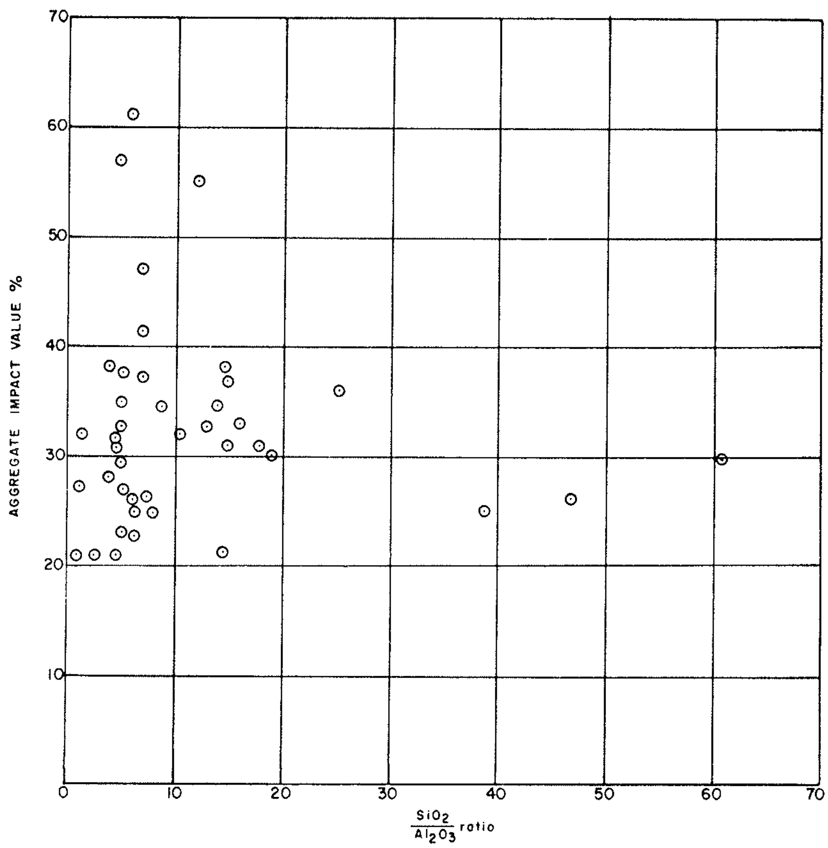

Fig. 12.—Relationship Between Aggregate Impact Value and SiO_2/Al_2O_3

or silica sesquioxide and the mechanical strength (Figs. 12 and 13). It could therefore be concluded that iron contributes considerably to the strength of lateritic gravels, whereas alumina plays relatively insignificant part in the development of strength.

Field Performance.—As a result of the earlier studies carried out by de Graft Johnson, et al. (8) and the present investigations supported by field data on road pavement performance, a relative rating of lateritic gravels is suggested. The four ratings suggested are: excellent, good, fair and poor.

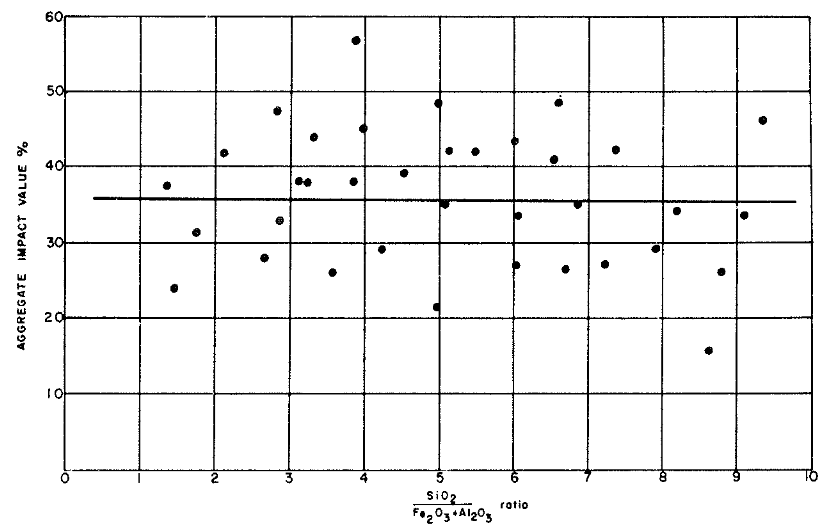

Fig. 13.—Relationship Between Aggregate Impact Value and $SiO_2/(Fe_2O_3 + Al_2O_3)$

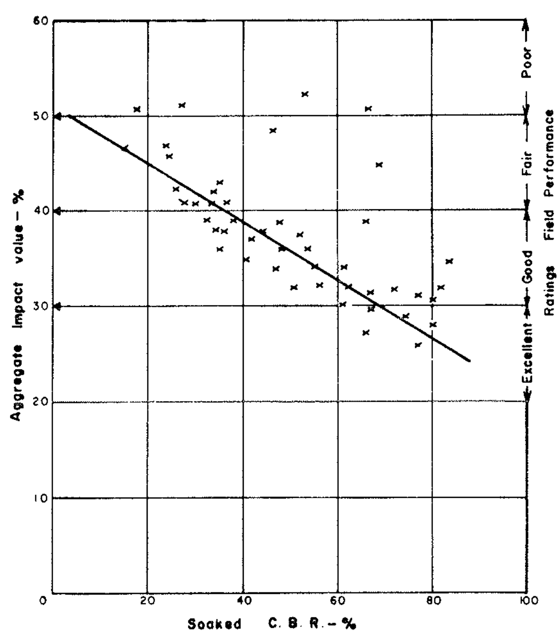

Fig. 14.—Correlation Between C.B.R. Values of Whole Base Material and AIV of Coarse Lateritic Gravel Fractions from Trunk Road Failure Studies in Ghana.

Table 1.—Range of Various Properties of Four Groups on Basis of Performance

Tests (1)	Excellent (2)	Good (3)	Fair (4)	Poor (5)	Source (6)
Aggregate Impact value (modified)	<20	20–30	30–40	>40	Ref. 8
Aggregate Impact value (standard)	<30	30–40	40–50	>50	Present study
Los Angeles Abrasion value	<40	40–50	50–60	>60	Present study
Water-absorption (24 hr)	<4	4–6	6–8	>8	Present study
Specific gravity	>2.85	2.85–2.75	2.75–2.58	<2.58	Present study

Field investigations were carried out recently in Ghana to study the general performance of lateritic gravels in the road pavements. In order to limit the scope of the study to only gravelly soils, materials having more than 50 % gravel content (particles 3/16 in.) were collected from base and subbase layers of road pavements and their physical and engineering properties correlated with field performance. The samples were collected from sections of the road pavements the performance of which could be described as excellent, good fair or bad on the basis of subjective performance rating. The base samples were also subjected to moisture-density and CBR tests, and their coarse fractions tested for aggregate impact values.

Hammond (12) observed earlier that generally soils having weak lateritic gravel fractions tend to break down during compaction in the laboratory and their gradings change towards finer fractions. During the failure investigations on trunk roads of Ghana, it was noted that road sections showing signs of distress had high proportion of fines in their base materials (74 % of the samples had 16 % to 28 % fractions passing No. 200 ASTM Sieve). Most of the failure studies were carried out on trunk roads. As most of these roads were constructed under reasonably controlled conditions and were preceded by detailed material investigation it was considered that the base materials used might have satisfied specification requirements and therefore initially did not have such high fine contents. The fines therefore seem to have increased during the construction and afterwards due to the breakdown of the coarse lateritic gravel.

It was also observed that the soaked CBR values of base samples were generally low, where the coarse gravel fractions were of poor quality. An interesting correlation between the CBR values of the base materials and the aggregate impact value of the coarse fractions emerged for the samples tested during the failure studies, and this is shown in Fig. 14. Generally factors like gradation, plasticity of fines have more significant effects on the value of CBR of a material than aggregate hardness. However, the correlation tends to support the hypothesis of aggregate breakdown and, therefore, change in gradation when aggregate impact values are high, leading to low CBR values.

As a result of the field assessment of the relative performance of various pavement sections, the CBR values of base material, and the Aggregate Impact values of coarse fractions in base material, a rating of the lateritic gravels is proposed. This is shown in Fig. 14 and Table 1. According to these ratings gravels having AIV's more than 50 were considered highly undesirable for road pavements. Gravels with AIV's between 40 and 50 showed fair performance, but were not usually satisfactory. All materials with AIV's below 40 were either excellent or good and their performance in the field as pavement material was quite satisfactory. Table 1, in addition, gives the Los Angeles Abrasion values, water absorption and specific gravity ranges of the proposed four groups of lateritic gravels.

CONCLUSIONS

1. A study was undertaken to investigate the factors responsible for the formation and mechanical strength of coarse laterite gravels of Ghana. The

study showed that topography and geology had considerable influence on the mechanical properties of residual materials. The primary residual gravels from well drained profiles generally had high concentration of iron and alumina, as a result of the leaching of more soluable minerals in a favorable pH medium. Rocks having high concentration of iron and aluminium minerals generally aid in forming lateritic gravels of relatively better mechanical strength.

2. The physical properties such as specific gravity and water absorption were also influenced by the topography and geology. All well drained lateritic gravels showed specific gravity values relatively higher. The typical lateritic gravels had generally low flakiness and elongation indices. Their angularity numbers were also low. The detrital materials either from the parent rocks (only stained red due to iron in the profile) or from high ground hardpans were, in some cases, flaky, elongated and angular.

3. The chemical analysis of the typical samples indicated that primary high ground gravels and few matured midslope gravels had silica sesquioxide ratio of less than 2.5. Most of the midslope gravels had the ratio between 2.5 and 6.0. Gravels from poorly drained sites at lower slopes had silica sesquioxide ratios above 6.0. In certain cases, very high silica sesquioxide ratios were also recorded because of free quartz in the samples, which was difficult to separate at the time of the preparation of samples.

4. The mechanical strength of aggregates was assessed by using the Aggregate Impact test and Los Angeles Abrasion test, which showed fair correlation between their values. It was further noted that for matured lateritic gravels from high grounds, the AIV's were generally less than 40, thereby showing that the mechanical strength was reasonably high. The LAA values for similar samples were usually below 50 %.

5. The effect of heating immature gravel samples from mid and lower slopes at temperature of 105° C to 110° C, was to improve their mechanical strength. The soundness test indicated that matured samples from high rainfall forest zone, showed no effect of sodium sulphate solution, whereas samples from coastal and inland savannah showed definite deteriorating effect.

6. The statistical analysis indicated significant statistical correlations between the various physical properties of the gravels, particularly, physical characteristics such as specific gravity and water-absorption with the mechanical strength. It was also noted that the ratio of SiO_2 to Fe_2O_3 had very significant correlation with the mechanical strength, though no such correlation seemed to exist between the ratios of SiO_2 to Al_2O_3 and silica sesquioxide. This indicated that iron plays relatively more significant role in the development of mechanical strength in lateritic gravels than alumina.

7. As a result of the laboratory studies and the field behavior of lateritic gravels in the road pavements, it was possible to divide the lateritic gravels into four groups. The four groups were evolved on the basis of the physical, and mechanical properties of gravels, in relation to their field performance. The four groups provide a general rating of performance in the pavements: excellent, good, fair and bad.

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APPENDIX I.—REFERENCES

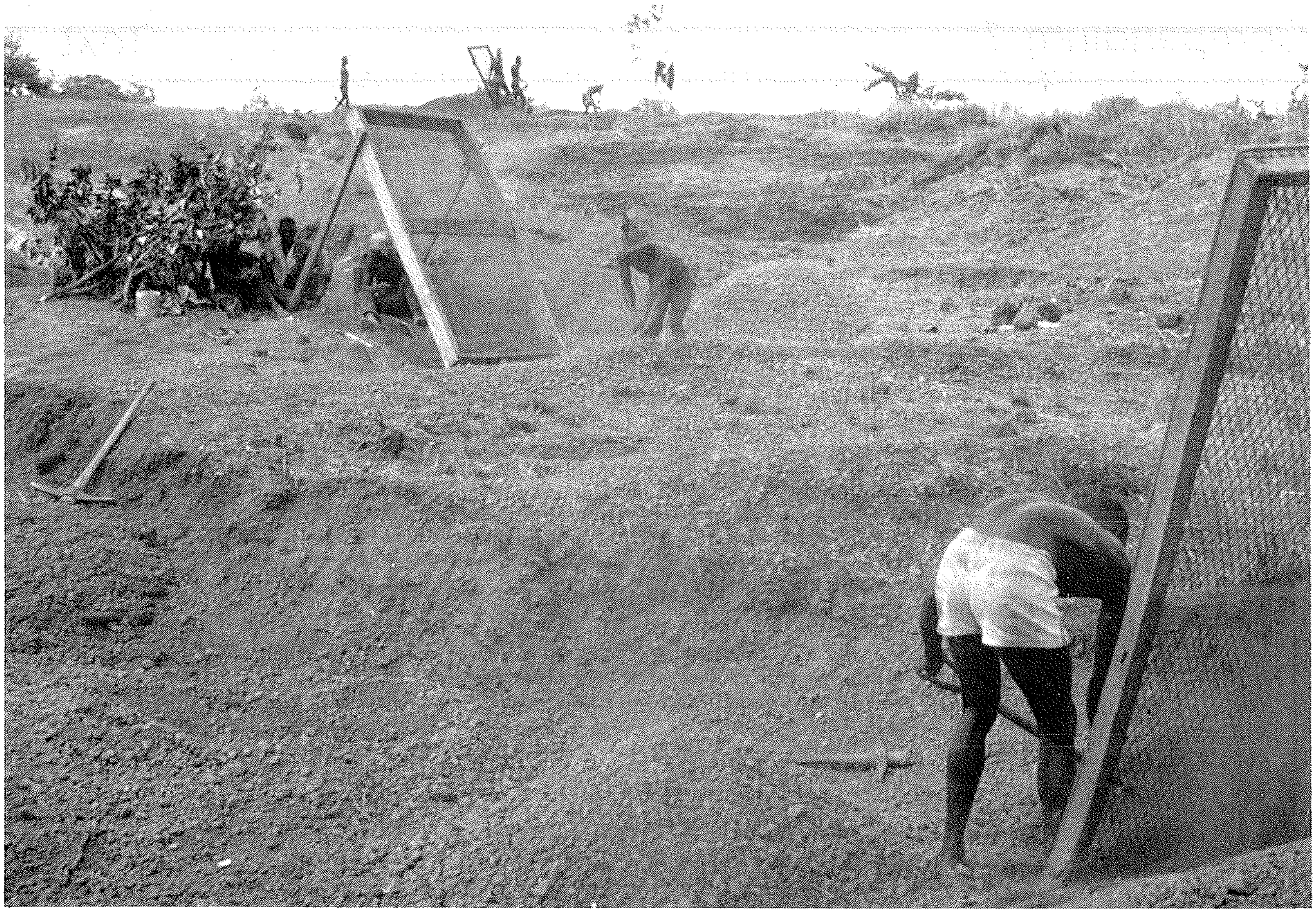
1. "AASHO Designation: T 104-65" *Highway Materials*, American Association of State Highway Officials, Part II Tests, 9th ed., 1965, pp. 460-464.
2. Ackroyd, L. W., "Notes on the Crushing Strength of Some Western Nigeria Concretionary Gravels and Their Selection for Use as Building Material," *Technical Note No. 6*, Ministry of Transport, Western Nigeria, 1960.
3. "ASTM Designation: C.131-64T" *American Society of Testing Materials*, 1964.
4. Bhatia, H. S., Gidigasu, M. D., and Hornsby-Odoi, A. G., "Impportance of Soil Profiles in Engineering Studies of Ghana Soils," *Project Report S.M. 8 (1970)*, Building and Road Research Institute, Kumasi, Ghana.
5. Brian Wills, J. ed. *Agriculture and Land Use in Ghana*, Oxford University Press, Oxford, England, 1962.
6. *British Standard Specifications No. 812* 1960, pp. 84.
7. Clare, K. E., "Road Making Gravels and Soils in Central Africa," *Overseas Bulletin No. 12*, D.S.I.R. Road Research Laboratory, London, England, 1960.
8. de Graft-Johnson, J. W. S., Bhatia, H. S., and Gidigasu, M. D. "The Engineering Characteristics of the Laterite Gravels of Ghana," *Proceedings of the Specialty Session on Engineering Properties of Lateritic Soils*, Vol. 1, Seventh International Conference on Soil Mechanics and Foundation Engineering, Mexico City, Mexico, 1969.
9. Evans, E. A. "A Laboratory Investigation of Six Lateritic Gravels from Uganda," *Research Note RN/234/EAE*, Road Research Laboratory (Department of Scientific and Industrial Research), 1958.
10. Gidigasu, M. D. "The Highway Geotechnical Properties of Ghana Soils," *thesis* presented to the State Technical University at Warsaw, Poland, in 1969, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
11. Hamilton, R. "Microscopic Studies of Laterite Formation in Ghana," *Soil Micromorphology*, A. Jongerius ed., Elsevier, Amsterdam, the Netherlands, 1964, pp. 269-278.
12. Hammond, A. A. "A Study on the Engineering Properties of some Gravels from Kumasi District," *Project Report No. S.M.5*, Building and Road Research Inst., Kumasi, Ghana, 1970.
13. Henry, J. K. M., and Grace, H. "The Incorporation of Decomposed Granite in the Design and Construction of Pavements in Hong Kong," *Proceedings*, 2nd International Conference S.M.F.E. Rotterdam, Netherlands, Vol. 4, 1948, pp. 190.

14. Irwin, M. J. "A Laboratory Investigation of the Resistance to Crushing of Some Tropical Gravels and Aggregates," *Research No. RN/3489/MJI* Road Research Laboratory (Department of Scientific and Industrial Research), 1959.
15. Junner, N. R. and James, T. "Chemical Analysis of Gold Coast Rocks, Ores and Materials," *Bulletin No. 15*, Ghana Geological Survey, 1947.
16. Kennedy, J. G., Collins, J. G. and Smith, M. H. "Moisture Strength Characteristics of Selected Soils in Thailand," *Analysis and Application of Data; Technical Report No. 3-791*, Vol. 1, U.S. Army Engrs., Waterways Experiment Station, Vicksburg, Miss., Aug., 1967.
17. Laterite and Lateritic Soils, and Other Problem Soils of Africa," *Report AID/csd-2164*, Engineering Study of U.S. Agency for International Development, 1971.
18. Mason, B. "Principles of Geochemistry," Third Ed., John Wiley & Sons. Inc. New York, N.Y., 1966, pp. 166-168.
19. Nanda, R. L. and Krishnamachari, R., "Study of Soft Aggregates from Different parts of India with a View to their Use in Road Construction," *Road Research Paper No. 15*, Central Road Research Institute, Delhi, India, 1968.
20. Novais-Ferreira, H., and Correia, J. A., "The Hardness of Lateritic Concretions and its Influence in the Performance of Soil Mechanics Tests," *Proceedings, Fifth International Conference on Soil Mechanics and Foundation Engineering*, Vol. 1, Montreal, Canada, 1965, pp. 82-86.
21. Vallerga, B. A., Shuster, J. A., Love, A. L., and Van Til, C. J., "Engineering Study of Laterite and Lateritic Soils in Connection with Construction of Roads, Highways and Airfields," *Contract No. AID/csd-1810*, U.S. Agency for International Development, 1969.

APPENDIX II.—NOTATION

The following symbols are used in this paper:

AI = acid igneous rocks;
AIV = aggregate impact value;
Al_2O_3 = alumina;
BI = basic igneous rocks;
Fe_2O_3 = ferric oxide;
LAA = Los Angeles Abrasion value;
Met = metamorphic rocks;
r = correlation coefficient;
Sed = sedimentary rocks; and
SiO_2 = silica.



