TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

COMPENDIUM 2

Drainage and Geological Considerations in Highway Location

Consideraciones de Drenaje y Geológicas en la Ubicación de Carreteras

Considérations sur les Facteurs de Drainage et de Géologie qui Influencent le Choix de l'Emplacement d'une Route

prepared under contract AID/OTR-C-1591, project 931-1116,
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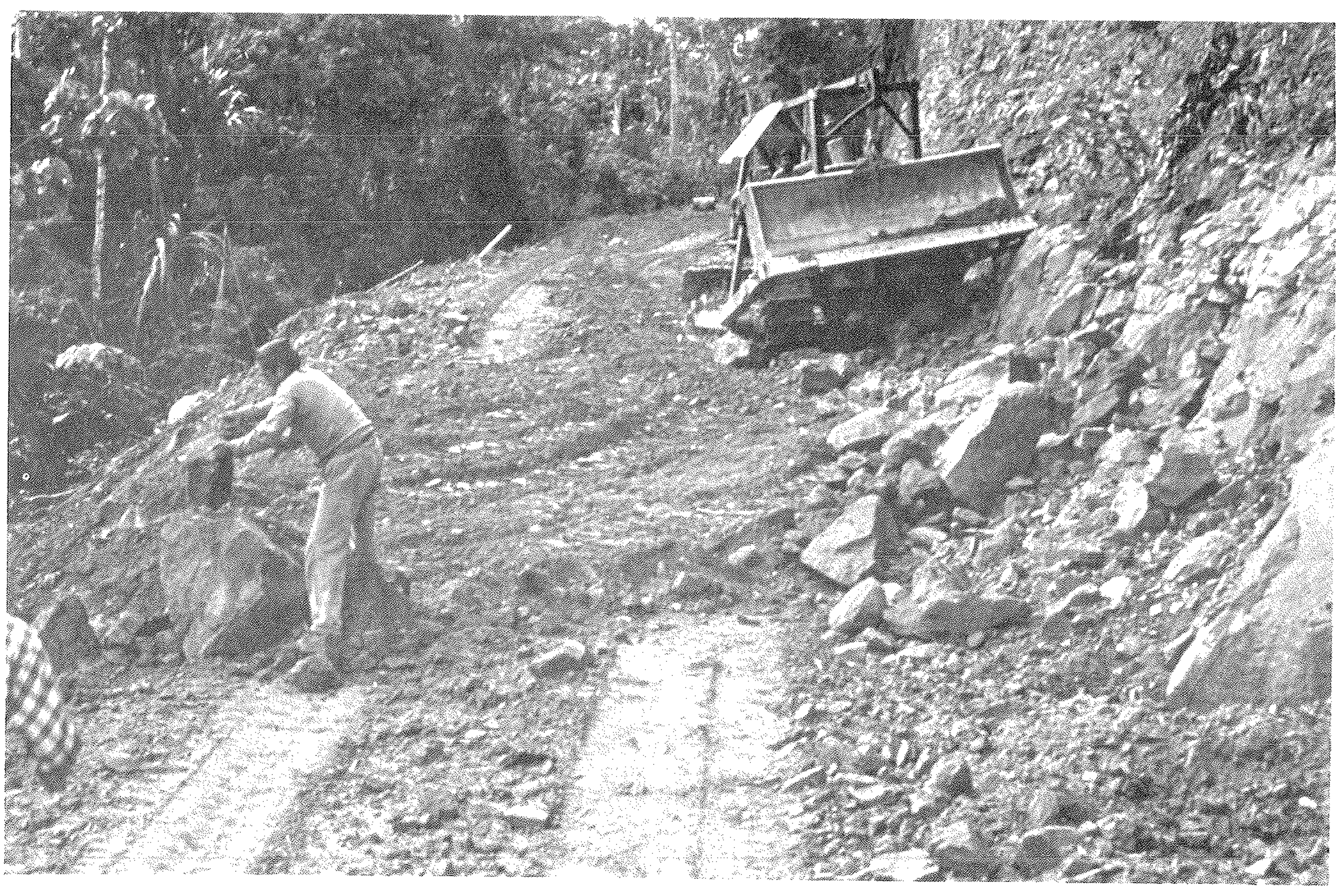
Notice

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.

Landslide problem near the Beni River in Bolivia.



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Project Description

The development of agriculture, the distribution of food, the provision of health services, and the access to information through educational services and other forms of communication in rural regions of developing countries all heavily depend on transport facilities. Although rail and water facilities may play important roles in certain areas, a dominant and universal need is for road systems that provide an assured and yet relatively inexpensive means for the movement of people and goods. The bulk of this need is for low-volume roads that generally carry only 5 to 10 vehicles a day and that seldom carry as many as 100 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 doc-

Descripción del Proyecto

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 en las regiones rurales de países en desarrollo todos dependen en gran parte de los medios de transporte. Aunque en ciertas áreas los medios de ferrocarril y agua desempenan una parte importante, una necesidad universal y dominante es para sistemas viales que proveen un medio asegurado pero relativamente poco costoso para el movimiento de gente y mercancías. La gran parte de esta necesidad es para caminos de bajo volúmen que generalmente mueven unicamente unos 5 a 10 vehículos por día y que pocas veces mueven tanto como 100 vehículos por día.

Con respecto a la economía, calidad, y rendimiento, el planeamiento, diseño, construcción y manutención de caminos de bajo volúmen para regiones rurales de países en desarrollo pueden ser mejorados en gran parte 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 mas desarrollados, y alguna se produce continuamente en los países menos y mas

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 à l'information par l'intermédiaire de moyens éducatifs et d'autres moyens de communication, dépendent en grande partie des moyens de transport. Bien que les transports par voie férrée 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 100 véhicules par jour.

L'utilisation des connaissances en technologie, qui éxistent déjà et sont accéssibles dans beaucoup 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 déumented in papers, articles, and reports that have been written by experts in the field. But much of the technology is undocumented 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 will define, produce, and transmit 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 will be provided through field visits, conferences in the United States and abroad, and

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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 esta documentada y existe principalmente en las mentes de aquellos que han desarrollado y aplicado la tecnología por necesidad. En cualquier caso, los conocimientos en existencia sobre la tecnología de caminos de bajo volúmen están grandemente esparcidos geograficamente, varían bastante con respecto al idioma y su forma, y no se encuentran facilmente disponibles para su aplicación a las necesidades de los países en desarrollo.

En octubre de 1977 el Transportation Research Board (TRB) comenzó con 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 manutención de caminos de bajo volúmen. Con el consejo y dirección de un comité de iniciativas para el proyecto, el TRB definirá, producirá, y transmitirá 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 información técnica, se proverán acciones recíprocas personales con los usuarios por

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veloppés, 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'éxiste que dans l'esprit de ceux qui ont développé et appliqué cette technologie par nécessité. 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 durée 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 éxistante 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 définira, produira, et transmettra cette documentation à l'aide d'un réseau de correspondants dans les pays en voie de développement. Généralement, l'aboutissement 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.

En plus de la dissémination de cette documentation technique, des visites, des conférences aux Etats Unis et à l'étranger, et 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

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medio de visitas de campaña, 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 asistir 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 tiene la responsabilidad para 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 relativamente limitados

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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 de 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.

Le personnel attaché à ce projet 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 sera relativement limité, des synthèses de connaissances et de pratique sur des sujets beaucoup plus généraux, et finalement des comptes-rendus practice on somewhat broader 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 12 per year; consultants are employed to prepare syntheses at the rate of 2 per year. At least two conference proceedings will be published during the 3-year period. In summary, this project aims to produce and distribute between 40 and 50 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 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 will be held for students from developing countries who are enrolled at U.S. universities.

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temas, la síntesis del conocimiento y práctica sobre temas un poco mas ámplios, 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 12 por año; se utilizan consultores para preparar las síntesis a razón de 2 por año. Se publicarán por lo menos dos expedientes de conferencias durante el período de tres años. En breve, este proyecto pretende producir y distribuir entre 40 y 50 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 formularios de retroacción con los productos informativos 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 directo 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, habrán diálogos con estudiantes de países en desarrollo que están inscriptos en universidades norteamericanas.

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de conférences sur les routes à faible capacité qui seront organisées complètement ou en partie par ce projet. Environ 12 recueils par an sont preparés par le personnel attaché au projet. Deux synthèses par an sont écrites par des experts. Les comptes-rendus d'au moins deux conférences seront écrits dans une période de 3 ans. En résumé, l'objet de ce projet est de produire et disséminer entre 40 et 50 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, le 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 le personnel et les usagers. Finalement, des colloques annuels sont organisés pour les étudiants des pays en voie de développement qui étudient dans les universités americaines.

Foreword and Acknowledgments

This compendium is the second 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 the location of low-volume roads. Feedback from correspondents in developing countries will be solicited and used to assess the degree to which this objective has been attained and to influence the nature of later products.

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

American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C.;
D. Appleton—Century Company (now Prentice-Hall, Englewood Cliffs, N.J.);
Institution of Highway Engineers, London;
National Association of County Engineers, Washington, D.C.;
Purdue University Engineering Experiment Station, Lafayette, Indiana;

Prefacio y Agradecimientos

Este compendio es el segundo 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 ubicación de caminos de bajo volúmen. Se pedirá a los corresponsales en los países en desarrollo información sobre los resultados, para utilizarse en el asesoramiento del grado al cuál se ha obtenido ese objetivo y para influenciar la naturaleza de productos subsequentes.

Se reconoce a los siguientes editores por el permiso dado para re-imprimir las porciones de texto seleccionadas de este compendio:

American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C.;
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Institution of Highway Engineers, London;
National Association of County Engineers, Washington, D.C.;
Purdue University Engineering Experiment Station, Lafayette, Indiana;
U.S. Department of the Navy, Washington,

Avant-propos et Remerciements

Ce recueil représente le deuxième 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 responsables du choix de l'emplacement des routes à faible capacité. 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 des éditeurs qui ont gracieusement donné leur permission de reproduire les textes sélectionnés pour ce recueil:

American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C.;
D. Appleton—Century Company (now Prentice-Hall, Englewood Cliffs, N.J.);
Institution of Highway Engineers, London;
National Association of County Engineers, Washington, D.C.;
Purdue University Engineering Experiment Station, Lafayette, Indiana;
U.S. Department of the Navy, Washington, D.C.; and

U.S. Department of the Navy, Washington, D.C.; and
Federal Highway Administration, Washington, D.C.

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.

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 Wilbur J. Morin, George W. Ring III, and Eldon J. Yoder, who provided special assistance on this particular compendium.

D.C.; and
Federal Highway Administration, Washington, D.C.

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 de la U.S. Department of Transportation y el Library and Information Service de la U.K. Transport and Road Research Laboratory.

Finalmente, el Transportation Research Board agradece el consejo y dirección valiosos provisto por el Comité de Iniciativas, con especial reconocimiento a los señores Wilbur J. Morin, George W. Ring III, y Eldon J. Yoder, que prestaron ayuda especial para este compendio en particular.

Federal Highway Administration, Washington, D.C.

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.

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 Wilbur J. Morin, George W. Ring III, et Eldon J. Yoder, qui ont bien voulu prêter leur assistance à la préparation de ce recueil.

Overview

Background and Scope

Route location is the phase in highway engineering that occurs between the planning and the design of a road. The planner determines the need for a route in a general area. The highway design engineer, on the other hand, uses appropriate geometric design standards (see Compendium 1 of this series) to determine the geometric properties of the route in detail. Route location is the process of determining the best alignment for a road between two points before the highway design engineer begins to make detailed calculations.

Route location has two phases. The first phase is a reconnaissance study to find several alternative alignments or corridors that meet the basic requirements of the project. The first phase will eliminate many possible alignments that do not meet the basic requirements of the project.

The second phase is the review of the alignments chosen in the reconnaissance study. More detailed surveying methods are used to develop (a) horizontal and vertical geometrics and (b) preliminary cost estimates for the alter-

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Vista General

Antecedentes y Alcance

La ubicación de la ruta llena el vacío entre el planificador de transporte y el ingeniero de diseño vial. El planificador determina la necesidad para una ruta en su sentido mas amplio. En muchos casos el período de planificación consiste unicamente en la determinación de las terminales del camino. El ingeniero de diseño vial determina en detalle las cualidades geométricas de la ruta, utilizando normas de diseño geométrico apropiadas mencionadas en el Compendio 1 de esta serie. La ubicación de la ruta es el proceso de determinar la mejor ubicación vial entre las terminales dadas antes de que el engeniero de diseño vial comience sus cálculos detallados.

Se puede considerar la ubicación de la ruta en dos fases. La primera fase consiste en un estudio de reconocimiento o una investigación. Se escogen varias alineaciones o vías alternativas que satisfacen los requisitos o controles básicos establecidos para el proyecto. Esta primera fase también puede describirse como la eliminación de las muchas alineaciones alternativas que no satisfacen los controles básicos del proyecto.

La segunda fase consiste en un estudio de ubicación o selección. Se repasan las alineaciones escogidas en el estudio de reconocimiento y se afinan las alineaciones de la alternativas mas prometedoras. Se utilizan métodos más detallados de estudio para desarrollar geométricos horizontales y verti-

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Exposé

Historique et Objectif

La détermination de l'emplacement d'une route réunit les responsables de la planification des transports et l'ingénieur routier. Le service de planification détermine qu'une route est nécessaire dans le sens le plus large du terme. Souvent, la phase de planification consiste seulement à déterminer les deux points entre lesquels la route va être construite. L'ingénieur routier détermine la géométrie de la route en détail, en utilisant les normes de dimensionnement géométriques que nous avons discutées dans le Recueil 1 de la série. Faire la sélection de l'emplacement d'une route est le procédé qui consiste à déterminer le meilleur chemin entre les deux points initiaux, avant que l'ingénieur routier ne commence à faire ses calculs en détail.

Cette sélection peut se faire en deux temps. La première phase consiste à faire la reconnaissance des lieux. Plusieurs tracés sont choisis, qui réunissent les conditions de base requises par le projet. La deuxième phase consiste à faire l'étude de l'emplacement. Les tracés qui ont été choisis lors de la première phase sont passés en revue, et ceux qui paraissent les plus prometteurs sont analysés. On détermine à l'aide de méthodes topographiques plus detaillées, la géométrie verticale et horinative alignments. The result of this phase is the selection of a preliminary design for the roadway in the most economical location.

Route location for major projects is a complex procedure that involves several teams of engineers, engineering geologists, soil engineers, and surveyors. They in turn are assisted by traffic engineers, economists, and estimators. Although this level of complexity is beyond the scope of this compendium, route location in its simplest form must still consider the same principles. Some form of geometric design standards must be followed. Construction and maintenance costs are very important, but it is not possible to provide a team of experts to find the ideal location for a low-volume road. This responsibility frequently falls to a highway engineer who has limited experience.

Technical support is usually given only if the engineer can identify a unique problem area in the location of a low-volume road. Many highway engineers apply only geometric criteria to their location problems. If drainage and geological controls are not considered together with geometric criteria, the location that is selected for the low-volume road may be unnecessarily costly to construct and to maintain. The purpose of this compendium is to present information about drainage and geological considerations that will assist the location

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cales y las valuaciones preliminares de costo de las rutas alternativas. La resultante de esta fase es la selección de un diseño preliminar del camino en la ubicación mas económica.

La ubicación de la ruta en proyectos mayores es un procedimiento complejo. Puede involucrar varios equipos de ingenieros, geólogos, expertos en suelos, y agrimensores. Ellos, a su vez, son asistidos por ingenieros de tránsito, economistas, estimadores, y una multitud de miembros de personal subsidiarios. Este nivel de complejidad en la ubicación de la ruta esta fuera del alcance de este compendio.

En su forma más simple la ubicación de la ruta todavía debe considerar los mismos principios. Se debe seguir alguna forma de normas de diseño geométricos. Los costos de construcción y manutención se vuelven muy importantes. Sin embargo, la naturaleza misma del camino de bajo volúmen prohibe el costo de encontrar la ubicación ideal por un equipo de expertos.

Sucede frecuentemente que la responsabilidad de la ubicación de un camino de bajo volúmen cae sobre un ingeniero de experiencia limitada. Se le dá asistencia técnica a este ingeniero unicamente si puede identificar un área singular con problemas. Los ingenieros viales confrontados con este dilema recurren a la aplicación de criterios geométricos únicamente en sus problemas de ubicación. La exclusión de otros controles, especialmente las consideraciones de controles de drenaje y geológicos, resulta muchas veces en la ubicación de un camino de bajo volúmen que es costoso para construir y mantener, sin haber necesidad para esto. El propósito de este compendio es el de presentar información

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zontale des tracés, et on établit un devis estimatif de ceux-ci. L'objectif de cette phase est le choix préliminaire de l'emplacement le plus économique.

Pour la construction de grands projets, ce procédé peut être très complexe et éxiger la coopération de toute une équipe d'ingénieurs, de géologues, de spécialistes des sol, arpenteurs, etc., qui sont à leur tour assistés par des spécialistes de la circulation, des économistes, et toute une multitude de personnel auxiliaire. Ce niveau de complexité dépasse l'objectif de ce recueil. La détermination de l'emplacement d'une route, même dans sa forme la plus simple exige quand même une adhérence aux mêmes principes de base. Un certain nombre de normes de dimensionnement géométrique doit être utilisé. Les frais de construction et d'entretien deviennent très important. Cependant, de par sa nature, la construction d'une route à faible capacité prohibite l'emploi de ces experts pour trouver l'emplacement idéal.

Fréquemment donc, la responsabilité de ce choix retombe sur les épaules d'un ingénieur routier qui n'a que des connaissances restreintes sur ce sujet. L'appui technique ne lui sera donné que s'il est capable d'identifier un problème spécifique. Face à ce dilemme, beaucoup d'ingénieurs routiers s'en tiennent à l'application de critères géométriques. L'exclusion de tout autre critère, notamment l'exclusion des critères géologiques et de drainage, résulte souvent en une route à faible capacité qui sera d'une construction et d'un entretien prohibitifs. Notre objectif, dans ce recueil, est engineer to select the best route.

Rationale for This Compendium

This compendium is designed to help the highway location engineer to identify problems of drainage and geological considerations. It does not present detailed design techniques that can be applied to specific problems. Future compendiums will describe these techniques.

Highway location engineers are usually selected from among engineers who have experience in roadway design. A location engineer who does not have such experience will have great difficulty in selecting the best alignment. Design experience is usually gained in an office environment. A design engineer may visit the actual location of a project during the design process in order to relate geometry to terrain. The design engineer may not have enough time during these visits to observe the fine points of drainage and characteristics of soils that are not critical to the particular design alignment. The soils may have been classified before the design process began. In this case, the design engineer does not even need to be able to identify specific soils in their natural state.

The location engineer's concept of a road

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relativo a drenaje y geología que puede asistir al ingeniero encargado de la ubicación para seleccionar la mejor ruta.

Exposición Razonada para Este Compendio

Este compendio trata únicamente sobre la identificación de áreas de problemas de drenaje y geológicos por parte del ingeniero encargado de la ubicación. Las limitaciones de espacio no permiten que presentemos las técnicas de diseño detalladas aplicables a áreas de problemas específicos. Se considerarán soluciones para algunas de las áreas de problemas, una vez identificados, en compendios futuros.

En forma lógica, se seleccionan los ingenieros viales encargados de la ubicación del personal que tiene experiencia en diseño vial. Sin tal experiencia el ingeniero de ubicación tendrá mucha dificultad en seleccionar la mejor alineación. Esta experiencia de diseño generalmente se obtiene en la oficina. Normalmente muchos ingenieros de diseño visitan la ubicación en campaña de un proyecto durante el curso de los procedimientos de diseño. Estas visitas ocurren con el propósito específico de relacionar geometría con terreno. Por consecuencia, el ingeniero de diseño muchas veces no tiene tiempo de observar los puntos más detallados del drenaje y de las características del suelo que no son críticos a la alineación de diseño dada. Ocurre muchas veces que los suelos que se encuentran han sido clasificados antes de iniciarse el proceso de diseño. En tal situación el ingeniero de diseño no necesita poder identificar los suelos específicos en su estado natural.

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donc d'offrir une documentation sur le drainage et les facteurs géologiques, qui permettra à l'ingénieur routier de determiner le meilleur emplacement.

Objet de ce Recueil

Ce recueil s'adresse seulement à l'identification des problèmes géologiques et de drainage par l'ingénieur routier qui déterminera l'emplacement de la route. Le peu d'espace dont nous disposons ne nous permet pas de présenter en détail les techniques de dimensionnement qui s'appliquent seulement à des problèmes spécifiques. Dans de futurs ouvrages, nous considérerons la solution de ces problèmes, une fois qu'ils auront été identifiés.

Les ingénieurs routiers qui feront le choix de l'emplacement d'une route doivent logiquement être selectionnés parmi ceux qui ont des connaissances solides de géométrie routière. Sans cette base, l'ingénieur routier aura beaucoup de difficultés à choisir le meilleur tracé.

Les connaissances en dimensionnement sont généralement acquises dans un bureau. L'ingénieur routier normalement visite le terrain pendant qu'il établit le dimensionnement—afin de vérifier si celui-ci se rapporte au terrain. Mais ces visites sont faites spécifiquement pour cela, et cet ingénieur n'aura peut être pas le temps de remarquer certaines caractéristiques de drainage et de géologie qui ne sont pas absolument indispensables au tracé de la route. Souvent la classification de sols a été faite avant que le tracé ne soit commencé. Dans ce cas, l'ingénieur n'aura même pas besoin de pouvoir identifier les sols dans leur état naturel.

Une fois que l'ingénieur passe du dimensionnement au tracé actuel de la route, sa conception must differ considerably from the design engineer's concept of the same road. Geometry is no longer the only concern. Route selection can be influenced as much by consideration of drainage, geology, and soils as it is influenced by clever geometric design. In fact, only the proper evaluation of the effects of these other factors can produce an economical preliminary geometric design.

Most design engineers have made some detailed drainage calculations during their design training. In this compendium the identification of drainage considerations is treated in a general way. Future compendiums will treat drainage problems and their solutions in greater detail.

The identification of geological considerations is treated here in greater detail because most design-oriented highway engineers do not have much training in these problem areas. Basic information on soils is included, since soils problems are part of the geological considerations in highway location. Detailed information about specific soil and rock types, such as tropical soils, shales, and volcanic materials, will be presented in future compendiums.

This compendium also considers the interpretation of drainage and geological features from aerial photographs. These photographs can be excellent tools for reconnaissance work. They allow rapid coverage of large areas,

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Una vez que el ingeniero de diseño se vuelve ingeniero de ubicación, su concepto de un camino debe cambiar en forma considerable. Yá la geometría no es su único interés. La selección de la ruta puede influenciarse tanto por consideraciones de drenaje, geología, y suelo, como por buén diseño geométrico. Un diseño geométrico preliminar económico es un resultado directo de la evaluación correcta de las modificaciones de otros controles sobre diseño geométrico básico.

Este compendio trata con las consideraciones de drenaje y geológicas. Estas consideraciones deben ser evaluadas en forma concurrente y contínua a medida que se evalúan las posibilidades geométricas. Las consideraciones de drenaje se tratan en forma general. Casi todos los ingenieros de diseño realizan algunos cálculos de drenaje detallados en algún punto de su curso de instrucción en drenaje. Otros compendios en este proyecto tratarán sobre los problemas de drenaje en mayor detalle.

Las consideraciones geológicas de la ubicación de carreteras son planteados en más detalle porque los ingenieros viales orientados hacia el diseño normalmente tienen menos enseñanza geológica. Se incluye información básica de suelos dentro del alcance general de las consideraciones geológicas que se tratan en este compendio. Se presentará información más detallada sobre tipos específicos de suelo y roca, tales como suelos tropicales, lutitas, materiales volcánicos, etc., en compendios posteriores.

También se incluye en este compendio la interpretación de fotos aéreas de ciertas características geológicas y de drenaje. Las fotos aéreas son una excelente herramienta en el trabajo de reconocimiento. Permiten un recorrimiento rápido de grandes áreas; y su dispo-

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de la route doit changer considérablement. La géométrie routière n'est plus son seul souci. Le choix de l'emplacement de la route doit être influencé autant par le drainage, et les facteurs géologiques, que par le dimensionnement géométrique. Pour en arriver à un dimensionnement géométrique préliminaire qui soit économique, il faut tout d'abord bien évaluer les différents facteurs qui pourraient avoir tendance à le modifier. On doit évaluer constammant et conjointement ces deux facteurs en même temps que les différentes possibilités géométriques sont examinées.

Le problème du drainage est traité en général dans ce recueil. La plupart des ingénieurs ont été exposés à des calculs de drainage detaillés, lors de leurs études. Nous adresserons le problème en détail dans un futur recueil. Par contre les facteurs géologiques sont examinés en détail, car les ingénieurs routiers normalement ont moins de connaissances géologiques. Une documentation de base sur les sols est incluse dans ce recueil. Une documentation plus detaillée concernant des sols spécifiques et des types de roche, comme les sols tropicaux, les schistes, les sols volcaniques, sera presentée dans un futur recueil.

Ce recueil examine aussi l'interpretation et la lecture de photos aériennes prisent de certaines caractéristiques géologiques et de drainage. Les photos aériennes sont un excellent outil pour le travail de reconnaissance. Elles permettent de faire la reconnaissance de larges étendues très rapidement, et sont accéssibles dans la plupart des pays. L'ingénieur routier qui ne doit s'attendre qu'à une and they are becoming available everywhere in the world. A road location engineer who does not have much outside assistance should investigate whether aerial photographs of the project area are available from any government agency.

The texts selected for this compendium include some information that does not apply to rural developing countries. For example, problems about permafrost do not influence road locations in jungles. The presence of this material should not prevent the reader from using the rest of the selected text in which it appears.

Discussion of Selected Texts

The first two selected texts provide a comprehensive review of the drainage considerations that should influence the choice of alignments.

The first, *Guidelines for Hydraulic Considerations in Highway Planning and Location* (AASHO, 1975), stresses the importance of recognizing drainage problems early. It is reprinted here in full.

The second, *Guidelines for Hydrology* (AASHO, 1973), also reprinted in full, describes the hydrologic analysis that should be performed before the hydraulic design of highway drainage

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nibilidad es casi mundial. Sería un buén plan por parte del ingeniero encargado de la ubicación del camino, que tiene el mínimo de asistencia fuera de su equipo, investigar la posibilidad de que alguna agencia en su gobierno pueda tener fotos aéreas de su área de proyecto.

Algunos de los textos seleccionados para este compendio incluyen alguna información que no es aplicable a países en desarrollo. Por ejemplo, las preocupaciones de derecho de vía de los Estados Unidos de Norte América pueden ser de poco interés para un ingeniero de ubicación en un ambiente de desierto. Los problemas de helada permanente no influencian las decisiones de ubicación del camino en la selva. Tal material ajeno no deberá suspender o desalentar el uso del resto del texto seleccionado en donde aparece.

Presentación de los Textos Seleccionados

Los primeros dos textos seleccionados proveen un resumen breve pero amplio de las consideraciones de drenaje que deberán influenciar sus alineamientos geométricos. El primer texto, *Guidelines for Hydraulic Considerations in Highway Planning and Location* (Pautas para Consideraciones Hidráulicas en Planeamiento y Ubicación Vial) (AASHO, 1973), subraya la importancia de un temprano reconocimiento de problemas en drenaje. Este texto ha sido reproducido totalmente en este compendio.

El segundo texto, *Guidelines for Hydrology* (Pautas para la Hidrología) (AASHO, 1973), también reproducido en toto, describe el análisis hidrológico necesario antes de cualquier diseño hidrológico de las estructuras de drenaje vial. El ingeniero encargado de la

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aide minimale devrait certainement examiner la possibilité que quelqu'organisme de son governement ait déjà des photos aériennes de l'endroit où il veut construire la route.

Les textes choisis pour ce recueil contiennent des information qui ne sont pas applicables à des pays en voie de développement. Par exemple, le problème de l'emprise aux Etats Unis, sera de peu d'intérêt pour l'ingénieur routier qui doit travailler dans une région inhabitée. Les problèmes de permafrost n'ont certainnement pas d'influence sur le tracé des routes dans la jungle. Bien que ces problèmes soient examinés dans les livres que nous citons, cela ne devrait pas décourager l'utilisation du reste des Textes Choisis.

Discussion des Textes Choisis

Les deux premiers textes donneront à l'ingénieur routier un bref aperçu d'ensemble de ces facteurs de drainage qui doivent influencer son tracé géométrique. Le premier texte, *Guidelines for Hydraulic Considerations in Highway Planning and Location* (Guide des Facteurs Hydrauliques pour la Conception et le Tracé d'une Route) (AASHO, 1973), met l'emphase sur l'importance de repérer tout de suite les problèmes de drainage. Le texte est reproduit en entier.

Le deuxième texte, *Guidelines for Hydrology* (Guide d'Hydrologie) (AASHO, 1973), reproduit en entier, décrit l'analyse hydrologique qui doit être faite avant que l'on prépare les plans des structures de drainage. L'ingénieur routier structures can proceed. This is important because the location engineer for a low-volume road may be the only engineer involved in the hydrology and hydraulics design for the alternative alignments of the project.

The third text, *Subsurface Soils Exploration* (National Association of County Engineers Action Guide Series, 1972), was prepared to present basic information on the need to explore subsurface soils. It reviews current techniques of soil sampling. It describes field and office procedures for logging, recording, and interpreting data on soils. The manual also introduces some of the more detailed methods of investigating soils that are included in other texts in this compendium. The appendixes to this manual are not reprinted.

The fourth text, *Field Identification of Soils and Aggregates for County Roads* (Purdue University, 1971), was published as a part of a highway extension and research project for counties in Indiana. It tells how to rate the quality of soils and pit-run materials that are used in the construction and maintenance of county roads and how to identify soil components by visual examination and simple hand tests. The Unified Soil Classification System (USCS) is introduced in a simplified form. Field identification procedures for each USCS group, using simplified methods of investigation, are

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ubicación del camino de bajo volúmen puede ser el único ingeniero involucrado en el diseño hidrológico e hidráulico para las alineaciones alternativas de su proyecto en particular.

El tercer texto es *Subsurface Soils Exploration* (Exploración de los Subsuelos) (National Association of County Engineers Action Guide Series, 1972). Este manual se preparó para darle al ingeniero de condado un entendimiento básico de la necesidad de la exploración de los suelos debajo de la superficie del terreno. El texto repasa técnicas de muestreo de suelos disponibles en el momento; incluye procedimientos de campaña y oficina para registrar e interpretar datos de suelos. El manual también sirve como una introducción a algunas de las investigaciones más detalladas de tratamiento de suelos incluídas en otros textos seleccionados en este compendio. Los apéndices del texto no han sido incluídos en el material reproducido.

El cuarto texto, *Field Identification of Soils and Aggregates for County Roads* (Identificación en Campaña de los Suelos y Agregados para Caminos de Condado), es un boletín que fué publicado en 1971 por la Universidad de Purdue como parte de un proyecto de extensión e investigación vial para los condados de Indiana. El propósito de este boletín es el de proveer instrucciones para la valuación de la calidad de suelos y materiales extraídos de canteras utilizados en la construcción y manutención de caminos de condado. El texto incluye instrucciones para la identificación de componentes del suelo por examinación visual y por pruebas simples de mano. El Sistema Universal de Clasificación de Suelos (Unified Soil Classification System—USCS) se introduce en forma simplificada. Se describen procedimientos de identificación en campaña para cada grupo del USCS utilizando métodos investigativos simplificados. Se incluyen

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en charge de la construction de cette route à faible capacité a des chances d'être en fait la personne qui devra étudier l'hydrologie et dessiner les plans des structures hydrauliques pour les differents tracés.

Le troisième texte, *Subsurface Soils Exploration* (Examen des Sous-Sols) (National Association of County Engineers Action Guide Series, 1972), a été écrit pour donner à l'ingénieur des connaissances de base sur les analyses des sols qui sont en usage à présent, y compris les méthodes employées, sur le terrain et au bureau pour enregistrer et interpréter les données de ces sols. Ce manuel sert aussi d'introduction à plusieurs autres méthodes d'analyse des sols plus sophistiquées, qui sont incluses dans d'autres textes de ce recueil. Les appendices de ce texte ne sont pas reproduits.

Le quatrième texte, *Field Identification of Soils and Aggregates for County Roads* (Identification sur le Terrain des Sols et des Granulats pour Routes Départementales) est un bulletin publié en 1971 par Purdue University. Ce bulletin faisait partie d'un projet de recherches et de prolongement des routes de l'état de l'Indiana. L'objectif du bulletin est de donner les moyens d'évaluer la qualité des sols et matériaux naturels utilisés pour la construction et l'entretien de la route. Le texte comprend des instructions sur l'identification des sols à l'aide d'examens visuels et manuels. Le Système Standard de Classement des Sols (Unified Soil Classification System—USCS) est introduit dans une forme simplifiée. Des méthodes simplifiées, d'identification de chaque classe described. Field tests to evaluate the quality of aggregate materials for use in base and surface course construction are included. Soils and aggregates are also rated as road materials. The location engineer should use these field tests to make preliminary soil surveys. The tests will indicate the type and amount of laboratory testing needed. This text is reprinted here in full.

The fifth text consists of excerpts from *Design Manual: Soil Mechanics, Foundations, and Earth Structures–NAVFAC DM-7* (U.S. Department of the Navy, Bureau of Yards and Docks, 1971). The complete manual contains practical information of interest to soil engineers. The portion reprinted here contains a more detailed USCS table that includes laboratory classification criteria. Data on the requirements for index properties tests, including the types and size or weight of samples needed for each test, are included. A plasticity chart is also reproduced. This information will be useful when the location engineer for low-volume roads needs the assistance of formal laboratory testing.

The sixth text, *The Identification of Rock Types* (U.S. Department of Commerce, 1960), was used as a training document by the Division

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pruebas de campaña simplificadas para la evaluación de la calidad de materiales de agregado para la construcción de hiladas de base y de superficie. Los suelos y agregados se clasifican como materiales de camino. Las pruebas de campaña delineados en este boletín son para utilizarse en estudios preliminares de suelo y exploración de suelos. Las pruebas proveen una indicación del tipo y cantidad de pruebas de laboratorio que se necesitarán. No se espera que el ingeniero encargado de la ubicación de caminos de bajo volúmen sea experto en procedimientos de laboratorio, pero debe tener un conocimiento práctico de las propiedades de suelos. Este texto se reproduce totalmente.

El quinto texto consiste en algunas páginas seleccionadas de *Design Manual: Soil Mechanics, Foundations, and Earth Structures–NAVFAC DM-7* (Manual de Diseño: Mecánicas del Suelo, Fundamentos, y Estructuras de Tierra) (U.S. Department of the Navy, Bureau of Yards and Docks, 1971). El manual completo contiene información práctica de interés para ingenieros de diseño de suelos. La parte seleccionada contiene una tabla del USCS más detallada, incluyendo criterios de clasificación de laboratorio. Se incluyen datos sobre los requerimientos para pruebas de propiedades de indice, incluyendo los tipos y tamaño o peso de las muestras para cada prueba. También se reproduce un diagrama de plasticidad. En ocasión el ingeniero de ubicación del camino de bajo volúmen necesitará la asistencia de pruebas de laboratorio. Estos extractos proveen los conocimientos necesarios para la entrega de muestras correctas al laboratorio.

El sexto texto es *The Identification of Rock Types* (La Identificación de Tipos de Rocas) (U.S. Department of Commerce, 1960). Esta publicación se utilizó como documento de

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du USCS sont données. Des méthodes simples pour l'évaluation de la qualité des granulats pour la couche de liaison et la couche de roulement sont incluses. Les sols et les granulats sont classés quant à leur qualité comme matériaux routier. Les essais sur le terrain indiqués dans ce bulletin doivent être faits au moment de l'étude préliminaire des sols. Ces analyses donnent alors une idée du genre et de la quantité d'analyses de laboratoire qui seront nécessaires. L'ingénieur routier de routes à faible capacité ne doit pas nécessairement être un expert, et connaître toutes les méthodes d'analyse de laboratoire, mais il doit bien connaître les propriétés des sols. Ce texte est reproduit en entier.

Le cinquième texte consiste en quelque pages du livre *Design Manual: Soil Mechanics, Foundations, and Earth Structures–NAVFAC DM-7* (Manuel de Dimensionnement: Mécanique des Sols, Sol de Fondation, et Terrassement) (U.S. Department of the Navy, Bureau of Yards and Docks, 1971). Le livre donne des renseignements utiles aux ingénieurs des sols. Les pages choisies contiennent un tableau plus detaillé de l'USCS, des données sur l'indice de groupe, y compris le genre, la mesure, ou le poids des échantillons pour chaque analyse. Un tableau de l'indice de plasticité est aussi reproduit. L'ingénieur des route à faible capacité aura, de temps à autre, besoin de faire faire des analyses à un laboratoire. Ces extraits lui indiqueront comment soumettre des échantillons convenables au laboratoire.

Le sixième texte est *The Identification of Rock Types* (Identification des Roches) (U.S. Department of Commerce, 1960). Cet ouvrage était utilisé comme livre de texte par la Division of Physical Research of the Bureau of Public Roads. It is reprinted in full. It presents identification procedures in simple terms to aid those who are not familiar with expressions normally used in petrographic descriptions. The equipment required is simple and readily available. Engineering properties of rock are discussed.

The fourth, fifth, and sixth texts help the location engineer for low-volume roads to evaluate the geological characteristics of alternative alignments. Understanding the geological characteristics of the soils in specific areas will make it possible for the location engineer to identify, by association, other areas where similar soils are likely to exist. This process is described in the next two texts.

The seventh text, *The Engineering Significance of Landforms,* by D.J. Belcher of Cornell University, was published in Highway Research Board Bulletin 13 in 1948. It is reprinted here in full. It discusses the relation between landforms and the characteristics of the materials that compose them, as well as how the relief, soil, rock, and groundwater characteristics are interrelated. Since landforms recur, if the characteristics of the soil for a specific landform have been determined, then the basic quality and type of grading, drainage requirements, and soil and rock conditions for similar landforms are generally known. This knowledge

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entrenamiento por la Division of Physical Research del Bureau of Public Roads. Los procedimientos de identificación se presentan en términos simples para beneficio de aquellos que no conocen los términos normalmente utilizados en las descripciones petrográficas. El equipo que se necesita es simple y facilmente obtenible. Se habla sobre las propiedades ingenieriles de la roca. El texto se reproduce totalmente.

Los cuarto, quinto, y sexto textos seleccionados ayudan al ingeniero de ubicación del camino de bajo volúmen a evaluar las características geológicas por las alineaciones alternativas seleccionadas. Una vez que el ingeniero de ubicación comprende las características geológicas de los suelos en áreas específicas, por asociación podrá identificar otras áreas donde es probable que existan suelos similares. Esta técnica se describe en los textos seleccionados siete y ocho.

El séptimo texto, *The Engineering Significance of Landforms* (El Significado Ingenieril de Formas de Terreno), por D.J. Belcher de la Universidad de Cornell, apareció en el Boletín 13 del Highway Research Board en 1948. Este artículo, reproducido en toto, trata sobre la relación entre formas de terrenos y las características de las materiales que las componen, y la interrelación de las características del relieve, suelo, roca, y agua de suelo. Ya que las formas de terreno recurren, una vez que se determinan las características del suelo para una forma de terreno específica, se pueden generalmente predeterminar la calidad básica y tipo de nivelación, requisitos de drenaje, y condiciones de suelo y roca para formas de terreno similares. Utilizando este procedimiento se reduce el trabajo investigativo y la ocurrencia de acontecimientos imprevistos. Por lo tanto, el ingeniero de ubicación del camino de bajo volúmen puede

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of Physical Research du Bureau of Public Roads. Les méthodes d'identification sont presentées en termes simples, à l'usage des personnes qui n'ont pas l'habitude de la terminologie pétrographique. Le texte est reproduit en entier.

Les quatrième, cinquième, et sixième textes choisis permettront à l'ingénieur routier d'évaluer les facteurs géologiques des différents tracés. Une fois que cet ingénieur a compris les caractéristiques géologiques des sols de certain endroits spécifiques, il sera à même d'identifier d'autres endroits où il existe des sols de même nature. Cette technique est décrite dans les textes choisis numéros sept et huit.

Le septième texte, *The Engineering Significance of Landforms* (Le Sens des Contours des Terrains pour l'Ingénieur) par D.J. Belcher de Cornell University, parut dans le Highway Research Board Bulletin 13 en 1948. Ce document, reproduit en entier, discute du rapport entre le contour des terrains et les caractéristiques des matériaux qui les composent, et des rapports qui existent entre le relief, le sol, les roches, et l'eau souterraine. Puisque les mêmes configurations de terrains se reproduisent, une fois que les caractéristiques du sol pour certaine configuration ont été déterminées la qualité de base et le type de granularité, les exigences de drainage, et les genres de sols et de roches pour le même genre de configuration sont généralement les mêmes. En utilisant cette méthode, le travail de recherches est minimisé, et la possibilité d'événements imprévus est réduite. L'ingénieur routier peut donc évaluer la similarité de conditions de terrain entre une route déjà construite reduces the need for investigational work, since the location engineer for low-volume roads can relate existing road conditions to the requirements for new roads on similar landforms.

The eighth text, *Terrain Evaluation for Road Engineers in Developing Countries,* was published in *Journal of the Institution of Highway Engineers* in June 1969. It describes the more recent developments of the basic principles that were described in the previous text. Specific examples of terrain evaluation are described to illustrate the principles involved. The paper is reprinted in full, but the published discussion of the paper is not included.

Landslides are among the most troublesome geological problems the location engineer must face. The ninth text, *Landslide Investigations: A Field Handbook for Use in Highway Location and Design* (U.S. Department of Commerce, 1961) is reprinted here in full. It was prepared by the Division of Physical Research of the Bureau of Public Roads. It was written primarily for use by the highway location engineer. An expert on landslides should be consulted if the location engineer encounters unusual or complex landslide problems.

The tenth text consists of excerpts from *Aerial Photographs and Their Applications,* by H.T.U. Smith (D. Appleton-Century Company, 1943). The excerpts provide a detailed description of

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relacionar las condiciones de camino en existencia a requisitos para caminos nuevos en formas de terreno similares.

El octavo texto, *Terrain Evaluation for Road Engineers in Developing Countries* (Evaluación del Terreno para Ingenieros Viales en Países en Desarrollo), apareció en el *Journal of the Institution of Highway Engineers* en junio de 1969. Este texto describe desarrollo adicional del mismo tema. Este texto se escogió porque amplía sobre los principios que se describieron en el texto previo, en su aplicación en países en desarrollo. Se describen aplicaciones específicas para los principios involucrados. El artículo se reproduce totalmente, pero no se incluye la discusión publicada de éste.

Uno de los problemas geológicos más molestosos para el ingeniero de ubicación del camino de bajo volúmen es el de derrumbe. El noveno texto es *Landslide Investigations: A Field Handbook for Use in Highway Location and Design* (Investigaciones de Derrumbes: Un Manual de Campaña para Uso en el Diseño y Ubicación de Carreteras) (U.S. Department of Commerce, 1961). Este manual fué preparado por la Division of Physical Research del Bureau of Public Roads. Se preparó principalmente para el ingeniero vial de ubicación. Como en otras áreas, cuando el ingeniero de ubicación del camino de bajo volúmen encuentra problemas de derrumbe excepcionales o complejos, deberá pedir el consejo de expertos que se especializan en el tema. Este texto se reproduce totalmente.

El décimo texto consiste de extractos del *Aerial Photographs and Their Applications* (Fotografías Aéreas y Sus Aplicaciones), por H.T.U. Smith (D. Appleton—Century Company, 1943). La porción extraída consiste en una

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et la route à construire, si les contours de terrain sont les mêmes.

Le huitième texte, *Terrain Evaluation for Road Engineers in Developing Countries* (Evaluation des Terrains à l'Usage des Ingénieurs des Pays en Voie de Développement) parut dans le *Journal of the Institution of Highway Engineers* de juin 1969. Cet ouvrage reprend et élabore le sujet qui a été discuté dans le septième texte. Nous l'avons choisi car il amplifie les principes décrits dans le texte précédent et les applique spécifiquement aux pays en voie de développement. Ce chapitre est reproduit en entier, mais la discussion du texte n'est pas incluse.

Parmi les phenomènes géologiques les plus ennuyeux que l'ingénieur routier dût confronter est celui des glissements de terrain. Le neuvième texte s'appelle *Landslide Investigation: A Field Handbook for Use in Highway Location and Design* (Etudes des Glissements de Terrain: Un Manuel pour le Dimensionnement et l'Emplacement des Routes) (U.S. Department of Commerce, 1961). Ce manuel a été preparé pour la Division of Physical Research du Bureau of Public Roads, pour l'ingénieur routier. Si cet ingénieur se trouve devant un probleme compliqué de glissement de terrain, nous lui conseillons vivement de prendre l'avis d'experts en la question.

Le dixième texte consiste en des extraits du livre *Aerial Photographs and their Applications* (Photos Aériennes et Leur Utilité), (D. Appleton—Century Company, 1943) de H.T.U. Smith. Les pages qui sont reproduites ici contiennent une description détaillée de la méthode the procedure for making stereoscopic observations, with or without instruments. Today, inexpensive simple-lens stereoscopes that give two- to three-power magnification are available everywhere in the world. Although a single aerial photograph provides many important details, stereoscopic viewing demonstrates the true value of aerial photographs. Monocular magnifiers that are used for reading photographs consist of hand-held two- to four-power reading glasses and more sophisticated magnifiers of medium power (5 to 25 diameters) or high power (45 or more diameters). The higher powered monocular magnifiers usually have a self-contained light source. This text also mentions that there is a problem concerning the orientation of the light source. Some interpreters of photographs see a reverse stereoscopic or pseudoscopic effect (i.e., the valleys appear as ridges and the ridges appear as valleys) when the shadows fall away from them. For this reason, stereoscopic photographs are normally viewed so that the shadows are toward the reader. Inexpensive stereoscopes are usually adjustable and are calibrated in millimeters. Since the normal eyebase is 63 mm (2.5 in), a person who is using a stereoscope for the first time should start at that calibration. The distance between the same feature on the two photographs that are being viewed should also be 63 mm. Most photographs in this text are set to this dimension. In practicing with

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descripción detallada del procedimiento para observaciones estereoscópicas, con y sin la ayuda de instrumentos. Hoy en día se pueden obtener estereoscopios poco costosos con una amplificación de dos o tres potencias en todas partes del mundo. Mientras que se pueden extraer detalles importantes de una sola foto aérea, la inspección esteroscópica demuestra el verdadero valor de los fotos áereas. Los amplificadores monoculares que se utilizan para la lectura consisten de oculares de lectura sostenidas por mano, de dos a cuatro potencias, y amplificadores más sofisticados de potencia mediana (de 5 a 25 diámetros) o de alta potencia (hasta 45 o más diámetros). Los amplificadores monoculares de alta potencia generalmente poseen una fuente de luz propia. El texto menciona la orientación del orígen de la iluminación con respecto a las sombras. Algunos traductores ven un efecto estéreo invertido o seudoscópico cuando las sombras caen en dirección opuesta a ellos. Por esta razón las fotos estéreo normalmente se observan con las sombras hacia el lector. El efecto suedoscópico origina una aparente inversión del relieve sobre la foto, los valles pareciendo cerros y los cerros, valles. Los estereoscopios baratos son generalmente ajustables y calibrados en milímetros. La base del ocular normal es de 63 mm (2.5 pulgadas), por lo tanto el principiante debería comenzar en esa calibración. La distancia entre la misma característica a observarse sobre las dos fotos también debería ser 63 mm. Casi todas las fotos en los textos seleccionados están puestas a esta dimensión. Al practicar con verdaderas fotos la foto izquierda si el que lo usa es de mano derecha deberá estar enrollada entre

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d'observation stéréoscopique, avec ou sans l'instrument. Aujourd'hui, on peut trouver partout dans le monde, des stéréoscopes peu coûteux à lentille simple, avec un pouvoir amplifiant de l'ordre de deux à trois. Bien qu'on puisse voir beaucoup de détails importants sur une photo aérienne, c'est seulement quand on la regarde avec le stéréoscope qu'on peut en exprimer toute sa valeur. Les loupes utilisées pour lire les photos consistent, soit en simple loupe avec un pouvoir amplifiant de l'ordre de deux à quatre, soit en loupes plus sophistiquées, avec une amplification de 5 à 25 fois le diamètre, ou même encore plus puissantes, jusqu'à une amplification de 45 fois le diamètre. Ces dernières loupes ont habituellement un éclairage intègre. Ce texte mentione aussi le problème de l'orientation de la source de lumière. Certaines personnes voient le contraire de l'effet stéréoscopique quand les ombres sont dirigées du côté opposé, et voient les vallées qui apparaissent en relief, et vice-versa. Pour cette raison, les ombres doivent être dirigées du côté de la personne qui utilise le stéréoscope. Les stéréoscopes bon marché peuvent être ajustés et sont calibrés en millimètres. Puisque la distance moyenne entre les yeux est de 63 mm (2.5 in) le novice devrait ajuster son appareil à cette calibration. La distance entre deux points de repère similaires sur les deux photos aériennes doit être aussi de 63 mm. La plupart des photos inclusent dans les textes choisis sont calibrées de cette façon. Quand on s'exerce avec de vraies photos aériennes, on devrait relever le bord de la photo de gauche entre les deux verres du actual photographs, the left photograph (if the user is right-handed) should be curled up between the eyepieces to give added coverage. The eyes of the observer should be approximately 13 mm (0.5 in) from the lenses. It is important to be relaxed when attempting three-dimensional viewing. To see the stereoscopic effect the beginner should concentrate on a single feature of the photographs. Because of difficulties in reproducing the photographs, some of the stereoscopic photographs in this compendium and future compendiums may be difficult to view. The reader should practice with actual aerial photographs until the examples in these texts can be seen in three dimensions.

The eleventh text consists of Appendix C, Mosaics, from ***Aerial Photography*** (National Association of County Engineers, Action Guide Series Vol. 13, 1972). This excerpt describes mosaics (composite aerial photographs) and describes one method for assembling a mosaic. Mosaics are necessary if the location engineer for a low-volume road is evaluating a large area.

The twelfth text, ***Drainage Pattern Significance in Airphoto Identification of Soils and Bedrocks,*** by Merle Parvis of Purdue University, was published in Highway Research Board Bulletin 28 in 1950. This paper describes how to use the analyses of drainage patterns to identify regional soils and bedrocks by means of aerial photographs. The examples in this paper are from the United States, but the

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los oculares para proporcionar mas cobertura. Los ojos del lector deberán estar aproximadamente 13 mm (0.5 pulgada) de los oculares. El principiante no deberá estar tenso al intentar una lectura de tres dimensiones. El efecto esteroscópico se obtendrá mas facilmente si el principiante se concentra sobre una sola característica de las fotos. Debido a dificultades de reproducción las fotos estéreo en este y compendios futuros podrán ser difíciles de observar. Se le aconseja al lector practicar con fotos aéreas verdaderas si las pares de fotos en estos textos no dan un efecto de tres dimensiones. Una vez que el lector adelanta en el uso del estereoscopio tendrá menos problemas con las fotos que acompañan al texto.

El onceno texto consiste del Appendix C, Mosaics (Mosaicos), de *Aerial Photography* (Fotografía Aérea) (National Association of County Engineers Action Guide Series Vol. 13, 1972). Este extracto describe los mosaicos (fotos aéreas compuestas) y describe un método de componer un mosaico. Los mosaicos son necesarios si el ingeniero de ubicación del camino de bajo volúmen necesita evaluar un gran área.

El dozavo texto, ***Drainage Pattern Significance in Airphoto Identification of Soils and Bedrocks*** (El Significado del Patrón de Drenaje en la Identificación por Foto Aérea de Suelos y Lechos de Roca), por Merle Parvis de la Universidad de Purdue, apareció en el Boletín 28 del Highway Research Board en 1950. Este informe es sobre el análisis de patrones de drenaje para su uso en la identificación de suelos y lechos de roca de la región por medio de fotos aéreas. Los ejemplos utilizados en

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stéréoscope, pour pouvoir voir une plus grande étendue—ou vice-versa, si le lecteur est gaucher. Les yeux doivent être à peu près à 13 mm (0.5 in) des verres. Le novice devrait être décontracté. Il sera plus facile, au debut, de voir l'effet stéréoscopique, si le novice se concentre sur un seul point de repère. A cause de difficultés de reproduction, certaines des photos stéréoscopiques de ce recueil et de futurs recueils, seront difficiles à interpreter. Le lecteur est invité à pratiquer sur de vraies photos aériennes, s'il ne voit pas les deux photos inclusent ici en trois dimensions. Une fois que le lecteur aura pris l'habitude d'utiliser un stéréoscope, il aura moins de difficulté avec les photos qui accompagnent ce texte.

Le onzième texte, Appendix C, Mosaics (Mosaiques), de *Aerial Photography* (Photos Aériennes) (National Association of County Engineers Action Guide Series Vol. 13, 1972), donne des instructions pour assembler les photos aériennes en mosaique, chose nécessaire si l'ingénieur routier veut interpréter une grande étendue de terrain.

Le douzième texte, ***Drainage Pattern Significance in Airphoto Identification of Soils and Bedrock*** (L'Importance des Caractéristiques des Bassins de Drainage dans les Photos Aériennes pour l'Identification des Sols et des Fondations), de Merle Parvis de Purdue University, parut dans le Highway Research Board Bulletin 28, 1950. Cet article analyse les bassins de drainage afin de s'en servir pour identifier les sols et les fondations à l'aide de photos aériennes. Les exemples cités dans cet article sont tous pris aux Etats Unis, mais drainage patterns and landforms of a region are always interdependent. In identifying soils and bedrocks by means of aerial photographs, the drainage patterns and other features of the terrain must be studied at the same time.

The thirteenth text is Chapter 5, Airphoto Interpretation, from *Landslides and Engineering Practice* (Highway Research Board Special Report 29, 1958). It is reprinted in full. It describes the use of aerial photographic interpretation as a tool for recognizing actual or potential landslides. Landforms, drainage and erosion, soil tones, vegetation, and man-made features are discussed. The text includes many stereoscopic photographs of landslide areas and a few groundview photographs of some of the same areas.

Bibliography

The Selected Texts are followed by a brief bibliography that contains reference data and abstracts for 25 publications. The first 13 describe the Selected Texts. The other 12 describe publications that are closely associated with the Selected Texts.

Although there are very many articles, reports, and books that could have been listed in the bibliography, it is not the purpose of this bibliography to contain all the possible references for the subject. The bibliography contains only those publications from which text has been selected or basic publications that would have been selected if there had been no limit on the number of pages in this compendium.

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este informe son todos de los Estados Unidos de Norte América, pero el principio de que las vías de drenaje y formas del terreno de una región son dependientes uno del otro es universal. No se puede depender solamente del elemento del patrón de drenaje en la identificación de suelos y lechos de rocas por el uso de fotos aéreas. Se debe utilizar conjuntamente con los otros elementos del terreno.

El decimotercer texto es Chapter 5, Airphoto Interpretation (Interpretación de Fotos Aéreas), de *Landslides and Engineering Practice* (Derrumbes y la Práctica Ingenieril), Informe Especial 29 del Highway Research Board, 1958. El capítulo se ha reproducido totalmente y describe la interpretación de fotos aéreas como una herramienta para identificar derrumbes verdaderos o posibles. Se trata sobre formas de terrenos, drenaje y erosión, matices de suelos, vegetación, y características hechas por el hombre. La selección contiene muchas fotos estéreo de áreas de derrumbe y fotos tomadas del suelo de algunas de las mismas áreas.

Bibliografía

La sección de textos seleccionados de este compendio es seguido por una breve bibliografía que contiene datos de referencia y resúmenes para 25 publicaciones. Las primeras 13 son para las publicaciones representadas por la sección de textos seleccionados de este compendio. Las 12 referencias restantes son para publicaciones que se asocian intimamente con los textos seleccionados.

Hay cienes de artículos, informes, y libros que son pertinentes a uno o más aspectos del

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le principe—les caractéristiques du bassin de drainage et les contours d'une région sont interdépendants—est universel. Bien sûr, l'étude des bassins de drainage à l'aide de photos aériennes ne suffit pas entièrement pour l'identification des sols et des fondations, et doit être accompagnée de l'étude des autres éléments du terrain.

Le treizième texte est tiré du chapitre 5, Airphoto Interpretation (L'Interprétation des Photos Aériennes), de *Landslides and Engineering Practice* (Glissements de Terrain et le Génie Civil), Highway Research Board Special Report 29, 1958. Ce chapitre est reproduit dans sa totalité et explique l'interprétation des photos aériennes et leur importance pour reconnaître les glissements de terrain actuels ou en puissance. Les contours du terrain, le drainage et l'erosion, les nuances de couleur des sols (du noir au blanc), la végétation, et les contour artificiels sont discutés. Cette sélection contient beaucoup de photos aériennes stéréographiques de glissements de terrain et aussi des photos prisent au sol de certains de ces mêmes terrains.

Bibliographie

Les Textes Choisis sont suivis d'une courte bibliographie contenant des données de référence et des analyses pour 25 ouvrages. Les 13 premières sont pour ceux qui sont dans les Textes Choisis. Les autres références sont pour des ouvrages qui sont étroitement associés au sujet des textes choisis.

Il y a des centaines d'articles, de livres, et de rapports qui touchent à un ou plusieurs aspects du sujet de ce recueil, et qui pourraient être tema de este compendio y que podrían ser numerados en la bibliografía. No es nuestra intención que la bibliografía para un compendio contenga las referencias para todas las publicaciones que se relacionen al tema, sino únicamente para aquellas publicaciones de las cuales se ha seleccionado texto o publicaciones básicas que hubieran sido seleccionadas si no hubiera un límite sobre el número de páginas de texto.

cités dans cette bibliographie. L'objectif de cette bibliographie n'est pas d'énumerer toutes les références pour tous les ouvrages qui sont pertinents, mais de donner seulement les références des ouvrages dont on a choisi des extraits, ou qui auraient été choisis s'il n'y avait pas de restrictions sur le nombre de pages de ce recueil.

Road to Porto Velho, Brazil.

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

Textos Seleccionados

Esta sección del compendio contiene páginas seleccionadas de cada texto que se catalogaron en la Tabla de Materias. Se utilizan recuadros rectangulares para encerrar las páginas que han sido reproducidas de la publicación original. Algunas de las páginas originales han sido reducidos para entrar en los recuadros. No se han hecho ningunos otros cambios en el material original exceptuando algunas notas aclaradoras que de vez en cuando han sido agregadas. De esta forma, cualquier error que hubiera existido en el texto seleccionado ha sido reproducido en el compendio mismo.

Los números de páginas del texto original aparecen dentro de los recuadros. Los números de páginas para el compendio están fuera de los recuadros y aparecen en los márgenes medio izquierdo o medio derecho de las páginas. Los números de páginas que se dán en los índices del compendio se refieren a los del compendio.

Cada texto comienza con una o mas páginas de material de introducción que contenía la publicación original. Este material generalmente incluye una página título, un índice, o ambas. Los astericos que han sido agregados al índice original significan lo siguiente:

* Algunas páginas (o partes de páginas) en

Textes Choisis

Cette partie du recueil contient les pages sélectionnées de chaque texte qui est énuméré dans la Table des Matières. Les pages du texte original qui sont reproduites sont entourées d'un encadrement rectangulaire. Certaines pages ont dû être réduites pour pouvoir être placées dans l'encadrement. Le texte original n'a pas été changé sauf pour quelques explications qui ont été insérées. Donc, si le texte original contient des erreurs, elles sont reproduites dans le recueil.

La pagination originale apparaît à l'intérieur de l'encadrement. La pagination du recueil est à l'extérieur de l'encadrement, soit à droite, soit à gauche de la marge extérieure des pages et est celle qui est citée dans la table des matières et dans l'index du recueil.

Chaque texte commence par une ou plusieurs pages d'introduction qui étaient incluses dans le texte original. Ces pages sont généralement le titre, ou la table des matières, ou les deux. Des astériques ont été ajoutés à la table des matières d'origine pour les raisons suivantes:

* Certaines pages, ou portions des pages,

the original document appear in the selected text, but other pages (or parts of pages) in this part of the original publication have been omitted.

**All pages in this part of the original document appear in the selected text.

The selected texts therefore include only those parts of the original documents that are preceded by asterisks in the tables of contents of the respective publications.

Broken lines across any page of selected text indicate those places where original text has been omitted. In a number of places, the selected text contains explanatory notes that have been inserted by the project staff. Such notes are set off within dashed-line boxes and begin with the word NOTE.

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esta parte del documento original aparecen en el texto original, pero otras páginas (o partes de páginas) en esta parte de la publicación original han sido omitidas.

** Todas las páginas en esta parte del documento original también aparecen en el texto seleccionado.

Por lo tanto, los textos seleccionados unicamente incluyen aquellas partes de los documentos originales que están precedidas por asteriscos en el índice de las publicaciones respectivas.

Líneas de guiones cruzando cualquier página del texto seleccionado significan que en ese lugar se ha omitido texto original. En varios lugares el texto seleccionado contiene notas aclaradoras que han sido introducidas por el personal del proyecto. Tales notas están insertadas en recuadros de guiones y comienzan con la palabra NOTE.

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dans cet extrait du document original sont incluses dans les Textes Choisis, mais d'autres pages (ou portion de pages) de l'édition originale ont été omises.

** Toutes les pages dans cet extrait du document original sont incluses dans les Textes Choisis.

Les Textes Choisis, donc, incluent seulement ces extraits des documents originaux qui sont précédés d'un astérique dans les tables des matières des publications respectives.

Les lignes brisées sur les pages des textes choisis indiquent les endroits où le texte original a été omis. A certains endroits, les textes choisis contiennent des explications qui ont été insérées par le personnel attaché à ce projet. Ces explications sont entourées d'un encadrement en pointillé et commencent toujours par le mot NOTE.

VOLUME I -HIGHWAY DRAINAGE GUIDELINES

Guidelines for Hydraulic Considerations In Highway Planning and Location

Prepared by

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

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FOREWORD

The Operating Subcommittee on Roadway Design, as part of its charge, investigates available data and pursues studies to prepare and keep current appropriate publications pertaining to principles, methods and procedures of roadway design, and recommends roadway design practices to protect and enhance the quality of the environment. Although the subject of drainage cuts across many phases of highway engineering, this Operating Subcommittee, believing that its charge included this aspect of design, requested and received approval from the Standing Committee on Engineering Policies to establish a task force to prepare needed publications on the subject of highway drainage.

The Task Force on Hydrology and Hydraulics first met in February, 1970, and developed a statement of purpose and outlined a program of activity. Its purpose is to assist the Operating Subcommittee on Roadway Design in developing guidelines and in formulating policy for highway drainage design and related hydrologic and hydraulic activities compatible with other highway disciplines, giving due consideration to safety and the environment.

Pursuant to this purpose, the Task Force on Hydrology and Hydraulics began preparing guidelines for highway drainage covering topics on the major areas of highway hydraulic design. Each major topic will be released as an individual guideline. The guidelines present an acceptable design approach to drainage and hydraulic problems, which integrates all related disciplines in highway engineering. Technical information is kept to a minimum by making reference to appropriate publications. No single guideline will necessarily be complete within itself. In order to avoid repetition, therefore; continual reference to other guidelines in the series will be required.

In preparing these guidelines, the Task Force recognized that drainage design can be accomplished in various ways and that further experience and research will indicate revisions necessary. It is expected that all involved in the drainage of highways will provide the continued surveillance of design procedures and offer constructive comments for future revisions.

The Operating Subcommittee on Roadway Design gratefully acknowledges the efforts of the members of the Task Force in preparing this guideline and appreciates the expertise offered by the participating States in this worthwhile endeavor.

MEMBERS

Task Force on Hydrology and Hydraulics
Operating Subcommittee on Roadway Design

Mr. Samuel V. Fox, Chairman (Supervising Hydraulic Engineer) – Texas
Mr. Mainard Wacker, Vice Chairman (Hydraulic Staff Engineer) – Wyoming
Mr. Lester A. Herr, Secretary (Deputy Chief Bridge Division) – FHWA
Mr. Floyd Ball, Engineering Coordinator – Oklahoma
Mr. Bruce Cole, Chief Drainage Engineer – Kentucky
Mr. Mark F. Looschen, Preliminary Bridge Engineer – Iowa
Mr. James L. Pierce, Hydraulic Engineer – Georgia
Mr. Arthur L. Pond, Assistant Location & Design Engineer – Virginia
Mr. Wilford T. Robertson, Chief Bridge Engineer – Washington
Mr. D. W. Stehmeyer, Engineer of Drainage – Florida
Mr. George T. Tucker, Hydraulic Engineer – Vermont
Mr. Adrianus VanKampen, Drainage Engineer – Michigan
Mr. W. A. Whitnack, Headquarters Hydraulic Engineer – California

Guidelines published on the date of this printing.

*(1) Guidelines for Hydraulic Considerations in Planning and Location

(2) Guidelines for Hydrology

(3) Guidelines for Erosion and Sediment Control

*This publication

HYDRAULIC CONSIDERATIONS IN HIGHWAY PLANNING AND LOCATION

CONTENTS

6

HYDRAULIC CONSIDERATIONS IN HIGHWAY PLANNING AND LOCATION

1.0 Introduction

Water and related climatic factors are important considerations in planning and locating highways. The effect of the highway construction on the existing drainage pattern and on the potential flood hazard, as well as the effect of floods on the highway, must be assessed in the preliminary planning and design stages. Often hydraulic factors are closely related to the environmental, ecological and economic aspects of the location of a new highway and critical evaluations must be made in the planning process, requiring compromises and a searching for alternate solutions and routes.

Some drainage, flood and water quality problems can be easily recognized and resolved; others may require extensive investigation before an adequate and satisfactory solution can be developed. Specialists experienced in hydrology and hydraulics can contribute substantially to the planning and location phases of a highway project by recognizing potentially troublesome locations, making necessary investigations and recommending practical solutions.

2.0 Preliminary Drainage Surveys

Since hydraulic considerations can influence the selection of a highway corridor and the alternate routes within the corridor, the type and amount of data needed for planning studies can vary widely depending on such elements as environmental considerations, class of the proposed highway, state of land-use development and individual site conditions. Topographic maps, aerial photographs and streamflow records provide helpful preliminary drainage data, but historical high-water elevations and flood discharges are of particular interest in establishing waterway requirements. Comprehensive hydraulic investigations may be required when route selection involves important hydraulic features such as water-supply wells and reservoirs, flood-control dams, water resource projects, and encroachment on flood plains of major streams. Special studies and investigations, including consideration of the environmental and ecological impact, should be commensurate with the importance and magnitude of the project and the complexity of the problems encountered.

3.0 Recognition of Possible Flood Hazards and Expensive Locations

Floodflow characteristics at a highway stream crossing should be carefully analyzed to determine their effect upon the highway as well as to evaluate the effects of the highway upon the floodflow. (1)[1] Such an evaluation can assist in

[1] Underlined numbers in parenthesis refer to publications in "References" (Section 7)

determining those locations at which construction and maintenance will be unusually expensive or hazardous. It is essential that such difficult or adverse conditions be recognized in the early stages of planning so that they may receive adequate consideration or indicate the need for alternate locations. Having identified the sources of difficulty, specific recommendations can be advanced for developing solutions. Although satisfactory solutions often can be obtained by making only minor changes in selected routes to take advantage of better natural hydraulic features as alternate sites, troublesome and uncertain conditions are sometimes best avoided altogether. Sometimes rerouting of a highway is the only practical solution where the cost of providing adequate drainage facilities for a proposed route or damage to the natural environment would be prohibitive. For a more detailed description of specific problems that may be encountered and their solution, refer to other sections of these guidelines.

3.1 Potential Problems During Construction

Many serious construction problems arise because important drainage and water-related factors were overlooked or neglected in the location and planning phases of the project. Erosion of some soils becomes critical during construction and measures necessary to minimize sediment problems must be recognized early. Also with respect to adequate soils, geologic and hydraulic studies will provide much guidance in solving drainage and landslide problems as well as being helpful in minimizing or avoiding these problems during construction. Risk of damage by siltation of ponds and reservoirs during construction often can be reduced by studying flood and precipitation records and proper scheduling of work.

Time of construction is important. A structure or embankment is usually most vulnerable to damage from floods when partially complete; therefore, due consideration should be given to this problem in the planning and location stage of design. Providing required protection for fish habitat is particularly important in some areas of the country. Irrigation practices cannot be interrupted nor can the pumping and distribution facilities be contaminated with sediment without causing serious difficulties or adversely affecting those who depend upon agriculture for their livelihood.

3.2 Potential Maintenance Problems

Planning and location studies should consider potential erosion and sedimentation problems upon completion of highway construction. If a particular location will require frequent and expensive maintenance due to drainage, alternate locations should be considered unless the potentially high maintenance costs can be reduced by special design. Experience in the area is the best indicator of maintenance problems and interviews with maintenance personnel could be extremely helpful in identifying potential drainage problems. Reference to highway maintenance and flood reports, damage surveys, newspaper clippings and interviews with local residents could be helpful in evaluating potential maintenance problems.

Channel changes, minor drainage modifications and revisions in irrigation systems usually carry the assumption of certain maintenance responsibilities by the agency constructing the highway. Potential damage from the erosion and degradation of stream channels and problems caused by ice and debris can be of considerable significance from the maintenance standpoint.

4.0 Coordination with Other Agencies

Interagency coordination is desirable because a more satisfactory design usually can be developed if the commonly shared interests of all concerned groups receive consideration during the project planning phase. Substantial benefits and economies frequently can be realized for highway and water resource projects through coordinated planning among Federal, State and local agencies that are engaged in water related activities, such as flood control and water resources planning. Interagency cooperation, through the instruments of regional planning, provides the best vehicle for serving the public interest.

4.1 Non-highway Projects

State and local water resource agencies or others who are responsible for flood control and drainage should be contacted to determine the status of existing facilities and plans for proposed projects. All water related projects should be considered when highway planning is undertaken. Every effort should be made to encourage interagency cooperation in planning, location and design so that proposed highway construction will be compatible with navigation, irrigation, flood control, storm sewer systems and land use. Because of funding and scheduling of cooperative or joint use projects, such arrangements must be initiated at the earliest possible date.

Care should be exercised in planning highway projects that are dependent upon the completion of a water resource project. For example, a highway located downstream from an existing flood control project might be designed with a lower grade line and reduced waterway openings. However, a highway project designed to accommodate or benefit from a proposed flood control project could be in serious trouble in the event that the flood control project is delayed or not constructed.

4.2 Permits

Permits are required for construction of highways or bridges along or across navigable streams. Applications for such permits should be filed with the Coast Guard for the construction of bridges and with the Corps of Engineers for other construction. Other permits usually are required by State or local agencies when construction affects fishing streams, outdoor recreational areas, reserved watersheds, and wetlands. Care must be taken to recognize and respect water rights. Permits, as required, should be obtained before construction begins, and preferably before detailed plans are prepared.

Federal, State and local agencies having review and, in some cases, permit authority in the construction of highway projects as related to flood control and environmental impact must be contacted early in the planning and location stage.

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5.0 Legal Considerations

In considering various route locations, planners should understand the liabilities that highway agencies assume with regard to drainage when construction necessitates changing local topography and drainage patterns. Although water laws vary widely throughout the United States and are subject to many different interpretations, statutes usually place responsibility for flood-inflicted damages upon the person or organization who alters the drainage patterns of a watershed or creates an obstacle to the flow of water in a natural watercourse. Even though an alteration or encroachment may be unavoidable and localized, costly legal proceedings may arise due to damages from erosion, silting and flooding. Therefore, planners and others who are responsible for selecting highway locations should be aware of conditions and factors that may contribute to difficulties. Flood-prone locations, however, may not be readily apparent and the assistance of a drainage specialist may be needed to identify, investigate and determine the magnitude and extent of the problem.

Whenever drainage problems are known to exist or can be identified, drainage and flood easements or other means of avoiding future litigation should be considered, especially in locations where a problem could be caused or aggravated by the construction of a highway. It is often helpful to document the history and present status of existing conditions or problems and supplement the record by photographs and descriptions of field conditions. Such thoroughness is essential because highway departments are often blamed for flooding or erosion damages due to conditions that existed prior to highway construction, regardless of the real cause.

6.0 Reports and Documentation

Hydrologic and hydraulic data, preliminary calculations and analyses and all information used in developing conclusions and recommendations related to drainage requirements, including estimates of structure size and location, should be compiled in a report. Such a report serves as documentation and back up for decisions on route location and is an excellent reference for more detailed studies needed in preparing construction plans. Although the depth or extent of such reports must necessarily be left to the professional judgment of the engineer making the preliminary surveys, the content generally should be commensurate with the cost and complexity of the project and the problems anticipated.

7.0 References

(1) Water Resources Council, *Regulations of Flood Hazard Areas to Reduce Flood Losses*, Volume 1, U.S. Government Printing Office, Washington, D.C. 20402, 578 pp., price $2.50.

(2) Water Resources Council, *Regulations of Flood Hazard Areas to Reduce Flood Losses*, Volume 2, U.S. Government Printing Office, Washington, D.C. 20402, 389 pp., price $2.00.

VOLUME II - HIGHWAY DRAINAGE GUIDELINES

Guidelines for Hydrology

Prepared by

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

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HYDROLOGY

CONTENTS

HYDROLOGY

1.0 Introduction

Hydrologic analysis is a most important step prior to the hydraulic design of a highway drainage structure. Such an analysis is necessary for determining the rate of flow, runoff or discharge that the drainage facility will be required to accommodate. The design discharge is a hydraulic "load" on the highway facility and the determination of its magnitude and possibly its duration is as important as the determination of the proper structural load. These guidelines give a recommended approach to the hydrologic analysis for the design of highway drainage facilities.

Highway drainage facilities range from very small culverts and channels to multi-million dollar storm drains and bridges. Although some hydrologic analysis is necessary for all highway drainage facilities, the extent of such studies should be commensurate with the importance of the structure.

2.0 Documentation

Experience indicates that the design of highway drainage facilities should be adequately documented. Frequently, it is necessary to refer to plans, specifications and hydrologic analyses long after the actual construction has been completed. One of the primary reasons for documentation is to evaluate the hydraulic performance of structures after large floods to determine if the structures performed as anticipated or to establish the cause of unexpected behavior, if such is the case. In the event of failure, it is essential that contributing factors be identified in order that recurring damage can be avoided. Documentation also provides factual information for use in preparing a defense against legal action.

The documentation of a hydrologic analysis is the compilation and preservation of all pertinent information on which the hydrologic decision was based. This might include drainage area and other maps, field-survey information, source references, photographs, hydrologic calculations, flood-frequency analyses, stage-discharge data and flood history, including narratives from highway maintenance foremen and local residents who witnessed or had knowledge of an unusual event.

Although the above list is not all inclusive, it does contain some basic items that should be contained in the design files. The documentation should be stored as a part of the permanent records of the highway department.

Hydrologic data shown on project plans insures a permanency of record, serves as a reference in making plan reviews and aids field engineers during construction. Such data could include: size of drainage area, magnitude and frequency of the design flood and the corresponding water-surface elevations at critical locations, and the elevation, discharge, and date of the maximum known flood, if available. Other drainage data, such as watershed delineation, arrows indicating direction of flow, proposed and existing structure locations, outfalls, ditches, and other surface drainage facilities, could be helpful to construction engineers, if readily available on the plans. See Figure 1 for an example (1).[1] Caution must be exercised not to clutter plans to the point of being illegible or confusing.

3.0 Factors Affecting Flood Runoff

The highway engineer should become familiar with the many factors that affect runoff before making a hydrologic analysis. Such factors can be broadly classified as topographic and climatic; however, the two classes are interrelated in their flood-producing effects. In addition, components within each class are so interrelated that experience and judgment are necessary to properly evaluate the various factors that apply to a particular situation. Generally, different factors affect the runoff as drainage area increases. Some of the major factors are discussed in the following sections. Benson made a study of the factors that affect the occurrence of floods in the humid New England area (2) and in the Southwest (3) where the climate varies from humid to arid. A study of these references is rewarding.

3.1 Drainage Basin Characteristics

In evaluating various hydrologic methods for determining flood runoff (Section 6.0), it is often necessary to compare drainage basins; therefore, the highway engineer should be familiar with drainage basin characteristics and how they affect flood runoff.

3.1.1 Size

The size of a drainage basin has an important bearing on the response of the basin to rainfall, and consequently on the methods used to predict flood runoff. Flood runoff for small streams in the same geographical area appears to be proportional to the size of the drainage area. As areas increase in size, the runoff becomes proportional to some power of the drainage area (Section 6.2.3). However, the effect of other basin characteristics often obscures the effect of size alone.

Determining the size of the drainage area that contributes to flow at the drainage structure site is a basic step in a hydrologic analysis. The drainage area, expressed in acres or square miles, is determined from field surveys, maps, or aerial photographs. In some cases, a drainage area can be obtained from gaging station information or by adjusting the area shown for Geological Survey or Corps of Engineers stream-gaging stations upstream or downstream from the crossing under consideration.

Topographic maps are valuable aids in obtaining the size of drainage areas. The most commonly used topographic maps are those of the U.S. Geological

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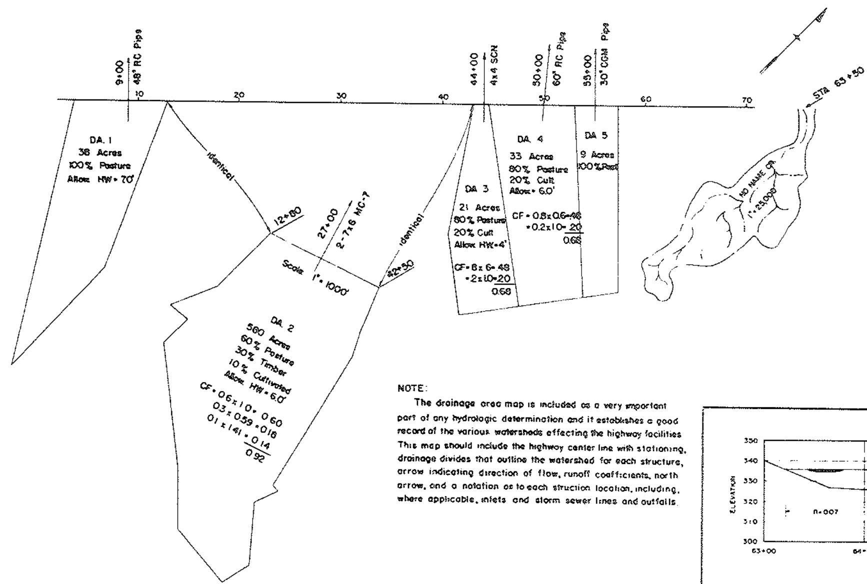
[1] Underlined numbers in parentheses refer to publications in "References" (Section 8).

Compendium 2

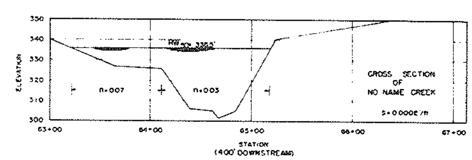


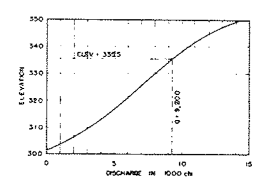
RUN-OFF COMPUTATIONS

STATION	DRAINAGE AREA	AREA (ac)	T (min)	C	I (in/hr)	Q (cfs)
9+00	1	38	21	0.50	6.5	124
27+00	2	580	45	0.20	4.6	552
44+00	3	21	16	0.60	7.1	89
50+00	4	33	20	0.58	6.6	127
55+00	5	9	15	0.40	7.3	26

NOTE:

The drainage area map is included as a very important part of any hydrologic determination and it establishes a good record of the various watersheds affecting the highway facilities. This map should include the highway center line with stationing, drainage divides that outline the watershed for each structure, arrow indicating direction of flow, runoff coefficients, north arrow, and a notation as to each struction location, including, where applicable, inlets and storm sewer lines and outfalls.





DA=44 Sq.Mi.
Q_{50}=9200cfs(Bulletin 6311)
HW_{50}@℄=335.58
Area thru struct. below HW_{50}=2,000Sq.Ft
$V_{STRUCT}=Q_{50}/A=4.6$fps
Area in stream below HW_{50} @400'D.S=3214Sq.Ft
$V_{CHANNEL}=Q_{50}/A=2.8$fps

TYPICAL CROSS-SECTION & DISCHARGE vs ELEVATION CURVE

MAP OF DRAINAGE AREAS

SCALE 1"=400'
unless otherwise noted

X-3

Figure 1

Text 2

Survey[2], and the Corps of Engineers. Information concerning these can be obtained from the Map Information Office, U.S. Geological Survey, Washington, D.C. 20242.

Accurate aerial photography[3] supplemented by vertical and horizontal control surveys provides a means of measuring the size of a drainage area. Although uncontrolled aerial photographs aid the engineer, they do not always provide an accurate basis for defining the boundaries of the drainage area, and they should be supplemented with field surveys.

3.1.2 Shape

Long narrow watersheds have long been considered to give lower peaks than fan or pear-shaped watersheds, other characteristics being equal. However, Benson (2, p. 28) found that none of several indices of basin shape or drainage pattern were significantly related to peak discharge, if tested after the effect of the drainage area and main-channel slope had been taken into account.

3.1.3 Slope

Many investigators have found that next to drainage area size, some index representing the slope of the basin is a very important basin characteristic in comparing flood magnitudes. Benson (2, p. 23) found that main-channel slope, tributary channel slope, and average land slope, were highly correlated. Main-channel slope, determined by simple measurements from topographic maps, has been used in a number of analyses and found to be a significant indicator in estimating runoff. This slope can also be useful in comparing one drainage basin with another when records are limited or not available. Benson (2) found a straight-line slope between main-channel points 10 and 85 percent above the gage to give best results. Potter (3) found the average slope between 30 and 70 percent above the gage to give good results in his analysis.

3.1.4 Land Use

Since the activities of man can change basin runoff characteristics, land-use studies are necessary to define present and future conditions, particularly with regard to the degree of urbanization or other changes expected to take place within the drainage basin that might affect runoff. Valuable information concerning land-use trends may be obtained from various local, State and Federal agencies and planning studies (4, Chapters 8 and 12).

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[2]Purchase orders for maps should be addressed to Distribution Section, U.S. Geological Survey, 1200 South Eads Street, Arlington, Virginia 22202, for areas east of the Mississippi River, including Puerto Rico and the Virgin Islands, and to Distribution Section, U.S. Geological Survey, Federal Center, Denver, Colorado 80225, for areas west of the Mississippi River, including Alaska, Hawaii, Louisiana, Minnesota, Guam, and American Samoa. Alaskan maps may be ordered from Distribution Section, U.S. Geological Survey, 310 First Avenue, Fairbanks, Alaska 99701.

[3]Aerial photographs may be obtained from the USGS Map Information Office or the Commodity and Stabilization Service, U.S. Department of Agriculture, Washington, D.C.

The effect of urbanization on peak flow depends upon the percent of the area made impervious and the changes made in the drainage pattern through the installation of storm sewers and the modification of surface channels. References (5) through (9) discuss the effect of urbanization on flood peaks. To obtain a true picture of the effects of urbanization at a particular location, the peak runoff should be compared for the drainage area in its natural state and after urbanization has taken place. Such measurements are seldom practical and require a number of years of investigation. From information now available, urbanization can increase flood peaks on small streams by 1.5 to 2 times over predevelopment conditions. With an unusual amount of channelization and storm sewer work, increases in peak discharge can be greater.

3.1.5 Geology

The basic make-up of underlying rock formations and other geophysical factors, such as glacial and river deposits, can be quite significant in effecting runoff in some areas. Stream flow records are an integrated effect of many factors and the study of such records often indicates the effect of surface soils and geology of the area on floods.

3.1.5.1 Soil Type

Soil type generally has an important effect on the rate of peak runoff, principally in its effect on infiltration (4, Chapter 7). The effect of soil type often varies with the magnitude and intensity of rainfall. The condition of soil at the time of precipitation can change the amount of runoff, especially the flood peaks. If the ground is frozen or saturated with moisture, most of the precipitation will run off.

3.1.5.2 Surface Infiltration

Infiltration is the flow or movement of water into the ground. Infiltration in most drainage basins represents one of the major losses of precipitation. Infiltration data are used with other hydrological data to evaluate water losses and to compute peak runoff as the residual of the rainfall minus the losses. Karst topography (sink holes) and volcanic terrain (lava caps) produce little surface runoff (10, Chapters 14 and 15). Chapter 2 of the ASCE Hydrology Handbook (11) states, "For all practical purposes, the infiltration curve approach applies only to relatively small, physically homogeneous areas such as may exist for airfields, urban developments and some smaller agricultural watersheds." It may have application in the design of interchange areas and pumping plants used to drain depressed locations.

3.1.6 Storage

Storage within a drainage basin may be detention storage, which is the rainfall lost in filling small depressions in the ground surface; storage in transit in overland or channel flow; or storage in ponds, lakes, playas, or swamps. Storage may also occur in flood-control or other reservoirs. The effect of storage on peak flows can be quite large.

In a study for the Delaware River Basin (12), flood storage in lakes and swamps was found to be an important factor in New York, northeastern Pennsylvania and in New Jersey. Except in New Jersey, this factor could be combined with others and delineated geographically in hydrologic areas. In New Jersey, a flood-reduction curve was constructed by plotting the flood reduction against the percent of drainage area in lakes and swamps. The factor for multiplying estimated peak rates ranged from 1.00 for no lakes and swamps to 0.09 for 25 percent lakes and swamps.

The effect of flood-control reservoirs in changing downstream conditions should be considered in evaluating flood peaks and river stages for design of highway structures. Often, helpful data can be obtained from the controlling public agency or the owner of the reservoir project. Particular attention should be given to degradation problems and increased tree and brush growth. Before consideration of these effects, the flood-control project should exist or be under construction. Many flood-control projects are authorized but never built because funds for construction were not appropriated.

3.2 Stream Channel Characteristics

Surface and subsurface runoffs are collected and disposed of through the stream channels. The natural or altered condition of these channels can materially affect the volume and rate of runoff and therefore, these conditions must be considered in the hydrologic analysis.

3.2.1 Geometry and Configuration

The geometry of the stream network sometimes affects the flood-producing characteristics of the basin and this effect should be considered in the hydrologic analysis.

Some streams have well-defined channels, others have relatively small, low-flow channels and wide flood plains. Some streams have numerous tributaries; while others have one main watercourse receiving runoff from overland flow. The sinuosity of channels affect channel storage and progression of flood peaks. Overbank storage, particularly in vegetated areas, can greatly reduce peak flows. The effect of the stream network often varies with flood magnitude. Field surveys and maps will reveal the nature of the stream channel network.

3.2.2 Natural and Artificial Controls

Controls, both natural and artificial, determine the relation of stage to discharge and regulate the flow.

Natural control of streamflow may occur at channel constrictions, gravel bars, rock outcrops and debris jams. Sometimes channel roughness is a control. Artificial controls include dams, highway and railroad bridges and embankments, floodwater-retarding structures, diversion dams, grade-control structures and recreational and water-use facilities. Usually information concerning these structures or facilities can be obtained from the agency responsible for the operation and maintenance.

The hydrologic analysis should determine the degree or effect of such controls upon flood flow.

3.2.3 Channel Modification

Any work being performed, proposed or completed, that changes the hydraulic efficiency of the stream must be studied to determine its effect on the streamflow. The effect on peak flows at the structure site due to modification of a stream's hydraulic characteristics must be determined. The highway engineer should be aware of plans for channel modifications, which might effect the stream hydrology and, insofar as possible, coordinate the highway design with the proposed channel modifications. Similarly, the effects of storm-drainage systems and other water-related projects should be investigated.

3.2.4 Aggradation – Degradation

The water surface profile of a stream or river will be affected through a reach where fill or scour occurs. This also affects the validity of using historical high-water marks to define present conditions. Aggradation may lessen the channel capacity, increase flood heights, and cause overflow at a lower discharge while degradation might increase channel capacity and result in higher flood peaks. Although difficult to determine quantitatively, the effect of present and future aggradation or degradation should be evaluated when designing a highway at or near a stream, so that a design can be provided to accommodate this phenomenon.

3.2.5 Ice and Debris

The quantity and size of ice and debris carried by a stream should be investigated and recorded for use in the design of drainage structures. The times of occurrence of ice or debris in relation to the occurrence of flood peaks should be determined; and the effect of backwater from ice or debris jams on recorded flood heights should be considered in using stream-flow records. The location of the constriction or other obstacle causing jams, whether at the site or structure under study or downstream, should be investigated and the feasibility of correcting the problem considered.

3.3 Flood Plain Characteristics

The major portion of the total flood discharges for the higher recurrence intervals often is carried by flood plains. Hence, it is logical to assume that factors associated with flood plain characteristics may have more effect on flood runoff than those relating to stream channels. Generally, a much greater range of conditions will be encountered on flood plains than in main channels.

3.3.1 Geometry and Configuration

The width-depth ratio of the flood plain is an important factor in evaluating flood runoff potential. Generally speaking, the greater this ratio the greater the effect of relatively minor depressions and adverse ground slopes on temporary storage losses and changes in velocity head, and the greater the effect of seasonal vegetation changes on roughness factors.

Another important factor is continuity of the flood plain or the relative freedom from natural constrictions such as encroaching hills on one or both sides, and from man-made constrictions or barriers such as road crossings, irrigation distribution systems, etc.

3.3.2 Seasonal and Progressive Changes in Vegetation

A realistic evaluation of the conveyance or carrying capacity of a flood plain requires consideration of both seasonal and progressive changes in vegetation. A reach of flood plain may carry at an appreciably lower stage a given discharge in late winter or early spring than for the same discharge during the height of a growing season. Whether a row crop, such as corn, is planted in rows normal to or parallel with the general direction of the flood plain, can, during the later part of the growing season, make nearly 50 percent difference in the conveyance of the flood plain. Such differences must be considered in selecting the friction factor in the conveyance equation.

Aside from a marked effect on conveyance, summer vegetation including weeds, tree leaves and crops, increases temporary flood plain storage and infiltration.

3.4 Precipitation

Precipitation in the form of rain, snow, hail or sleet is the principal source of runoff (11, Chapter 1). The total amount of precipitation is most important in producing peak flows from large areas, while the intensity of precipitation is most important in producing peak flows from small areas. Rainfall is sometimes used as a factor in estimating peak runoff (13).

Precipitation data are collected and published by the National Weather Service, National Oceanic and Atmospheric Administration, formerly the Weather Bureau.

3.4.1 Rainfall

Although the relationship between rainfall and runoff is not well defined, runoff usually increases in proportion to the rainfall on a drainage basin. Basin characteristics and antecedent conditions, particularly precipitation, have a major effect on the proportion of rainfall which becomes runoff. For example, most of the rain falling on frozen or saturated ground runs off quickly, while most of the rain falling on dry, porous soil infiltrates. There is little correlation between the recurrence interval of rainfall and the recurrence interval of the corresponding peak runoff (14, p. 15). However, studies (15 and 16) have shown that when peak runoff and rainfall were considered separately, the ratio of peak runoff rate of a given frequency to rainfall intensity for the same frequency remained reasonably constant for the various frequencies. This indicates that rainfall can be used to estimate design floods, although a rainfall of a given frequency will seldom produce a peak runoff of the same frequency for any one storm.

3.4.2 Snow

Snow generally results in a delay of runoff. If the snow melts slowly, low-peak runoff results. In areas of diverse terrain, i.e., mountain and valley topography, the snowpack serves as a storage mechanism. During periods of normal spring runoff, a particular watershed will have what might be called primary and secondary peaks. During the early period of runoff, the lowlands contribute most, causing the primary peaks. Later, the highlands begin contributing, creating secondary peaks. The use of the hydrograph method outlined in Section 6.4 is useful in describing this lag in basic response to the snowmelt runoff. At present, gaging station records are the best means of observing this phenomenon.

After an accumulation of snow, a rain with increasing temperatures can cause runoff peaks much greater than would occur from the rainfall alone. The relation of inches of rainfall to inches of snow, or the water content of snow, varies over the country and from year to year. There are various procedures for computing snowmelt runoff (4, Chapter 11, and 17), but streamflow records are the best source of data.

4.0 Flood History

Good highway design practice recognizes that flood hazards must be evaluated whenever highway locations cross or encroach upon flood plains. The history of past floods and their effect on existing structures are of exceptional value in making flood hazard evaluation studies, including needed information for sizing structures. Flood-control works and land-use planning data relative to restricting flood heights and reducing flood discharges are also a necessary part of a flood hazard evaluation.

4.1 Historical Floods

Major floods that have been experienced before the start of records are often called historical floods. In describing these events, it is necessary to determine the period of years during which they have occurred, as well as their magnitude, in order that the information may be fully utilized. Some information on past floods usually can be obtained from old newspaper accounts, long-term residents, and other sources. Often, experienced personnel of the Geological Survey and other agencies who make flood determinations can find flood marks or other positive evidence of the height of historical floods. Changes in channel and watershed conditions should be evaluated in relating historical floods to the present. Historical floods of unusual magnitude are valuable data in flood-frequency analysis, particularly when the gaging-station record is short.

4.2 Flood Data

Much streamflow and flood-related data are available to the highway engineer. Most streamflow data are obtained by the Geological Survey at numerous gaging stations over the United States. These data and that collected by other agencies are published periodically in the surface water records of the Geological Survey and available at their local offices.

Railroad maintenance files often contain accurate information regarding flood stages that have been experienced at railway structures or along tracks bordering a stream. Newspaper accounts and magazine articles should not be overlooked as sources of documentation of unusual floods.

All of these sources may provide valuable assistance and supplementary information that can be used advantageously; however, discrepancies sometimes are revealed when these data are compared. This indicates the need for verification and evaluation of flood data, regardless of the source. Development within the watershed should be evaluated before using old flood data.

4.2.1 Flood-Control Projects

One of the main purposes of a flood-control project is to reduce damage from unusual or infrequent floods. Several methods have been used to accomplish this such as: storage reservoirs, levees, channel modifications, and flood diversion. The method of control should be studied, especially its effect on reducing flood magnitude, in evaluating the potential flood hazard in highway design. Storage space reserved for flood water should be considered in reducing waterway openings of highway structures from that normally provided. However, storage for power, irrigation, water supply or other purposes might not be available when needed to reduce flood peaks. Flood routing procedures are given in references (4) and (45).

4.3 Flood History of Existing Structures

Structures that have existed for many years may have experienced unusual floods. If an existing structure is located in the vicinity of the proposed highway structure, a field inspection may indicate flood heights and damage that has occurred. Local witnesses and examination of maintenance records may be helpful in evaluating past floods at a structure.

High water elevations, indicated by deposits of debris, by seed or mud lines on tree trunks and bridge abutments, by wash-lines or fine-debris lines on banks, by whisps of grass or hay lodged in tree limbs or fences, and by other flood evidence, such as erosion and scour, can provide information for arriving at flood discharges and reliable flood stages for use in designing a proposed structure. More obvious items of flood evidence such as large deposits of debris or prominent wash-lines do not necessarily indicate the true peak stage. Usually the actual peak is somewhat higher than would be indicated by the rather obvious marks, unless such marks were affected by pile up or the rebound of trees or shrubs after the flood. Interviews with highway maintenance foremen and the long-time residents in the area can be very helpful.

A record of the performance of drainage structures during floods, including photographs, is valuable for use in designing future structures and for determining modifications to structures which might reduce maintenance or increase safety. Such records may also be helpful in defending the State against damage claims. These records might include:

1. Maximum flood height, upstream and downstream from a structure. Observed differences in water surface elevations on the upstream and downstream side of the embankments at several points from each abutment.
2. Distribution of flow and approximate velocities in different sections of the stream. Relative quantity of overbank flow and how it returns to the channel.
3. Direction of flow with respect to the piers and the low-water channel.
4. Observe drift-size and concentration. Remarks on clearance or freeboard.
5. Duration of flooding.
6. Magnitude of flood and its relation to other notable floods.
7. Headwater at culverts.
8. Scour, erosion and sediment or gravel deposits.
9. Damage to structure and adjacent property.

All of these observations may not be necessary for every structure. The size of the structure, magnitude of the flood, extent of damage, or probability of legal action might determine the extent of the observations.

4.4 Methods of Determining Flood Magnitudes

The accurate determination of flood magnitudes requires a background in open-channel hydraulics and a knowledge of floodwater behavioral patterns; however, knowledge must be coupled with experience if the results are to be correctly interpreted.

Geological Survey publications (18 to 27) outline procedures for making such determinations. The engineer can study the recommended procedures that are outlined in these publications and gain an adequate knowledge of the techniques of measuring floodflow, but only by using the methods can he become proficient in their application.

The basic methods of measuring floodflow are discussed in the following paragraphs.

4.4.1 Direct Measurements

The direct measurement of floodflow consists of measurements that are made during a flood (18). Discharge is determined by simultaneously measuring the flow depth and velocity at a sufficient number of points in a cross section to define significant changes in either depth or velocity. From these measurements, the area and average velocity can be determined and the discharge calculated. Discharge measurements at various stages at a site or gaging station provide data for developing a rating curve (19) or a plot of stage versus discharge. Continuous records of stage gaging stations provide discharge data for studying the recurrence interval or frequency of floods (20, 21).

4.4.2 Indirect Measurements

Indirect measurements are made when it is impossible or impractical to measure floodflows directly. Generally, these measurements are made after the flood subsides (22). Such measurements include high-water marks, channel geometry, and an estimate of roughness coefficients (23). From these data, the flood magnitude is calculated using basic hydraulic equations. Indirect methods for determining the magnitudes of actual floods include the slope-area (24), flow-through culverts (25), contracted opening (26), and flow over dams (27). This tool in measuring floodflows is most valuable to the highway engineer and a thorough understanding of the methods used in the listed publications is necessary.

4.5 Evaluation of Observed High-Water Marks

Often a flood stage can be determined from observed high-water marks in evidence after a flood recedes. Usually, several high-water marks are required to compute the discharge of a particular flood. 25

Each high-water mark and its quality should be noted, and a profile plotted to evaluate the consistency of the marks (22, p. 26). Experienced personnel in this work are of extreme importance. The apparent quality of a high-water mark can be deceiving if not properly evaluated. For instance, a mark on the upstream side of a tree or building will reflect a higher stage than actually existed due to the rise in water surface upstream from the obstruction. Conversely, a high-water mark taken within the drawndown area of a hydraulic structure or an obstruction may reflect a lower stage for the stream than actually existed. Also, stages affected by ice, log jams, confluences, varying land use over the years, and an aggrading or degrading channel, can cause fictitious stage-discharge relationships which are not particularly representative of the natural channel conditions.

5.0 Selecting a Design Flood Frequency

One of the first steps in making a hydrologic analysis for any highway drainage facility is the selection of a design flood magnitude. The selected design flood magnitude is just one of many possible flood magnitudes that has occurred or may occur at the site in question. The selection of a particular flood magnitude is a complex problem which involves consideration of many factors.

The fundamental approach is to analyze the peak flood magnitudes at a site on a frequency basis (28, 29, 30, and 31), i.e., based on the average recurrence interval or on the probability of a peak flood magnitude being exceeded in any one year. With this frequency analysis goes the associated factors of economy and risk. By selecting a large peak flood magnitude for design at a site, the probability of having such a flood occurring and the risk of damage is reduced, but structure costs to accommodate such large floods are increased. Conversely, the selection of a small flood reduces the initial cost of structures and increases the risk of damage from larger floods.

5.1 Highway Classifications

Unfortunately, the selection of a design flood frequency has become oversimplified. Over the years, a range of frequencies on recurrence intervals has been used for the design of various highway drainage facilities. Roads with minor classifications are designed using a high frequency of occurrence (small floods), and important major highways are designed using low-frequency (rare) floods. Often, too little regard is given factors likely to cause damage at the individual location.

In the past, availability of funds and the lack of hydrologic data have played a major role in the adoption of the concept of associating highway classification with a specified design frequency. However, with more adequate coverage of hydrological data, better methods of analysis, and an increasing public awareness of the potential hazards associated with highways encroaching upon flood plains, the engineer now must consider both the risk and economics involved in selecting the design frequency for each highway hydraulic facility. The degree of consideration given to risk for a particular site should depend upon the importance of the structure and the flood hazard potential, as well as the traffic and highway classification.

5.2 Risk and Economics

When a flood frequency or recurrence interval is selected for a particular location, the designer is implying that the estimated effects of a larger flood on life, property, traffic and the environment do not justify constructing a larger structure at the time. Risk of serious damage begins when floods exceeding the design flood occur. Damage from lesser or more frequent floods should be minimal and acceptable. Optimal designs considering all factors are often idealistic and cannot be built because of constraints imposed by budgetary limitations, but such conditions do not relieve the engineer from his professional responsibility to strive for a good design.

5.2.1 Risk

Risk has been defined by some in terms of the recurrence interval of a flood of stated magnitude being exceeded or the probability of a flood of stated magnitude being exceeded in any one year. Possibly a risk factor is a more appropriate term. Risk factor has been defined (32) as "the probability or likelihood that a given flood will be equaled or exceeded at least once in some given period of years." For instance, the chances of a 50-year frequency flood occurring in a 50-year period is about 2 out of 3.

Selecting a design flood frequency by risk as defined above is not the complete answer. The 50-year flood can be exceeded at one location with minimal damage, but at another location, occurrence of the same frequency flood might approach a disaster. Risk and the selection of the design flood recurrence interval involves an evaluation of possible loss of life, property damage and the interruption of traffic.

5.2.1.1 Loss of Life

Loss of life associated with highway flooding can occur when a vehicle and its occupants are washed from an inundated highway, fall in a stream or river because of the failure of a highway structure, or when a highway embankment is washed away and causes flooding in downstream areas.

While it is difficult to place a value on a human life, potential flooding involving possible loss of life related to a highway must be given careful consideration. It is also obvious that it is not generally economically feasible to provide for all flood eventualities, but this does not relieve the engineer of the obligation to weigh all factors before making a decision. Factors to be considered in potential loss of life situations should include the probability of future flood occurrence and loss of structure, duration, depth, and velocity of hazardous flood waters, the dependability of adequate warning systems or devices, roadway approach grades, sight distances, and the availability of detours.

5.2.1.2 Property Damage

Property, as used here, denotes any property, whether private or public, involved with potentially damaging flood waters as related to the highway or its drainage facilities. Damages to such property from flood waters can include eroded highway embankments, loss of highway structures, and damage to adjacent property. Damage to highway property causes increased maintenance costs and sometimes involves the cost of replacing a structure. Such costs should be listed in a detailed estimate and considered in selecting the design frequency.

5.2.1.3 Traffic Interruption

When a portion of highway is closed due to flooding, the travelling public's journey is interrupted and delayed. Traffic interruptions are always a serious occurrence. The seriousness of the situation may be evaluated by considering, for a given highway site, the traffic volume, the traffic delay incurred, the availability of alternate routes, and the overall importance of the route, including the provision of emergency supply and rescue.

Interruptions and short delays due to floods sometimes can be tolerated. For instance, short duration flooding of a low-volume highway might be acceptable, or, if the duration of flooding is long and there is a nearby, good quality, alternate route, then the flooding of a higher-volume highway might be acceptable.

The importance of the route to national defense and to the economic well-being of a community plays a large role in evaluating the risk of traffic interruptions.

5.2.2 Economics

The engineer should not separate hydrology and hydraulic design, but the two should be considered together. Several frequencies with their corresponding peak discharges should be selected and hydraulic designs made for each. Floods of selected frequencies and related hydraulic designs are compared weighing both cost and risk, until the optimum design is obtained.

As illustrated in Figure 2, the annual cost of drainage structures would be very high if large floods or high return periods were used for design. Also, it can be seen from Figure 2 that designing for small, frequent floods can be costly since expensive repairs and damage to property can be high. Somewhere between these extremes should be an economical and acceptable design. Some State highway departments (33) have shown this type of analysis in their design manuals and present (1971) research is aimed (34) at further developing the procedure. Other references on economic evaluation will be found useful (35 to 39), Appendix C).

Table 1 shows a qualitative approach to selecting frequency of flood. The importance of one factor or a combination of factors in this table can give the designer some guidance for using a given design frequency or recurrence interval.

6.0 Predicting Flood Magnitudes

After considering the available hydrologic data as discussed in these guidelines, the engineer is ready to determine the design discharge to be used in sizing the waterway opening of the highway facility in question.

Four methods for estimating discharge are given in these guidelines. They were selected primarily for their applicability to highway engineering. There are basic deficiencies in these as in all hydrological methods; therefore, engineering judgment and a good understanding of hydrology are essential in selecting the method to be used in a particular design. One method can supplement the results of another method. For instance, recorded data at a gaging station can be used to supplement a regional method of analysis, if indeed the gaged data represent present or future conditions. Selected references are supplied so that the engineer can familiarize himself with the techniques required for each method and the basis for its development.

6.1 Predicting Future Flood Magnitudes Using Methods Based upon a Regional Analysis

By statistically combining streamflow gaging station records within a hydrologically homogeneous region (28 and 40), hydrologists and statisticians can

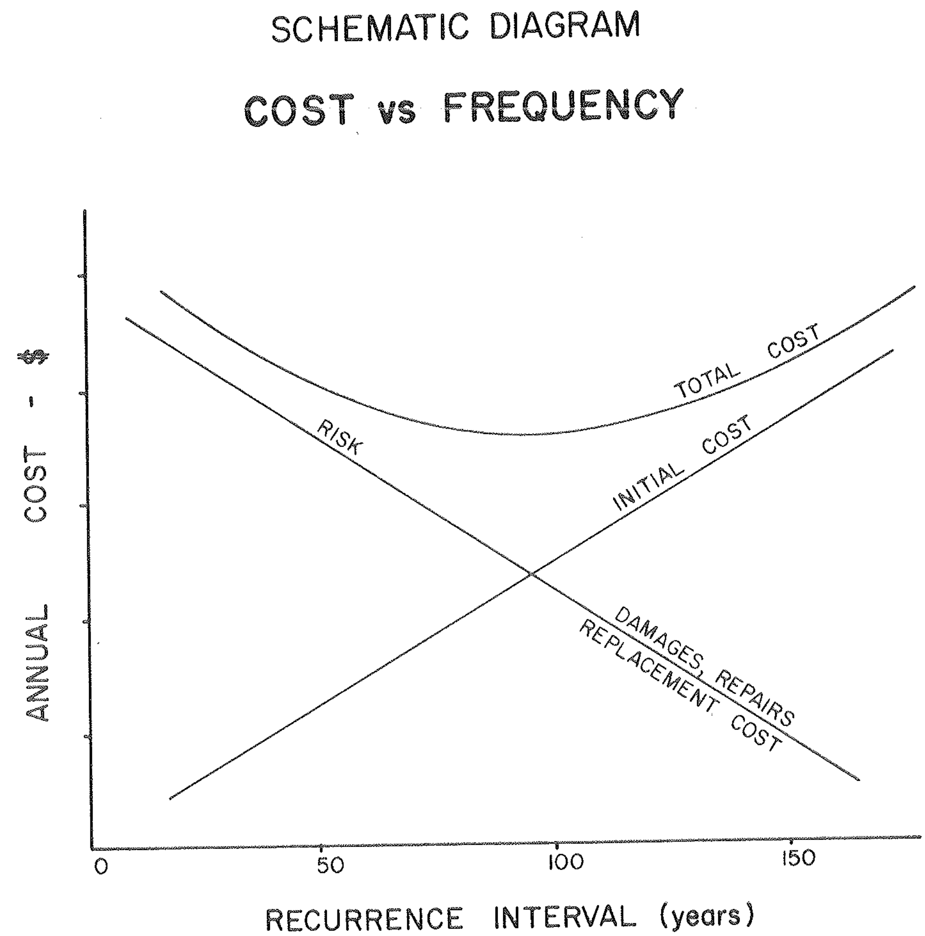
SCHEMATIC DIAGRAM
COST vs FREQUENCY
ANNUAL COST - $
TOTAL COST
RISK
INITIAL COST
DAMAGES, REPAIRS
REPLACEMENT COST
0
50
100
150
RECURRENCE INTERVAL (years)

Figure 2.

develop methods which produce flood-frequency relations generally applicable throughout the region. The methods thus developed allow the engineer, with the use of prescribed parameters, to determine the magnitude of a future flood event corresponding to a selected recurrence interval for either a gaged or an ungaged stream site within the region. If the site under consideration lies within an area for which an accepted regional analysis method has been developed, the engineer has a valuable tool that can be used to determine the magnitude of a future flood for a selected frequency. The local district offices of the U.S. Geological Survey can furnish information concerning analyses available.

The basis of any regional analysis method must be studied for applicability since most all regional analyses are based upon gaged streamflow data from rural-type watersheds, and it is possible to have an area within the region that does not compare hydrologically with the entire region. For instance, runoff from an area where the land use is significantly urban should not be determined by using a regional analysis based on runoff records from rural, natural watersheds, unless some adjustment to the estimated discharge is made (see section 3.1.4).

6.2 Predicting Future Flood Magnitudes from Flood-Frequency Analyses Using Recorded Data

The method of analyzing flood-frequency relationships from actual streamflow data enables the use of records of past events to predict future occurrences. This method assumes that there are no changes in the nature of the factors causing the peak magnitudes. The ramifications of this assumption can be minimized by making every effort to determine the past conditions of the drainage area, and if possible, making allowances for changes. The most common changes are man-made and consist of such modifications as storage and land development. At best, the recorded data can be considered as only a small sample of the total population of peak discharges, consisting of both past and future floods, and the records of any individual station may depart considerably from a true representation of the overall long-time frequency relationship. The user of hydrologic data must be acquainted with the procedures for evaluating streamflow data, the techniques for preparing a flood-frequency curve and the proper interpretation of the curve (28 and 41).

There will be times when estimates made from a regional analysis will not agree with a flood-frequency analysis of a gaging station on the stream being studied. Various factors such as length of runoff record, storm distribution and parameters used in the regional analysis could account for some discrepancies. If the stream record is sufficiently long to give a good flood-frequency relationship, considerable weight should be given to the stream record in estimating design floods. A regional analysis is generally preferred over a station analysis, especially when the station record is short.

6.2.1 Development of Flood-Frequency Curve

A flood-frequency analysis of recorded data requires developing a flood-frequency curve. A study of the selected references (9, 11, 28, 29, 30, and 31) gives

TABLE NO. 1

FLOOD DESIGN FREQUENCY SELECTION CHART

FACTOR *	RATING 1	2	3
Non-Highway Damage	Low	Medium	High
Highway Damage	Low	Medium	High
Potential Loss of Life	Low	Medium	High
Height of Fill	to 20'	20' - 50'	Over 50'
Cost of Replacement	Low	Medium	High
ADT	<100	100 to 750	>750
Detours Available	Yes	Poor	No
Roadway Overflow Section	Yes	Nominal	No
Number of Known Floods greater than Q_{50}	None	One	Several
National Defense Highway	No	No	Yes
Impact Local Economy (School buses, food, etc.)	Low	Medium	High

Weighted Rating **	Design Frequency
1	10-25 years
2	25-50 years
3	50 years or more

* Additional factors may be added to list for consideration.

** All factors are not of equal weight under all circumstances; therefore, weighted rating is subjective and serves only as a guide in selecting a design frequency.

procedures for preparing and interpreting a flood-frequency curve. A flood-frequency curve is prepared from recorded streamflow data at a single gaging station. This data may be obtained from the files or publications of the agency operating the gaging station, usually the Geological Survey.

A flood-frequency curve may be developed by graphically fitting (eye-fit) a curve to points plotted on special graph paper or by mathematically determining floods for various recurrence intervals. Several methods have been used in analyzing flood records, but only one method of each type is described as the preferred method at this time. These methods have been adapted for electronic computer computation and plotting (41). In both methods, an extremely high peak discharge should be carefully evaluated with respect to reliability and its probability of occurrence, especially regarding its effect on the drawing of a frequency curve or the method used in determining recurrence intervals.

6.2.1.1 Graphical Method

The graphical method, based on Gumbel's extreme value distribution, Powell's special plotting paper and Weibull's plotting position formula, is a simple and reasonably satisfactory procedure for constructing a frequency curve (28). Details of the method and plotting paper may be obtained from the offices of the Geological Survey or the Federal Highway Administration.

The Weibull formula is:

$$RI = \frac{n+1}{m}$$

WHERE:

RI = Recurrence interval

n = Number of years of record

m = The order of descending magnitude of the annual flood peaks with the largest flood as number one.

6.2.1.2 Mathematical Method

The preferred mathematical method for establishing a flood-frequency relation for recorded data is known as Log Pearson Type III (42). This method is very time consuming unless an electronic computer is available for the computation work.

6.2.2 Extending Flood-Frequency Curves

Because of the short-term records of most gaging stations, frequency curves often must be extended beyond the recorded data to enable the estimation of larger floods for the design of highway structures. Obviously, such extensions are subject to considerable error and care must be taken in evaluating results. Regional analyses and ratios of 25 or 50-year floods to mean annual floods on streams within the same region can be a helpful guide.

6.2.3 Transfer of Data

Where the site being studied is on the same stream and near a gaging station, peak discharges at the gaging station can be adjusted to the site by drainage area ratio using drainage areas to some power, usually between 0.5 and 0.8. Gaging stations records of similar streams in the region should be used as a guide in making this adjustment. If the bridge site is between two gaging stations on the same stream, the peak discharge at the bridge site can be determined by logarithmic interpolation of the peak discharges at the two stations on the basis of drainage area.

The stage corresponding to the peak flow being transferred is preferably determined from high-water marks for the same flood at the site being studied. The stage can be calculated by a slope-conveyance calculation using measured cross sections (24).

Where the bridge site is not near a gaging station on the same stream, a regional analysis of gaging station data on other streams is recommended.

6.3 Predicting Floods Using the Rational Formula

The rational method is an empirical formula relating rainfall to runoff (16 and 43, Chapter 2). Its use in America dates back to approximately 1889. It is the method used almost universally for computing urban runoff. The formula is simple to use; and this simplicity, plus the lack of a suitable alternative, has helped maintain its popularity among engineers.

The Rational Formula is:

$$Q = CIA$$

WHERE:

Q = Discharge in cfs

C = Runoff coefficient

I = Average rainfall intensity, in inches per hour, for the selected frequency and for duration equal to the time of concentration

A = Drainage area in acres.

Discharge, as computed by this method, is related to frequency by assuming the discharge has the same frequency as the rainfall (44) used (see section 4.3.1). Because of the assumption that the rainfall is of equal intensity over the entire watershed, it is recommended that this formula be used only for estimating runoff from small areas, say up to 200 acres.

6.4 Predicting Floods Using the Hydrograph Methods

Several hydrograph methods (9, section 20) have been in general use by some governmental agencies and the storm sewer design departments of Chicago and Los Angeles for a number of years. Although these methods are generally more difficult to use than the Rational Formula, many authorities believe the hydrograph methods are more appropriate for use in estimating floods from small areas, especially in the design of storm sewers.

As runoff data are accumulated and the need for considering storage in design is stressed, hydrograph methods have promise in giving the engineer a more flexible and accurate design tool in estimating flood flows.

7.0 Research and Development

Research in highway-oriented hydrology has lagged far behind the needs. Recognizing the lack of design information in this area, the Surface Drainage Committee of the Highway Research Board has listed research in hydrology as a number one priority for several years. With this emphasis and the interest and participation of State highway departments in funding flood data collection and analytic studies, much progress has been made. Continued support must be given to ongoing programs and new basic research encouraged if the objectives of good design are to be achieved.

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VOLUME XVI

SUBSURFACE SOILS EXPLORATION

NATIONAL ASSOCIATION COUNTY ENGINEERS
NACE

NATIONAL ASSOCIATION OF COUNTY ENGINEERS
ACTION GUIDE SERIES

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The National Association of Counties Research Foundation is pleased to cooperate with the National Association of County Engineers in developing and applying a series of manuals, called Action Guides. These 17 manuals provide the county engineer - manager with organizational and technical information based on best nationwide practices. Members of NACE have provided valuable assistance by contributing their knowledge of county engineering to this project.

The manuals also provide background information for the elected county officials who must make the decisions concerning road activities.

This project builds on an earlier NACE program which developed the first edition of some of the manuals, updating them and adding new technical information. New manuals address such wide-ranging subjects as maintenance management, public support, bridge and spot safety improvements, traffic generation, drainage and soils, water pollution and aerial photography.

NACORF and NACE are deeply indebted to the U.S. Department of Transportation, Federal Highway Administration, which is providing funds and guidance for the program.

Bernard F. Hillenbrand
Executive Director
National Association of Counties
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County governments have a real opportunity to play a continuing and increasingly important role in the future growth and development of our country. This Action Guide Series should assist the county engineer and other county road officials to provide the best local highway service at the most reasonable cost. The Federal Highway Administration is very pleased to cooperate with NACo and NACE in this effort.

Ralph R. Bartelsmeyer
Acting Federal Highway Administrator
U. S. Department of Transportation

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SUBSURFACE SOILS EXPLORATION

by

Fred N. Finn

National Association of County Engineers
Action Guide Series

National Association of Counties
Research Foundation
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** 5. REPORTING

FIGURES AND TABLES

1. INTRODUCTION

Bridge foundations, retaining walls, highways, or virtually any facility can be designed properly, only if the designer has at least a reasonably accurate conception of the physical properties of the subsurface soils. (Subsurface soil explorations are variously referred to in the literature as site investigations, soil investigations, and foundation investigations.)

Since most county engineers are charged with responsibility for the design of facilities, such as bridges and highways within their jurisdiction, they should, therefore, be familiar with subsurface explorations to define the type and extent of various subsurface conditions. Although you or your staff may or may not be directly in charge of planning and executing the explorations, you are not relieved of the responsibility to be knowledgeable about such procedures.

1.1 PURPOSE OF SUBSURFACE EXPLORATIONS

The purpose of a subsurface soil exploration is to determine the engineering properties and conditions which exist below the surface.

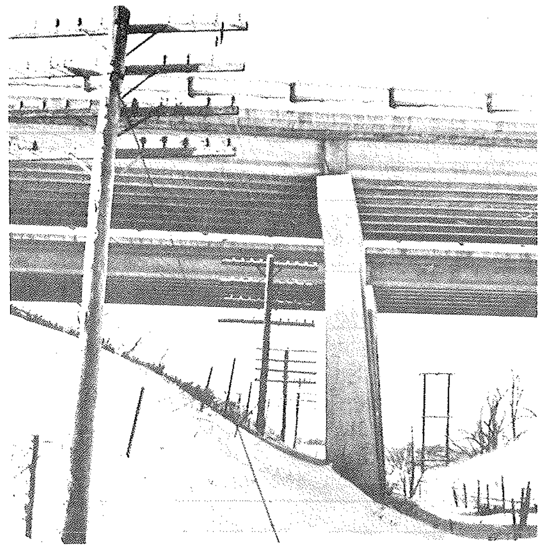
Over 40 percent of the highway construction dollar is spent directly on earthwork and foundations. Most of the remainder is spent on items which are directly dependent on the soil such as drainage, pavement and structures. In order to get economical construction and maintenance, to minimize costly failures, overdesigns, or overruns, a design based on an adequate foundation investigation is necessary.

For the engineer, "soil" refers to the organic and inorganic materials overlying bedrock. With adequate soils information, you or your consultant can apply the principles of foundation and highway engineering to the development of designs which will make the best use of local materials without excessive expense. Modern technology makes it possible to do things which formerly were not feasible. However, to make use of this technology you must have knowledge of subsurface soils; the best way to obtain this information is to plan and execute a subsurface investigation.

It is recognized that these soil explorations cost money, take time and a considerable amount of staff effort. At times this combination leads to a decision to abbreviate the investigation or just not to make one at all. When this is done it is common practice to increase the safety factor in the design of facilities, or in effect, to overdesign and throw the extra cost into construction. The plea of this manual is to urge you not to overdesign for lack of subsurface information.

There are situations when some overdesign may be justified: for safety considerations, to avoid the risk of costly damage to public and private property (usually in highly developed urban areas), or in cases where minor failures could excessively inconvenience the public. Conversely, there will be times when a low factor of safety can result in economic benefits, where failures would cause little inconvenience to the public. You, the county engineer, must make such decisions. Remember that no safety factor can be assigned without knowledge of the type, condition, location and extent of these subsurface materials.

It must be recognized that an infinite number of subsurface conditions can exist, and even the most thorough investigation may at times fail to disclose a critical condition. Experience obtained from conducting many subsurface tests will play a major role in minimizing the possibility of serious errors due to unforeseen subsurface conditions. So, even here, when trying to anticipate unforeseen events, soil explorations have their value. See figures 1-1, 1-2, 1-3, and 1-4 for examples of failures resulting from poor subsurface conditions.



Bridge Pier Movement Requiring Expensive Jacking Procedures to Reestablish Vertical Alignment

44

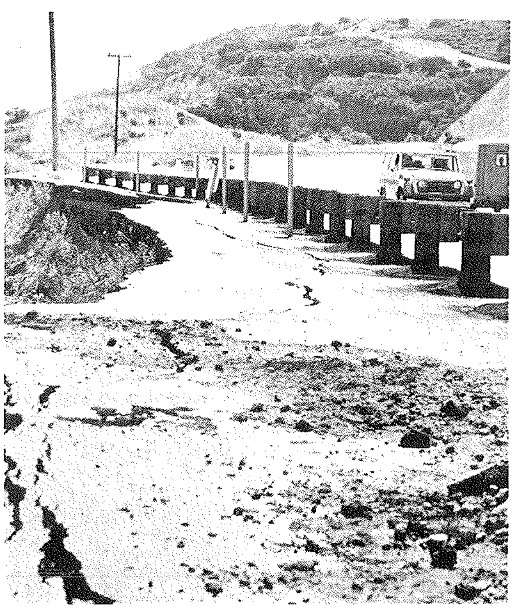


figure 1-1

Unstable Slope Requiring Relocation of Highway

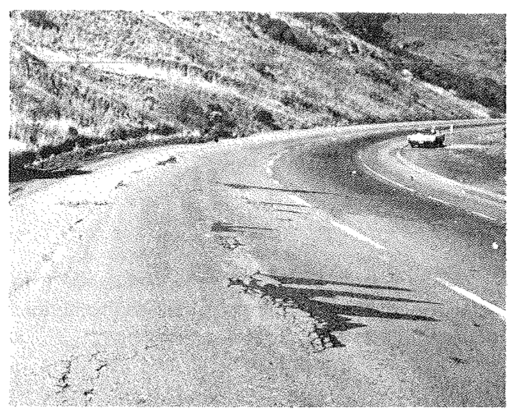


figure 1-3

Seepage Causing Pavement Distress

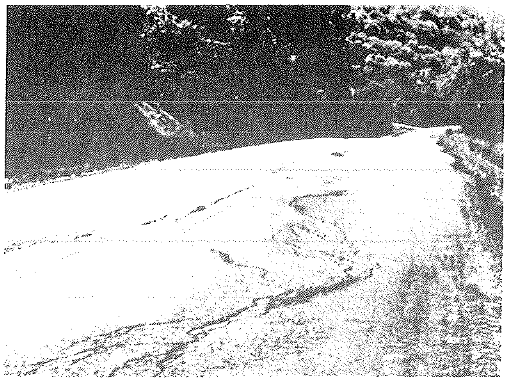


figure 1-4

Pavement Damage Resulting from Subsurface Deformation

1.2 PURPOSE OF MANUAL

The purpose of this manual is to provide you with information on how to conduct a subsurface soil investigation. This manual will provide adequate information to allow you to plan and implement a modest subsurface exploration–one with a fairly limited scope and set of objectives. For the most part, however, it is recommended that you supplement the information in this manual by reading appropriate references in the attached bibliography or other pertinent publications.

A well-planned investigation need not be costly in terms of facility costs. And when considering the cost of overdesign or the cost of future repairs due to an improper investigation, it is quite inexpensive. This manual should help you in defining the scope of work in an exploration and will encourage you to undertake systematic, well-planned investigations. It is emphasized that subsurface soils exploration does not need to be complicated; much useful information can be obtained with a shovel, a post hole digger or a small auger–providing you have some knowledge of what you are doing.

The subject can be approached in several different ways. However, in this Guide we believe it is most helpful to first give pointers on planning the soil investigation process, followed by a brief review of the properties of soils and their strength values for design purposes. The main purpose of the Guide–the conduct of the exploration–is then detailed, followed by a final chapter on reporting results.

2. THE PLANNING PROCESS

Soil explorations are made to verify and amplify information from surface examinations, from reference materials, and from local maps and records. Before the actual exploration is started, some planning is required. This entails first determining the scope and objective of the exploration and following with a detailed plan of each stage of the exploration.

2.1 SCOPE

When considering the need for soil investigation, the first step is the *scope* of the work. In this case scope simply refers to the type and amount of work involved. For example, the scope could call for investigation of subsurface soil conditions for a proposed highway project, including bridges and culverts. On the other hand, it may be simply a short highway realignment over an area known to have good subsurface conditions. In the first case the scope may be so large as to require consultants; the second can be done with a hand auger and shovel and should be within the capability of even a one-man organization.

In preparing the scope you should consider the thoroughness required for the investigation. The degree of underdesign which can be justified will be one of the prime factors to consider, as mentioned earlier. Some situations will justify underdesign; for example, a rural road that goes through productive and relatively expensive farm areas but which serves a small volume of traffic. You might design a slightly less conservative backslope and risk some isolated slides (slip-outs) which can easily be cleaned up with only minor inconvenience to the user and without undue expense to the county. The scope of this investigation could be minimal to meet this particular need. On the other hand, for expensive facilities or ones which are located in areas subject to unusual conditions, e.g. earthquakes, your scope should be complete enough to be sure that it will adequately describe the subsurface conditions, to avoid the loss of an expensive structure, and provide greater safety.

If you decide that the scope of work does not permit the use of county personnel, you will need to retain a consultant or drilling contractor. Some of the items to consider in a typical contract are described in Appendix A.

2.2 OBJECTIVES

Once the scope has been determined, it is necessary to establish a specific set of *objectives.*

Simply stated, this means the type of samples you need to satisfy the scope. Remember that a subsurface soil investigation should obtain information about foundation conditions and location of natural construction materials. For example, if a large cut is to be made, the objective would be to obtain undisturbed samples of the various materials exposed by the cut. (See Section 4.4 for discussion of disturbed and undisturbed samples). The investigation will be conducted in the office (reference materials), in the field (borings and sampling) and in the laboratory (classifying and testing). It involves a "learn as you go" procedure in which properties of the soil and subsurface conditions are developed in successively greater detail as the work proceeds.

Some specific objectives are:

- To determine locations, depth, thickness and extent of each soil layer including description and classification of the soils and geology of the bedrock
- To determine depth to bedrock as well as soundness and general description of rock
- To determine depth and characteristics of ground water including whether the water table is perched, whether it is potable, or if there are artesian zones
- To obtain samples, disturbed and undisturbed, as may be necessary for the design of a given facility

For routine highway and airport paving, the objective of investigations is to identify soils at depths ranging from three to ten feet along the proposed paved area. The emphasis on locating rock (first two items listed above) is less important.

When the objectives are determined, a working plan for the exploration should be prepared to assure adequate information for the design and construction phases.

2.3 PLANNING THE SUBSURFACE SOIL EXPLORATION

Before any subsurface exploration investigation is planned and implemented, information from reports and official records of public or private agencies should be reviewed.

Typical sources of information available are:

- Topographic maps
- Geological maps
- Agricultural maps (Soil Conservation Service)
- Aerial photographs
- Well drilling logs
- Reports associated with existing structures

A description of each of these sources and the type data they contain is given in Appendix B.

In this discussion of the planning process, specific suggestions should not be considered as requirements; there is no "best" way to conduct an investigation. You can make it as extensive as funds will allow and as comprehensive as necessary. It should be pointed out that there is a tendency to overdo some investigations by following a "cookbook" approach without tailoring the work to the project. Good planning will avoid this and will help match funds to design requirements.

You have considerable latitude in planning a subsurface soil investigation. In most cases, work can be staged depending on the amount of information required for design, the amount of information available from various publications, maps and records, and the resources available (funds, equipment, etc.). During initial planning you should obtain as much information as is available about the project. Details may be lacking until the initial evaluations have been made, but any information such as preliminary sketches can be helpful.

Many projects require a multiple stage investigation. The three basic stages are:

- Preliminary or Reconnaissance Stage
- Design or Feasibility Stage
- Final or Control Stage

A fourth stage, monitoring, may be necessary during actual construction to assure that the actual foundation materials found are those indicated during the design stage.

2.3.1 Reconnaissance Stage

During the reconnaissance stage all data obtained should be used in the preliminary design estimate to evaluate the engineering and economic possibilities of the project and to determine whether further soil investigations are justified. The reconnaissance stage should include as a minimum the following elements:

- Review of plans to date
- Review of data from records, reports, photos, etc. (See Appendix B)
- Visual examination of the site, preferably from the ground, but alternatively from the air. (See also NACE Action Guide, *Aerial Photography)*
- Identification of surface geology, land forms, and surface soil types. Surface geology can usually be estimated by use of geological maps for a given area. Land forms (topography) and terrain can be identified on site and with the aid of topographic maps and air photos. Drainage patterns should be noted.
- Existing cuts and natural slopes should be studied. Such information can be useful in identifying soil types (clay, sand, rock) and the amount of surface weathering
- Review old and existing highway problems with maintenance foreman
- In some cases geophysical methods may be used at this stage provided they are planned by an experienced specialist. (See Sections 4.1.6 and 4.1.7)

2.3.2 Design and Feasibility Stage

The design and feasibility stage will expand and confirm information obtained in the reconnaissance stage. As a minimum, the investigator should:

- Review results of reconnaissance stage
- Identify possible engineering problems; i.e., if deep cuts are planned in a highway project it is important to locate possible slip planes by accurately identifying and plotting the location of materials with low shear strength and areas with water seepage
- Include the following items in the field investigations:
  - location of proposed test holes and test pits
  - order in which holes and pits are to be developed
  - depths to which holes and pits will extend
  - kinds of samples required
- Summarize the information obtained, including inputs from the reconnaissance

To perform the above work, using the services of other public agencies may be desirable. That is, larger agencies such as the state highway department can perform subsurface explorations for a county according to an established schedule of charges. It is your responsibility to see that whoever does the work is qualified and has the required experience and equipment.

You may want to combine the design and reconnaissance stages into one expanded design investigation. In all probability, a final stage will be necessary to clarify questions left from the first stage(s) and to sharpen up some information needed for design.

2.3.3 Final Design Stage

The object of this stage is essentially to fill in gaps in information developed earlier. Additional samples may be required or better definition of the soil profile may be necessary. Close coordination with the designer is required in planning this stage. However, if sufficient information is available from the previous stages, this stage may be eliminated.

3. PROPERTIES OF SOILS

Having considered the planning and implementation of soil exploration, a discussion of the properties of soil is in order. Soils may be considered engineering materials; and therefore, the county engineer should know something about its physical, chemical and mechanical properties.

The important soil properties are:

- Shear strength
- Compression and consolidation
- Permeability
- Plasticity
- Volume change
- Thermal characteristics
- Chemical properties

Each of these is discussed below.

3.1 SHEAR STRENGTH

Shear strength is the property that enables material to remain in equilibrium when its surface is not level. All solids exhibit this property to some extent. Shear strength is the major structural property of soils. It is the property that determines the bearing capacity of a footing, the angle at which a cut or fill slope can resist slides, the pressure against a retaining wall. In most cases, except for embankments, shear strength tests will be made on undisturbed samples. Tests are conducted in a drained and undrained condition depending on the conditions developed in the field.

The shear strength of a soil is the result (sum) of friction between the particles and cohesion. Most fine-grained soils, primarily clay (and to a lesser extent, silts), develop most of their shear strength from cohesion. Granular materials, and clean sands in particular, develop strength from friction between adjacent particles.

Shear strength can be measured in the laboratory by direct shear tests and by triaxial shear tests. The shear strength of cohesive soils may be determined by the unconfined compression tests (American Society for Testing and Materials-ASTM-Designation D 2166) and in the field by the vane shear tests (ASTM-Designation D 2573). See Appendix C for further discussion of strength values.

3.2 COMPRESSION AND CONSOLIDATION

The term *compression* is usually used to denote the total change in height of a soil mass due to applied loads. Observations show that when a load is applied to soil, the volume decreases. Since the individual soil grains are for all practical purposes incompressible, the change in volume must be due to a decrease in the volume of the voids. If the soil is dry, the voids are filled with air, and the volume change will depend on the rearrangement of the particles, which can be both shear strength-dependent and structure-dependent. If the soil is saturated, the voids are filled with incompressible water, and the water must flow out of the soil mass before the soil grains can rearrange themselves. In soils of low permeability, this process requires a time interval for completion; hence, the movement occurs slowly.

The term *consolidation* is the time lag associated with the volume change under an applied load. The application of a stress to any material will cause a corresponding movement. For common construction materials such as steel or wood, the movement occurs simultaneously with the application of stress. In contrast, fine-grained soils will usually exhibit a measurable time lag between the application of a stress and the resulting movement. It is most noticeable in saturated or nearly saturated soils of low permeability.

Both properties are determined in consolidation tests (ASTM-Designation D 2435) usually performed on undisturbed samples. Interpretation of the test results depends on the thickness and presence of layers of sand or other drainage layers which can act as escape channels for the water being forced out of the compressible layer.

Consolidation and compression coefficients are used to predict the amount of settlement and rate of settlement for building foundations, bridge piers, high fills or embankments. Excessive settlement often can be avoided by keeping the soil loads less than the weight of the overburden to be removed in order to build the foundation. In some cases preloading of the foundation area well in advance of construction will provide sufficient preconsolidation to adequately minimize differential and total settlement after construction is completed.

3.3 PERMEABILITY

To the soils engineer, permeability is the property of a soil which permits water to flow through its pores. Coarse-grained soils have a relatively high coefficient of permeability and fine-grained (silts and clays) have a low coefficient. Small volumes of fine grained materials can significantly reduce the permeability of otherwise permeable coarse-grained materials. Permeability must be known in order to compute the quantity of water that will flow through a given soil layer. It is used in problems dealing with drainage; e.g., subsurface drains for highways or airfields or in dewatering areas under construction.

It is imperative that the foundation engineer or pavement designer know where the permeable and impermeable layers are at a given site, including potential seepage layers which will be encountered in cuts and in foundation excavations. In a great many cases, it is not only practical but necessary to modify the seepage paths and water table by termporarily or permanently interrupting the natural flow channels at a site, by lowering the water table.

3.4 PLASTICITY

One of the distinguishing properties of cohesive soils is their ability to undergo large strains without rupture. This property is termed *plasticity,* and it is unique to fine grained soils usually referred to as clays. However, grain size by itself cannot be used to differentiate between plastic and non-plastic fine grained soils.

For any particular plastic soil, the amount of plasticity is a function of the water content. If a clayey material is uniformly mixed with sufficient water, the result is a fluid-like material which will deform freely under very low levels of stress. The water content at which measurable shear strength becomes apparent is called the *liquid* limit. As the water content decreases, shear strength will develop to the point where very small strains will cause fracture. The *plastic* limit is the water content at which a 1/8-inch diameter thread may be rolled without crumbling. The difference in water content between the liquid limit and the plastic limit is called the plasticity index (PI).

The principal application of such limits is in the classification of soils to identify the plasticity of the clay fractions.

3.5 VOLUME CHANGE

Frequently, volume changes occur due to deformations in soil masses without any apparent application or removal of external loads. They may be caused by at least two different phenomena. For example, the lowering of the ground water table in an area would result in increased soil stresses which in turn are effective in producing a volume change within compressible layers below the original ground water level. This can lead to the settlement of fills or structures at or near the surface.

In other instances, volume changes may be the result of what is known as shrinkage or swell phenomena. Shrinkage and swelling are more pronounced in the fine grained soils, especially clays and most particularly clays of a particular mineralogical composition: e.g.—bentonite. Fortunately, (in the United States), most soils with high volume changes occur in belts or regions that are well known to soils engineers. This volume change or potential swell pressure can be measured for specific soils by consolidation tests, by the CBR (California Bearing Ratio, see Appendix C) or resistance value test procedures used by highway departments.

3.6 THERMAL PROPERTIES

In the design and construction of highways or foundations, care must be taken to avoid possible damage as a result of frost action. Research has indicated that frost susceptible soils include all inorganic soils which contain greater than three percent by weight of particles finer in size than 0.02 millimeters.

The possibility of frost heave and the melting of ice lenses must be taken into consideration when trying to avoid possible frost related structural damage. Frost heave can cause pavements to deform irregularly and footings to move while the melting of ice lenses will cause a loss of strength resulting in an unstable soil condition.

Ice layers or lenses will grow in the soil when freezing temperatures are present, when the water table is close enough to the frost line to feed the growing ice lenses, and when the soil characteristics are favorable to the rapid movement of capillary water upward from the water table. It is therefore very important to utilize subsurface soil investigations as well as laboratory tests because they will determine the location of the water table as well as the characteristics of the soil. The temperature information can be obtained from various state and federal agencies.

3.7 CHEMICAL PROPERTIES

Little information is available to the engineer on the influence of a soil's chemical properties on its physical properties. It is known that the chemical properties can influence the volume change of clay or to stabilize clay with admixtures. It is also known the portland cement concrete can be adversely affected by the use of alkali aggregates.

In a different way, it is known that certain soils, due to their chemical properties, will accelerate the corrosion of metal pipes, i.e., culverts, etc., which are placed below the surface.

Consultants as well as state and federal agencies can advise you of problems which may be associated with chemical properties. Be sure to make inquiries to ascertain if laboratory tests would be useful.

4. CONDUCTING THE SUBSURFACE SOIL EXPLORATION

There are many ways to conduct the actual field work. The choice will depend on the scope and the specific objectives together with the planning suggested in Chapter 2. Obviously, availability of both funds and equipment will influence how the work is to be accomplished.

The importance of the field work in subsurface explorations cannot be overemphasized. Experienced supervision becomes extremely important in choosing methods, locating and logging holes, identifying materials, and in obtaining proper samples. If field testing for in-place shear strength or permeability is planned, the supervision will be even more critical.

4.1 METHODS

As already indicated, the methods or techniques for a soil investigation vary from digging a hole to highly sophisticated procedures involving geophysical techniques. The method selected will depend on objectives, on available equipment, and to some extent on the laboratory tests which are necessary for design. Seven methods are discussed below, five require penetrating into soil and rock and two are geophysical procedures. Even though the geophysical methods may sound complicated and overly sophisticated, you should be aware of their use and, when appropriate, avail yourself of local consultants who can provide the necessary equipment and experience.

4.1.1 Test Pits

The most obvious method of finding out what lies beneath the surface is to dig a hole and see. Holes large enough to permit visual inspection of subsurface soil profiles are called test pits. They may be dug by hand or by excavating equipment. Test pits are comparatively inexpensive, but the depth to which test pits can be dug is rather limited. In soils with little or no cohesion, the sides must be sharply sloped. In cohesive soils, bracing may be required below a depth of ten feet. At depths of 20 to 30 feet, bracing usually must be continuous, and the advantage of visual examination is lost. Bracing must be done in conformance with state and federal safety codes. Test pits provide an excellent way of looking at the soils in place, and for obtaining undisturbed samples. If the test pit is shallow and can be dug by hand, it is less expensive than bringing drilling equipment to the site.

4.1.2 Probing

Probing or a sounding, is an inexpensive way of finding bedrock and of identifying zones of relatively soft or firm soil layers. Probing methods can be classified by two techniques; i.e., static and dynamic.

Static methods give useful information on the relative stiffness of cohesive soils. The equipment consists of a slender conical penetration point. The point is fastened to the lower end of a string of drill rods and is forced into the soil by means of static weights. A record of the load versus penetration and time are used to compare and identify different zones.

Dynamic methods are more commonly used. In general, the equipment consists of a conical penetration point attached to the end of a solid rod fitting close within a pipe. Points are often of larger diameter than the pipe to eliminate the effect of friction along the pipe sides. Probes are forced into the ground by a falling weight or mechanical hammer. The energy is constant, and a record is kept of the number of blows per foot of penetration. The outer pipe should follow the probe down. In some situations, this will occur due to the weight of the pipe; sometimes it must be driven. The rod and pipe are always recovered, but the point is considered expendable.

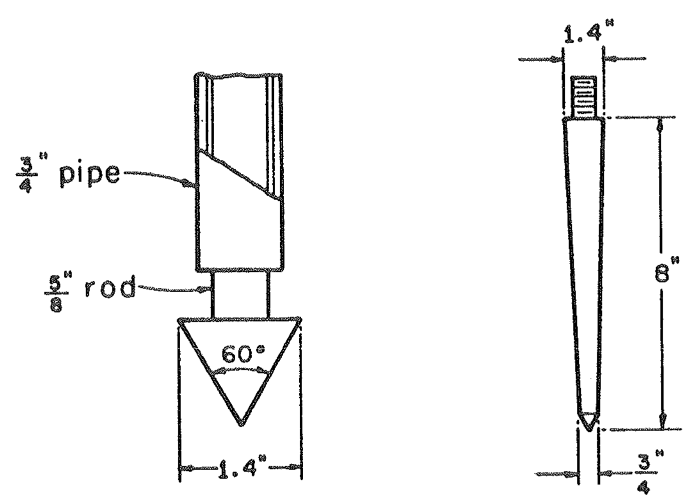
Some typical probe points are shown in figure 4-1. Although any number of points may be used, it is better to pick one particular setup and stay with it. Correlations with borings become more meaningful if one probe type is used throughout the county.

If probing is used, you should also plan on one or more borings in the same area. By comparing information from the boring with the results of probings, you will be able to interpret the results of the probings more specifically. After probing has been used in specific geographic areas, it is possible to extract more and more useful information on the location of known soils in a particular location.

The most widely used dynamic probing technique is the so-called Standard Penetration Test (SPT). Unfortunately, there is more than one kind of test with this designation. All tests utilize a drop hammer to drive the sampler, with the number of blows required to drive the samples 12 inches, designated as the standard penetration count or blow count. One of the more common standard penetration tests is described in AASHO (American Association of State Highway Officials) Test Method T 206-64 (See Bibliography). You should refer to this procedure and correlate with subsurface conditions which have been established.

figure 4-1

TYPICAL PROBE POINTS



The major disadvantages of probing are:

- The point can be stopped or significantly influenced by an isolated rock or boulder
- Although a soft or weak layer can be identified, it is risky to conclude that such a condition is due to loose sands or granular materials, or due to soft clays and silts
- In fine-grained soils, there may be an abrupt change in driving resistance below the water table
- Probes are virtually useless in glacial deposits or in very coarse granular deposits

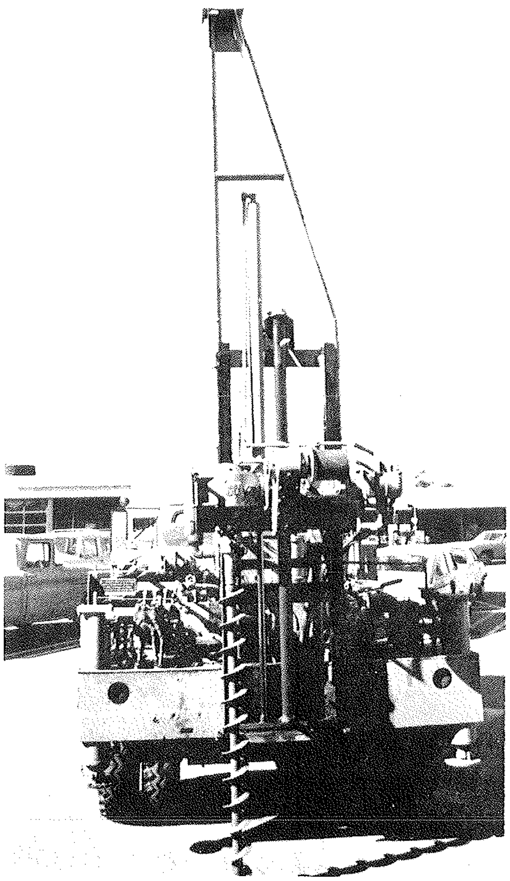


figure 4-2

PORTABLE AUGERING EQUIPMENT

4.1.3 Augering

Augers are very effective in exploring subsurface conditions. Either hand operated or mechanical augers can be used, depending on the situation. Hand augers or post hole diggers range in diameter from four to eight inches and can be used when appreciable quantities of soil are necessary for laboratory testing. Small helix type augers can be used for visual examination and preliminary depth identification.

The advantages of mechanical augers are their speed and mobility (See figure 4-2). No drilling fluid is required, and a drilling rig may be set up and taken down in minutes. When the lead auger is equipped with rock heads, it is possible to work through soft rock and gravel. (See figure 4-3)

For most conditions, augering cannot be used below the ground water level unless special provisions are made to contain the soil. Some clays can be augered below the water table, but you have to experiment to find out if this equipment can be used in such cases. See Section 4.4 for more information on augering.

4.1.4 Wash Borings

Wash boring is a method used by well drillers and is also useful in soil investigations. Heavy pipe (casing) is driven into the ground. A chopping bit is lowered in the casing with hollowed drill rods. Water is pumped through the drill rods, coming out at the chopping bit. The bit is lifted, dropped, lifted, rotated and dropped. The water carries the loosened soil particles to the surface. At the surface, a portion of the water can be diverted into a settling vessel. Periodic sampling of the water will provide some indication of the material being encountered. Accurate estimates of the depth and extent of material are not possible; however, the method is useful as an indicator of subsurface materials and is particularly useful in getting through coarse-grained materials.

It is worth emphasizing here that the need for experienced field supervision is very important. Talk with your field people; be sure they know what you want; put it in writing!

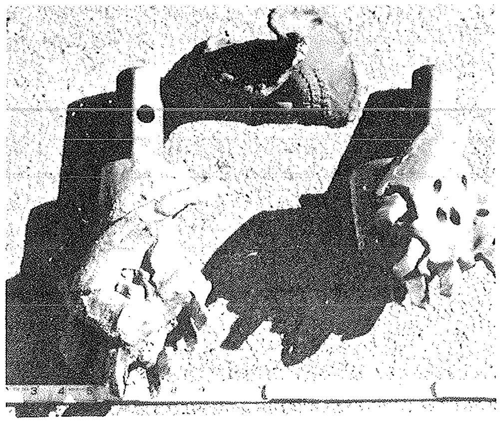


figure 4-3

Drilling Heads for Augering Through Soft Rock and Gravel

4.1.5 Rotary Borings

In this method, the hole is advanced by the rapid rotation of the drill bit and by the eroding action of the drilling fluid sumped through the rods. Bits are available to work in materials ranging from sands to hard rock. The unit is power driven and usually truck mounted. Rotary drilling is similar to the wash boring procedure except that one drills and one chops.

In order to prevent the sides of the hole from caving or sloughing, it may be necessary to case the hole or to use driller's mud, a special mixture of clay and water plus some chemicals, when necessary.

Rock coring is a special application of rotary drilling. Special bits are necessary for coring into rock, depending on the kind and hardness of the rock.

4.1.6 Seismic Refraction

Seismic refraction consists of creating sound or vibration waves within the earth, usually by exploding small charges of dynamite buried three to four feet beneath the surface and measuring the time of travel from their point of origin to each of several detectors. Seismic refraction is most often used in preliminary phases of a site investigation or as a technique to supplement borings by extending soil profile information. In rough terrain involving numerous deep cuts, seismic procedures may be an economical method of obtaining the rock profile. For the experienced operator, no difficulty should occur in distinguishing between soil and rock; in some cases, useful information can be given on the characteristics of both materials.

4.1.7 Earth Resistivity

Many of the materials making up the earth's crust can be identified, in some degree, by their reaction to the flow of electricity. The electrical resistance of the soils may be used for locating, at least in a preliminary way, the identity of subsurface formation.

The procedure is fast, portable and relatively economical. The technique depends on the ability to correlate measurements with actual profiles in the general area. As with seismic procedures, electrical resistivity should be used only with a full understanding of the technique. 55

4.2 LOCATING AND SAMPLING BORINGS

Locating and obtaining test samples from borings and test pits will depend on the engineering problems involved. For example, slope stability for cuts, bearing capacity for structure foundations, or retaining-wall pressure will require the determination of in-situ shear strength at certain locations by testing undisturbed samples. Samples for pavement design, slope stability of fills or for borrow materials can be obtained from disturbed samples along the alignment for the appropriate tests on remolded materials.