Screening lateritic gravel for road surface in Ghana.

LATERITE AND LATERITIC SOILS AND OTHER PROBLEM SOILS OF THE TROPICS

AN ENGINEERING EVALUATION AND
HIGHWAY DESIGN STUDY FOR
UNITED STATES AGENCY FOR
INTERNATIONAL DEVELOPMENT

AID/csd 3682

by W.J. MORIN
PETER C. TODOR

VOLUME I I

INSTRUCTION MANUAL

LYON ASSOCIATES INC.
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ROAD RESEARCH INSTITUTE
BRAZILIAN NATIONAL HIGHWAY DEPARTMENT
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CHAPTER 6

MATERIAL AND CONSTRUCTION SPECIFICATION

Specifications are used to insure proper construction and to minimize or eliminate all basis for disputes between designers and contractors. Ideally, specifications should be used as a guide, for both the engineer and contractor in the performance of work outlined in the contract documents.

SPECIFICATIONS FOR SUBBASE; BASE AND SURFACE COURSE MATERIALS

Subbase and Base Courses

Recommended specifications for subbase and base course materials are given in Table 6.1. Six classifications of base course materials are shown in the table. The required base classification is determined by the design period which is the accumulated equivalent standard axle loadings in both directions (single lane design) used in the design computations. The six classifications also provide efficient use of available materials since thickness requirements are dependent upon the CBR of the component layers.

Limits for grading and Atterberg limits are shown for each classification. These are used as criteria in construction control testing. If a surface treatment is used in design it is recommended that the durability requirements given for surface course materials be included in the specifications for the base course material.

The design CBR is determined by a statistical analysis of samples obtained from the proposed borrow area. An illustrated example is shown in Figure 6.1. The percentage of the samples greater than a given CBR value is computed and plotted as shown on the lower right of Figure 6.1. An acceptable practice of selecting an appropriate CBR value is that which corresponds to a 90 percent confidence limit, i.e., the CBR value where 90 percent of all samples tested are greater than the selected value. For statistical purposes the minimum number of tests is 6. However, more tests may be required to evaluate a given borrow area. The number required would depend upon variations in the material and size of the borrow pit. In the illustrated example the CBR would be 55 or a Class VI base course. An alternative would be to use "selective" excavation which would eliminate areas exhibiting the lower CBR values. The borrow area would then receive a higher classification.

Determination of CBR Values

A common practice is to soak the CBR sample for four days prior to testing. The reasoning is that the CBR should be determined at the worst possible condition that will exist during the design period. In high rainfall regions such a pretreatment prior to testing is warranted. The in-situ moisture contents within the various component layers were examined in Brazil. Figures 6.2 and 6.3 show the relationship between optimum moisture content at AASHO Modified compaction and in-situ moisture content for base, and subbase layers. The annual rainfall has been indicated for the individual test sections. Examination of these plots shows that the in-situ moisture content of the base materials does not exceed the optimum moisture content of the material until the annual rainfall exceeds 1500 mm. The in-situ moisture content of the subbase materials does not exceed the optimum moisture content of the material until the annual rainfall exceeds 800 mm. Figure 6.4 shows the relationship between annual rainfall and coefficient of equilibrium moisture content (c) for the subgrade materials. The equilibrium moisture content represents the amount of moisture the soil can accumulate which in subgrades under pavements is close to the plastic limit. The coefficient of equilibrium moisture content relates the plastic limit to the equilibrium moisture;

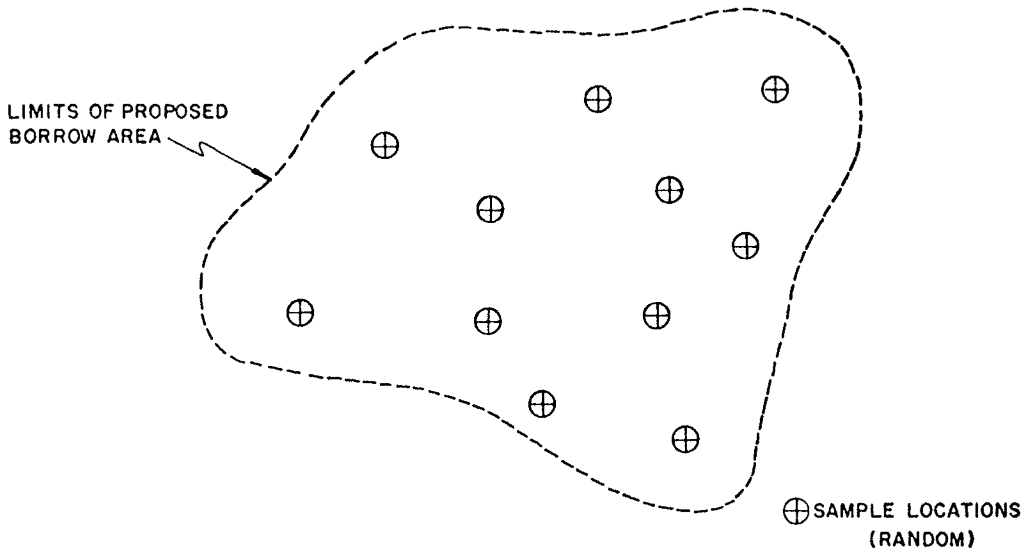
Equilibrium moisture = (c) (PL) .... (6.1)

The band in Figure 6.4 represents the range of moisture contents which should be considered in the determination of the design CBR of the subgrade. Table 6.2 gives the range of moisture contents to be used in examining the CBR value of the respective layers for design purposes.

TABLE 6.1
Specifications, Base and Subbase Materials

Criteria	Base Classification I	II	III	IV	V	VI	Subbase
Design CBR	+100	90	80	70	60	50	25 - 40
Maximum traffic AESALBD	10^7	10^7	10^7	2×10^6	9×10^5	5×10^5	–
Gradation	1	1	1	2	2	2	3
Maximum LL X (-200)	600	900	900	900	1250	1250	1600
Maximum PI X (-200)	200	400	400	400	600	600	800
Maximum Granularmetric Modulus	490	525	550	580	600	615	630

AESALBD – Accumulated Equivalent Standard Axle Loadings in Both Directions
Granularmetric Modulus – Percent passing 1, 3/4, 1/2, 3/8, 4, 10, 40, 200 – sieves.

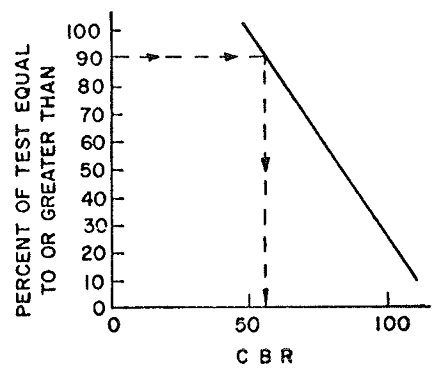


RESULTS OF LABORATORY TESTS

CBR = 50-60-65-70-75-80-80-90-90-90-110

STATISTICAL TEST

CBR	NUMBER	PERCENT ≥
50	11	100
65	9	82
70	8	73
75	7	64
80	6	55
90	4	30
110	1	9



CBR = 55 ~ CLASS VI

FIGURE 6.1 – CLASSIFICATION OF BASE COURSE MATERIAL

TABLE 6.2
Recommended Moisture Range for Evaluation of Design CBR Values

Structural Layer	Annual Rainfall <800 mm 30 in	Annual Rainfall 800 to 1500 mm 30 to 60 in	Annual Rainfall >1500 mm 60 in
Base	OMC	OMC - 1.25 OMC	4 day soak
Subbase	OMC	OMC - 1.5 OMC	4 day soak
Subgrade	0.4 - 0.6 PL	0.7 - 1.2 PL	0.9 - 1.5 PL

Conditions: Water table at least 1 meter below pavement surface and good surface drainage.

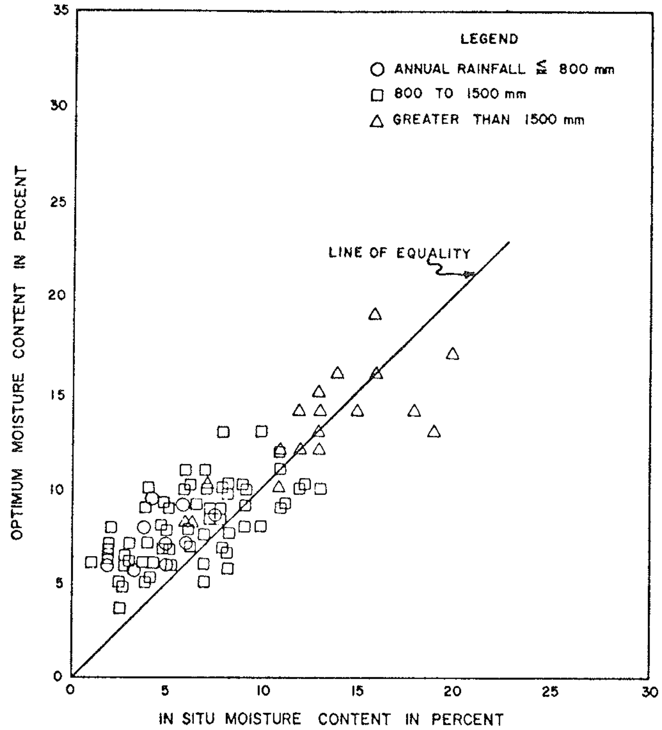


FIGURE 6.2 – RELATIONSHIP BETWEEN OPTIMUM MOISTURE CONTENT AND IN SITU MOISTURE CONTENT – BASE COURSES

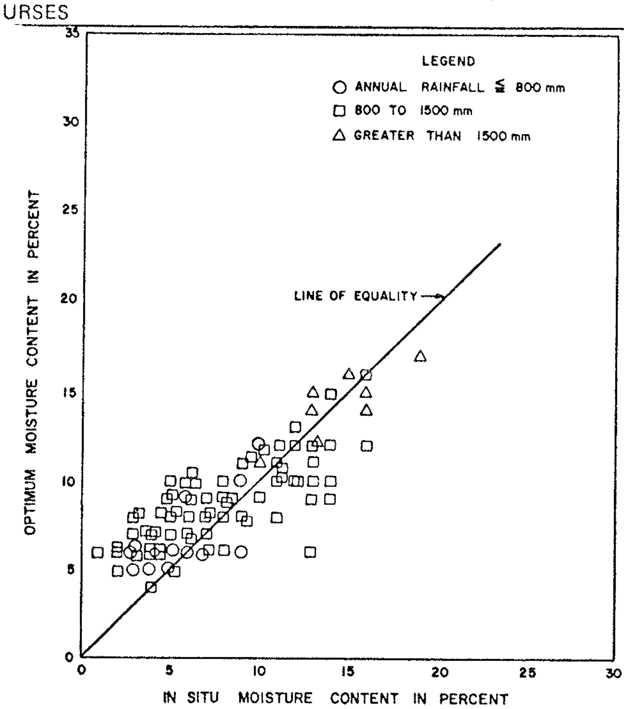


FIGURE 6.3 – RELATIONSHIP BETWEEN OPTIMUM MOISTURE CONTENT AND IN SITU MOISTURE CONTENT – SUBBASE COURSES

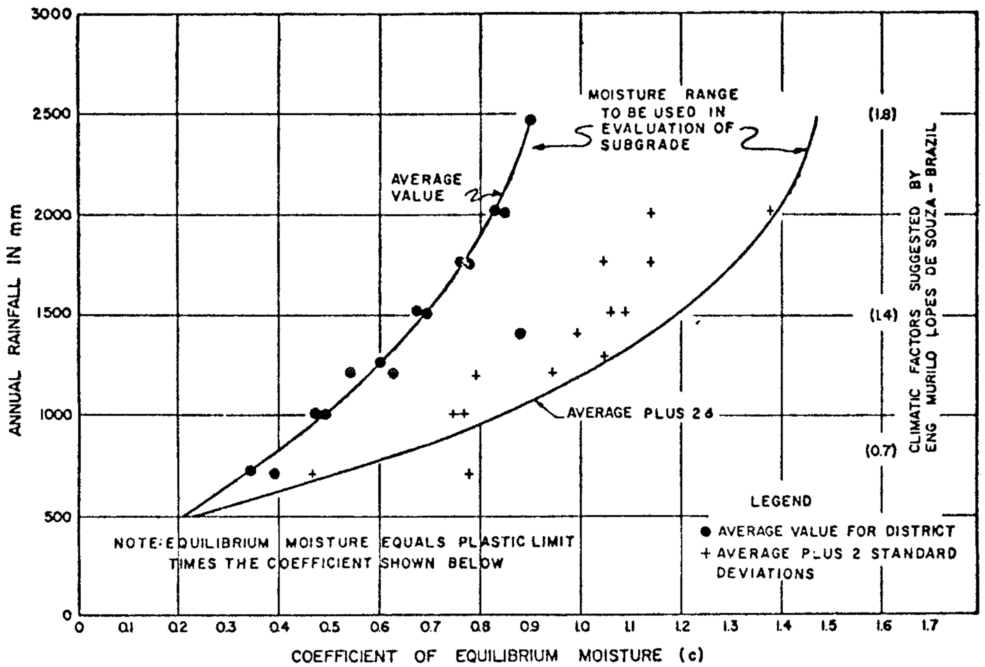


FIGURE 6.4 – ANNUAL RAINFALL VS COEFFICIENT OF EQUILIBRIUM MOISTURE

Surface Course Materials

The selection of surface course materials is governed by gradation. Table 6.3 shows the various gradings used in selecting materials for the component layers. Grading 4 represents the recommended gradation for untreated surface course materials. The grading envelope was arrived at by studies of reports covering the performance of untreated gravel roads. The minimum CBR value for surface course materials is 40. The physical properties given for Class VI base courses or subbases can be used for control purposes.

The quality of ironstones and concretionary gravels should be evaluated before these materials are utilized for surface course materials.

Several types of durability tests were evaluated in Volume I Chapter 8. The most promising of these is the slake durability test. A tentative specification of a minimum slake durability value of 95 is recommended for ironstones and concretionary gravels when these materials are to be used in the surface course.

TABLE 6.3
Recommended Gradations

Sieve		1	2	3	4
ISO*	ASTM-E11				
50 mm	2 in	100	100	100	100
37.5	1 1/2	80 - 100	90 - 100	100	100
25	1	50 - 100	70 - 100	85 - 100	100
19	3/4	45 - 100	60 - 100	75 - 100	100
12.5	1/2	35 - 100	45 - 100	65 - 100	90 - 100
9.5	3/8	30 - 90	40 - 100	55 - 100	80 - 100
4.75	No. 4	20 - 70	30 - 75	45 - 80	55 - 85
2	10	10 - 50	25 - 60	35 - 65	35 - 65
425 µm	40	5 - 35	20 - 45	30 - 45	20 - 40
75	200	0 - 25	15 - 35	25 - 40	15 - 30

*ISO International Standards Organization, Geneva, Switzerland.

SPECIFICATIONS FOR EXCAVATION OF BORROW AREAS, COMPACTION EQUIPMENT AND COMPACTION REQUIREMENTS

Excavation of Borrow Areas*

In developing the layout of a borrow site, area utilization and drainage (especially during the rainy season) are key factors to consider. If scrapers are to be used, the borrow pit should be excavated from an uphill position down, and the furrows made by the scrapers should be continuous and provide for drainage away from the pit. However, if power shovels are to be used, the pit should be excavated from a down hill position up. This technique will permit natural drainage and prevent local ponding. All stripped soil should be placed in a location outside the borrow area. While the ironstone or concretionary gravel is being excavated, care should be taken to prevent excavation into underlying clayey silt. If silt is mixed in with the borrow material during excavation, it must be washed out prior to placement, otherwise serious local failure may be expected. Most lateritic soil can be excavated with a scraper or a scraper pushed by a bulldozer. However, the ironstone must be excavated with a bulldozer with a 35 to 45 cm ripper tooth. Blasting to excavate laterite is relatively impractical because the laterite has a high natural porosity.

Compaction Equipment*

(1) Ironstone or concretionary gravel (Laterite)
During excavation, transportation, and compaction, an effort should be made to prevent unnecessary structural degradation of the laterite; therefore, compaction should be light and shaping kept to a minimum to avoid high shear stresses. The reference to "light compaction" is to indicate that lighter rollers and good moisture control should be employed to obtain the specified density and that heavy compactors should not be used as panacea to all compaction processes. For the wormhole laterite, the 7,258 to 9,720 kg vibratory steel wheel roller gives the best result. For pellet laterite, the 4,536 to 7,258 kg steel wheeled or pneumatic tire rollers are the most effective.

(2) Lateritic Soils
In Thailand, a variation of a sheepsfoot roller was used effectively in compacting a lateritic soil. The roller is similar to a sheepsfoot roller except that the feet are flatter and have a larger surface area. It has the capability of compacting thick lifts, for example, a 30 cm loose lift can be compacted to a 15 cm. However, the loose lift thickness is usually limited to 15 cm and is compacted to a thickness of 8 to 10 cm. Contrary to popular opinion, the sheepsfoot roller can be used effectively if the weight of the roller is reduced (usually by only half filling the drum) and the roller is pulled slowly to avoid high shear stresses. The 45,360 kg roller can be used, but the load and tire pressure are critical; they must be adjusted to approximately 22,680 kg and 6.3 to 7.7 kg/cm^2 respectively. A versatile roller which provides the "compaction action" of both a steel wheel and a sheepsfoot is the "Hyster" Grid Roller. This type of roller should prove to be very effective in the compaction of both laterite and laterite soils.

Lateritic soils compacted on the wet side of OMC often give a spongy section instead of a suitable compacted layer. A good rule of thumb for the field is to apply water at 2 percent less than the lab optimum moisture content.