Subsurface information should be obtained in a planned systematic way. The locating of test holes, sampling, and field testing should be carried out under standard procedures with which the field crews can become familiar. Also, boring and test pit locations should be thoroughly surveyed prior to actual field work. Hole locations should be staked to indicate hole number, with coordinates or stationing for locations, and with the ground elevation shown. Usually ground elevations to with ± 0.1 foot are sufficient. Depth below the surface can be measured from drill rods or casing.

Boring sites should be located within ± 1 foot. The actual boring can be varied from the staked locations by ± 2 feet. Should holes be relocated from an original site by a greater distance than 2 feet, notation should be made in the field reports and on the boring logs.

table 4-1

SAMPLING PROCEDURES

General Procedures

- Uniformity of the subsurface conditions, more than any other factor, determines the final number of borings required. Check borings, intermediate to those included in the initial plan, should be provided for in the budget unless previous experience in the area makes this unnecessary.
- When borings must extend more than a few feet (10 feet), it may be desirable to use geophysical procedures (seismic, resistivity) to reduce the number of required borings.
- When rock is encountered at shallow depths, additional borings may be required to adequately develop the rock contours.
- The size of undisturbed samples does not follow any specific rule. In most cases 50-lb. sack samples are adequate for testing. Smaller (jar) samples are sometimes useful for display purposes and in writing the final report.
- Bucket augers are very effective in obtaining large samples in potential borrow areas.
- For borrow areas, explorations can be of two types:
  - specific exploration to find select materials needed for road construction, filter beds or drains, etc. The exploration need only be carried on until enough material has been located to satisfy needs
  - general exploration to determine extent and type of material available in the area
- Location of borings should be based on an evaluation of landforms.

Structures

- Standard sampling intervals should be defined. For example, it may be the policy to sample each 2 feet to a depth of 15 feet below the proposed footing and then sample at 5 foot intervals. Continuous sampling may be feasible, depending on equipment being used.
- For foundation investigations core borings shall be at least 10 feet into bedrock. The percent recovery into bedrock should be at least 75 percent.
- One boring per bridge footing is normally adequate in weathered rock.

4.3 SAMPLING PROCEDURES

Specific sampling procedures vary for those used for structures (bridges, buildings, culverts, etc.) and for highways. However there are several general guidelines that can be used for both types. This section outlines general procedures for each case. (See table 4-1) Additionally, suggested depths for structures are shown in figure 4-4.

(table 4-1 continued)

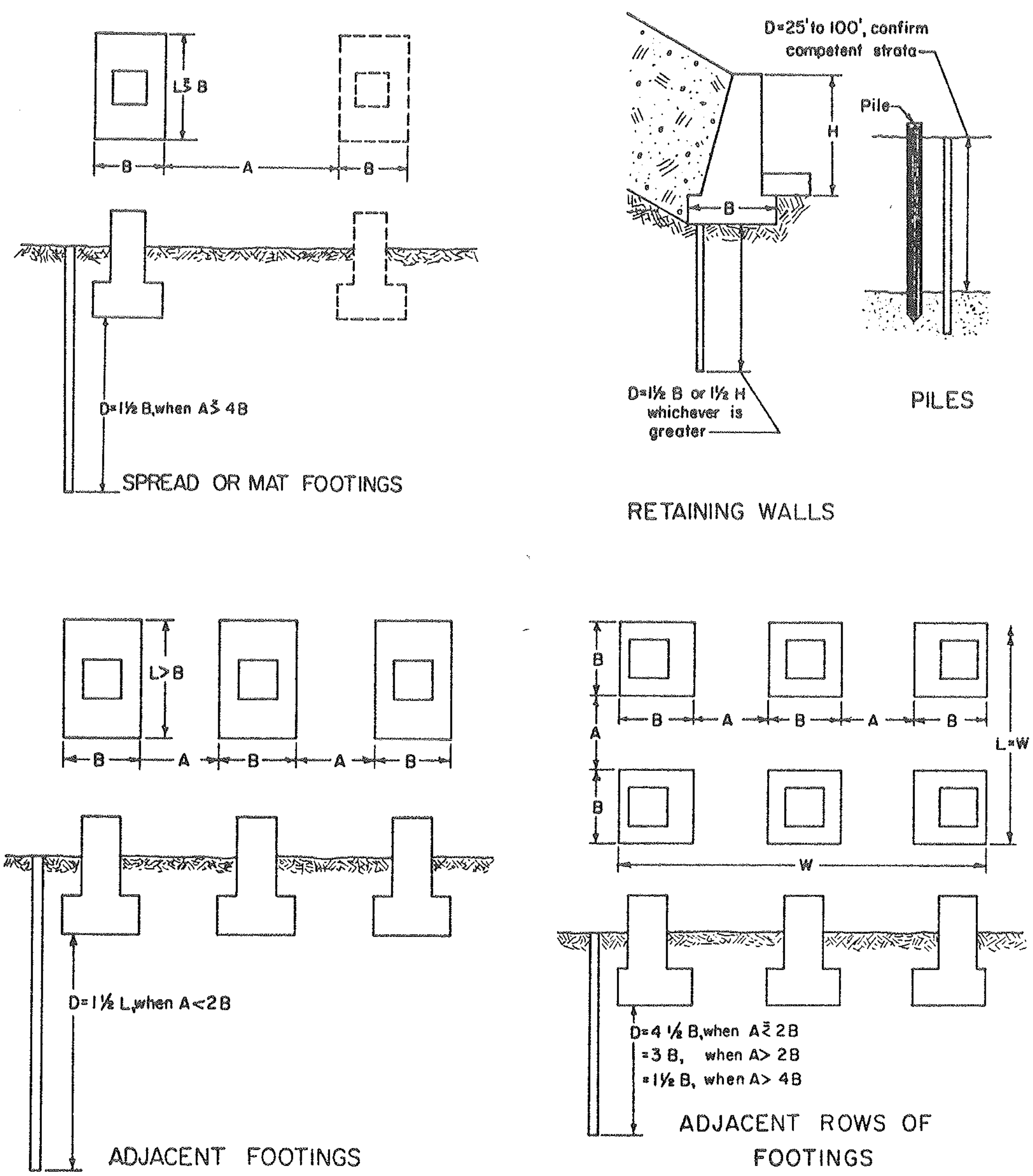
- One boring per bent will suffice in areas underlain by bedrock.
- One boring for every bent (up to 60-foot spacing) will be adequate in uniform shallow water deposits.
- An extra boring can be made at the center of each end bent or abutment.
- One boring for each spread footing is suggested.

Highways

- Borings for highway exploration are usually made at intervals of 500 to 1,500 feet, depending on uniformity and general familiarity with the site. Supplemental borings may be made along the side of the proposed roadway as local conditions dictate.
- Where unstable surface materials exist, such as swampy soils, borings are often on 50-100 foot intervals. These borings should be of sufficient depth to determine the extent of the unstable conditions.
- In flat alluvial deposits, a minimum of borings will be required.
- For side hill construction, borings will frequently be spaced at 500-foot intervals with a parallel line on either side of the center line at 1,000-foot intervals.
- For highways, AASHO (AASHO Number T 86) recommends that borings be carried to at least three feet below the proposed grade line. Some organizations recommend five feet as a minimum. AASHO also recommends:
  - when the road lies within uniform layers of soil profile, the borings should extend to the first layer below the ditchline or planned subsurface drains which would intercept seepage waters, or through a pervious layer which would carry water
  - when fill material is to be borrowed from ditches along the road, the borings should extend to the estimated depth of borrow
  - in areas of frost penetration, the borings should extend to the mean depth of frost penetration
  - when the location line follows an existing road for which previous explorations have been made, the soils may be mapped by examining exposed materials and by supplemental borings, especially in areas of adverse pavement performance. As a general rule, the above suggestions apply to within three to five feet of the depth below pavement grade
- One very good and relatively inexpensive method of exploration for highways is with a backhoe or bulldozer. Both procedures provide a shallow test pit. Visual inspection is permitted and large sack samples can be easily obtained.

figure 4-4

BORING DEPTHS



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Source: *Earth Manual*, U.S. Bureau of Reclamation

4.4 SAMPLING TECHNIQUES

The previous sections discuss various methods by which borings or test pits can be made. In addition to holes made strictly to probe subsurface conditions, borings may be made to obtain samples of subsurface materials. These samples can be used for visual identification of various strata and for delivery to testing laboratories where specific tests will be performed.

Dry borings are useful for accurate sampling and in identifying the depth and thickness of subsurface soil layers. The method is comparatively expensive. The least expensive is a mechanical auger inside a pipe. Uncased auger holes may be used to sample shallow depths when ground water and caving soils are not a problem. Because of mixing action, continuous auger sampling is not satisfactory for accurate examination, classification and logging purposes. Samples and soil descriptions of borrow materials may be obtained for short depth intervals if the entire flight is brought to the surface for removal of all materials. Cohesionless soils cannot be readily sampled by using augers. Special sampling tools (spoons) with one way flaps are useful in obtaining samples of these materials. There are any number of these tools available, and their selection will be a matter of local preference.

Continuous sampling is seldom done because of the expense. Samples are taken at intervals of approximately three to five feet depending on experience in the area. Samples should be taken at every change in the soil properties. Observations of auger cuttings can be used to identify a change in soil properties.

Samples are generally placed into two categories: disturbed and undisturbed samples.

Disturbed samples. Disturbed samples are those in which the in-place condition of the subsurface material has been destroyed. These samples are used for visual identification and for laboratory tests when pertinent to the scope of the investigation. They are obtained by using either a hand auger or rotary or power augers.

The simplest method is the hand auger which is widely used in subsurface exploration. Hand augers can be used to depths of 15 or 20 feet and sometimes to even greater depths, if subsurface conditions permit. The rate of progress can be slow, particularly if large size samples are required. The auger bit is usually about 6 to 12 inches long, and reasonably representative samples can be obtained by monitoring the rate of advancement with each insertion and carefully withdrawing samples from the hole. Its use is particularly well-suited for highway and airfield investigations. Its main disadvantages are slow progress, limited depth, and it cannot be used below the water table, especially in noncohesive soils.

Rotary and power augers are probably among the most useful and common methods for obtaining disturbed samples. Two major precautions to consider are caving of the sides and possible mixing of cuttings from two or more soil layers.

A small truck-mounted power auger unit, suitable for most county needs, has great utility in the field (see figure 4-2). Some units have enough power to auger 48-inch diameter holes to depths of 50 feet (or more under favorable conditions) while smaller units will usually operate with four-inch diameter augers. Bucket units in the larger diameters are also available for obtaining large disturbed samples.

When the single-flight type auger is used, the cutter head is rotated and advanced into the soil a distance approximately equal to the cutter head length. The rotation is stopped, the head retracted to the surface, and the soil examined and retained if needed for further classification or laboratory testing.

The continuous flight auger, as shown in figure 4-5 can also be used with power rigs. To operate this type of auger, the first length (usually three to five feet) is rotated into the ground; a second flight is added, rotated and so on to the depth required. Soils are continuously brought to the surface for visual examination. In order to obtain any kind of representative sample, it is necessary to clean the flight, advance the auger a specific distance, and then withdraw the entire set to the surface and remove sample from lower-most flight.

Hollow-stem continuous flight augers have been developed that permit the taking of "drive samples" and rock cores below the bottom of the flight through the hollow stem. The hollow stem serves as a casing, lining the hole and preventing the hole from caving in, particularly below the water table in cohesive soils.

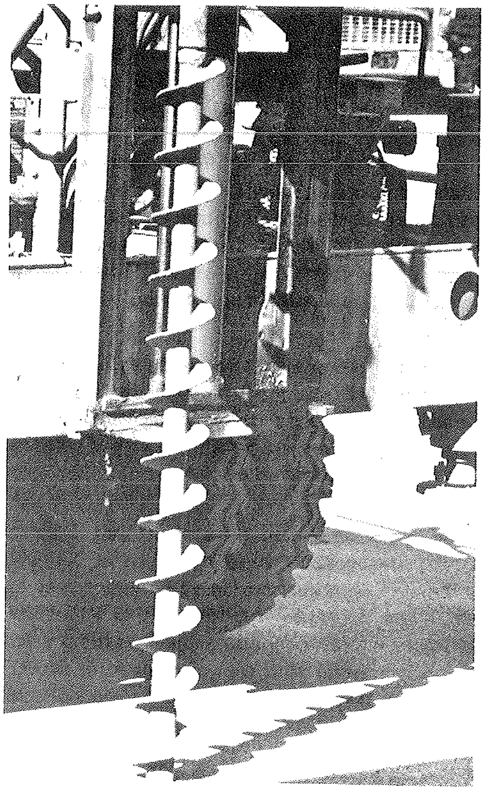

figure 4-5

Continuous Flight Auger

Disturbed samples for foundations can also be obtained by driving a heavy walled sampler into a clean hole. In this procedure, various methods (rotary auger, etc.) may be used to advance the hole in increments with a drive sample being obtained at specified intervals.

Undisturbed samples. Tests for permeability, shear strength, and consolidation are often made on soils in their natural, in-situ condition. For this purpose, undisturbed samples of subsurface materials must be obtained. The term can be misleading since it is impossible to remove a sample without some disturbance. Disturbance depends on the sampler used and the manner in which the sampler is forced into the soil. If standard samplers designed to obtain undisturbed samples are used, disturbance can be influenced in the field by the technique used. Driving the sampler with some kind of dropping weight will usually cause disturbance and should be avoided when possible. Disturbance is least when the sampler is pushed rapidly into the soil by mechanical or hydraulic jacks.

The Shelby thin-walled sampler is the most common tool for obtaining undisturbed samples. The tubing is usually sharpened and drawn at the penetrating end to a slightly smaller diameter than the inside of the tubing. For this reason, the sample must be carefully extruded in the same direction it was pushed. Recovery of the sample without further disturbance can be equally as important as the care taken in obtaining the sample.

Block samples from the side of a test pit or large diameter shaft can also be used to obtain excellent undisturbed samples. Hand tools and wire cutters are used to obtain the samples. Coating with paraffin and wax will help keep the sample in its in-situ condition.

Obtaining undisturbed samples of cohesionless materials is more difficult and requires some artificial means to provide cohesion. Freezing the water in the sample is one method, injecting petroleum derivatives is another. Fortunately, testing of undisturbed cohesionless material is not as critical as for cohesive materials. In-place density is the prime information required, which can be obtained by the careful operation of appropriate sampling devices.

New types of samplers are constantly being developed, so keep in touch by reviewing the literature and talking with suppliers.

4.5. FIELD IDENTIFICATION OF SOILS

Soil and rock identification is accomplished initially in the field; in most cases identification is supplemented by laboratory tests for more specific classification.

In the field, soils are identified by visual and quasi-mechanical tests and are described in terms of their color, grain size, water content, plasticity and strength.

In discussing field observations, it is important to standardize terminology and procedures for identification. Standardization is also of value in correlating soil types and their performance in engineered structures; i.e., foundations, fills, highways, etc.

4.5.1 Grain Size

Grain size can be divided into six divisions: boulders, cobbles, gravel, sand, silt, and clay. Silts and clays require mechanical analysis in the laboratory for grain size identification. With practice, the others can be identified in the field.

Boulders are rock fragments of 12 inches or more in average dimensions. Cobbles are rock fragments between three and 12 inches. Gravel is smaller than three inches but will be retained on a No. 4 sieve (slightly smaller than 1/4 inch). Sand ranges from the No. 4 sieve to material retained on the No. 200 sieve (.074 millimeters). Silt ranges from .074 millimeters to .002 millimeters, and clay is anything less than .002 millimeters in size.

4.5.2 Water Content

Water content can be divided into four categories: dry, moist, wet, and water bearing. Table 4-2 can be used as a guide for classifying fine-grained soils. Obviously, some experience is required for accurate identification. To some extent, the classification depends additionally on grain size distribution. Visual identification and judgment will determine this identifying factor.

table 4-2

CLASSIFICATION OF FINE-GRAINED SOILS

CONDITION	ESTIMATED WATER CONTENT %
Dry	0 - 10
Moist	10 - 30
Wet	30 - 70
Water Bearing	A Water Producing Formation

4.5.3 Soil Plasticity and Strength

Plasticity and strength of the fine-grained silts and clays can be identified by a series of manual tests in the field, i.e. dilatancy, dry strength and toughness. A guide to field identification is shown in table 4-3. Methods of preparing field samples for rapid identification follow.

- *Dilatancy.* Remove the larger particles (greater than No. 40 sieve size, 1/64 inch and larger), prepare a pat of moist soil with enough water to make the soil soft but not sticky. Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. Very fine, clean sands give the quickest and most distinct reaction (see table 4-3), whereas plastic clay has no reaction. (Note: For field purposes, screening is not intended; simply remove the coarse particles that interfere with the test by hand.)

- *Dry Strength.* After removing particles larger than No. 40 sieve, mold a pat of soil to the consistency of putty, adding water as necessary. Allow the pat to dry completely (oven, sun or fan may be used) and then test its strength by breaking and crumbling it between the fingers. This strength is a measure of the character and quantity of the colloidal fraction. The dry strength increases with increasing plasticity.

- *Toughness.* After particles larger than the No. 40 sieve size have been removed, a specimen of soil about one-half inch cube in size is molded to the consistency of putty. The specimen is then rolled by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation, the moisture content is gradually reduced, and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached. After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. The tougher the thread near the plastic limit and the stiffer the lump when it crumbles, the more effective is the colloidal clay fraction.

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table 4-3

GUIDE TO FIELD IDENTIFICATION

Characteristics	Silts	Clays
DILATANCY: (reaction to shaking) Movement of water in voids.	Rapid reaction. Water appears on the surface to give a livery appearance when shaken. Squeezing the soil causes water to disappear rapidly.	Sluggish or no reaction. Surface of the samples remains lustrous. Little or no water appears when hand is shaken. Sample remains lustrous during squeezing.
DRY STRENGTH: (Cohesiveness in dry state)	Very low. Even oven-dry strength is low. Powder easily rubs off surface of the sample. Little or no cohesive strength – will crumble and slake readily.	High to very high. Exceptionally high if oven-dry. Powder will not rub off the surface. Crumbles with difficulty. Slakes slowly.
TOUGHNESS: (plasticity in moist state)	Plastic thread has little strength. Dries quickly. Crumbles easily as it dries below plastic range. Seldom can be rolled to 1/8-inch without cracking.	Plastic thread has high to very high strength. Dries slowly. Usually stiff and tough as it dries below plastic range.

4.6 SOIL CLASSIFICATION SYSTEMS

In the laboratory there are three common systems used to classify soils. They are:

- The AASHO (American Association of State Highway Officials) System
- The FAA (Federal Aviation Agency) System
- The Unified Soil Classification System

The details of each system are beyond the scope of this manual. Appropriate references to pertinent publications can be found in the Bibliography.

Another approach used by some highway agencies is to classify the soil according to strength tests. For example, the Resistance (R-Value) or California Bearing Ratio (CBR) values could be used to classify the soils. This method can be effective in investigations for highways and airports but would not be useful for bridge foundations, buildings, etc. See Appendix C for additional information.

The system used is a matter of local preference. However using the same system as state and federal agencies in your area, as well as neighboring counties, has some advantages. With all agencies using one system, it is possible to pool your information and minimize on extensive laboratory testing.

4.7 FIELD IDENTIFICATION OF ROCK

For most soil exploration investigations, it is not necessary to develop a precise field identification of rocks. However, it is important to include at least some information about the rock encountered at any particular site. Highway engineers in particular will want to know something of rock type to determine if local materials will be difficult to excavate or if the rock can be used in the manufacture of aggregates for base, portland cement concrete or asphalt concrete.

4.7.1 Rock Descriptions

Geologists place bedrock into the three broad categories of igneous, metamorphic, and sedimentary, according to their origin.

Igneous rocks are those formed by the cooling and solidification of hot molten materials erupted from or trapped beneath the earth's crust. The most common igneous rocks are described as intrusive or extrusive as typified by granite and basalt, respectively.

Metamorphic rocks are those formed by the modification of sedimentary and igneous rocks as the result of intense pressures set up by severe earth movements and by excessive heat. One distinguishing feature of some metamorphic rocks is termed *foliation*, which means that the minerals are arranged in parallel planes. These planes are zones of weakness along which the rocks may be split much more easily than in other directions. Examples of foliated rocks are gneisses and schists (from igneous rock) and slate (shale sedimentary). Marble and quartzite are common types of metamorphic rocks which are not foliated.

Sedimentary rocks are those formed by the accumulation of sediment in water or from air. A characteristic feature of sedimentary deposits is a layered structure known as bedding or stratification. Each layer can be seen to have been horizontal at one time, although at the time of sampling may be displaced through angles up to 90 degrees or more. Examples of sedimentary rock are shale, limestone, sandstone, dolomite, chalk, conglomerates and tuff.

4.7.2 Field Techniques

Four techniques should be used in the field identification of rocks:

- Observe luster, metallic or non-metallic
- Determine hardness of minerals
  - 3.5 to 5.5–Can be scratched with knife
  - Over 5.5–Cannot be scratched with knife
  - Over 6.0–Will scratch glass
- Observe color
- Observe texture (coarse or fine-grained rock)

The following additional techniques can be included with adequate training of field personnel:

- Observe and rate fracture and cleavage
- Identify as many minerals as possible

5. REPORTING

Up to this point, the discussion has included the search for published information, site investigation, and laboratory testing. The final step is compiling the information into a report to be used by the designers during construction and as a record for future investigations. This report will be useful not only in your own county but perhaps as the basis for publication of unusual conditions or solutions.

As with most aspects of subsurface investigations, there is no single procedure for preparing reports. Generally, a subsurface exploration report will contain six types of information:

- Graphical presentations of soil borings and soil profiles
- A written report for special use of materials or potential problem areas
- Photographs which show the land forms
- Profiles of surface and subsurface materials
- Properties, strength and grading
- Unusual problems and recommended solutions

5.1 SOIL BORING LOG

The graphical presentation of soil borings is based on the data obtained from the soil boring log. The log is a summary of information obtained at each individual location (auger holes, test pits and drive borings). Some of the information included in the log is:

- Boring number
- Boring location
- Date of boring
- Names of field personnel
- Compaction of existing ground to determine swell or shrinkage factors
- Blows per foot to advance casings, sampling spoon, probes, etc., plus weight of hammer and free fall; if chopping, the rate of advance made
- Reason for terminating boring
- Location of sample and type of sample obtained
- Soil strata locations with description, identification and classification of material
- Percent core recovery in bedrock
- Ground elevation
- Footing or finished grade elevation, when possible
- Groundwater elevation

Some agencies provide laboratory test results on the soil borings; some prefer a tabular summary. It makes little difference as long as the information is included in the report.

Figure 5-1 is an example of a field boring log used by a county in California. Modification of this example should be freely explored to develop a log or record that fits the needs of your county.

figure 5-1

EXAMPLE OF A FIELD BORING NO. LOG

______ COUNTY ROAD DEPARTMENT
SOIL, MATERIALS, INVESTIGATION
BORING RECORD

Location: ______

Dist.______ Co.______ Rt.______ Sec.______ Sta.______

______ Ft., Right, Left ______ Cont. Line W.O. ______

Contractor's Men	ON	OFF	COUNTY MEN	ON	OFF

SAMPLE ELEVATION DATA

Sample No.	Plug Raised	Overall Length	Stick Up	Depth	Elev.	Retained Sample Elev.	No. Tubes	No. Jars
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	
	From							
	To						Core Length	

REMARKS

Weather:

HOURS SPENT TODAY IN					Contractor's Pay Time - Hours	
Sampling	Drilling	Casing	Moving	Repairing	Today	
					To Date	

TO LABORATORY

Contractor ______ Inspector ______

ELEV.	Reference	Dia. of Sampler	Date	Page
	Surface	Wt. of Hammer #	Job No.	Boring No.

Depth	Elev.	Blows Per Ft.		Tubes	WT PER CU. FT.	MOIST % DRY WT	LOG OF MATERIAL

5.2 SOIL PROFILE

The soil profile can be drawn along either transverse or longitudinal lines. This is done by plotting the soil borings at their true elevations, but with the vertical scale exaggerated. If material strata are uniform, lines can be drawn between soil borings to suggest the general subsurface soil profiles. If the strata appear to be mixed and non-uniform in their subsurface orientation, individual holes must be analyzed to determine if sufficient information is available to interpolate between borings. The groundwater elevation should be shown, and perched water tables identified.

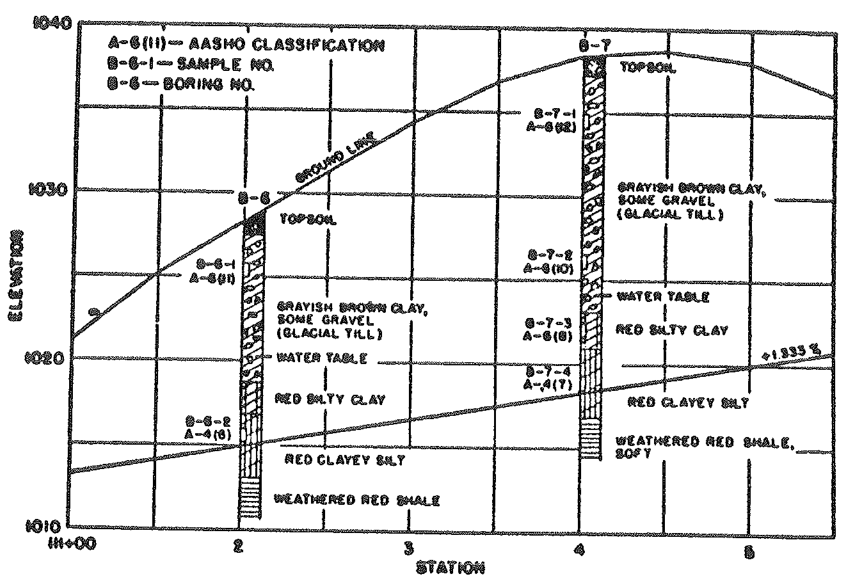
In general the information shown on the soil profile will be similar to that shown on the soil boring log. Figure 5-2 illustrates a simple soil profile with a limited amount of information on each boring log.

5.3 LABORATORY TEST DATA

In reporting the results of laboratory tests, often a simple table or tabular summary is adequate. Such a summary should include identifying information; i.e., sample number and location, boring number, etc., as

figure 5-2

BORING LOGS AND SOIL PROFILE



Source: *Manual on Foundation Investigations,* American Association of State Highway Officials well as such items as unconfined compression strength, coefficients of permeability or consolidation, as needed, or pavement design strength values.

Another procedure is to use the soil boring log as a means of summarizing laboratory information. Figure 5-3 illustrates one example of combining the boring log (left half) with a summary of laboratory information (right half). By using special keys or legends, it is possible to put all of the pertinent laboratory information on one drawing readily available for design determination.

Laboratory personnel and the designer should be consulted when setting up the reporting forms. The Bureau of Reclamation *Earth Manual* or AASHO's *Manual on Foundation Investigations* present excellent reporting forms.

5.4 RECOMMENDATIONS

Most subsurface soil exploration reports will contain specific recommendations relative to the structure (building, highway, etc.) for which the investigation was made. For many counties, this may not be possible simply because staff is not available to make the necessary analyses and evaluation. If the county uses consultants, the following tabulation summarizes the type of information you should request from them:

Foundations

- Footing elevation
- Strata upon which footing will rest
- Allowable bearing capacity
- Estimated settlement
- Water table location
- Subsurface drainage

Fills

- Settlement of the foundation
- Fill stability (inclination of slopes)
- Drainage
- Special keying requirements
- Need for streets

Highways

- Pavement design, i.e., thickness of surfacing, base and sub-base
- Placement of borrow materials
- Drainage
- Depth and extent of unstable soils

Cut Slopes

- Inclination of slope
- Drainage
- Need for benches
- Placement of cut material due to physical and chemical properties

Pile Support

- Type of pile
- Length of pile
- Allowable pile loading

5.5 SPECIAL CONSIDERATIONS

You and your staff should be familiar with reports which deal with special solutions to unusual problems. For example, California, for many years, was experiencing large numbers of slope failures through cut areas. Investigations indicated that the major problem was the collection of water along zones of material which become unstable when wet. The answer was to drill horizontal drains into the sides of the cuts in order to drain away the water. Figure 5-4 shows a typical installation on a county road. Another example is the use of sand drains to stabilize marshlands and to convert unsuitable terrain into stable areas. Preconsolidation procedures can be used for the same purpose. For highways, chemical (lime) stabilization of otherwise unstable subgrade materials can convert on-site materials into base and sub-base quality material. Substandard aggregates can be utilized by means of asphalt and cement stabilization. These are just a few of the possibilities available to the well-informed county engineer.

figure 5-3

COMBINING SOIL BORING LOG AND LABORATORY TEST RESULTS

SCALED DEPTH	DEPTH TO LAYER	DEPTH TO SAMPLE	SAMPLE NO	RECOVERY	SOIL TESTS	BLOWS PER FOOT CASING	BLOWS PER FOOT SAMPLER	SOIL SYMBOL	SOIL DESCRIPTION	UNIT WEIGHT	NATURAL WATER CONTENT	ATTERBERG LIMITS LL	ATTERBERG LIMITS PL	MOISTURE DISTRIBUTION DIAGRAM % 10 20 30	GRAIN SIZE DATA	CONSOLIDATION DATA Cc	CONSOLIDATION DATA Po	UNCONFINED COMPRESSION PSF	UNCONFINED COMPRESSION STR		SHEAR STRENGTH KIPS/FT2 0.5 1.0 1.5
0 – 5	G.W.T.				C1	3 3 10 17 26			BROWN CLAY W/LAYERS OF FINE SAND												
10	7.5'	6.5'	1	12	V1 M1 L1	30 34 40 48 40	8			122	29.0	31.0	19.0		10 Sa 70 Si 20 Cl	0.24 0.50		250	8.5%		
15		11.5'	2	12	V2 L2	44 43 45 50 56	12		BROWN SILTY CLAY W/LAYERS OF FINE SAND	120	28.1	29.0	22.5								
20	17.5	16.5'	3	13	T1 L3 V3	40 52 68 71 65	17			127	24.6	28.3	23.2								
25		20.5'	4	15	M2 L4 C2 T2 V4	70	24		BROWN SILTY CLAY W/FINE SAND	120	17.0	21.1	N.P.		33 Si 67 Sa	0.12 1.50					
30																					
35																					
40																					
45																					
50																					
55																					
60																					

NOTES:

V1 = FIELD VANE TEST & NO.
C1 = CONSOLIDATION TEST & NO.
L1 = ATTERBERG LIMITS & NO.
M1 = MECHANICAL ANALYSIS TEST & NO.
T1 = TRIAXIAL SHEAR TEST & NO.
C_c = COMPRESSION INDEX
P_o = PRE-CONSOLIDATION PRESSURE
+ FIELD VANE TEST
X TRIAXIAL SHEAR TEST
● UNCONFINED COMPRESSION TEST

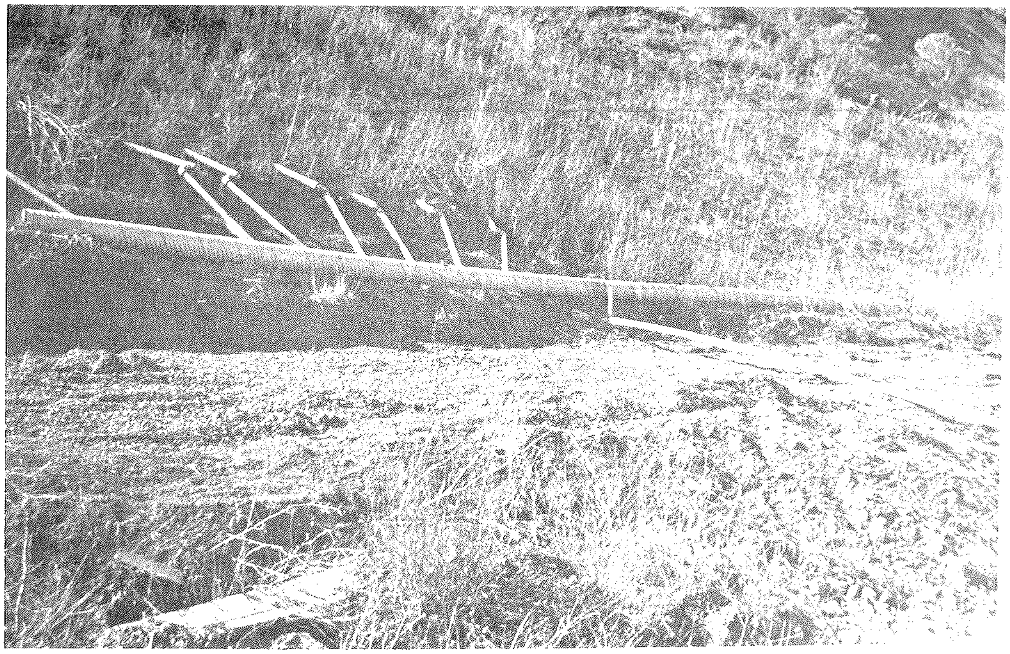


figure 5-4

Horizontal Drains Used to Stabilize Cut Slope

To be able to make recommendations, you should keep up with technology by maintaining contact with research agencies. The Highway Research Board of the National Academy of Sciences, the American Society of Civil Engineers, and the American Society for Testing and Materials are excellent sources of up-to-date, useful material.

Collection of soil samples during a material survey in Malaya (courtesy TRRL).

COUNTY HIGHWAY SERIES

field identification of soils and aggregates for county roads

By

D. G. Shurig
Research Associate
and
Jean E. Hittle
Highway Engineer
Engineering Experiment Station

purdue university • lafayette, ind.

CONTENTS

I. INTRODUCTION

Purpose and Scope

The primary purpose of this bulletin is to provide instruction to Indiana county road personnel on rating the quality of soils and pit-run materials used in the construction and maintenance of county roads. A system of soil classification is presented which provides the county highway engineer, road supervisor and inspector alike, with a *common language* for identifying soil types, properties and problems.

Identification of a soil by the system outlined in this bulletin will do much to evaluate it. The properties and problems of various soils determined previously by engineers have been recorded. Therefore, the identification of a soil tells much about how it will: (1) drain, (2) carry loads, (3) react to frost, and (4) be most effectively compacted. This information, of course, is basic to the construction and maintenance of strong, durable roads.

Chapter II of this bulletin, "Soil Components, Properties and Identification Tests" provides instructions on the identification of soil components, based on their physical properties as determined by visual examination and simple hand tests. Five soil components are defined, along with their size ranges, properties and simple hand tests for identification.

The Unified Soil Classification System is presented in Chapter III. This system is easily learned and is widely used by the U.S. Army Corps of Engineers and other public works agencies. The classification recognizes 15 basic soil groups; however, only seven or eight of these commonly occur here in Indiana. Definitions, word descriptions and classification symbols are summarized in Chart I—Unified Soil Classification System, at the end of Chapter III.

Chapter IV, "Field Identification Procedure" outlines instructions and procedures for identifying each of the 15 soil groups, using visual examination and simple hand tests. The soil identification process is summarized in Chart II—Soil Identification Procedure at the end of Chapter IV.

Chapter V, "Field Tests for Aggregate Materials" outlines additional field identification tests. These "indicator" tests are mainly for pit-run gravels and sands but can serve for both identification and general quality evaluation tests. Guide gradings are presented for gravel base and surfacing aggregates. Tests to indicate the relative amount of fines and relative plasticity of fines are also outlined.

In the last section, Chapter VI, "Rating Soils and Aggregates as Road Materials," the 15 soil groups are rated with respect to their inherent properties as road-building materials. Each soil group is rated for its: (1) load-carrying properties, (2) drainage properties, (3) frost properties, and (4) compaction properties.

Building strong durable roads that are safe and economical is a universal goal of county highway departments in Indiana as well as elsewhere. Achieving this goal has always been a difficult task, mainly because of inadequate funds. However, central to the proposition of building strong, durable, economical roads is the need to evaluate the quality of road-building materials, especially subgrade and base course materials. This bulletin is intended to serve this need and hopefully will assist Indiana county highway departments in achieving their goal of stronger and more durable county roads.

Limitations of Field Identification Tests

The relatively simple hand tests on soil materials outlined in this bulletin have been developed solely for the purpose of identifying pertinent properties of soil materials. These tests are used widely in preliminary soil surveys and soils exploration to provide an indication of the type and amount of laboratory testing needed.

It must be stressed that the field tests outlined here are only "indicator" tests; they *are not* applicable to design and control of major construction projects. Likewise, these tests *are not* intended as a substitute for standard specification tests, covering commercially processed aggregates, either purchased by the county or used in contract construction or contract maintenance.

In order to learn the soil field tests, county road personnel should begin with soil materials that have been previously tested and classified in the laboratory. Test instruction by an experienced soils technician or engineer is recommended.

Suggested Reading and References

The Unified Soil Classification System included in this bulletin was developed and is widely used by the U.S. Army Corps of Engineers. The system has also been adopted by several other public works agencies. The procedure for soil classification, by this system, includes both *field* and *laboratory* methods.

The procedure outlined in this bulletin emphasizes the field identification method, mainly because the simple field tests seem better suited to the needs of Indiana county highway departments. The laboratory methods require more time and involve more precise equipment and testing techniques. Therefore the following list of publications are included as suggested reading and reference for the county engineer, highway supervisor or inspector who desires to broaden his knowledge on methods of evaluating soils and road materials.

(1) *Soils Engineering,* Section 1, Volume 1, Chapter I-V, Student Reference, U.S. Army Engineer School, Fort Belvoir, Virginia, revised October 1969.

(2) *Unified Soil Classification System,* (A Supplement to the Earth Manual), U.S. Bureau of Reclamation, Denver, Colorado, March 1953. [An excellent reference dealing only with the Unified Soil Classification System.]

(3) *Soil Tests for Military Construction,* by Major George E. Bertram, U.S. Army Corps of Engineers, published by American Road Builders Association, Washington, D.C., Tech. Bull. No. 107, Reprinted 1960. [A good reference on routine soil tests; well illustrated; easy to follow and understand.]

(4) *PCA Soil Primer,* Portland Cement Association, Chicago, Illinois.

(5) *Soils Manual* (for Design of Asphalt Pavement Structures), The Asphalt Institute, College Park, Maryland, April 1963.

Both the Asphalt Institute and PCA publications provide excellent fundamental data on the engineering properties of soils, soil profiles, soil sampling, and pavement design relative to soil types.

II. SOIL COMPONENTS, PROPERTIES AND IDENTIFICATION TESTS

The identification of soil components in this manual is based on their physical properties as determined by visual examination and simple hand tests. This section defines five soil components, their size ranges and properties, along with simple hand tests for identification. The meaning of plasticity, gradation, percent of gravel, percent of sand and percent of fines must be clearly understood.

Soil Components

The five soil components discussed herein are: (1) gravel, (2) sand, (3) silt, (4) clay, and (5) organics. Natural soils may be composed entirely of only one component but usually are composed of mixtures of two or more components. The main physical characteristic used to identify soil is particle size. Gravels and sands are defined as coarse-grained components; silts and clays as fine-grained components. Any of these materials may contain varying quantities of organic material.

Coarse-Grained Components

GRAVEL has a size range of three inches (baseball size) to about ¼ in. (dried pea size). Relative to Standard U.S. Sieve sizes, it has a size range between the 3-in. sieve and the No. 4 sieve. Gravel is further divided into coarse and fine sizes—see Figures 1 and 4.

SAND sizes range from below ¼ in. to about 3/1000 in.—about the smallest size the naked eye can observe. Sand has a size range between the No. 4 sieve and the No. 200 sieve. Sands are divided into coarse, medium and fine sizes—see Fig. 2.

Fine-Grained Components

SILTS and CLAYS, also called FINES, are smaller than 3/1000 in. They both pass a No. 200 sieve. Individual silt and clay particles are essentially too small to be seen by the naked eye—see Fig. 3. They can be identified by a simple plasticity test—clays are plastic, silts are nonplastic.

In the laboratory, sand and fines are separated with sieves as shown in Fig. 4. Tables I and II also provide more information on soil component sizes.

Fig. 1. In the Unified Soil Classification System, gravels are divided only into course and fine sizes. Coarse gravel ranges from 3 in. (baseball size) to ¾-in. (about the diameter of a nickel). Fine gravel ranges from below ¾ in. to about ¼ in.—the size of a dried pea.

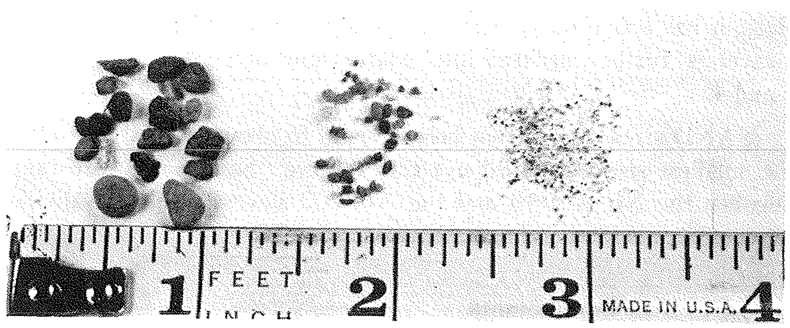


Fig. 2. The Unified System classifies sands into coarse, medium and fine sizes —they are shown in true or actual size above from left to right. The inspector should try to fix these size ranges in his mind and make an association with certain familiar objects as in Fig. 1.

Organic Components

ORGANICS are decomposed plant (mainly grass, leaves and woody materials) and animal remains. Organics form a significant part of some soils, and have strong influence on their engineering behavior. They are identified mainly by: (1) their dark colors—

Fig. 3. This photograph shows the size relationship between fine sand and fines (silt and clay particles). Sharp observation of the photograph shows that the silt and clay particles fit down into the crevices of the "finger prints" (right) and that the fine sand particles do not (left). Fine sand feels sharp and gritty while both silt and clay particles feel soft and smooth like flour.

black, gray and brown; (2) their odor of decay, and (3) their general composition of plant and animal remains. Peat and muck are the two main organic materials.

PEAT is primarily brown, fibrous, partially decomposed plant debris. Particle size is highly variable but most individual fibers are easily visible—see Fig. 5.

MUCK is more highly decomposed, or completely decomposed, plant and animal remains. Most of the remains have turned to carbonaceous particles of silt and clay size—particles too small to identify by ordinary observation.

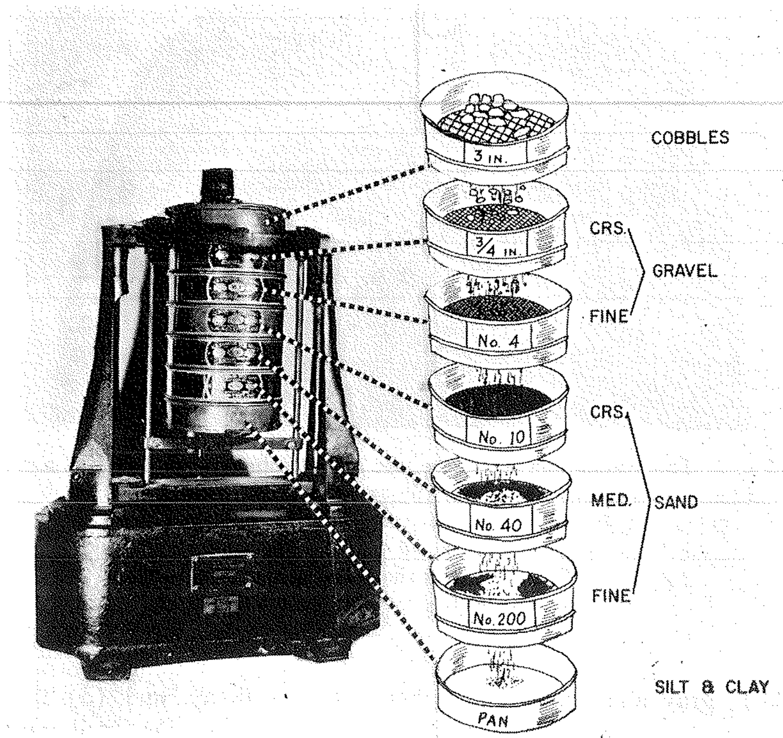


Fig. 4. In the laboratory, the most informative soil test is the sieve (or size) analysis test. The various soil sizes are separated as indicated above. Each size collected is weighed and its percent by weight is calculated. In the field, the inspector estimates the quantity (percent by volume) of only gravel, sand and fines.

Fig. 5. Peat, on the left, is composed primarily of partially decomposed plant life. Muck, in the center, is mainly highly decomposed plant and animal remains—but may contain fresh leaves, grass, twigs, etc. In mucks, decomposed materials turn to black carbonaceous particles of silt and clay size as indicated on the right.

Soil Components Summarized

GRAVEL and SAND, the *coarse-grained* components, are identified by particle size. CLAYS and SILTS, the *fine-grained* components, or FINES, are identified by their plasticity and lack of plasticity. ORGANICS—PEAT and MUCK are identified by color, odor and composition.

Table I SIEVE SIZE RANGE OF SOIL COMPONENTS

Soil fractions are normally designated by a range of sieve sizes. The words "pass," "retained," "plus" and "minus" refer to the particle size in relation to sieve size. For example, fine gravel passes a ¾-in. sieve and is retained on a No. 4 sieve; fine gravel may also be designated as minus ¾-in. sieve and plus No. 4 sieve. Soil fractions relative to sieve size are listed below.

Soil Components	Sieve Size Range	
	Pass	Retained on
COBBLES	—	3 in.
GRAVEL		
Coarse	3 in.	¾ in.
Fine	¾ in.	No. 4
SAND		
Coarse	No. 4	No. 10
Medium	No. 10	No. 40
Fine	No. 40	No. 200
FINES		
Silt and Clay	No. 200	

Table II SIEVE SIZES AND SIZE OF OPENINGS

The Unified Soil Classification System uses particles sizes arbitrarily set at certain U.S. Standard Sieve sizes as shown below in the listings. Note the actual and approximate smaller sieve openings. This information is provided only for reference.

Sieve Size	Sieve Openings	Approximate Openings
3 in.		
¾ in.		
No. 4	0.1870 in.	3/16 in.
No. 10	0.0787	5/64
No. 40	0.0165	1/64
No. 200	0.0029	3/1000 (barely visible)

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Plasticity

Soil plasticity, degree of plasticity and simple field plasticity tests are defined below.

Soil Property of Plasticity

The soil property of plasticity is simply that of being putty-like—clays are putty-like, silts are not. Silts behave more like extremely fine sands.

Degree of Plasticity

Degrees of soil plasticity used in soil identification are nonplastic, low plastic and high plastic. Silts are nonplastic and clays are plastic—either low or high plastic. The great majority of Indiana's surface soils are low plastic clays.

Degree of plasticity, used to identify soils, can be determined by simple hand tests. *Moist,* fine-grained soils that can be formed into ribbons are clays. The longer the ribbon formed—the more plastic the clay. Degree of plasticity can also be detected in *dry,* fine-grained soils. The more effort required to break and powder lumps of dry, fine-grained soils—the more plastic (and cohesive) the soil.

Ribbon Test

The ribbon test is used to determine if a soil is plastic or nonplastic and also whether plastic soils are low or high plastic.

The test is usually performed on predominately fine-grained soils. However, if the fines in a predominantly coarse-grained material are to be checked for plasticity, the fines should be separated by hand (described on p. 17) or by sifting dry granular material through a No. 40 sieve.

Usually the fines (about a handful) must be wetted and kneaded to attain a good, moldable condition. Wet soil that sticks to the hands is too wet; it must be worked until it is no longer sticky. A roll, about ½ in. to ¾ in. in diameter and 3 in. to 5 in. long, should be formed. The roll is then very carefully squeezed into a ribbon ⅛-in. to ¼-in. thick as shown in Fig. 6. The vertically hanging ribbon is formed until its own weight causes it to break. Ribbons of a certain length indicate the degree of plasticity.

Ribbon Length	Soil Type
over 8 in.	high plastic clay
under 8 in.	low plastic clay
none formed	nonplastic soils (namely silt)

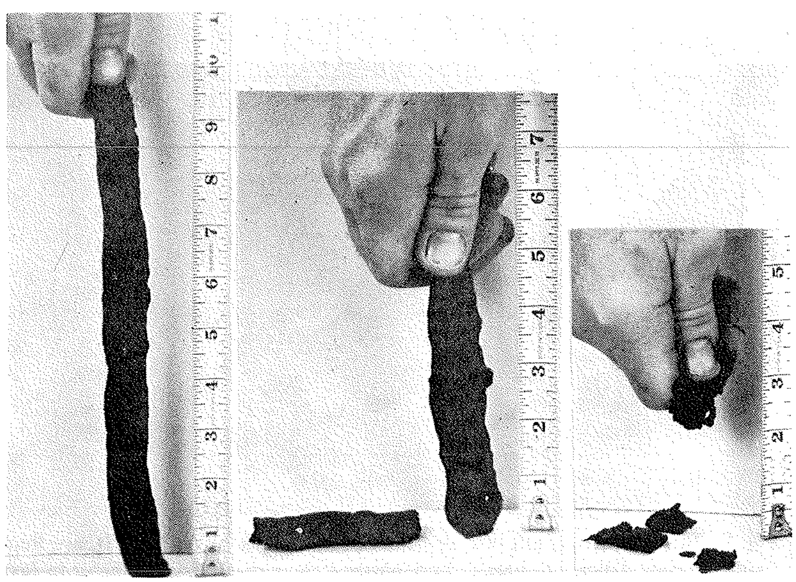

Fig. 6. In the ribbon test, high plastic clays form ribbons over eight inches long, low plastic clays (includes medium plastic clays) form ribbons less than eight inches long. Silts do not form ribbons—the very short silt ribbons shown above formed with one forward push of the thumb and then broke.

Dry-Strength Test

The dry-strength test, like the ribbon test, will distinguish plastic and nonplastic soil types and whether plastic soils are high or low plastic. The test is performed on dry lumps of predominantly fine-grained soils or on fines separated out of coarse-grained soils by hand or with a No. 40 sieve.

Test samples should be thoroughly air-dried, sun-dried or dried with applied heat. The finger force (thumb and forefinger) required to break dry lumps into smaller lumps and to pinch the smaller lumps into powder indicates soil plasticity—see Fig. 7. Dry silts can usually be pinched entirely to powder; clays usually form very small lumps and powder as indicated below:

Difficulty of Breaking Lumps	Degree of Powdering	Soil Type
Difficult to impossible	none	high plastic
Easy to difficult	incomplete	low plastic clay
Very easy	complete	nonplastic silt

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Fig. 7. In the dry strength test, dry high plastic clays, as on the left, are impossible or very difficult to break. Low plastice clays range from difficult to easy to break. The low plastic clay lump, in the center, broke fairly easily, but it was impossible to very difficult to pinch the smaller lumps into powder. The dry silt lump, on the right, pinched easily into a completely powdered form.

Percent Gravel, Sand and Fines

In the field identification of soils, and particularly in the identification of predominantly gravelly and sandy materials, one should be able to visually estimate the approximate percent of gravel, percent of sand and percent of fines. An accurate estimate of the percent of fines in gravels and sands is especially important when they are used for base or surfacing materials.

Clean and Dirty Gravels and Sands

It takes only a small amount of fines to seriously reduce the general quality of gravel or sand as a base material. Aggregates can be classified as *"clean," "dirty"* and borderline (or slightly dirty) as indicated below. Identification of clean and dirty aggregates are discussed in more detail later.

Percent Fines (minus No. 200)	Gravel and Sands
under 5%	"clean"—little or no fines
5-12	borderline
over 12	"dirty"—appreciable fines

Percent Gravel, Sand and Fines by Observation

In field identification, material percentages are estimated by observing the relative quantities or volumes of gravel, sand and fines and it can be done with the sample dry or moist. Gravelly or sandy materials should be spread thin on a flat surface or in the palm of the hand. By brushing with the finger, the gravels and larger sand sizes can be easily separated but not so the fine sands and fines. Rub some of the generally finer material between the thumb and forefinger—fine sand feels gritty; silt and clay fines feel soft and smooth, like flour. After touching and scrutinizing, and possibly trying the simple tests described below, make a thoughful estimate of the percentages of gravel, sand and fines—see Fig. 8.

Dust Formation Test

In this test a large handful of completely *dry*, coarse-grained soil (gravel removed) is dropped about 18 inches onto a hard surface. If little or no dust flies, the material is essentially clean—less than five percent fines. If a small dust cloud forms, the material is dirty. See Fig. 9.

Hand Stain Test

On moist, coarse-grained soils (gravel removed) a handful is squeezed in the hand. If the material is clean, the hand will not be discolored or stained. If dirty—the hand will be discolored or even look "muddy"—see Fig. 10.

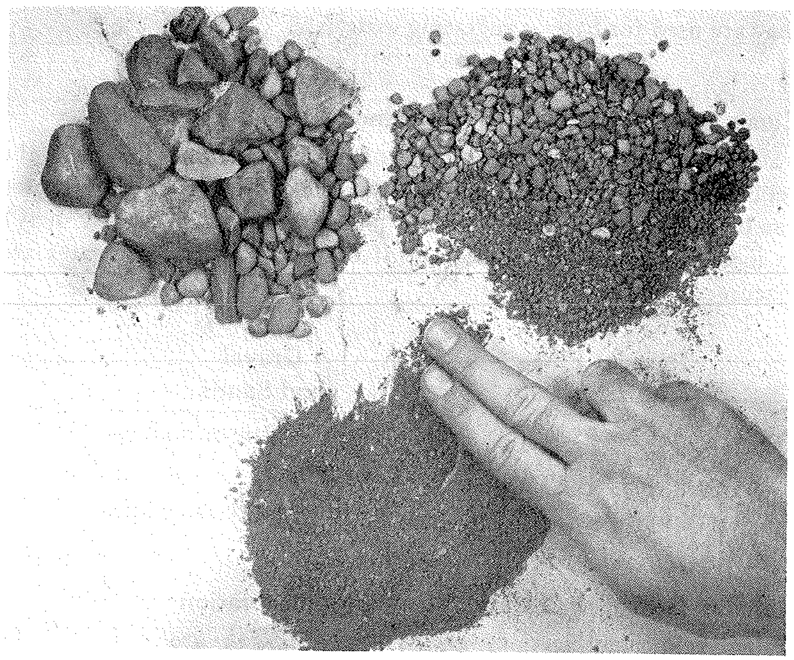

Fig. 8. By picking and brushing (as above) with the fingers, a sample of coarse-grained soil can easily be separated into gravel, coarse sand and a third pile, lower center, of medium sand, fine sand and fines. Hand separation of particles below about a $\frac{1}{16}$ in. is difficult. However, by spreading the latter pile thin and by careful observation and carefully rubbing and feeling, the percent of fines can be estimated within five percentage points with a little practice.

Gradation

Gradation refers to the grain-size composition of a coarse-grained soil or the amounts of various particle sizes in the soil. It is a relative term used to describe predominantly coarse-grained soils only. Gravels and sands are either well-graded or poorly-graded.

Well-Graded Gravels and Sands

Well-graded materials have various amounts of larged and smaller particles such that the voids between the larger particles can be

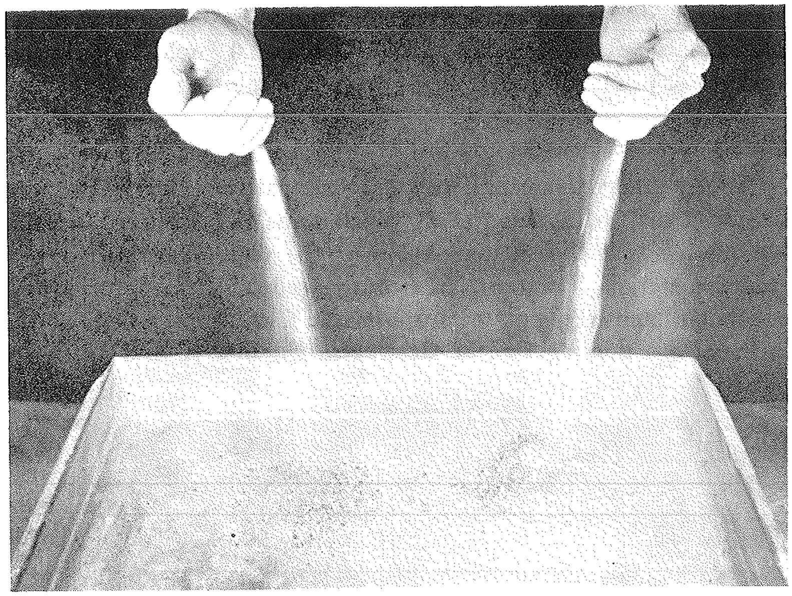

Fig. 9. In the dust formation test, a handful of sand and fines of a dirty, coarse-grained soil, dropped about 18 in. onto a hard surface, will produce a dust cloud as on the right. Clean materials do not cause a dust cloud. (Actual observation will show the dust more distinctly than the above photo).

Fig. 10. In the hand stain test, wet or thoroughly damp coarse-grained soils may be determined to be clean or dirty. Dirty material, after being firmly squeezed in the hand, leaves a stain or discoloration—as on the left. A clean material leaves essentially no stain—as on the right.

filled with smaller and smaller particles to make a tight (chinked-in), dense, stable mass—see Fig. 11. The material could be primarily a gravel, or primarily a sand, or a gravel-sand mixture.

Poorly-Graded Gravels and Sands

Poorly-graded materials may have all particles nearly the same size or it may be a material in which some particle size, or sizes, are missing such that it does not meet the requirements of a well-graded material. The term "uniformly-graded" is used for gravels or sands composed mainly of one size; the term "gap-graded" is used to indicate a missing size or sizes. See Figures 12 and 13.

Fig. 11. This is a photograph of a well-graded gravel. It is obvious, from the distribution of particle sizes, that a large quantity, well mixed, would form a tight or dense, chinked-in mass and make a strong stable road base when properly compacted. When a material such as this is used as a base coarse, it is called dense-graded aggregate.

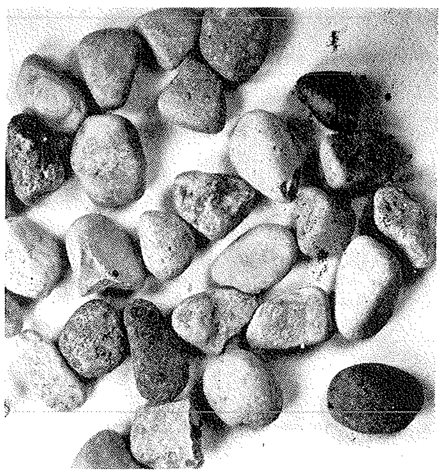

Fig. 12. This is a poorly graded gravel. Since all the particles are about the same size it is also called a uniformly-graded gravel. It is obvious that this uniformly-graded gravel, especially with its rounded and subrounded particle shapes, would not make as stable a base as the well-graded gravel. When a material such as this is used as a base course it is called an open-graded aggregate.

Fig. 13. This is also a poorly-graded gravel. Since several sizes are missing, to qualify as a well-graded gravel, the material is also called a gap-graded gravel. As a base, it would be more stable than the uniformly-graded gravel but less stable than the well-graded gravel.

III. THE UNIFIED SOIL CLASSIFICATION SYSTEM

The Unified Soil Classification System recognizes 15 basic soil groups. Each group has distinctly different soil properties and thus behaves differently as an engineering material. The basis of classification involves three factors:

(1) Soil component percentages (gravel, sand and fines)

(2) Plasticity of fines (clayey if plastic and silty if nonplastic)

(3) Gradation of coarse grains (well-graded or poorly-graded)

The specifications or boundary limits for each of the 15 basic soil groups, relative to the above three factors, are listed in Chart I—Unified Soil Classification System. Each soil group is also briefly described in the following pages.

Classification Symbols

The Unified System also provides a series of letter symbols for a short-hand method of designating each soil group. The following is a brief review of the letter symbols. The symbols, for each soil group, are also shown on Chart I.

Symbols for Coarse-Grained Soils

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G=Gravel	W=Well graded
S=Sand	P=Poorly graded
M=Silt	
C=Clay	

Thus, GM designates a silty gravel, SW designates a well-graded sand, etc.

Symbols for Fine-Grained Soils

M=Inorganic silt	L=Low liquid limit*
C=Inorganic clay	H=High liquid limit*
O=Organic silt or clay	

Thus, OL designates a low plastic, organic silt; CH designates a high plastic, inorganic clay, etc.

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* Liquid limit is the moisture content of a soil, as determined by the standard liquid limit test, at which a soil passes from a plastic to a liquid state.

Compendium 2

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CHART I – UNIFIED SOIL CLASSIFICATION SYSTEM ①
(Including Identification and Description)

MAJOR DIVISIONS			GROUP SYMBOLS	SOIL GROUP NAME	FIELD IDENTIFICATION PROCEDURES②
COARSE GRAINED SOILS Over half of material larger than No. 200 sieve size. About 3 in. to 0.003 in.	GRAVELS Over half the coarse grains larger than No.4 sieve size. About 3 in. to ¼ in.	CLEAN GRAVELS Less than 5% fines	GW	WELL-GRADED GRAVEL	Wide range in grain sizes and substantial amounts of all intermediate sizes
			GP	POORLY-GRADED GRAVEL	Predominantly one size or a range of sizes with some intermediate sizes missing.
		DIRTY GRAVELS More than 12% fines	GM	SILTY GRAVEL	Nonplastic fines. Identify fines with tests listed below for ML or plasticity test – Chapter IV.
			GC	CLAYEY GRAVEL	Plastic fines. Identify fines with tests listed below for CL or plasticity test – Chapter IV.
	SANDS Over half the coarse grains larger than No.200 sieve size. About ¼ in. to 0.003 in.	CLEAN SANDS Less than 5% fines	SW	WELL-GRADED SAND	Wide ranges in grain sizes and substantial amounts of all intermediate sizes.
			SP	POORLY-GRADED SAND	Predominantly one size or a range of sizes with some intermediate sizes missing.
		DIRTY SANDS More than 12% fines	SM	SILTY SAND	Nonplastic fines. Identify fines with tests listed below for ML or plasticity test – Chapter IV.
			SC	CLAYEY SAND	Plastic fines. Identify fines with tests listed below for CL or plasticity test – Chapter IV.

IDENTIFICATION PROCEDURES③
On Fraction Smaller than No. 40 Sieve Size

MAJOR DIVISIONS		GROUP SYMBOLS	SOIL GROUP NAME	RIBBON TEST (Ribbon Length)	DRY STRENGTH TEST (A.Breaking B.Powdering)	OTHER FEATURES
FINE GRAINED SOILS Over half of material smaller than No.200 sieve size–about 0.003 in.	SILTS NONPLASTIC	ML	SILT	None forms	A. Easy B. Complete	
		MH	MICACEOUS SILT	None forms	A. Easy B. Complete	Abundant Mica Flakes
		OL	ORGANIC SILT	None forms	A. Easy B. Complete	Color Odor Composition
	CLAYS PLASTIC	CL	SILTY CLAY	Less than 8 in.	A. Easy to difficult B. Incomplete	
		CH	HIGH PLASTIC CLAY	More than 8 in.	A. Difficult to impossible B. None	
		OH	ORGANIC CLAY	Variable	A. Variable B. Variable	Color Odor Composition
PREDOMINANTLY ORGANICS		Pt	PEAT AND MUCK			Composition Color Odor

NOTES: 1. Modified for Indiana county highway personnel. 2. Primary discussion of field identification procedures is in Chapter IV. 3. Tests are oversimplified and therefore are designed to have a tendency to indicate soils of relative poorer quality from what they are.

Text 4

Coarse-Grained Soils

Coarse-grained soils have more than 50 percent coarse grains. More than 50 percent of all the particles are retained on a No. 200 sieve. Coarse-grained soils are classified as either gravel or sand soils.

Gravel (G)

A coarse-grained soil is basically a gravel if more than half its coarse-grains are gravel size—more than half is *retained* on the No. 4 sieve (plus No. 4 sieve)

Sand (S)

A coarse-grained soil is basically a sand if more than half its coarse-grains are sand size—more than half *passes* the No. 4 sieve (minus No. 4 sieve).

Clean Gravels and Clean Sands

Clean gravels and clean sands have less than five percent fines—less than five percent passes the No. 200 sieve. Clean gravels and clean sands are either well graded (W) or poorly graded (P). The four clean gravels and sands are:

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Clean Well-Graded Gravel	(GW)
Clean Poorly-Graded Gravel	(GP)
Clean Well-Graded Sand	(SW)
Clean Poorly-Graded Sand	(SP)

Dirty Gravels and Dirty Sands

Dirty gravels and dirty sands have more than 12 percent fines—more than 12 percent pass the No. 200 sieve. There are four dirty gravel and sands.*

Silty Gravel	(GM)
Clayey Gravel	(GC)
Silty Sand	(SM)
Clayey Sand	(SC)

* When a coarse-grained soil has more than 12 percent fines the effect of gradation of coarse particles is reduced and the effect of fine particles increased—the type of fines clayey (plastic) or silty (nonplastic) is designated.

Fine-Grained Soils

Fine-grained soils have more than 50 percent fines—more than 50 percent passes the No. 200 sieve. Fine-grained soils are classified as either silts or clays.

Silts (M)

The three silt classifications are:

Silt (Inorganic) (ML)
Micaceous Silt (MH)
Organic Silt (OL)

Clays (C)

The three clay classifications are:

Low Plastic Clay (CL)
High Plastic Clay (CH)
Organic Clay (OH)

Organics

Peat (Pt)

In the Unified System, only the one word is used to designate both peat and muck—they are described on page 10.

IV. FIELD IDENTIFICATION PROCEDURE

One of the main advantages of the Unified Soil Classification System is that soil samples can be identified in the field by visual examination and simple hand tests, requiring little, if any, test equipment. Using word descriptions, below, of each of the 15 soil groups and/or a chart, field identification of soils is made easy. Chart II—Soil Identification Procedure, at the end of this chapter, provides a technique for identifying a soil by simple elimination.

Representative Samples

This is a key factor in evaluating the quality of any road-building material, and especially so for soils and base course materials. Therefore, the county highway inspector, must be constantly alert to selecting test samples that are *typical* and *representative* of the materials used in the roadway structure.

A knowledge of soil weathering and the development of soil profiles (A, B and C horizons) is invaluable in sampling subgrade soils. (See the references for soil profile data)

Obtaining representative samples from stratified sand and gravel pits can be done as described in Appendix A.

Equipment for Testing Soil Samples

Little or no equipment is required for most field identification tests. However, for a few tests on aggregates, described in the next chapter, several ordinary household items may be used. The equipment is illustrated in the following chapter and listed in Appendix B.

Preparation of Sample

Select a representative sample of the soil to be identified and spread same out on a flat surface or in palm of hand.

(a) Estimate maximum particle size in sample.

(b) Estimate percentage of material larger than 3 in.

(c) Remove material larger than 3 in. from sample. Only that portion of sample smaller than 3 in. is identified.

(d) Other sample preparation is outlined in the description of the various field tests.

Identification of Coarse-Grained Soils Versus Fine-Grained Soils

To identify the sample as coarse-grained or fine-grained, make an estimate of the percentage of individual particles that can be seen by the naked eye.

Soils containing *more than 50 percent* visible particles are *coarse-grained* soils.

Soils containing *less than 50 percent* visible particles are *fine-grained* soils.

When a sample appears to have about equal amounts of coarse grains and fine grains (borderline sample), break clay-cemented lumps into individual particles and break away fines adhering to larger aggregates. It may be necessary to dry the sample in order to break it down into individual particles. Identification may also be helped by running the sample through a piece of ¼-in. mesh hardware cloth (or No. 4 sieve) to separate out the gravel sizes.

Identification of Clean Gravels and Sands Well- and Poorly-Graded Gravels and Sands (GW) (GP) (SW) (SP)

A *clean,* coarse-grained soil (over 50 percent gravel and/or sand) with less than five percent fines is either a well-graded or poorly-graded gravel (GW)(GP) or either a well-graded or poorly-graded sand (SW)(SP).

To identify a clean, coarse-grained soil, spread the sample thin on a flat surface, carefully observe all particles, carefully feel the smallest particles, try the dust formation test and the hand stain test.

When gravel is the predominating material in the coarse-grained portion of a soil, the soil is basically a gravel—when sand predominates, the soil is basically a sand.

Clean gravels and sands are usually readily detected by careful observation and examination of the finer particles. Fine sands feel gritty—silts and clays feel soft like flour. Dry, clean gravels and sands form no dust cloud in the dust formation test and moist, clean gravels and sands do not stain the hands in the hand-stain test.

Finally gradation, well-graded or poorly-graded, must be determined simply by observation according to definitions previously provided.

Clean sand and gravels rarely occur as a natural subgrade soil in Indiana, nor are they likely to be well-graded. As a general rule, Indiana's sand and gravel deposits are poorly-graded and contain more than five percent fines. Clean, well- or poorly-graded gravels and sands usually must be obtained as commercially processed aggregate.

Identification of Dirty Gravels and Sands Silty and Clayey Gravels and Sands (GM) (GC) (SM) (SC)

A *dirty* coarse-grained soil (over 50 percent gravel and/or sand) with over 12 percent fines is either a silty gravel (GM) or clayey gravel (GC) or a silty sand (SM) or clayey sand (SC).

Spread the sample thin, carefully observe, examine and test for a dust cloud and hand staining.

If gravel predominates in the coarse grains, the sample is basically a gravel; it is basically a sand if sand predominates.

If appearance indicates more than 12 percent fines, and the dust formation test shows a substantial dust cloud, and the moist samples stains the hands—the material is dirty. The sedimentation test outlined in the next section under "Field Tests for Aggregate Materials" will also prove helpful in estimating the percent of fines in the sample.

When gravels or sands are found to have more than 12 percent fines, the fines must be examined for plasticity. The fines maybe brushed out or sieved out (using a piece of window screen). Fines, (silt and clay) collected in this manner usually contain considerable fine sand but it does not matter because the fines need to be identified only as plastic or nonplastic (not low or high plastic).

If the fines are plastic, as indicated by the formation of a moist ribbon (probably short), and have noticeable dry strength, the soil is a clayey gravel or sand. If the fines are nonplastic, as indicated by their inability to form a ribbon, and by dry lumps having essentially no dry strength, the soil is a silty gravel or sand.

Silty sand subgrade soils are quite common in northern Indiana. They are found in sand dune areas, in the large Kankakee basin and many smaller outwash plain areas. They are found in hundreds of square miles of beach sand areas around Lake Michigan. Subgrade soils of silty gravel, clayey gravel and clayey sand are much less common than silty sand.

Identification of Silts

A fine-grained soil (over 50 percent fines) that can easily be broken and pinched into powder when dry, and that *can not* be ribboned when moist, is either a silt (inorganic), micaceous silt or organic silt.

Silt (ML)

Silt (inorganic silt) can be distinguished from micaceous and organic silt simply by the lack of mica flakes and dark, organic materials.

"Clayey," "sandy" or "gravelly" can be used as modifying words before silt if more than a trace of these materials are present. Clayey silts have very slight dry strength and may form very short ribbons. Fine sands are often found with silts and can be detected by their gritty feel.

Windblown silts ("dune" silts) are found along many bordering uplands of Indiana's large rivers. Silts and fine sands are found on most flood plains. Surface soils tend to become silty because clay-size particles migrate downward with the passage of time.

Micaceous Silt (MH)

Micaceous silts are silts with an obvious abundance of tiny mica flakes. Micaceous silts in Indiana come mainly from the breakdown of micaceous sandstone bedrock in southern Indiana.

Organic Silt (OL)

Organic silts are the black or dark silts—with about ten percent or more organic fines. They are usually shallow surface soils found in basin areas or around swamps.

Identification of Clays

A fine-grained soil (over 50 percent fines) that can be readily formed into a ribbon when moist and that has obvious dry strength is either: (1) low plastic clay or (2) high plastic clay or (3) organic clay.

Low Plastic Clay (CL)

Low plastic clays form ribbons one to eight inches long (clays forming ribbons approaching eight inches may be called moderately plastic). Dry lumps may be broken fairly easily with the fingers but usually considerable effort is required. It is difficult (or impossible) to pinch the smaller lumps into a completely powdered condition.

Nearly all of Indiana's low plastic clays have a low plasticity because of a high silt content. Therefore low plastic clays in Indiana are commonly identified as *silty clays*. If there is a significant amount of sand or gravel—the material may be classified as a sandy, silty clay or a gravelly, silty clay.

It is estimated that "silty clays" account for approximately three-fourths of the surface soils occurring in the State of Indiana.

High Plastic Clay (CH)

Highly plastic clays form long ribbons—eight to ten inches long. Dry lumps of highly plastic clay are very difficult or impossible to break into smaller lumps and, of course, it is impossible to pinch small lumps into powder.

Highly plastic clays will rarely be encountered in Indiana. When they are encountered they most likely will not contain significant amounts of silt, or sand, or gravel. Such clayey soils are therefore usually called highly plastic clays.

Organic Clay (OH)

Organic clays are composed predominantly of clayey soils but as little as ten percent of black organic fines (black carbonaceous particles of silt and clay sizes) can change the behavior (and color) of the clay and make it unsuitable for a subgrade soil.

Organic clays form short to medium length ribbons of one to several inches. But their black to dark colors, light weight, and their soft and spongy feel distinguish them from the other clays.

The location of organic clays also helps to identify them. They are usually found in low, undrained, or poorly-drained, basin areas and especially in and around swampy areas.

Borderline Soils

Many soils will exhibit properties of two groups because they are borderline between the groups, either in percentage of sizes estimated or in degree of plasticity. In such cases, soil designations are used which incorporate both group symbols connected by a hyphen, such as GW-GM.

Coarse-grained soils will often have nearly equal proportions of sand and gravel sizes. In such cases, proceed with the identification assuming the soil is a sand. Continue the identification until a final soil group is reached, say clayey sand (SC). Since the soil might also be assumed to be a *gravel*, the borderline field identification would be GC-SC. This is appropriate since the criteria for gravel and sand subgroups are the same. Likewise, other borderline soils within the sand or gravel groupings might be SW-SP, SM-SC, SW-SM, GW-GP, GM-GC, etc.