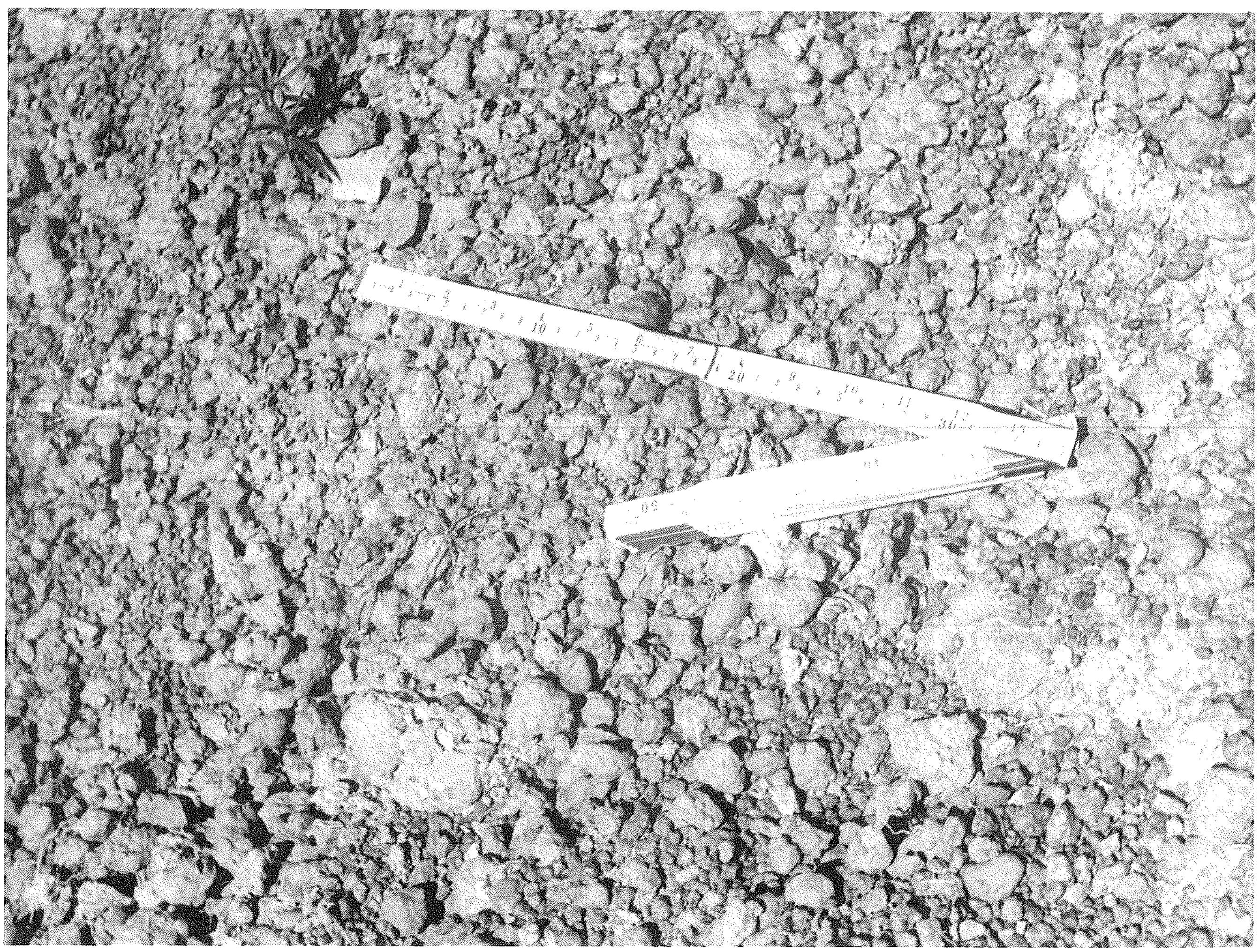
Compaction Requirements

The specified compaction requirements have been developed through analysis of the deflection and compaction relationships discussed in Volume I Chapter 12. The recommended density requirements shown in Table 6.4 are expressed as a function of the depth beneath the surface of the pavement. The requirements are applicable to natural subgrades in which case the required compaction will prevent excessive deflection of the layer but do not necessarily provide for the development of shear strengths required in the stability of high fills.

TABLE 6.4
RECOMMENDED COMPACTION REQUIREMENT FOR COMPONENT STRUCTURAL LAYERS AND NATURAL SUBGRADE

Depth Below Surface	Compaction
0 – 25 cm (0 – 10 in)	100% AASHO MOD
25 – 45 cm (10 – 18 in)	95% AASHO MOD
45 – 60 cm (18 – 24 in)	100% AASHO STD
60 – 90 cm (24 – 36 in)	95% AASHO STD

* From U.S. Army Corps of Engineers (1968).



Placement of pit material on top 15 cm of Brazilian road shown in cover photo.

BLADING AGGREGATE SURFACES

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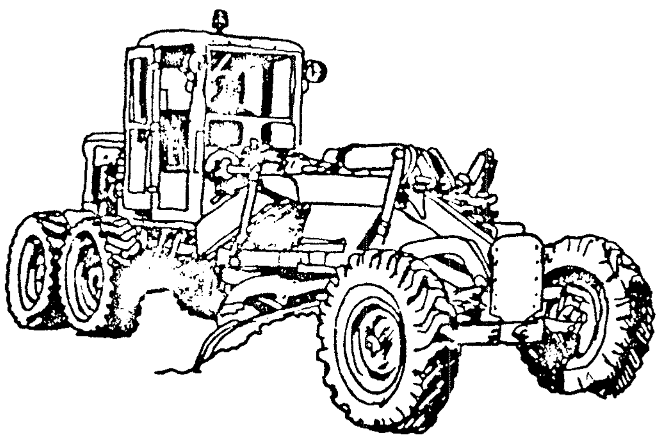

What It's All About

Aggregate surfaced roads represent a large portion of the total road mileage in the United States and may represent a large portion of the all-weather, low-volume roads you maintain.

This guide provides tips for grader operators on blading aggregate surfaced roads and can be especially helpful for training on the grader at the job site. *Blading Aggregate Surfaces* can help crews do a better maintenance job and thus help reduce the costs of keeping aggregate surfaced roads in good condition.

Tips used should be based on your judgment, experience, and knowledge of your specific area and conditions, such as terrain and climate.

This guide can be useful for new and experienced foremen, motor grader operators, and multi-purpose crews working on aggregate surfaced roads in states, cities, townships, as well as in counties.

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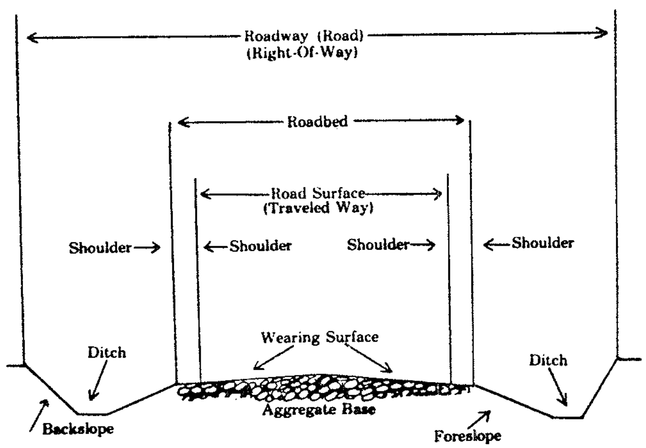


Typical Section Of Aggregate Surfaced Roadway

Aggregates And Aggregate Surfaced Roads

All roads, even those that carry small amounts of traffic, should be built of materials and soils that will make them passable in all kinds of weather.

The soils used in road building differ. They may swell when wet; may break into fine pieces under heavy traffic; or may be so hard they are nearly unworkable.

Coarse soils or mineral particles are called *aggregates*. Those that are very hard and not easily broken up are best to use for road surfaces and shoulders. The main types of aggregates are:

- Crushed stone — made by breaking or crushing rock, usually limestone
- Gravel and natural sands — usually found in river beds or as natural deposits in old stream beds
- Slag — a by-product of iron and steel manufacturing
- Burnt clay or expanded shale — a by-product of heavy industry or commercially produced as aggregate material

Other local materials make good aggregates for road surfaces:

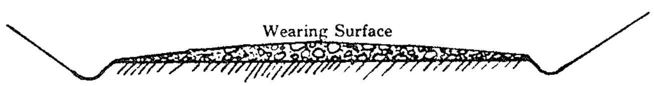
- Crushed sea shells — found in areas along the Gulf Coast and close to oceans
- Natural soil — suitable for road surfaces in some parts of the Midwest, such as Kansas

- Crushed basalt — a fine-grained hard rock
- Chert — a quartz-type rock

BLENDING AGGREGATES

The proper blend of different size aggregates on a road produces a surface that can be used in all types of weather. An aggregate surface is most economical for roads carrying low volumes of traffic because materials are usually available locally.

To make a wearing surface, different size aggregates are blended together and spread across the road base. The largest size is usually no more than ¾ inch. Blending different sizes allows the pieces to lock and pack (compact) together to make a strong, tight surface.

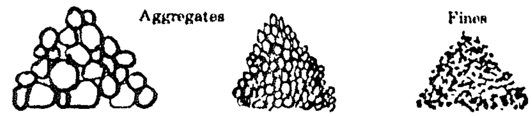


Different Size Aggregates Compact For A Strong Wearing Surface

Fine Material [Fines]

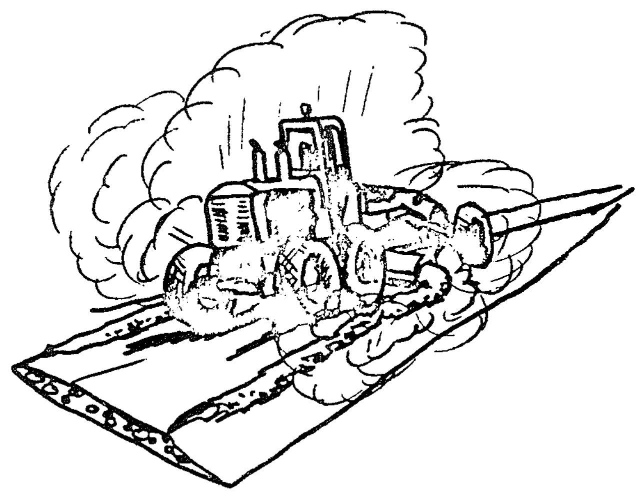
Fine material is added to a mixture of different size aggregates to fill the small spaces (voids) between the pieces.

- Fine material, often called binder or mineral filler, is a very important part of the mixture because when water is added, it acts like cement to hold the aggregate together



Aggregates Of Different Sizes Are Blended With Fines

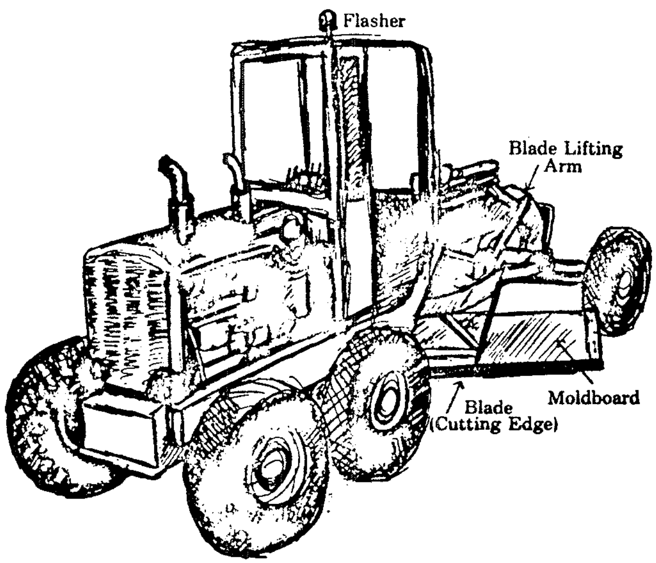
- Without enough fines, moist aggregate will not dry to form a hard wearing surface
- Dust blowing from an aggregate surface indicates that fines are blowing away



Fines Blowing Away As Dust

EQUIPMENT USED ON AGGREGATE SURFACED ROADS

Different kinds of equipment are used to maintain aggregate surfaced roads. The motorized road grader is most commonly used.



Motorized Grader

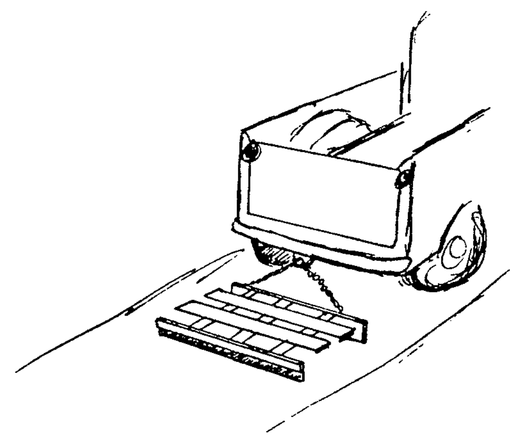
Other kinds of equipment used to maintain aggregate surfaced roads are:

- Pull type blades
- Underbody blades
- Drags (single or multiple blade)

Small drags are often pulled behind light-weight equipment (mower tractors, pick-ups, etc.) during the spring break-up, primarily to aerate the road surface to speed up drying. Normal blading with a heavy grader would only aggravate the situation by further puddling the wet, unstable material and leaving deep, wide ruts to fill with water.

Drags may be used in emergencies when the work load is so great there are not enough motorized graders available.

Regardless of the kind of equipment, the method used to maintain aggregate surfaced roads is nearly the same.



Pull-Type Drag

Maintaining Aggregate Surfaces:

Smoothing And Reshaping

To keep a road in good condition, the road surface and shoulders must be maintained.

Maintenance operations shown in this guide are:

- Blading to smooth road surfaces and shoulders
- Blading to reshape aggregate on road surface and shoulders

What It Is

SMOOTHING

The surface of the road is smoothed by dragging.

Smoothing is usually done when aggregate and fines are moist. Smoothing may be done in *dry weather* but you should not cut deep enough to disturb the hard crust (see page 17).

A dragging, rolling action created by the curve of the grader's moldboard helps compact the road surface as it is bladed.

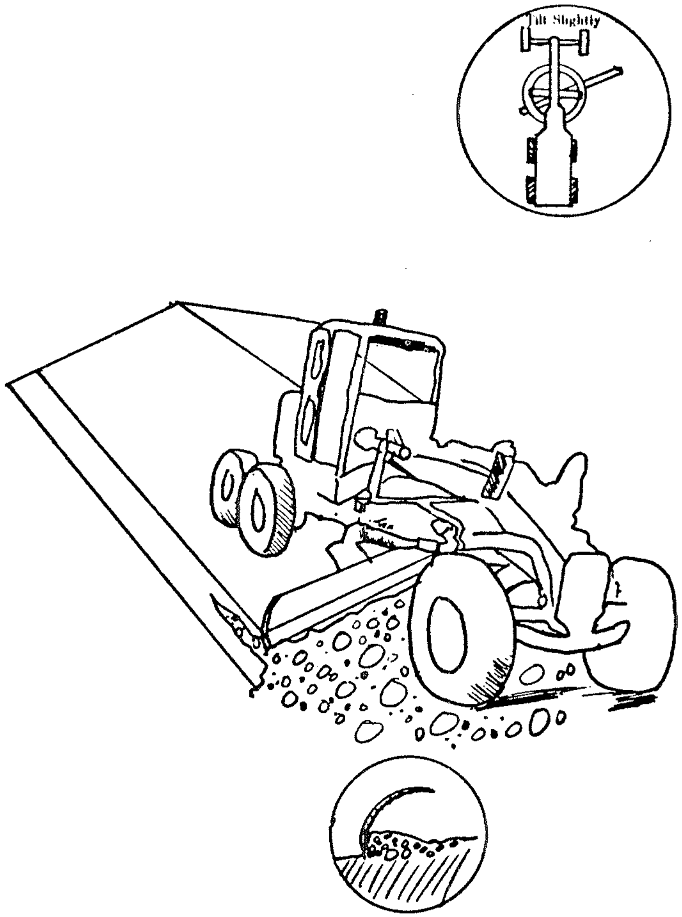
Blading speed will depend on the grader, pressure of tires and condition of the road surface. Going too fast will cause the grader to bounce, making a good job impossible.

How To Do It

TO DRAG THE ROAD SURFACE:

- Check grader blade (cutting edge) to make sure it is in good condition
- Shift moldboard so end of blade is at edge of road and at beginning of shoulder
- Tilt moldboard forward to get a dragging rather than cutting action (see picture, page 12)
- Angle moldboard at about 30° to 45° to spread loose material to center of the road
- Lean or slightly tilt front wheels about 10° to 15° from the vertical in direction aggregate rolls across blade

(Continued, page 13)



Tilt Moldboard To Get Dragging Action

How To Do It

(Continued from page 11)

- Periodically blade surface of the road against the flow of traffic to eliminate drifting of aggregate onto ends of bridges, culverts, intersections, and railroad crossings
- Stop to repair minor bad spots such as holes, rutted areas and poor surface drainage conditions. Always have a shovel available

What It Is

Crown

A road must be bladed so that the center is higher than the edges to allow water to drain into ditches as quickly as possible. That is called *blading a crown on the road.*

- Keeping a crown on the road is probably the most important part of blading because lack of a crown causes trapped water to break up the crust, producing potholes, washboards, and an overall rough road
- The amount of crown is the amount of slope on the road. For good drainage, a road should have a crown of 1/3 to 1/2 inch for each foot of width measured from center of road to outside edges where road meets shoulder

The most desirable crown is shaped like the letter A; in other words: a straight, sloped line from the center of the road down to the edge of the shoulder. The A-type crown is hard to maintain because motorists tend to drive down the middle of an aggregate surfaced road, straddling the crown. As traffic goes down the center of the road, it compacts the road surface on each side of the center line. Consequently, as you carry on your dragging operation, your cutting edge will wear faster in this harder, off-center area. This accounts for the moon-shaped wear in the cutting edge. The crown resulting from such a worn blade resembles an inverted letter U, or the shape of a parabola; thus, the term parabolic crown.

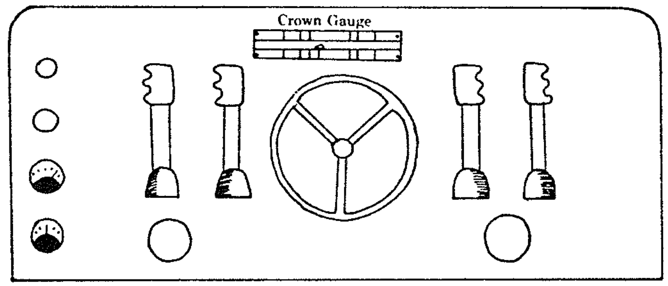
A bad feature of a parabolic crown is that it is relatively flat across the center of the road; it holds moisture longer and defeats the purpose of crown. When the roadbed is wet and ready for reshaping, you will be able (with new cutting edges) to rebuild the A-type crown (See Reshaping, pages 25-29.)

The best way to insure that a road has the proper crown is to use a crown gauge (slope meter) on the grader. The gauge or meter is attached to the grader to give a constant reading of the amount of crown as the road is being bladed.

How To Do It

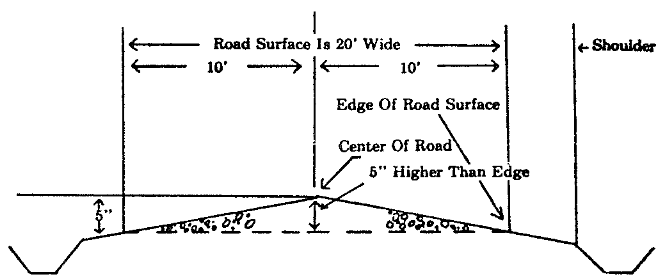
TO BLADE A CROWN ON THE ROAD:

- Raise end of the blade near the center of the road so it is higher than end of blade on outside edge of the road
- Use a crown gauge to insure that you blade the proper amount of crown on the surface



Crown Gauge Mounted On Control Panel

- Be careful not to cut too deeply at the shoulder of the road. Deep cutting will leave a groove near edge of the road and shoulder; this will stop drainage of water from the road into the ditch



A Crown 1/2 Inch Per Foot On Road With Surface Width Of 20 Feet Is A Crown 5 Inches High

What It Is

Crust

Properly blended aggregate and fines will dry to form a hard crust that provides a wearing surface. The crust will carry traffic until it breaks; it also sheds water to keep the base stable.

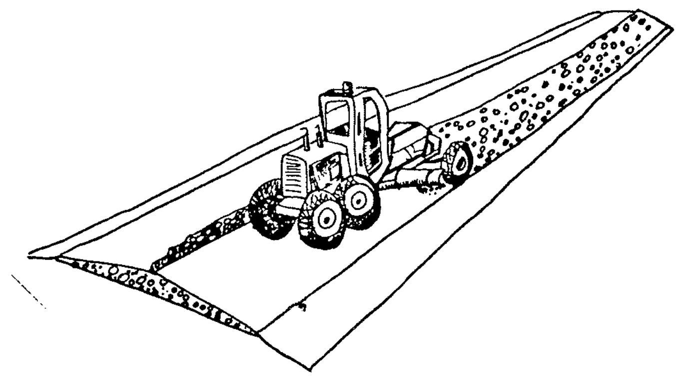
When smoothing, you must not break the hard crust on the surface of a road.

Eventually traffic and climatic conditions will completely break down the crust and the road will need reshaping.

How To Do It

TO AVOID BREAKING CRUST:

- Put only enough pressure on blade to smooth surface and drag excess material across the surface



Blade Surface Without Breaking Crust

What It Is

Passes Over Surface

One pass over a road surface blades that surface one time. For most roads, one pass on *each side* of the center line of the surface (one round) is enough to smooth because the grader blade is usually wide enough to cover one-half of the surface.

When you blade, aggregates usually roll to the back end of the grader blade. These excess aggregates form a windrow.

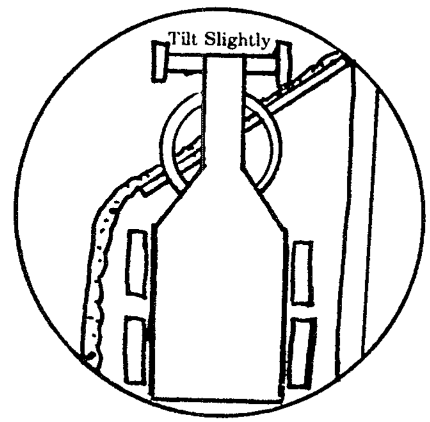
The aggregates in a windrow from one blading pass on one side of the road must be spread across the other side of the road when a pass is made on that side.

When the grader blade is not long enough to blade the road surface and shoulder on one side at the same time, a second pass in the same direction is needed to blade the road and shoulder and move any windrow left by the first pass to center of the road.

How To Do It

TO HANDLE WINDROW DURING PASSES:

- When making first pass, angle grader blade so excess surface material is windrowed to center of the road
- When making second pass on the other side, spread windrow from center across the other half of the road



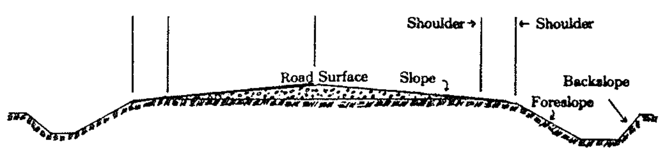
For First Pass, Move Blade To Edge Of Road Surface And Angle Blade To Windrow Excess Materials To Center Of Road

What It Is

Shoulders

A shoulder is an additional width along the outside edge of the road surface. Shoulders vary in width. The shoulder may have an aggregate surface like the road, and — if so — it should be bladed in the same manner.

- Shoulders must be sloped so water will drain into the ditch
  - — The slope of the shoulders *must be equal to or slightly greater* than the slope of the road surface to allow for drainage



On Wide Roads, Shoulder Should Slope As Much As Or Greater Than The Road Surface

How To Do It

TO BLADE SHOULDERS:

- Blade so shoulder slope is *equal to or slightly greater* than slope of road surface
- Always blade so the inside of the shoulder is as low as the outside edge of the road surface. (You do this so water will drain from the road into the ditch, minimizing the chance of forming a secondary ditch)
- Blade shoulders as needed to recover loose aggregate and valuable fines and to destroy unwanted vegetation
- Spread loose aggregate and fines from shoulder across road surface to help build the crown and stabilize surface aggregate

On Narrow Roads, Surface Extends To Edge Of The Road. There Is Little, If Any, Shoulder

What It Is

Dry Weather Blading

Sometimes blading has to be done during long periods of dry weather, mainly to remove excess dry, loose aggregate from the road surface.

Under some local conditions, you can blade this excess aggregate into a small windrow at the edge of the road. Be careful not to carry the windrow so far out on the shoulder that part of it spills into the ditch.

When the windrow of loose aggregate becomes moist (from rain or sprinkling) it should be spread back over the road surface.

Keep windrows to a minimum since they are hazardous to traffic.

Drains [Weepholes]

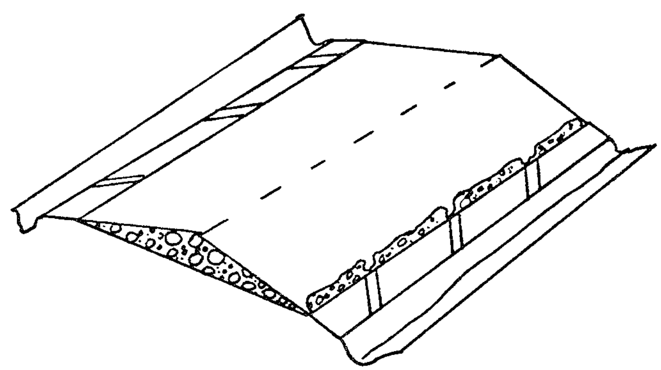
Water must drain quickly to keep a road in good condition. When windrows are left at the edge of the road, cuts in the windrow must be made short distances apart so that water can drain from the road. Otherwise, runoff water will flow along, with the windrow as a curb, and wash out a section of the shoulder at low points in the road.

If windrows are not removed after each rain, succeeding rains will start the formation of a secondary ditch.

How To Do It

TO BLADE IN DRY WEATHER:

- Tilt moldboard forward to get a dragging rather than cutting action
- Angle moldboard at about 30° to 45° to windrow loose aggregate to edge of the road
- Spread loose aggregate over road surface when blading narrow roads; do not leave it in a windrow
- When practical, sprinkle water on aggregate that is being spread back over road surface
- When windrows are left, make cuts (drains or weepholes) in windrow short distances apart so water can drain from the road
- Periodically, blade across shoulders and remove accumulation of road materials and vegetation that may act as a curb to hold water on the road



Drains In Windrow Let Water Drain Into Ditch

RESHAPING

Reshaping a road involves more than just smoothing the surface.

After a period of rainfall or slow melting snow, traffic scatters the aggregate, flattens the crown, makes potholes and deep ruts in the road, and produces a rough surface with ridges that look like a washboard. These conditions cannot be corrected by just smoothing the surface — you must reshape the aggregate base.

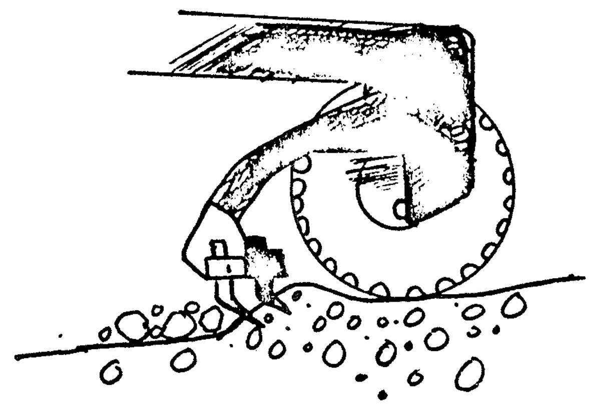
Reshaping Cuts Away Washboard Ridges And Breaks Up Potholes

Reshaping involves remixing the aggregate base to get a proper *blend* of fines and different size aggregates and blading this blended material into a properly crowned road surface. When remixing, you may need to add additional aggregates and fines to road surface and shoulders, particularly in rough spots or washed-out places.

The development and maintenance of a proper crust can bring great personal satisfaction, since the quality of the crust and its length of useful life depend on the skill used in blending coarse and fine materials which, together with moisture, form the desired crust.

The art of proper blending is a cut-and-try proposition depending on types of materials at hand. Experience will provide know-how to determine the correct blend.

The crust that forms what is left of the old wearing surface is broken up during remixing, often with a scarifier. The scarifier is an attachment to the grader used when the crust is too hard to cut easily with the grader's blade.



Scarifier Helps Break Crust

After the aggregate base is remixed, it is bladed to obtain a smooth road surface with the proper crown. (A new set of cutting edges, of course, gives the best results.) Traffic will compact this base, and a crust will form to give a new smooth wearing surface.

As with smoothing, reshaping should be done when the aggregate is moist. If reshaping is done in dry weather, water must be added to the aggregate to make it moist.

What It Is

Reshaping The Road Surface And Aggregate Shoulders

Mixing of fines and aggregates in reshaping requires more than one pass with the grader. Width of the road surface and shoulders, amount of loose aggregates, and depth of potholes and washboard ridges determine how many passes are needed.

The surface of the road must have the proper crown after reshaping is completed.

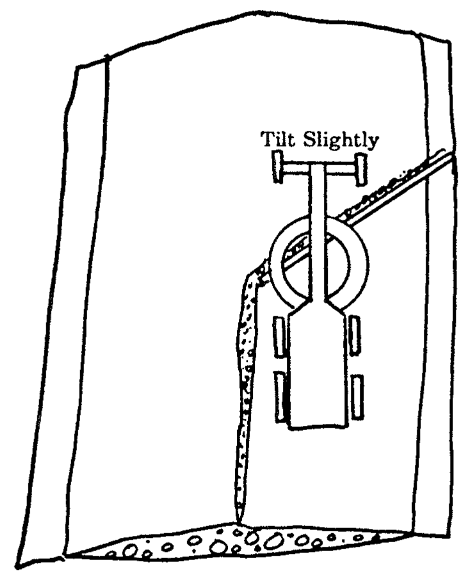
Shoulders must slope downward from the edge of the road surface toward the ditch so that water draining from the road surface will continue to drain across the shoulders into the ditch. A shoulder should have a slope equal to or slightly greater than the slope of the road.

How To Do It

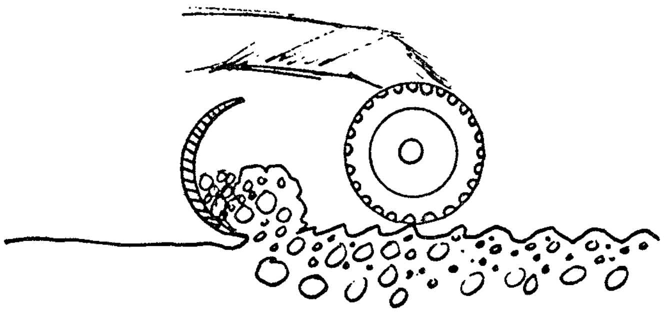
TO RESHAPE ROAD SURFACE AND SHOULDERS (APPLIES ONLY TO AGGREGATE SHOULDERS, NOT DIRT SHOULDERS):

- Check with your foreman to see if more aggregate or fines need to be added to surface and shoulders, particularly in rough spots or washed-out places
- Shift moldboard so end of blade is at outside edge of shoulder for the first pass

(Continued, page 29)



Shift Blade To Outside Edge Of Shoulder On First Pass



In Reshaping, Blade Cuts Into Washboard Ridges And Potholes

How To Do It

(*Continued from page 27*)

- Tilt moldboard so it is in a cutting position
- Angle moldboard at about 30° to 45° to provide for moving and rolling aggregate in a mixing action toward center of the road
- Lean or slightly tilt front wheels about 10° to 15° from the vertical in direction aggregate rolls across blade
- Put enough pressure on blade to cut shoulders and washboard ridges
- Scarifying, when necessary, should go as deep as the average pothole or washboard — usually two to three inches
- Watch blade action very closely and continuously adjust controls to get good cutting and mixing action
- Check to see if more passes are needed in the same direction to continue mixing, cutting to bottom of potholes and ridges, and to windrow aggregate to center of the road
- Spread half the aggregate back over each side of the road and shoulders, blading the material into a proper crown
- **Blade shoulder downward to ditch so slope is at least as much as slope of the road**

What It Is

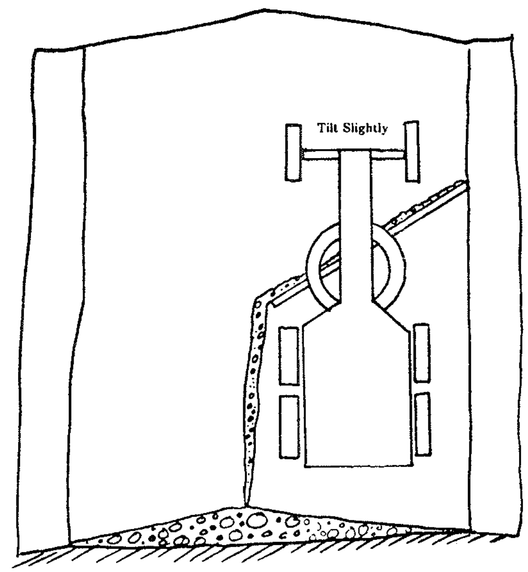
Reshaping The Road Surface Without Reshaping The Shoulders

The road can be reshaped without reshaping the shoulders. The blading operation is the same except that the shoulders are not included.

How To Do It

TO RESHAPE ROAD SURFACE WITHOUT RESHAPING SHOULDERS:

- Shift moldboard so end of blade is at edge of the surface and at inside edge of shoulder for the first pass
- Follow the same blading operation you do for reshaping road surface and shoulders (see pages 26-27)



To Reshape Road Surface Without Blading Shoulders, On The First Pass Shift Moldboard To Edge Of Road Surface

Blading Under Special Road Conditions

Some road sections require special attention when they are bladed.

What It Is

INTERSECTION OF AGGREGATE SURFACED ROADS

Beginning at a point about 50 to 100 feet before the intersection of two aggregate surfaced roads, the crown should be gradually eliminated so that, at the point of intersection, there is no crown apparent in either road. If the crown is not eliminated, vehicles will bounce as they cross the intersection, particularly on a "no-stop" road at the intersection.

How To Do It

WHEN BLADING INTERSECTION OF TWO AGGREGATE SURFACED ROADS:

- Gradually eliminate crown on each road, starting about 50 to 100 feet before roads intersect
- Check to see if an extra blading pass or two is needed to eliminate crown and to insure that shoulders have a slope at point the roads intersect

(See picture, page 35, which shows a similar situation.)

What It Is

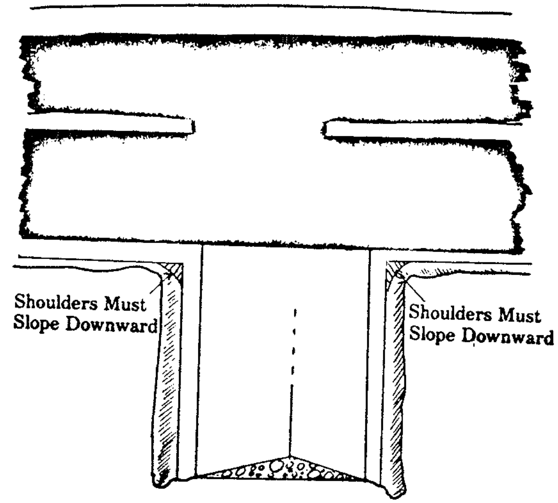
INTERSECTION OF AGGREGATE SURFACED AND PAVED ROADS

Beginning at a point about 50 to 100 feet before the intersection, the crown should be gradually eliminated from the aggregate road so that, at the point of intersection, there is no crown in the aggregate road. The aggregate road and the pavement must be at the same grade where they intersect.

How To Do It

WHEN BLADING INTERSECTION OF AN AGGREGATE SURFACED ROAD AND PAVED ROAD:

- Gradually eliminate crown on the aggregate road, starting about 50 to 100 feet before the roads intersect
- Do not blade loose aggregate onto the paved road. Pull onto pavement, drop blade, put grader in reverse and pull off the aggregate
- Check to see if an extra blading pass or two is needed to eliminate crown and to insure that shoulders have a slope at point the roads intersect



Eliminate Crown On Aggregate Surfaced Road At Point It Intersects Paved Road

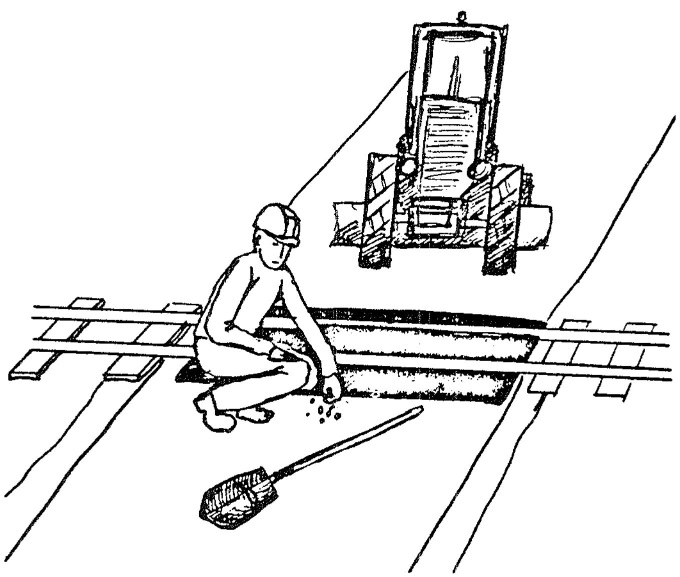
What It Is

ROAD CROSSING RAILROAD TRACKS

The crown should be gradually eliminated on each side of the railroad tracks, so that at the point the road intersects the tracks, there is no crown in the road.

Aggregate must not be bladed onto the crossing. It will get wedged in the flanges and could cause derailment.

To maintain a good approach to crossings, in many cases, you may need to use your hand shovel.



Loose Aggregate Must Be Removed From Railroad Tracks

How To Do It

WHEN BLADING A ROAD CROSSING RAILROAD TRACKS:

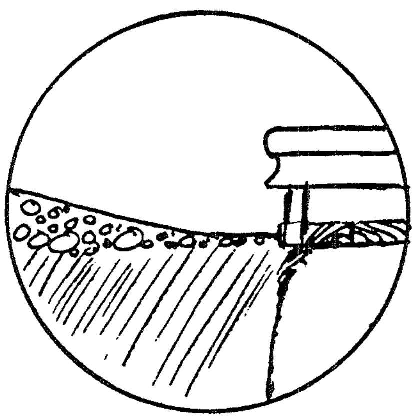
- Gradually eliminate crown on road, starting about 50 to 100 feet before road intersects railroad tracks
- **Do not blade loose aggregate onto railroad tracks.** Always stop the grader after you have bladed on each side of the tracks and check to make sure there is no loose aggregate on any part of the tracks or between tracks and metal flanges along the tracks. If there is, use a broom or hand shovel to remove it
- Check to see if an extra pass or two is needed to eliminate crown and to meet the grade of the railroad tracks

What It Is

ROAD CROSSING BRIDGE

Most wood bridge floors or decks do not have a crown; however, decks of most other bridges, particularly concrete, have crowns of varying degrees.

Regardless of the shape of the bridge floor, the crown of the road surface must conform to that of the bridge. The road surface must be bladed a short distance on each side of the bridge so that it is the same height as the deck or floor of the bridge.