Soils borderline between coarse grained and fine grained are identified first as a coarse-grained soil and next as a fine-grained soil. Borderline soils such as SC-CL and SM-ML are common.

In the fine-grained group, borderline soils can develop between soils of high plasticity and low plasticity, also between silty and clayey soils of the same plasticity. Examples of such soils would be: ML-MH, CL-CH, OL-OH; and CL-ML, CL-OL, MH-OH, etc.

Summary of Soil Identification Procedure

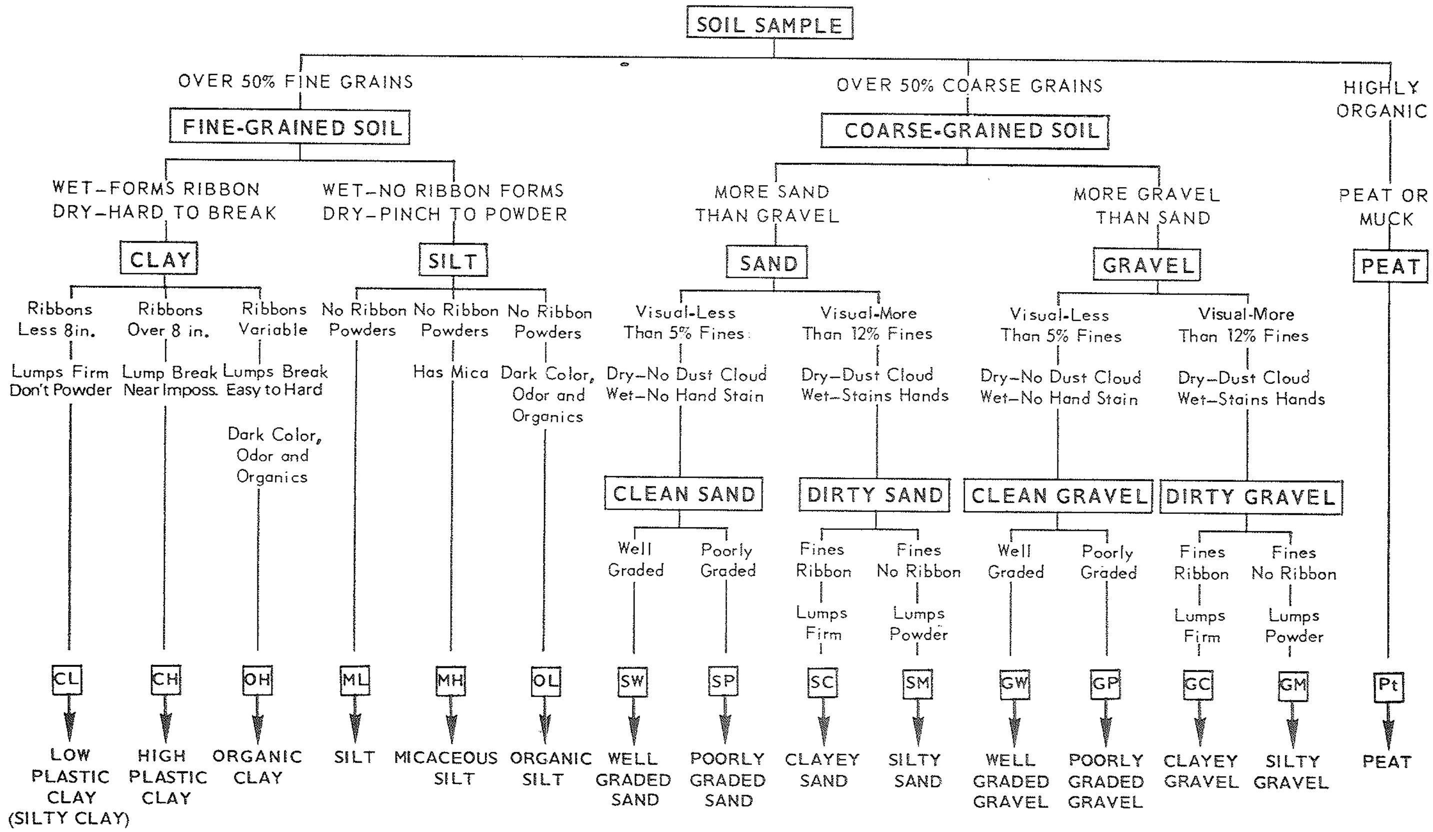
Chart II, Soil Identification Procedure, serves two purposes. It summarizes all the previous information on soil identification and it provides a step-by-step procedure for identifying an unknown soil sample.

The identification procedure is, in effect, a process of elimination—beginning at the top of the chart and working downward until the soil is identified. The main requirement for using the chart is to have the "know-how" for running four simple hand tests:

(1) Ribbon Test — page 15
(2) Dry Strength Test — page 16
(3) Dust Formation Test — page 17
(4) Hand Strain Test — page 18.

Test results and the soil type indicated are shown on the chart.

CHART II – SOIL IDENTIFICATION PROCEDURE



Use of Identification Chart—An Example

Starting with an unknown soil sample, the inspector notes at the top of Chart II, Soil Identification Procedure, that he must first determine if the sample is predominantly fine grained, coarse grained or organic. Visual observation and feel indicate that the example soil has well over 50 percent fine grains—it is a fine-grained soil. Immediately nine group names are eliminated as possibilities—four gravels, four sands and peat. Moving to the left on the chart, under fine-grained soils, the inspector notes that his sample must be one of the three clays (CL, CH, OH) or one of the three silts (ML, MH, OL).

The chart next indicates application of the ribbon test and dry strength test. Say the inspector finds that the wet soil forms a ribbon and a dry lump has obvious dry strength. This information now eliminates all three silts as possibilties. The inspector then finds that the longest ribbon he can form is about five inches and also notes that the sample has essentially no organic matter. Thus, the high plastic clay (CH), and the organic clay (OH), are eliminated as possibilities and the one remaining choice is a low plastic clay (silty clay—CL).

Additional Descriptive Information

After a soil has been identified, it may be desirable to add additional descriptive information—especially for the coarse-grained soils.

When the material is well graded the maximum aggregate size may be recorded; when poorly graded, the maximum size and the predominant size are frequently recorded.

More information on the granular particles such as hardness, general shape, surface texture and mineralogy may be important *depending on the use* of the material. Rock particles may be classed as soft, medium or hard. In shape they may be: rounded, subrounded, angular or subangular. Surface condition may be rough or smooth. Mineralogical data usually pertains to listing percentages of soft rocks and materials: shale, coal, limonite, etc.,—see the ISHC 1969 Standard Specifications for Aggregates.

V. FIELD TESTS FOR AGGREGATE MATERIALS

In addition to evaluating local soils as subgrade materials, the county highway inspector frequently needs to evaluate the quality of aggregate materials used in base course and surface course construction. Poor quality in base and surfacing aggregates is often a cause of roadway distress or failure.

Poor quality in base and surfacing materials can usually be attributed to either poor grading or an excess of plastic fines. County highway construction and maintenance forces must be on constant alert to guard against these deficiencies.

The "indicator" tests presented here will assist county highway inspectors in evaluating the quality of base and surfacing aggregates sampled from either an existing roadway, an existing stockpile, or a local gravel pit.

It is emphasized that these "indicator" tests are not intended as a substitute for standard specification tests covering commercially processed aggregates.

Aggregate Gradation

The field tests for aggregate grading are basically the same as for the identification of coarse-grained soils.

Visual Estimate of Grading

A representative sample (say a quart can-full) is spread out on a flat surface. Carefully note the maximum size of particle present and the representation of decreasing sizes in the sample.

Next, make an estimate of the relative proportions of gravel (plus No. 4), sand (plus No. 200) and fines (minus No. 200). A closer estimate can be made of the proportion of gravel present if the sample is sieved through a No. 4 sieve or an ordinary piece of wire hardware cloth with about ¼-in. openings.

Satisfactory Gradings

If the sample of aggregate material from the roadway, stockpile or local gravel pit is reasonably well graded, contains 40 percent or more of gravel sizes (plus No. 4) and only minor traces of fines (minus No. 200), then the material will probably produce a satisfactory base or gravel road surface.

Borderline Gradings

If however, the sample contains less than 40 percent gravel sizes and noticeable amounts of fines, then the material may produce road materials of borderline quality, depending on the actual amount and plasticity of fines. Field tests for estimating the amount and plasticity of fines are outlined below and on page 37.

Guide Gradings

Road experience has shown that satisfactory road bases and road surfacing materials can be constructed from a fairly wide range of aggregate gradings. A tabulation of guide gradings is set forth below to assist in evaluating the gradation for test samples of base and surfacing aggregates. The grading limits shown below represent ISHC No. 53B and No. 53 aggregates, which have proven both desirable and satisfactory.

Guide Gradings For Gravel
Base and Surfacing Aggregates
Base Aggregate for Flexible Pavement

Gravel (plus No. 4)	40%—65%	(max. size=1½ in.)
Sand (No. 4—No. 200)	35 —60	
Fines (minus No. 200)	0 — 5	(nonplastic)

Gravel Road Wearing Surface Material

Gravel (plus No. 4)	40%—65%	(max. size=1 in.)
Sand (No. 4—No. 200)	25 —55	
Fines (minus No. 200)	5 —10	(slightly plastic)

Amount of Fines

Estimating the amount of fines in a sample of base or surfacing aggregate is actually a part of the field test for estimating gradation. This estimate uses a water-settlement technique which is based on the fact that particles settle in water at a rate proportional to their size. Thus, sand sizes settle first, silt sizes next and clay sizes last.

Sedimentation Test

The sedimentation test is another "indicator" test. With reasonable care, an estimate or approximation can be made of the amount of sand, silt and clay sizes present in the test sample. The test procedure is as follows:

(1) Secure a representative sample (say a quart-can full) of the base or surfacing material to be tested.

(2) Separate gravel sizes from the sample by screening the sample through a No. 4 sieve or a piece of hardware cloth with about ¼-in. openings—Fig. 14.

(3) Fill a straight-sided glass jar with about 5 in. of water. Pour the sand and fines, separated from the gravel, into the jar. A closer estimate can be made if a tall, slender jar is used—Fig. 15.

(4) Agitate or stir the mixture until the soil is completely broken up into individual particles.

(5) Get all soil particles into suspension, by shaking jar vigorously, end to end—Fig. 16.

(6) Quickly place the jar at rest on a level surface and instantly begin a 25-second count. Give the jar a quick 180 degree rotation in order to make the particles settle in a level plane.

(7) Sand sizes will settle in about 25 seconds; silt sizes in about 60 seconds; clay sizes in about 1½ hours. Using a pencil, mark the jar, on masking tape, at the top level of sand sediments—those accumulated after 25 seconds (Fig. 17—lower mark). Marking the jar after 60 seconds, to distinguish silt and clay, is optional. The test is designed primarily to determine percent of fines.

(8) Repeat 5, 6 and 7 to recheck the 25-second-level mark and the 60-second-level mark.

(9) After an average 25-second mark (and optimal 60-second mark) have been determined, allow the sample to settle in the jar until the water clears, or until 1½ hours have elapsed—whichever comes first.

(10) Next, using a pencil, mark the top level of sediments in the jar between clay and clear water—Fig. 17, upper mark.

(11) With an appropriate scale, measure to the nearest 1/10 in. the following vertical distances along the side of the jar—Fig. 18.

a=bottom of jar to 25-second level (sand)

b=25-second level to top of sediments (silt and clay)

Example: Assume that a sample of gravel road surfacing is being inspected. A representative sample has been screened through ¼-in. hardware cloth (or No. 4 sieve if available) and the separation of plus ¼-in. sizes yields a visual estimate of:

45% Gravel (plus No. 4)

55% Sand plus fines (minus No. 4)

A sedimentation test on the minus No. 4 material provided the following values: a=3.0; b=0.5

$$\text{Percent sand} = \frac{a}{a+b} \times 100 = \frac{3.0}{3.5} \times 100 = 86\%$$

$$\text{Percent fines} = \frac{b}{a+b} \times 100 = \frac{0.5}{3.5} \times 100 = 14\%$$

Gravel = 1.00 x 45% = 45.0%
Sand = .86 x 55% = 47.3%
Fines = .14 x 55% = 7.7%
100.0%

Note: The results of the sedimentation test are only *approximate*, since the time-rate of settlement for a given grain size is at best only an average theoretical figure.

Plasticity of Fines

The plasticity of fines is a critical factor in the evaluation of either gravel base or surfacing materials. Plastic fines, even in small amounts, can seriously reduce the quality of base or surfacing materials.

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Plasticity Test

Plasticity is a property of soil which allows it to be kneaded to a putty-like consistency at the proper moisture content. The following is an "indicator" test which will yield fairly reliable results if performed with reasonable care and attention to details.

(1) Secure a representative air-dry sample (say a quart-can full) of the base or surfacing material to be tested. Break-up lumps of fine materials by hand or with a short piece of a broomstick.

(2) Screen a portion of the sample through a No. 40 sieve (a piece of ordinary window screen may be substituted for the No. 40 sieve)—Fig. 19.

(3) Screen a sufficient amount of the sample to yield three or four heaping tablespoonsful of fine material passing the No. 40 sieve (or screen wire).

(4) Place the material passing through the sieve (fine sand, silt and clay) in a small bowl and add water two or three drops at a time, mixing and kneading thoroughly with the fingers—Fig. 20.

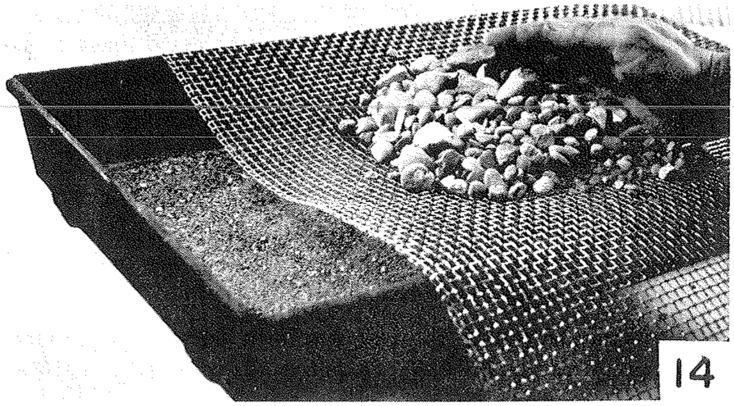
Fig. 14. A fairly accurate means of separating gravel, sand and fines, in order to estimate the percentage of each, is to first separate the gravel by working the sample through a piece of ¼-in. mesh hardware cloth as shown here. The sand and fines are then separated as shown in Figures 15, 16 and 17.

Fig. 15. In this photo, sand with fines, obtained from the pan in Fig. 14, is carefully placed in a straight sided jar with five inches of water in preparation for a sedimentation process to separate the sand and fines.

Fig. 16. The jar with sand, fines and water is vigorously shaken and then placed at rest. In five inches of water, all the sand will settle in about 25 seconds and all the fines, silt and clay, in about 1½ hours—or more—when the water clears.

Fig. 17. In this photo, the lower pencil mark was placed after 25 seconds to mark the top of all the settled sand particles. Actually, another line could have been similarly located by drawing it between the smallest particles visible to the naked eye and those not visible—no timing would be required. The upper line, drawn on top of the sediments after 1½ hours or after the water clears, marks the top of the fines. With the gravel separated on the wire mesh (Fig. 14) and the sand and fines separated, as above, the percent of each can be estimated—with or without computations.

Fig. 18. This photo shows how the thickness of the fines and sand can be measured to the nearest $\frac{1}{10}$ in. The text provides instruction on how to mathematically compute the percentages of gravel, sand and fines.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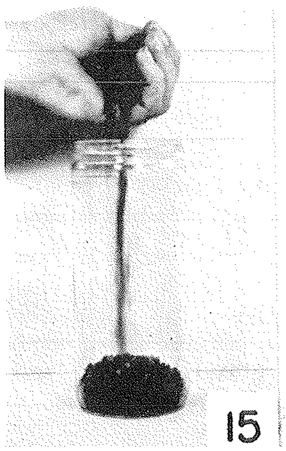
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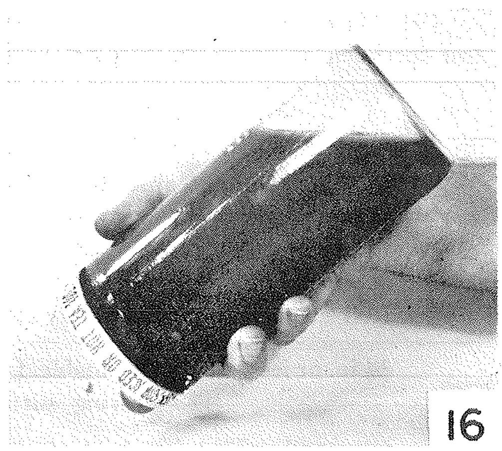
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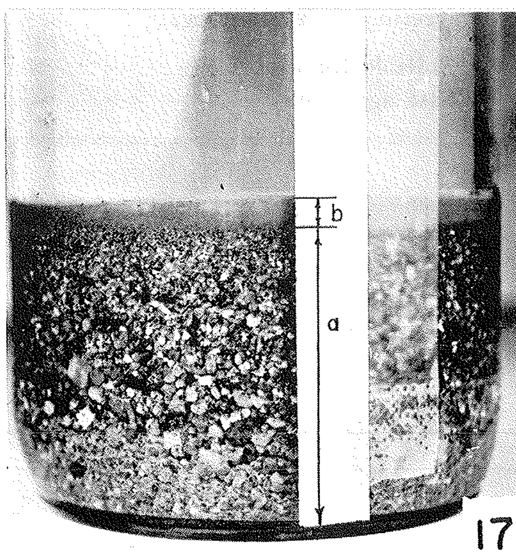

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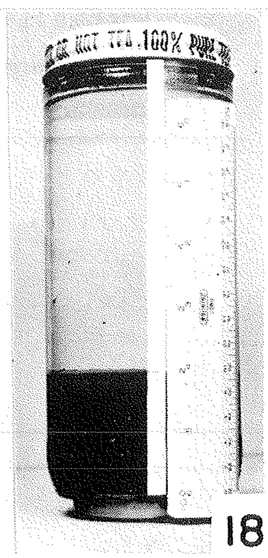
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(5) Add the minimum amount of water to easily mold material into a "golf-ball." Do not add so much water as to make it sloppy wet. Obtaining the proper moisture content is important.

(6) Form test specimen into a ¾-in. roll, adding a little more water if necessary.

(7) With the "flat" of the hand, using a light finger pressure, roll the test specimen on a flat waterproof surface. If surface becomes wet or muddy, the soil specimen is too wet and should be reworked to reduce the moisture content—Fig. 21.

(8) Continue rolling the test specimen on the flat waterproof surface, using sufficient finger pressure to gradually reduce the diameter of the test specimen.

(9) The object of the test, is to determine the *diameter* of the test specimen at which the roll breaks or crumbles—Fig. 22.

Guide Values for Plasticity Test

Diameter at which Roll Crumbles	Suitability and Use
⅛ in. or less	Unsuitable for gravel base or wearing surface aggregate
Over ⅛ in. to less than ¼ in.	Suitable for gravel wearing surface aggregate
¼ in. or larger	Suitable for gravel base aggregate

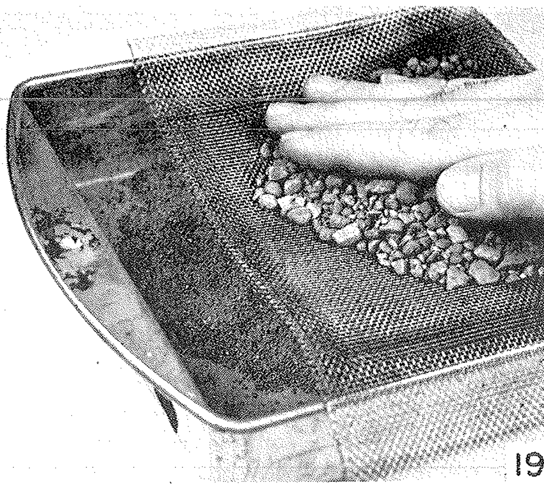
NOTE: This page (41) is blank in original text.

Fig. 19. To test the plasticity of fines in a aggregate, an ordinary piece of window screen may be used to separate out the fines. Actually the fines will include: silt, clay, fine sand and some medium sand but this mixture should be satisfactory for the simple plasticity test described in the text and illustrated in Figures 20, 21 and 22.

Fig. 20. The "fines", obtained as shown in Fig. 19, are placed in a small bowl and thoroughly mixed with water—a few drops at a time. The material should be thoroughly wetted but not dripping wet.

Fig. 21. Using an amount about the size of a golf ball, it is first formed into a ¾ in. roll and this roll is rolled with the fingers, as shown above, to the smallest possible diameter without breaking or crumbling.

Fig. 22. If the roll crumbles (above-top) at or before reaching a diameter of about ¼ in. (pencil thickness) the fines are probably suitable in a base course aggregate—the fines serve as a filler. If the roll reduces to between ¼ in. and ⅛ in. the fines are probably suitable in a gravel surfacing aggregate—the fines serve both as a cohesive agent and filler. If a roll reduces to ⅛ in. or smaller the fines are not suitable for either above use.



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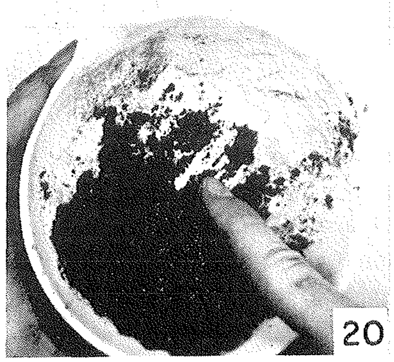

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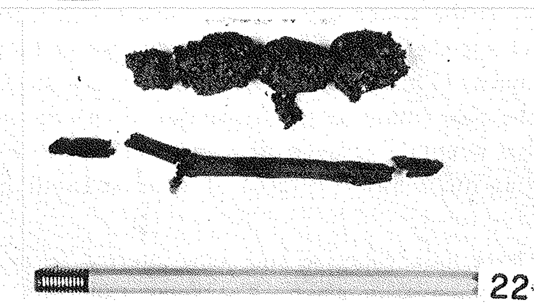

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VI. RATING SOILS AND AGGREGATES AS ROAD MATERIALS

All soils have certain properties that influence their behavior and usefulness as road materials for construction and maintenance; the most pertinent properties include: (1) load-carrying properties, (2) drainage properties, (3) frost properties and (4) compaction properties. These properties are given a relative rating for each soil classification group in Chart III — Soil Use Chart, page 45.

Load-Carrying Properties of Soils

The load-carrying capacity of a soil may be defined as its ability to resist penetration or lateral movement when loaded. This property depends upon the ability of a soil to resist shear—see Fig. 23. Shear strength in soil is derived from cohesion (stickiness) and from internal friction (grain-to-grain interlocking). Cohesion is best developed in clayey soils and internal friction is best developed in clean and slightly dirty sands and gravels.

Strength of Fine-Grained Soils

Cohesion develops in clays because the grains are extremely fine and have a flat, plate-like shape. As the water content of a clay decreases (drying), the capillary and surface tension of the moisture films cause the clay particles to move closer together. With continued drying the clay particles develop a strong adhesion for each other, forming lumps (or clods) with high dry strengths.

Conversely, as the water content increases, the attractive forces lose their effect, the clay particles absorb thicker water films, forcing the particles apart with a resulting loss in cohesive strength. The more plastic the clay (more of the finest clay sizes) the greater the loss in cohesive strength between dry and wet conditions. Clayey soils can lose as much as 75 percent of their strength in the wet spring season.

Silty soils have some cohesion and some internal friction, but are only slightly stronger than clays. The fines (silts and clays) in dirty gravels and sands reduce the load-carrying capacity by: (1) reducing the grain-to-grain contact points between the coarse grains, and (2) acting as a lubricant.

In the Soil Use Chart, the strengths of clays and silts are rated poor to fair. Clayey and silty gravels and sand are rated fair to good. Any soil with more than about 12 percent fines will have a considerable loss of strength between dry and wet conditions.

CHART III – SOIL USE CHART

(Numbers in the Chart refer to footnotes)

SOILS	SYMBOL	PROPERTIES[1] Permeability	Load Carrying Ability	Frost Susceptibility	COMPACTION EQUIPMENT[2]	USES Base Course[3]	Wearing Course[4]
WELL-GRADED GRAVEL	GW	Pervious	Excellent	None to very slight	Vibratory[5] Rubber tire Steel wheel[6]	Excellent[7] to good	Fair
POORLY-GRADED GRAVEL	GP	Very pervious	Good	None to very slight		Fair	------
SILTY GRAVEL[8]	GM	Semi-perv to impervious	Good to fair	Slight to medium	Vibratory Rubber tire Sheepsfoot Steel wheel	Excellent to fair	Good to fair
CLAYEY GRAVEL[8]	GC	Impervious	Good to fair	Slight to medium		Good to poor	Excellent to good
WELL-GRADED SAND	SW	Pervious	Excellent	None to very slight	Vibratory Rubber tire Steel wheel	Poor	Fair
POORLY-GRADED SAND	SP	Pervious	Good	None to very slight		Poor	------
SILTY SAND[8]	SM	Semi-perv to impervious	Good to fair	Slight to high	Vibratory Rubber tire Sheepsfoot Steel wheel	Fair to poor	------
CLAYEY SAND[8]	SC	Impervious	Good to fair	Slight to high		Fair to poor	Good to fair
SILT	ML	Semi-pervious to impervious	Fair	Medium to very high	Rubber tire Segmented wheel Steel wheel		
MICACEOUS SILT	MH		Fair to poor				
ORGANIC SILT	OL		Poor				
SILTY CLAY	CL	Impervious	Fair	Medium to high	Rubber tire Sheepsfoot Steel wheel		
HIGH PLASTIC CLAY	CH		Poor	Medium			
ORGANIC CLAY	OH		Very poor	Medium			
PEAT AND MUCK	Pt	Remove from subgrade.					

1. Qualitative values listed below are for properly compacted soils.
2. Equipment listings are in order of efficiency – first is best.
3. Qualitative values listed are for bases on high traffic roads.
4. Gravel road wearing surfaces for roads with less than 100 vehicles per day.
5. Crawler tractors can be used as vibratory equipments – other types are listed in text.
6. Steel-wheel rollers are best used as grade finishers.
7. Well-graded gravels are usually very difficult to compact.
8. These materials cover a considerable quality range – from a low percentage of fines (5%–12%) and well graded to a high percentage of fines (over 12% to about 20%) and poorly graded.

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Strength of Base Aggregates

The load-carrying capacity, or shear strength of base aggregates (clean and slightly dirty aggregates) range from good to excellent. The shear strength depends mainly on internal friction which is related to the gradation, size, shape, and surface texture of the individual aggregate particles.

Bases of well-graded aggregates are stronger than bases of poorly-graded aggregates because of better chink-in and more grain-to-grain contact produces a tight, dense mass with minimum voids and maximum strength.

The maximum size of aggregate is also a factor in base strength. In general, the larger aggregate sizes (up to 1½ in.) produce a stronger base through better interlock and internal friction. Crushed particles, with their greater angularity, also improve the strength of the base aggregates.

Thick Bases for Weak Subgrades

The main function of a base course in the construction of roads and streets is to spread the applied traffic loads and there-by reduce the stress or pressure reaching the subgrade soil. Increasing the base thickness simply increases the "snowshoe" effect by causing a greater reduction in the pressure reaching the subgrade soil—see Fig. 24. Increased pavement thickness (and increased pavement rigidity) also increases the "snowshoe" effect for applied roadway loads.

The great majority of Indiana's surface soils are silty clays that provide a relatively weak subgrade support. For this reason, our county road improvements should provide for base courses constructed to adequate thickness, of quality materials and with proper compaction. However, this can only be accomplished through engineering design, specifications and inspection—all beyond the scope of this manual.

Considering Indiana's high rainfall, generally high ground-water levels, and poorly-drained soils, the matter of drainage deserves a high priority in planning county road improvement projects. In most of Indiana's flat terrain, and especially in poorly-drained basin areas, great improvements in road life could be made by raising the grade-line profile one to two feet above the natural ground surface. See HERBIC Bulletin No. 4, "Principles of Highway Drainage and Erosion Control."

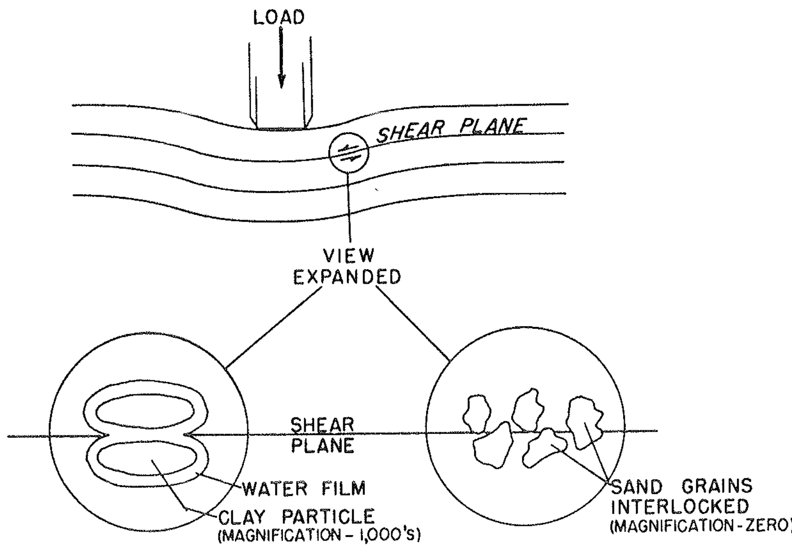

Fig. 23. Weak subgrades and bases usually fail by shearing when overloaded —there is slippage along the shear planes shown above. As clays absorb water, the water film thickens and cohesion (stickiness) between clay particles decreases. Wet clays can lose 75 percent of their dry strength. Interlocking (internal friction) and strength of clean sand and/or gravel particles is not affected by water.

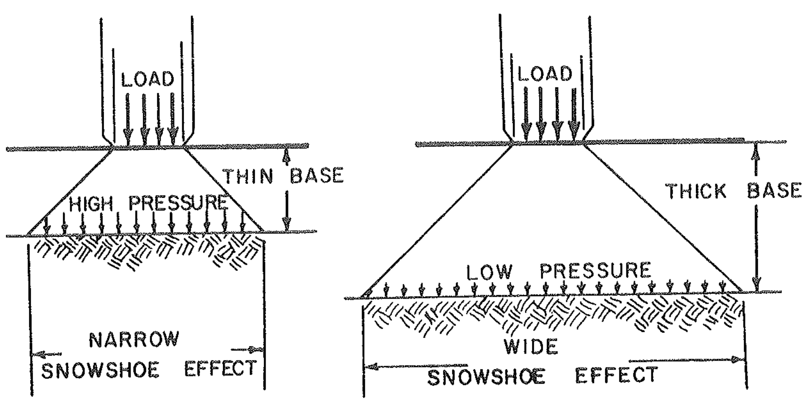

Fig. 24. This drawing shows how increased base thickness reduces the load pressure on the subgrade. Note that for the thin base on the left the diameter of the area of load distribution on the subgrade is narrow (narrow snowshoe effect) but with the thicker base, on the right, the same load is distributed over a much wider area (wide snowshoe effect). Weak subgrade soils require relatively thick bases.

Drainage Properties of Soils

The drainability of a soil is measured by its permeability—or the ease or difficulty with which water will pass through the pores of the soil.

The Soils Use Chart divides soils into four general groups: (1) very pervious — instant drainage (2) pervious — fast drainage (3) semi-pervious—slow to very slow drainage (4) impervious—essentially no drainage.

Drainability of Subgrade Soils—Indiana

The Soil Use Chart lists the three clays, clayey sand and clayey gravel (over 12 percent clayey fines) as impervious. The three silts, silty sand and silty gravel (over 12 percent silty fines) are rated as semi-pervious to pervious. Therefore, the great majority of Indiana's surface soils would have a drainability of fair to poor.

Drainability of Base Course Aggregates

The permeability of clean and slightly dirty aggregates (such as used for base courses) ranges from very pervious, pervious, and semi-pervious to impervious. The permeability of these materials depends on: (1) gradation, (2) type and amount of fines and (3) density.

116 (1) *Gradation:* Uniformly-graded, or open-graded aggregates drain faster than well-graded, or dense-graded aggregates. The chart shows poorly-graded gravels (clean) to be very pervious and well-graded gravels (clean) to be pervious—the latter has less voids.

(2) *Type and Amount of Fines:* Clay fines in aggregates, slow drainage more than silt fines. Silty gravels (GM) and sands (SM) are rated semi-pervious to pervious, while clayey gravels (GC) and sands (SC) are rated impervious.

(3) *Density:* Increased densities of a given soil material will decrease the voids in the compacted soil and accordingly decrease the permeability and drainage. Clean, dense-graded base materials can be compacted to such a high density that they are essentially impervious.

Aggregate Placement for Good Drainage

When bases are constructed with open-graded aggregates it is best to extend the aggregates through the shoulders for adequate drainage. Also when open-graded aggregates, mostly larger than 3/8 in. are used, it would be ideal to use a 2-in. to 4-in. thick sand blanket or screenings as an inverted choke between the base and a subgrade composed of fine-graded soil especially in consistently wet areas.

When dense-graded base materials are used they may be constructed in a trench only under the roadway itself. As they are nearly impervious, water can not penetrate them and these bases need not go through the shoulder for drainage. The low areas however, should have drainage outlets. Also, dense-graded bases do not require the sand blanket to prevent subgrade intrusion.

Frost Properties of Soils

Frost action is a general term referring to freezing and thawing of water in soils. As the soil freezes in winter, ice crystals in the soil pores tend to attract more water from unfrozen lower levels. The ice crystals grow to ice lenses and heave the roadway upward—see Fig. 25.

As the ice lenses melt in the spring, the melt water softens the roadway and causes pot holes or chuck holes. This road damage is commonly called "spring breakup".

Frost Susceptible Soils

The most frost susceptible soils are those that carry the greatest amounts of capillary water to the freeze zone. The most susceptible soils are silts and fine sands. Their minute pores act as capillary tubes whose very small size attract and feed water generally upward and relatively fast—like a wick in a kerosene lamp.

Clays can draw water to greater heights (over 30 ft.) than silts, but the clays draw smaller amounts at a slower rate and so are not as frost susuceptible as silts. Organic clays are an exception. The chart shows organic clays to be the most frost susceptible of all soils—but, overall, organic clays are not commonly encountered in Indiana.

Further review of the chart shows the following: silts and fine sands are the most frost susceptible; clays in general, are second; dirty sands and gravels—third; and clean sands and gravels essentially are not susceptible to frost. Clean gravels and sands are free draining with voids large enough to preclude capillary action; such materials are not susceptible to frost action.

Preventing and Minimizing Frost Damage

(1) *Replacement of Frost Susceptible Soils*—The only sure way to prevent frost action is to replace frost susceptible soils with clean, free-draining, nonfrost-susceptible, granular materials to the full depth of frost penertation—about 18 in. to 24 in. However, this is often not economically feasible for Indiana counties.

(2) *Keep the Subgrade Dry*—If there is no water in the subgrade, there will be no heave. Ditches and subdrains should be used

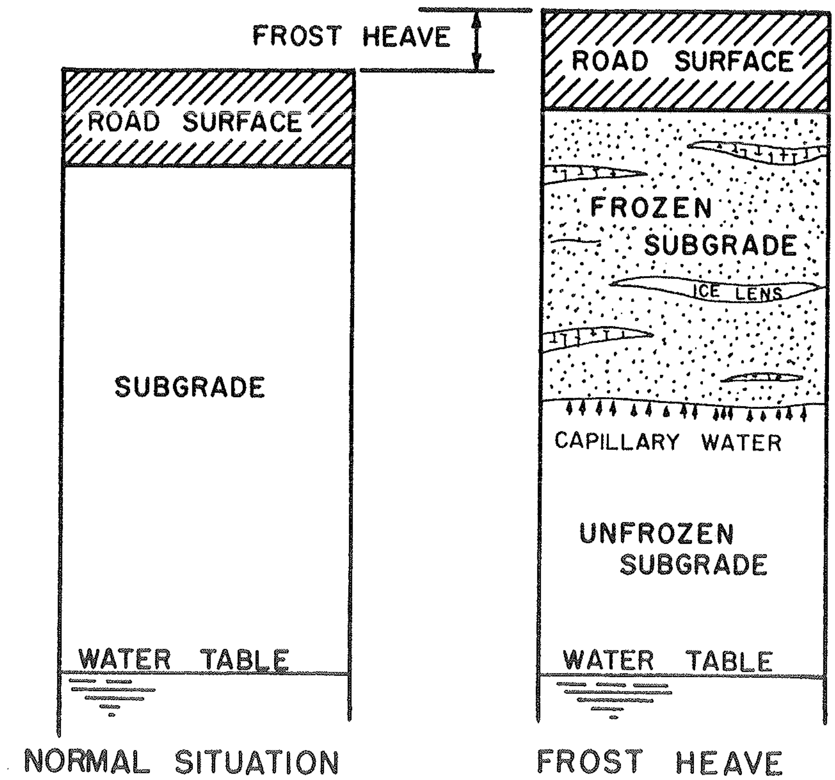

Fig. 25. This sketch shows how ice lenses growing and melting in frost susceptible soils cause upward and downward movement and break-up of pavements. The three factors involved are: (1) freezing temperature, (2) source of water, and (3) frost susceptible soils. The last two factors can be controlled.

to lower the ground water level and/or to intercept springy or water-bearing strata. Make especially sure that ditch levels are below bases—see HERPIC Bulletin No. 4, "Principles of Highway Drainage and Erosion Control."

Where the ground-water level is near the surface, and cannot be lowered, an ideal solution is to raise the grade one or two feet with clean, granular materials. If this is not feasible, then raising the grade, say two feet, with fine-grained soils will help minimize frost damage if the soils are properly compacted.

(3) *Good Maintenance Practices*—Good maintenance, especially the use of good surface drainage, plus keeping the pavement surface sealed, will help to minimize frost damage. Posting of damage-susceptible roads is also advisable.

Compaction Properties of Soils

The primary objective of this section is to emphasize the benefits of proper soil compaction. Indiana county highway departments need to make better and more consistent use of this tried and proven construction procedure.

There is no other single treatment, at so low a cost, that produces as much improvement in the physical properties of a subgrade or base material as does proper compaction. Compaction makes a soil: tighter, denser, stronger, keeps it drier, makes it less frost susceptible, minimizes volume changes (swelling and shrinking) with wetting and drying and minimizes settlement. A pavement on a well-compacted fill or subgrade is stronger, more durable and less costly to maintain than one on a poorly-compacted or uncompacted fill or subgrade.

Compaction Defined

Soil compaction is defined as a mechanical process in which soil materials are made more dense. Density is increased by reducing air voids—air is literally squeezed out—the water content remains constant. In general, increased soil density increases soil strength.

Compaction Factors

There are five factors involved in soil compaction: (1) soils, (2) equipment, (3) lift or layer thickness, (4) number of equipment passes, and (5) soil moisture content. Each of these factors is briefly discussed below. Detailed specifications for subgrade and base compaction are provided in the Indiana State Highway Commission Standard Specifications.

Soil Type and Compaction Equipment

Certain soils are more efficiently compacted by one type of compactor than another. The Soil Use Chart lists the most efficient compactors for each soil classification—also see Fig. 26.

In general, the rubber-tired roller is presently the best universal roller—it is good for all soils. The sheepsfoot roller is excellent for clayey soils and dirty gravels and sands but inefficient for silts and fine sands. The latter are best compacted by the tamping action of pad-feet on segmental-wheel rollers.

The steel-wheel roller is listed on the chart for all soils, mainly because there are so many readily available. When the steel-wheel roller is used as the prime compactor, minimum lift thickness and/or

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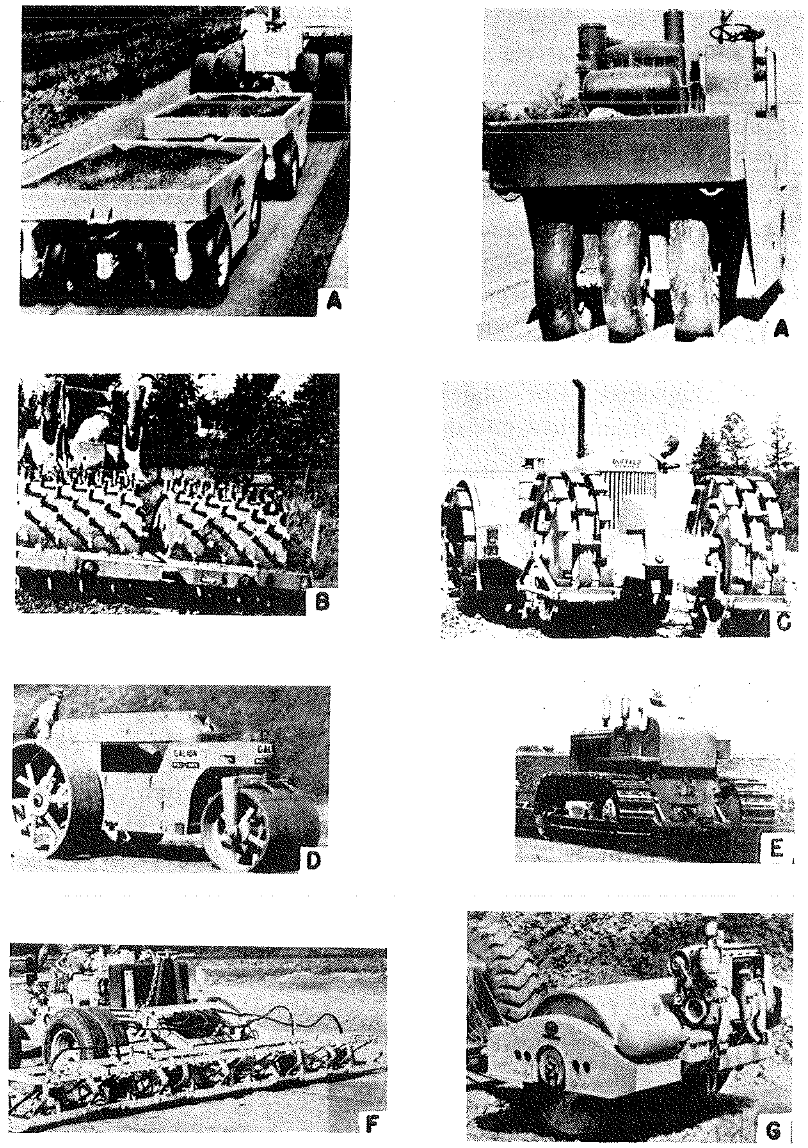

Fig. 26. Certain soil types are more efficiently compacted by one type of roller than another. However, the rubber-tired roller is about the best universal roller—it is good on essentially all types of soils. See text for most efficient use of: (A) rubber-tired roller, (B) sheepsfoot roller, (C) segmental-wheel roller (with pad feet), (D) steel-wheel roller; and vibratory compactors, (E) crawler tractor, (F) vibratory shoes or plates, (G) vibratory roller.

maximum passes should be used. The steel-wheel roller is best used as a finisher.

Gravels and sands, with less than 15 percent fines, are most efficiently compacted with vibratory equipment. Crawler-type tractors can effectively serve as vibratory compcators. Vibratory equipment includes: vibratory shoes or plates, vibratory rollers, and nobby-grid rollers. With less than 15 percent fines, vibrations travel fast and deep, through hard particles, rotating them into a tight fit.

Lift Thickness

Usually soils should be spread in layers 6-in. to 8-in. thick in a loose condition. As the fine-grained soils tend to bulk up more, their loose lift thickness would come closer to 8 in. and the more granular soils closer to 6 in. Usually the average compacted lift thickness is about 6 in.

Granular base course materials may be compacted in lifts ranging up to 6 in.—depending upon the type of compaction equipment utilized. If smooth-wheeled compactors are used, the lifts should be controlled to about 4 in. However, if vibratory compactors are used, lifts of up to 8 in. or 10 in. may be permitted.

Number of Equipment Passes

The average number of passes for "standard" equipment, average lift thickness and optimum moisture content (see below) is four to six. Soils on the dry side will require more passes. Excessively wet soils should be given time to reach a drier state. 121

For rollers with pegs or pad-feet, compaction is completed when the pegs or pads "walk-out" or "walk" on the compacted soil surface.

Soil Moisture and Compaction

For each soil type there is a certain moisture content at which a relatively high density can be attained with a minimum number of equipment passes. This favorable moisture content is called the optimum moisture content. At optimum moisture there is enough moisture to lubricate the particles and just enough to fill most of the void spaces after compaction. When there is too much water in the voids, soils tend to wave-up in front of the roller and do not properly compact.

There is a rather detailed laboratory test to determine optimum moisture to produce maximum compaction. Below however, is a simple field test to determine if a soil is near optimum.

Field Test for Approximate Optimum Moisture Content

Fine-grained soils and dirty gravels and sands should be thoroughly damp—not wet and sticky—and not dry and dusty—Fig. 27. The soil should be damp enough that a ball of the soil will stick together when squeezed in the hand—Fig. 28. As a further check, drop the ball of soil on a hard surface from a height of 18 in. to 20 in. It should be moist enough that it cracks but does not shatter after striking the solid surface.

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Fig. 27. For efficient compaction of fine-grained soils, and dirty gravels and sands, the soil should be thoroughly damp but not wet and sticky. The above photo, and Fig. 28, illustrate a very simple field test for this optimum moisture content.

Fig. 28. The soil shown above is at optimum moisture content. A handful, firmly squeezed in the hand, holds together and does not stick to the hands. A further check, is to drop the ball 18 in. to 20 in. on a hard surface. The ball should only crack and not shatter.

APPENDIX A—SAMPLING PIT-RUN SANDS AND GRAVELS FOR TESTING

Obtaining a Representative Sample

The primary concern in obtaining a sample from a gravel pit for testing is to get a representative sample. If a power shovel is to scoop across several layers, the sample obtained should include material from each layer mixed together just as the shovel mixes it when loading it into a truck. Test results represent only the sample and the more closely the sample represents the material to be placed on grade, the more valid the test results.

Reducing Size of Representative Samples

Obtain a representative sample of about 40 lbs. of gravel and/or sand, place it on a piece of canvas and mix it well. Remove cobbles larger than 3 in. With a broom stick, quarter the large sample, as shown in Fig. 29, to get a smaller yet representative sample for testing. After quartering, discard two diagonally opposite quarters and thoroughly mix the remaining two quarters. This is a representative sample reduced to about 20 lbs. To obtain an even smaller representative sample, of about 10 lbs., the above process should be reepated.

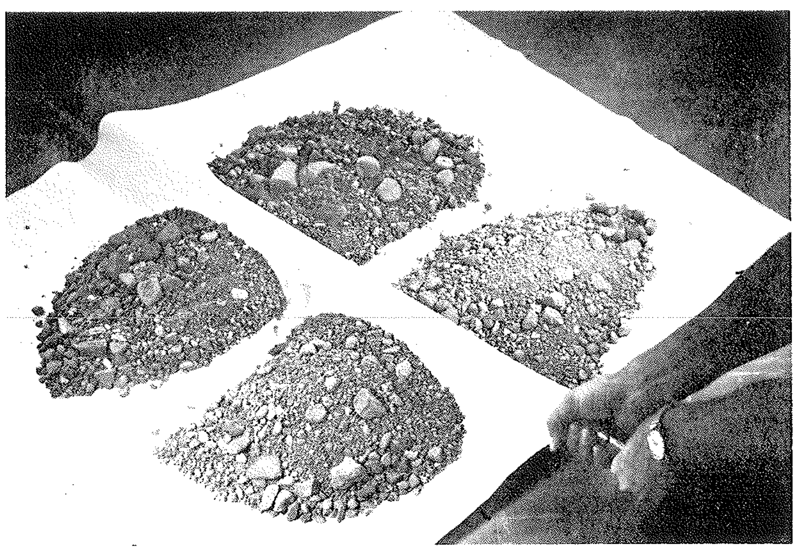

Fig. 29. Large representative soil samples can be reduced to smaller representative samples by quartering. It is usually done on coarse-grained samples. A piece of canvas and a long broom stick or shovel handle can be used as shown above.

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APPENDIX B—SUGGESTED TEST EQUIPMENT FOR SOIL IDENTIFICATION

Soil classification in the field generally requires little or no equipment; however the following items will facilitate the work.

(a) A rubber syringe or small oil can of about $\frac{1}{2}$ pt. capacity for adding water.

(b) Porcelain pan, approximately 12-in. diameter and 5 in. deep.

(c) Small porcelain bowl, approximately 5-in. heavy-duty cereal bowl or similar container.

(d) Standard Test Sieves, 8-in. diameter, sizes No. 4 and No. 40.
Note: A piece of wire, hardware cloth with approximately $\frac{1}{4}$-in. openings may be substituted for the No. 4 test sieve. Likewise, a piece of screen wire with openings of about $\frac{1}{64}$-in. may be substituted for the No. 40 sieve.

(e) Tall, slender, straight-sided, glass jar, at least 6 in. in height with a good cap.

DESIGN MANUAL

SOIL MECHANICS, FOUNDATIONS, AND EARTH STRUCTURES

NAVFAC DM-7
March 1971

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DEPARTMENT OF THE NAVY
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200 STOVALL STREET
ALEXANDRIA, VA. 22332

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Section 4. UNIFIED SOIL CLASSIFICATION SYSTEM

1. **REFERENCE.** Soil designations in this manual conform to the Unified Soil Classification MIL-STD-619B (ME), 12 June 1968, which was modified from the former Airfield Classification in 1952 for adoption by the U.S. Corps of Engineers (USCE) and the U.S. Bureau of Reclamation (USBR).

2. **UTILIZATION.** Classify soils in accordance with the Unified System and include the appropriate group symbol in soil descriptions. See Table 1-4 for elements of the Unified System. A soil is placed in one of 15 categories or as a borderline material combining two of these categories. Laboratory tests may be required for positive identification.

a. **Sands and Gravels.** Sands are divided from gravels on the No. 4 sieve size, gravels from cobbles on the 3-inch size. The division between fine and medium sands is at the No. 40 sieve, between medium and coarse sand at the No. 10 sieve.

b. **Silts and Clays.** Fine grained soils are identified according to plasticity characteristics determined in Atterberg limit tests. Categories are illustrated on the plasticity chart in Figure 3-1.

c. **Organic Soils.** Materials containing vegetal matter are characterized by relatively low specific gravity, high water content, high ignition loss, and high gas content. Decrease in liquid limit after oven-drying to a value less than three-quarters of the original liquid limit is a definite indication of an organic soil.

TABLE 1-4
Unified Soil Classification System

Primary divisions			Group symbol	Secondary divisions	Laboratory classification criteria	Supplementary criteria for visual identification
Coarse grained soils. (More than half of material is larger than No. 200 sieve size.)	Gravels. (More than half of the coarse fraction is larger than No. 4 sieve size.)	Clean gravels. (Less than 5% of material smaller than No. 200 sieve size.)	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	Wide range in grain size and substantial amounts of all intermediate particle sizes.
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.	Not meeting all gradation requirements for GW.	Predominantly one size or a range of sizes with some intermediate sizes missing.
	... do	Gravels with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	GM	Silty gravels, and gravel-sand-silt mixtures, which may be poorly graded.	Atterberg limits below "A" line, or PI less than 4[2} — Atterberg limits above "A" line with PI between 4 and 7 is borderline case GM-GC	Nonplastic fines or fines of low plasticity.
			GC	Clayey gravels, and gravel-sand-clay mixtures, which may be poorly graded.	Atterberg limits above "A" line, with PI greater than 7 — Atterberg limits above "A" line with PI between 4 and 7 is borderline case GM-GC	Plastic fines.
Do	Sands. (More than half of the coarse fraction is smaller than No. 4 sieve size.)	Clean sands. (Less than 5% of material smaller than No. 200 sieve size.)	SW	Well graded sands, gravelly sands, little or no fines.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.
			SP	Poorly graded sands, gravelly sands, little or no fines.	Not meeting all gradation requirements for SW	Predominately one size or a range of sizes with some intermediate sizes missing.
	... do	Sands with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	SM	Silty sands, and sand-silt mixtures, which may be poorly graded.	Atterberg limits below "A" line, or PI less than 4 — Atterberg limits above "A" line with PI between 4 and 7 is borderline case SM-SC	Nonplastic fines or fines of low plasticity.
			SC	Clayey sands, and sand-clay mixtures, which may be poorly graded.	Atterberg limits above "A" line, with PI greater than 7 — Atterberg limits above "A" line with PI between 4 and 7 is borderline case SM-SC	Plastic fines.

TABLE 1-4 (Continued)
Unified Soil Classification System

Primary divisions		Group symbol	Secondary divisions	Laboratory classification criteria		Supplementary criteria for visual identification: Dry strength	Supplementary criteria for visual identification: Reaction to shaking	Supplementary criteria for visual identification: Toughness near plastic limit
Fine grained soils. (More than half of material is smaller than No. 200 sieve size.)	Silts and clays. (Liquid limit less than 50.)	ML	Inorganic silts, clayey silts, rock flour, silty very fine sands.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" line with PI between 4 and 7 is borderline case ML-CL	None to slight	Quick to slow	None
	... do	CL	Inorganic clays of low to medium plasticity; silty, sandy or gravelly clays.	Atterberg limits above "A" line, with PI greater than 7		Medium to high	None to very slow	Medium
	... do	OL	Organic silts and organic silt-clays of low plasticity.	Atterberg limits below "A" line		Slight to medium	Slow	Slight
Do	Silts and clays. (Liquid limit greater than 50.)	MH	Inorganic silts, clayey silts, elastic silts, micaceous or diatomaceous silty or fine sandy soils.	Atterberg limits below "A" line		Slight to medium	Slow to none	Slight to medium
	... do	CH	Inorganic clays of high plasticity, fat clays.	Atterberg limits above "A" line		High to very high	None	High
	... do	OH	Organic clays and silty clays of medium to high plasticity.	Atterberg limits below "A" line		Medium to high	None to very slow	Slight to medium
	Highly organic soils	Pt	Peat, meadow mat, highly organic soils.	High ignition loss, LL and PI decrease after drying		Organic color and odor, spongy feel, frequently fibrous texture.		

[1]Materials with 5 to 12 percent smaller than No. 200 sieve are borderline cases, designated: GW-GM, SW-SM.
[2]See Ch. 3, Figure 3-1, for position on plasticity chart.

CHAPTER 3. LABORATORY TESTS AND TEST PROPERTIES

Section 1. INTRODUCTION

1. **SCOPE.** This chapter covers laboratory test procedures, typical test properties, and the application of tests to design and construction. Symbols and terms relating to tests and soil properties conform, generally, to definitions given in ASTM D653.

2. **RELATED CRITERIA.** For additional requirements concerning laboratory tests for highway and airfield design, see the following:

Subject	*Source*
Tests for airfields.	NAVFAC DM-21
Tests for highways	NAVFAC DM-5

3. **LABORATORY EQUIPMENT.** For lists of laboratory equipment required for performance of tests, see Lambe, *Soil Testing for Engineers* and other criteria sources given for test procedures.

4. **TEST SELECTION FOR DESIGN.** Standard or suggested test procedures, variations which may be required, and type and size of sample are included in Tables 3-1, 3-2, and 3-3; Table 3-4 contains soil properties determined from tests and their applications.

132 a. **Index Properties Tests.** Index properties are used to classify soils, to group soils in major strata, and to extrapolate results from a restricted number of structural properties tests to determine properties of other similar materials. Procedures for most index tests are standardized (Table 3-1). Either representative dry samples or undisturbed samples are utilized. Tests are assigned after review of boring data and visual identification of samples recovered.

b. **Structural Properties Tests.** These must be planned for particular design problems. Rigid standardization of test procedures is inappropriate (Table 3-2). Perform tests only on undisturbed samples obtained as specified in Chapter 2 or on compacted specimens prepared by standard procedures. In certain cases, completely remolded samples are utilized to estimate the effect of disturbance. Plan tests to determine typical properties of major strata rather than arbitrarily distributing tests in proportion to the number of undisturbed samples obtained. A limited number of high quality tests on carefully selected undisturbed samples is preferred to many mediocre tests on specimens selected at random.

c. **Compacted Sample Tests.** In prospecting for borrow materials, index tests or tests specifically for compacted samples may be required in a number proportional to the volume of borrow involved or the number of samples obtained. Structural properties tests are assigned after borrow materials have been grouped in major categories. Select samples for test to represent the main soil groups and probable compacted condition.

TABLE 3-1
Requirements for Index Properties Test

Test	Reference for standard test procedure	Variations from standard test procedure	Type of sample for test[1]	Size or weight of sample for test[2]
Sample preparation. . . .	ASTM D421	None	Disturbed or undisturbed.	As required for subsequent tests.
Moisture content	ASTM D2216	None	Disturbed or undisturbed with unaltered natural moisture content.	As large as convenient.
Dry unit weight.	None	Determine total dry weight of a sample of measured total volume.	Undisturbed with unaltered natural volume.	As large as convenient.
Specific gravity: Material smaller than No. 4 sieve size.	ASTM D854	Volumetric flask preferable; vacuum preferable for de-airing.	Disturbed or undisturbed.	25 to 50 gm for fine grained soils; 150 gm for coarse grained soil.
Material larger than No. 4 sieve size.	ASTM C127	None	Disturbed or undisturbed.	500 gm.
Atterberg limits: Liquid limit	ASTM D423 (One-point method AASHO T89)[3]	Harvard liquid limit device and grooving tool acceptable;[3] open wire grooving tool acceptable.	Disturbed or undisturbed, fraction passing No. 40 sieve.	50 to 100 gm.
Plastic limit	ASTM D424	Ground glass plate preferable for rolling. Material for Atterberg limit tests should not be dried before use.	Disturbed or undisturbed, fraction passing No. 40 sieve.	15 to 20 gm.
Shrinkage limit	ASTM D427	In some cases a trimmed specimen of undisturbed material may be used rather than a remolded sample.	Disturbed or undisturbed.	30 gm..
Gradation: Sieve analysis	ASTM D422	Selection of sieves to be utilized may vary for samples of different gradation.	Disturbed or undisturbed, nonsegregated sample, fraction larger than No. 200 sieve size.	600 gm for finest grain soil; to 4,000 gm for coarse grained soils.
Hydrometer analysis . .	ASTM D422	Fraction of sample for hydrometer analysis may be that passing No. 200 sieve. Entire sample of fine grained soil may be used.	Disturbed or undisturbed, nonsegregated sample, fraction smaller than No. 10 sieve size.	65 gm for fine grained soil; 115 gm for sandy soil.

1. Disturbed or undisturbed indicates that the source sample may be of either type. ASTM standard test procedures given in *Standards, Part 4;* AASHO standard test procedures given in *Standards, Part III.*
2 Weights of samples for tests on air-dried basis.
3 Lambe, *Soil Testing for Engineers.* One-point method of liquid limit test must not be used for control of construction or for determining compliance with specification requirements.

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TABLE 3-2
Requirements for Structural Properties Tests

Test	Reference for suggested test procedure	Variations from suggested test procedure	Size or weight of sample for test (undisturbed, remolded, or compacted)
Permeability:			
Constant head procedure.	(1)	For clean, coarse grained soils, the procedure of ASTM[2] is preferable.	Sample size depends on max grain size, 4 cm dia by 35 cm height for silt and fine sand.
Variable head procedure.	(1)	Generally applicable to fine grained soils.	Similar to constant head sample.
Constant head procedure for coarse grained soils.	ASTM[2]	Limited to soils containing less than 10% passing No. 200 sieve size.	Diameter varies from 3 in. for 3/8 in. max grain size, to 6 in. for 3/4 in. max grain size.
Capillary head . . .	(1)	Capillary head for certain fine grained soils may have to be determined indirectly.	200 to 250 gm dry weight.
Consolidation . . .	(1) ASTM[2]	To investigate secondary compression, individual loads may be maintained for more than 24 hr.	Diameter preferably 2½ in. or larger. Ratio of diameter to thickness of 3 or 4.
Direct shear.	(1) ASTM[2]	Limited to tests on cohesionless soils or to consolidated shear tests on fine grain soils.	Generally 0.5 in. thick, 3 in. by 3 in. or 4 in. by 4 in. in plan, or equivalent circular cross section.
Unconfined compression.	(1)	Alternative procedure given in ASTM[2] (p. 321).	Similar to triaxial test samples.
Triaxial compression: Unconsolidated--undrained (Q or UU). Consolidated--undrained (Qc or UD). Consolidated--drained (S or D).	(1)	For measurement of pore water pressures during test, special additional equipment is required. In this case rate of shear must be no faster than certain limiting speeds.	Ratio of height to diameter should be less than 3 and greater than 2. Common sizes are: 2.8 in. dia, 6.5 in. high; 1.4 in. dia, 3.5 in. high.

[1] Lambe, *Soil Testing for Engineers*.
[2] ASTM, *Procedures for Testing Soils*.

d. Typical Test Properties. Various correlations between index and structural properties are available, showing the probable range of test values and relation of parameters. In testing for structural properties, correlations should be investigated to extend results to similar soils for which index values only are available. Correlations are of varying quality, expressed by standard deviation, which is the range above and below the average trend, within which about two-thirds of all values occur. These relationships are useful in preliminary analyses but must not supplant careful tests of structural properties. The relationships should never be applied in final analyses without verification by tests of the particular material concerned.

TABLE 3-3
Requirements for Compacted Samples Tests

Test	Reference for standard test procedure[1]	Variations from standard test procedure	Size or weight of sample for test[2]
[1] Moisture-density relations: Standard Proctor 5½-lb hammer, 12-in. drop.	ASTM D698	Preferable not to reuse samples for successive compaction determinations.	Each determination: Method A: 6 lb Method B: 14 lb Method C: 10 lb Method D: 22 lb
Modified Proctor 10-lb hammer, 18-in. drop.	ASTM D1557	Preferable not to reuse samples for successive compaction determinations.	Method A: 7 lb Method B: 16 lb Method C: 12 lb Method D: 25 lb
Harvard compaction apparatus . .	ASTM[2]	None	2 to 3 lb of material passing No. 4 sieve size for complete curve.
Maximum and minimum densities of cohesionless soils.	ASTM D2049	Alternative methods using vibrating tamper given in ASTM.[3]	Varies from 10 to 130 lb depending on max. grain size.
Moisture-penetration resistance relations.	ASTM D1558	None	As required for compaction. Methods A or B above.
California bearing ratio	USCE TM-5-852-6 Appendix III.	Compaction energy other than that for Modified Proctor may be utilized.	Each determination requires 15 to 25 lb depending on gradation.
Expansion pressure	AASHO T174	None	10 to 15 lb depending on gradation.
Permeability and compression characteristics.	U. S. Bureau of Reclamation E-12.	Testing procedures of Table 3-2 may be utilized.	15 lb of material passing No. 4 sieve size.

[1] For other sources of standard test procedures, see Table 3-1.
[2] Weight of samples for tests given on air-dried basis.
[3] *Procedure for Testing Soils* (ASTM).

TABLE 3-4
Soil Properties for Analysis and Design

Property	Symbol	Units[1]	How obtained	Direct applications
Volume-weight characteristics:[2] Moisture content	w	D	Directly from test	Classification and in volume-weight relations.
Unit weights	γ	FL^{-3}	Directly from test or from volume-weight relations.	Classification and for pressure computations.
Porosity	n	D	Computed from volume-weight relations.	Parameters used to represent relative volume of solids in total volume of soil.
Void ratio	e	D	Computed from volume-weight relations.	
Specific gravity	G	D	Directly from test	Volume computations.
Plasticity characteristics: Liquid limit	LL	D	Directly from test	Classification and properties correlation.
Plastic limit	PL	D	Directly from test	Classification.
Plasticity index	PI	D	LL-PL	Classification and properties correlation.
Shrinkage limit	SL	D	Directly from test	Classification and computation of swell.
Shrinkage index	SI	D	PL-SL	
Activity	A_c	D	$\frac{PI}{\%\ \text{"clay size"}}$	Identification of clay mineral.
Liquidity index	LI	D	$\frac{w - PL}{PI}$	Estimating degree of preconsolidation.
Gradation characteristics: Effective diameter	D_{10}	L	From grain-size curve	Classification, estimating permeability and unit weight, filter design, grout selection, and evaluating potential frost heave.
Percent grain size	D_{30}, D_{60}, D_{85}	L	From grain-size curve	
Coefficient of uniformity	C_u	D	$\frac{D_{60}}{D_{10}}$	
Coefficient of curvature	C_c	D	$\frac{(D_{30})^2}{(D_{10}) \times (D_{60})}$	
Clay size fraction	......	D	From grain-size curve, % finer than 0.002 mm.	Classification.
Drainage characteristics: Coefficient of permeability	k	LT^{-1}	Directly from permeability test or computed from consolidation test data.	Drainage, seepage, and consolidation analysis.
Capillary head	h_c	L	Directly from test	Drainage and drawdown analysis.
Effective porosity	n_e	D	Directly from test for volume of drainable water.	
Consolidation characteristics: Coefficient of compressibility.	a_v	L^2F^{-1}	Determined from arith. –e vs p curve.	Computation of ultimate settlement or swell in consolidation analysis.
Coefficient of volume compressibility.	m_v	L^2F^{-1}	$\frac{a_v}{1 + e}$	
Compression index	C_c	D	Determined from semilog e vs p curve.	
Recompression index	C_r	D		
Swelling index	C_s	D		
Coefficient of secondary compression.	C_α	D	Determined from semilog time-consolidation curve.	
Coefficient of consolidation.	c_v	L^2T^{-1}		Computation of time rate of settlement.
Preconsolidation pressure.	P_c	FL^{-2}	Estimated from semilog e vs p curve.	Consolidation analysis.

TABLE 3-4 (Continued)
Soil Properties for Analysis and Design

Property	Symbol	Units[1]	How obtained	Direct applications
Shear strength characteristics:				
Angle of internal friction . .	ϕ	D	Determined from Mohr envelope for total normal stress.	Analysis of stability and load carrying capacity of foundations.
Cohesion intercept	c	FL^{-2}		
Angle of internal friction . .	ϕ'	D	Determined from Mohr envelope for effective normal stress.	
Cohesion intercept	c'	FL^{-2}		
Unconfined compressive strength.	q_u	FL^{-2}	Directly from test.	
Shear strength	s	FL^{-2}		
Sensitivity	S_t	D	$\frac{q_u \text{ (undisturbed)}}{q_u \text{ (remolded)}}$	Estimating effect of disturbance.
Modulus of elasticity	E_s	FL^{-2}	Determined from stress-strain curve.	Computation of elastic settlement or rebound.
Characteristics of compacted samples:				
Maximum dry unit weight. . .	γ_{max}	FL^{-3}	Determined from moisture-density curve.	Compaction control and computation of weights and forces in stability analysis.
Optimum moisture content . .	OMC	D		
Needle penetration resistance.	P_r	FL^{-2}	Directly from test	Moisture control in compaction.
Relative density	D_d	D	Determined from results of max and min density tests.	Compaction control.
California bearing ratio . . .	CBR	D	Directly from test	Pavement design.

[1] Units: F = force or weight; L = length; T = time; D = dimensionless.
[2] For complete list of volume-weight relationships, see Table 3-5.

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3. **ATTERBERG LIMITS.** For classification of fine grained soils by Atterberg limits, see Figure 3-1. In addition to their use in soil classification, Atterberg limits also are indicators of structural properties, as shown in the correlations in this chapter. Limit tests should be performed discriminately, and should be reserved for representative samples selected after evaluating subsoil pattern. Determine limits of each consolidation test sample and each set of samples grouped for triaxial shear tests. For selected borings, determine Atterberg limits on samples at regular vertical intervals for a profile of limits and corresponding natural water contents.

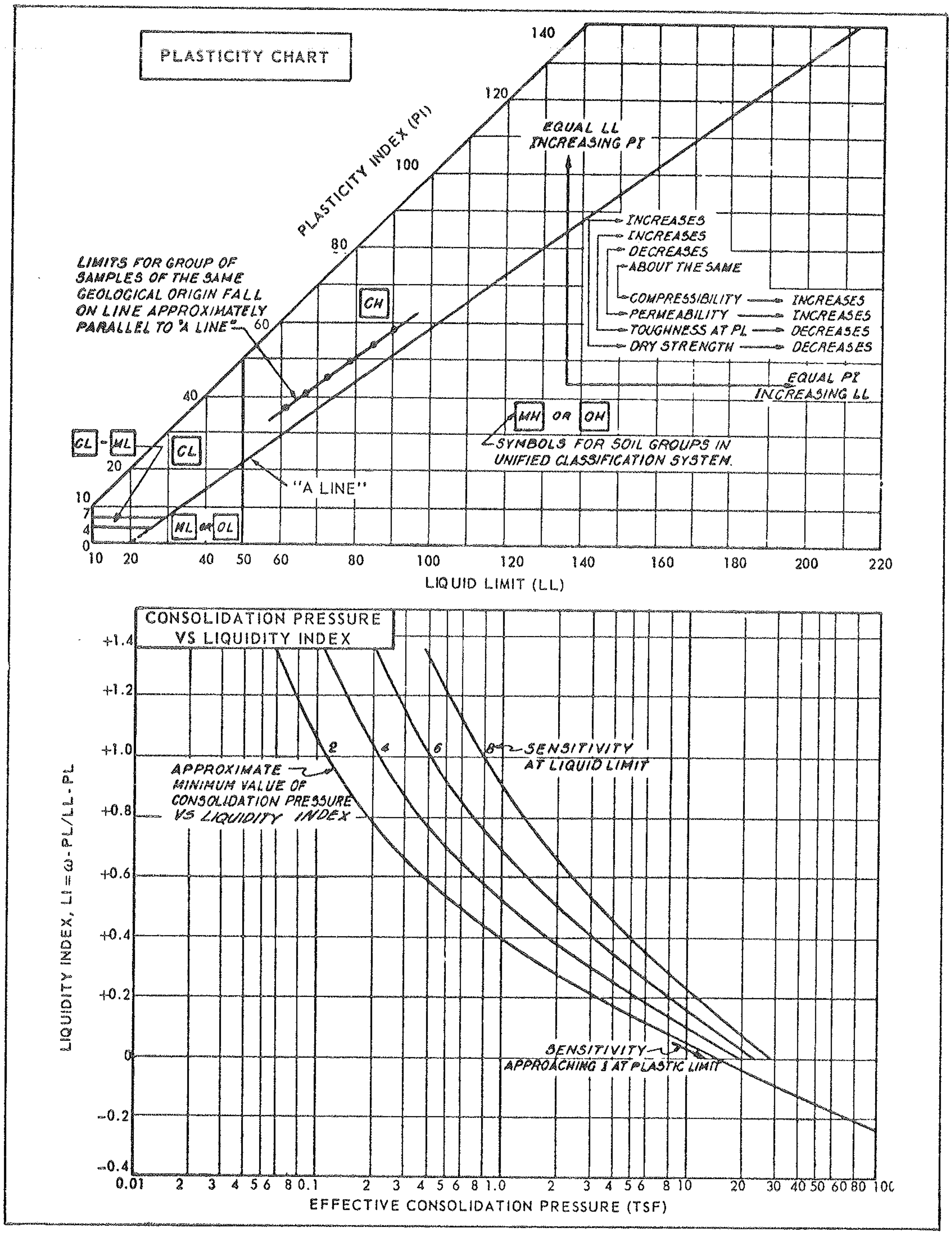

FIGURE 3-1
Utilization of Atterberg Plasticity Limits

The Identification of Rock Types

Revised Edition

BY THE DIVISION OF PHYSICAL RESEARCH
BUREAU OF PUBLIC ROADS

Reported by D. O. Woolf
Highway Research Engineer

U.S. DEPARTMENT OF COMMERCE
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The Identification of Rock Types

Introduction

The interest of highway engineers in selecting the best rock for use in different types of highway construction suggests the need for a simple method of identification of rock types which can be applied in the field. A suitable method which will assist the highway engineer in identifying many of the different types of rock with which he is concerned is presented in this article. An attempt has been made to present this method in simple terms for the benefit of those who are not familiar with expressions normally used in petrographic descriptions.

A previous edition of this publication [1] has been used in the training of engineers assigned to the Division of Physical Research of the Bureau of Public Roads for instruction. Some of these engineers suggested certain changes in the text, and the use of more illustrations to assist in the explanation of terms used. These suggestions have been followed as fully as has been practicable. In addition, some changes have been made to eliminate certain classifications of rock which were of little interest to the practicing engineer, or types which could not be identified in the field using the equipment normally available.

The method of identification of rock presented here is intended to be applied to pieces large enough so that the structure of the rock can be observed clearly. In small pieces, the alinement, if any, of the minerals composing the rock may not be observed as readily as it would be in a larger piece. The user of this method is urged to obtain for study as large a piece of the rock as is convenient to handle. Pieces about 3 inches by 4 inches by 2 inches thick may be found to be suitable.

The equipment needed consists only of a knife blade of good steel, a small magnifying glass of 6 to 10 power, and a bottle of dilute hydrochloric acid, preferably with a dropper (available at most drug stores). In some texts, statements will be read that household vinegar could be used if the acid is not available. Experiments with vinegar obtainable from grocery stores and marked "reduced to 5 percent acidity with water" showed that this vinegar is a poor substitute for ordinary diluted hydrochloric acid. Since the latter may contain 20 to 33 percent of the normal concentrated acid, the unsuitability of vinegar as a replacement of dilute hydrochloric acid can readily be understood.

Sometimes a fragment of quartz or a quartz crystal will be found useful in the identification of minerals. Generally minerals which are large enough to be tested for hardness with the quartz can be identified visually. The core of a bullet from a round of 30-caliber armor-piercing ammunition is easy to carry and has been found of considerable value in the identification of quartz and feldspar. A machinist's or glass-marking scriber with a tungsten carbide tip will also be found useful for this purpose.

The method of rock identification presented in this publication follows that given by Pirrson and Knopf,[2] which in turn was based on that given by Geikie in his *Textbook of Geology*.[3] It uses a combination of simple physical and chemical determinations to identify the rock.

[1] Originally published in PUBLIC ROADS, vol. 26, No. 2, June 1950, and subsequently printed in pamphlet form.