Road Intersects Bridge At Same Grade

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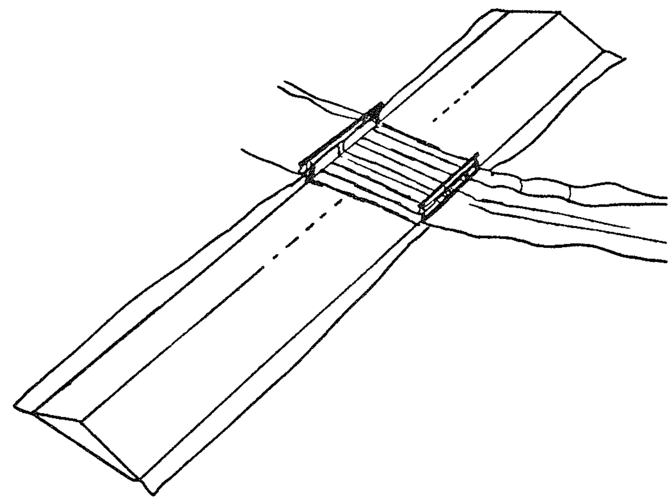
How To Do It

WHEN BLADING A ROAD CROSSING A BRIDGE:

- Gradually shape crown on the road to fit the bridge floor, starting about 50 to 100 feet from ends of the bridge
- Check to see if an extra pass or two is needed to properly fit crown of the road to shape of the floor
- Do not blade loose aggregate onto bridge unless bridge is designed for an aggregate cover — check with engineer
- Do not let aggregate build up on ends of bridge. Drive onto bridge, drop blade, put grader in reverse and pull off excess aggregate. Doing this also helps smooth the approach



Eliminate Crown On Each Side Of Bridge

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What It Is

AT DRIVEWAYS

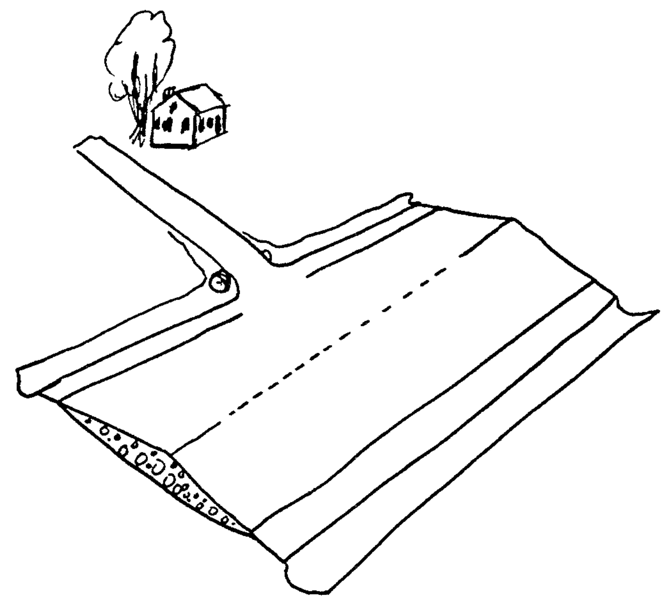
When smoothing or reshaping a road that passes a driveway, attention must be given to the finished road surface height. Although the road has preference, there should be no "drop off" from the edge of the road onto the driveway or no "jump up" from the edge of the road onto the driveway.

The edge of the road and entrance to a driveway should be at the same elevation. To accomplish this level connection (do not create humps in the road grade line), the crown in the driveway must be eliminated at its junction with the edge of the road.

How To Do It

WHEN BLADING A ROAD PASSING A DRIVEWAY:

- Blade edge of the road to the same grade as the entrance into the driveway
- Do not raise blade and deposit loose aggregate in front of driveway
- Make extra passes, if necessary, to smooth entrance into the driveway



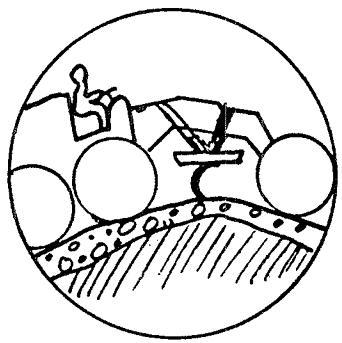
Edge Of Road Must Be At Same Grade As Driveway

What It Is

ON HILLTOPS [CRESTS]

Control the grader blade when it crosses the top of sharp crested hills. As the front wheels of the grader cross the top of the hill and start down, the grader blade will cut into the surface of the road and will scrape the aggregate surface off.

Increased pressure on the blade when going downhill will cut through the surface and can cause slick grades and excess aggregate at the bottom of the hill.



Don't Scrape Aggregate Off A Hilltop

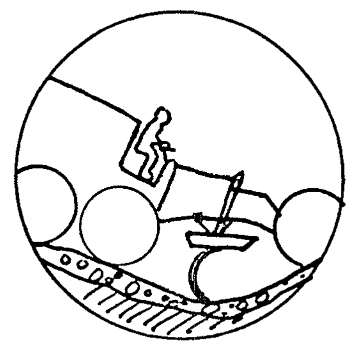
AT BOTTOM OF VALLEYS [SAGS]

Control grader blade when blading a road at the bottom of a valley. As the front wheels of the grader cross the valley and start up the road, the grader blade will be raised above the road surface because the rear wheels of the grader have not reached the bottom of the valley. Grader controls must be continuously adjusted to prevent aggregate from accumulating at the bottom of the valley.

How To Do It

WHEN BLADING ON A HILLTOP (CREST):

- Gradually adjust blade up and back down again as the front and rear wheels pass over the top of the hill so you don't cut into aggregate surface at the top of the hill
- Check to see if extra passes are needed over the top of the hill to smooth the aggregate
- Be careful not to cut too heavy going downhill as grader speed increases; shift to lower gear; do not use blade as a brake



Don't Pile Loose Aggregate In A Valley

WHEN BLADING BOTTOM OF A VALLEY (SAG):

- Gradually adjust blade up and back down again as the front and rear wheels pass the bottom of the valley to prevent aggregate from piling up
- Check to see if extra passes are needed to insure a smooth surface with proper crown at the bottom of the valley

What It Is

CURVED ROADS

On curved roads, the outside edge of the road is higher than the inside edge. This is called banking (superelevating) the road. Banking the road helps a vehicle to stay on the road as it goes around the curve.

The crown is gradually eliminated just before beginning the curved part of the road, and the curved part of the road is banked when bladed.

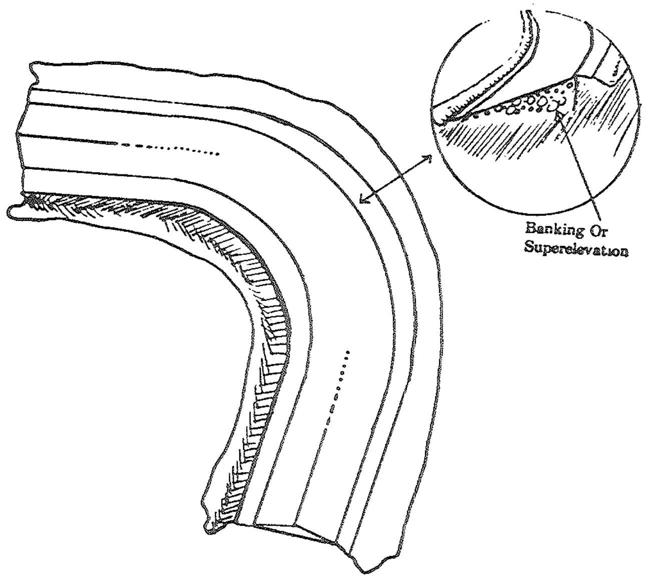
Care must be taken when banking the road. The roadway must not be so steep that a vehicle will slide off when moving at a slow speed when the road is wet or covered with snow. However, the curved part of the road should be banked enough so that a vehicle traveling at a safe speed around the curve will not pull to the shoulder on the outside edge of the road.

How To Do It

WHEN BLADING A CURVED ROAD:

- Eliminate crown on the surface by gradually raising end of blade on the outside edge of curve about 50 to 100 feet before starting into the curve (use your crown gauge)
- At the point where the curve begins, the outside edge of the road should be about the same height above the center of the road as the inside of the curve is below the center — in other words, practically a straight line from edge-to-edge of road surface, tipped towards the inside of the curve
- Blade outside edge of the curved part of the road higher than the inside edge (superelevate or bank the road)
- Do not blade any crown on curved part of the road
- Change road surface from a crown to superelevation and back to crown smoothly and gradually
- Slope shoulder on the superelevated part of road downward from edge of the road surface to the ditch

(See picture, page 46.)



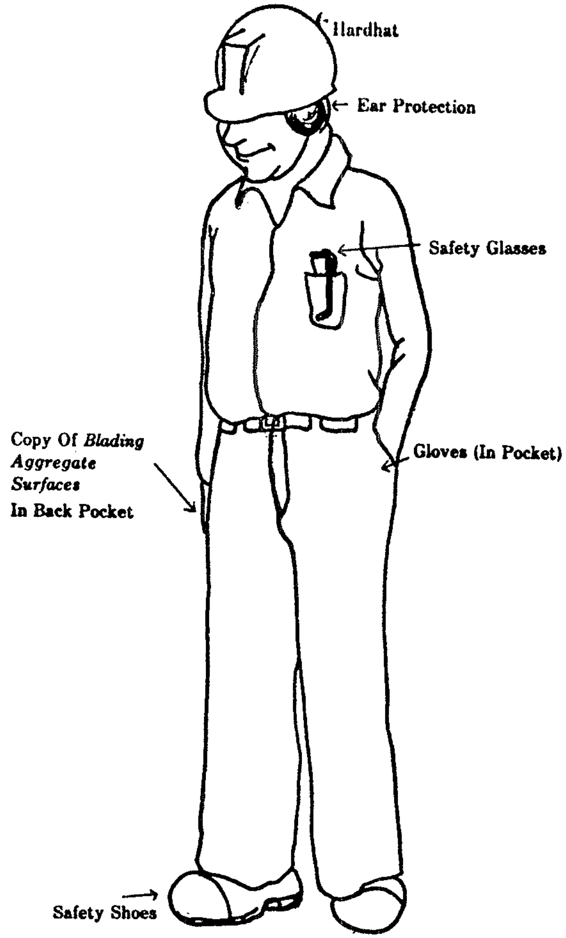
Bank Road Surface On Curve

Condition Of Blade

The condition of the grader blade affects how fast and how well a road can be smoothed or reshaped.

A lot of power is needed to cut washboard ridges and blend materials. Using a worn out blade reduces the working speed of the grader by about half.

- Check the condition of your grader blade each time you start to blade to see if it needs replacing



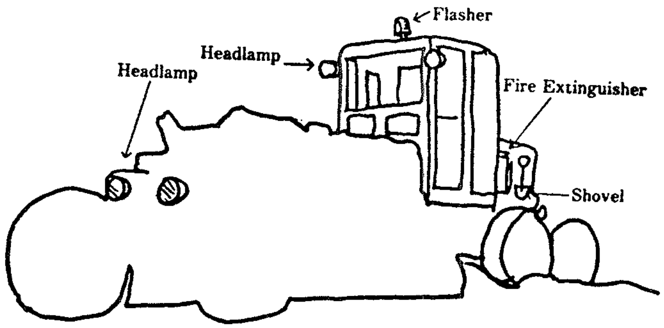
Personnel And Equipment Safety

Operating a grader on the road, especially when traffic is passing, can be hazardous. Safety hazards can be reduced by using adequate personnel, equipment, and signing safety measures.

FOR SAFETY:

- *Always wear a hardhat when blading*
- Always wear safety shoes and appropriate safety gear on the job
- Put colored flags on each end of moldboard when blading
- Have *Slow-Moving Vehicle* triangle on back of grader
- Use flashing safety light on grader when blading
- Turn on grader headlights when blading against traffic
- See that a visible fire extinguisher is on the grader and make sure it is properly charged
- Watch in rear view mirror for traffic wanting to pass
- Make sure there is a hand shovel in good condition on the grader
- When blading downhill, put grader transmission in low range for braking power
- Always ground blade when leaving grader
- Shift blade to center of the grader and lock it when parking grader

- Always remove ignition key when leaving grader unattended
- Use signing and proper flagmen where needed to warn traffic of work in progress or as warning if grader is left unattended
- Signs and sign locations should conform to the *Manual On Uniform Traffic Control Devices* (MUTCD) or the official manual on traffic control devices (sign manual) for your state



Use Safety Features On Grader

Acknowledgments

Blading Aggregate Surfaces was written by NACoRF staff, under the guidance of the following NACE committee:

Milton L. Johnson, Clayton County Engineer, Iowa (Chairman)
Gerald E. Hann, Athens County Engineer, Ohio
Daniel J. Hostler, Hall County Highway Superintendent, Nebraska
H. A. McCann, Franklin County Engineer, Washington
Berton A. Retz, Kosciusko County Engineer and Superintendent, Indiana

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Labor-intensive construction of gravel surface in Oaxaca, Mexico.

HIGHWAY RESEARCH RECORD

Number 91

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63 Mechanics (Earth Mass)
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Contents

Crown on Soil-Aggregate Roads

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This paper summarizes a study of the relationship between road surface slopes and the severity of potholing on soil-aggregate roads. Although practice in crowning soil-aggregate roads often disregards the influence of longitudinal grade, the study suggests that the effect of grade on the potholing tendency is considerably more than a token effect; a resultant of transverse slope and longitudinal grade appears to be more strongly related to presence and severity of potholing than is crown slope alone. Because a tendency to tilt road crown downhill in sidehill locations can result in flatter crown (and often more severe potholing) on the uphill side of the road, caution in "by eye" shaping of soil-aggregate roads in such locations is suggested.

• POTHOLING is surely one of the primary maladies of soil-aggregate or gravel roads. Materials with good mechanical stability and hence immunity to rutting, and even materials protected against the dry weather problems of dusting and corrugation, may be far from immune to the development of potholes during the wet months. Although safety and convenience in vehicle operation do place some practical maximum on road crown, it has long been observed that soil-aggregate roads with flatter crown slopes are more likely to pothole than those with steeper crown slopes. It has also been observed that potholing is generally more severe on flat, or nearly flat, longitudinal grades. This study has explored the relationship between severity of potholing and crown slope and, perhaps more significantly, between potholing severity and a resultant of crown slope and longitudinal grade. The study has also explored an hypothesis that transverse terrain slope (or the misjudgment of vertical or horizontal which it creates) promotes a tipping or tilt of road crown in a downslope direction by grader operators. The tendency to flatter crown slope on the uphill side may be a primary explanation for an often observed greater frequency of potholes on the uphill side of soil-aggregate roads.

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CROWN AND GRADE VS POTHOLING SEVERITY

In 1959, a comprehensive summary of current practice in the design, construction and maintenance of soil-aggregate roads, Huang (1) reported that the maximum rate of crown for soil-aggregate surfaces is usually between ¼ and ½ in./ft (0.02 to 0.04 ft/ft). A 1949 publication of the U. S. Bureau of Public Roads (2) suggests this same range in crown slope; it is pointed out that needed crown slope is influenced by steepness of grade, but just how grade should influence needed crown is not defined.

In 1961, his study of circumstances associated with the occurrence of potholes on soil-aggregate roads in Illinois, Huang (3) noted a relationship between crown and pothole formation. Categories used were high crown (½ in./ft or more), low crown (¼ in./ft), and no crown. Longitudinal grade was not indicated. In an earlier study of crown vs potholing of soil-aggregate roads in Indiana, Illinois, Missouri and Kansas, Burggraf (4) reported that the average of 29 determinations of crown slope where soil-aggregate roads had a good surface was 0.50 in./ft and that for 14 determinations where the road surface was

Paper sponsored by Committee on Soils-Calcium Chloride Stabilization and presented at the 44th Annual Meeting.

potholed or rutted, the average crown slope was 0.24 in./ft. The longitudinal grades at the locations of these determinations were not reported. In recommending an A-shaped crown, Burggraf suggested that crown slope during construction should be $\frac{1}{2}$ in./ft, and should never be less than $\frac{3}{8}$ in./ft in the final compacted road. He recommended the use of the crown formula, $C = W(100 - 4\,L)/4{,}800$, in which L was the longitudinal grade in percent. This formula (very similar to the Rosewater formula (5, 6, 7) gives a crown of $\frac{1}{2}$ in./ft on level sections and would reduce it only to 0.4 in./ft on a 5 percent grade. Burggraf suggested that "for ordinary purposes, the longitudinal gradient factor may be disregarded... ."

Still earlier recommendations or standards of practice concerning crown slope were perhaps as much the result of observation and experience as of specific investigation. Design suggestions are quite plentiful in the early literature but most suggestions are related to a curb and gutter cross-section. Green (5) reported in 1909 that the Chicago West Park Board used a crown height equal to 2 percent of the width of the roadway. Warren (6) suggested in 1909 that crown should be 1 in. for each 4 or 6 ft between curbs where longitudinal grade was 2 percent or less. The greater of these crown slopes was suggested for pavements "providing more secure foothold." Warren considered longitudinal grade in recommending that for 2 to 4 percent grades crown should be only one-half of that required where the grade was 2 percent or less; where longitudinal grade was above 4 percent, crown would be only one-third the basic value. It appears that Warren's corrections for longitudinal grade were as much related to foothold as to hydraulic or road performance considerations. In 1910, Zahniser (7) considered longitudinal grade in suggesting that for "rougher cartways," the crown (in ft) should be equal to the width of the roadway divided by 24 times the percent longitudinal grade. In 1916, an ASCE committee (8) recommended that the crown slope on gravel roads be from $\frac{1}{2}$ to 1 in./ft. Longitudinal grade was not considered in the tabulation of recommended crown slope for various roadway surfacings. The words "the practice generally observed and to be recommended..." suggest that the committee recommendations were essentially a compilation of standard practice at that time.

The more recent studies have helpfully related soil-aggregate road performance to crown slope, but they have not seriously considered effects of longitudinal grade. Although some of the very early writings considered corrections for longitudinal grade, the recommendations are not related to the performance of soil-aggregate roads.

Method of Study

Roads Selected.—Twelve soil-aggregate roads on various town(ship) highway systems in Tompkins County, N. Y., were selected for this study. All roads were surfaced with local bank-run gravels of such gradation and containing enough soil binder that a consolidated but nonrutting surface was produced. Most roads had been treated with chlorides at the time of initial graveling (2 to 8 yr before this study); approximately half had follow-up chloride treatments. Roads selected had a minimum traveled-way width of 16 ft and were generally used full width; narrower roads were not selected to avoid tracking situations likely to leave a W cross-section. Traffic averaged 50 to 150 veh/day. Measurements and observations on these roads were made in early April, after thawing of the roadbed but before any spring maintenance.

Measurements and Observations.—At intervals of 250 ft along both sides of each of these roads, transverse slope and longitudinal grade were measured and severity of potholing was observed in the immediate area. The immediate area for pothole observations was about 20 ft long and included only that side of the road where slope measurements were then being taken. This predetermined spacing of points for measurement and observation minimized any bias in sampling. Measurements and observations were made at a total of 320 points. The size of sample was arbitrary but covered reasonably well the ranges in crown slope and longitudinal grade within which potholing is observed.

Measurements of transverse slope and longitudinal grade were made by liquid-level devices mounted on a pickup truck (Fig. 1). At a point located by use of an auxiliary odometer, the left wheels were placed (by eye) on the crest of the crown. The previously calibrated liquid-level devices gave longitudinal grade over the wheelbase of the

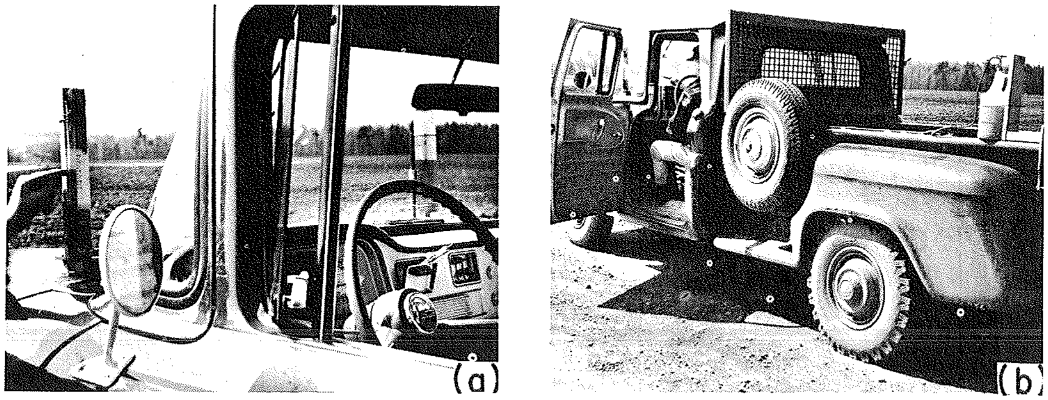

Figure 1. Devices for measuring (a) transverse slope, and (b) longitudinal grade.

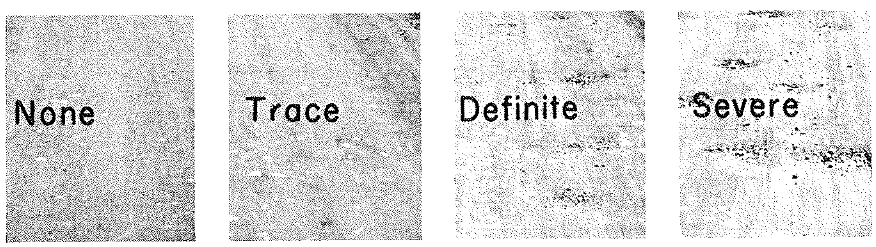

Figure 2. Visual definition of pothole severity.

vehicle and average transverse slope over the distance between left and right wheels. Transverse slopes were recorded to the nearest $\frac{1}{16}$ in./ft and longitudinal grade to the nearest 0.5 percent.

Pothole severity at the location of the measurements (on only that side of the road where slope measurements were then being taken) was observed and classified as none, trace, definite or severe. Visual definition of these degrees of potholing is provided in Figure 2.

Results

Results of this portion of the study are shown in Figure 3. To minimize clutter, Figure 3a defines only those situations where no potholing was observed. Figure 3b defines situations where potholing was observed and, by symbol, whether the potholing at that location was classified as trace, definite or severe. On both plots, each symbol represents one location of measurements and observation, with longitudinal grade plotted on the vertical axis and transverse slope on the horizontal axis. Where there were two or more observations at a particular combination of transverse slope and longitudinal grade, slope and grade are indicated by a point near the center of the symbol cluster. Maximum resultant slope, defined in Figure 4, at any of the points plotted in Figure 3 is indicated by its radial distance from the origin of coordinates.

Interpretation of Results

Crown Slope vs Potholing.—The relationship between crown slope only and the frequency and severity of potholing is summarized in Figure 5. Observations are grouped in crown slope ranges of 0 to 0.01 ft/ft (equal to or greater than 0 but less than 0.01), 0.01 to 0.02 ft/ft (equal to or greater than 0.01 but less than 0.02), etc.

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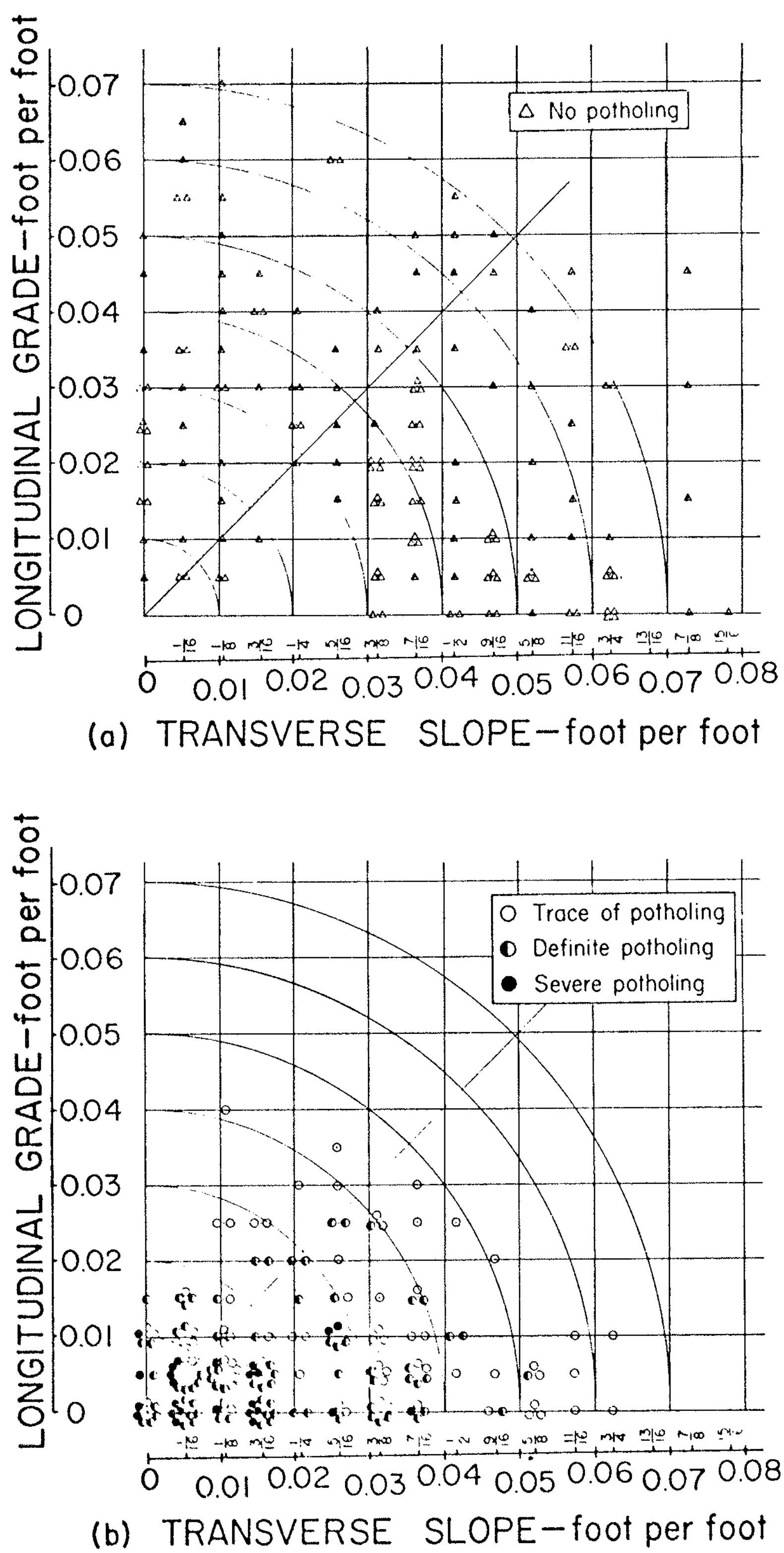


Figure 3. Relationship of potholing severity to transverse slope and longitudinal grade: (a) no potholing, and (b) potholing.

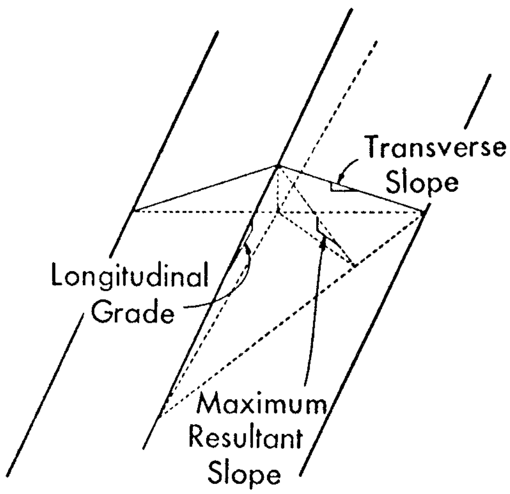


Figure 4. Definition of maximum resultant slope.

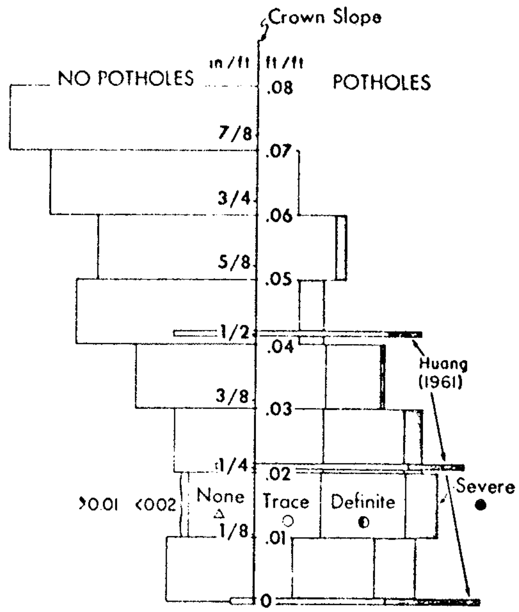


Figure 5. Relation of crown slope to frequency and severity of potholing.

With the total length of each bar made equal to 100 percent, the percent of observations of no potholes in each crown slope range is indicated by the portion of bar length extending to the left of the vertical line. Portions of bar length to the right of the vertical line indicate the percent of observations where potholing was in the trace, definite and severe categories. There is a general trend of decrease in frequency of potholing with increase in crown slope. Where potholing was observed, there is a more definite trend of decrease in severity with increase in crown slope.

Trends in the data from this study are somewhat similar to those reported by Huang (3) from his work in Illinois. The frequencies he found of no potholing, slight potholing and severe potholing at no crown (¼ in./ft, and ½ in. or more per ft) are also plotted in Figure 5. Although the trends are similar, the Huang data indicate one-third to one-half the frequency of no potholing found in this study at the various crown slopes. At these same crown slopes, Huang's frequency of observation of severe potholing is considerably higher in each case. A partial explanation may be the probability of flatter topography and, hence, generally lesser longitudinal grades in Champaign County, Ill., than in Tompkins County, N. Y.

Maximum Resultant Slope vs Potholing.—A comparison of Figure 6 with Figure 5 suggests a more definite relationship when potholing frequency is plotted against maximum resultant slope than when it is plotted against crown slope alone. Frequency of pothole observations as well as severity of potholing decreases with increasing maximum resultant slope. This is as might be expected since where a road has some longitudinal gradient, runoff of surface water is not along the transverse crown slope but along some resultant of crown slope and the longitudinal grade.

Regression analysis of percent of no potholes observations in the various slope ranges on midpoint of each slope range (0.005, 0.015, ..., 0.075 ft/ft) for the data summarized in Figures 5 and 6 indicates regression coefficients of 10.2 for crown slope alone and 14.0 for maximum resultant slope. These coefficients, or slopes, are for regression lines not passing through the origin. Standard deviations from regression are 9.6 for crown slope alone and 6.7 for maximum resultant slope. Correlation coefficients are 0.94 for crown slope alone and 0.98 for maximum resultant slope.

It will be noted that the data from this study more closely approach Huang's frequency and severity pattern in Illinois (superimposed on Figure 5) if crown slope alone is replaced by maximum resultant slope.

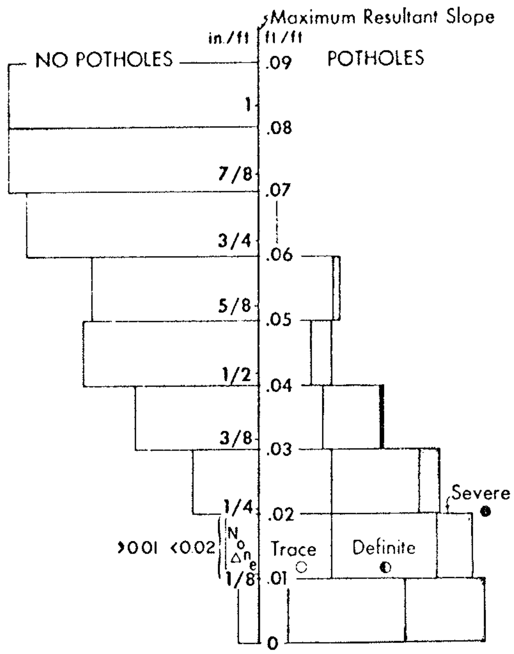


Figure 6. Relation of maximum resultant slope to frequency and severity of potholing.

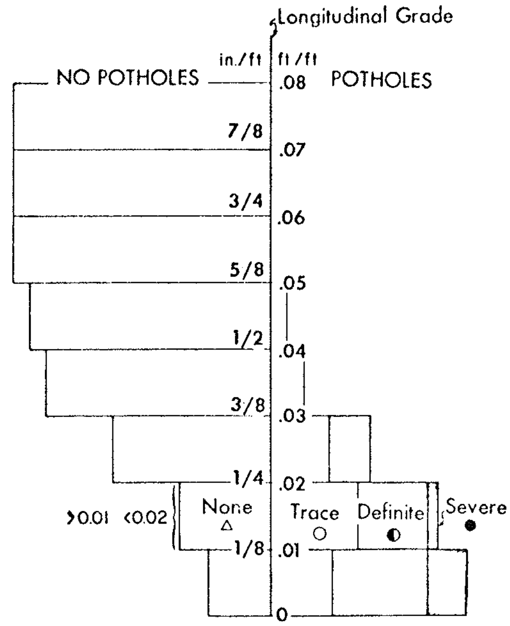


Figure 7. Relation of longitudinal grade to frequency and severity of potholing.

Longitudinal Grade vs Potholing. —Figure 7 indicates the relationship between longitudinal grade only and the frequency and severity of potholing. Although longitudinal grade is usually fixed by considerations other than potholing, its relation to potholing tendencies is at least of academic interest. Figure 3 indicates that, in this study, only traces of potholing were observed, irrespective of crown, where longitudinal grade exceeded 2½ percent. In contrast, there were more than traces of potholes where grades were flat or slight and crown slope exceeded 2½ percent. Figure 3 also indicates that there was lesser severity of potholing (for the several ranges in maximum resultant slope) where longitudinal grade exceeded transverse slope than where a predominant slope was in the transverse direction.

Why should more longitudinal than transverse orientations of maximum resultant slope be related to lesser frequency and severity of potholing? It might be reasoned that the greater length of catchment area for a particular slight depression and potential pothole results in higher velocity of runoff and a greater tendency to form rivulets which may drain or even obscure the slight depression. Another factor may be the longitudinal orientation of traffic which tends to pound down generally longitudinal spillways for slight depressions or birdbaths left from grading or shaping operations. High velocities of runoff are not an unmixed blessing, of course, since erosion also causes maintenance problems on soil-aggregate roads. The importance of transverse slope in heading surface water toward the side of the roadbed must not be neglected, but perhaps the influence of longitudinal grade when selecting minimum tolerable crown on soil-aggregate roads deserves more attention than it has received in research efforts as well as in standard practice.

Implications. —The selection of minimum tolerable crown on the basis of some value of resultant slope is less than an ideal approach, if only because frequency and severity of potholing appear to be related to orientation as well as amount of this maximum resultant slope. In addition to acknowledging variation in potholing tendency with variation in orientation of maximum resultant slope, it should be noted that runoff may, in reality, deviate from the maximum resultant slope. Such deviation would perhaps most frequently be caused by the longitudinal velocity component of runoff on grades

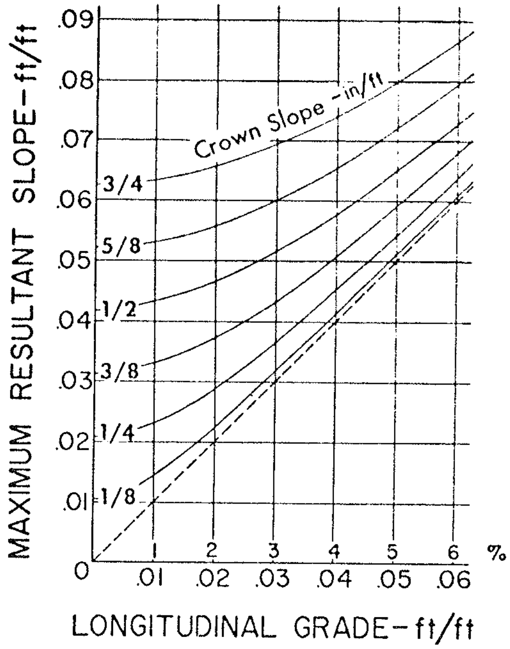


Figure 8. Maximum resultant slope for variations in longitudinal grade and crown slope.

where there is flattened crown at the road centerline. Until additional study suggests a more reliable design characteristic than maximum resultant slope, however, it may be more valid to base selection of minimum tolerable crown in a particular situation (for an acceptable frequency and severity of potholing) on this characteristic than to select minimum tolerable crown without any attention to longitudinal grade.

Figures 6 and 8 may be useful as guides for design. Assuming that about 9 to 1 odds against definite or severe potholing are acceptable, a minimum tolerable maximum resultant slope in the range of 0.04 to 0.05 ft/ft might be ½ in./ft (Fig. 6). Where longitudinal grade is absolutely flat, a minimum crown slope of ½ in./ft would, of course, be indicated. Where there is some longitudinal gradient, Figure 8 indicates the extent to which crown might be lessened and still maintain the desired resultant slope. For example, if longitudinal grade is about 2 percent, minimum crown slope could probably be between ⅜ and ½ in./ft, and if the grade is about 4 percent, the slope could be as low as ⅛ in./ft. Although zero crown is shown as a dotted line in Figure 8, some crown would be necessary to keep surface runoff heading for the edge of the roadbed.

Erosion considerations may well dictate a greater crown slope than that which would be needed for protection against potholing. Just as there may be minimum crowns for control of potholing and/or erosion, there may also be maximum crowns for safety and convenience in vehicle operation. In suggesting that minimum tolerable crown (from a potholing viewpoint) is related to longitudinal grade, it is not suggested that a crown slope should be changed with every minor change in gradient. Frequent changes in crown may be not only impractical from a maintenance operations viewpoint but undesirable from the viewpoint of road-user safety.

TRANSVERSE TERRAIN SLOPE VS TILT OF ROAD CROWN

Soil-aggregate roads on sidehill locations are more likely to be potholed on the uphill than downhill side of the road. Such situations usually reflect, as in Figure 9, a lesser crown slope on the uphill side. It was hypothesized that crown slope should tend to be flatter on the uphill side of the road because of a downhill tilt of the crown caused by a misjudgment of vertical (or horizontal) datum in sidehill terrain by a grader man shaping a road by eye.

Study Method

To explore whether there is, in fact, a higher frequency of downhill than uphill tilt of road crown and whether amount of tilt is related to transverse terrain slope, measurements of the traveled way cross-section and transverse terrain slope were made at some 66 locations. These locations, on eight town highways in Tompkins County, were taken semi-routinely at 0.1-mi intervals and at intermediate points where transverse terrain had dictated a cut-fill cross-section; data on curves were omitted because of the probability of intentional banking or warping of the cross-section.

Measurement of Crown.—Crown measurements were made with the liquid-level device shown in Figure 10. With the gallon jug placed approximately (by eye) at the center

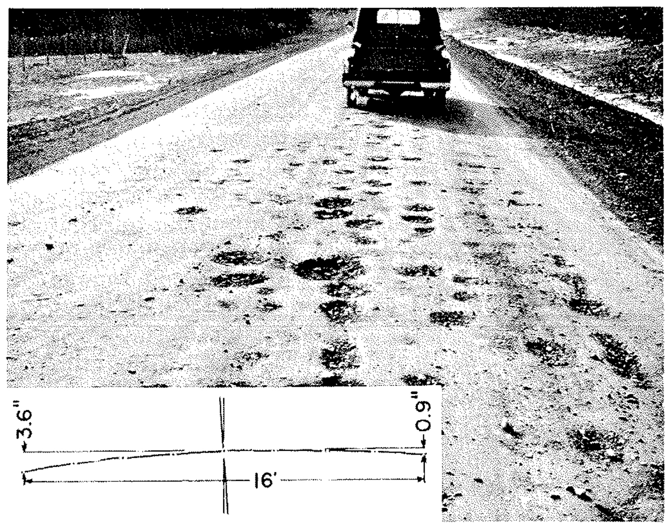


Figure 9. Potholing on uphill side of soil-aggregate road.