[2] *Rocks and Rock Minerals*, by Louis V. Pirrson and Adolph Knopf, 3d edition; John Wiley and Sons, Inc., New York; 1947.

[3] *Textbook of Geology*, by Sir Archibald Geikie, 3d edition; Macmillan and Company, London; 1893.

Table 1.—General classification of rock

Class	Type	Family
Igneous	Intrusive (coarse-grained)	Granite [1]
		Syenite [1]
		Diorite [1]
		Gabbro
		Peridotite
		Pyroxenite
		Hornblendite
	Extrusive (fine-grained)	Obsidian
		Pumice
		Tuff
		Rhyolite [1 2]
		Trachyte [1 2]
		Andesite [1 2]
		Basalt [1]
		Diabase
Sedimentary	Calcareous	Limestone
		Dolomite
	Siliceous	Shale
		Sandstone
		Chert
		Conglomerate [3]
		Breccia [3]
Metamorphic	Foliated	Gneiss
		Schist
		Amphibolite
		Slate
	Nonfoliated	Quartzite
		Marble
		Serpentinite

[1] Frequently occurs as a porphyritic rock.
[2] Included in general term "felsite" when constituent minerals cannot be determined quantitatively.
[3] May also be composed partially or entirely of calcareous materials.

Table 2.—Rock-forming minerals

Name	Composition
PRIMARY MINERALS	
Quartz	Silicon dioxide.
Feldspar:	
Orthoclase	Silicate of potassium and aluminum.
Microcline	Silicate of potassium and aluminum.
Plagioclase	Silicate of sodium, calcium, and aluminum.
Pyroxene:	
Augite	Silicate of calcium, iron, magnesium, and aluminum.
Amphibole:	
Hornblende	Complex silicate principally of calcium, iron, magnesium, and aluminum.
Mica:	
Muscovite	Hydrous silicate of potassium and aluminum.
Biotite	Hydrous silicate of potassium, magnesium, iron, and aluminum.
Magnetite	Iron oxide.
Rock glass	Variable.
Garnet	Silicate of aluminum, iron, and calcium.
Olivine	Silicate of magnesium and iron.
SECONDARY MINERALS	
Calcite	Calcium carbonate.
Dolomite	Calcium and magnesium carbonate.
Kaolin	Hydrous silicate of aluminum.
Chlorite	Hydrous silicate of iron, magnesium, and aluminum.
Epidote	Hydrous silicate of calcium, aluminum, and iron.
Limonite	Hydrous iron oxide.
Opal	Hydrous silicon dioxide.

In some cases the individual minerals can be identified, and the rock can be named from a knowledge of its component minerals, their abundance, and the relative amounts of each. In other cases the minerals may be too small to identify with the hand lens, and recourse must be had to the general distribution of the minerals and to the structure of the rock. It should not be expected that this method will permit the identification of any and all rocks, but it is believed that the user will be able to identify the more common rocks used in highway construction. In those cases where the rock can not positively be identified, the user of this method should have no hesitancy in stating which type of rock the sample under study most closely resembles, and describing the particular features of the sample which are not in agreement with the characteristics of the type mentioned.

General Classification

A general classification of rocks of interest in highway construction is given in table 1.[4] The rocks are first separated into three classes—igneous, sedimentary, and metamorphic—on the basis of their origin, and each class is subdivided with regard to physical characteristics or chemical composition.

In the igneous class, the intrusive or coarse-grained rocks include such familiar materials as granite and gabbro. These rocks were formed from molten material and cooled slowly so that the crystals composing the rock developed to an appreciable size. The extrusive rocks were also formed from molten material,

[4] Based on table 2 in *Relation of Mineral Composition and Rock Structure to Physical Properties of Road Materials*, by E. C. E. Lord; U.S. Department of Agriculture Bulletin No. 348; April 4, 1916

but these cooled so rapidly that the crystals are very small. In a few cases, the molten material formed as a glass, resulting in obsidian or similar rocks. The fine-grained crystalline rocks include rhyolite, trachyte, andesite, basalt, and diabase. The first three of these rocks are sometimes grouped under a general family name of felsite which includes light- to medium-colored, very fine-grained igneous rocks. Basalt and diabase are frequently described in engineering terminology as "trap rock".

The sedimentary class of rocks, formed by deposition of water- or wind-transported rock grains, is separated into two groups on the basis of the principal mineral component. The calcareous rocks, which are composed essentially of compounds of lime or magnesia, include limestone and dolomite. Sedimentary rocks, which are composed chiefly of silica, include shale, sandstone, and chert.

The metamorphic class is separated into two groups based on the structure of the rock. In the foliated or layered types are included gneiss, schist, and slate, while quartzite and marble are included in the nonfoliated type. The metamorphic class includes those rocks which have been formed from another type of rock by heat or pressure. For example, gneiss may be formed from granite, marble from limestone or dolomite, and quartzite from sandstone. Sometimes this alteration improves the quality of the rock, as in the case of quartzite, which is a much harder and tougher material than sandstone. In other cases, the reverse applies: marble

Table 3.—Mineral composition of rocks

Name of rock	Number of samples tested	Essential mineral composition, percent [1]											
		Quartz	Orthoclase, Microcline	Plagioclase	Augite	Hornblende	Mica	Calcite	Chlorite	Kaolin	Epidote	Iron ore	Remainder
Igneous rocks:													
Granite	165	30	45	(8)	---	---	6	----	----	(6)	---	---	5
Biotite granite	51	27	41	9	---	---	11	----	----	(7)	---	---	5
Hornblende granite	20	23	34	12	---	13	4	----	----	(10)	---	---	4
Augite syenite	23	(4)	52	7	8	---	4	----	(3)	(11)	(3)	(4)	4
Diorite	75	8	7	30	---	27	(4)	----	(3)	(8)	(5)	(3)	5
Gabbro	50	---	---	44	28	9	---	----	(3)	(6)	---	---	10
Rhyolite	43	32	45	(3)	---	---	(5)	----	(4)	(3)	---	(4)	4
Trachyte	6	(3)	42	---	---	6	---	(3)	(3)	(14)	(8)	(7)	[2] 5
Andesite	67	---	---	48	14	3	---	----	(6)	----	(3)	(8)	[2] 6
Basalt	70	---	---	36	35	---	---	----	----	----	---	(3)	[2] 5
Altered basalt	196	---	---	32	31	---	---	----	(9)	(4)	---	(4)	[2] 8
Diabase	29	---	---	44	46	---	---	----	----	----	---	(4)	6
Altered diabase	231	---	---	35	26	---	---	----	(15)	(9)	---	(4)	11
Sedimentary rocks:													
Limestone	875	(6)	---	---	---	---	---	[3] 83	----	----	---	---	3
Dolomite	331	(5)	---	---	---	---	---	[3] 11	----	----	---	---	2
Sandstone	109	79	(5)	---	---	---	---	----	----	(4)	---	(9)	3
Feldspathic sandstone	191	35	26	---	---	---	---	(3)	(3)	(22)	---	(4)	7
Calcareous sandstone	53	46	(3)	---	---	---	---	42	----	----	---	(3)	6
Chert	62	93	---	---	---	---	---	------	----	----	---	---	[4] 7
Metamorphic rocks:													
Granite gneiss	169	34	35	(4)	---	---	20	------	----	----	---	---	7
Hornblende gneiss	18	10	16	15	(3)	45	(4)	------	----	----	---	---	7
Mica schist	59	36	14	(1)	---	---	40	------	----	----	---	---	9
Chlorite schist	23	11	---	10	---	(5)	---	------	39	----	28	(4)	3
Hornblende schist	68	10	(3)	12	---	61	---	------	----	----	(7)	---	7
Amphibolite	22	(3)	---	8	---	70	---	------	----	----	12	---	7
Slate	71	29	(4)	---	---	---	55	------	----	----	---	(5)	7
Quartzite	61	84	(3)	---	---	---	(4)	------	----	----	---	---	9
Feldspathic quartzite	22	46	27	---	---	---	(7)	------	(3)	(10)	---	---	7
Pyroxene quartzite	11	29	19	15	24	---	---	------	----	----	---	(5)	[5] 8
Marble	61	(3)	---	---	---	---	---	96	----	----	---	---	1

[1] Values shown in parentheses indicate minerals other than those essential for the classification of the rock.
[2] Includes 10–20 percent rock glass.
[3] Limestone contains 8 percent of the mineral dolomite; the rock dolomite contains 82 percent of this mineral.
[4] Includes 3 percent opal.
[5] Includes 3 percent garnet.

generally is inferior to limestone or dolomite as an aggregate for highway construction.

Mineral Composition of Rocks

The more important rock-forming minerals are listed in table 2. These are separated into primary and secondary minerals depending upon whether they are found in the original igneous rocks or were derived by alteration of the minerals in these rocks.

The essential mineral composition of the more common rocks used in highway construction is given in table 3. This is a condensation of material given in United States Department of Agriculture Bulletin No. 348.[5] In table 3, the average percentage distribution of the minerals which are characteristic of each variety of rock is shown, together with incidental minerals which are indicated by values in parentheses. Minerals which are present in the rocks in amounts less than 3 percent are not mentioned separately but are grouped in the table under "remainder".

In figure 1, a graphical representation of the composition of igneous rocks is shown. This is based on the data given in table 3, but has been idealized to a certain extent for purposes of simplification. In the segment marked "glass or iron ore," the rock glass applies to the fine-grained extrusive rocks only.

The color of the rock furnishes some indication of the mineral content. If the rock is white or light in color, the predominant minerals probably are quartz and feldspar. Red, brown, green, gray, and black colors usually indicate the presence of minerals containing iron. In sedimentary rocks, gray or black colors may be caused by carbonaceous matter.

Classification by Geologic Type

It will be helpful if the user can classify rock with respect to its general geologic type; that is, whether the rock was formed directly from a molten mass (igneous class), or was formed by deposition of the rock grains transported by water or wind (sedimentary class), or was formed by the action of heat or pressure or both on previously existing rock (metamorphic class). Features which will assist in this classification of rock are the following:

Igneous class:
- Absence of fossils.
- Presence of glass.
- Uniformity of structure.
- Interlocking crystals.

Sedimentary class:
- Rounded grains.
- Presence of fossils.
- Stratification in relatively thick layers.
- Abrupt changes in color from layer to layer.

Metamorphic class:
- Separation of crystals into approximately parallel layers.
- Formation in thin parallel layers.
- Broken readily into slabs.

All features mentioned for a given class probably will not be found in one single piece of rock, but one or more of those mentioned should be found.

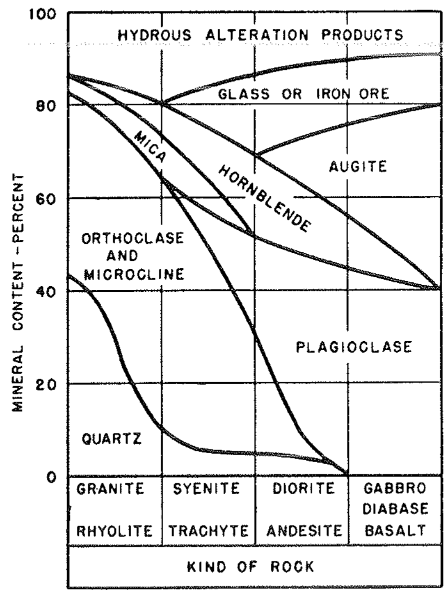

Figure 1.—Diagrammatic representation of the mineral composition of igneous rocks.

[5] See footnote 4, page 2.

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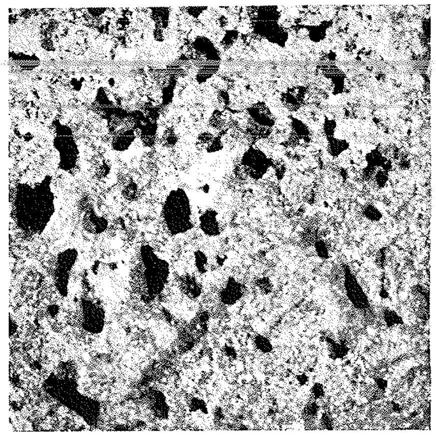

Figure 2.—A vesicular basalt.

Rock Structure

The structure of the rock is of considerable assistance in determining the general classification of the rock and also in determining the precise name for the material. Masses of rock which show a marked resemblance to columns are unquestionably of an igneous origin. Rock which is vesicular—that is, containing large or small cavities which sometimes are separated by thin walls of rock—is usually an igneous type. An example of this is shown in figure 2. In some igneous rocks these cavities are filled with a material which is of a different nature from that of the rock itself, and the rock is said to have an amygdoloidal structure.

Some types of metamorphic rocks show a peculiarity of structure which is described as foliation. Such rocks could as well be described as banded or layered, except that these terms imply an abrupt change in the appearance of the rock from one layer to the next. Bands and layers are frequently used in descriptions of sedimentary rocks. Three types of foliation—gneissoid, schistose, and slaty—are used in descriptions of metamorphic rocks. All of the foliated rocks will split or cleave more or less readily in one plane, and the type of foliation describes the degree of smoothness of the cleaved surface. Rocks with a gneissoid foliation have a rough, uneven surface while those with a slaty foliation have a very smooth cleaved surface. Schists or rocks with a schistose foliation have cleaved surfaces which are much smoother than the gneisses but not as smooth as the slates.

Under the effect of heat or pressure, the minerals in the foliated metamorphic rocks have been caused to arrange themselves in more or less parallel planes. The dark-colored minerals may separate from the light-colored minerals and form bands or streaks which are characteristic of certain foliated rocks. Figure 3 shows typical specimens of gneiss and schist. A close examination of such rocks will show that there is seldom an abrupt and complete separation between the dark- and light-colored minerals. Usually there is a zone of transition from light to dark bands, or the dark bands will contain an appreciable percentage of light-colored minerals. Banded sedimentary rocks which may be confused with the metamorphic rocks generally have an abrupt change in color or texture from one layer to the next, as shown in figure 4.

Identification of Quartz and Feldspar

In the use of this method of rock identification, it is necessary that quartz and feldspar be identified when these minerals occur in crystals or grains large enough to be seen with the aid of the hand lens. Their identification as constituents of rock may present some difficulties, since even in rocks of coarse grain these minerals may be so small that the usual determinations made on the ordinary mineral specimen frequently cannot be applied. For example, in hand specimens of minerals, feldspar may be identified in part by the fact that it is scratched by quartz. This test can seldom be applied to rock specimens unless the component minerals or grains are of suitable size. The carbide-tipped scriber will be found of advantage in this case. Usually, however, recourse must be made to visual examination with reference to the color, shape, luster, and fracture of the grains.

In igneous rocks, quartz usually has a gray or smoky color, while feldspar is white, gray, or various shades of red. Grains of quartz are usually transparent or translucent, but those of feldspar are opaque. Quartz and feldspar are dissimilar in cleavage: if the grains are sufficiently large, those of feldspar will be found to break with flat surfaces forming an angle of about 90 degrees. By rotating the hand sample of rock so that light strikes the surface at different angles, the cleavage faces of feldspar crystals may be observed. A photograph showing the reflection of light from a cleavage face of a rather large crystal of feldspar in a specimen of granite is shown in figure 5. Quartz has no cleavage, and breaks with a conchoidal or shell-like fracture similar to that in figure 6. Quartz has a glassy luster while feldspar has a luster more nearly like porcelain. Feldspar is affected by weathering, and the luster tends to become dull.

In the cooling of the molten rock, the feldspars crystallize before quartz. As a consequence the feldspars tend to occur in crystal form, while quartz develops in more or less shapeless masses. Feldspar crystals frequently are compound structures of intergrown crystals which developed simultaneously. The longitudinal axes of the portions of the crystals are parallel, but the transverse axes of one crystal segment are rotated through 180 degrees from those of the adjacent segment. At the junction between crystal segments, a plane of twinning is produced. In rock-making feldspars, these

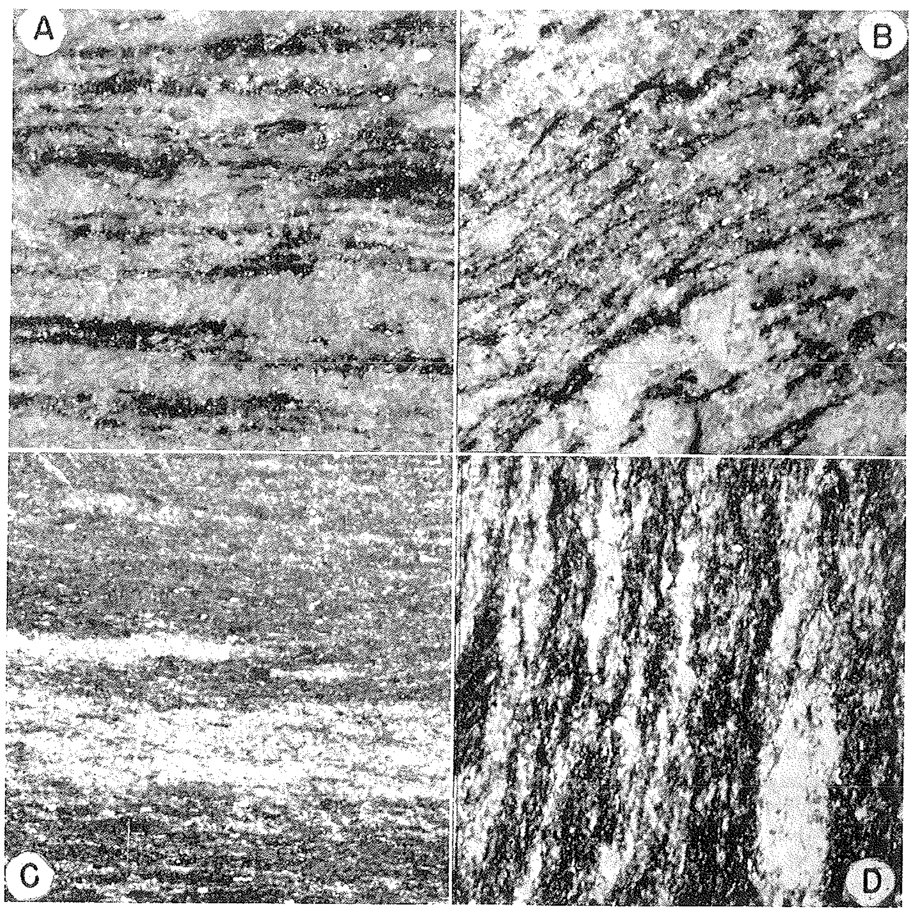

Figure 3.—Typical banding in foliated metamorphic rocks: (A) granite gneiss; (B) biotite gneiss; (C) hornblende schist; (D) mica schist.

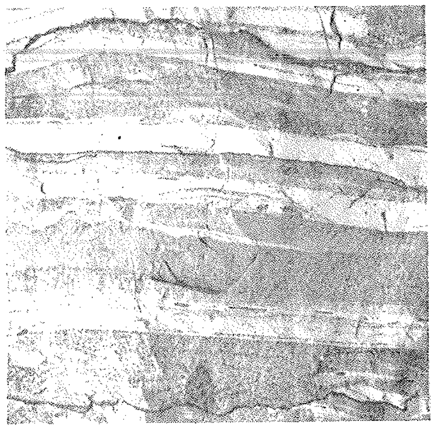

Figure 4.—Abrupt change between layers is characteristic of banded sedimentary rocks (banded limestone).

planes of twinning usually are very closely spaced, and the cleavage surface of a crystal of feldspar may appear to have been ruled with fine, parallel lines, as shown in figure 7. This twinning is not found in quartz.

A summarization of the principal characteristics of feldspar and quartz as components of igneous rocks is shown in table 4.

Identification of Other Minerals

In some cases, the common forms of the ferromagnesian minerals augite, hornblende, olivine, and biotite may also be

Table 4.—Characteristics of feldspar and quartz as components of igneous rocks

Characteristic	Feldspar	Quartz
Color	White, pink	Gray, smoky.
Transparency	Opaque	Translucent.
Luster	Porcelaneous to dull.	Glassy.
Cleavage	Good on two faces forming angles of about 90°.	None.
Form of crystal face	Parallelopiped	Shapeless.
Multiple twinning	Frequent	None.

identified in rocks. The ferromagnesian minerals contain iron or magnesia or both as a principal component, and are identified by shape and color. In some rocks the minerals are sufficiently well crystallized for identification, but frequently they occur as grains or irregular masses and identification in the hand specimen may not be possible except by color.

Olivine is seldom found in well-developed crystals in rock. It occurs usually as grains or masses, and is identified by its color which varies from an olive green to a yellow green.

Augite and hornblende are the more common varieties of two large families of minerals, the pyroxenes and the amphiboles. Both augite and hornblende have a dark green to black color, and both frequently occur as grains or masses in

(Continued on page 10)

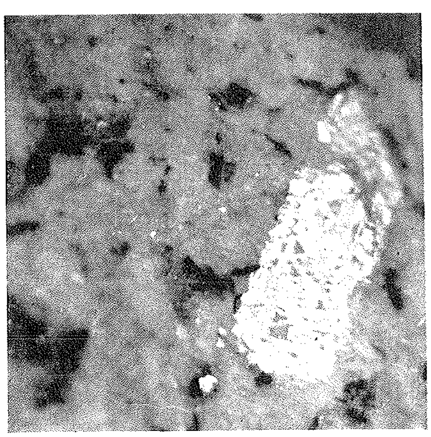

Figure 5.—Reflection of light from cleavage face of a feldspar crystal in granite.

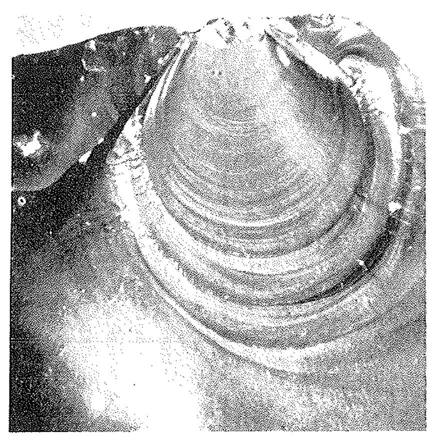

Figure 6.—Conchoidal fracture found in glassy and fine-grained rocks such as quartz, obsidian, and chert.

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SYSTEM FOR THE IDENTIFICATION OF COMMON ROCKS

PRELIMINARY CLASSIFICATION

Group I.—Glassy, wholly or partly.
Group II.—Not glassy; dull or stony; homogeneous; so fine-grained that grains cannot be recognized.
Group III.—Distinctly granular.
Group IV.—Distinctly foliated; no effervescence with acid.
Group V.—Clearly fragmental in composition; rounded or angular pieces or grains cemented together.

GROUP I.—GLASSY ROCKS

1. Glassy luster; hard; conchoidal fracture; colorless to white or smoky gray; generally brittle. *Quartz.*
2. Solid glass; may have spherical inclusions; brilliant vitreous luster; generally black. *Obsidian.*
3. Cellular or frothy glass. *Pumice.*

GROUP II.—DULL OR STONY, VERY FINE-GRAINED ROCKS

SUBGROUP II A.—Not scratched by fingernail, but readily scratched with knife.

1. Particles almost imperceptible; dull luster; homogeneous; clay odor; little if any effervescence with acid; laminated structure; breaks into flakes. *Shale.*
2. Little if any clay odor; brisk effervescence with acid. *Limestone.*
3. Little if any clay odor; brisk effervescence with acid only when rock is powdered or acid is heated. *Dolomite.*
4. Soapy or greasy feel; translucent on thin edges; green to black; no effervescence. *Serpentinite.*

SUBGROUP II B.—Not scratched with the knife or scratched only with difficulty; no effervescence with acid.

1. Light to gray color; clay odor possible; may have a banded flow structure. *Felsite.*

GROUP III.—Continued

5. Mainly quartz.
   (a) Fracture around grains. *Sandstone.*
   (b) Fracture through all or through an appreciable percentage of grains. *Quartzite.*

SUBGROUP III C.—Hard; not scratched with knife or scratched with difficulty; large distinct crystals in finer groundmass.

1. Crystals of feldspar and quartz with some of a ferromagnesian mineral (generally biotite) in a light-colored groundmass. *Granite porphyry.*
2. Crystals of feldspar and usually a ferromagnesian mineral in a light-colored groundmass. *Syenite porphyry.*
3. Crystals of ferromagnesian minerals, or of striated feldspar, or both, in a medium-colored groundmass. *Diorite porphyry.*
4. Crystals of quartz, or feldspar, or both, generally with a ferromagnesian mineral, in a predominant, fine-grained groundmass of light color. *Felsite porphyry.*
5. Crystals of feldspar, or of a ferromagnesian mineral, or both, in a fine-grained, dark or black, heavy groundmass. *Basalt porphyry.*

2. Very hard; pale colors to black; no clay odor; conchoidal fracture; waxy or horny appearance. *Chert.*
3. Heavy; dark color; may have cellular structure; may contain small cavities filled with crystalline minerals. *Basalt.*

GROUP III.—GRANULAR ROCKS

SUBGROUP III A.—Easily scratched with the knife.

1. Brisk effervescence with acid. *Limestone* or *Marble.*
2. Brisk effervescence only with warm acid, or with powdered rock. *Dolomitic marble.*

SUBGROUP III B.—Hard; not scratched with knife or scratched with difficulty; grains of approximately equal size.

1. Mainly quartz and feldspar; usually light colored, sometimes pinkish. *Granite.*
2. Mainly feldspar; little quartz (less than 5 percent); light colors of nearly white to light gray or pink. *Syenite.*
3. Feldspar and a dark ferromagnesian mineral.
   - (a) Major constituent feldspar; rock of medium color. *Diorite.*
   - (b) Ferromagnesian mineral equal to or in excess of feldspar; rock of dark color.
     - (1) Grains just large enough to be recognized by the unaided eye. *Diabase.*
     - (2) Coarse-grained rock. *Gabbro.*
4. Mainly ferromagnesian minerals; generally dark green to black.
   - (a) Predominant olivine with pyroxene or hornblende. *Peridotite.*
   - (b) Predominant augite. *Pyroxenite.*
   - (c) Predominant hornblende. *Hornblendite.*

GROUP IV.—FOLIATED ROCKS

1. Medium to coarse grain; roughly foliated. *Gneiss.*
2. More finely grained and foliated. *Schist.*
   - (a) Consists mainly or largely of mica with some quartz. *Mica schist.*
   - (b) Medium green to black; consists mostly of a felted or matted mass of small, bladed or needle-like crystals arranged in one general direction. *Hornblende schist* or *amphibolite.*
   - (c) Glassy or silky luster on foliation surfaces; splits readily into thin pieces. *Sericite schist.*
   - (d) Soft, greasy feel; marks cloth; easily scratched with fingernail; whitish to light gray, or green. *Talc schist.*
   - (e) Smooth feel; soft; glimmering luster; green to dark green. *Chlorite schist.*
3. Very fine grain; splits easily into thin slabs; usually dark gray, green or black. *Slate.*

GROUP V.—FRAGMENTAL

1. Rounded pebbles embedded in some type of a cementing medium. *Conglomerate.*
2. Angular fragments embedded in a cementing medium. *Breccia.*
3. Fragments of volcanic (fine-grained or glassy) rocks embedded in compacted volcanic ash. *Volcanic tuff* or *Volcanic breccia.*
4. Quartz grains, rounded or angular, cemented together. *Sandstone.*
5. Quartz and feldspar grains cemented together to resemble the appearance of granite. *Arkose* (feldspathic sandstone).

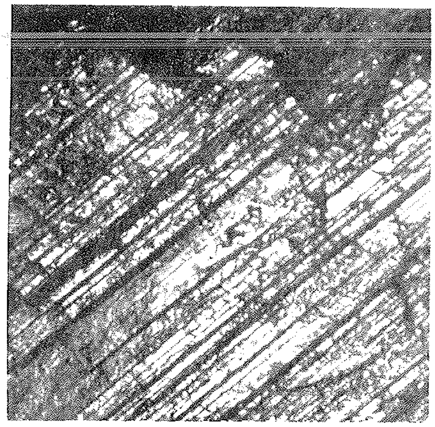


Figure 7.—Twinning planes in feldspar produce an appearance of fine, parallel lines.

rock. Identification of these minerals in the hand specimen depends upon whether the crystal shape can be determined. Augite tends to develop in short, thick crystals with a square or rectangular cross section. Hornblende commonly occurs as long, slender blades with irregular ends, and the cross section has a diamond shape with the acute angles replaced by parallel planes at right angles to the longer transverse axis of the crystal.

Biotite is black mica, and is recognized by its black, shining color, its softness, and its occurrence as irregular flakes or scales in granites, syenites, and metamorphic rocks.

System for Rock Identification

The system for the identification of rock is presented in tabular form on pages 8–9. In this method, all considerations are based on the appearance or character of newly fractured surfaces of the unweathered rock. In determinations of gravel, many pieces may be found to be weathered, and some modifications of the characterisitics mentioned may be expected. For example, pieces of feldspar in gravel may have a dull luster, and some pieces may be so soft that they can be scratched with the knife.

The first determination in the system is the preliminary classification by which the specimen is placed in one of five general groups

When a determination of the lithological composition of a gravel is made, it is believed to be most desirable to separate the entire sample into the various general groups, and to examine each group of particles as an entity, subdividing each by the methods described. This should permit the identification to be performed most rapidly, and should group individual particles which show variations from a given class of rock due to slight differences in color, texture, or the effects of weathering.

In group I, glassy rocks, quartz is included as a rock. Actually this is not technically correct since quartz is a mineral, differing from rock in that it has a chemical composition expressible by a formula and also has a definite crystalline structure. However, quartz does occur in sufficiently large masses so that it is quarried as a rock, and is the most common material in a large percentage of gravels used for construction purposes. Due to these reasons quartz is included in the table. Figure 8 shows a piece of quartz with its typical glassy luster. This luster may be dimmed by weathering or staining.

In subgroup II A, limestone is identified in part as showing a brisk effervescence when treated with acid. This is illustrated in figure 9. Some rocks which contain calcium carbonate as a secondary mineral may show effervescence, but this probably will not be as marked as in the illustration.

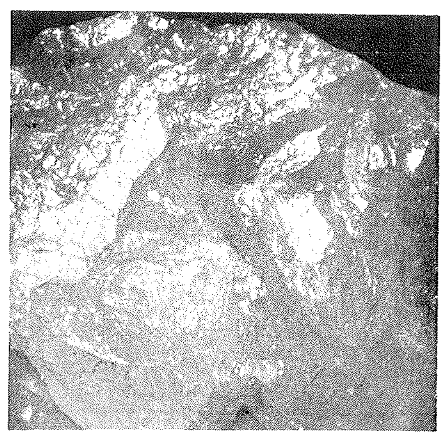


Figure 8.—Glassy luster of quartz.

Subgroup II B, covering hard, fine-grained rocks, contains some types of rock which lately have become of considerable interest to those concerned with the durability of portland cement concrete. Included in the general term "felsite" are a number of varieties of rock which may be chemically reactive to a detrimental degree with the alkali in cement. These include rhyolite, trachyte, and andesite. The identification of these rocks requires that both the kind and amount of feldspar present be determined. This determination can not be made on the hand specimen, and the practice of grouping all fine-grained, light- or medium-colored, igneous rocks containing feldspar as a major constituent under the general term of "felsite" has been adopted. This is believed to be a sound procedure as the various rocks so grouped appear to have essentially the same properties from the engineering viewpoint.

In most groups, but especially in groups II and III, consideration must be given to the size of grains or crystals composing the rocks. The sizing of rock grains may be a relative matter and difficult to define more exactly than has been done in the table. A "very fine-grained" rock can best be considered as one in which the grains are not resolved by the unaided eye. For most granular rocks, the grains can be seen clearly without magnification, as shown in figure 10 (left) of a sample of granite. The diabase shown in the same figure (right) is representative of fine-grained rocks showing grains (or crystals) just large enough to be seen by the unaided eye.

In subgroup III B, item 4, the rocks mentioned may be difficult to identify unless the olivine is well-colored and the augite and hornblende are well-crystallized. If these conditions are not evident, the rocks under study might all be called peridotities.

In subgroup III B, item 5, separation between sandstone and quartzite is made by examination of the plane of fracture of the rock. If the fracture is around the grains of quartz, the rock is sandstone. If the fracture passes through the grains, or through an appreciable percentage of the grains, the rock is quartzite.

Subgroup III C covers rocks of a porphyritic texture. Originally, a porphyry referred to a rock composed of feldspar crystals embedded in a compact, dark red or purple groundmass. This name now refers to rocks containing large crystals of any kind, either well-formed or corroded to a rounded or irregular shape, which are embedded in a more finely crystalline or glassy groundmass of any color. A porphyry could refer to a rock containing crystals as big as an inch long which are embedded in a groundmass of crystals one-fourth inch in size; or it could refer to a rock containing crystals one-tenth of an inch in in size embedded in a groundmass of barely visible crystals. In the labora-

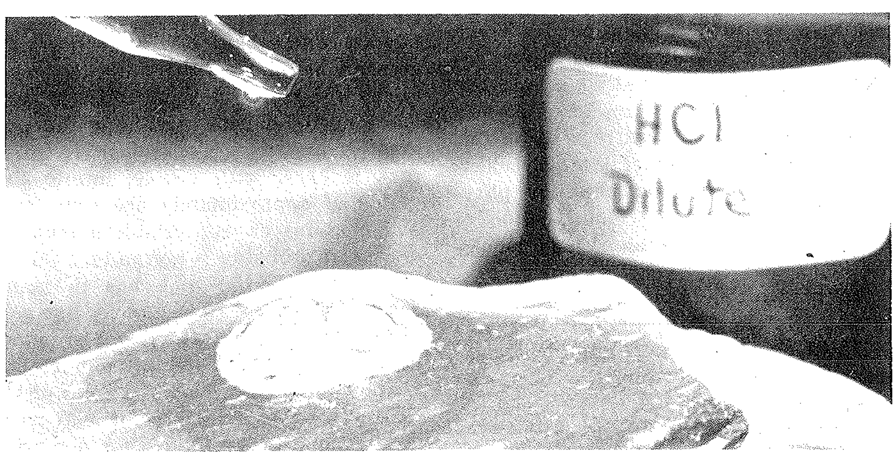


Figure 9.—Brisk effervescence of limestone treated with acid.

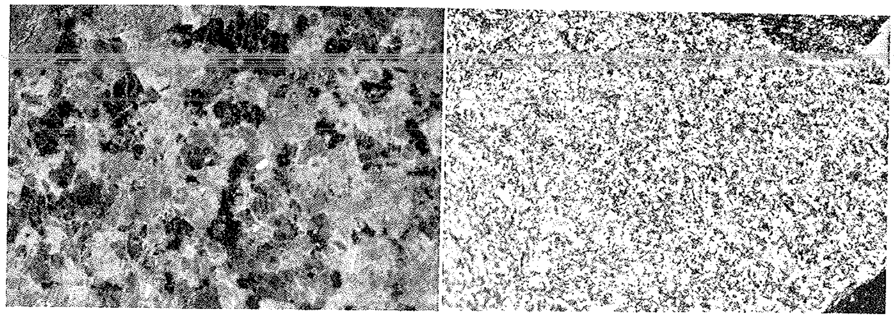


Figure 10.—A hard, coarse-grained rock, granite (left), and a hard, fine-grained rock, diabase (right). These photographs are approximately full scale.

tories of the Bureau of Public Roads, the name porphyry is used to refer to a rock containing numerous and more or less uniformly distributed crystals over one-eighth inch in size embedded in a groundmass so fine-grained that the individual grains are not recognized by the unaided eye. Such a rock is shown in figure 11.

Kemp[6] states that porphyries are commonly classified from the larger crystals (phenocrysts), with little regard for the composition of the groundmass even though the latter comprises over half of the rock. If the ground mass is of very fine grain, no other practice than that mentioned above can be followed without the use of the petrographic microscope or analysis by chemical methods.

In group IV, foliated rocks, it is doubted that the many variations of schist can always be determined in the hand specimen. A few of the more common varities are mentioned. There are many others, depending upon the presence of some mineral which may be in sufficient quantity or have certain unique properties to warrent its use as a modifier of the general term, schist. Most schists have about the same physical properties and the identification of the rock by this name alone may usually be sufficient.

In group IV, item 2(b), hornblende schists contain a small amount of quartz whereas amphibolites contain plagioclase feldspar instead of quartz. This distinction may be impossible to make in the hand specimen.

Conglomerate and breccia, mentioned in group V, frequently look like concrete prepared with rounded or angular coarse aggregate, respectively. A conglomerate is shown in figure 12.

Difficulties with Intrusive Igneous Rocks

In trials of this method by selected groups of students, more difficulty was found in identification of the intrusive type of igneous rocks than any other general group. The difficulty may have been due to too much emphasis on the feldspar content of the rock, and too little regarding the other essential constituents. A study of figure 1 will show that of the coarse-grained igneous rocks, granite is the only kind which contains an appreciable amount of quartz, and that gabbro contains the greatest amount of the dark ferromagnesian minerals (mica, hornblende, and augite) with diorite containing the next greatest amount. Consequently, if the rock is hard, with visible, interlocking grains of approximately the same size, and contains an appreciable amount of quartz, it probably is a granite. On the other hand if the rock has the same characteristics as given above, but contains little if any quartz, it can be named by reference to the ferromagnesian mineral content as indicated by the color of the rock. A rock of light color may be a syenite, one of medium color a diorite, and one of dark color a gabbro.

A Handbook of Rocks, by J. F. Kemp; 6th edition, revised by F. F. Grout; D. Van Nostrand Co., Inc., New York, 1942.

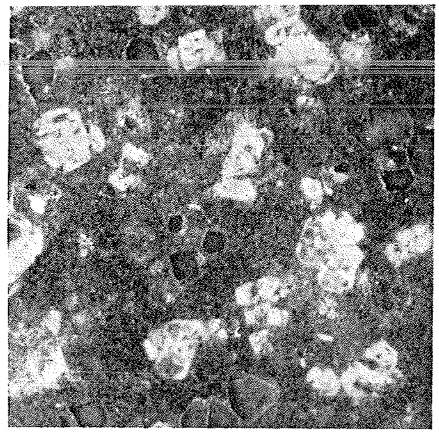


Figure 11.—A porphyry containing quartz and corroded feldspar crystals in a fine groundmass.

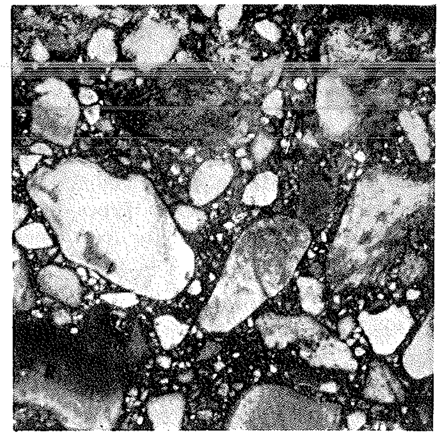


Figure 12.—Conglomerate resembles concrete prepared with rounded coarse aggregate.

Attention should be given to the transition of rock by insensible stages from one kind to another. Granites will grade into syenites, and syenites into diorites, for instance; or a coarse-grained rock will grade into a fine-grained rock of the same mineralogical composition. Two samples of rock from the same deposit may be sufficiently different to warrant different names. Consequently, the identification of the hand specimen by the method given here does have some limitations. However, a careful study of the sample, following the method outlined, should permit the user to name the rock with a relatively small margin of error.

Engineering Properties of Rock

The highway engineer should have many occasions to profit from a knowledge of the identification of rock. By his ability to furnish a suitable name for a deposit of rock, he can in a word or two convey to others a statement of the suitability of the rock for use in highway construction. By this name, he would indicate the quality of the rock and also suggest whether the rock contains mineral unsuitable for the proposed use. For this purpose, there follows a brief review of the more important characteristics of the different types of rock that are generally considered for use in the construction of roads and associated structures.

Average values for certain physical properties of different types of rock mentioned in this publication are given given in table 5. Slightly over 6,000 samples tested in the laboratory of the Bureau of Public Roads are represented here. The rocks have been arranged in the three general classes, igneous, sedimentary, and metamorphic, and then by type of rock in each class. These samples were submitted for test to determine their suitability for use as road-building material. It is possible that these samples represent on the whole a better grade of each type of rock than would be found if all deposits of rock were considered.

Besides having different properties, as shown in table 5, rocks may be affected differently in crushing and some types may have better shape than others for use in road building. In addition, some types of rock contain impurities of an objectionable nature which may not be removable by the usual processing methods.

In the text that follows, brief descriptions of the engineering properties of the various types of rock are given, with statements of the impurities which may be found. When possible, different types of rock are grouped for discussion.

In addition, a summary of engineering properties of rocks is given in table 6. An attempt has been made in the table to state various properties by single words. It is admitted that there may be many exceptions to the ratings mentioned, but these are considered quite suitable with respect to types of rock commonly considered for construction purposes.

Granite

Granite of the quality used in road building is a light-colored, granular igneous rock. It is composed of crystals of feldspar with a considerable amount of quartz and usually a small amount of mica. Its outstanding properties include durability, hardness, toughness to a reasonable degree, and relatively low absorption of water. Usually granite crushes to fragments of good shape with a minimum of flat or elongated pieces. It contains little material which would be objectionable in crushed stone. If used as cut stone for facing on bridges where appearance is important, the granite should be inspected for the presence of pyrite which might oxidize and stain the face of the stone. Due to the high quartz content of granite, bituminous coatings may be stripped by the action of water, and antistripping agents should be used when the rock is used as aggregate in bituminous pavement.

Syenite

Syenite has sometimes been termed a granite without quartz. Actually a small amount of quartz is usual, but ferromagnesian minerals are more prominent. This accounts for the increase in the bulk specific gravity of syenite over granite. Syenite has about the same resistance to frost action and hardness as granite, but is appreciably more resistant to impact. Syenite crushes well and holds bituminous coatings better than granite.

Diorite

Diorite is similar to granite in that it is composed of crystals visible to the unaided eye, but it contains an abundance of ferromagnesium minerals, has a dark color, and is quite heavy. It is slightly less resistant to frost action, but is about

Table 5.—Average values for physical properties of the principal types of rock

Type of rock	Bulk specific gravity	Absorption [1]	Loss by abrasion		Hardness [4]	Toughness [5]
			Deval [2]	Los Angeles [3]		
Igneous:		*Pct.*	*Pct.*	*Pct.*		
Granite	2.65	0.3	4.3	38	18	9
Syenite	2.74	.4	4.1	24	18	14
Diorite	2.92	.3	3.1	--------	18	15
Gabbro	2.96	.3	3.0	18	18	14
Peridotite	3.31	.3	4.1	--------	15	9
Felsite	2.66	.8	3.8	18	18	17
Basalt	2.86	.5	3.1	14	17	19
Diabase	2.96	.3	2.6	18	18	20
Sedimentary:						
Limestone	2.66	.9	5.7	26	14	8
Dolomite	2.70	1.1	5.5	25	14	9
Shale	1.8–2.5	--------	--------	--------	--------	--------
Sandstone	2.54	1.8	7.0	38	15	11
Chert	2.50	1.6	8.5	26	19	12
Conglomerate	2.68	1.2	10.0	--------	16	8
Breccia	2.57	1.8	6.4	--------	17	11
Metamorphic:						
Gneiss	2.74	.3	5.9	45	18	9
Schist	2.85	.4	5.5	38	17	12
Amphibolite	3.02	.4	3.9	35	16	14
Slate	2.74	.5	4.7	20	15	18
Quartzite	2.69	.3	3.3	28	19	16
Marble	2.63	.2	6.3	47	13	6
Serpentinite	2.62	.9	6.3	19	15	14

[1] After immersion in water at atmospheric temperature and pressure.
[2] AASHO Method T 3.
[3] AASHO Method T 96.
[4] Dorry hardness test, U.S. Department of Agriculture Bulletin No. 949.
[5] AASHO Method T 5.

Table 6.—Summary of engineering properties of rocks

Type of rock	Mechanical strength	Durability	Chemical stability	Surface characteristics	Presence of undesirable impurities	Crushed shape
Igneous:						
Granite, syenite, diorite	Good	Good	Good	Good	Possible	Good.
Felsite	Good	Good	Questionable.	Fair	Possible	Fair.
Basalt, diabase, gabbro	Good	Good	Good	Good	Seldom	Fair.
Peridotite	Good	Fair	Questionable.	Good	Possible	Good.
Sedimentary:						
Limestone, dolomite	Good	Fair	Good	Good	Possible	Good.
Sandstone	Fair	Fair	Good	Good	Seldom	Good.
Chert	Good	Poor	Poor	Fair	Likely	Poor.
Conglomerate, breccia	Fair	Fair	Good	Good	Seldom	Fair.
Shale	Poor	Poor		Good	Possible	Fair to poor.
Metamorphic:						
Gneiss, schist	Good	Good	Good	Good	Seldom	Good to poor.
Quartzite	Good	Good	Good	Good	Seldom	Fair.
Marble	Fair	Good	Good	Good	Possible	Good.
Serpentinite	Fair	Fair	Good	Fair to poor.	Possible	Fair.
Amphibolite	Good	Good	Good	Good	Seldom	Fair.
Slate	Good	Good	Good	Poor	Seldom	Poor.

as hard as granite and appreciably more resistant to impact. It crushes to well-shaped fragments and has a good bond with portland cement paste and bitumens.

Basalt, diabase, and gabbro

Basalt, diabase, and gabbro have the same mineralogical composition and differ mainly in size of grain. Basalt has very small crystals, almost invisible to the unaided eye. Gabbro is composed of large crystals similar to granite, and diabase contains crystals of a size between those in basalt and gabbro. Diabase has been described as a basalt having crystals just visible to the eye. Basalt and diabase are the rocks commonly termed "trap rock." Some persons include gabbro as a trap rock due to its color, but the size of the crystals in gabbro should preclude this.

Basalt, diabase, and gabbro are dark, heavy rocks characterized by marked resistance to abrasion and impact, and to the action of frost. Although they have a marked tendency to crush to thin, flaky fragments in sizes smaller than 1 inch, they have an enviable reputation for furnishing road stone of the highest quality.

Within recent years, reports have been received stating that basalts from certain regions have not proven satisfactory when used in base-course construction. The crushed stone was stated to break down rapidly when wet, forming fine material having plastic properties and resulting in the destruction of the wearing surface. It is probable that these rocks were in a highly altered state, and not typical of basalts customarily used for road building.

Peridotite

Peridotite has a structure similar to granite but is composed chiefly of olivine (peridot) with some pyroxene, possibly some hornblende, but no feldspar. It is a dark rock, usually green to black in color. Its high gravity and dark color cause it to be confused with gabbro, into which it may grade. The two may be separated by the greater abundance of olivine in peridotite, lack of feldspar, its higher specific gravity, and lower resistance to impact.

Peridotite may weather rapidly, altering to serpentine or possibly talc. One instance in which a highly altered peridotite was used in the wearing course of a bituminous macadam resulted in the failure of the road after only 2 years of service.[7]

[7] *Weathering Study of Some Aggregates*, by Phillip L. Melville, Proceedings, Highway Research Board, vol. 28 (1948), pp. 238-248.

Pyroxenite and hornblendite

Pyroxenite and hornblendite are similar to peridotite, and like that rock may be confused with gabbro. They are of questionable suitability for use in road-building.

Felsite

Felsite is a general term used for rocks having mineralogical compositions similar to granite and syenite, but so fine-grained that the constituent minerals can not be resolved with the aid of the hand lens. They are of about the same specific gravity and hardness as granite, but are much more resistant to abrasion due to superior toughness. Felsite has a tendency to sliver and flake when crushed.

Some felsites contain quartz in a form which is soluble in alkaline solutions. When these materials are used in concrete with high alkali cements, a so-called alkali-aggregate reaction may occur which results in the formation of a gelatinous material having a great affinity for water. If adequate amounts of water reach the gel, the latter will expand and possibly develop sufficient pressure to crack the concrete. Failure of the concrete by frost action, if present, may then occur. For this reason, examination of felsites for the presence of alkali-soluble forms of quartz should be made if the rock will be used in concrete.

Limestone and dolomite

Limestone and dolomite are mainly carbonates of calcium and magnesium. They are probably more widely used in road building than any other type of rock. Of sedimentary origin, they are liable to contain clay, silica, and other impurities which might have a strong influence on their satisfactory use in construction. Structurally, they are of average specific gravity, and have moderate to high absorption, moderate resistance to abrasion and impact, and relatively low hardness. But they vary in structural properties to a great extent. Some may be almost the equal of the trap rocks while others are greatly inferior.

Limestone and dolomite may contain sufficient clay to be termed clayey or argillaceous rocks. Such a designation should be a warning that the rock may have low resistance to freezing and thawing. Other rocks may contain shale or chert. The presence of shale may indicate an unsound rock, while chert-bearing rock should be viewed with suspicion as a material of high expansion or reactive with alkali in portland cement.

Unless in thin layers, limestone and dolomite usually crush to well-shaped fragments with a minimum of thin or elongated pieces. They generally hold films of bitumen to a satisfactory degree. If they contain silica in large grains, they furnish one of the best aggregates for skid-proof pavements.

Sandstone

Sandstone, like limestone and dolomite, may be a rock of great variance in its physical properties. It is composed of grains of quartz bound together with some cementing medium. If the cement is silica or iron, a hard rock of excellent quality should be found. Cementing mediums such as calcite or clay furnish a rock of generally inferior quality in some respects.

Table 5 shows sandstone to have a relatively low specific gravity and high absorption, and to have adequate strength to resist impact and surface abrasion. The high amount of absorption indicates that for construction in locations where frost conditions prevail, sandstones should be checked fully for soundness.

Sandstones crush to well-shaped fragments, and have an excellent bond with cementing agents. Varieties in which the sand grains are not firmly bonded furnish rock of excellent quality for obtaining skid-proof pavements.

Chert

Chert is a very fine-grained rock composed of varieties of silica. It is one of the most troublesome rocks the construction engineer has to handle. Although it is very hard and has adequate resistance to abrasion and impact, it frequently shows a marked increase in volume upon absorption of water. This leads to disfiguring pop-outs in concrete construction. The lighter (in weight) varieties of chert are readily damaged by freezing and thawing. Cherts from many deposits contain alkali-reactive forms of silica and are suitable for use in concrete only with adequate safeguards against the alkali-aggregate reaction. Unweathered chert has a smooth, almost glassy surface and good bond with cement paste or bitumen may not be obtained.

Attention is called to the extreme range in quality shown by chert which may be more marked in gravels than in ledge rock. Some cherts may be found of suitable quality for use in concrete, but it would be best to consider all as suspect until found otherwise.

Shale

Shale is another material which may cause the construction engineer considerable concern. Like chert, shale may be good or bad, and may have a great range in physical properties. If shale of poor quality is used in construction, the resistance of concrete or bituminous wearing surfaces to damage by frost action may be lowered greatly.

Breccia and conglomerate

Breccia and conglomerate are formed by the bonding together of angular or rounded fragments of rock by a cementing medium such as silica, iron oxide, calcite, or other materials. They may be of engineering importance in some regions. Their properties largely reflect those of the cementing medium.

Gneiss

Gneiss is a metamorphic rock formed by heat or pressure from rocks of granitic structure. It is somewhat heavier than granite but in other physical properties the two rocks are much the same. Due to its foliation, gneiss has a tendency in crushing to form flat fragments. This is the main objection to use of this rock.

Schist

Schists may be formed from a number of igneous or sedimentary rocks by recrystallization when subjected to pressure. They are fine-grained, foliated rocks which may have an objectionable habit of crushing to thin and flat fragments. Schists are fairly tough when tested perpendicularly to the plane of foliation, but if tested parallel with this plane, the rock may fail readily. They are fairly durable and seldom have been found to be chemically unstable.

Quartzite

Quartzite, a metamorphosed sandstone, is one of the hardest, toughest, and most stable of rocks. Its chief objectionable characteristic is that due to its hardness and toughness, it crushes to thin and elongated pieces. Quartzite has been used widely in road construction with excellent results provided consideration is given to the excess of fragments of poor shape.

Marble

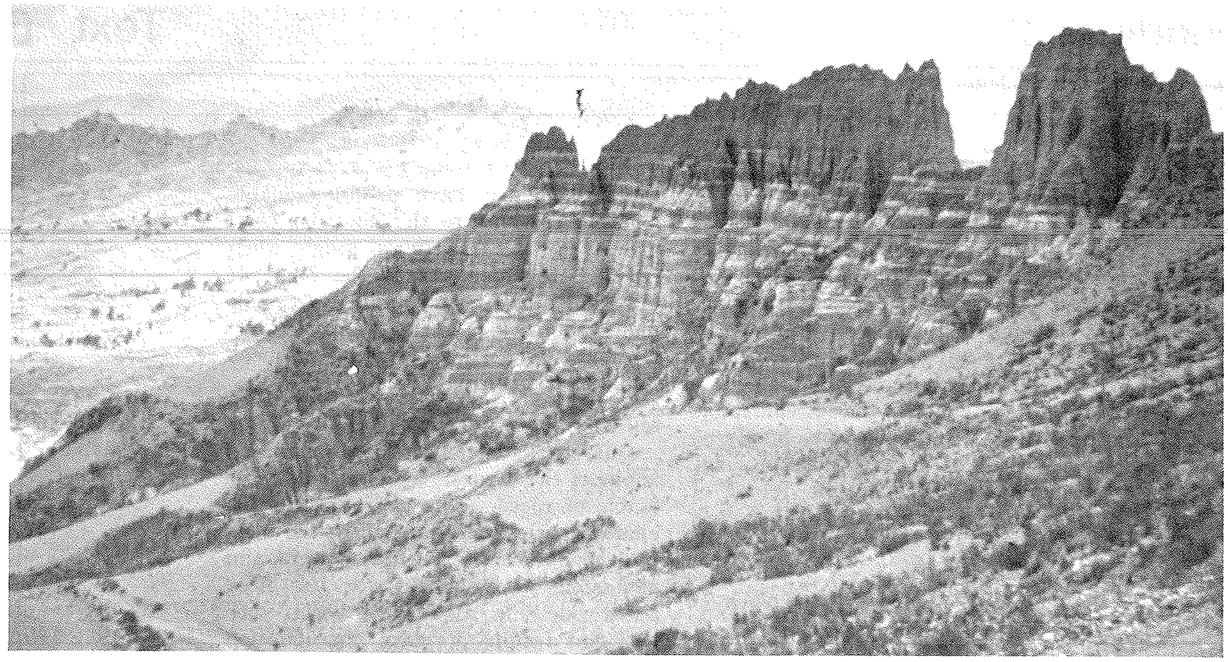
Marble is metamorphosed limestone. It occasionally is used as a road-building aggregate although it may be inferior in physical strength. Strangely enough, marble is shown in table 5 as having a lower bulk specific gravity than limestone and a much lower absorption. The latter would indicate that marble should be more resistant to frost.

Serpentinite

Serpentinite is a soft, metamorphic rock formed by alteration of peridotite or similar basic igneous rocks. In crushing this rock, a soft powder may be produced which prevents good adherence of bitumens, and of portland cements unless the mixing of the concrete is prolonged. Serpentinite is reasonably durable but its use is not desirable if better types of rock are available.

Amphibolite

Amphibolite is a hard, heavy, dark rock which is frequently confused with hornblende schist. It crushes to a fair shape, is reasonably resistant to frost, and bonds well to cementing mediums. It is widely used as a road-building aggregate. Amphibolite has occasionally been sold as a "trap rock."



Example of a distinctive landform in Bolivia.

HIGHWAY RESEARCH BOARD

Bulletin No. 13

THE APPRAISAL OF TERRAIN CONDITIONS FOR HIGHWAY ENGINEERING PURPOSES

PRESENTED AT THE TWENTY-SEVENTH ANNUAL MEETING

1947

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Washington 25, D.C. November, 1948

TABLE OF CONTENTS

THE ENGINEERING SIGNIFICANCE OF LANDFORMS

D. J. BELCHER
Cornell University

SYNOPSIS

The design, construction, and maintenance of highways are influenced to a large degree by the land unit or land form with which it is locally associated. Primarily, land form means the form of the land. While this is important in identifying a land form, it is more important to know that specific solid rock and moisture conditions exist in that land form. Therefore, a given land form possesses a distinctive type of relief, the texture of the soil varies in a prescribed way from a "normal" for that land form; the ground water and soil moisture follow typical trends.

Land forms are of significance in engineering because they influence the quality and type of grading, pre-determine the drainage requirements and fix the soil or rock conditions. They have added significance because there are an infinite number of duplicates of each type. Consequently, when the best practice is established for a given land form, those procedures can be generally applied to other similar units.

Such a process permits a high degree of standardization. At the same time it confines that standardization to permissible limitations not always recognized in the blanket application of standard methods. Using this procedure, investigational work is minimized and the occurrence of "unforeseen" events is reduced.

In the training of personnel, the land form gives them a tangible physical form to visualize. Since we learn by association, this helps by taking a soil out of the abstract or detached condition and definitely relates it to topography and moisture conditions. In small organizations where testing equipment and skill cannot be financially justified, design can be a matter of relating existing road conditions to new road requirements on similar land forms.

In the discussion of various land forms, emphasis is placed on the physical characteristics of the materials that compose them, and the inter-relationship of the relief, soil, rock and ground water characteristics.

In engineering practice, it is desirable to consider small units such as individual hills, as land forms. If, then, there is a series of hills composed of the same material, they represent a repetition of the same land form - a repetition of the same conditions.

Generally, each of these forms has some prominent characteristic that requires special consideration by the engineer. Among these to be discussed are the landslide tendencies of the basalt, clay, and clay shale land forms; special considerations in loessial areas; unusual soil conditions in dry areas, and the special problems found in the Arctic.

Aerial and ground photographs have been used to illustrate individual forms as well as to identify the variations that occur within each unit area.

The object of a soil survey is to provide useful information on ground conditions so that engineering structures can be designed economically. In the category of useful information is to be found soil textural descriptions, indications of plasticity, elasticity, shrinkage, and other physical properties of the soil and its bearing capacity. In addition to the soil itself, there are considerations of soil moisture and ground water conditions and the location and type of bedrock when it is present. The depth to which the survey extends depends upon the type of structure involved and the depth of the excavation with reference to the ground surface.

The operation of soil surveying is an expensive one; when combined with the cost of testing the material sampled, the amount often becomes prohibitive. This cost is a function of the number of samples obtained and tested; therefore, each sample must be representative as well as significant. On the majority of highway projects, detailed station-to-station sampling, testing of these samples, and the plotting of profile information can not be justified economically. On heavily travelled roads where hundreds of thousands of dollars are expended for each mile, considerable sums can be allotted for the detailed work that may be necessary. In contrast, thousands of miles of road have and will be built without the benefit of soil information. Where these roads have failed repeatedly, a soil survey of some order would normally have anticipated and corrected or compensated for the unsatisfactory condition. At the other extreme, a soil survey may have indicated an equally satisfactory and a more economical design.

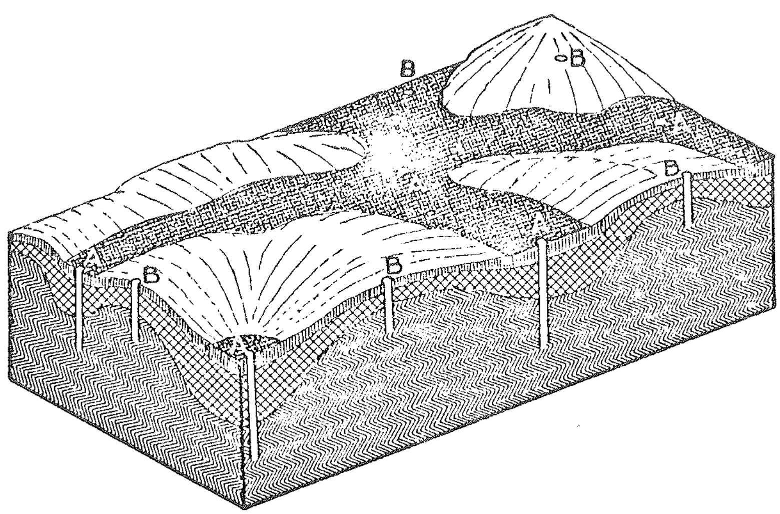


Figure 1

The basis of making soil surveys economical lies in the judicious selection of sampling locations. The samples obtained from such locations should represent an area of soil having some considerable depth. Figure 1 illustrates the principle of soil-area surveying in which a) one sample location is the key to a soil area, and b) soil areas recur, eliminating the need for additional samples in similar soil areas. This land form subdivides, on a pedological basis, into two recurring soil areas. A representative location permits the soil to be classified in three dimensions, in area, and in depth. Sampling at all "A" locations would produce the same types of soil material at corresponding depths. Sampling at locations "B" differ from the "A" but are similar within the "B" group. Without this concept the samples from a given location have little significance beyond the hole from which they were obtained.

Where it is applicable, the principle of recurring soil areas is directly derived from soil science (pedology). That principle can be stated as: similar soils are developed on similar slopes (positions) under the action of weathering of similar materials. This is best illustrated by example: where limestones occur, the action of weathering produces a reddish silty clay soil. Where the slopes are the same, and the climate not greatly at variance, the depth and nature of the soil mantle are similar regardless of geographic location. Evidence of this has been presented elsewhere (*10*, (*2*)[1] This concept forms the basis of the "Michigan" method where a large amount of design detail has been related to specific soil occurences (*3*).

It was implied previously that the pedological methods are not always applicable to highway engineering. Such instances may occur particularly in the semi-arid areas where weathering influences are minimized and soil profiles are weakly developed. Attention is directed to the fact the principles of pedology apply, but that under those circumstances soil changes mapped on a pedological basis may often be too refined for utilization by engineers.

[1] Figures in parentheses refer to the bibliography at the end of the paper.

It is not the purpose of this paper to propose a specific method to be used in the execution of surveys. The intent is to direct attention to the land form as a unit common to all regions and climates. A land form is a unit of land having a definite form. The form of a land unit is controlled by its originating process, subsequent earth movement, and the weather resistance of the materials that compose it. For example, a volcano is a land form. It is a unit having a definite shape and that shape is caused by the repeated process of molten lava welling up through a vent, flowing out, and cooling to form a cone. In this instance, the origin is unique to this one land form and therefore there are no similar land forms having another origin.

The group of land forms that comprise the sedimentary rock group (sandstone, limestone, and shale) have the same origin, and therefore the same initial form - level surface and horizontal beds. In spite of this original similarity the resistance of these materials to weathering is so varied that they readily assume separate and distinctly individual forms. Figure 2 shows two adjacent, unlike land forms. Within the valley area the numerous low hills comprise a group of morainic (glacial) land forms. The particular road problems associated with this form are repeated in each cut. The massive hills rising above the moraine are composed of hard shale. Rock cuts and seepage are considerations in this land form. In those regions where climate has relatively little effect on soils the land form may suffice as a unit in the highest (most detailed) order of surveys. In the regions of higher rainfall and/or greater weathering, the pedologic soil series may be an acceptable unit. Under those circumstances a land form may have two or three or more soil-areas possessing characteristics sufficiently different to warrant separate engineering consideration.

(Photo: Robinson)
Figure 2. An Example of Two Adjacent Unlike Land Forms.

Likewise, it is not an objective to advance a particular means of achieving the survey. All methods of executing the soil survey are based upon the indispensible field sampling. Depending upon the quality and detail required, the nature of the area, type of personnel available and other requisites, this basic type may be expedited by the use of county soil survey maps (USDA Bureau of Plant Industry), topographic maps, and aerial photographs. The degree to which these can supplement detailed sampling and testing depends upon circumstances; it suffices to point out that a growing number of organizations are able to produce soil-design recommendations at a reasonable cost by utilizing these supplementary methods.

At the present time the Highway Research Board Committee on The Sampling of Subgrade and Foundation Soils (F. R. Olmstead, Chairman) has secured an up-to-date compilation and evaluation of soil survey maps through the cooperation of the Soil Survey Division (USDA). The US Geological Survey has recently published index maps showing the status of topographic mapping and ci aerial photographic coverage.

The soil survey listing shows that in some states mapping has been completed to an extent that their use would permit the adoption of the pedologic method as a basis of gathering and applying soil information.

The following quotation indicates the topographic mapping situation, "Barely half of the United States is topographically mapped in some manner and less than one-quarter of the country is covered by maps of sufficient detail to meet present day engineering requirements." (4). In contrast, more than eighty percent of the country has been photographed. Those arras not now covered are generally the mountainous and desert areas.

Land forms are perfectly recorded on a low contour interval map and in aerial photographs; they are indirectly shown on soil maps. The land form as a unit is the common denominator of civil engineering construction; in the pedologic type of soil mapping the land form is synonomous with a parent material area, a catena area, or a soil-association area. In geologic mapping it becomes the smallest land unit that consistently receives the attention of the geologist. It is important to engineers because it is more than a basis of soil surveying; it is also the controlling factor in drainage requirements and excavation quantities. It specifies the type of material to be excavated and otherwise includes such characteristics as susceptibility to (land) sliding.

The land forms discussed are generally subdivisions of the land forms acceptable in geomorphology. The broad and general classification of land forms is not often sufficiently specific for the detailed treatment of engineering projects; therefore, when the geologist stops with the third (lowest) order land forms (valleys, ridges, basins, etc.) an engineer must continue to subdivide these into sub-forms of a suggested fourth or fifth order. The need for this may be illustrated by visualizing two contour maps of the same area; one map having a 50-ft. contour interval may present a general picture of the area but details necessary to engineers are shown only on the map having a 5-ft. contour interval. Where sub-order land forms are considered, more than topographic form is involved, for within a given land form type the mass of soil and/or rock and ground water conditions will vary to some extent and these are reflected in variations in soil color and vegetative cover. (5).

LAND FORMS

The earth's features may be divided into land forms so that each form presents separate and distinct soil characteristics, topography, rock materials, and ground water conditions. The recurrence of a land form, regardless of location, implies a recurrence of the basic characteristics of that land form.

The bedrock land forms follow the conventional delineation with several notable exceptions: granites are ultimately subdivided into low and high quartz granites; soluble limestones are separated from the dolomites and young coraline limestones; shales into the clay and sandy types; sandstones into hard-massive and soft. Glacial drift is subdivided into moraines, till plains, outwash plains, kames, eskers, drumlins, valley trains, lake beds, and peat bogs; aeolian materials into sand dunes and loess. Water-laid materials also include flood plains, terraces, alluvial fans and costal plains as well as those already assigned to other categories.

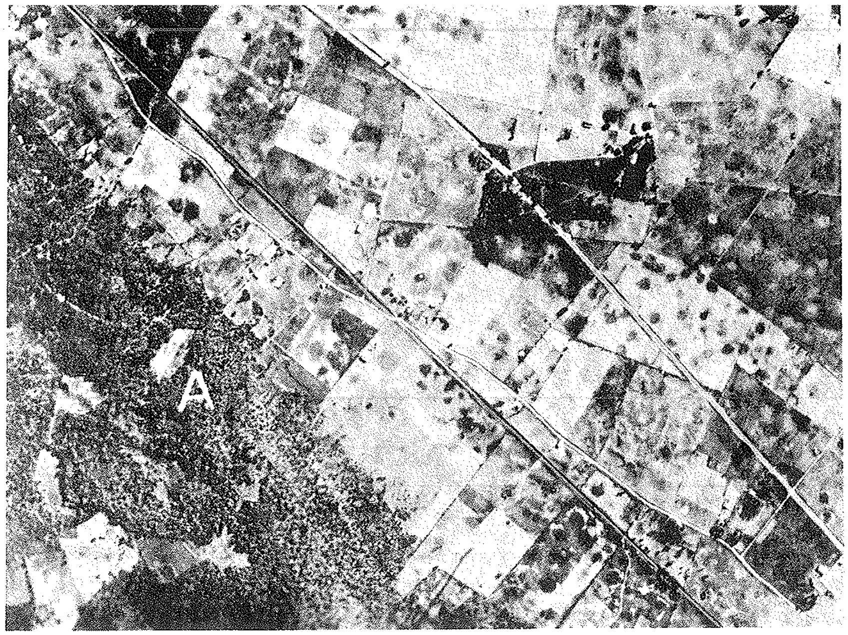
While several of the forms are usually recognized as geological units, each has been classified primarily upon its physical characteristics, especially those that are closely related to engineering.

The following examples have been selected to illustrate a variety of land forms and to point out the effect of extreme climatic conditions in the arid and arctic regions.

SOLUBLE LIMESTONES

The wide distribution of limestone on the surface of the earth, and the information existing regarding the soil material weathered from these rocks, are considerations that make this an excellent illustration of a bedrock land form.

The soluble limestones weather to forms having combined characteristics that set them apart from all other types. These features are recognizable particularly in aerial photographs by those having the most elementary training, whereas, on the ground they may be indistinguishable to all but the expert. The identifying features to be seen on topographic maps of aerial photographs are found in the cross-section and profile characteristics of the valleys supplemented by the presence of sink holes in the upland and the relatively angular outline of the land form. Figure 3



(USDA Photo)

Figure 3. (Scale: 1 in. = 1250 ft.) Surface Physical Features Identifying the Soluble Limestone Bedrock.

is a vertical photograph recording in exact detail the surface physical features and the numerous sink-holes identifying the soluble limestone bedrock. Water standing in the sinks marks those blocked with eroded soil. The majority are dry and free draining. The dark area (A) is a group of forested clay-shale hills differing in every way from the adjacent limestone. The outline is represented in a plan view by the line marking the contact between the alluvium and the upland, or between the limestone and an underlying formation. Modification of this is found in the tropics under advanced stages of weathering and also in tilted structures. The process of weathering reduces the limestone to a reddish silty-clay soil varying in thickness between one and 20 ft. Inspection identifies the land form as limestone; the general depth of the mantle can be estimated by reference to outcrops. By sampling, the general texture of these soils has been established. Table 1 is an extract of data accumulated from the samples of these soils.

Within the limestone types of land form there is a relatively narrow variation from average conditions. However, this material presents so much of a contrast to others that it is unique. Initially, the horizontal beds of limestone presented a relatively level surface. Subsequent weathering produces sink hole topography in the upland. This topography creates many small cuts and short fills in road alignment together with a special need to protect the roadway from the further caving of the sinks. Inasmuch as some sinks are free-draining into underground caverns and others are plugged, their presence creates alternate conditions of bad and excessive drainage. As in Florida on Highway No. 9 (6) these provided the only reasonable means of disposing of

TABLE 1
Geographic Correlation Of Limestone Soils Based Upon Some Atterberg Limits[a]

Geographic Location	Atterberg LL	Atterberg PI
1. US - Alabama	69.3	27.6
2. US - Arizona	57.4	33.9
3. US - Indiana	63.6	29.5
4. US - Kansas	56.8	28.4
5. US - Kentucky	59.1	20.3
6. US - Ohio	65.0	35.5
7. US - Oklahoma	60.0	40.9
8. US - West Virginia	54.1	31.7
9. W. Indies - Barbados	107.0	79.1
10. W. Indies - Puerto	61.8	26.2
11. E. Indies - Papua	68.5	37.3

Without exact data, soils at the following locations have been classified as indicated.

12. Zanzibar, Tanganyika, N. W. Africa, Spain, Greece, Turkey, Palestine Trinidad, Cuba, Haiti and Java as medium heavy clay to fat waxy clay ranging from plastic to very plastic in consistency.

[a]Source: Nos. 1-8 (*8*); 10 (*9*); 12 (*10*)

surface water.

The peculiarities of weathering produce a smooth but highly irregular rock surface. In cuts the soil mantle is often found to vary as much as 10 ft. in thickness within a few feet measured horizontally, thus the soil cushion beneath the pavement may vary from one to many feet within short distances. Although a silty clay, these limestone soils, normally developed, seem to be the exception to the textural criteria for pumping beneath rigid pavements.

LAND FORMS OF WIND-TRANSPORTED MATERIALS

Windblown materials or extensive and important deposits in many parts of the world. They vary in size from the vast loess plains of North China, Central Europe, and the Central United States, to relatively insignificant isolated dune deposits occurring in almost every country. The texture and uniformity of these deposits has been shown by local investigations but only in isolated instanees have there been efforts to bring the significance of these to the attention of engineers.

The loess (silt) and sand have separate and distinct land forms. While there are some wide variations from the normal forms, it has been observed (5) that loess is usually deposited in ridges whose axes are approximately parallel. This tendency that is apparent in aerial photographs and in some topographic maps is lost to an individual on the ground. Figure 4 is a vertical photograph of deep loess near the source. The axes of the individual ridges have been indicated to emphasize the parallelism of this land form. Studies have shown the presence of very fine sand near the source (flood plains) with a replacement by silt and clay at great distances. Samples listed in Tables 2 and 3 reflect their position with respect to the source by the amount of sand present or higher indices where sand was absent.

The data shown in Tables 2 and 3 also illustrate the remarkable uniformity of texture and consistency regardless of geographical location. This is emphasized by the similar construction methods that are practiced in widely separated areas. These characteristics are so consistent from land form to land form that several highway departments have found that in the loess areas numerous elements of design and construction achieve identical results, even though widely separated. On this basis, the "shrinkage" of the material between the excavation and the embankment is relatively

(USDA Photograph)

168 Figure 4. (Scale: 1 in. = 3520 ft) Deep Loess Near the Source.

TABLE 2

Grain-size Date on Various Loess Deposits[a]

Geographic Location	Percentages of: Sand	Silt	Clay
1. China	6.4	67.1	26.5
2. Germany	8.0	66.0	26.0
3. Iowa	6.5	76.0	17.5
4. Nebraska	13.0	75.0	12.0
5. Illinois	19.0	73.0	8.0
6. Missouri	15.0	67.0	18.0
7. Idaho	17.5	60.5	22.0
8. Tennessee	11.5	72.5	16.0
9. Mississippi	11.0	83.0	6.0
10. Kansas	9.0	71.2	26.6
11. Washington	6.8	64.0	29.2
12. Wisconsin	1.0	68.0	31.0
13. Colorado	11.0	68.8	20.2
14. South Dakota	2.0	76.3	20.4
15. Louisiana	4.0	88.0	8.0
16. Kentucky	0.6	88.8	10.6

[a]Source (*12*) (*8*)

TABLE 3

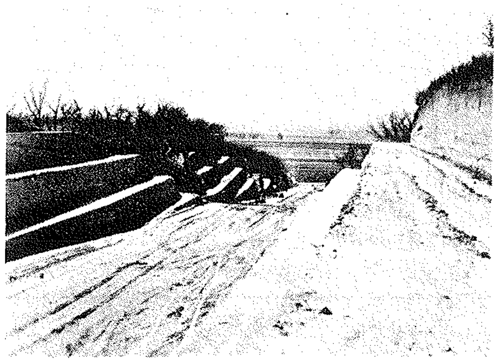
Some Physical Test Results On Loessial Materials[a]

Geographic Location	LL	PI	Max. Wt.[b]	Opt. Moist
1. China	29.	6.1	-	-
2. Tennessee	29.0	4.9	104.5	18.2
3. Mississippi	31.8	3.1	104.9	17.8
4. Illinois	26.2	3.9	106.2	15.5
5. Washington	30.7	7.5	99.5	21.4
6. Missouri	33.6	16.3	-	-
7. Nebraska	32.0	8.0	-	-
8. Indiana	29.6	7.6	-	-
9. Iowa	28.0	9.5	-	-

[a]Source: 1-9 (*5,8*)

[b]Lb. percu. Ft. (dry) Proctor

fixed since the natural density and the compacted density are nearly constant values. Likewise, limited data on the amount of portland cement required to stabilize loess indicates that over considerable areas, 10 to 12 percent by volume has been satisfactory. Figure 5 illustrates a construction characteristic to be observed in all loess areas. When a land form type exhibits this degree of uniformity in soil and related conditions, the amount of field sampling and laboratory testing becomes insignificant. The rule of vertical cut slopes introduces an element of instability in deep cuts in loess. In sub-humid climates of the northwestern U. S. and China, simple slopes in 80 to 100 ft. cuts have been satisfactory. Excessively erosion, these soil materials require special protection from running water. The source area of the loess can be seen in the background of this picture. Back of the camera the loess extends, as a gradually thinning deposit, for more than 100 mi.

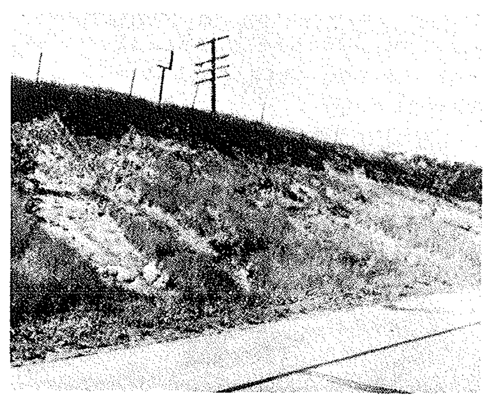


(Courtesy: The Highway Magazine)

Figure 5. Bench-type Construction in Loess

The tendency to assume a vertical slope can be seen developing at the original ground line in Figure 6. In this instance, the loessial silt was sloped and sodded in a cut section. Subsequent erosion has been so severe as to destroy the established cover.

Dune sand also presents a remarkable uniformity that has been caused by the sorting action of the wind. The recognition of the dune forms of all sizes in airphotos established the limits of the grain size within a narrow range. A specific soil series will be found to be related to old dunes when found on soil maps. Recent or active dunes are so labeled. Seldom are topographic maps suitable for this land form identification. Figure 7 shows a typical dune pattern in the sub-arctic in a vertical photograph of a heavily forested dune and swamp area. In spite of the vegetative cover the light gray of the dry sand is obvious. Similar dunes are commonplace in the tropics. Samples of dunes from the arctic coast to the southern hemisphere have furnished the statistical proof of their uniformity in topographic and textural characteristics. Protection of slopes against



(Photo: H. E. Nelson)

Figure 6. Erosion of Loessial Silt Cut Section

wind erosion, excessive wear on equipment, high binder-soil requirements and an exceedingly porous

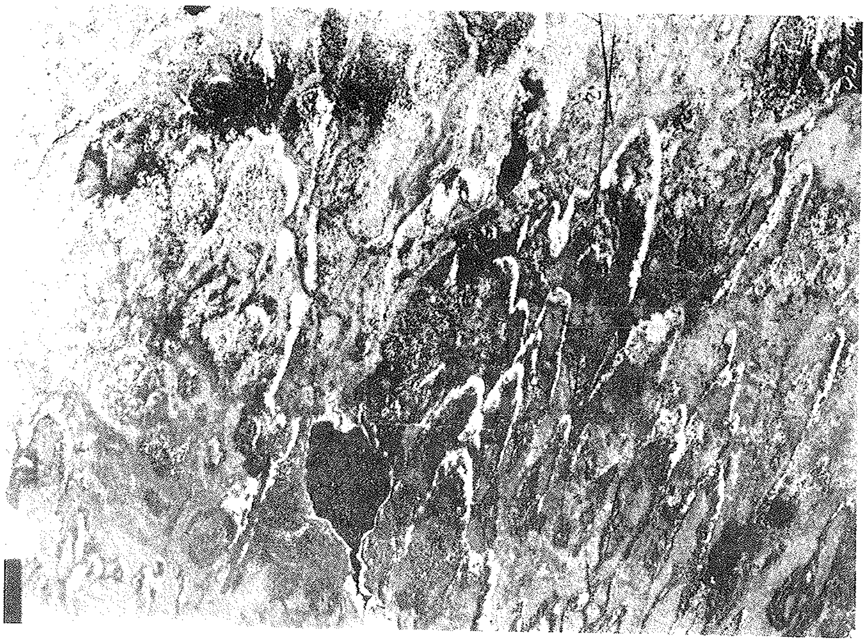
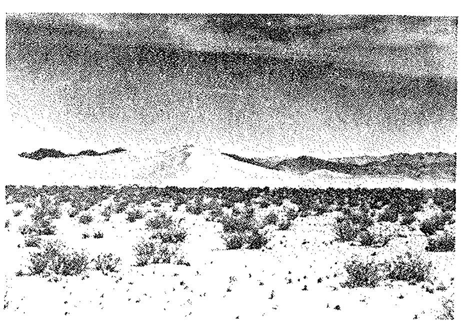


Figure 7 (Scale: 1 in. = 1259 ft.) Heavily Forested Dune and Swamp Area.

subgrade are features of the many dune areas whether in Maine or in Nevada, as shown in Figure 8. The white sand hills in the foreground of the picture contrast in every way to the dark rock hills in the background.



(Photo: Nevada Dept of Highways)

Figure 8. The Sand Dune as a Land Form

A brief of this data is shown in Table 4. Recognizing the characteristic form of dunes and estimating their distance from the source permits reference to the table for a close approximation of the grain size distribution. Having established the land form and the texture of these soils by one of the methods, observations and records will indicate the best practice to be followed in dealing with them as sub-grade or foundation material. Thus the concept of the land form provides a tangible basis for gathering and comparing, not only soil data but design and subsequent performance records.

LAND FORMS IN GLACIATED REGIONS

The areas of the earth that have been influenced by glaciation may contain any or all of the land forms

TABLE 4

Mechanical Analyses Of Dune Sands[a]

Geographic Location	Number Samples	Plus 20	Sieve Analysis (Average) Pass 20 Ret. 40	Pass 40 Ret. 60	Pass 60 Ret. 100	Minus 100
1. U. S. Nebraska	20	Trace	5.9	20.8	66.1	6.9
2. U. S. Wisconsin	3	0.4	20.8	33.4	36.6	8.6+
3. U. S. Illinois	8	-	2.1	14.0	69.9	14.0
4. U. S. N. Dakota	5	Trace	9.2	20.3	58.9	11.4
5. U. S. Kansas	3	Trace	4.7	24.3	67.3	2.6+
6. U. S. Massachusetts	2	Trace	5.5	23.4	67.6	2.3+
7. U. S. Washington	1	6.0	14.0	41.0	27.5	11.5
8. U. S. Alaska	2	-	-	21.8	58.2	20.0
9. British Columbia	1	-	6.5	31.2	43.6	17.5+
10. Peru, S. A.	1	-	Trace	0.3	87.3	12.3+
11. Laborador	1	-	3.2	26.6	59.2	11.0
12. Churchill, Manitoba	1	-	6.6	38.5	54.7	0.2
13. Pan American Hwy., C. A.	1	-	0.5	5.4	59.2	34.7

[a]Source: 1-6 *(12)*

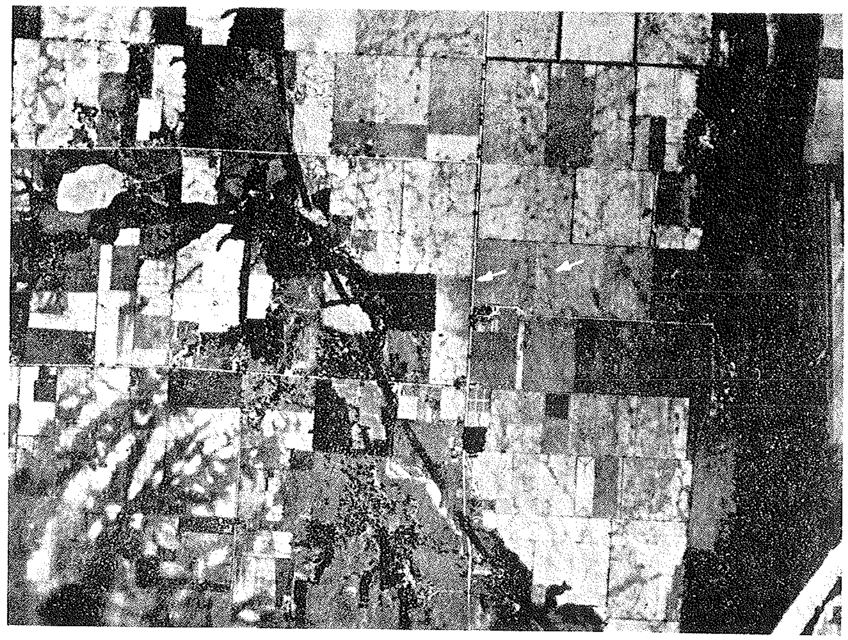
previously enumerated. Of particular interest to engineers are the level, well-drained terraces or "valley trains." A ground view of a terrace land form is shown in Figure 9, showing the flat surface, the associated upland, and the recent alluvium in the foreground. The well defined edges, lack of surface drainage, and absence of gulleys on the terrace face indicate the presence of gravel. The low mountain in the background is a typical "granite" land form to be found in many parts of the world.

These gravel and sand plains offer excellent sites for airports and highways since the essential feature of this land form is its nearly level surface. While good sub-drainage is the rule in such areas, an inspection of soil maps or aerial photos will show considerable variation in soil and drainage conditions within the terrace area. Figure 10 illustrates such an area. The vertical view presents

(Photo: H. E. Nelson)

Figure 9. Terrace Land Form

the strong contrast in soil patterns found in relatively impervious silty clay and that associated with gravels. The integrated drainage pattern and the mottled black and white soil pattern mark two-fifths of the area as a silty clay. The relatively plain appearance of the central portion is a typical gravel pattern. The small irregular dark dots in this area are very slight depressions acting as "infiltration basins" for surface water. Although the area represents several square



(AAA Photograph)

Figure 10. (Scale: 1 in. = 5000 ft.) The Strong Contrast in Soil Patterns Found in Relatively Impervious Silty Clay

miles, no surface runoff occurs. Coarse gravel occurs in the light band that parallels the boundary between the two deposits.

Figure 11 is a ground view of a flexible road surface on a terrace land form corresponding to that shown in Figures 9 and 10. This illustrates the "standard" performance expected on the level, well-drained (gravel) land forms. Ground-line profiles, insignificant ditch requirements, few culverts and a thin (4-in.) base are commonplace elements that produce satisfactory service on this road. The small dark areas within the terrace land form, mentioned in reference to Figure 10, are shown at close range in Figure 12. In such areas, two or three extra inches of base materials are needed to distribute the traffic load to the soil that is more plastic and imperfectly drained.

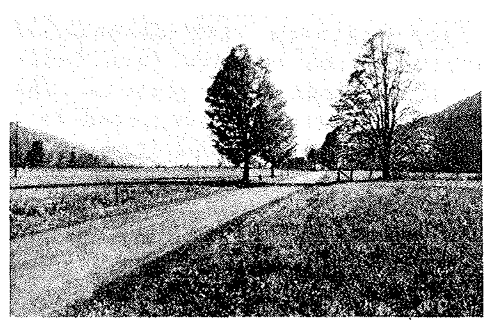


Figure 11. Flexible Surface Road on a Terrace Land Form

In many areas large quantities of sand and gravel are required for construction work. As aggregate, as base course material, or as fill material, these granular materials are often of utmost importance. An esker is a land form in which gravel and sand are found.

One of these ridges is shown in Figure 13. This gravel ridge resembling a long "fill" has an unmistakable land form. Eskers, common in most glaciated areas, sometimes reach the length of 100 mi., other a few hundred yards. In this view, lakes interspersed among bare granite hills comprise the balance of the area. This unique form consists of water-washed and assorted gravels and sands. They are excellent as a source of gravel and because of their well-drained character they are adapted to winter grading. Even in the arctic they remain unfrozen when adjoining deposits become filled with ground ice.

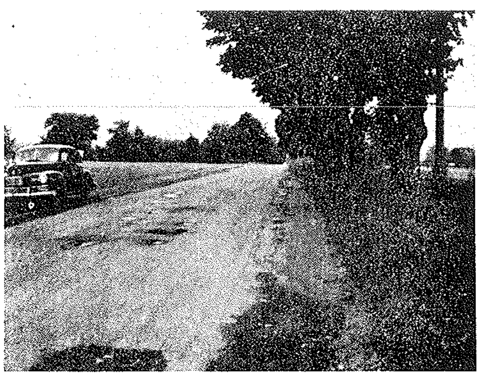
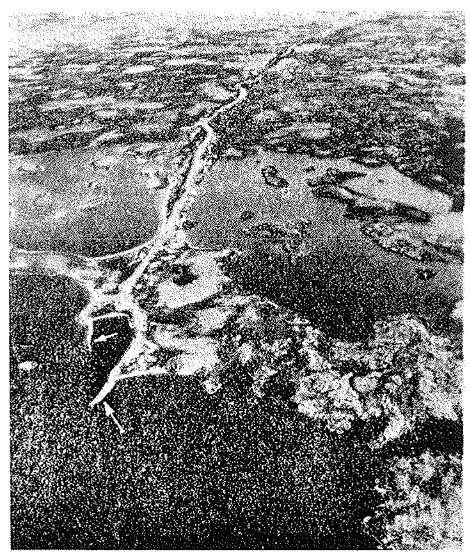


Figure 12. "Infiltration Basins" in Terrace Land Form

CLIMATIC INFLUENCES ON LAND FORMS

In areas where extremes of climate are experienced there are numerous influences which are not present under moderate climatic conditions. In such areas airphotos are particularly valuable because of the limited knowledge of terrain conditions and the lack of maps of other types. Desert areas and the arctic regions are examples of extremes of climate that exert great influence on soil and foundation conditions. In such areas where the climate influences engineering works the land forms naturally present are not greatly altered by the climatic forces. These unusual effects are found superimposed upon land forms found elsewhere; thus as a unit it remains a common denominator regardless of climate.

The particular problems of the arctic are associated with areas where the average annual temperature falls below the freezing point; under such circumstances the temperature of the ground is generally



(RCAF photo)

Figure 13. An Oblique View of an Esker.

below freezing. Perennially frozen ground, or permafrost, exists under these conditions but the problem becomes critical only when water has been supplied to the soil and that water has been concentrated into ice lenses and masses of ground ice. The construction of buildings, roads, and runways, or in fact any disturbance of the ground cover initiates melting and a resulting excessive settlement.

Two general conditions are encountered. In areas where unconsolidated materials are present, the young deposits such as flood plain (land form) materials have ice present in minor lenses and veins 1/8 to ½ in. in thickness. In older materials (coastal plain, morain, terrace land forms) the ground ice has formed into massive wedges of ice that are often several feet wide at the surface and taper downward to depths of as much as 40 ft. In plan these wedges form into the polygonal pattern shown in Figure 14. The polygon pattern is outlined by very slight depressions in which swamp grass is found. Arctic moss covers the surface on the interior of the polygon. Large masses of ground ice are coincident with the outlines. The hill in the center of the foreground is a rock land form. Figure 15 is a ground view of arctic terrain on Baffin Island showing the level surface of a terrace (marine)

Figure 14. Arctic Land Form Containing Ground Ice.

land form in the foreground and bare rock in the background. Ground ice has accumulated in the terrace material to form the polygon outline partially shown. The block diagram in Figure 16 shows the relationship between the surface pattern and the sub-surface conditions

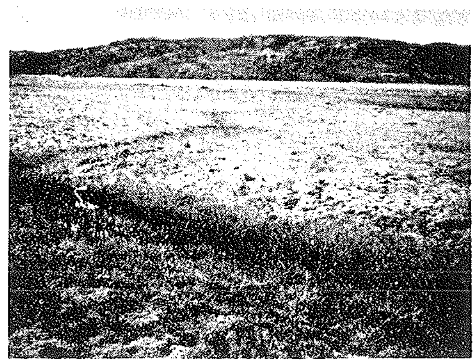


Figure 15. Ground View of Arctic Terrain Showing Polygon Outline Formed by Ground Ice.

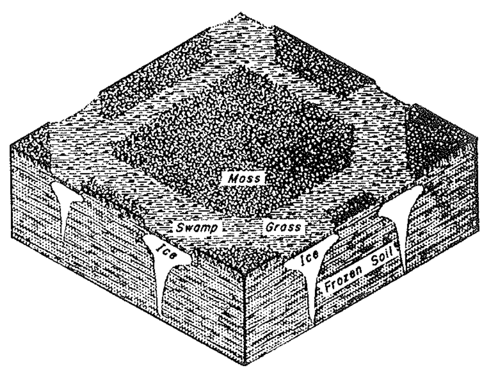


Figure 16. Section of an Old Alluvial Land Form Containing Ground Ice.

Figure 17 shows a wedge of ground ice melting after the surface insulation of moss had been removed. The distance from the ground surface to the top of the ice is about 12 in. The process of thawing, as seen in Figure 18, produces deep

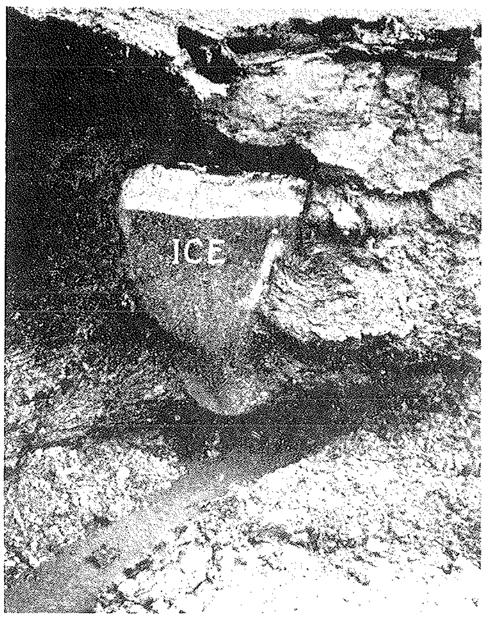
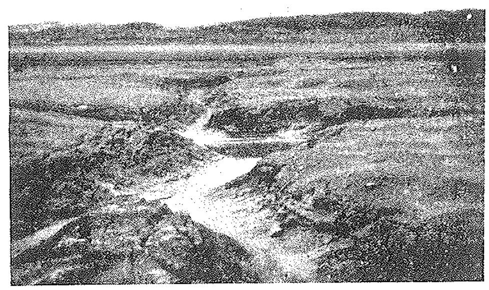


Figure 17. Wedge of Ground Ice

Figure 18. Process of Thawing Produces Deep "cave in" Trenches

"cave in" trenches. Here, thawing along one arm of a polygon exposes a connecting ice wedge. The stripping of the area in Figure 19 resulted in the formation of a polygon "trench" system. There has been no erosion or loss of soil. The run-way in the background of the picture and sections of road were similarly "dissected." Failure of the simplest types of structures resulting from the thawing of ground ice are difficult to repair. Continued melting at a variable rate proceeds over a period of several years. Progressive failure results in the deep caving shown in Figure 20.



(Ungava Bay, NWT.)

Figure 19. Formation of a Polygon "trench" system

As a result of studies in the arctic it is possible to establish a series of land forms in which permafrost may be expected. Photo-analysis of these land forms indicates the degree of development of the ground ice in these, and the exact location of the ice in some. Ground examination of representative land forms of this grouping from western Alaska to Laborador and Baffin Island establish this similarity.

The apparent alternative to construction on these land forms is to seek bedrock land forms. Exploration in the Canadian Shield area reveals that massive and resistant rock such as granite or quartzite is susceptible to distortion by permafrost. Figure 21 shows massive blocks of rock weighing many tons

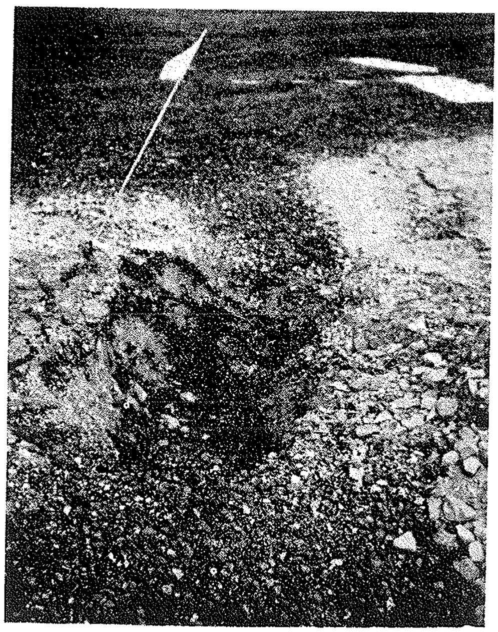


Figure 20. Progressive Failure Results in Deep Caving

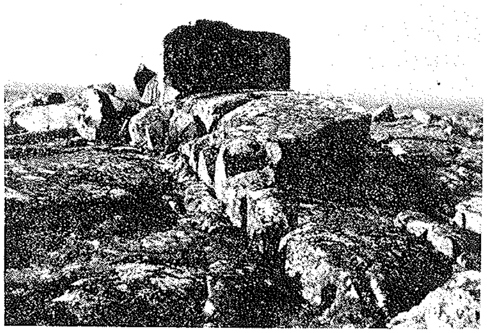


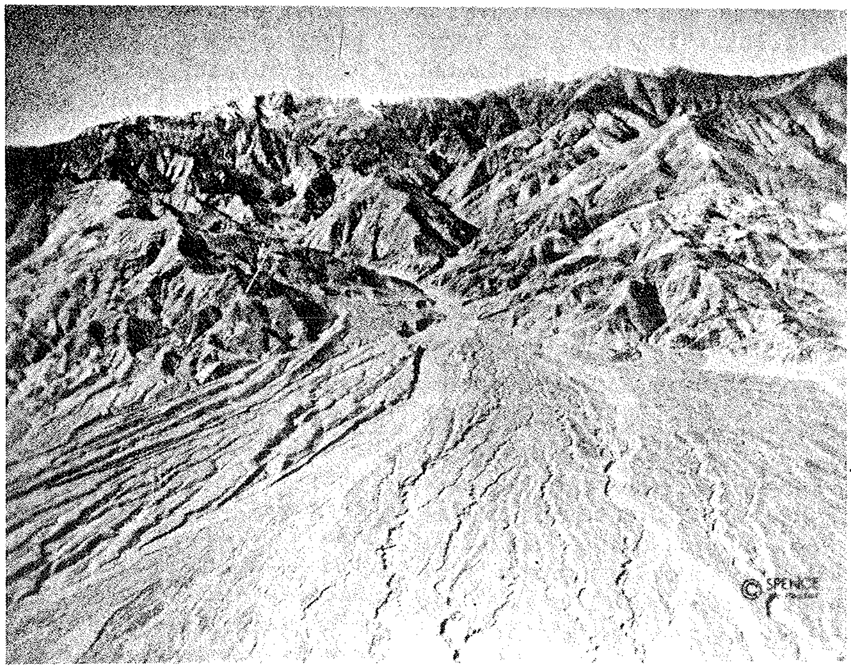
Figure 21. Rock Heaved from Original Position by Ground Ice

that have been heaved by the formation of subsurface ice. The highest projection is about 20 ft. above the original surface. As in other land forms containing ground ice, ordinary construction practice may result in disasterous settlement.

ARID REGIONS

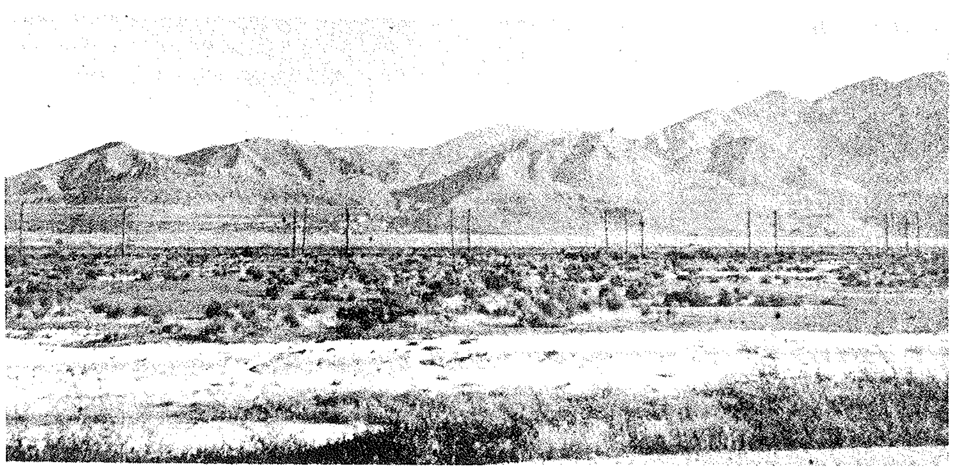
In dry areas the excessive runoff occassioned by the lack of vegetation carries great masses of soil material and rock debris from the mountain slopes out into the low valley areas typical of these regions. Because of the detail shown these areas are of great value in selecting the best available location for engineering works. Railroads and highways, because of soil and water conditions are generally located on the transition slopes between the hills and valley floor. These transition slopes generally take the form of alluvial fans or outwash material. Figure 22 is an oblique view of a land form of this type, showing the general shape of this land unit formed by the deposition of materials washed from the mountain valley. The numerous channels are an indication of the difficulty in locating roads on these land forms. In this transition area the shifting channels and accumulating debris require detailed planning for the protection of the right-of-way. Aerial photographs provide the precise record of many details that are necessary for proper original location and subsequent protection.

Pipe lines and airports, as well as the other transportation lines also must transect the "Basin" areas that lie at the outer fringe of these fans such as that shown in Figure 23. Alkali flats are found in the arid regions of all countries. In addition to identification of soil areas on the basis of texture, soil maps and aerial photographs can be used to locate alkali soils, ground water seepage zones, and active channel areas. The white area in the foreground is crusted with salts of potassium, magnesium,



(Photo: Spence)

Figure 22. Oblique View of an Alluvial Fan



(Photo: H. E. Nelson)

Figure 23. Alkali Flats

sodium, calcium and other compounds. These alkali flats (lake-bed land form) are relatively important since in these, high concentrations of salts are to be found; the same compounds used in the accelerated weathering or "soundness" tests of aggregates and concretes. Early disintegration of concrete and the rapid corrosion of pipe lines and metal culverts are associated with the alkali soils in this land form. For example, the U. S. National Bureau of Standards correlation (7) shows that 8-in. steel pipes placed in such areas can be expected to corrode and leak within five years. Similarly, muck soils (a land form common in glaciated areas) can be expected to corrode pipe within seven years.

LANDSLIDE LAND FORMS

The risk of the unexpected is often a contributing item to high construction costs. This factor also carries on into the service life of highways and other engineering structures. While landslide occurrances are but an example of a great many varieties of risk, they well illustrate the use of the land form as a basis of projecting experience. Here the land form establishes the permissible limits t which experience can be projected from one land form to another similar one.

In the consideration of landslides, two facts are outstanding:

1. There is a group of land forms (identified by rock type) such as clay shale, mixed shale, sandstone and/or limestone, and basalt that are prone to sliding along their unsupported edges. Conversely, a large number of land forms do not fail by sliding.

2. Landslides are a means by which nature adjusts slopes to a stable form. For that reason it is true that old landslides may be found in these land forms. Rarely will an engineer create an original landslide in a given land form. Therefore, a land form should be examined carefully when it is one of the susceptible types. Old slides will indicate the landslide tendencies of the land form; drainage conditions on the upland will indicate the possible locations of new slides. Photo-analysis is particularly well suited to this type of an investigation.

Figure 24, a vertical photograph, records the predisposition of the above-mentioned materials to fail by sliding. The highway (white line) is located on sloping terrain. Recent, A (indicated by arrows) and old, B slides along the unsupported face, running diagonally upper left to lower right, show that roads and structures near this face are susceptible to destruction by slides. Dense forest cover prevents adequate ground reconnaissance. The light gray area C which the road engineers attempted to circumvent is a shallow swamp; its upper border marks the approximate limit of material susceptible to sliding.

A stereo pair of vertical photographs showing numerous landslide scars in a basalt land form are shown in Figure 25. Encircling arrows indicate three major slides. The outcrops of basaltic rock appear as contour outlines at lower left center. Where surface streams parallel the border of these land forms, sliding is imminent.

SUMMARY

A study of the engineering history of a land form would include the investigation of design methods and construction procedures. Such an investigation would inevitably show that within that land form, the process of trial and error, as well as intelligent engineering planning, had evolved certain practices that are the best for those particular conditions. Those particular conditions are characteristics of the land form under study conditions of topography, soil, water, and bedrock.

Since there are a small number of land form types and a great number of each type, they assume a

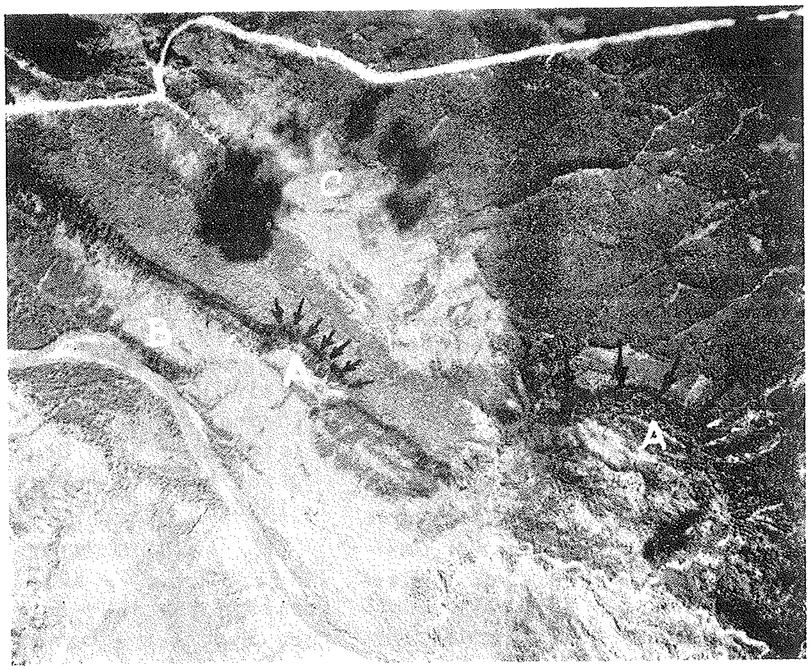
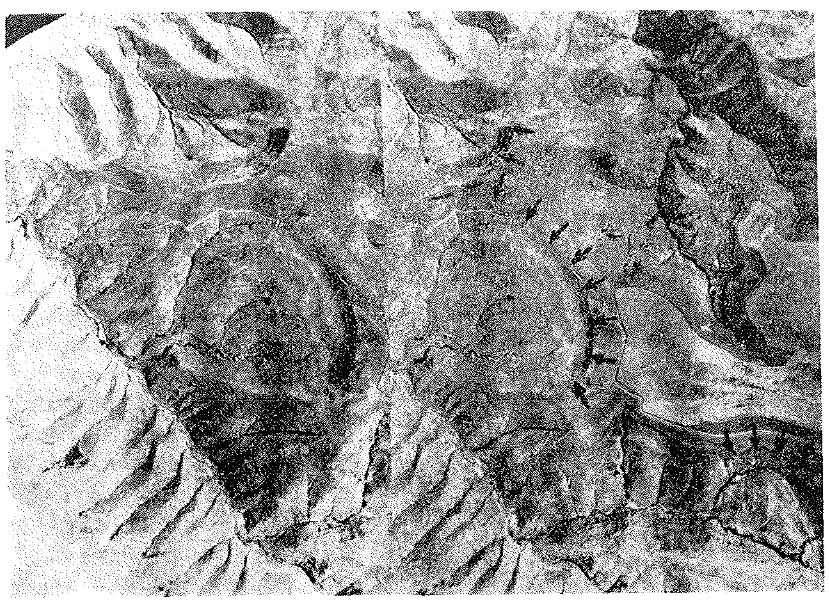


Figure 24. Predisposition of Materials To Fail by Sliding Shown by Old Slides



(Photo: US Air Force)

Figure 25. Landslide Scars in a Basalt Land Form

significance to engineers, for they represent a repeating situation, a basis for scientific standardization, a means to economy in men and money.

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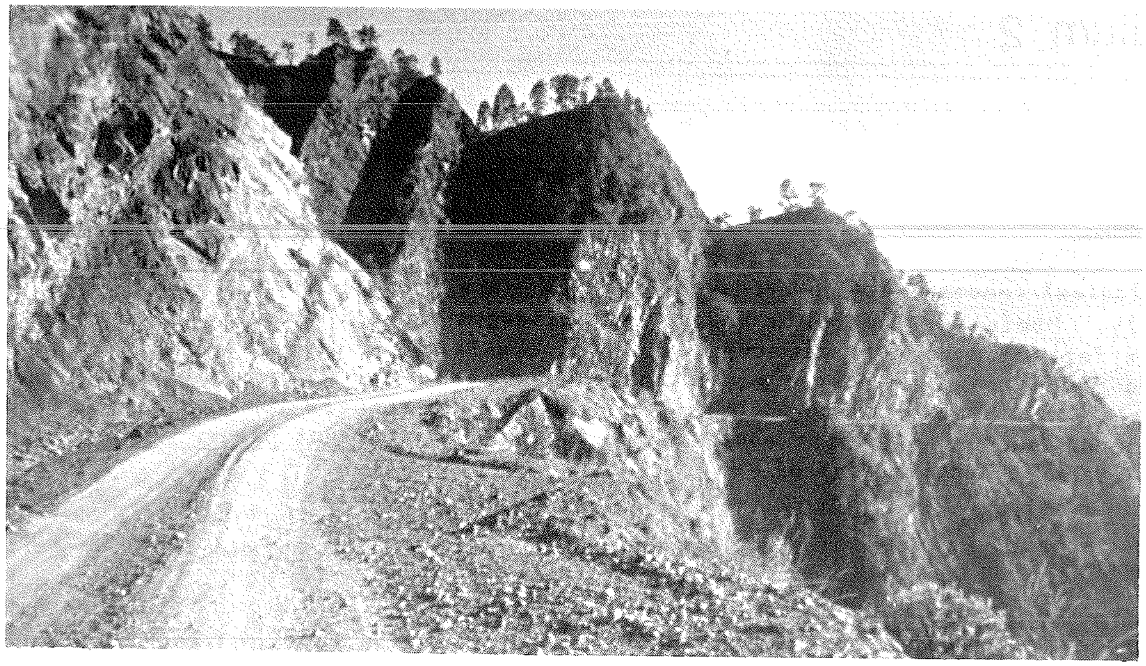
DISCUSSION

PROFESSOR D. P. KRYNINE, *Yale University* The last quarter of a century has been characterized by the growing interest of the engineering profession in soil mechanics and geology. Particularly, the highway engineers are influenced in all phases of their activities by soil performance and local geological features. Soil mechanics, a branch of engineering knowledge created by engineers, rapidly found common language with its users. Geology, however, is not in the same situation; and engineers are often lost in the mass of geological information available. It seems to the writer that articles and books on geology for engineers should be written with a two-fold purpose: a) to acquaint the engineer with the geological problems that he has to face and to help him understand and overcome the ordinary and routine geological difficulties that he meets in his everyday practice and b) to indicate to him the major difficulties when he may have to call a geologist for consultation and to make it possible for him in such a case to interpret and apply geological recommendations successfully. Professor Belcher's paper is a fortunate and proper step in this direction. The title of the paper rightly indicates to both the engineer and the geologist what is important in applications of geology to engineering - "the engineering significance" of geologic features. Without entering into details, the writer wishes to call attention of the highway engineers to this interesting and important paper.



Western Hills Road, Nepal (courtesy U.S. AID).

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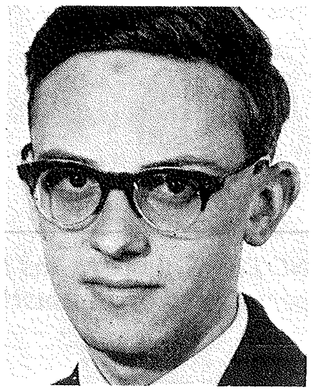
Terrain Evaluation for Road Engineers in Developing Countries

J. W. F. Dowling, B.Sc., F.G.S., and P. J. Beaven, B.Sc.

J. W. F. Dowling



P. J. Beaven

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BIOGRAPHIES

Mr Dowling was born in Liverpool and educated there at the Liverpool Institute High School for Boys and Liverpool University where he gained an Honours Degree in Geology in 1953. A period of postgraduate study was followed by National Service in the Royal Engineers.

It was at the Military Engineers Experimental Establishment (MEXE) that the author first took an interest in rapid methods of terrain appraisal for engineering purposes. He joined the Tropical Section of the Road Research Laboratory in 1959 and has since carried out a number of investigations, mainly in Nigeria, to determine the value of aerial photography, and other geological aids in locating engineering materials and in planning roads.

Mr Beaven graduated in 1958 from Exeter University with a Degree in Geology and joined the Road Research Laboratory at the end of that year. He works in the Tropical Section and his main interest has been the classification, testing and mapping of roadmaking materials. This has led to visits to Nigeria, Northern Borneo, Hong Kong, the Caribbean, Southern Africa and India.

He has recently returned from a long tour in Western Malaysia where he organised a survey of roadmaking materials.

SUMMARY

Existing road-location and materials surveys are often carried out without reference to variation in terrain conditions. Terrain evaluation relates the soil's properties and the associated engineering problems and solutions to a land-classification scheme, thus establishing a system for storing and relating information from one project to another. The basic unit of the classification is the land facet which by definition is reasonably uniform in properties and behaviour in road engineering.

Land facets recur together in larger units called land systems which are usually identified on air-photo print lay-downs at scales above 1:80,000. At this level the land system can store more general information relating to availability of materials, suitable construction methods and costs of construction or maintenance. A terrain evaluation can lead to a more logical soil-survey procedure, concentrating effort on problems relevant to the project. This can often lead to a decrease in the amount of survey work, together with an increase in its effectiveness.

The Paper is illustrated by examples of terrain-evaluation studies from Northern Nigeria and Western Malaysia.

This Paper was presented at a Joint Meeting of the Institution and the Royal Institution of Chartered Surveyors in London on March 7th, 1969. Mr H. Criswell, D.F.C., B.Sc.(Eng), F.I.C.E., M.I.Struct.E., F.Inst.H.E., President of the Institution, County Surveyor of Devon, was in the Chair.

Introduction

In developing countries, especially the newly independent ones, transportation is one of the key factors for major economic and social advancement. In most, transport development receives a generous share of the national development budgets and of foreign aid, often amounting to as much as 20-30 per cent of the total investment. However, because the financial resources are never quite sufficient, there is always a pressing need to spread the investment as effectively as possible. For this reason it is always desirable that transport development should be undertaken within the framework of overall economic planning and in close co-ordination with other economic sectors.

In highway engineering, economic feasibility studies are being increasingly used to provide a basis for effective policy decisions and for planning investment. That such studies can be applied with confidence is largely due to the careful analysis of data obtained from developing countries in recent years[1].

The purpose of this Paper is to review some of the developments which have taken place recently in those aspects of engineering planning which involve route location, site investigation and surveys of engineering materials. An attempt is made to show how some of the difficulties connected with terrain can be overcome by the adoption of a recently developed method for collecting and storing engineering experience and data about terrain conditions.

Many highway engineers, especially those engaged in projects overseas, are aware of the limitations of existing methods of road surveying and design. In most developing countries road distances tend to be great and site access often proves difficult. The ground is very often unmapped, and geological

Terrain Evaluation for Road Engineers in Developing Countries

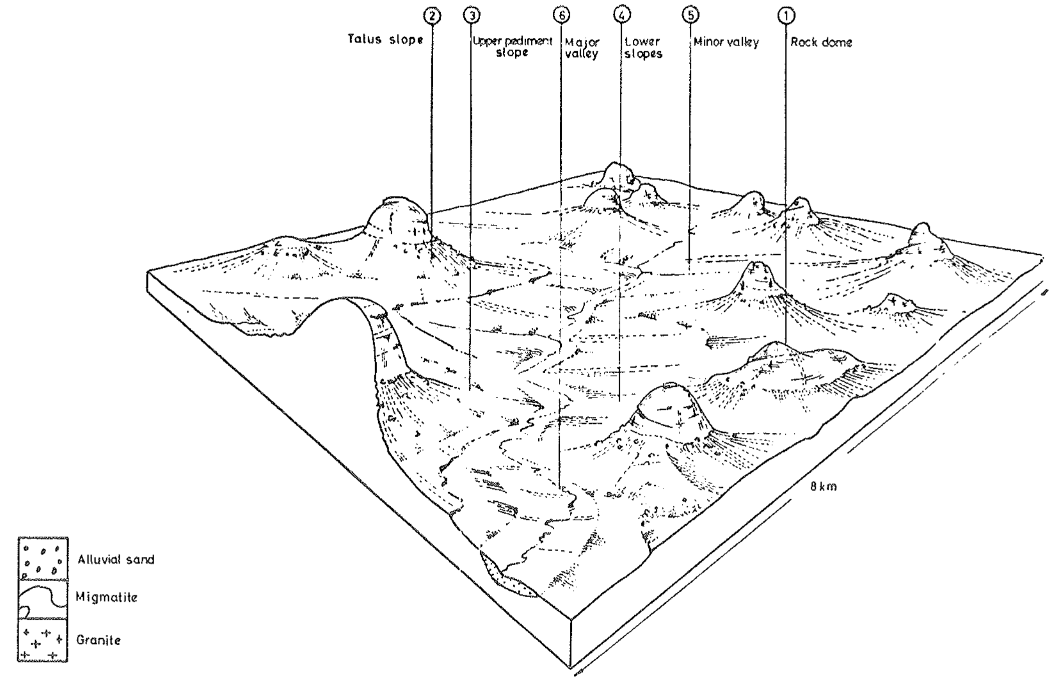

Figure 1. Block section of the Lugge land system, Nigeria, showing component land facets.

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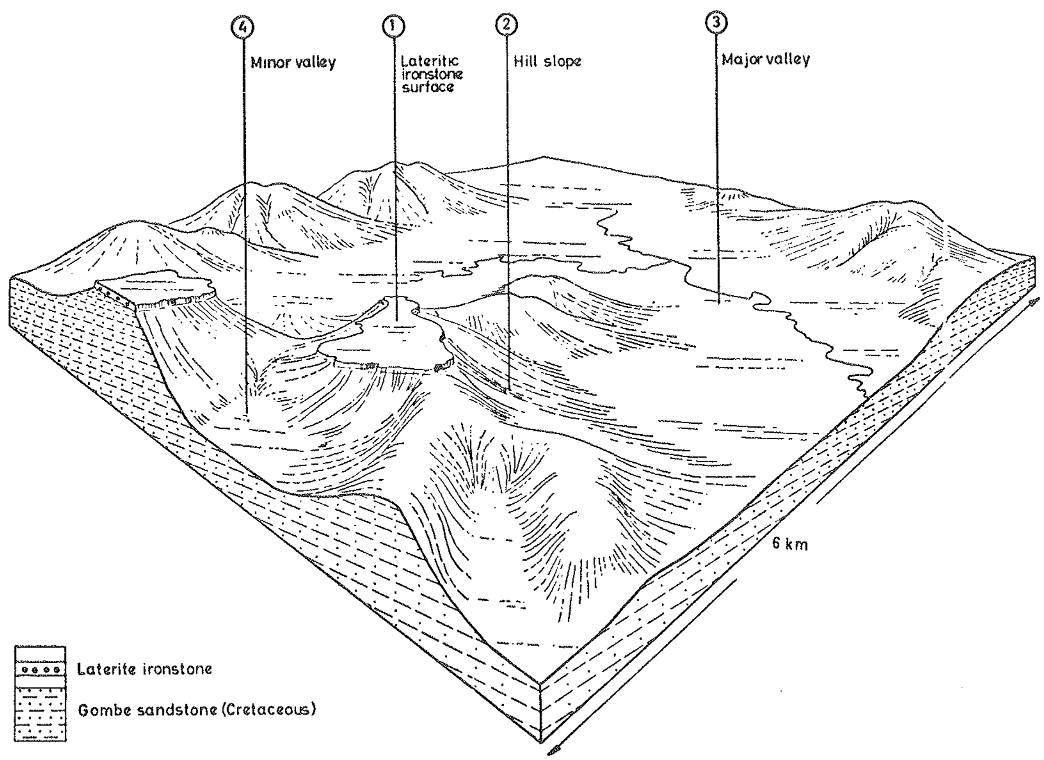

Figure 3. Block section showing the land facets of the Gombe land system, Nigeria.

TABLE 1
Lugge land system

Climate:	Semi-arid to hot equatorial tropical (Sudan savanna zone transitional to Sub-Sudan and Northern Guinea zones), 4 humid months, June–September. Average daily maximum temperature above 33.5°C.
Rock:	Granite gneisses and migmatites of the Pre-Cambrian Basement Complex.
Landscape:	Inselberg landscape with exfoliated granite rock domes and whale backs. Less resistant migmatites often underlie plains. Lateritic ironstone corresponding to the Upper African Surface is developed on upper pediment slopes.
Soils:	Ferruginous soils developed on gently sloping ground with local occurrences of weakly developed soils which include a subsidiary group of lithosols. Basic gneisses give rise to occasional areas of vertisolic soils. Coarse, bouldery talus forms waste mantle to rock domes. Generally well drained, stony soils developed on pediment slopes, with sandy alluvium in valleys. Clay soils patchily distributed in small valleys and areas of locally impeded drainage.
Vegetation:	Mixed Northern Guinea Savanna woodland with transition to Sub-Sudan zone.
Altitude:	650 m. (approx.).
Relief:	350 m.

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TABLE 2
Some values of lateritic ironstone gravels obtained from four widely separated sites with the same land facet – land facet 3 Lugge land system.

No.	Sample No.	Linear Shrinkage %	Dry Density (B.S. heavy compaction) lb/cu. ft.	Moisture Content %	CBR %
1	191	4	133	9.0	80
	190	7	133	9.0	104
	189	5	134	8.9	70
	186	—	129	9.4	84
	183	—	134	7.7	117
	184	—	130	10.8	66
2	131	4	134	9.1	82
	129	12	134	10.4	44
	126	7	135	8.4	109
	125	8	134	9.4	64
	124	5	139	9.3	106
	123	8	136	8.6	64
	110	4	137	10.5	63
3	102	2	140	8.4	88
	101	8	132	9.8	82
	1A	—	136	8.0	72
	1B	6	132	10.5	94
	2	—	133	9.7	96
	14	4	135	8.2	78
4	30	8	133	9.4	116
	29	8	137	8.5	94
	27	6	135	8.8	94
	26	—	134	10.2	82
	25	10	138	7.9	80
	22	7	134	10.9	96

information, if available at all, is often too general to be of much assistance to engineers. Again, the environment generally poses problems that are unfamiliar to engineers whose training and experience are limited to conditions in the more temperate regions of the world.

In road-building perhaps the most important difference between developed and underdeveloped countries is that in the latter there is often more freedom to choose the route of the road. It is also important to make effective use of local engineering material resources. Both of these factors affect costs and it is in response to the need to make early and effective planning decisions that increasing interest has been shown in the development of rapid methods of terrain appraisal and of methods for storing engineering experience and data connected with terrain.

In spite of the intimate connection between all forms of civil engineering and the natural materials of the earth's surface and in spite of the obvious benefits that can be obtained from prior knowledge of the engineering conditions of terrain, it is perhaps surprising that so few attempts have been made to systematically record data for future use.

In the United States of America the pioneer work by Belcher[2] and the Engineering Experiment Station, Purdue University[3] has led to considerable use of aerial photography to map the distribution of engineering materials. As a result many maps have been prepared which show the distribution of agricultural soil units in America as well as information about the engineering properties of these soil units; these are a valuable aid to road planning. The early interest shown in mapping engineering materials in America arose directly from the need, similar to that in many developing countries, to build roads over long distances in areas where insufficient information about soil conditions was available.

In the United Kingdom, the Tropical Section of the Road Research Laboratory has made a number of studies connected with the identification and classification of information on the engineering properties and performance of tropical road-building materials. These can be separated roughly into four spheres of interest. Firstly, the laboratory testing of soil and aggregate samples selected from many different tropical and sub-tropical situations; secondly, the production of regional surveys of roadmaking materials for a limited number of selected territories; thirdly, studies to determine the value of aerial photography in the identification and location of engineering materials; and fourthly, more recent studies of the use of terrain evaluation techniques to retain engineering experience for future use.

Methods of Terrain Evaluation

The Road Research Laboratory has produced a number of reports dealing with the roadmaking materials and road building problems of Central Africa, Nigeria, northern Borneo and the Commonwealth countries of the Caribbean and Lesotho. The main aim of these surveys has been to compile an inventory of engineering experience to serve as a guide to engineers with little knowledge of local roadbuilding conditions by drawing attention to the connection between road-building materials and geology. A further aim was to demonstrate how experience once gained could be transferred to other situations where geological conditions were similar. For two of the territories, namely Guyana and Northern Borneo, maps have been produced at scales of 1:250,000 and 1:1,000,000 showing the regional distribution of roadmaking materials and indicating general roadbuilding problems[4,5]. As in most instances the regional surveys represent the sole record of engineering experience for each of the territories concerned, they form an especially useful source of information for road planning purposes.

However, in the case of individual road projects, regional surveys of this kind have their limitations and are not always capable of accommodating the wide variety of terrain information with which the engineer is concerned. Commonly, geological maps, even where these are available, by their neglect of the unconsolidated soil mantle, are too broadly based to cope with the fine distinctions that the engineer needs to draw between different types of materials used in road construction. In this respect, agricultural soil maps have proved to be more satisfactory although, once again, in most developing countries the amount of ground covered by such maps is small. In addition, the pedological terms used are not always easily understood by engineers.

During the course of an earlier investigation undertaken by the Laboratory in northern Nigeria to find out how aerial photography could be used to locate engineering materials[6], it became evident that the most suitable method for classifying the engineering features of terrain lay in adopting the principles of land classification. These involve the recognition of distinctive patterns of landscape, brought about by the interaction of the many different components that make up the natural environment, such as rocks, soil, topography, vegetation and climate. The most important principle of land classification is that, in any number of different situations where these components have the same character and operate together in the same manner, the physical form of the landscape will be essentially the same.

Most engineers are aware of the repetitive nature of ground and, in countries that they know well, would easily recognise associations between certain rock types, hill shapes, soils and vegetation. Land classification simply sets out to define and record these relationships more accurately. When the various features of landscape have been described the next step is to obtain values for the physical attributes of different portions of the landscape. In this way, a land classification becomes a land (or terrain) evaluation and when the values obtained are concerned with soil strength, plasticity or any of the other properties on which the design of roads is based, the ground can be said to have been evaluated for engineering purposes.

To the engineer, the importance of terrain evaluation lies in its ability to deal with a wide variety of engineering considerations which are not restricted to soils, but, in addition, include information about rocks, relief and hydrology. Moreover, because patterns of landscape can be easily identified using aerial photography, large areas of ground can be examined quickly.

The concept of land classification was first described by Christian[7] after it had been developed and used in the Northern Territories of Australia and New Guinea to express the agricultural potential of ground. Subsequently, these concepts were expanded and modified in the United Kingdom by the Department of Agriculture, Oxford University, working under contract to the Ministry of Defence. In a series of reports dealing with parts of Oxfordshire, Beckett and Webster showed for the first time that land-classification techniques could be used satisfactorily to define the engineering features of ground. Similar studies had been made in South Africa and Australia, and in 1964 a joint meeting was held at which the terms used in this Paper were agreed upon[8].

Ground can be subdivided into distinctive patterns of landscape. Each pattern is made up of several components, which are generally interrelated, and recur together to give a pattern its characteristic form. These patterns can be picked out readily from aerial photographs of the appropriate scale.

Units of landscape which have a reasonably high degree of homogeneity for most practical purposes, and can be readily identified in aerial photography at scales between 1:10,000 and 1:80,000, are termed *land facets*. They are significant units of landscape in terms of engineering and agricultural land use. Land facets are themselves comprised of smaller units called *land elements*. These are generally small components within the landscape and a number of related elements are linked to form a land facet. Restricted outcrops of lateritic ironstone, which may form a useful source of building material, and small, incised, watercourses are two examples of land elements. Generally, land elements are too small to be identified easily in aerial photography at conventional mapping scales. It can be seen, however, that they may have considerable significance in engineering terms.

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TABLE 3
Gombe land system

Climate:	Semi-arid equatorial tropical (Sudan savanna zone): three humid months (July–September), 750–850 mm. rainfall. Average daily maximum temperature above 33.5°C.
Rock:	Upper Cretaceous Gombe Sandstone comprising flaggy siltstones, generally fine grained sandstones often heavily ferruginised especially adjacent to lateritic caprock.
Landscape:	The Gombe Sandstone hills form a buried land surface and are overlain by the Palaeocene, Kerri Kerri Formation. Flat-topped hills are capped by a thick lateritic ironstone, part of an old erosional surface which dips beneath Quaternary sediments of the Chad Formations. The topography comprises moderately steep, rubble-clad stopes separated by flat-floored valleys.
Soils:	Thin, stony soils on hillslopes, with fine sandy colluvium and alluvial material forming the flat, valley floors. More coarser-grained sands have been washed in from the adjacent Kerri-Kerri Formation.
Vegetation:	Sudan savanna woodland.
Altitude:	400–630 m. (approx.).
Relief:	150 m.

Reference: Klinkenberg, K. et al. *Soil Survey Section,* Bull. No. 21, 1963. Regional Research Station, Ministry of Agriculture, Samaru, Zaria, Northern Nigeria.

TABLE 4
Facets of Gombe land system

Land facet	Form	Soils, materials and hydrology	Land cover
1	**Lateritic ironstone surface** Flat to gently undulating mesa surface with uneven micro relief. Size may vary from 100 m² to 5 km².	Flat, hill-crests capped with hard lateritic ironstone and/or heavily ferruginised sandstones which underlie caprock. Bare ironstone, ferruginised sandstones with shallow, stony soils. Reasonably well-drained sites, with only. local impedance.	Detarium woodland occurs in soil pockets.
2	**Hill slope** Moderate steep slopes usually less than 35°, locally steepening below caprock and occasional mid-slope rock outcrops. Gentler lower slopes, sometimes with uneven bouldery micro relief.	Thin, boulder soils up to 0.5 in thick form a conspicuous protective sheath to underlying finer grained soils. Erosion proceeds rapidly where this armour is removed, perhaps by sliding.	Detarium woodland on upper slopes. Mixed Anogeissus woodland on lower slopes.
3	**Major valley** Flat to gently sloping valley floors, of large size.	Fine sandy colluvium and alluvium forming valley floors and derived in part from adjacent Kerri-Kerri Formation. Juvenile soils developed on recent alluvium. Rock occasionally exposed in valley walls and floors. Colluvium tends to be coarser in areas adjacent to land facet 2. Intensive erosion produces deep dissection of river channels.	Heavily cleared and cultivated. Elsewhere, mixed Anogeissus Savanna woodland occurs.
4	**Minor valley** Flat to gently sloping valley floors, often deeply dissected.		As above.

Terrain Evaluation for Road Engineers in Developing Countries

Land facets recur together to form larger units called *land systems*. These form distinctive patterns, and are usually identified in the first instance from air-photo print-laydowns (or photo mosaics) at scales above 1:80,000.

Thus, the terrain of a region is conceived as a series of recognisably distinct land systems, each of which contains typical land facets which have similar features wherever they occur and which can be readily identified on aerial photographs. Land facets usually include a number of smaller land elements, which are invariably more homogeneous than facets in engineering character. Some of these may be of special significance in road construction, especially where they present a problem or provide a source of building material.

Examples of Terrain Evaluation

A number of examples have been selected to illustrate the way in which terrain evaluation can be applied in different environments in Nigeria and Malaysia.

In Nigeria, an investigation was made of 30,000 square miles of the North-East State (formerly Bauchi and Bornu Provinces). It covered an extensive range of soil types derived from a wide variety of parent materials, including Basement Complex granites, Cretaceous sandstones and shales, and Tertiary sandstones, together with more recent aeolian, lacustrine and alluvial sediments. Lateritic ironstones associated with a number of separate erosion surfaces were also encountered. Climatically, the area falls within the West Africa savanna zone and is characterised by a brief rainy season in the summer months with a long dry season in the winter. The vegetation has been ascribed to the Sudan and Sub-Sudan vegetation zones[9].

The engineering materials data were obtained from a number of road projects undertaken by the former Northern Nigeria Ministry of Works and comprised measurements of the particle-size distribution of plasticity characteristics including Atterberg limits and linear shrinkages, of maximum dry densities at different levels of compaction, and of the soil strength at optimum moisture content expressed in terms of the California Bearing Ratio. In accordance with conventional site-survey practice, samples were mostly obtained at fixed intervals along the centre line of roads.

Initially, print lay-downs (photo mosaics) were used to identify provisional land-system boundaries. Later, a more detailed interpretation was made using aerial photography at scales between 1:10,000 and 1:40,000. This enabled revisions to be made of the land-system boundaries where these were required. The component land facets of each land system were identified and described. Supplementary information was obtained from geological sources[10] and agricultural reconnaissance soil maps where these were available[11].

Field information obtained during the course of a number of engineering surveys was used to check the results of the photo study.

Subsequently, a land-system classification of the same area was carried out by the Land Resources Division of the Directorate of Overseas Surveys, an extension of an earlier survey that had been undertaken in Adamawa Province[12]. These results have been used to revise the land classification carried out by the Laboratory and the land-system boundaries now employed are substantially the same.

In all, some twenty land systems were defined and mapped. Each of the land systems was described in terms of its main environmental features, such as climate, geology, relief and altitude; a brief account was also given of the geomorphology, soils and vegetation. The individual land facets were described and block diagrams were prepared to illustrate their position within each land system.

The first example of a land system from Nigeria is shown diagrammatically in the block section in Figure 1. This is the Lugge land system located near Bauchi. It forms a distinctive inselberg landscape consisting of rock domes and whale backs separated by gently sloping plains and river valleys. The underlying parent rock belongs to the Basement Complex and comprises granite gneisses and migmatites. More basic gneisses occur infrequently. A typical ground photograph is shown in Figure 2.

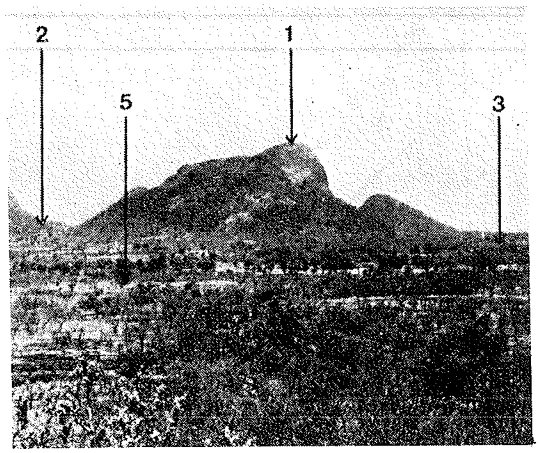


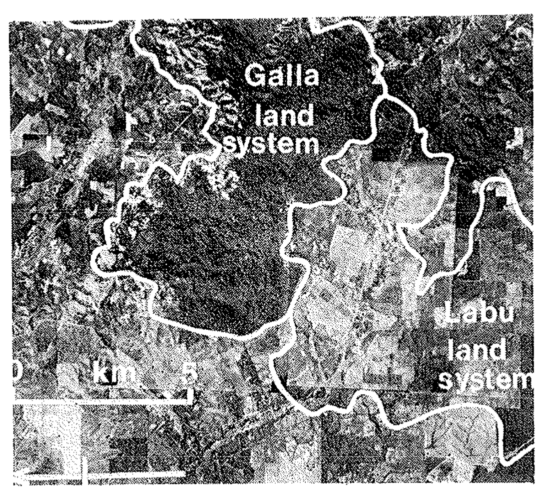
Figure 2. Ground photograph showing typical land facets of the Lugge land system, Bauchi, northern Nigeria. 1. Rock Dome. 2. Talus Slope. 3. Upper Pediment Slope. 5. Minor Valley.

A summary of the environmental features of a land system is essential for classification purposes and an example for the Lugge land system is given in Table 1.

The Lugge land system comprises six land facets which recur together throughout the area occupied by the land system. One of these, Land facet 3, characteristically contains extensive deposits of lateritic ironstone which form a useful source of road-building gravels. During the course of a road survey, samples were obtained from four widely separated sites within the same land facet. Laboratory testing subsequently proved the homogeneity of the lateritic gravel deposits for most roadbuilding purposes. Some of the values obtained from the four sites are shown in Table 2. A similar investigation into the engineering properties of the remaining land facets indicated that these in turn showed considerable homogeneity[13]. Major valleys were associated generally with coarse sands, while minor valleys were often associated with weak clays.

The second example from Nigeria is of the Gombe land

Figure 5. Air photo-mosaic showing Labu and Galla land systems, Malaya.



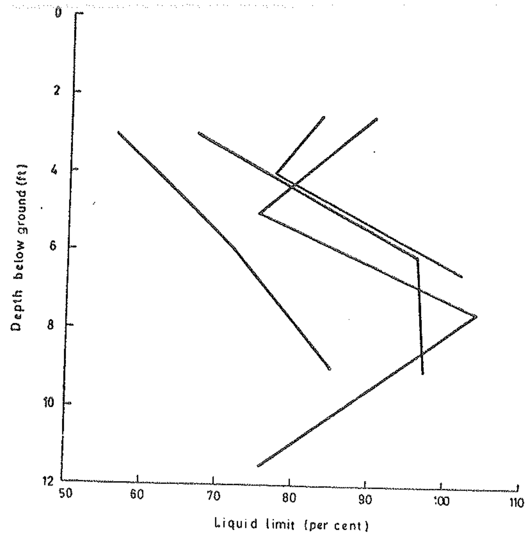


Figure 6. Variation of Liquid Limit with depth of granite soils.

system developed over Cretaceous sandstones. In this example considerably more detail is provided. Tables 3 and 4 give a brief summary of the environmental features of the landscape, including a description of the soils, hydrology and vegetation of each land facet. A diagrammatic block section of the land system is shown in Figure 3. Tables 5, 6 and 7 show the types of information that can be collected and stored for future use. These include laboratory test data on representative soils, and engineering material resources. Table 7 shows how an assessment can be made of the suitability for road location of each land facet within the land system.

The work in Western Malaysia covered an area approximately 200 x 30 miles in the south of the Malay peninsula. The area is backed by mountains parallel to the coast, which are mostly formed of granite. The lowlands are more commonly formed on sediments, which may be slightly metamorphosed, but the area also includes lowlands developed over granitic rocks.

An initial division of the terrain was made from contoured 1 : 63,360 maps. When air photographs became available more detailed division was possible, and a more intensive analysis is now in progress at the Road Research Laboratory.

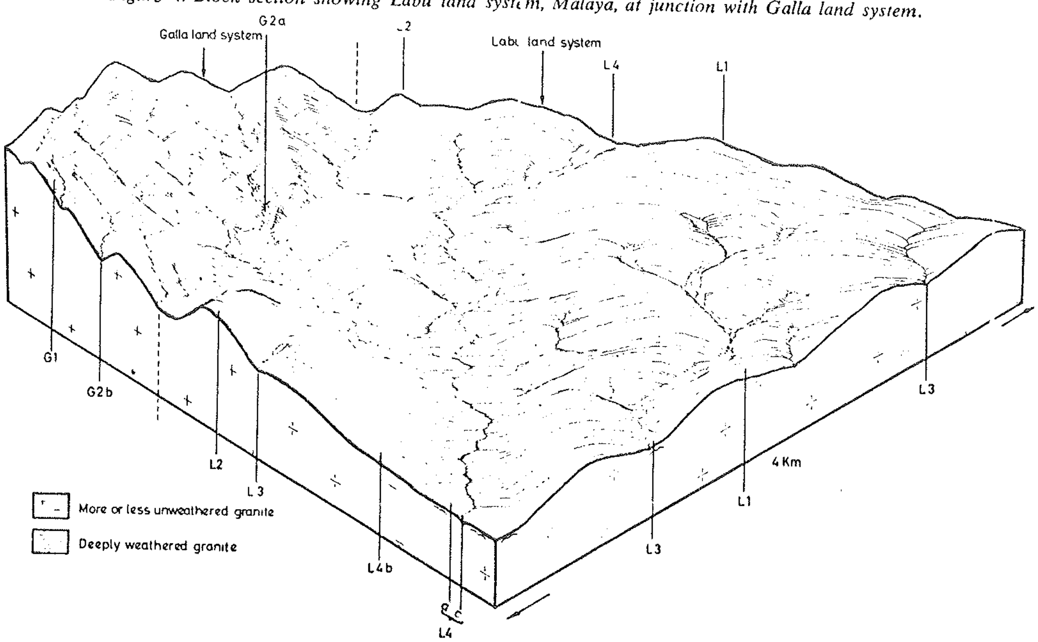
From the first analysis, sites were selected for soil sampling to cover the main variations of rock type and terrain. Small samples for classification tests and larger samples for more detailed analysis were collected from boreholes, borrow pits and cuttings. A copy was also made of the test results produced over the past ten years by the Malayan Public Works Department.

Examples of Malaysian land classification are shown in the block diagram of the Galla and Labu land systems (Figure 4). A characteristic feature of the Malaysian topography is the abrupt change from mountain to lowland as shown in this diagram. The photo-mosaic (Figure 5) shows the jungle-covered mountains, which are too steep for cultivation, against the low, gently sloping ground, large parts of which have slopes of less than 3°. Details of the environmental features of the Labu system are given in Tables 8 and 9.

The main difference between the two systems to the engineer, apart from the obvious topographical differences, is the depth of the bedrock. For road engineering purposes it can be assumed that solid rock will not be encountered in the Labu system. Weathering continues to a great depth, and low hills and gentle slopes lead to moderate depth of cut. In the Galla system, rock is present in many stream channels and is often encountered in road cut. Thus this system is likely to provide good quarry sites, often with negligible overburden. However, on the end of spurs, cuttings often show 15 to 20 metres of soil and weathered granite.

The soils in both of these systems are very similar as all are derived from the weathering of granite rocks. In the Labu system the soils have highly plastic fines, with liquid limits ranging from 55 to over 100. The range is normal for this soil type as a single soil-profile may show great variation (Figure 6). This figure also demonstrates that in the upper

Figure 4. Block section showing Labu land system, Malaya, at junction with Galla land system.



Terrain Evaluation for Road Engineers in Developing Countries

Table 5 Engineering properties of materials — Gombe Land System

Land facet: No. Name	Dominant engineering soil class (USCS): Name	Symbol	Plasticity characteristics: Liquid Limit %	Plasticity index %	Linear shrinkage %	BS compaction (heavy): Maximum dry density lb/cu.ft	Optimum moisture content %	CBR% at BS (heavy) compaction	Typical particle size distribution %, passing BS sieves: 1½"	¾"	⅜"	3/16"	7	14	25	36	52	100	200	Depth	Drainage (internal)
1. Lateritic ironstone surface	(a) Ironstone rock																			2.5m	generally well drained but with short lived local impedance
	(b) Residual surface gravel	GW	38	15	8	135.7	10.9	92	100	68	55	36	26	20	18	17	16	15	13	0.5m	
2. Hillslope	(a) bouldery gravel	GW/GC	46	20	12	138.5	10.6	82	100	68	54	38	29	26	26	26	26	25	24	1m	well drained, but surface scour occasionally results in erosion
			40	20	8	126.7	11.5	82	100	91	83	72	65	63	62	62	62	60	33		
	(b) sandstone (ferruginised)																				
3. Major Valley	(a) sand/silt	SW/SP	NP			108.6 (BS standard)	11.4	29.5				100	99	99	99	98	98	97	35		well drained permeable surface soils
			23	10	5	121.7 (BS standard)	11.0	11					99	99	98	98	98	96	56		
	(b) lateritic gravels	GW	44	21	12	135.7	8.5	100	100	84	57	24	14	11	9	8	8	7	5		
4. Minor Valley	(i) sand/silt		NP			114.8	9.8	22					100	98	91	83	69	25	9		Well drained

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Table 6 Engineering resources: Gombe Land System

Land facet No. Name	Water supply	Construction materials: Concrete sand	Concrete aggregate	Timber	Road works: Sub-base	Base	Chippings
1. Lateritic ironstone surface	Very feeble. Supply unimportant due to restricted situation				Suitable but uneconomic Surface gravels are suitable	Suitable after crushing and screening Suitable but may require stabilization with lime or cement	Suitable after screening, if no better materials are available Suitable after screening if no better materials are available
2. Hill-slope			Limited supply of medium hard flaggy, sandstone rock and boulder gravels suitable for crushing and screening		Suitable, but usually ill-sorted and with clay fines	Not generally suitable unless stabilised	
3. Major Valley	Perennial supply from relatively shallow surface wells in permeable sand	Limited supply from alluvium		Orchard-bush suitable for kindling but not for construction	Sands are suitable, if better-graded materials are selected. Laterites are suitable	Not generally suitable. Would require stabilisation if used. Low-lying laterites suitable.	
4. Minor Valley	Perennial supply from smaller wells				Suitable if better-graded materials are selected	Suitable but would require stabilisation	

layers of these soils plasticity increases with depth. This leads to the presence of perched water tables after heavy rainfall. In general these soils are permeable and free draining and tend to have low *in situ* densities. At Kuala Lumpur airport the weathered granite soil had a relative density of 85 per cent B.S. heavy compaction, and in construction two feet of soil was excavated and recompacted to achieve a suitable foundation[14].

In the Galla system a typical soil profile consists of a red granite soil overlying decomposed granite over fresh granite. The properties of the soils are very similar to those of the Labu system, and in both systems the soils are influenced by the texture of the parent rock. The results of plasticity and compaction tests on soils derived from fine and coarse grained granite are shown in Table 10.

It can be seen that the soils derived from fine granite have a lower maximum dry density and tend to be of lower plasticity than those derived from the coarse granite. The decomposed granite is of much lower plasticity reflecting the lower degree of weathering.

These soils have a high rating as subgrade material, combining good strength with a free draining soil profile. Laboratory tests show that the addition of cement or lime can produce base-quality material, and soil stabilisation has been used in airfield construction at Kuala Lumpur and Singapore.

Discussion

One of the most important aims of these investigations was to prove that with the assistance of aerial photography it was possible to extrapolate the information gained from one land facet to another area where the same land facet occurred. Thus, it enabled survey effort to be reduced in those areas where the soils were known to present few problems and little variation so permitting greater survey activity in the more difficult situations.

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In current survey practice, the frequency of sampling seems to bear little relationship to the complexity of terrain; terrain evaluation can therefore do much to improve existing methods of survey.

By examining a wide range of soil types, it became apparent that much of the effort put into soil surveys is wasted. Under some roads the variation in subgrade conditions is so small that the design can remain unchanged in essentials for many miles. Often the sources of borrow materials are restricted. Any information, therefore, which can identify the available engineering material resources in advance of surveying on the ground can produce substantial savings in time and costs.

Landscape classification is being carried out by a number of organisations throughout the world. The Land Resources Division of the Directorate of Overseas Surveys is currently extending the mapping in Nigeria after completing similar work in other parts of Africa. Although these mapping schemes are mainly carried out for agricultural purposes, there is growing awareness of the need to include information about engineering features of terrain. Thus, very shortly the Road Research Laboratory expect to contribute a section dealing with engineering terrain conditions to a memoir describing the agricultural potential of North-East Nigeria.

The Department of Agriculture, Oxford University, have recently completed the landscape mapping of Uganda and have produced a map at 1:1,000,000 showing the distribution of some 90 land systems. Each of these has been described, after detailed examination of aerial photography. Supplementary information was obtained from existing geological and agricultural soil reports. So far no immediate plans have been made to gather engineering information, but it is hoped that a start will be made as soon as the necessary co-operation has been achieved.

Terrain evaluation has received considerable attention in Australia. The Division of Soil Mechanics, CSIRO, have developed a method called the P.U.C.E. system involving the use of aerial photographs and land classification, which in principle is very similar to the methods developed in the United Kingdom[15].

In America, attention has been directed mainly towards developing mathematical models for predicting the performance of terrain for different types of engineering usage. This approach has much to offer, and could be used to great benefit in developing countries, provided sufficient data were available. Land classification methods would play a large part in retrieving the necessary information.

Conclusions

Work in the United Kingdom, and in other parts of the world, has shown that terrain evaluation can be used for both classifying and mapping the engineering features of the ground. The system is flexible enough to handle information at all levels and thus can be used to store data accumulated during road-building projects, or any other civil engineering work.

The following points have emerged from the work described in this Paper.

(1) The extent and nature of roadmaking materials and of associated road building techniques can be displayed more effectively by land classification than by interpretation of geological and pedological mapping units. The relation of the soil properties, and of engineering problems and solutions, to land classification is the basis of terrain evaluation.

(2) At the level of the land system, broad but useful generalisations can be made about the availability of materials, suitable construction methods and costs of construction or maintenance.

(3) Land facets and land elements classify information in the detail required for road projects and thus provide a means of recording data in such a way that they can be used to design roads on similar ground elsewhere.

(4) As terrain evaluation is based on a classification of land form it is particularly suited for use with aerial photographs viewed stereoscopically. The initial identification of land systems is often established from single photographs or photo-mosaics.