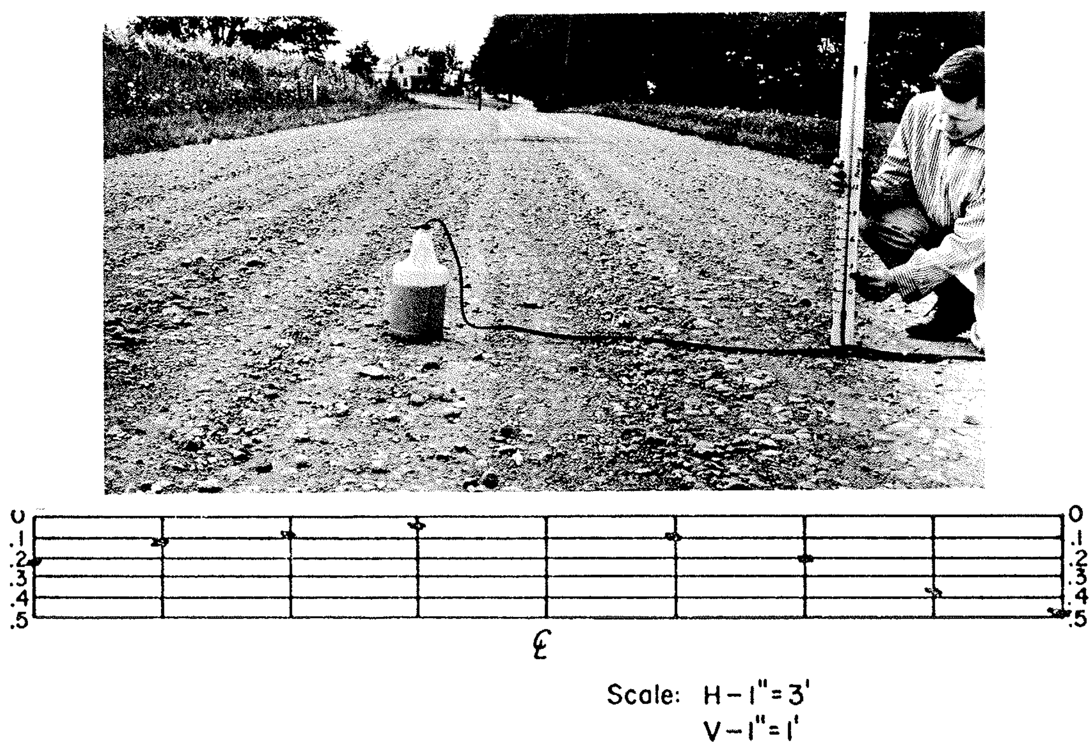


Figure 10. Measurement and recording of crown.

line of the road, readings of the drop in elevation were taken at intervals of 2 ft to the left and right of the center line. The readings were plotted on a record card, shown in Figure 10.

Computation of Crown Tilt.—Tilt of crown was computed as illustrated in Figure 11. A straight line of best fit was drawn through the plotted road surface elevations on each side of the road. At the intersection of these straight lines representing average crown

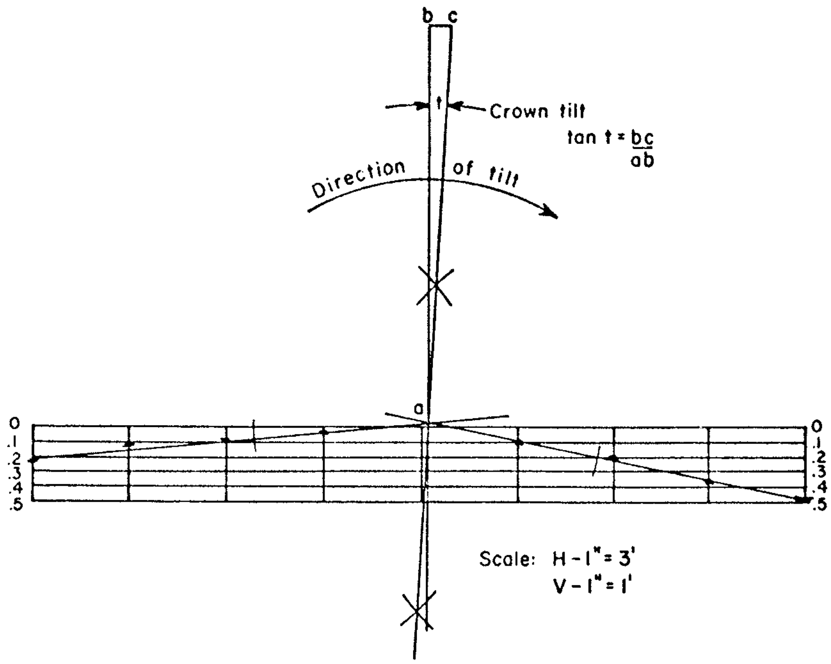


Figure 11. Determination of crown tilt.

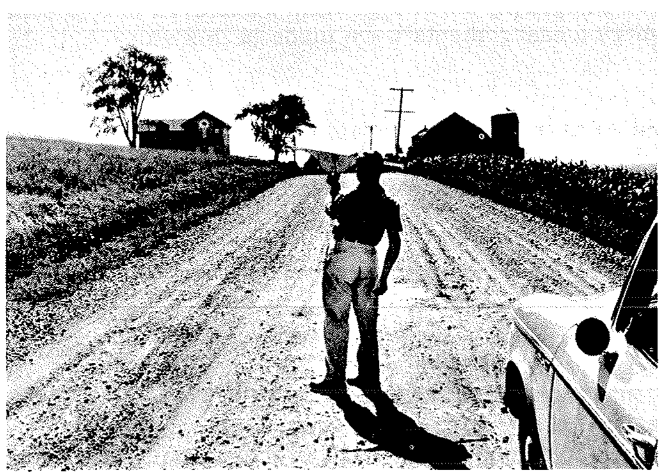


Figure 12. Measuring transverse terrain slope.

slope were erected vertical lines (ab and ac) bisecting the angle formed by the lines of average crown slope. The angle (t) between lines ab and ac was computed from scaled distances bc and ab. It was necessary, of course, to adjust the ratio of these scaled distances to correct for the 3:1 ratio of vertical to horizontal scale on the plots of crown cross-section. Direction of crown tilt, whether uphill or downhill, was noted.

Measurement of Transverse Terrain Slope.—Average terrain slope was determined with a protractor as shown in Figure 12. The observer stationed himself so as to be able to align the flat edge of the protractor with average slope of terrain at the location

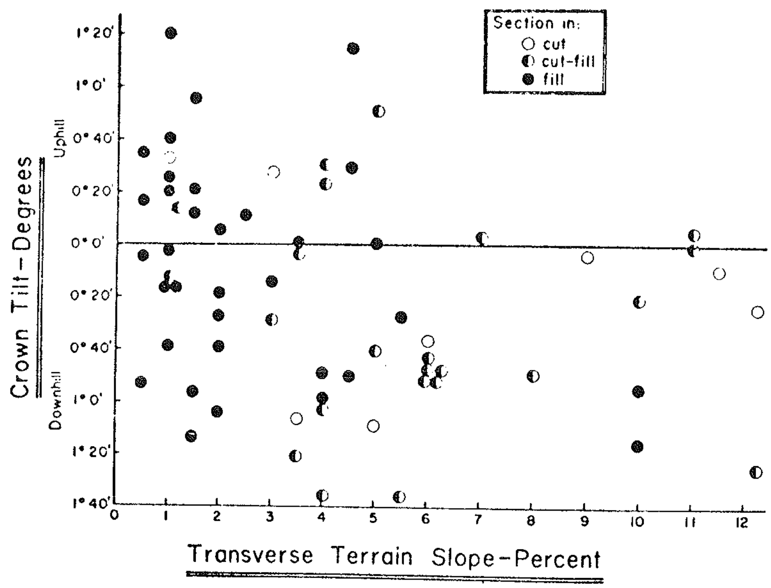


Figure 13. Crown tilt vs transverse terrain slope.

where crown measurements had been made; slope was recorded to the nearest ½ percent. Although for simplicity, this terrain slope was measured at the location of crown measurement, it is recognized that a grader operator's concept of vertical (or horizontal) was influenced by topography as he approached and even looked some distance beyond the points where measurements were made in this study.

Results

Crown tilt in relation to transverse terrain slope at the 66 points included in this study is summarized in Figure 13. Points on the chart are coded to indicate whether the road cross-section at that point was in cut (8 points), on fill (35 points), or on cut-fill (23 points).

Interpretation of Results

Considering all 66 points together (ignoring whether sections were in cut, fill or cut-fill), it is noted in Figure 13 that for transverse terrain slopes of 2 percent or less, there was equal frequency of uphill and downhill tilt (13:13). For transverse slopes of 2½ through 5½ percent, there were 14 downhill tilts in contrast to 7 uphill tilts and 2 sections without perceptible tilt. For transverse terrain slopes of 6 percent and over, there was considerably higher frequency of tilt in the downhill direction; in these situations, 15 cross-sections were tilted downhill in contrast to only 2 uphill. Although frequency of downhill tilt appears generally to be related to transverse terrain slope, the amount of tilt does not.

There are too few points in Figure 13 to make any conclusive statements concerning relative tendency to tilt road crown downhill on cut, fill, and cut-fill cross-sections. It is noted, however, that average tilt for the cut-fill cross-sections was 0° 30' for the fill sections and 0° 9' for the cut sections; average tilt in each case was in the downhill direction. Mention of average tilt should be qualified by average transverse terrain slope for each type of cross-section; these were 5.8, 2.7 and 5.9 percent for the cut-fill, fill and cut cross-sections, respectively.

The significance of such small angles of tilt may be questioned. It should perhaps be pointed out that a road with intended crown slopes of ½ in./ft on each side of the centerline would need to be tilted downhill less than 2° to reduce the crown slope on the uphill side to less than ¼ in./ft.

CONCLUSIONS

Potholing of soil-aggregate roads, though generally related to crown slope, appears to be more closely related to some resultant of crown slope and longitudinal grade. The maximum resultant slope, though less than an ideal design characteristic, may be useful as a guide in selecting minimum tolerable crown. Figures 6 and 8 provide a guide to selection of the lowest maximum resultant slope for an acceptable risk of potholing and, for a given longitudinal grade, determination of the minimum crown to produce this resultant slope. Although soil-aggregate roads on longitudinal grades steeper than about 2½ percent were observed to have potholed very little, irrespective of crown slope, the benefits of crown in minimizing erosion problems cannot be disregarded.

There is evidence that grader operators shaping roads by eye in sidehill terrain tend to tilt the crown in the downhill direction. Probably due to a misconception of vertical, a practical implication is a less-than-desired crown slope on the uphill side and increased vulnerability to potholing. Sidehill locations should be an invitation to periodic checks on crown slope during grading or shaping operations.

ACKNOWLEDGMENTS

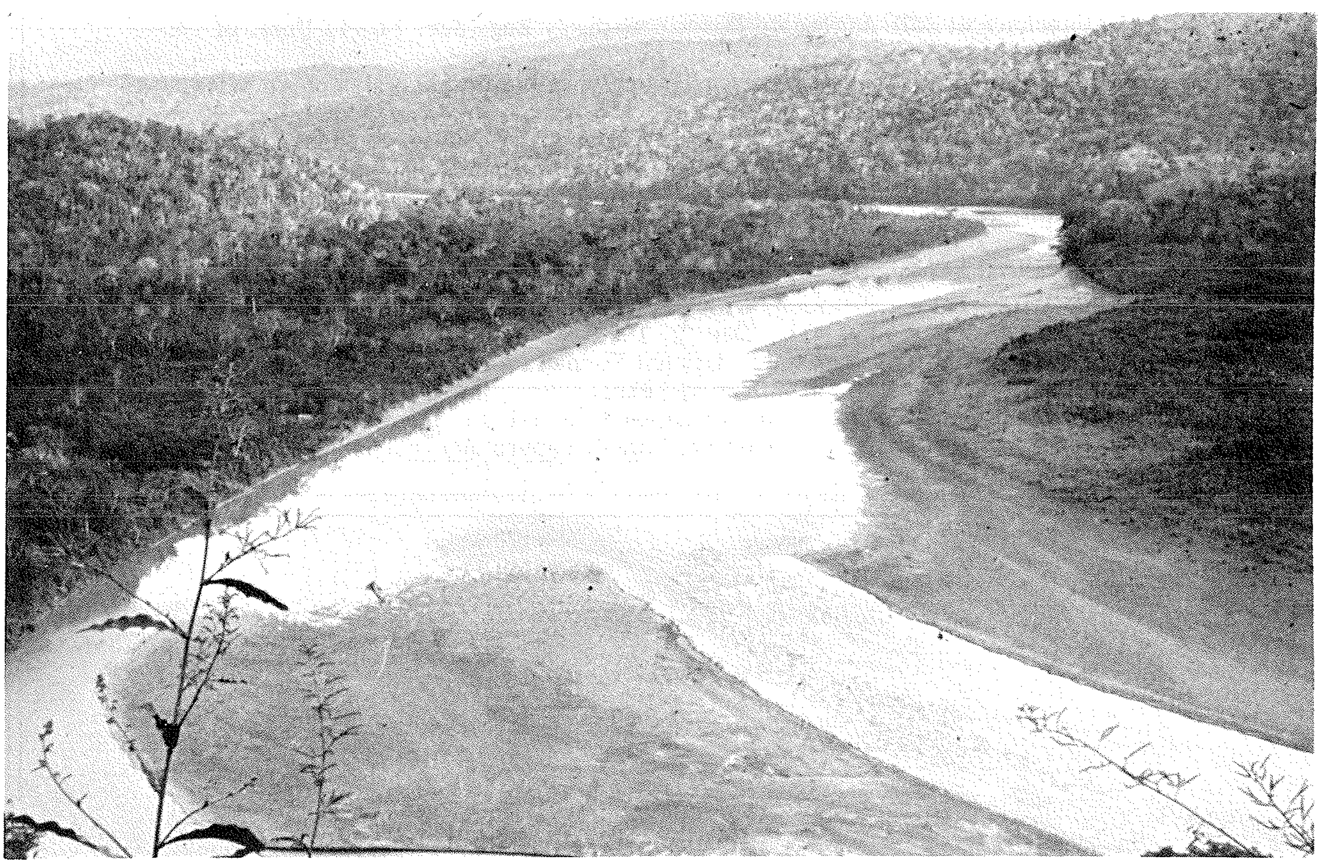
The author gratefully acknowledges the assistance of C. D. Ditmars, F. E. Blair, R. L. Hansen, Prof. W. W. Gunkel, Prof. T. D. Lewis, H. L. D. Weldon, Jane Jorgensen, Josephine Wilson and Mr. Hansen.

REFERENCES

1. Huang, E. Y. Manual of Current Practice for the Design, Construction, and Maintenance of Soil-Aggregate Roads. Highway Eng. Ser. No. 1, Univ. of Illinois, 1959.
2. Public Roads Administration. Highway Practice in the United States of America. 1949.
3. Huang, E. Y. A Study of Occurrence of Potholes and Washboards on Soil-Aggregate Roads. Highway Research Board Bull. 282, pp. 135-159, 1961.
4. Burggraf, F. Importance of Suitable Crown on Calcium-Chloride Stabilized Roads. Calcium Chloride Assoc., 1935.
5. Green, P. E. A Review of Chicago Paving Practice. Proc. ASCE, Vol. 35, No. 6, p. 626, Aug. 1909.
6. Warren, G. C. Paving Practices with Respect to Crown of Roadway Pavements. Eng. News, Vol. 62, p. 611, Dec. 2, 1909.
7. Zahniser, G. B. Suggestions for a Rational Formula for Street Pavement Crowns. Eng. News, Vol. 63, p. 516, May 5, 1910.
8. Progress Report of the Special Committee on Materials for Road Construction and on Standards for Their Test and Use. ASCE Papers and Discussions, Vol. 42, p. 1615, 1916.

180

Water-deposited gravel source along Rio Beni, Bolivia.



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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→ 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
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→ 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.

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SELECTED TEXT REFERENCES

Reference 1
LOW COST ROADS

Kelley, E.F. Lexington, Virginia: Proceedings of the second annual Virginia Highway Conference; 1948. variable paging. (November 11, 12, 13, 1948).

Out-of-print; may be consulted at U.S. Department of Transportation, Library Services Division, Room 2200, 400 Seventh Street, S.W., Washington, DC 20590.

The history of road construction procedures is briefly reviewed, and progress in the knowledge of the engineering properties of soils is discussed. The most important properties of a soil for highway construction are identified as its size grading, its plasticity, and its optimum moisture content. The principles which should be observed in the construction of low-volume roads are set forth and include a consideration of subgrade strength, proper compaction of fills, proper use of material excavated from cuts, treatment of subgrades in cut sections, and the division of the pavement structure into a sub-base, if required, a base, and a wearing surface. Granular or mechanical stabilization and the use of granular-stabilized mixtures as base courses for bituminous surfaces and also for wearing courses are discussed. Although the specification requirements for these respective courses differ in their binder content, it is possible to design a mixture which is satisfactory for both a base-course and a surface-course application. Other types of stabilization which may be considered include the use of portland cement with fine-grained soils and sand-clay gravel. Hydrated lime has also been successfully used. Three types of bituminous stabilization with tar, cutback asphalt, or asphalt emulsion are described: soil bituminous stabilization, sand-bituminous stabilization, and waterproofed granular stabilization. The performance of stabilized base courses and subsurface drainage problems are discussed, and comments are made on the trench method of base-course construction.

Reference 2
LOW COST ROADS; DESIGN, CONSTRUCTION AND MAINTENANCE

Odier, L.; Millard, R.S.; dos Santos, Pimentel; Mehra, S.R. London: Butterworths: 1971. 158 p. (Sponsored by UNESCO).

Out-of-print; may be consulted at U.S. Department of Transportation, Library Services Division, Room 2200, 400 Seventh Street, S.W., Washington, DC 20590.

Engineering codes relating to road planning, design, construction, materials, and maintenance for use in the developing countries are presented. Basic principles of road construction and maintenance policy, including social and economic aspects, master plan and feasibility studies, as well as stage construction, are covered. Traffic and design speeds, design related to vertical alignment and horizontal alignment, and cross-section elements are discussed; design principles for unimproved roads, improved roads, roads with permanent surfaces, and flexible pavements are set forth. The drainage of the road is considered including the control of erosion and the stability of embankments and cuttings. Defensive measures during wet-weather construction are noted. The location and waterway requirements for bridge culverts are discussed, and the principal factors to be considered in the design of bridge foundations and structures are indicated. Notes are provided on construction operations and plant which include preliminary and detailed surveys, setting out, earthworks, compaction, quarrying, soil stabilization, bituminous surfacing, and concreting. The discussion of road maintenance distinguishes between short-term, largely manual, maintenance and long-term maintenance usually involving the use of mechanical equipment. Methods of estimating costs are outlined and special consideration is given to the choice between manual and mechanized methods or combinations of the two.

Reference 3
LOCATION AND EVALUATION OF GRAVEL SOURCES FOR HIGHWAY USE

Spencer, James W.; Dart, Olin K., Jr. Ithaca, New York: Cornell University, Department of Agricultural Engineering; March 1956. 53 p. (Short Course).

Out-of-print; may be consulted at U.S. Department of Transportation, Library Services Division, Room 2200, 400 Seventh Street, S.W., Washington, DC 20590.