(5) The storage of information from road projects, in a manner allowing reference when similar ground conditions are encountered, should lead to a decrease in the amount of survey work and an increase in its effectiveness.

(6) The frequency of soil sampling and testing in many site investigations is often disproportionate to that necessary for adequate design purposes. A terrain evaluation can be used to decide the appropriate places and frequency of sampling. Studies made so far have shown that in some cases survey effort could have been reduced by as much as 70 per cent if such information had been available.

(7) Terrain evaluation for engineering purposes uses a classification similar to that widely adopted in agricultural and land-use surveys. This leads to the possibility of integrating engineering surveys with surveys for land development.

In addition to the types of data referred to in the present study, terrain evaluation can be used to record other kinds of engineering information. An example that is directly related to terrain is the quantity of earthworks associated with road building to different geometric standards. There is interest in the use of terrain evaluation as the basis of a highway sufficiency rating; if a highway sufficiency survey were combined with a land-use survey, which is also a form of terrain evaluation, this would form the foundation of an economic feasibility study.

TABLE 7

Suitability for road location: Gombe land system

No.	Land facet Name	Appraisal	Features
1	Lateritic ironstone surface	Unsuitable, owing to isolated facet situation	Flat to gently undulating topography. Generally well drained with abundant supplies of gravel.
2	Hill slope	Generally unsuitable.	Moderate steep slopes, characteristically armoured with bouldery talus overlying heavier soils. Hill wash, sliding and erosion are possible hazards.
3	Major valley	Suitable	Flat to gently undulating topography. Well drained owing to permeable nature of the sandy soils. Spring lines developed at boundary with clay soils.
4	Minor valley	Suitable	Gently undulating topography. Gullying owing to erosion from hill wash may cause problems.

TABLE 8

Labu land system

Climate:	Monsoonal. N.E. monsoon November–March, S.W. monsoon May–September. Mean annual rainfall about 2200 mm. p.a., mean annual temperature about 27°C.
Geology:	Weathered granite of Jurassic or Cretaceous age. Depth to bedrock may be at least 15 m.
Landscape:	An undulating landscape of low, regular, straight-sided interfluves, with a dendritic network of thin fairly straight stream courses and broad flat-bottomed major valleys.
Soils:	Deep brownish and yellowish silty clays with quartz grains (Rengam and Jerangau Series)
Vegetation:	Mostly rubber plantations, with occasional patches of jungle and scrub.
Altitude:	30–60 m.
Relief:	Up to 30 m, but may be up to 50 m in the vicinity of isolated hills.

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TABLE 9
Facets of Labu land system

Land facet	Form	Soils, materials and hydrology	Land cover
L1	**Interfluves** Slopes very gentle to gentle (2–5°), more or less straight; sides about 100 m long meeting in a convex elongated interfluve crest; up to about 100 m high. Margins with Facet L4 may be very gently concave or abrupt.	(i) Rengam Series. Up to 15 cm of dark greyish-brown friable sandy clay loam over brownish-yellow sandy clay which may be 2–15 m deep. (ii) Jerangau Series. Similar to Rengam except that subsoil is strong brown to yellowish red sandy clay loam.	Almost entirely planted with rubber; small patch of jungle remains in the south.
L2	**Isolated hills** Straight, moderate to steep slopes (up to 30°), usually elongated in plan, sides meeting in narrow ridge crest; up to 600 m long and 10–30 m high; occur locally at N. end of land system.	As Facet L1, but depth to bedrock may be less.	Sundry tree cultivation; rubber on less steep slopes.
L3	**Minor valley floors** Flat, more or less straight, narrow, but width may suddenly vary between 10 and 100 m; valley heads often about 50 m across; abrupt margins with Facet L2. Sinuous stream course a few m. wide.	Perak Series. Grey, mottled yellow silty clay loam over blue-grey silty clay loam over alluvium; iron concretions may occur. Imperfectly drained: streams flow for short periods a ter rain.	Mostly rubber, with occasional small patches of grassland.
L4	**Major valley floors** (a) Floor. Level, fairly straight, 150–500 m across; margins with Facet L1 sinuous in plan. (b) Footslopes. Level to very gently sloping; straight or slightly uneven slopes; 150–600 m wide, 400–1200 m long, irregular outline in plan. Upper margin with Facet L4a may be a short steep bluff up to 2 m high, or gently merging. Occurs locally only in N. part of land system at the foot of the adjoining granite hills (Galla land system). (c) Small stream. Very narrow (few metres wide), and sinuous.	(a) As Facet L3 (Perak Series). (b) As Facet L1 (Rengam Series) (c) Perennial flow.	(a) Flattest areas under paddy fields, better drained parts mostly sundry tree cultivation; small areas of rubber and scrubland. (b) Rubber plantations.

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TABLE 10
Plasticity and density characteristics of granitic soils.

	Liquid limit %	Plastic limit %	Plasticity Index	Linear shrinkage %	Max. B.S. Dry density lb./cu. ft.	Optimum moisture content %
LOWLANDS (LABU)						
Coarse granitic soil*	85	34	51	16	109.5	16.0
Coarse granitic soil	88	40	48	18	108.5	16.4
Fine granitic soil	64	30	34	16	89.5	28.8
MOUNTAIN (GALLA)						
Coarse granitic soil	69	36	33	15	111.5	16.0
Decomposed coarse granite	39	29	10	5	108.2	17.1
Fine granitic soil*	62	35	27	15	93.0	22.5

* Samples taken outside area shown in Fig. 5.

LANDSLIDE INVESTIGATIONS

A Field Handbook for Use in Highway Location and Design

By Arthur B. Cleaves
Highway Research Engineer
Division of Physical Research
Bureau of Public Roads

(Presently Professor of Geology and Vice Chairman
Department of Geology and Geological Engineering
Washington University, St. Louis, Mo.)

U.S. DEPARTMENT OF COMMERCE
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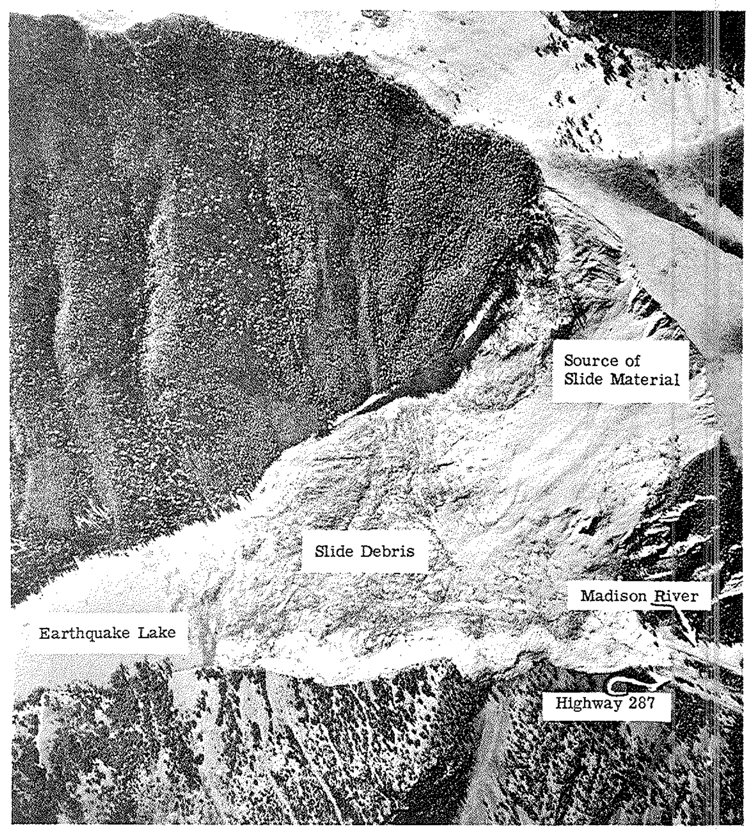
THE MADISON CANYON LANDSLIDE

The Madison Canyon landslide, illustrated on the facing page and on the cover, occurred about 20 miles northwest of West Yellowstone, Montana, and was triggered by an earthquake on the night of August 17, 1959. Rocks in the canyon wall consist of gneiss and schist supported by dolomite. The earthquake broke the dolomite support and about 40 million cubic yards of debris tumbled into the canyon, creating a dam 400 feet high and two-thirds of a mile long.

The slide buried Montana State Highway 287 and blocked the Madison River. Faults in the vicinity also cut Route 287 in several places and disrupted traffic on U.S. Highway 191. Earthquake Lake, which developed by impoundment of water behind the slide-dam, covered additional portions of Route 287.

(Photograph courtesy Jack Ammann, Photogrammetric Engineers, Inc.)

MADISON CANYON LANDSLIDE



PREFACE

This field handbook on landslides and related problems has been prepared primarily for the highway location engineer, although other engineers, as well as geologists, teachers, and students, may find it useful. It is not, however, intended to be represented as an exhaustive treatise, comparable to the reference mentioned below. The typical field engineer is expected to have a working knowledge of a wide variety of subjects, and can hardly be expected to be expert in them all. As in other areas, when the field engineer encounters unusual or complex landslide problems he should seek the advice of experts specializing in this subject.

The handbook is condensed in a deliberate effort to provide a work that may be used in the field. It is divided into four parts. The first is a very brief introduction to geologic processes, rocks and soil types, and geologic structures which provide the setting for landslides. The second involves the recognition of phenomena presaging the advent of slide movements, and those characteristic of the landslide itself. The third is devoted to methods of landslide prevention, control, and correction. The fourth discusses details of mapping and reporting landslides.

The numerous illustrations are so captioned that they are self-explanatory. They include not only conventional techniques but some unique methods in overcoming landslide problems.

The brief glossary defines the words and their usage that might be unfamiliar to the highway location engineer.

Five principal references are listed at the back of the manual. In them, in addition to their own valuable content, the interested reader will find bibliographies covering books, articles, and other references on landslides far beyond the intended scope of this manual.

The author is a member of the Committee on Landslide Investigations of the Highway Research Board, which prepared *Landslides and Engineering Practice*, HRB Special Report No. 29, 1958. Acknowledgment is made of close adherence to the form and outline of several chapters in that report.

Acknowledgment is made of the courtesy of several State highway departments and others in furnishing some of the illustrations. In addition to those specifically credited, figures 22, 23, and 27 were taken (with some modification) from Highway Research Board Special Report No. 29, mentioned above, and some of the other illustrations are from a file of photographs of the HRB Committee on Landslide Investigations.

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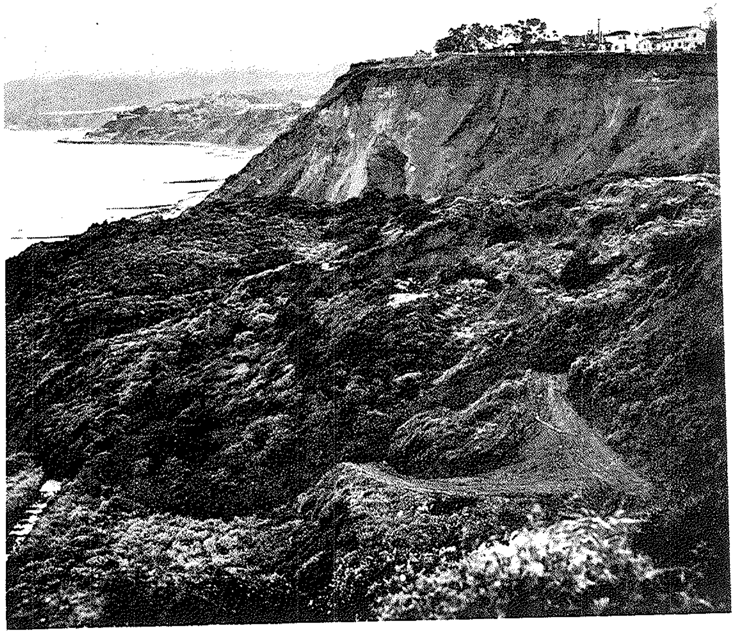

Figure 1.—Slump-type landslide which covered U.S. Highway 101 at Pacific Palisades, Los Angeles County, Calif. (Courtesy California Division of Highways.)

Part 1.—INTRODUCTION

Primary Features of Landslides

A landslide is the "downward and outward movement of slope forming materials composed of natural rock, soils, artificial fills, or combinations of these materials." [1] Landslides in the strict sense do not include creep phenomena, or subsidence, but these topics are included here because of their relation to the nonstability of slopes and because they merge into embankment and slope failure.

The movement may be fast, as in the case of an avalanche, or it may be slow, involving hours or even days. The volume of material may be millions of cubic yards (frontispiece and fig. 1) or it may be very small.

The downward and outward movement of materials normally results in the development of the features shown in figure 2, although some of these features may not be readily identified in a specific landslide.

Problems and Cost

The landslide threat to highway location has always been present, but as we emerge farther and farther from the age of Indian trails and oxcart traces, the danger of slides has become more apparent. The demand for highways with gentler grades and straighter alinement has required deeper cuts, higher fills, and frequent location on unsuitable terrain. The inclusion of these necessary features in the highway design and location has interfered with both natural surface and subsurface drainage systems and compounded the slide problem.

The problems created by landslides are too numerous to list, but include highway clearing and relocation, procurement of additional right-of-way, and disruption of traffic. Dislocation of utilities, loss of land and buildings, in addition to street damage, are the most common results observed in urban areas. Landslides in urban areas, along highways, railways, irrigation canals, reservoirs, and in other similar environments usually require control or correction.

[1] Quoted from first reference cited on page 67.

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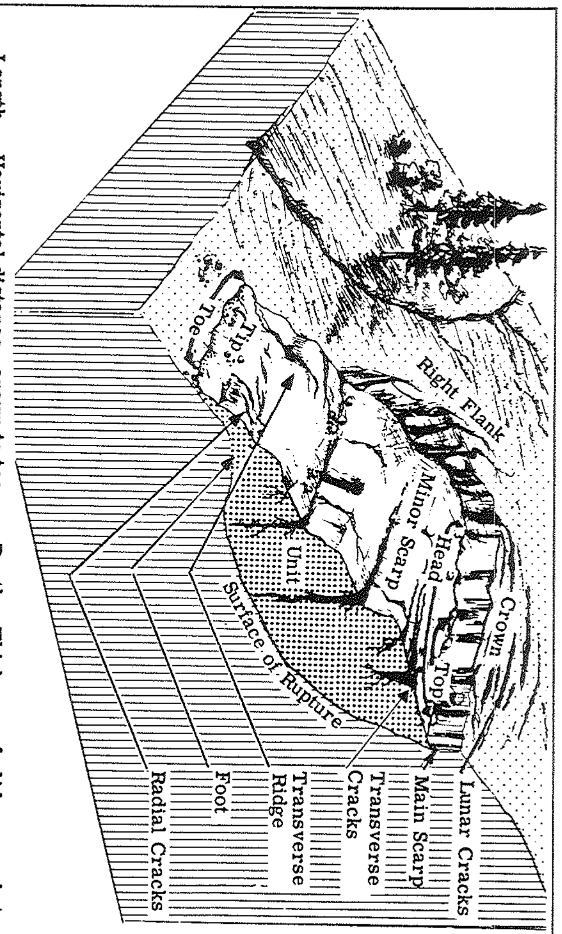

Length = Horizontal distance, crown to toe.
Width = Horizontal distance, flank to flank.
Height = Vertical distance, toe to crown.

Depth - Thickness of slide mass, between foot and crown. (Foot is line of intersection between the lower part of the surface of rupture and the original ground surface.)

Figure 2.—Slide nomenclature.

Attempts have been made to evaluate the costs of landslides in the United States. However, so many factors become involved, in addition to actual physical damage and the necessary corrective measures, that it probably will never be practicable to estimate them accurately. The costs undoubtedly amount to millions of dollars annually, without including the loss of human life and the interruption to normal use of public facilities.

Importance of Preliminary Office Study

The initial approach to any highway location investigation involves a library study of the literature and of aerial photographs. There is no necessity for embarking on a highway location study without some prereconnaissance knowledge of the problems likely to be encountered, because essentially all of the United States, and much of other countries, are well described in geographic and geologic literature. The general topographic and drainage features, the soil types, and the basic geology and geologic structure can be roughly evaluated before the field study is begun.

Preknowledge of this type means different things to different engineers. If the highway engineer has a good background in physical geology, geomorphology, and groundwater hydrology, he can anticipate potential subsidence and landslide areas, unfavorable foundation problems, soil origin (transported or residual), and can even approximate a good estimate of the physical properties of the soil. On the basis of his training or review of the literature, he would also have an inkling of the soil fabric, the bedrock structure, the subsurface hydrology, and many other phenomena.

Obviously, a location engineer who does not know the difference between basalt and granite, metamorphic and sedimentary rocks, and ancient beach deposits and glacial tills, is not going to profit much from an investigation of the geological and soil literature. Nevertheless, and in spite of a limited background in geologic knowledge, a perusal of the literature will be of some help to him.

Although a literature investigation does not obviate any part of the actual location studies in the field, it does simplify them.

Geologic Processes and Their Effect on Terrain

The ground conditions encountered in the field are the direct result of geologic processes operating on and within the earth. Such processes are the movement of surface and subsurface water, weathering, glaciation, tectonics, wind, and vulcanism. The terrain features also are the result of the same processes having operated in the geologic past. These processes, significant in themselves, are often interrelated; hence, the ground features may be the result of a composite of them.

The intensity and importance of many geologic processes in any specific area are dependent upon geographic location, climate, relief, parent material, and time. Variations in any one or a combination of these can result in a totally different landform. For example, limestone strata in arid regions may form protective caps on mesas. In semihumid areas, the softness and relatively high solubility of the limestone accounts for its presence in valley floors.

The highway location problems in relation to the effects of glaciation are very different with respect to the relief of the region. In areas of the North Atlantic States, nearly mountainous country, steep-sided moraines, kames and kame terraces, kettle holes, and similar features pose quite different problems than do the areas of low relief, flat till plains, and loess deposits of Illinois, Indiana, and Missouri. Therefore, although one geologic process—glaciation—has been dominant over the others, the highway problems are not the same in the two regions.

Rock Type and Geologic Structure

The rock types provoke problems of many different kinds that have to be considered by the highway engineer. Forgetting for the moment all of the variations in each attributable to geologic processes, let us consider only the general rock types—igneous, sedimentary, and metamorphic. Each of these major rock divisions can be broken down into many categories, but it is proposed to consider here only broad characteristics.

Igneous rocks

Igneous rocks originate from a molten melt deep below the surface of the earth. Those that solidify within the upper layers of the earth's crust cool slowly, are coarse grained, and are called intrusive. Those that flow, or are blown out onto the surface of the earth, are called extrusive.

The intrusive igneous rocks, such as most granites, diorite, gabbro, and the like, are reasonably homogeneous and, unless fractured and broken by subsequent deformation and mechanical weathering, make excellent foundation rock and permit steep excavation slopes. When

the rocks are crushed, the coefficient of friction on the rupture planes is usually high, and steep slopes and stability may still be obtained.

The extrusive igneous rocks vary from medium- to fine-grained lava flows, and volcanic ejecta ranging from coarse, angular blocks and spindle-shaped volcanic "bombs" to cinders and fine-grained ash. Lava flows, cinders, and ash deposits, whether firmly indurated or not, have to be treated the same as layered sedimentary rock. The degree of induration or lithification controls the steepness of the slopes excavated in them, but interlayering of "hard" and "soft" sequences, such as lava underlain by cinders or ash, may require compound slopes.

Sedimentary rocks

Sedimentary rocks are derived from the disintegration, decomposition, transportation, and deposition of materials derived from preexisting parent rock. They are divided into two principal groups: (1) mechanical, or clastic sediments, in which transportation and deposition have been chiefly by mechanical means; and (2) chemical sediments, in which the material has been carried in solution and later precipitated. The clastic sediments consist of such rock strata as conglomerate, sandstone, siltstone, and shale, whereas the chemical sediments include most limestones, dolomites, chert and flint, rock salt, anhydrite, and others.

There can be no broad generalizations about which sedimentary rocks will stand up well with steep slopes. If the strata are thick-bedded and firmly cemented or lithified, they will stand well; if not, the engineer must use judgment in determining the permissible slope. Shales are perhaps the most difficult to analyze because of the tremendous range in their physical characteristics. Some, as the Pennsylvanian clay shales of Missouri, are essentially hardpans or claypans. Others, as the Conemaugh shales of western Pennsylvania, eastern Ohio, and West Virginia, disintegrate and slough very rapidly, and are foci of weakness for landslides in this region. Still other shales are very highly lithified and stand weathering well.

In general, the thin-bedded and "soft" strata, and interbedded sequences of firm, massive rock and soft, weak rock, will require gentle slopes, or compound slopes.

If the sedimentary strata are steeply inclined and the highway cut is made at a right angle to the strike, or trend of the rock, steep slopes are possible even though there may be weak members in the sequence. However, if the highway line parallels the strike in a cut area, it is obvious that on one side of the cut the strata dip away from the excavation, and on the other, toward it. In the case of the former, steep excavation slopes (fig. 3) are feasible, but in the latter, unless the cut slope parallels the dip of the bedding planes, special precautions must be taken to prevent slope failure.

Metamorphic rocks

Metamorphic rocks are formed from previously existing igneous or sedimentary rock by the action of heat or pressure, or both. There are two principal types of metamorphism: (1) contact metamorphism, coming chiefly from the action of heat and solutions; and (2) dynamic metamorphism, resulting primarily from the action of differential pressure.

Marble, quartzite, and slate may be stronger and more durable than their sedimentary equivalents, limestone, sandstone, and shale, but the strongly foliated schists and gneisses can be very treacherous. The dynamic stresses to which these rocks have been subjected caused the development of foliation, which implies the ability to split along approximately parallel surfaces due to the distribution of layers or lines of one or more conspicuous minerals in the rock.

Structural features

Fractures, faults, crush zones, and similar structural features in rock must be evaluated in relation to their effect on the stability of slopes and the supporting value of the rock. Fractures in carbonate sedimentary rocks and other soluble rocks, such as gypsum, may allow circulating groundwater to develop solution channels and caverns, which pose their special types of problems to the road builder.

Rock Weathering and Soils

The distinction between soil and rock is not always clear. Engineers generally consider unconsolidated or semiconsolidated material that can be moved by common excavation equipment without blasting as soil material.

The weathering of rock in situ produces a residual soil. Two types of weathering are responsible for the destruction of rock and the ultimate production of residual soil—mechanical (disintegration) and chemical (decomposition). The climate (temperature and rainfall) determines the type of weathering that prevails. Mechanical weathering predominates in northern cold climates and in arid regions, while chemical weathering dominates in tropical regions with high year-round temperatures and rainfall. For example, the soils developed in the Arctic from a granite parent material are granular, chiefly colluvial soils, and are derived primarily by mechanical weathering. The various mineral components that made up the granite are chemi-

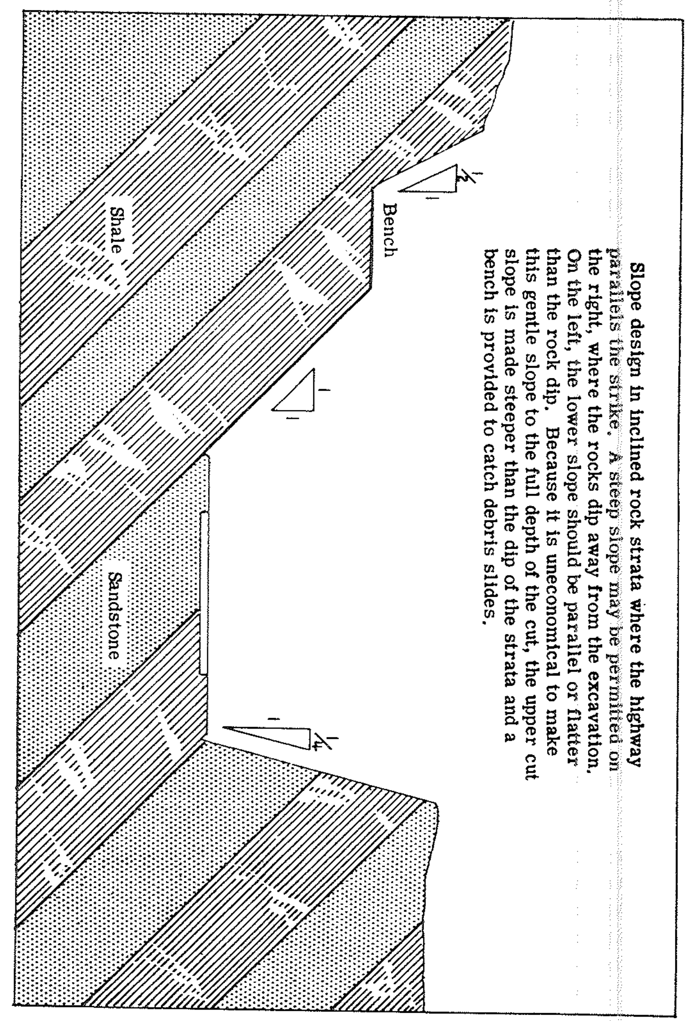

Figure 3.—Compound slope design in inclined rock strata.

cally unaltered. On the other hand, the same granite in the wet tropics is chiefly affected by chemical weathering so that, except for its quartz mineral component, all of its other constituents are chemically altered and many are decomposed into clay-type soils.

Grain size and structure of the rocks (rock type) and the length of time the geologic materials are subjected to weathering play an important role in determining the soil that is developed. Geologic materials exposed in tropical climates for extended periods of time may be weathered to depths of more than a hundred feet.

Downward movement of the water through the weathered soil material results in leaching near the ground surface and accumulation of clay-size particles at a slight depth. These accumulations of clay particles, which occur mostly in humid, temperate climates, may restrict the downward movement of water and have low strength when wet.

Slides in residual soils are common when there is seepage due to variations in permeability of strata or layers of the soil or when seepage from the underlying rock permeates the residual soil on sloping ground. Residual soils in areas underlain by stratified sandstone and shale are particularly susceptible to landslides. Soils with a high mica content derived from schist, gneiss, or phyllite are easily eroded and are subject to slumping when saturated with water.

Transported soils are those that have been deposited by the action of wind, water, or ice. There is a variety of transported soils because of the varying agencies of deposition, composition, time exposed to weathering, and climate.

Glacial deposits are extensive in the northern United States and other parts of the world that were subjected to continental glaciation. "Glacial drift" is a term commonly used when referring to all glacial deposits, irrespective of their mode of deposition. These deposits are usually divided into two classes: (1) those that were deposited directly by glacial ice, and (2) those that were deposited by glacial melt waters.

Glacial ice deposits are called moraine or till. These till deposits are characterized by being heterogeneous in grain size (sometimes varying from boulders to clay), unsorted, and variable in composition.

Glacial water deposits such as eskers, kames, kame terraces, glacial river terraces, outwash, and lacustrine sediments are generally associated with till, but unlike the latter these have been reworked, transported, and deposited by water. Rounding of particles, stratification, lensing, and abrupt changes in grain size vertically and laterally are characteristics of these materials.

Seepage zones occur frequently in glacial water deposits that consist of alternating permeable and impermeable layers. Similarly, saturated pockets or lenses of sandy soil occurring in glacial till result in water seepage in backslopes of highway cuts. Such sequences of soil materials, coupled with high water contents, are likely to result in slumping and sliding of these materials in highway cut slopes, particularly in steeper topography. Since these situations cannot always be avoided, adequate drainage provisions must be made to insure stable backslopes.

Glacial till has a tendency to creep or slump downward along steeper hillsides (solifluction) under the influence of freezing and thawing. Movement occurs during spring thaws, when the soils are waterlogged.

Windblown silty sediments known as loess are widespread in the midwestern and northwestern States. These deposits are fairly uniform in composition and grain size. A peculiar characteristic of most loess is that vertical backslopes of highway cuts are relatively stable, whereas those on a flatter slope are more susceptible to erosion and slumping. However, this structural characteristic of some loess is not universal, and local field investigation of existing cut slopes is needed before deciding that vertical backslopes should be recommended.

Sand dunes are wind deposits that contain coarser grained materials than loess. Although highly susceptible to wind or water erosion, the dunes are not susceptible to sliding unless the angle of repose of the sand grains is exceeded.

Fluvial or alluvial (water) sediments such as river alluvium (recent river deposits and terraces), alluvial fans, valley fill, and Coastal Plain sediments represent a large portion of transported soils in the world. These have many of the characteristics indicated for glacial water deposits.

Colluvial deposits occur at the base of steep slopes, and are primarily due to gravity action. However, considerable sorting of particles by water action has occurred in some deposits. The colluvial deposits that have lenses of fine-grained material interspersed with layers or lenses of coarser grained material are particularly susceptible to sliding or slumping.

In addition to the soils discussed above, there are particular weathering conditions and topographic situations that produce special soils, such as organic deposits (peat bogs, tidal marshes), lateritic soils, and alkali or saline soils.

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Effect of Construction on Local Stress Conditions

Changes in stress conditions of geological and soil materials in the roadway section may have a dynamic effect on the highway. The location engineer should have sufficient training and experience that he will recognize the possibility of potentially deleterious stress conditions in the soils and geologic materials of the proposed highway location, and assure that an adequate investigation and analysis will be made.

Stresses in the geologic or soil material may be increased by any of the following factors:

The addition of a fill or other structure;

Traffic loads;

Blasting and construction vibrations.

Other factors that may affect the ability of the geologic or soil material to withstand the change in stress condition caused by construction are as follows:

An increase in the water pressure in the soil by impoundment of surface water or through blocking of subsurface flow by impervious fill, freezing, or compaction under fills;

Leakage of water from culverts, water mains, and canals;

Infiltration of surface water resulting from stripping the protective overburden from a stiff, fissured clay;

Exposure of geologic materials, permitting water to enter fractures and joints and accelerate weathering;

Swelling of clays when the confining load is removed.

This brief discussion has been included with the intention only to give the engineer some appreciation of the relationships of geological processes, structures, and rocks to landslide phenomena.

Part 2.—LANDSLIDE RECOGNITION

Approach to the Problem

In any location study, assuming that the territory is one where the engineer has had no previous experience, the first and obvious step is a study of the geological and soil literature and any aerial photographs available for the projected route. Through this study, he becomes acquainted with the rock types and their relationships and structural attitude, as well as the soil and ground conditions that must be considered in route location and highway design.

Survey of geological and soil literature

The highway location engineer needs specific geological and soil information relative to an exact geographic area. The broad generalities and enunciation of basic principles found in text books are not much help when what he needs applies to a certain area in a particular county and township. Consequently, he must know where to look, and what types of geologic information are available.

The principal sources of such information are the maps and publications of the United States Geological Survey and the State Geological Surveys. These essential source materials may be found in most government engineering agencies, in many public libraries, and college libraries wherever geology is taught. Many utility companies, engineering organizations, and others possess geological literature and maps pertinent to their local areas of interest.

The geologic maps range from general, covering the entire area of North America or South America (published by the Geological Society of America), and State geological maps, published by the individual States, to county and quadrangle geological maps. In many States the county maps are accompanied by published bulletins detailing the local geology. In addition, New Hampshire has modern coverage on a topographic quadrangle basis, published by the New Hampshire Planning and Development Commission.

The U.S. Geological Survey is publishing more and more quadrangle geologic maps on a topographic base. One series of these is specifically to cover the development of the Missouri River Basin. Comprehensive geologic data and some engineering information are printed on these map sheets.

The U.S. Geological Survey has published geologic map indexes for all States. These may be purchased from the Distribution Section, U.S. Geological Survey, Washington 25, D.C., or from the Distribution Section, U.S. Geological Survey, Federal Center, Denver, Colo.

The geological literature being published annually is not all found in Federal and State publications, but also in publications of many different geological organizations. To search out and find a particular report on a specific area would be a hopeless task were it not for two principal, regularly published bibliographies. For North America, the Hawaiian Islands, and Guam, the U.S. Geological Survey publishes the *Bibliography of North American Geology* in bulletin form, containing separate indexes listed by author, subject, and State. Geological literature and maps published for areas outside of the United States are reported in the *Bibliography and Index of Geology Exclusive of North America*, published regularly since 1933 by the Geological Society of America, 419 West 117th St., New York 27, N.Y.

In addition to these sources, the State Geological Surveys will furnish lists of maps and geological reports issued under State auspices.

The Soil Survey maps and bulletins, prepared by the U.S. Department of Agriculture in cooperation with State agencies, provide useful information regarding the soil mantle that overlies the bedrock. The recently published bulletins may be obtained from the Superintendent of Documents, Government Printing Office, Washington 25, D.C. Reference copies are usually available in the local offices of the Soil Conservation Service, U.S. Department of Agriculture, and in State and public libraries. The Bureau of Public Roads and most of the State highway departments assist in preparing the engineering applications section of these bulletins, which makes them have greater value in engineering. Some of the bulletins published in the 1958–61 period have an engineering applications section and most of those published after 1961 will have one.

Use of aerial photographs

From aerial photographs, the engineer can obtain a measure of understanding of terrain features, such as slopes, drainage, vegetation, roads and trails, and similar phenomena. If highly skilled in photo-interpretation, he can gain an understanding of much of the basic geology and physiographic features.

Many location engineers have not had sufficient training in either geology or aerial photographic interpretation to be able to visualize the geologic structure or the meaning of the geomorphology from photographs. Nevertheless, even those without such experience can interpret the presence of such ground conditions as landslides, swampy

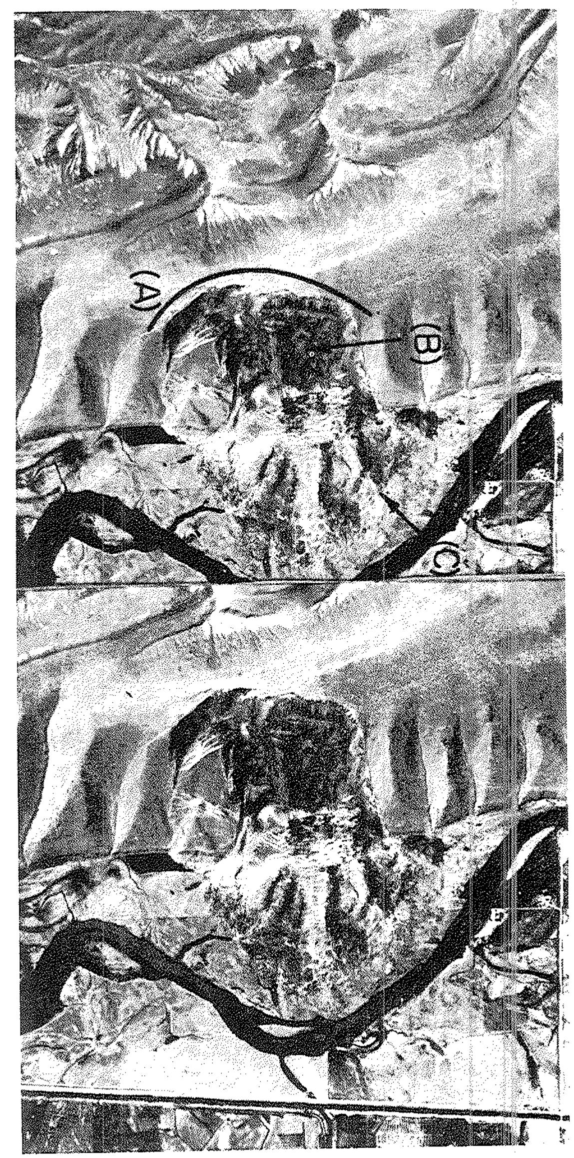

Figure 4.—Stereogram showing typical characteristics of a landslide on aerial photographs: Semicircular scarp (A); depression (B); and hummocky topography (C). Location in Yakima County, Wash. (Courtesy U.S. Department of Agriculture.)

areas, flooded areas, highly erodible areas, and rugged topography from the aerial photographs. He can also identify many simple geologic formations. It does not take a geologist or a skilled aerial photographic interpreter to identify a volcanic cone or an alluvial fan. It is axiomatic, therefore, that with very little specialized training, the location engineer can derive significant benefits from the use of aerial photographs. It is also axiomatic, of course, that a location engineer who is well equipped with knowledge of geology and aerial photographic interpretation can do a far better job.

Of what help is the study of these photographs in spotting actual landslides? Landslides have a typical appearance on aerial photographs that makes them easily discernible (fig. 4). The typical characteristics include a semicircular scar (main scarp in fig. 2), and a spoon-shaped area of disturbed ground with hummocky topography and undrained depressions. For the most part, only relatively large slides are likely to be identified on photographs having a scale smaller than 1:20,000. The one exception to this somewhat broad statement is the avalanche, where long, light-colored, linear scars, in areas of great relief, show up on the slope (fig. 5).

Within the scope of the author's experience, more than 90 percent of all landslides requiring control or correction have been small, averaging less than 500 feet in width from flank to flank, and 100 to 200 feet in length from crown to toe. The majority of these are discovered when they have only begun to encroach on the highway shoulder; hence, they are hardly discernible on aerial photographs with scales of 1:20,000 or smaller. Consequently, these small-scale photographs are of more help in spotting suspicious or potential landslide areas than in identifying the slides themselves (fig. 6). However, with the use of modern photogrammetric methods for the preparation of topographic maps and the design of highways, aerial photographs with scales of 1:10,000 or larger are obtained for many highway projects. Many of the small slides can be identified on the large-scale aerial photographs.

Location traverse

Subsequent to a study of geologic reports and the aerial photographs, the location engineer makes a reconnaissance study of the proposed line in the field. With this background, he should be able to recognize and identify old or active slides and, in many cases, pin-point potential ones. Recognition and planning for corrective action at this time constitute slide prevention. Many future slide areas cannot be identified positively at this time, of course, because of the vegetative mat masking the overburden and bedrock. However, preliminary core

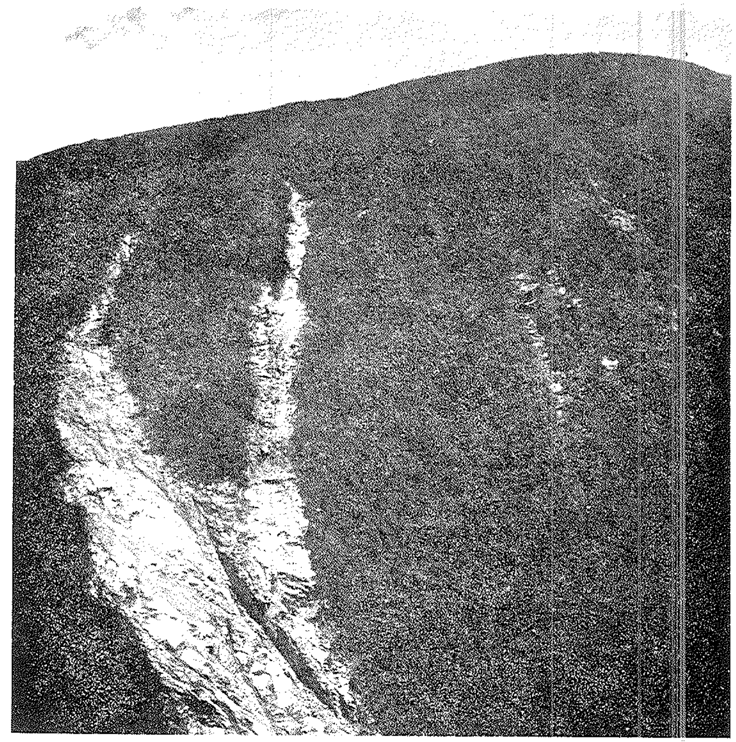

Figure 5.—These long narrow scars are characteristic of avalanches. Although such slides are shallow in depth, their movements may attain very high velocities. They are generally restricted to regions of high relief, and highway location in such areas is difficult. When relocation is not feasible, sheds and even tunnels are resorted to in efforts to keep the highway open. Location in Franconia Notch, N.H. (Courtesy New Hampshire Department of Public Works and Highways.)

borings and geophysical surveys in proposed cut areas may reveal suspect conditions, and result in a design to prevent or avoid serious slides.

The depth of a proposed cut and whether it is a sidehill cut or not may have little bearing on whether excavation will initiate a slide.

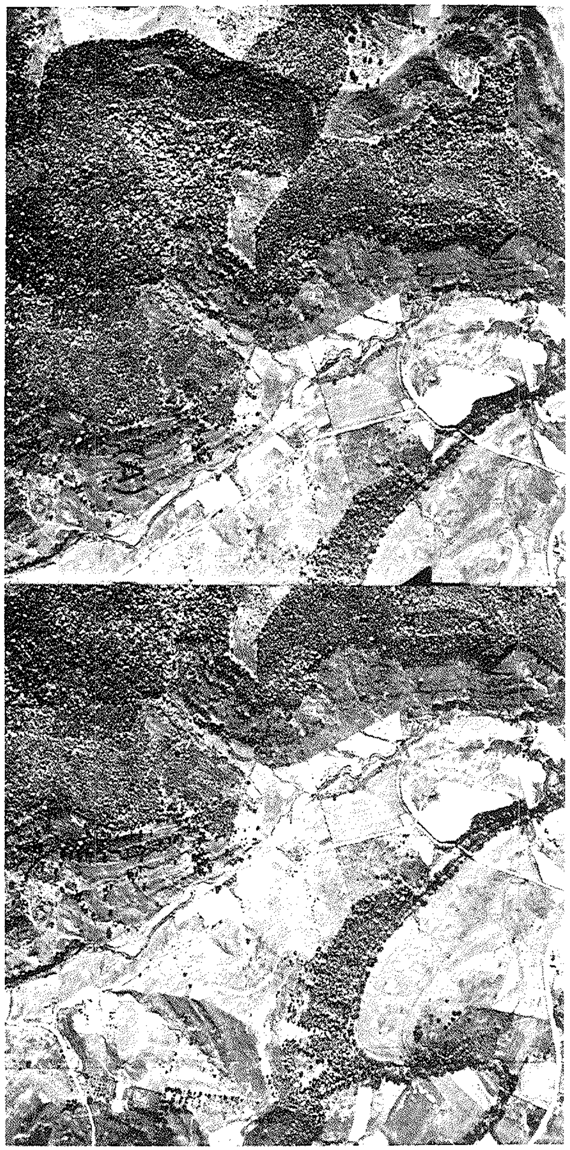

Figure 6.—Stereogram showing a potential or at least suspicious landslide area (A). The presence of steep slopes, stratified sandstones and shales, seepage zones, and small slumps are evident in the stereogram and indicate that this is an area where road construction should be avoided. Location in Jackson County, W. Va. (Courtesy U.S. Department of Agriculture.)

For example, in one community near Pittsburgh, Pa., an 8-foot cut made at the toe of a slope triggered a slide about 500 feet wide and several hundred feet long. This resulted in the total destruction of six homes and damage to others, and dislocation of a State highway, a streetcar line, and overhead and underground utilities.

Another urban landslide involving less than 25 cubic yards of material caused the rupture of an underground gas line. Subsequent gas seepage through the shale bedrock entered two buildings near the crown of the slide and caused explosions that resulted in extensive damage. This slide was chiefly caused by a surcharge of paving blocks dumped on the slope, but also owed slope sensitivity to recent heavy rainfall and thawing ground.

These examples serve to point out the fact that small slides deserve just as serious consideration as large ones.

Problems in Cut Areas

What should the location engineer look for, with respect to landslides, in future cut areas?

Steep slopes

On steep slope locations, the engineer should look for the following:

Cohesive clayey soils that are, or may become saturated. These are soils in a sensitive condition which, when disturbed by removal of the vegetative cover, or by excavation, will start to move.

Unconsolidated materials having relatively low shear strength.

Inclined bedding planes of sedimentary rock strata, when the bedding planes incline toward the proposed excavation (fig. 3).

Foliated and schistose metamorphic rock, where the planes of foliation and schistosity not only incline toward the proposed excavation, but where micas or serpentine are concentrated on the lineation planes.

Decomposed igneous and metamorphic rocks susceptible to large increase in moisture content. Additional chemical weathering of such rocks may very quickly reduce their shear strength past the critical point.

Fracture systems, faults, and crush zones, in the excavation slopes, acting as decomposition zones, and even as water conduits.

Unfavorable rock sequences likely to produce rock or soil falls. These may be anticipated by recognition of geologic conditions apt to produce overhanging or over-steepened cliffs (fig. 7). Examples are: massive lava flow over strongly fractured flow, or poorly consolidated tuff; thick beds of sandstone or limestone underlain by clay, soft

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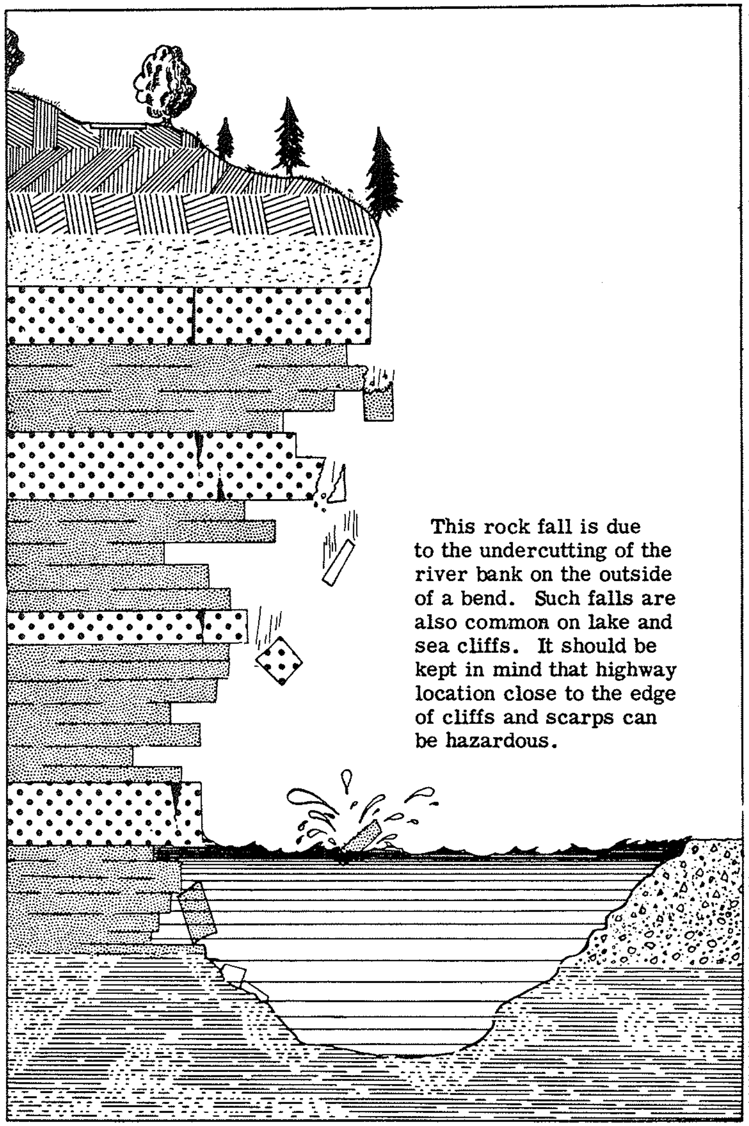


Figure 7.—Rock fall.

shale, or coal; frozen ground or fractured rock subject to local thawing; and firm, cohesive, or partly consolidated soil over noncohesive soil that is subject to erosion.

Water

Water conditions that the engineer should look for include the following:

Surface water accumulated in sags, depressions, or ponds, in the slope, above the slope, or near the toe of the slope (fig. 8).

Groundwater seeping through the soils, rocks, or rock structures in the slope, or saturating it so that there are high pore pressures, or hydrostatic pressures; and seeps over impervious beds underlying pervious beds. An occasional or seasonal high groundwater table may produce these conditions in an otherwise stable slope. Furthermore, the blockage of "piping" through a pervious layer may suddenly increase hydrostatic conditions and the pore pressure, and cause a slope failure. Groundwater, it is generally agreed, is the most important contributory cause of landslides.

Location close to bodies of water

The location of highways close to rivers, streams, and reservoirs should be examined closely, not only because of the possible poor supporting value of the terrain of low ground, but also because of the phenomena listed below:

Undercutting of the banks on the outside of bends of streams, and wave action on the sides of reservoirs.

Sudden release of "bank storage" water in streams after flood stage (fig. 9). This is most likely to occur in streams tributary to major rivers.

Rapid drawdown of reservoirs, resulting in release of pressure and "bank storage."

Surcharge on river banks, subject to sudden changes in moisture content. The surcharge might be stockpiling or wasting of materials, or even highway embankment construction (fig. 10).

Erosion of silty river banks too rapidly for slide development during the erosion. A cessation of erosion can cause slide failure of the silt banks.

Reduction of evaporation, causing failure due to swelling of clays by absorption of water.

Slopes situated above mines, etc.

On slopes above mines (fig. 11), actively pumping oil fields, or shallow water aquifers from which large volumes of liquids are being

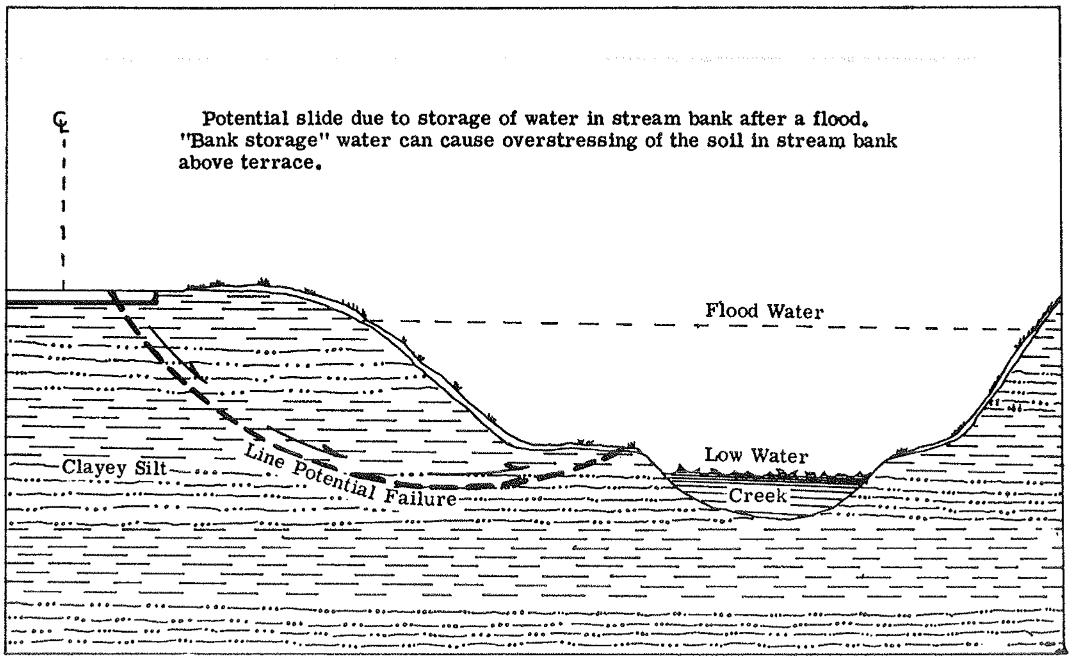


Figure 9.—Potential slide due to streambank water storage.

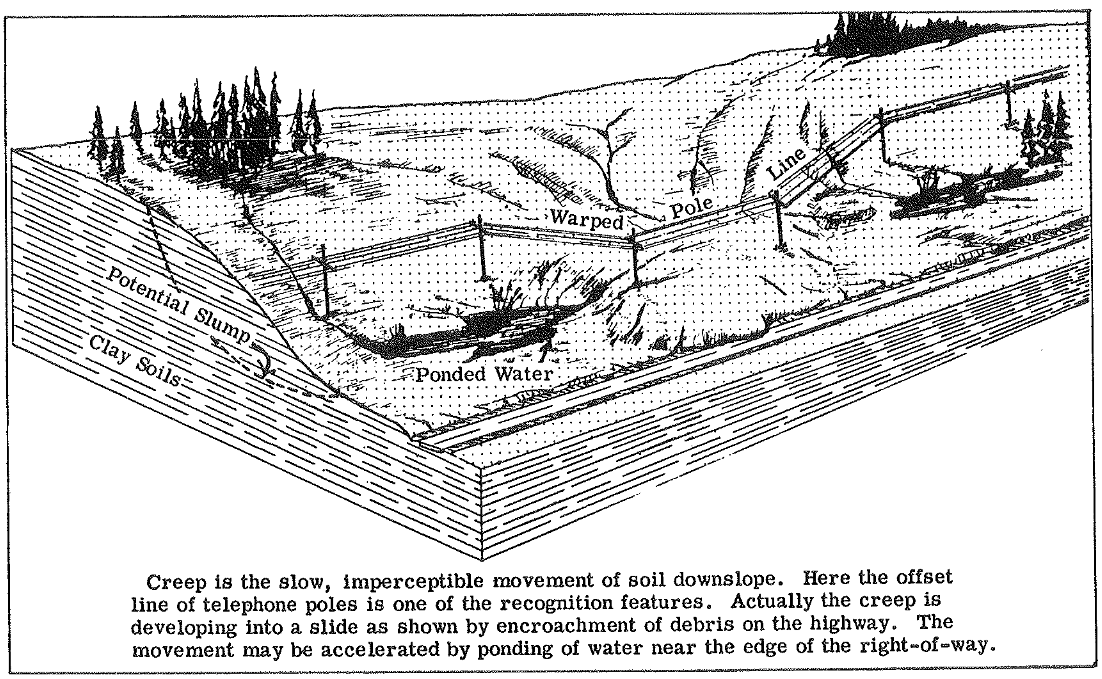


Figure 8.—Creep and ponded water.

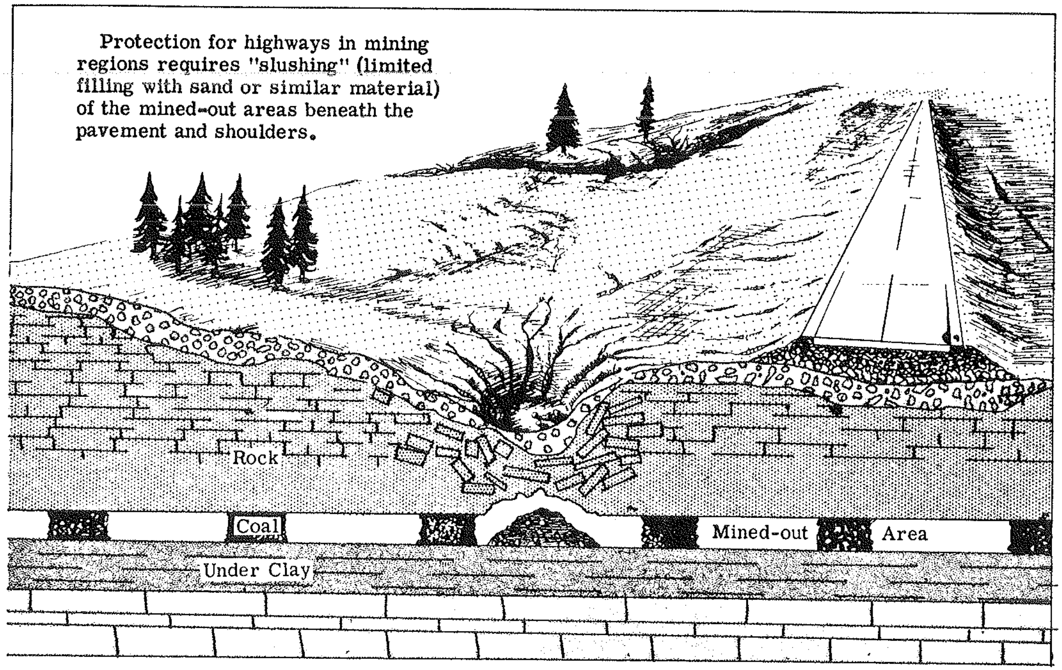


Figure 11.—Mine-caved aréa.

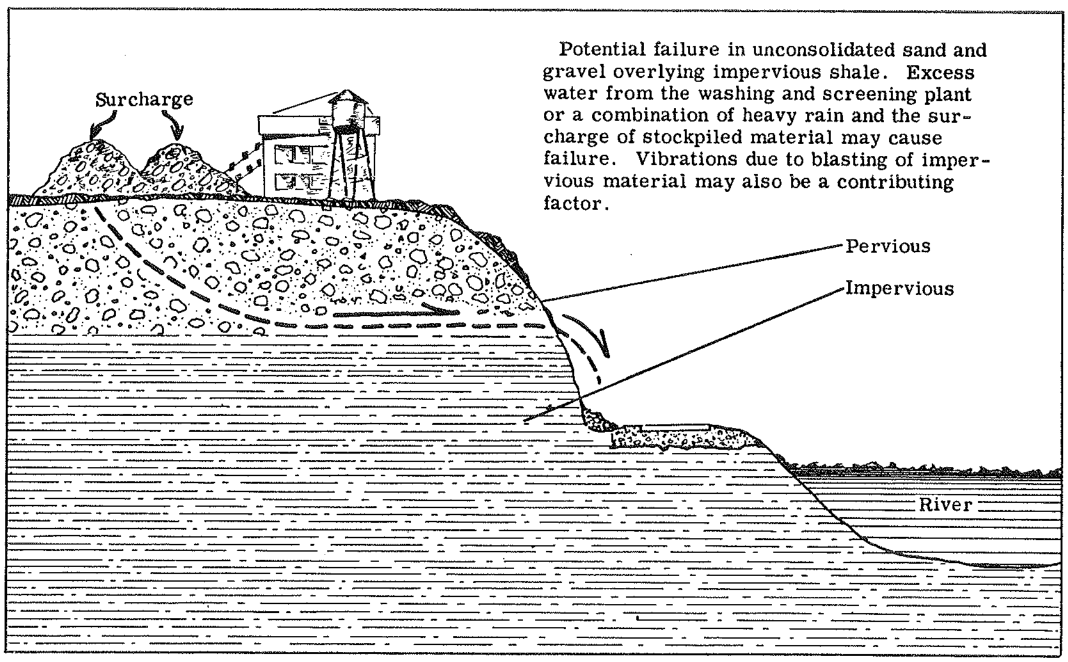
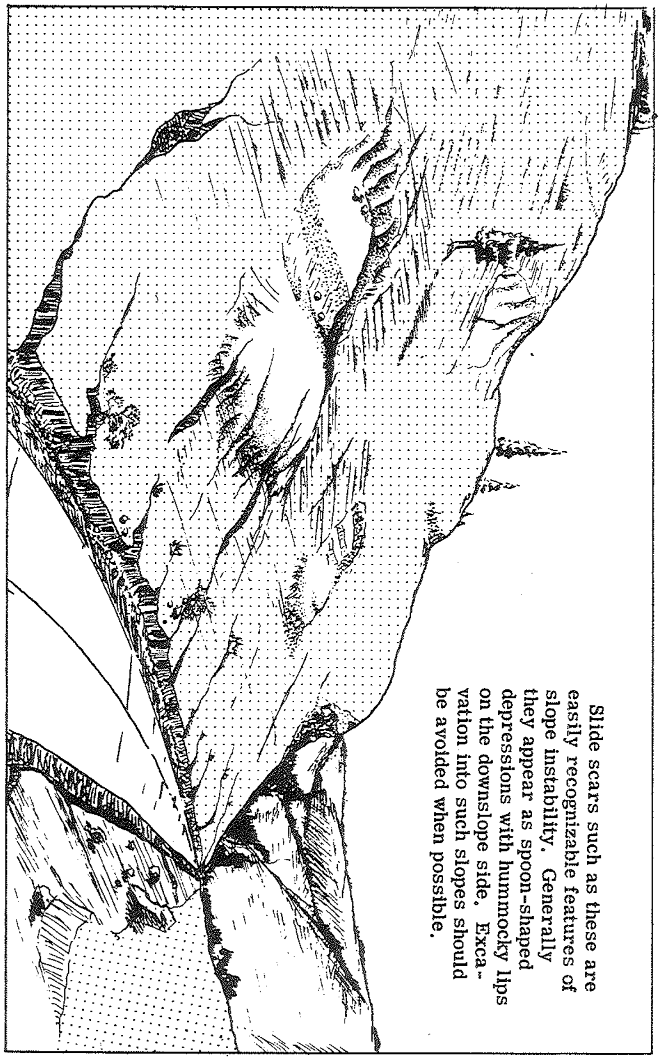


Figure 10.—Potential slide due to surcharge.



Slide scars such as these are easily recognizable features of slope instability. Generally they appear as spoon-shaped depressions with hummocky lips on the downslope side. Excavation into such slopes should be avoided when possible.

Figure 12.—Slide scars.

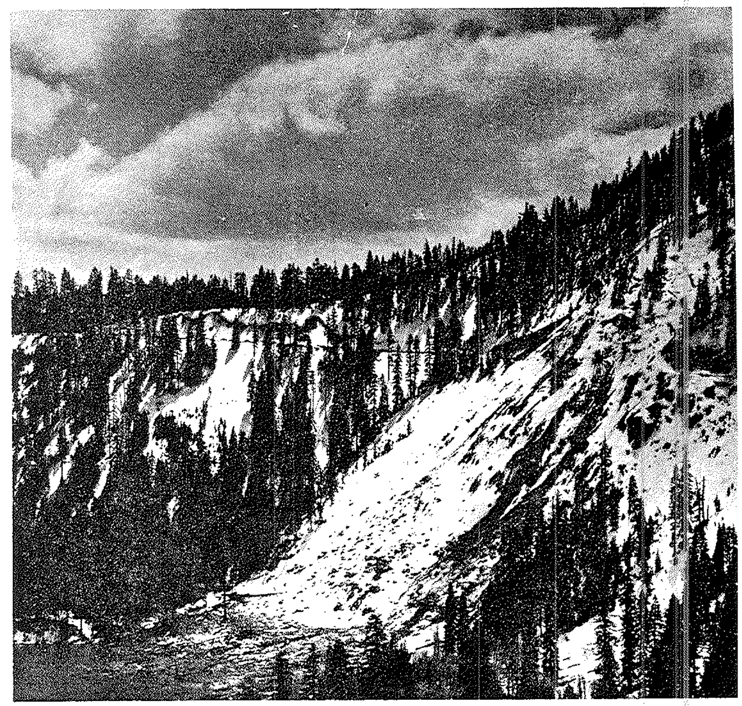


Figure 13.—Typical snow and rock avalanche which completely closed a State highway in 1956. Considerable debris accumulated near the water line. Location at the head of Emerald Bay, Lake Tahoe, Calif. (Courtesy California Division of Highways.)

withdrawn, subsidence is quite common. Evidence of such conditions is readily recognized as sags, ponds, and other undrained depressions which are often circumscribed by cracks and terracettes.

Lines of springs and seeps on slopes

Lines of springs and seeps on slopes are indications of permeable materials underlain by nonpermeable soils or rock, and are indicative of potential slide conditions.

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Colluvial soils

Construction over colluvial soils at the base of slopes (as a talus cone) may encounter extremely unstable conditions.

Ancient slide scars

Old slide scars, ranging from large to small, generally appear as escalloped or spoon-shaped depressions in a slope, with hummocky ridges at the base or lowest part of the depression (fig. 12). They often look like slumped, long-abandoned mine drifts. In areas of pronounced relief, avalanche scars and rock chutes may occur, and talus cones develop at the break in slope (fig. 13).

Ground cracks

Lunar-shaped cracks, parallel lines (en-echelon) of cracks, and shrinkage cracks in the surface soil (fig. 14) are not readily seen, particularly on grassy slopes and in forest litter. More careful scrutiny is required than for the previously mentioned features, but these types of cracks often can be seen and are among the first signs of active slide movement.

Creep phenomena

Like ground cracks, creep phenomena (fig. 8) demand careful observation. They include terracettes, which resemble cattle traces paralleling the contours on sloping ground. Fence lines, stone walls, roads, pole lines, and hedgerows that are warped downhill and out of alinement, are indications of creep. Leaning trees, and soil stretching, which may be recognized by series of small cracks contiguous to or touching roots, boulders, or other rigid bodies, are also indications of movements in surficial soils. Some of these features may be recognized in aerial photographs. Excavation into such slopes may produce major slides. Creep conditions have often been observed to develop subsequently into avalanches, or earth and mud flows.

Problems in Fill Areas

So-called "slip-out" slides are not only common in fill areas, but are often more costly to repair than slides that move down and bury a highway (fig. 15). Included in this category are "slip-out" slides caused by subsidence of the ground beneath the fill. Many of the clues and means of recognizing potential slides in future fill areas, and in already constructed fills, are the same as in cut areas.

A thorough surface and subsurface investigation should be made where high embankments or bridge approach embankments are to be

Tension cracks as typically developed in a slump slide in cohesive materials.

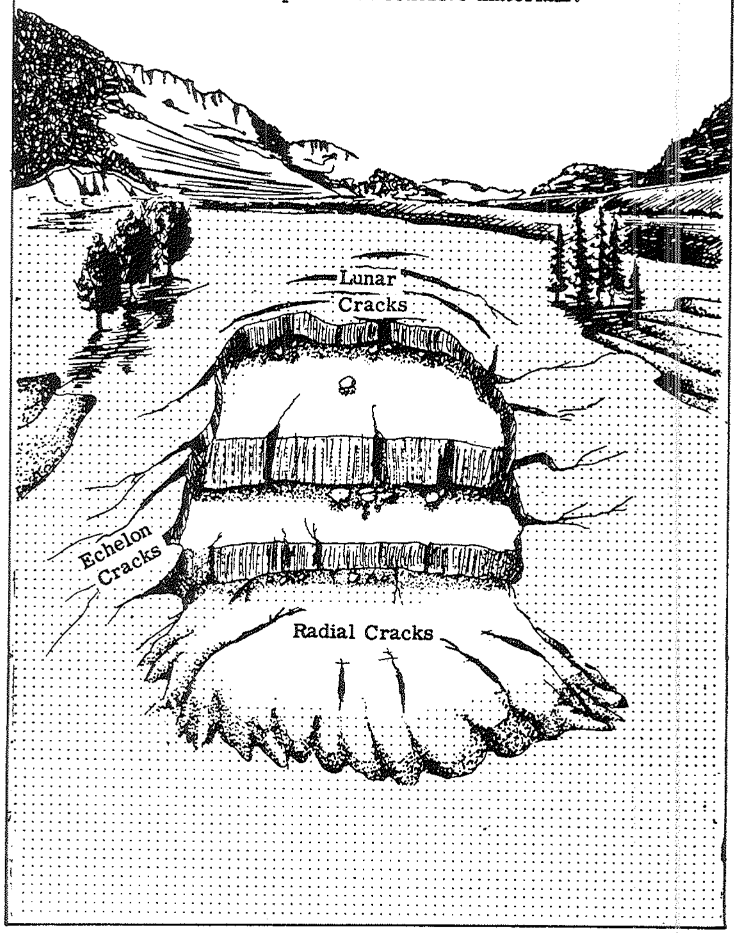

Figure 14.—Tension cracks developed in a slump slide.

Figure 15.—Sidehill fill failure, with "slipout" type of slump slide. Traffic was slowed down but not disrupted. The situation was later corrected with a deep drain at the base of the back cut slope and a benched, stone buttress in the area of slope failure.

constructed, in order that an unsuitable soil condition can be corrected or an appropriate embankment design be made. Soil strata with low bearing capacity or high compressibility that occur within the depth and area that may be affected by the proposed embankment should be detected.

What should the location engineer look for, with respect to landslides, in fill areas?

Need for benching and drainage at sidehill fill areas

Improper benching and drainage are probably the most common causes of failure in sidehill fills. Drainage may be unnecessary in heavy stone fills, especially in view of the permeable characteristics

of the fill. In the case of sidehill earth fills, however, drainage in the bench next to the backslope may be essential. Preliminary subsurface exploration may have revealed the presence of water on particular planes, or in certain stratigraphic horizons. In such cases, the bench should be located at the elevation of the bottom of the water-bearing zone.

Damp to wet or soggy areas on a slope may be spotted during location surveys, indicating need for proper design of benches and drainage. However, the permeable stratum should be accurately located before the bench and drainage designs are made, inasmuch as water may seep along flat-lying or gently dipping strata and follow the base of the overburden downslope.

Inadequate toe bearing of sidehill fill

The base of the natural ground slope and the valley flatland adjacent to it, and that portion of the valley wall immediately downslope from the probable location of the toe of the proposed fill, should be scrutinized for seepage, high moisture content, and the presence of organic or other highly compressible materials.

Swamps

Swamps owe their existence to intersection of the ground surface by the water table, or a perched water table, or because the ground forms a basin or receptacle for water seeping from the slope. The ground is saturated and in the swamp there is an accumulation of vegetation and organic soils. The compressibility and low shear strength of these materials threaten the stability of a fill. Some swamps, however, may be underlain by good, firm bedrock at shallow depths, in which case satisfactory bearing for the fill may be obtained with a minimum of excavation, or by other techniques utilized for settling the fill on the material having adequate bearing capacity. Other swamps, particularly in former glaciated or glacial outwash areas, may have organic material underlain by glacial rock flour which, when agitated, becomes "quick." This must be ascertained in advance, for fill construction over such ground requires very special treatment, sometimes as extensive as vertical sand drains and a sand blanket.

Irrigated ground

The construction of fills over irrigated ground or adjacent to irrigation canals, or over ground likely to be irrigated in the future, requires careful study. A relatively dry foundation soil may sustain the weight of the fill but may be vulnerable to an increase in moisture content that is caused by land flooding or seepage from a leaking canal. The physical condition of such soils to considerable depths must be determined.

Alluvial fans

Construction of fills over the marginal ends of alluvial fans may be a hazardous undertaking. Near the apex of an alluvial fan, the interconnecting or branching water channels may have unstable walls or new channels may develop during flood stages. Generally, the topographic relief makes this ground undesirable for crossing by highways. On the other hand, the lower margin of the fan may go unsuspected; yet here, where the groundwater lies near the surface, and the soils are fine grained, the moisture content can be very high and the strength of the soil very low. Any surcharge imposed on such soil may result in rapid development of shear failures. Considerable terrain analysis and soils investigation in such areas are necessary.

Surcharge on pervious material overlying impervious stratum

Fills or any other type of surcharge placed on sand, gravel, or other highly pervious deposits, which in turn rest on sloping surfaces above clays or impervious rock, or adjacent to scarps, are subject to potential failure. Water moves through the pervious material and is concentrated at the contact with the impervious material, and the combined weight of the surcharge and pervious material may cause a slide to develop (fig. 10). Some years ago, under such conditions, a slide moved over an escarpment on the west bank of the Hudson River in New York, and buried the West Shore Branch of the New York Central Railroad.

Mine settlement and sinkhole areas

The placement of a fill across mine settlement or sinkhole areas is a calculated risk. The danger is apparent to the location engineer if he observes the subsidence at the ground surface. If he only suspects there are such phenomena in the region, it behooves him to make an investigation (fig. 11).

Where mining has been by the room and pillar method, and the ore is relatively flat-lying, a cover of about 60 feet, which includes bedrock, has been found reasonably safe. However, if the ore is coal and the long-wall mining method has been used (where the pillars are progressively removed as ore is extracted), subsidence is very likely to occur. Such subsidence invariably brings ground water up to the surface soils and frequently causes ponding on the ground surface.

Failure of fills due to subsidence of the foundation materials is quite likely in regions where the ore beds or deposits are steeply dipping, as in the anthracite coal fields of northeastern Pennsylvania. Surface indications are generally present in the form of open cracks and downfaulted areas.

Sinkhole areas may pose serious problems. This depends on whether they indicate large caverns at shallow depths. Investigation is essential so the selected highway route will avoid large caverns underlying the area.

Rapid drawdown

A fill located on a soil foundation adjacent to a reservoir or stream is susceptible to failure if there is a rapid drawdown or lowering of the water level.

Problems in Existing Fills

What should the location engineer look for in fills that have failed or show evidence of potential failure?

Upside-down fills

Fills may fail when built with surface soils and weathered rock at the base of the fill and rock at the top. Water moves readily through the rock and saturates the upper portion of the soil fill. This sort of construction may happen if there is inadequate inspection.

Frozen material

Freezing of a soil lift, or use of frozen material in the lift, may constitute a plane of weakness within a fill when thawing occurs, and result in a "slip-out" slide.

Part 3.—LANDSLIDE CONTROL AND CORRECTION

Basic Landslide Types

There are three basic types of landslide movement:

Falls, which are influenced by the laws governing free-falling bodies, and by mechanical and chemical weathering;

Slides, which are failures in elastic or semi-elastic materials; and

Flows, which follow the principles of viscous flow of fluid and semi-fluid materials.

The control or prevention of slides and flows involves one or both of two basic principles: Reduction of the motivating force, and increase of the resisting force. Inasmuch as the same basic principles are involved in control and prevention of both slides and flows, the latter are not treated separately in the following discussion. The economics of the proposed control or corrective work has a strong bearing on the feasibility of the method chosen. Quite often the best and most positive method of treatment cannot be employed because of its high cost and limitation of available funds.

Falls

The choice of techniques for highway protection from falls is governed, first, by whether the problem involves materials from slopes above the road, or the falling out of materials from steep slopes below the road (fig. 7). Secondly, the fragments, whether slabs or blocks of rock, or earth-size material, determine those methods most likely to be successful.

Relocation

Relocation is resorted to when space is available and the cost of other corrective work is too great. If space is not available and the road must be maintained in its original alinement, other methods have to be evaluated.

Wall-support construction

Wall support is applicable where, in a very steep rock cut, an overhang has developed. Support may be given to the overhang by the construction of a concrete, brick, or masonry wall or facing (fig. 16). This method is chiefly used in slopes developed in jointed and fractured, blocky rock, and where medium- to massive-bedded strata rest on easily erodible shales and soft rock. The technique is generally limited to relatively small areas.

Rock anchoring

Rock bolting, dowelling, and associated use of tie-rods and channels is a relatively inexpensive method of securing rock slabs and blocks in the face of steep cuts, and platy to blocky rock on bedding, fault, or fracture planes that are inclined toward the excavation (fig. 17). They are only for use in solid, firm, lithified rock. They should not be used in clay shales or in thin-bedded, highly schistose, foliated, or deeply weathered rock that tends to slough upon weathering, or in poorly consolidated, granular rock.

Where the rock is less blocky, wire mesh can be draped over the slope face, and heavy wire fencing or rubble, masonry, or concrete walls can be used to protect the roadway from bounding rock (fig. 18).