The formation of glacial gravel deposits (eskers, kames, beach ridges, deltas, out-wash terraces) and deposits from present-day streams is described, and profile development on gravel landforms (formation of overburden and the importance of the thickness of overburden) is discussed. The methods of locating possible gravel deposits reviewed here include the checking of available agricultural soils maps and the available geologic information for the area. Aerial photographs are noted as the most complete inventory of possible gravel deposits. The advantages of aerial photographs, their availability, and costs are discussed. The orientation of the aerial photographs for study and the recognition of gravel landforms from such photographs are described. Characteristics that must be noted about a possible gravel deposit are listed, and questions to be considered before opening the deposit are reviewed. Factors that must be considered in evaluating the gravel resource are detailed and include depth of overburden, character of gravel particles, maximum gravel sizes expected, gradation of granular material (desirable specifications, sampling and preparation of sample for testing, testing the sample for gradation), plasticity of fines, position of water table, and degree of cementation. Comments are also made on the combining of materials for satisfactory gradation.

Reference 4
STANDARD SPECIFICATIONS FOR CONSTRUCTION OF ROADS AND BRIDGES ON FEDERAL HIGHWAY PROJECTS. FP-61

U.S. Department of Transportation, Federal Highway Administration Bureau of Public Roads. Washington, DC; 1961 January (Reprinted 1968 March). 383 p.

Out-of-print; may be consulted at U.S. Department of

Transportation, Library Services Division, Room 2200, 400 Seventh Street, S.W., Washington, DC 20590.

This book contains specifications for those items of work, materials, and construction methods that are generally applicable to direct the Federal Highway contract, but the specifications are adaptable for use in other highway construction projects. The book reviews general requirements such as bidding, the award and execution of the contract, the scope and control of work, the control of materials, legal and public responsibilities, prosecution and progress of work, the measurement of work quantities, and payments. The major section of the book is devoted to construction details related to earthwork, bases, surfacing and pavements, structures, and incidentals such as riprap, underdrains, manholes, sidewalks, cattle guards, guardrails, seeding and sprigging, etc. A later edition, FP-74, is available from the Superintendent of Documents, U.S. Government Printing Office (Washington, DC 20402), but it does not include specifications for gravel surface courses; a Spanish translation of this edition is also available. It is expected that another edition, FP-79, will be available in 1979.

Reference 5
ROAD RESEARCH: ROADMAKING GRAVELS AND SOILS IN CENTRAL AFRICA

Clare, K.E. Harmondsworth, U.K.: Great Britain Road Research Laboratory, Tropical Section; 1960. 44 p. (Overseas Bulletin No. 12).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG 11 6AU, U.K.

The more important roadmaking gravels and soils occurring in the Central African Federation are described, and their known engineering characteristics are reviewed. The bulletin also discusses how knowledge of these factors may be used in locating potential sources of roadmaking materials. Some of the factors influencing soil-formation in Central Africa are briefly discussed, and the gravels and soils encountered in the area are grouped into three categories depending on the rainfall. In low rainfall areas the petrological characteristics of the underlying rock have a great influence on the properties of the soils derived from it, and sub-categories can be recognized on this basis. Although the pavement rock is important, the large-scale geological structure of the land in areas of intermediate or high rainfall affects soil formation to a greater degree by influencing drainage. Although sub-categories have yet to be distinguished here, it is thought that the catena concept (a series of soils on the same parent rock, but under different drainage conditions) may be useful. Effort in locating gravel deposits can be greatly reduced by examination of geological, agricultural and forestry maps and of landforms revealed by aerial photographs. The occurrence of mine waste materials useful for building roads in economically important areas is noted.

Reference 6
LATERITIC GRAVEL EVALUATION FOR ROAD CONSTRUCTION

de Graft-Johnson, J.W.S.; Bhatia, Harbhajan; Hamonond, A.A. Journal of the Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers. American Society of Civil Engineers, New York, New York; Vol. 98 No. SM11; Proceedings Paper 9375; 1972 November; pp. 1245-1265.

Order from: American Society of Civil Engineers, 345 East 47th Street, New York, New York 10017.

This study investigated the factors responsible for the formation and mechanical strength of coarse laterite gravels in Ghana and evaluated laterites from four climatic regions (coastal Savannah, rain forest, forest, interior Savannah), which are typical of most laterites found in the tropics. The geological formations associated with the gravel formations are identified as acid igneous (granite, gneiss, quartzite); basic igneous (basalt, gabro); metamorphic (shale, phyllite, schist); and sedimentary (sandstone, limestone). Physical, chemical, mechanical, durability, and weathering tests are described. On the basis of test results and field performance data, a relative rating of lateritic gravels is suggested. The tests used to rate the gravels included the aggregate impact value (modified from the British standard), the aggregate impact value (British standard), the Los Angeles abrasion value, water absorption, and the specific gravity test. The study showed that topography and geology had considerable influence on the mechanical properties of residual materials. The primary residual gravels from well-drained profiles generally had high concentrations of iron and alumina. Such rocks aid in forming lateritic gravels of relatively better mechanical strength. Significant statistical correlations were developed between various physical properties and mechanical strength. A very significant correlation exists between the ratio of oxides of silica to iron and the mechanical strength.

Reference 7
LATERITE AND LATERITIC SOILS AND OTHER PROBLEM SOILS OF THE TROPICS; AN ENGINEERING EVALUATION AND HIGHWAY DESIGN STUDY FOR UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT, VOLUME II, INSTRUCTIONAL MANUAL

Morin, W.J.; Todor, Peter C. Baltimore, Maryland; Lyon Associates, Inc.; 1975. 92 p. (Performed jointly with the Brazilian National Highway Department Road Research Institute; report # PB-267 263).

Order from: National Technical Information Service 5285 Port Royal Road, Springfield, Virginia 22161.

This is an instructional manual for field inspectors and laboratory technicians who work on engineering and construction projects that utilize tropical soils. The engineering descriptions, procedures, and specifications described are a consolidation of information obtained from Volume I: Laterite and Lateritic Soils and Other Problem Soils of the Tropics (see Reference 14). Both volumes are the final report of a worldwide tropical soil study. This manual summarizes background information (on soils classifications, physical and engineering properties, red tropical soils, and volcanic soils) and reviews test procedures for the evaluation of tropical soil properties (preparation of soils samples, particle size analysis, liquid limit, plastic limit and plasticity index, moisture density relations, specific gravity, California bearing ratio, sand equivalent value, and test for durability of aggregates). Details are given of flexible pavement design (an appendix describes the determination of the coefficient of variation) and the stabilization of selected tropical soils. Design considerations for roads over tropical black clays and a recommended design procedure are set forth. Specifications for sub-base, base- and surface-course materials, for excavation of borrow areas, compaction equipment and compaction requirements, and for materials and construction in tropical climates are also presented.

Reference 8
BLADING AGGREGATE SURFACES

Washington, DC: National Association of Counties, Research Foundation; 1974. 54 p. (National Association of County Engineers Training Guide Series).

Order from: National Association of Counties, 1735 New York Avenue, N.W., Washington, DC 20006.

This guide provides tips for grade operators on blading aggregate-surfaced roads and can be helpful for training on the grader at the job site. The booklet, which can help crews do a better maintenance job and so reduce the cost of keeping aggregate-surfaced roads in good condition, can be useful for new and experienced foremen, motor grader operators, and multi-purpose crews working such roads. The areas covered in this booklet include the blending of aggregates, the equipment used on aggregate-surfaced roads, smoothing, reshaping, and blading under special conditions (intersections of aggregate-surfaced roads, intersection of aggregate-surfaced and paved roads, road crossing railroad tracks, road crossing bridges, at driveways, on hilltops - crests, at bottom of valleys-sags, and curved roads). Condition of the blade and personnel and equipment safety are also considered.

Reference 9
CROWN ON SOIL-AGGREGATE ROADS

Spencer, J.W. Road Crown, Testing, Compaction, Soil Bitumen; The Alaska Earthquake: 7 Reports. Presented at the 43rd Annual Meeting January 13-17, 1964 and the 44th Annual Meeting January 11-15, 1965. Washington, DC: Highway Research Board; 1965; pp 48-58. (Highway Research Record No. 91).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This paper summarizes a study of the relationship between road surface slopes and the severity of potholing on soil-aggregate roads. Although practice in crowning soil-aggregate roads often disregards the influence of longitudinal grade, the study suggests that the effect of grade on the potholing tendency is considerably more than a token effect; a resultant of transverse slope and longitudinal grade appears to be more strongly related to presence and severity of potholing than is crown slope alone. Because a tendency to tilt road crown downhill in sidehill locations can result in flatter crown (and often more severe potholing) on the uphill side of the road, caution in "by eye" shaping of soil-aggregate roads in such locations is suggested.

ADDITIONAL REFERENCES

Reference 10
DENSITY STANDARDS FOR FIELD COMPACTION OF GRANULAR BASES AND SUBBASES

Roston, J.P.; Roberts, F.L.; Baron, W. Washington, DC: Transportation Research Board, 1976. 73 p. (National Cooperative Highway Research Program Report 172).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

This report presents the findings of a study to evaluate current procedures and criteria for the setting of density standards to control compaction during construction of granular base and sub-base courses and to develop more appropriate procedures and criteria. An extensive laboratory test program was carried out, involving seven methods of compaction and four materials under various moisture conditions and gradations. The aggregates tested were a granite-gneiss, a crushed gravel, a dolomitic limestone, and a basalt. A prototype field compact testing program was conducted using the same four aggregates. Procedures and criteria are proposed for use by highway agencies.

Reference 11
PROCEEDINGS FROM A CONFERENCE OF GRADED AGGREGATE BASE MATERIALS IN FLEXIBLE PAVEMENTS

National Crushed Stone Association; National Sand and Gravel Association; National Slag Association; March 25-26, 1974; variable paging.

Order from: National Crushed Stone Association, 1415 Elliot Place, N.W., Washington, DC 20007.

Papers are presented which deal with graded aggregate bases as logical components of serviceable flexible pavements and with the ways by which aggregates can be used to best advantage. Design considerations and time-tested design practices are reviewed. A computerized approach permitting multiple choices considering 12 classes of input variables is described, as well as a simplified treatment of the complex problem of defining the functions of various pavement layers. Design considerations applicable to areas where severe frost action is to be expected are thoroughly reviewed, and the effect of gradation on permeability is graphically demonstrated. A straightforward and practical system of flexible pavement design is summarized. The Corps of Engineers continuing program of pavement evaluation is described and some 14 modifications to the Corps' CBR design system are listed. The second session, which was concerned with materials and construction requirements to enhance the probability of successful performance, covered such topics as the relation of graded aggregate characteristics to their behavior under various conditions of load and environment and the critical role of compaction in the performance of graded aggregate bases. An informal panel discussion covered experiences in four states. The final session dealt with methods of production, construction, and acceptance testing. Quality control and quality assurance were covered in this session.

Reference 12
THE DESIGN OF LOW-COST PAVEMENTS IN ARID AREAS

Bofinger, H.E. Crowthorne, U.K.: Great Britain Transport and Road Research Laboratory; 1974. 16 p. (PA 77/74 Paper presented at Conference on Low-Cost Roads, Kuwait, November 25-28, 1974).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U.K.

This paper reviews the experience gained by the overseas unit of TRRL and other authorities in the design, construction, and performance of low-cost road pavements in arid environments. It covers earth, gravel and surface-dressed roads and discusses the engineering principles of stage construction, i.e. the subsequent upgrading of pavements to meet the structural requirements for increased traffic loadings. The strength of many subgrade materials is sensitive to moisture changes, and the value at which the strength of the subgrade is estimated for pavement design is therefore very important, particularly in arid environments where subgrades are dry and quite strong. Several methods have been used for determining the relevant moisture content. These are described and the sensitivity of the thickness design to changes in subgrade strength is discussed. In arid areas, there may be insufficient water to enable the formation to be compacted at the optimum moisture content. The compaction of soils at moisture contents lower than the optimum and the resulting properties of the compacted material are described. Types of base which require no water for construction, such as dry-bound macadam, are particularly useful in arid climates. A reliable construction procedure for dry-bound macadam bases is included.

Reference 13
GEOLOGY AND GEOTECHNICAL PROPERTIES OF LATERITE GRAVEL

Krinitzsky, Ellis L.; Patrick, David M.; Townsend, Frank C. Vicksburg, Mississippi: U.S. Army Engineer Waterways Experiment Station, Soils and Pavements Laboratory; 1976 June. 214 p. (Final Report-Wes-TR-S-76-5; report #AD-A026505/8ST).

Order from: National Technical Information Service 5285 Port Royal Road, Springfield, Virginia 22161.

Laterization processes were studied and samples of laterite gravel were collected at 40 sites in Thailand, Australia, Brazil, Ghana, Portuguese Angola, and Georgia (USA) to determine classification, field associations, genesis, and engineering properties important in road and airfield construction. Lateritic soils are self-hardening and may contain laterite rock or nodular laterite gravel. Tropical soils that are not self-hardening and that lack appreciable laterite rock or laterite gravel are called tropical red soils. The soils studied in this report classify as sands and gravels in the Unified Soil Classification System. Generally they are poorly sorted, strongly fine-skewed, leptokurtic, and, on the average, contain approximately 12 percent fines. These soils have originated by the hydrolytic destruction of primary silicate minerals in warm, tropical to subtropical weathering environments that exhibit distinct wet and dry seasons, and are generally free draining. Laterite gravel is of primary importance in construction. Laterite rock requires crushing, and self-hardening laterite may be difficult to identify and thus may be confused with tropical red soils. Foreign engineers have found that two official U.S. specifications are too restrictive. They have developed base and sub-base specifications suitable for road and airfield construction using laterite gravel.

Reference 14
LATERITE AND LATERITIC SOILS AND OTHER PROBLEM SOILS OF THE TROPICS: AN ENGINEERING EVALUATION AND HIGHWAY DESIGN STUDY FOR UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT, VOLUME I

Morin, W.J.; Todor, Peter C. Baltimore, Maryland: Lyon Associates, Inc.; 1975. 369 p. (Performed jointly with the Brazilian National Highway Department, Road Research Institute; report # PB-267 262).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

This product of 5 years of worldwide research gives a comprehensive description of tropical soils including their chemical, mineralogical and physical properties and engineering behaviors, as well as their appropriate classification. A new pavement design procedure developed in the tropics for tropical application is described, and a practical range of strength values attainable by stabilizing tropical soils is given. Specifications for common materials used in highway construction and methods of working with and using problem soils such as black clay and volcanic soils are also described. All tropically weathered red residual soils including true lateritic soils as well as those undergoing laterization were studied. The more descriptive pedological classifications are preferred, and it is noted that variations in properties among groups in different classification systems should be established in each country. Correlations of properties of red tropical soils are established that can be used in identification of soil type and preliminary assessments of engineering properties. The special pretreatments and procedures for soils over volcanic rocks and the use of the one-point liquid limit test for tropical soils are discussed. The findings are reported and recommendations are made regarding the following: the soil compaction curve, the establishment of the CBR, maximum deflection values for standard axle applications, structural coefficients, flexible pavement design, design tables, overlay design, unpaved road design, Los Angeles abrasion and aggregate impact test, shale durability test, repetitive triaxial load tests, soil stabilization with cement, lime, and asphalt, African black clays, classification of terrain by remote sensors, and specifications.

Reference 15
THE KENYA ROAD TRANSPORT COST STUDY: RESEARCH AND ROAD DETERIORATION

Hodges, J.W.; Rolt, J.; Jones, R.E. Crowthorne, U.K.: Great Britain Transport and Road Research Laboratory, Overseas Unit; 1975. 56 p. (TRRL Laboratory Report 673).

Order from: Transport and Road Research Laboratory, Crowthorne, Berkshire RG11 6AU, U.K.

This report describes a study of the performance of paved and unpaved roads which was undertaken in Kenya as a part of a larger study designed to provide suitable relationships for use in a computer model capable of estimating the construction costs, maintenance costs and road-user costs throughout the life of a road in a developing country. The paved-road sample consisted of thirty-nine sections located on surface-dressed roads with cement-stabilized bases and ten sections located on asphaltic concrete roads with crushed stone bases. The unpaved-road sample consisted of thirty-eight test sections located on properly engineered gravel roads (lateritic, quartzitic, volcanic and coral) and eight sections on earth roads. The deterioration of the surface of the paved roads was quantified in terms of surface roughness, amount of cracking, and depth of ruts. These parameters together with the transient deflections and the CBR and the moisture content of the various pavement layers were monitored for a period of up to four years. The deterioration of unpaved roads was quantified in terms of surface roughness, depth of ruts, depth of loose surface material, and the thickness of the gravel layer. These parameters were monitored for a period of two years.

Reference 16
SIMULATION OF THE ROAD-CORRUGATION PHENOMENON

Riley, J.G.; Furry, R.B. Soil Compaction and Corrugations. Highway Research Board, Washington, DC; 1973; pp. 54-62 (Highway Research Record 438).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

A mathematical model was formulated to simulate the phenomenon of washboarding on unpaved roads. Both the vehicle and the road components were treated as spring-mass-damper assemblies. A digital computer program was written to solve the equations of motion of the system; displacement forcing functions represented irregularities in the path of a moving wheel. The program was executed with varying road and vehicle characteristics, and thus the relations among those primary characteristics and washboard presence and dimensions were established and then verified by physical model tests in the laboratory. In both the simulation and the physical tests, the primary and secondary variables were expressed as dimensionless ratios. Results showed that vehicle weight, tire pressure, and vehicle speed affected primarily the wavelength of the corrugations but that there were maximum or minimum values of those parameters above or below which corrugations would not occur. Results also showed that, for the particular surface materials used, washboarding occurred more readily in a material with a relatively high specific damping capacity and that this property was related to particle shape, effective size, and uniformity coefficient.

Reference 17
A STUDY OF OCCURRENCE OF POTHOLES AND WASHBOARDS ON SOIL-AGGREGATE ROADS

Huang, Eugene Y. Influence of Stabilizers on Properties of Soils and Soil-Aggregate Mixtures. Highway Research Board, Washington, DC; 1961, pp. 135-159 (Bulletin 282).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This report presents the results of a study aimed at determining some of the circumstances associated with the occurrence of potholes and washboards on soil-aggregate roads. The study consisted of a statistical analysis of the qualitative data obtained from a road condition survey involving road surfaces of the coarse-graded aggregate type composed of mineral aggregate such as gravel or crushed stone and some binder material. Results of the study indicate that the occurrence of potholes and washboards was definitely associated with the volume of traffic, the type of surface material, and the drainage condition of the road surface. Although the findings are admittedly limited to the types and conditions of the roads studied, it is hoped that the data may be of value in further understanding the formation of potholes and washboards.

Reference 18
CONFORMACION A CUCHILLA DE SUPERFICIES DE AGREGADOS

U.S. Agency for International Development, Washington, DC. 1976. 52 p.

Order from: U.S. Agency for International Development, Office of Engineering, Washington, DC 20523.

This is a translation of the publication, Blading Aggregate Surfaces: (NACE 1974). See Reference 9.

Reference 19
PITS AND QUARRIES

U.S. Department of the Army. Washington, DC; 15 December 1967. 142 p. (Technical Manual 5-332).

Order from: U.S. Department of the Army, Army AG Publications Center, 1655 Woodson Road, St. Louis, Missouri 63114.

This manual, which is designed for personnel engaged in the selection and operation of pits and quarries, outlines methods and procedures used in explorations for pits and quarries, and provides information on the equipment required to operate pits and to supply crushed stone. Site selection is discussed with details of preliminary and field reconnaissance as well as details of evaluation of the pit and quarry sites. Quarry layout and development are also detailed. The review of pit operations covers site preparation, excavation with scrapers, excavation with power shovel and trucks or front loader and trucks, excavation with draglines, and loading ramps. Cut design blasting and quarry records in rock excavation are described. Soft rock operations discussed in the publication cover coral, tuff, caliche, and laterite. A sample quarry problem, information on retaining walls, and further advice on exploration and operation of pits and quarries are included 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

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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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Index

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.