Reducing and benching of slopes

Where feasible, reduction and benching of slopes may be used. Benching is particularly effective where massive beds of hard rock overlay thinly bedded, easily weathered materials.

Avoidance of scarps

Where the highway must be located on a rock or earth bank above the bend of a river, or next to a lake or the ocean, the best protection against slides is to keep a reasonable distance away from the scarp. Massive rock or thick-bedded, competent rock that is not subject to undermining or excessive frost spalling permits much closer construction to the cliff brink than weathered, thin-bedded, and poorly consolidated "rock" or soils.

Surface drainage

Surface drainage adjacent to the top of the cut slope, where rock and earth falls are anticipated, may be necessary. Shallow, paved, peripheral ditches and interceptor ditches, with outlet drains where necessary, can be installed. However, such ditches are often placed

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Rock bolting is used in blocky rock to prevent sliding of the rock down onto the roadway. It may also be used in vertical slopes and to hold rock in place in the roofs of underground excavations.

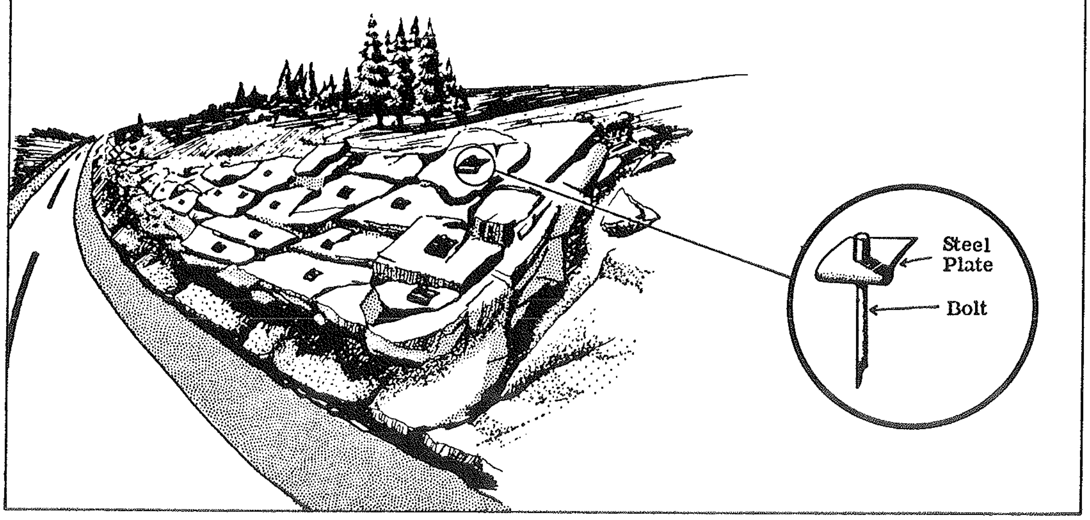

Figure 17.—Rock bolting.

Walls are used in localized areas as protection from rock falls.

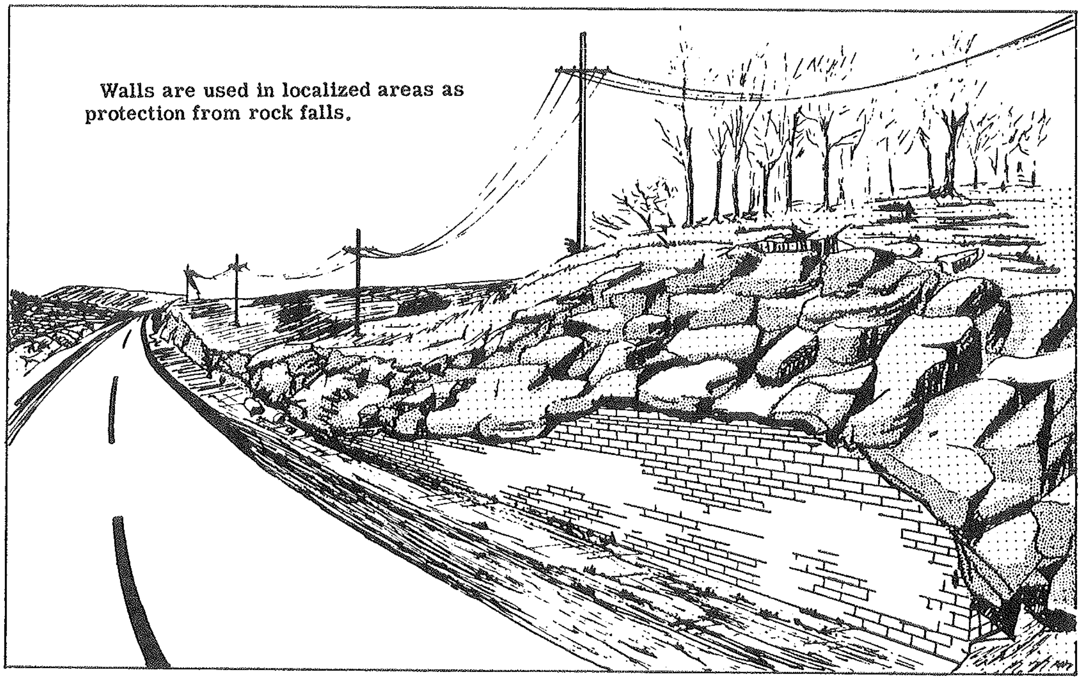

Figure 16.—Wall-support construction beneath overhanging rock.

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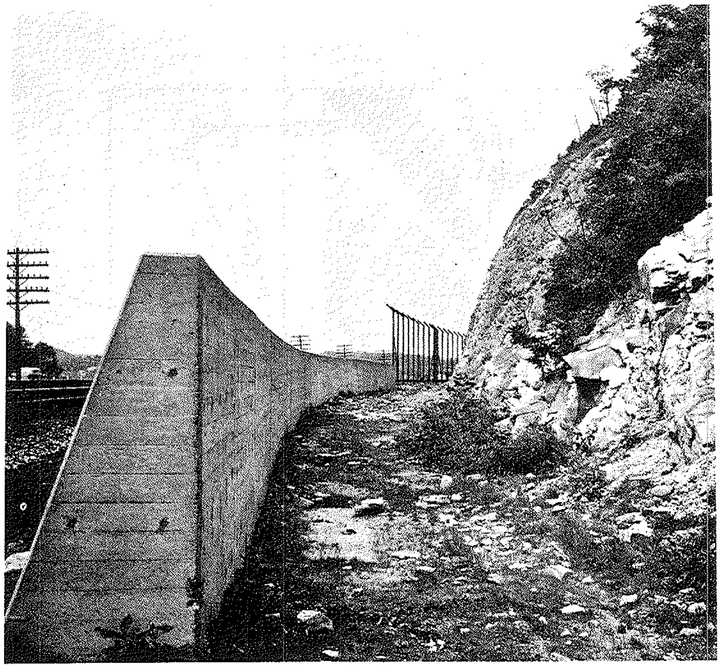


Figure 18.—Retaining wall and high wire fence protect a railway and highway from falling, bounding rock. Location on U.S. Highway 22 across the Susquehanna River from Duncannon, Pa. (Courtesy Pennsylvania Department of Highways.)

without realization that seepage water may pass under the ditches, through or beneath the overburden, and undermine them. When such seepage and ground conditions exist, a solid-type ditch lining, such as concrete, should be installed. The ditch may be lined with waterproof paper, sprayed with a bituminous coating, as a temporary expedient prior to final construction.

Slides

There are many methods and techniques for controlling and correcting true landslides. No one method or combination of methods is

universally applicable. Consequently, each slide must be considered on the basis of its own individual characteristics.

Avoidance

Avoidance of slides or potential slide areas should be a primary consideration of the engineer when selecting a new highway route, particularly in a region that is susceptible to slides. After the slide has occurred, avoidance by relocation or by bridging must be compared with other remedies, and may not be feasible because of excessive cost.

Excavation

Excavation, in part or total, is usually the first remedy applied after a slide has occurred. Partly this is a primary necessity incident to reopening a road for traffic. Removal of slide debris at the toe very often aggravates an already serious condition. Consequently, this step should be carefully analyzed in conjunction with alternatives or additional measures.

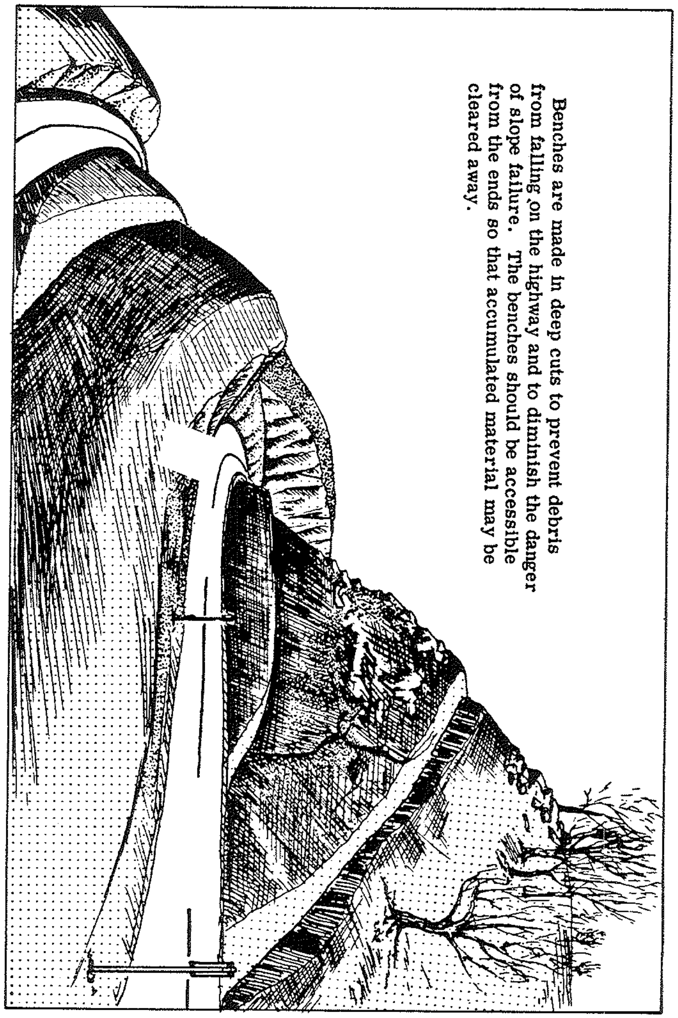
Usually, where possible, an attempt should be made to remove some of the material at the head of the slide so as to reduce the motivating force. However, if this means removing a row of houses or the affected roadway, for example, some other method must be considered.

Some slides are so large that it may not be economically feasible to remove sufficient material to do any essential good. Reducing the slope, perhaps by using a compound slope, and construction of benches (fig. 19) are remedies that are frequently successful. These two methods are also recommended as slide prevention measures. Both of these methods tend to reduce the motivating force.

Surface drainage

Excavation techniques are usually used in conjunction with various forms of surface or subsurface drainage, or both. In the case of a relatively small slide, where the motivating forces are not great, regrading the moving mass, treating the surface with a rock or concrete facing, and installation of appropriate pervious blankets and underdrains, have been successful.

Surface ditches, circumferential around the crown of a slide, are almost always employed. Such ditching often goes hand-in-hand with regrading of the slide surface, and sealing or filling of all cracks, including joints, faults, and fissures. These measures almost invariably require continuing maintenance, hence they only help control the slide but do not stop it. Circumferential ditches, as mentioned previously, should usually be lined.



Benches are made in deep cuts to prevent debris from falling on the highway and to diminish the danger of slope failure. The benches should be accessible from the ends so that accumulated material may be cleared away.

Figure 19.—Bench construction in deep cuts.

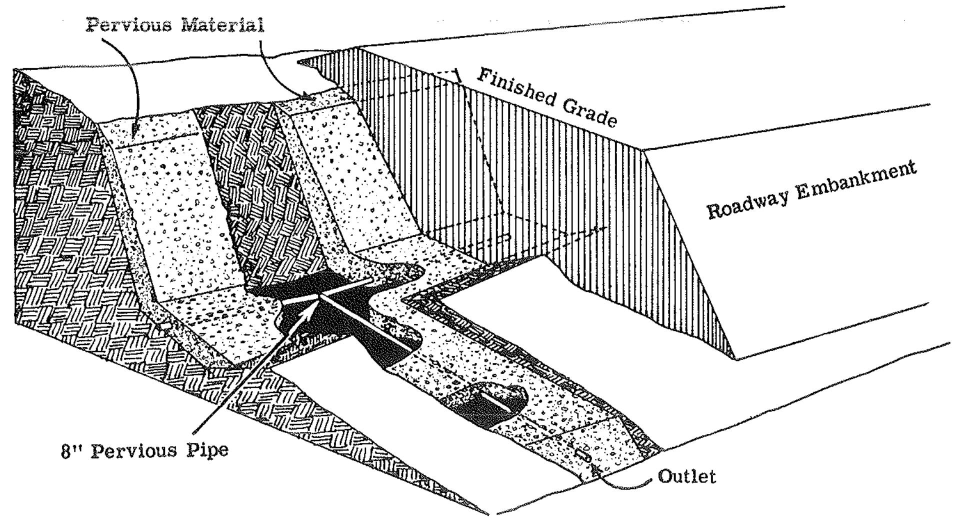
Subsurface drainage

Subsurface drainage methods are varied in kind and effectiveness, depending in large part on the physical characteristics of the material to be drained.

"Horizontal" perforated-pipe drains have been used with a high degree of success by the California Division of Highways and by some other State highway departments. Horizontal drains are very effective where the soils have a relatively high permeability, are semi-granular to granular, and are poorly cemented (fig. 20). Their useful application in clayey soils is highly speculative, but if attempted, they should be sand-filled in order to filter out the clay-size particles and keep the drain free-flowing.

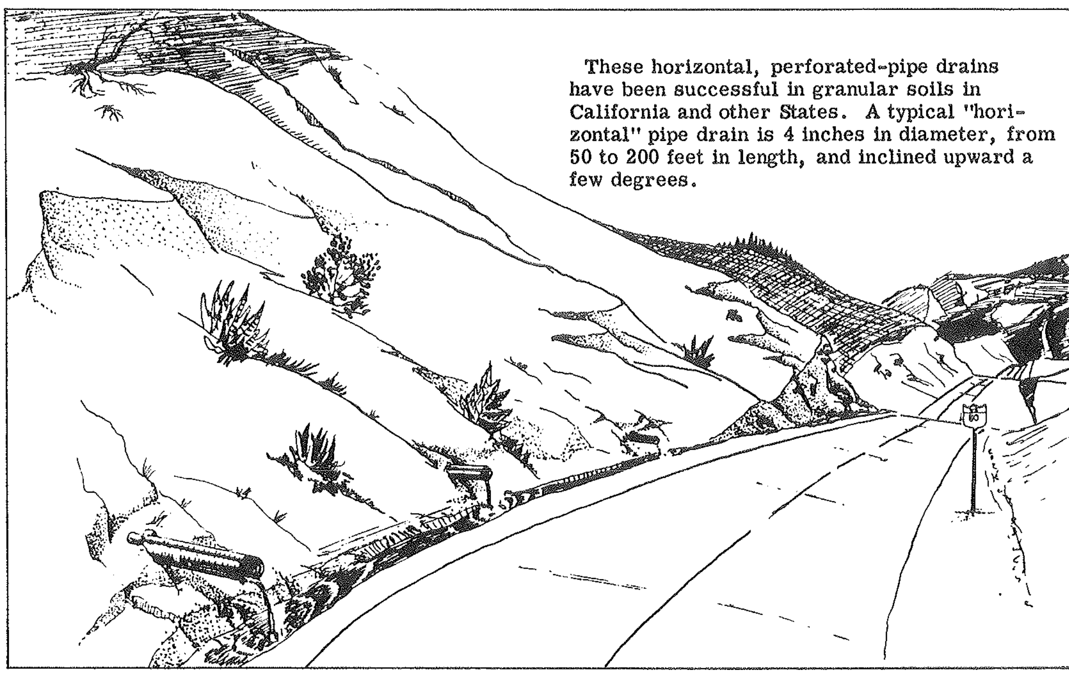
Interceptor trenches in slides, or in potential slide areas, involving cohesive, clayey soils, have been one of the most successful techniques (figs. 21, 22). These utilize a granular filter and perforated pipe. When placed above the slide crown the object is to intercept the horizon or zone of groundwater flow or seepage. This presumes, of course, that the water horizon has been located by borings. A ditch depth of 16 to 20 feet is about the limit of practical and economic feasibility. When the seepage zone is too deep to reach from above the crown of the slide, it is often possible to use a dragline or back-hoe, trenching upslope through the slide debris until the water-bearing horizon is located. Such a trench must cut through the slide debris and original overburden on the slope, until the edges of the undisturbed strata are exposed. When the water-seepage horizon or zone is located, lateral sand-filter, perforated-pipe drains may be installed and the slide mass stabilized. This technique has been successfully employed in the solution of several urban landslides in clayey, loessial soils in the St. Louis area.

There are differences of opinion about the requirements for the bedding of the perforated pipe in the filter trench. The base of the trench should be a few inches beneath the plane upon which the water is moving. The Bureau of Public Roads' *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP–61)* calls for a 4-inch layer of granular material beneath the pipe. Some State highway departments permit a thinner layer, and others vary the thickness by showing on the project plans the thickness required for the local conditions. For municipal work in the St. Louis area, a 1½- to 2-inch sand bed has been found effective. Some engineers lay the pipe on the natural ground in the base of the trench and then build the sand-filter up around the pipe.



Use of interceptor trench, pervious blanket and perforated-pipe drains to stabilize foundation for sidehill fill on portion of Dunsmuir Freeway, U.S. Hwy. 99, Northern California. Bottom of longitudinal trench, outlet trench, and upslope side of trench have 3 ft. blanket of gravel.

Figure 21.—Interceptor trench with pervious blanket and perforated-pipe drain from sidehill fill. (Courtesy Western Construction and California Division of Highways.)



These horizontal, perforated-pipe drains have been successful in granular soils in California and other States. A typical "horizontal" pipe drain is 4 inches in diameter, from 50 to 200 feet in length, and inclined upward a few degrees.

Figure 20.—Sidehill horizontal drains.

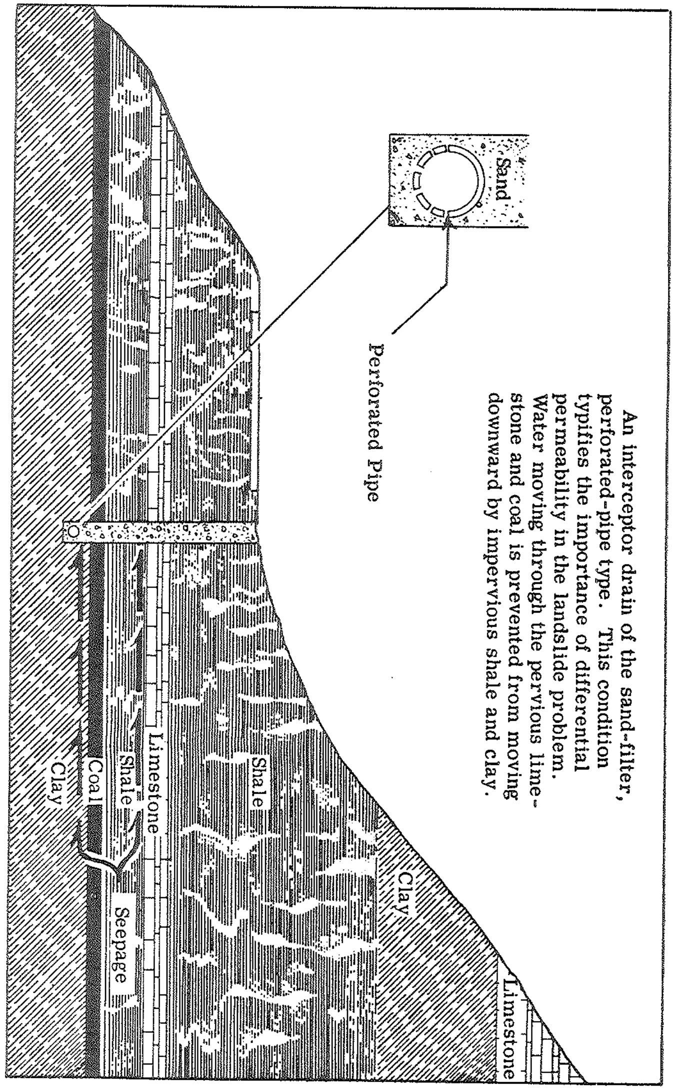


Figure 22.—Interceptor drain for differential permeability situations. (Courtesy Missouri State Highway Department.)

Plastic pipe, clay tile, and metal pipe have all been found adequate. However, metal pipe should not be used if the water to be drained has a pH below 5. Preferably, the pipe should be perforated only on the invert side.

Drainage tunnels are rarely used today, largely because of the high cost involved, but there still are occasions where property values or the importance of a utility, such as a railroad or vehicular tunnel, are so great that drainage tunnels may be necessary.

Vertical sand drains and drain wells are often used to speed up the consolidation of compressible soils on which a fill is to be constructed, or to prevent a slide failure in the foundation soil during construction of the fill. Vertical sand drains are generally made from 12 to 24 inches in diameter, are closely spaced in a grid pattern, and are connected at their tops with a sand blanket which serves as the base of the fill. During and after construction of the fill, water squeezed from the foundation soil ascends the vertical drain and then moves laterally through the blanket. Outlets are placed to lead the water beyond the embankment slopes. Extensive use of this method was made in the construction of the New Jersey Turnpike over tidal marsh lands.

The Washington siphon (developed in the State of Washington) is a relatively inexpensive device that may be used in conjunction with drainage wells or sumps (fig. 23). When the siphon is operating, a nearly constant water level is maintained in the soil adjacent to the slope in which the 8-inch sump pipe is placed. When the flow of water in the siphon pipe is interrupted, the pipe can be refilled and the siphon restarted by filling with water from the storage tank. This continuous siphon has the depth limitations of all siphons, but, where applicable, it has proved very efficient.

Vertical drains are used not only to intercept strata and prevent a rise of the water table, but also to carry water down through compressible materials and into a permeable stratum that will carry excess water away (fig. 24).

Restraining structures

Restraining structures are placed for the purpose of increasing the resistance to slide movements. They are dependent on the ability of the structure to resist sliding on or below its base, overturning, and failure within the wall.

Retaining walls and bulkheads have had very general usage. Where the ground to be restrained is free-draining, and it is reasonably certain that subsurface water will never become a factor, then such structures may be expected to serve their function well. If the ground to be held is not free-draining, provisions must be made for adequate

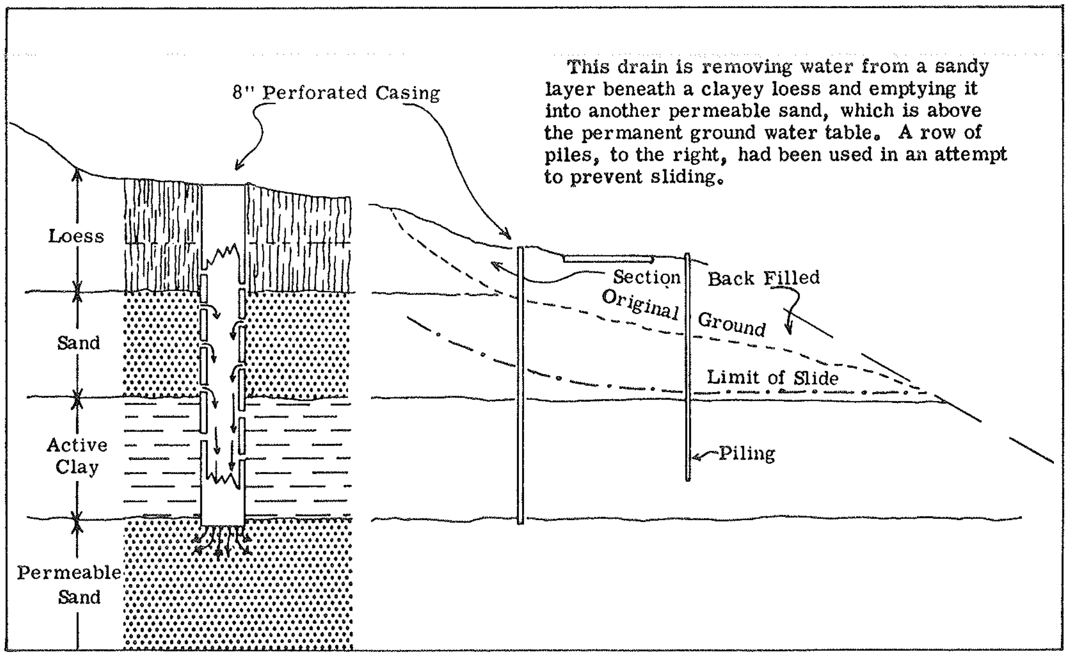


Figure 24.—Loess drained to water-bearing sand.

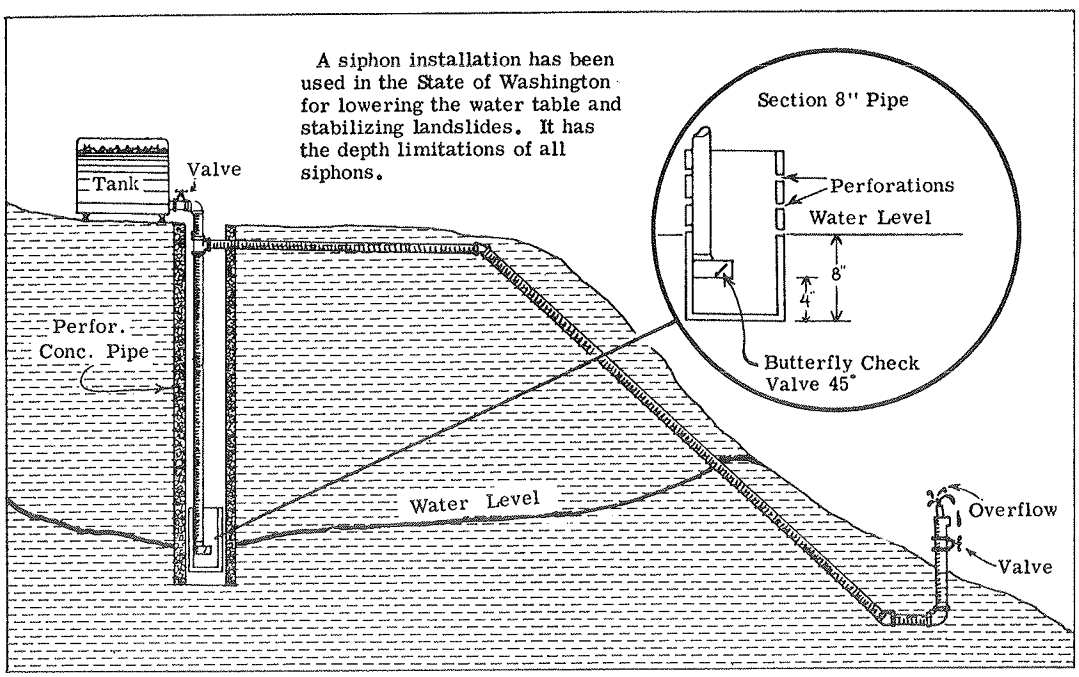


Figure 23.—Washington siphon. (Courtesy Washington Department of Highways.)

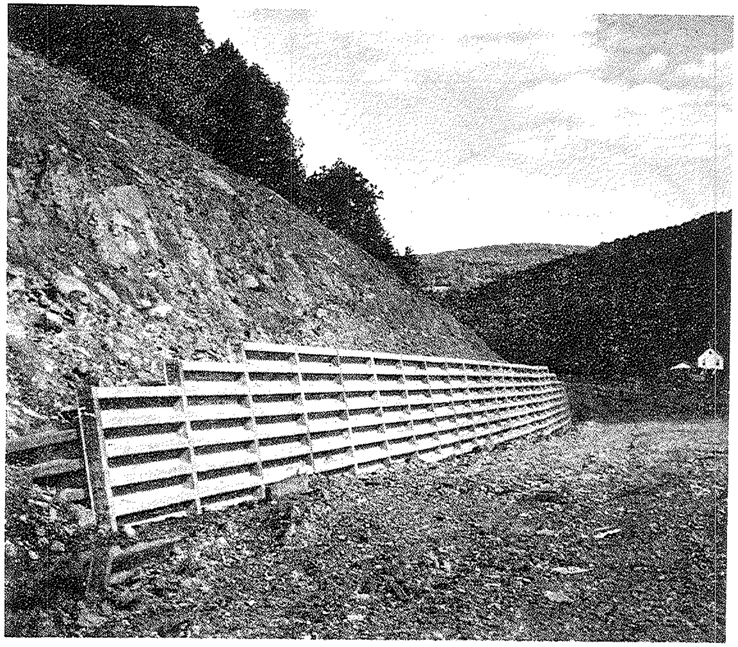


Figure 25.—Cribbing incorporated in slope design. (Courtesy Armco Drainage and Metal Products, Inc.)

drainage, which includes pervious backfill, drain pipes, and weep holes. Sometimes, even with all these provisions made, the resistance of the foundation materials may prove inadequate and failure occurs.

Crib walls are frequently used at the toe of an oversteepened cut slope, but they are built as a part of the slope design and may not be placed primarily as a slide correction device (fig. 25). Crib walls and bins have very definite limitations and, unless planned with drainage and foundation conditions fully satisfied, can be expensive failures.

Buttresses are also used to resist the motivating force of a slide (fig. 26). They are chiefly used in association with embankments and may be rockfill, earthfill, or concrete. Buttresses of these types have been used to restrain cut slopes (figs. 27, 28). They may be used for the purpose of adding weight at the toe of a landslide, or as "strut" fills. The latter require a reverse slope in order to obtain bearing

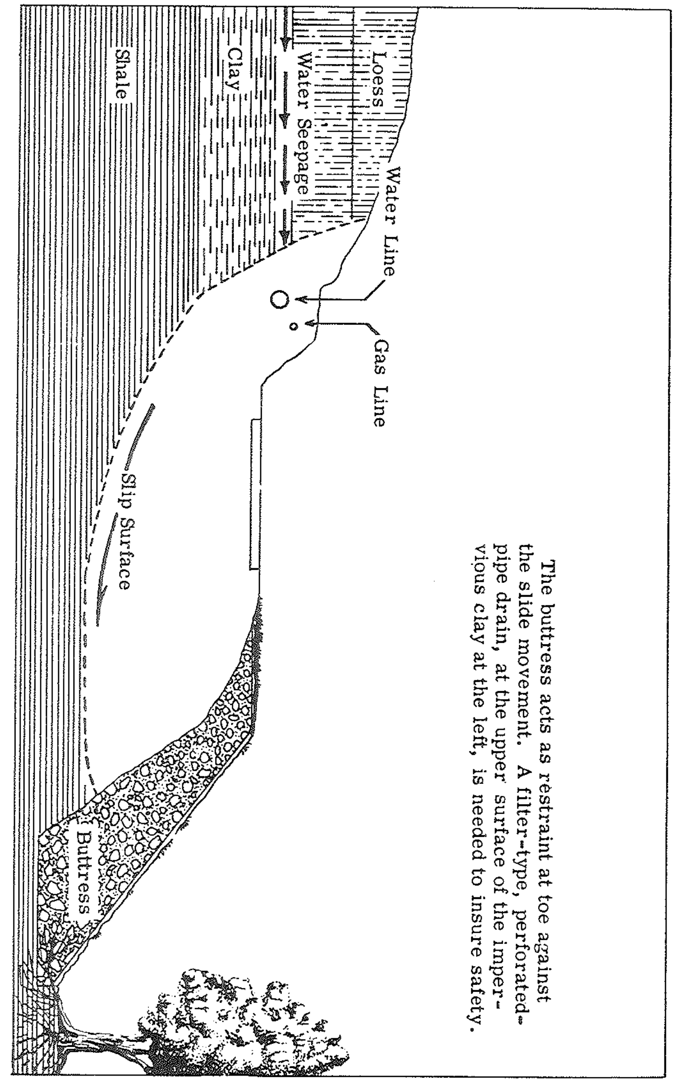


Figure 26.—Buttress as restraint against slide movement.

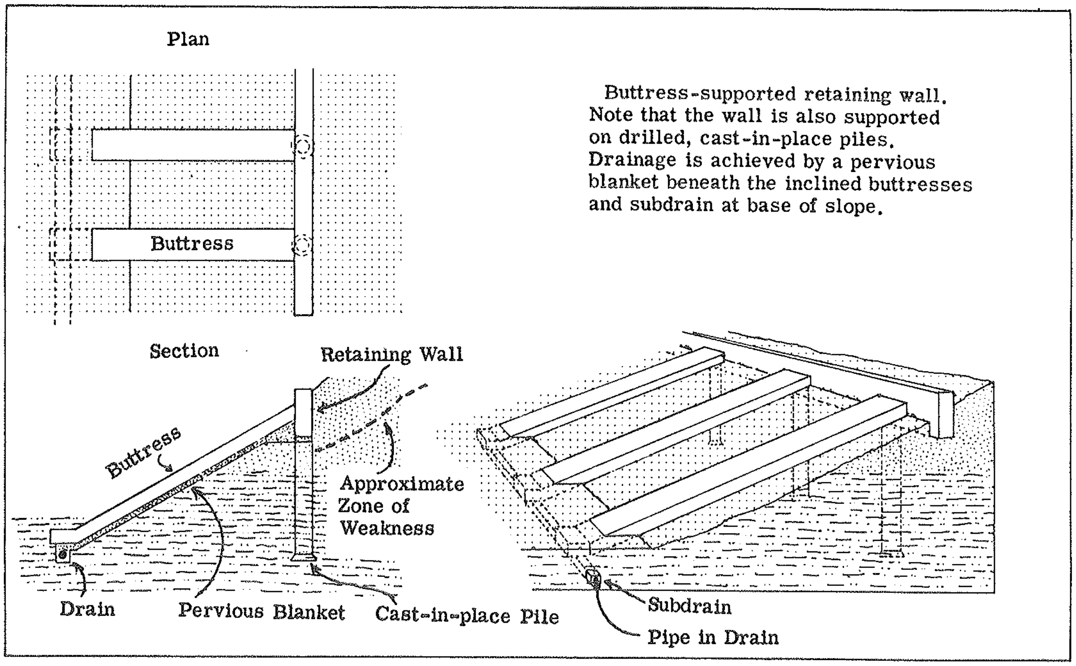


Figure 28.—Strutted retaining wall on piles. (Courtesy California Division of Highways.)

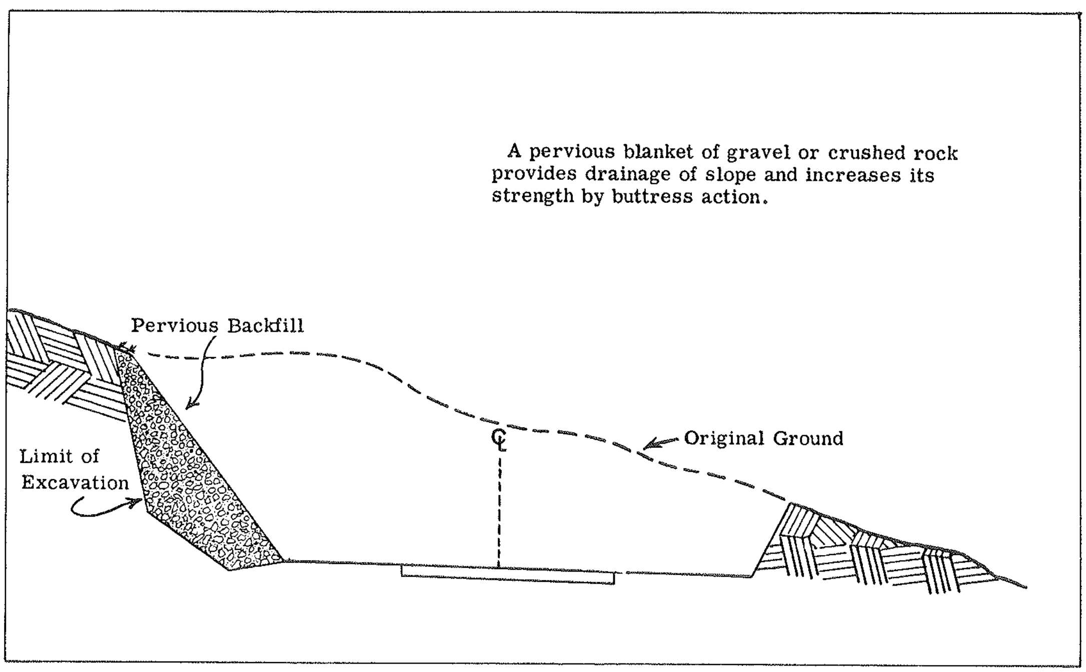


Figure 27.—Modified buttress. (Courtesy California Division of Highways.)

opposite the slide. A unique example of strutting involved seven horizontal concrete buttresses used as restraining devices for slope failure near Belle Vernon, Pa. (fig. 29). The seven buttresses, made of precast solid concrete blocks, are on 25-foot centers and have an exposure 10 feet vertically and 18 feet horizontally, at each end.

Buttresses constructed of crushed stone or other materials having higher shear strength than the native soil may be used. However, there is always the danger that the added load may increase the driving force of the slide.

In many cases the effectiveness of the buttress is insured by the use of drainage facilities.

Piles are used as restraining devices in an effort to control and stop landslides. Oil-well casings have been a favorite type in many States, and telephone poles and sheet piles are commonly used. It is common practice to place about three-fourths of the pile length below the ground surface. No doubt there have been successes, but in general they prove ineffective (fig. 30). The soils may flow through the intervals between the piles, overturn them because the slide forces have been under-estimated, shear the piles, or develop a surface of rupture below their tips.

A unique method in St. Louis (fig. 31) involved benching the slide area and then casting the piles in place in 24-inch diameter auger holes. Five feet of pile extended above the bench in fiber tubes and established a new toe for the backslope above the bench. This technique was used to restore a steeply sloping lawn in front of deluxe apartments where exposed restraining devices were not desired, regardless of cost.

Blasting

Blasting is frequently cited as an old-time favorite method for slowing down and stopping a slide that is moving on a well-defined slip surface. The theory is that rupture of this slide surface increases the shearing resistance. Blasting has been employed with apparent success in relatively shallow slides on rock planes. When strata, or ground beneath the slip surface, are highly permeable, the water within the slide mass and on the slide surface may be drained into this pervious ground, thereby increasing friction in the slide mass and stopping the slide. There is always the possibility, of course, that the use of explosives may accelerate the slide movement and make the situation worse. Most engineers are reluctant to employ this technique.

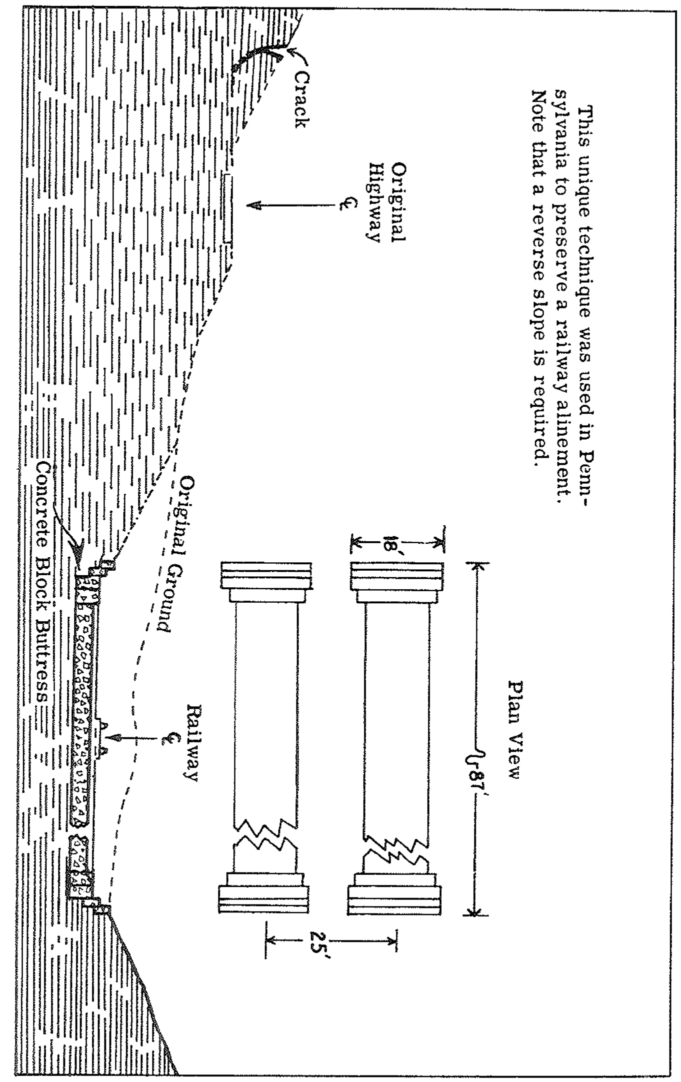


Figure 29.—Horizontal buttresses.

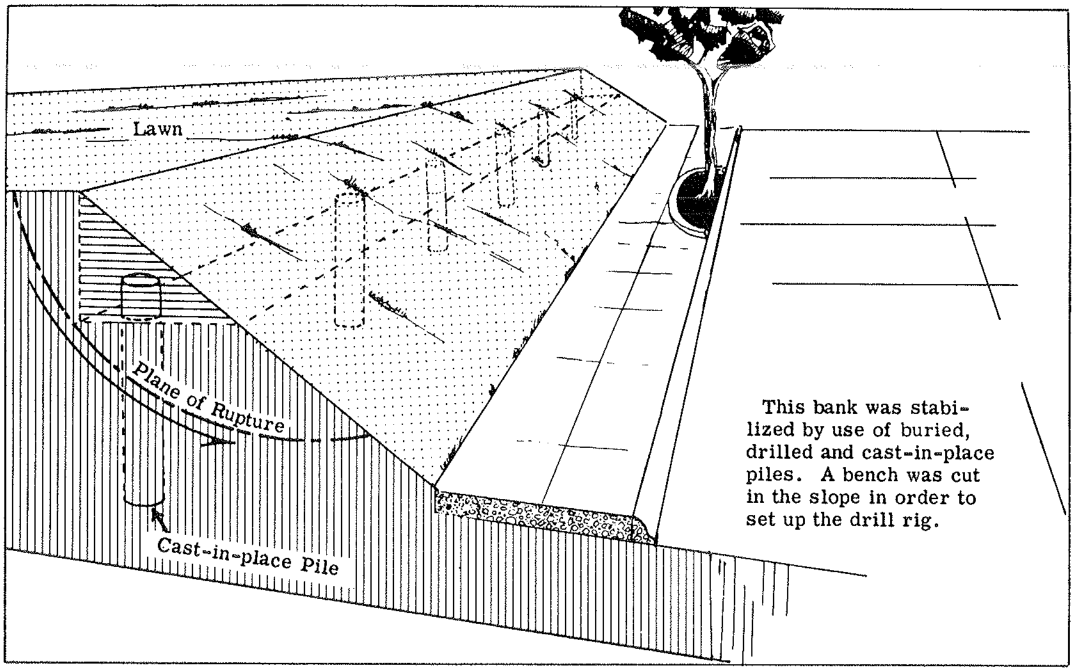


Figure 31.—Slope stabilization with buried piles.

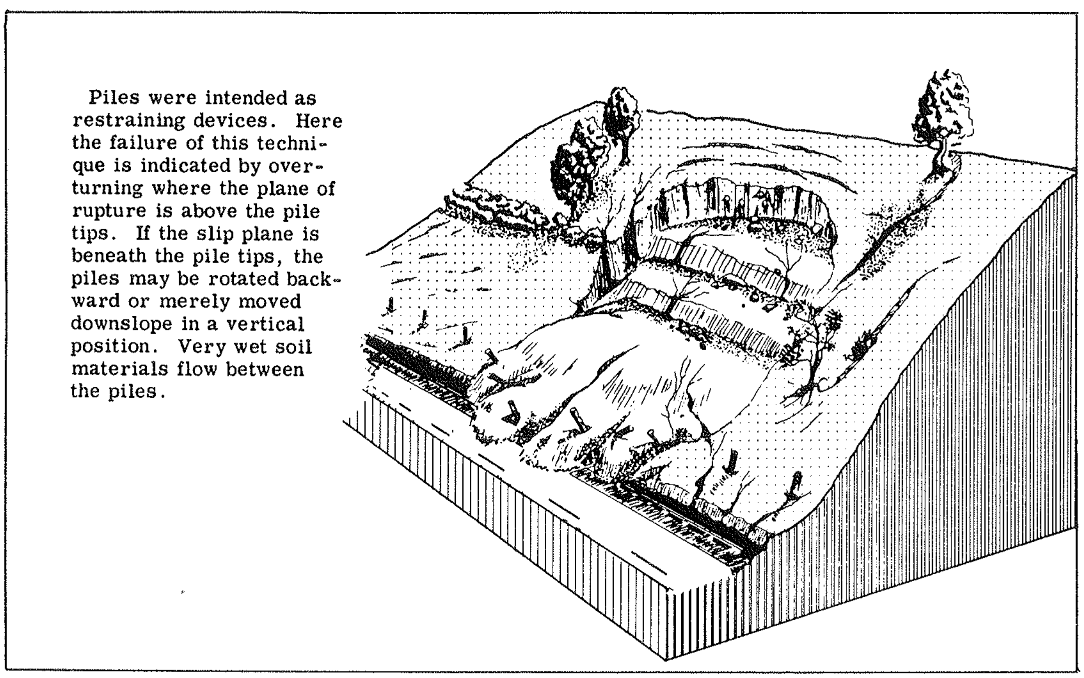


Figure 30.—Failure of piles as slide protection.

Hardening the slide mass

Chemical injection or cement grouting, whereby discrete particles within the slide mass are cemented together, has been used successfully in stone, and in sandy or other granular material, to prevent or stop slides. Cement grouting and chemical grouting require that careful soil analyses be made in advance. The high unit cost and poor "mixing" assurance of chemical grouting mitigate against its recommendation. Electro-osmosis has been used for reducing the water content of clayey, cohesive soils, and thus increasing their strength, but high power costs usually prohibit the use of this method.

Sinkhole correction

Sinkholes, unless indicative of a large cavern at shallow depth, when relocation or realinement is necessary, may be blocked by choking the hole with field stone and topping off the upper few feet with finer stone, which is then grouted. If the subterranean channel must continue to serve as an outlet for surface water drained from the area, provision for drainage must be made in the stone fill. In some cases it is desirable to construct a manhole so that future inspection is possible.

Part 4.—MAPPING AND REPORTING SLIDES AND POTENTIAL SLIDE AREAS

Purpose and Scope

The location engineer not only faces the responsibility of recognizing slides and potential slides in the field, and possibly recommending control and corrective measures, but also mapping the slide and collecting materials for laboratory analysis. It is logical that he do this, inasmuch as he is the first engineer in the field, may have to accept the responsibility for corrective work, and his report will determine the scope and magnitude of any further investigations.

The purpose for which the investigation is made, and its scope, must be determined early in the study. It is pointless to initiate an exhaustive program unless necessary. Obviously the purpose is determined by whether the objective is prevention, control, or correction, or a combination of these measures.

While the following text is generally phrased in terms of the mapping and reporting of slides that have actually occurred, it can readily be interpreted for application to the mapping and reporting of potential slide areas as well.

Purpose

The usual purpose of a landslide investigation, after its recognition, is to determine the cause of the slide and plan the proper repair and correction measures. However, the purpose may be to obtain essential data for prosecution or defense in a damage suit. The magnitude of any slide study depends on the property damage done or threatened, the values involved, the importance of the land area concerned, the time permitted for the study, and the urgency for control or corrective measures.

Scope

The scope is governed by the economic aspects and by the actual or potential hazard posed by the particular slide. The majority of slides require only a reconnaissance type investigation rather than a detailed one. An outline[2] of the various factors essential to any analysis is as follows:

1. Location: Station, milepost, distance from well-known point; whether above or below grade.
2. Effect on traffic: Whether the road is closed, partially open, or open.
3. Size: Surface limits—crown, toe, flanks; subsurface limits—maximum depth to surface of rupture.
4. Material: Types of soil and rock.
5. Water conditions.
6. Weather conditions.
7. Evidence of movement.
8. History of slope.

The reconnaissance report provides a basis for determining whether a more detailed report is necessary before any final decision on the appropriate control or corrective measure is made.

The outline above will ordinarily afford ample information for studies of minor slides of the nuisance type. Furthermore, the details indicated can be ascertained rapidly and with a minimum of expense.

The balance of this discussion is primarily devoted to slides of considerable magnitude and importance.

Mapping and Reporting Procedures

The mapping procedure embraces two technical areas: general or areal, and geologic.

Location

It is essential to locate the slide so that there is no doubt about its geographic position. Some point on or near the slide must be referenced to an acceptable benchmark, such as those placed by the U.S. Geological Survey or the U.S. Coast and Geodetic Survey. These are generally found on bridge abutments, cornerstones of public buildings, monuments, or on easily recognized topographic features.

Legal reference points should be used, such as property lines and corners, highway or railway survey stations, or State coordinate systems.

Geographic references are easily applied to readily identified terrain and drainage features such as hills, streams, and springs, all of which should be referenced in with precise distances and directions.

[2] This outline and the general discussion following are adapted from chapter 6 of the report listed as the first reference on page 67.

Field survey methods

Regular surveying or plane-table methods may be used for preparing contour or planimetric maps and for determining points of reference within and outside of the slide area. Accurate maps can also be made by special techniques from aerial and terrestrial photographs, but these generally would not be applied to the average small landslide investigation.

To obtain a high degree of accuracy in landslide mapping, triangulation stations should be established on stable ground, outside of the slide area. From these, a base line may be established above or below the disturbed mass. From the base line, points may be established within the slide area and checked periodically for movement.

If more precision is desired a grid system can be established over the slide area, with the grid lines at any convenient spacing. The grid corners, when determined and staked, may be used to check both vertical and horizontal movement.

Map scale and contour interval

The map scale chosen will vary with the intended use, the area involved, and the economic aspects of the slide being mapped. A very small landslide, but involving loss of life and great property damage, may deserve mapping on a scale of 1 inch to 5 or 10 feet. Another slide covering several hundreds of acres may be mapped on a scale of 1 inch to 200 feet or smaller.

A contour map of the physical features of the slide may be desirable. Depending on the judgment of the investigator and the importance of the study, a 2-foot contour interval may be required in one instance, whereas anywhere from 5- to 50-foot contour intervals may be entirely adequate in others.

Mapping the slide

The final map should show the slide proper, all associated water and other pertinent conditions, and the geographic frame.

The area to be mapped must be determined with care. More than the actual disturbed ground should be shown. The position of the slide with respect to adjacent terrain and cultural features, such as highways, railroads, powerlines, buildings, and similar features, must be shown. A more or less arbitrary scheme for small slides is to include a distance about twice the slide width on either side. A lesser side margin proportion is usually mapped for larger slides. The minimum distance upslope from the crown should extend to the first break in slope. Downslope from the toe the minimum distance again should extend to the first major break in slope.

The limits of the slide proper should be mapped first in order to illustrate its size and shape. The slide nomenclature (crown, head, flanks, toe, etc.) as shown in figure 2, should be used so that the description will be clear to all readers, and so that there will be uniformity of language with reports from other investigators.

Internal features within the slide mass properly frequently need to be shown. These include scarps, fractures, flow lines, and recognizable displacements of surface features.

The characteristics of fractures and cracks that may be recorded include the strike, dip, and elevations; vertical and horizontal displacements, and any components of the same, including rotational movements; and depths of openings. These will vary from one fracture to another, as well as individually with time, according to adjustments within the slide mass.

In the more plastic materials, flow features may merge with the fractures and cracks associated with drier materials. In mapping potential landslides or the early stages of slides and flows, the trend of flow paths and the gradients of soil flows within the mass, or in associated terrain, should be shown.

Surficial features indicating deformation should be shown. These include offsets of linear features such as fences, lines of vegetation, ditches, roads, railroads, pipelines, walls, and utility lines. Deformed rectangular elements, such as buildings and fields, should also be shown.

A map and cross sections showing all the surficial and subsurface data of the slide area are considered basic.

Water sources within or adjacent to the slide area, such as springs, seeps, pipelines, sewers, ponds, canals, reservoirs, and permeable strata, should be reported and shown on the map. Seepage from any one of these could be a contributing factor in a slide movement.

Slide materials within the slide area should be mapped. The soils should be described in terms of a standard classification, and also in terms of structure (prismatic, granular, dense, etc.). If it is a rock slide, the physical and structural characteristics, any mappable geologic units, and pertinent features, should be recorded.

Weather and hydrology should be reported. Precipitation and temperature data are important in analyzing not only the chronologic data of actual movements but also the slope history, as both factors are important in arriving at the cause or causes of a slide. The terrain stability may be upset by only a minor variation in the normal climate. Barometric pressures, seemingly unimportant, may be the

triggering effect that set the slide in motion. Records of precipitation and the temperature should be noted for the period prior to and after a slide. Because the year may have been unusual, weather data for a period of years should be recorded. The essential records are obtainable from the U.S. Weather Bureau and most utility companies.

The importance of hydrologic data to landslides should not be underestimated. Groundwater data, showing water-table fluctuations and groundwater flow, may reveal an intimate relation with the landslide. Hydrologic data should be plotted against rate of movement.

Subsurface investigations

Subsurface investigations are made for the purpose of ascertaining the physical, geologic, and mineralogic characteristics of the slide material, and should include a study of the adjacent stable rock and soil, and the location of the surface of rupture and groundwater conditions. Some of these data may be determined from surface investigations. Subsurface examinations may not be feasible in some very mobile, active slides.

Drill holes, test pits, and test trenches are the methods of subsurface exploration in most common usage, but identification samples may be obtained by core and auger borings, and standard penetration tests may be made.

The large earth augers that can rapidly drill a hole tens of feet deep and 3 or more feet in diameter are useful tools in landslide investigations in materials other than rock. In slow-moving slides such auger holes can be drilled and visually inspected conveniently, whereas a test pit would not stay open long enough to be completed and examined.

Water investigations relative to landslides are concerned with the movement of water, the groundwater level, and hydrostatic pressure. Dyes may be employed to trace the movement of water in a slide area, using household bluing or fluorescein dye in neutral water and uranine dye in acid water. Trace amounts of radioactive isotopes have been used experimentally for detection of seepage, and further investigation may prove that this method is just as effective and more economical than some of the conventional methods. The level of the water table and its fluctuations may be measured by the use of observation wells. Hydrostatic pressures may be determined by the use of piezometers. When exploratory borings are made, it is often desirable to use one or more as observation wells and to install a piezometer in one for future observations of water-table fluctuations.

Geophysical methods have been used for the purpose of locating the slip plane in many landslides. The electrical resistivity method has given accurate results in many areas and it may be considered a primary exploration technique in the study of actual as well as potential landslides. Both seismic and resistivity methods are useful in determining the depth to firm bedrock, in detecting the thickness and general characteristics of layers of soil or weathered rock overlying the firm bedrock, and in obtaining data from which bedrock contours may be plotted.

Slope history

The history of the slope is one of the most important features in terrain analysis relative to landslides. The landslide causes and mechanics have a definite relation to the geological history and the slope characteristics. Both natural and artificial changes in the slope should be analyzed. Such changes include construction changes, such as excavation of a slope or the placement of surcharges on the slope; and hydrologic changes in response to seasonal and cyclical variations in temperature and precipitation. These result in variations in hydrostatic and pore pressures, and the position and rate of movement of the groundwater.

Examination of the slope for evidence of previous movements in it should be made, and available eye-witness descriptions should be included in the slide report.

Because vibrations may trigger off a slide, it is important to report location in an earthquake belt, near an operating quarry, stamp mill, crushing plant, railway, or heavily traveled highway, or any other phenomenon likely to produce earth tremors.

Photographs

The importance of terrestrial and air photographs cannot be overestimated in terrain study. They can be the most convincing evidence in any damage suit or academic study. Terrestrial preslide photographs may be impossible to obtain in many cases, but in areas of deep cuts, and in areas of predetermined potential slide areas, they should be taken at the time of the original location study or construction. They can be most convincing in illustrating "before and after" effects. Two types of landslide photographic coverage after the fact are needed: General, showing the overall picture of the slide; and specific, illustrating details of particular slide features.

Laboratory tests

Effective control of slides, either corrective or preventive, may require a laboratory investigation of the physical properties of the soils and rocks in the affected area. The extent of such an investigation will vary, depending on the nature of the particular slide problem.

It may include routine tests for identification of materials, shear strength, types and amounts of minerals, and degree of weathering. They may be classified as soils tests and mineralogical tests. In some landslide investigations experience alone will afford all the information necessary; in others, where quantitative information is desired, at least a nominal number of tests will be necessary.

Soils tests should include determination of the natural (field) moisture content, liquid and plastic limits, and grain-size analyses. These identification tests help in estimating the probable behavior of the soil in the field. The assignment of standard test values to a soil eliminates confusion in interpretation and allows engineers from widely separated areas to speak in terms common to all. The shearing resistance may be determined by direct shear, triaxial compression, or unconfined compression tests.

Mineralogical tests may also be needed. All soils and rocks are aggregates of minerals, each with its own physical and chemical properties. Because of these characteristics the soils and rocks may have a positive relation to the individualistic nature of the landslide and consequently to the method of treatment selected.

For example, if the material is a glacial rock flour composed of discrete particles that are primarily quartz, a position below the water-table may make the soil "quick." Under special conditions of physiographic location and water content, such material is known to "break out" and flow as a result of spontaneous liquefaction.

As another example, a reasonably stable clay soil may become unstable or sensitive if percolating water affects the exchangeable cations of the constituent clay minerals or leaches out soluble salts. Because such factors will affect the type of treatment to be used, certain laboratory studies are useful, among which are:

X-ray diffraction.—This test is made when the rock or the soil contains minerals of such small grain size that other identification methods are impracticable. A diffraction pattern of the rock or soil is compared with the patterns of known minerals for identification.

Differential thermal analysis.—This method involves heating samples of a material to an elevated temperature and determining the temperatures at which thermal reactions take place, and the intensity and general character of such reactions. Because exothermic and endothermic reactions in a given mineral take place at typical temperatures and with typical intensities, identification of the mineral is possible.

Petrographic tests.—If the sample material contains mineral grains of appropriate size, or is suitable for the preparation of thin sections, constituent minerals and their relations to each other may be determined with the petrographic microscope from the optical properties of each specific mineral.

Synthesis of Information

Once all of the essential data described above are assembled for a given landslide, the information may be studied as a whole and the several observations and investigations interrelated so as to permit reasonable judgments from which will emerge a true picture of the landslide, its causes, and possible corrective measures.

GLOSSARY

Most of the definitions that follow are from the two glossaries listed immediately below. The specific glossary from which the definition was taken is indicated by the italic number in parentheses at the end of the definition.

(*1*) Glossary of Selected Geologic Terms, *by W. L. Stokes and D. J. Varnes, Colorado Scientific Society Proceedings, vol. 16, 1955.*

(*2*) Glossary of Geology and Related Sciences, *by the American Geological Institute, National Academy of Sciences, 1957.*

Alluvial fan: A sloping fan-shaped mass of loose rock material deposited by a stream at the place where it emerges from an upland into a broad valley or a plain. The highest point is at the apex of the fan, which is generally composed of boulders and cobbles that are dropped as soon as the stream emerges from its confining wall. . . . If the mass of material has steep slopes, it is generally called an alluvial cone, but if the slopes are relatively flat, it is called an alluvial fan. (*1*)

Aquifer: A geologic formation or structure that transmits water in sufficient quantity to supply pumping wells or springs. (*1*)

Basal till: Dense, clay-rich till with glacially worn stones. Deposited by lodgment beneath the ice, in contrast to "ablation" or superglacial till which is let down by the melting of the ice.

Clastic: Composed of broken fragments of minerals or rocks. . . . Familiar examples of sediments belonging to this group are gravel, sand, silt, and clay, and their consolidated equivalents, conglomerate, sandstone, and shale. (*1*)

Cohesion: The capacity of sticking or adhering together. In effect, the cohesion of soil or rock that is part of its shear strength which does not depend upon inter-particle friction. In soils, true cohesion is attributed to the shearing strength of the cement or the adsorbed water films that separate the individual grains at their areas of contact. (*1*)

Colluvium: Earth material that has moved or been deposited mainly through the action of gravity. Talus piles, avalanches, and sheets of detritus moved by soil creep or frost action are examples. (*1*)

Conglomerate: The consolidated equivalent of gravel. The constituent rock and mineral fragments may be of varied composition and of a wide size range. The matrix of finer material between the larger fragments may be sand, silt, or any of the common cementing materials such as calcium carbonate, silica, clay, or iron oxide. The rock fragments are rounded and smoothed from transportation by water, or from wave action. . . . *(1)*

Consolidation: Used here as densification of soil by natural earth processes, in contrast with artificial densification of a soil.

Creep: An imperceptibly slow and more or less continuous downward and outward movement of slope-forming soil or rock. Creep may affect only the top layer of a slope, and thus result not only from gravity but also from the seasonal influence of freezing and thawing, alternate wetting and drying, and thermal forces; or the movement may be deep-seated under the action of gravity alone. In creep, the movement is essentially viscous under shear stresses sufficient to produce permanent deformation but too small to produce shear failure, as in a landslide. *(1)*

Erosion: The wearing away and removal of materials of the earth's crust by natural means. . . . The agents that accomplish the transportation and cause most of the wear are running water, waves, moving ice, and wind currents. . . . *(1)*

Foliation: The banding or lamination of metamorphic rocks as contrasted with stratification of sediments. Foliation implies the ability to split along approximately parallel surfaces due to the parallel distribution of layers or lines of one or more conspicuous minerals in the rock. The layers may be smooth and flat or they may be undulating or strongly crumpled. *(1)*

Geomorphology: Through common usage it has come to mean the science of landforms. It is interpretative and descriptive in that it deals with the evolution of surface features as well as their morphology. *(1)*

Induration: The hardening of rocks due to heat, pressure, or the introduction of some cementing material. The term may also be applied to a hardened mass of rock or soil. *(1)*

Kame terrace: Stratified drift deposited by melt water between glacier ice and adjacent higher ground and left as a constructional terrace after disappearance of the ice. *(1)*

Kettle hole: A depression found in glacial drift believed to have originated when a block of ice, left isolated by general melting away of a glacier, is partly buried by sediments and later melts entirely away. . . . *(1)*

Lithification: That complex of processes that converts a newly deposited sediment into an indurated rock. It may occur shortly after deposition—may even be concurrent with it—or it may occur long after deposition. *(2)*

Loess: An unconsolidated or weakly consolidated sedimentary deposit composed dominantly of silt-sized rock and mineral particles deposited by wind. . . . The particles are mostly fresh and angular and are generally held together by calcareous cement or binder. . . . In many places, the accumulation of loess seems to be associated with past glacial or interglacial climates. *(1)*

Moraine: An accumulation of drift with an initial topographic expression of its own, built within a glaciated region chiefly by the direct action (deposition and thrust deformation) of glacier ice. . . . *(1)*

Petrography: The branch of petrology dealing with the description and systematic classification of rocks. Specifically, it deals with the textures, mineral associations, and chemical compositions of the rocks and it aims to provide a systematic classification of rock types. . . . *(1)*

Rock flour: Very finely ground rock material of silt and clay size formed by the abrasive action of glaciers. It consists predominantly of angular, unweathered mineral fragments and thus does not possess the cohesion characteristics of fine-grained materials composed of clay minerals. Rock flour is common in glacial outwash stream and lake deposits. *(1)*

Schistosity: The property of a foliated rock by which it can be split into thin layers or flakes. The property of splitting may be due to alternating layers of differing mineral composition or to preferred orientation and parallelism of cleavage planes of the minerals. *(1)*

Sink (or sink hole): A depression in the land surface . . . in limestone regions often communicating with a cavern or subterranean passage, so that waters running into it are lost. . . . *(1)*

Soil fabric: Arrangement of the soil constituents in relation to each other.

Stratum: A single layer of homogeneous or gradational lithology, deposited parallel to the original dip of the formation. It is separated from adjacent strata or cross-strata by surfaces of erosion, nondeposition, or abrupt change in character. . . . Restricted to sedimentary rocks. *(1)*

Structure (geologic): The attitudes and relative positions of rock masses as caused by deformational processes such as faulting, folding, and igneous intrusion. *(1)*

Subsidence: A sinking down of a large area of the earth's crust. (*1*)

Tectonic: Pertaining to the rock structures and external forms resulting from the deformation of the earth's crust. (*1*)

Terracettes: Small "cat-steps" or "sheep-tracks," that occur in the soil on steep grassy slopes above valley floors. These features are due to small landslips, which, as they are of frequent occurrence, contribute to the removal of mantle deposits. They parallel the contours. The essential conditions are lack of support in front and lubrication behind. (*1*)

Till: That part of glacial drift deposited directly by ice, without transportation or sorting by water. (*1*)

Till plain: The surface of a broad body of till. (*2*)

Vulcanism: The phenomena related to or resulting from volcanic action. (*1*)

Weathering: The various chemical and mechanical processes acting at or near the surface of the earth to bring about the disintegration, decomposition, and comminution of rocks. Weathering is accomplished in place; no transportation of the loosened or altered particles is involved. . . . (*1*)

SELECTED REFERENCES

The references listed below are probably the key publications on landslides in recent years. The excellent lists of references at the ends of chapters in the first publication afford a remarkably comprehensive bibliography for the student of landslides.

Highway Research Board, *Landslides and Engineering Practice*, Special Report No. 29, Washington, D.C., 1958.

Highway Research Board, *Landslide Occurrence and Analysis*, Bulletin 216, Washington, D.C., 1959.

Ladd, G. E., *Landslides, Subsidences and Rockfalls as Problems for the Railroad Engineer*, Am. Ry. Eng. Assoc., Proc., V. 36, pp. 1091–1162, 1935.

Sharpe, C. F. S., *Landslides and Related Phenomena*, Columbia University Press, New York, N.Y., 1938.

Terzaghi, Karl, *Mechanism of Landslides*. In *Application of Geology to Engineering Practice*, Berkey Volume, Geol. Soc. America, pp. 83–123, 1950.

Aerial Photographs

AND THEIR APPLICATIONS

by

H. T. U. Smith
Assistant Professor of Geology
in the University of Kansas

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Contents

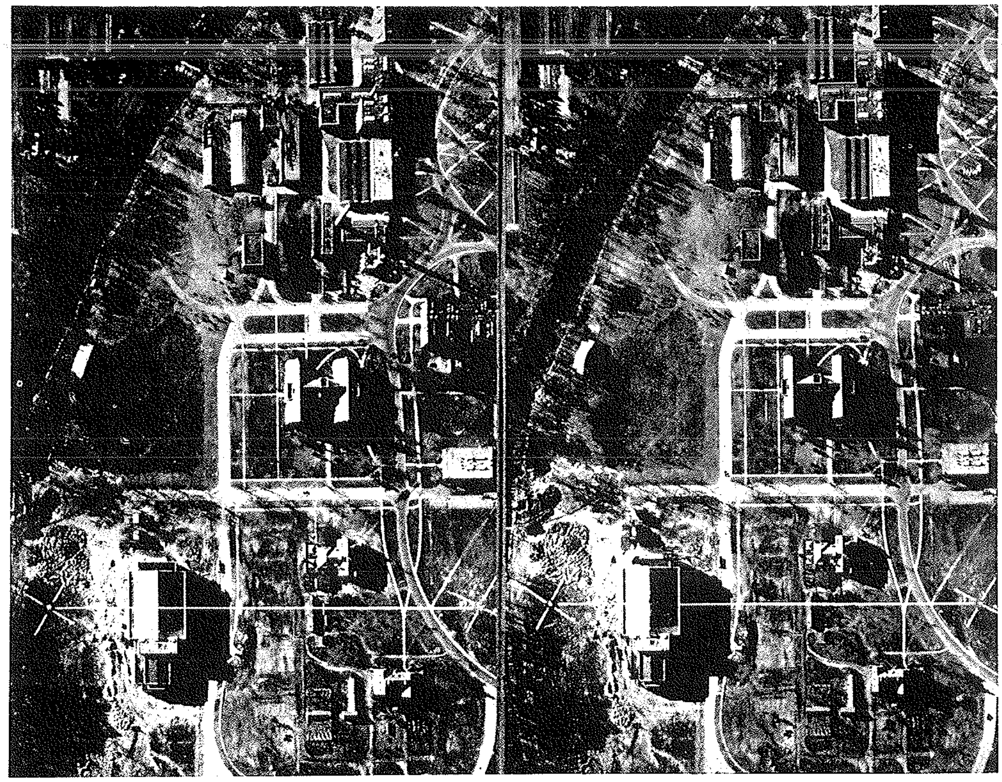

PLATE 5. A. Parallactic displacement on parts of a stereo pair of photos. The white lines represent photo base, and mark a ground distance of about 1175 ft. The outermost crosses indicate the center points of the two photos. Note "tilt" of buildings and smokestack. [*Photos courtesy of Abrams Aerial Survey Corporation.*]

PROCEDURE FOR STEREOSCOPIC OBSERVATION

In using the stereoscope for the first time, correct procedure and photos of good quality are important. The photos should be fairly well matched for average color tone, should have at least moderate contrast, and should show well-defined features on a topography of at least moderate relief. Gloss finish is preferable, but not essential. Correct orientation of the photos with respect to one another and to the instrument is particularly important, as otherwise there may be some difficulty in obtaining stereoscopic "fusion" of the two views. As experience is acquired, however, photos departing far from the ideal may be used successfully, and less attention to details of procedure is needed.

In discussing procedure, three new terms are used, which may first be defined. *Eye base* represents an imaginary line between the pupils of the eyes. Its length equals the distance between the pupils when the eyes are focused at infinity, with zero convergence. *Stereo base* may be defined as the direction and distance between complementary image points on a stereo pair of photos correctly adjusted for comfortable viewing under a given stereoscope, or under the unaided eyes. In the lens type of stereoscope, it lies in a plane containing the axes of the two lenses. In the mirror type, it lies in a plane vertical to that of the mirrors. In length, it varies for different instruments. *Photo base* is a term here introduced to refer to lines, on each photo of a stereo pair, connecting the center point of one with that point corresponding to the center of the other (Plate 5 A). In direction, it parallels the line of flight, and in length it equals the air-line distance between exposure stations reduced to the scale of the photos. Unless there is distortion, the length is the same on each photo of the pair.

Correct orientation of photos for stereo vision requires that eye base, stereo base, and photo base be parallel. There are various ways of effecting correct orientation, and the one outlined below is representative. As facility is gained, modifications and short-cuts may suggest themselves.

1. If the center points are not already marked on the photos, they are located by drawing intersecting lines between opposite collimating marks. If it is desired to avoid marring the emulsion side of the photo, the collimating marks may be transferred to the reverse side by pricking with a fine needle held perpendicular to the photo. Crossing lines are then drawn as above, and their intersection point transferred to the opposite side by carefully pricking.

2. The stereo base for the instrument used is measured by means of a scale such as that shown in Figure 22.

3. The two photos are next placed in correct overlapping relation to one another, and detail along the edge of one is matched with corresponding detail on the other. A straight-edge is then aligned with the center points of the two photos, and one of the pair is moved along the straight-edge, maintaining the same relative position with respect to it, until complementary image points are separated by the distance measured in (2) above. If image points along the straight-edge on one photo do not correspond exactly with those on the other, one or both photos may be rotated slightly about their center points until the de-

sired alignment of complementary points with the straight-edge is attained. The photos may then be fastened in position with drafting tape if desired.

4. A stereoscope is now placed over the photos and is aligned with the straight-edge by noting whether the images of the latter in the two eyes fall in line. The photos should be evenly lighted, and the light source should be correctly oriented with respect to the shadows, as explained on page 55.

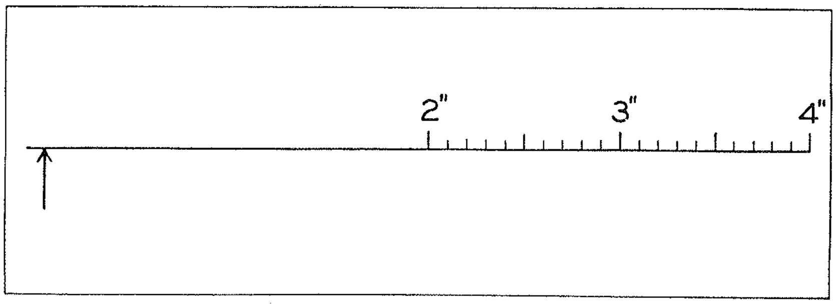

FIG. 22. Scale for measuring stereo base for a lens type of stereoscope. When viewed under the stereoscope, the arrow will appear to be in contact with the scale at the right, and the number to which it points will represent the length of the stereo base. For a mirror type of stereoscope, a longer scale is necessary. [*Suggested by L. Desjardins.*]

5. It should now be possible for the observer to bring complementary images on the two photos into stereoscopic fusion. Attention should first be directed at some sharp and well-defined object or feature, and the gaze allowed to rest on it until a three-dimensional picture emerges. After obtaining fusion for one point, the gaze is gradually moved from point to point over the photo, until the entire area is seen stereoscopically. After a short period of practice with different pairs of photos, it should be possible to obtain fusion instantaneously, and to maintain it while glancing rapidly from point to point.

Stereovision comes more slowly to some persons than to others, and for those who encounter difficulties, special aids may be helpful. Any one who can see even moderately well with both eyes, however, should sooner or later be successful. If difficulty is experienced with one type of stereoscope, it may be found more satisfactory to try the other. One device which may be of assistance when fusion is not readily obtained is to place a marker, such as the corner of a plain white or black card, at each of the photo points on which the attention is directed. If this fails, it may be well to check the alignment of photos and instrument by alternately closing each eye, and noting whether complementary points on the two photos seem to be in the same position and to be equally distinct. If not, slight readjustment of photos or of lighting may help.

If one eye is dominant, or stronger than the other, it may be of assistance to have stronger lighting on the photo under the weaker eye, and to close the stronger eye until a clear image is first seen with the other eye. If these various devices fail to bring about stereoscopic fusion, it may be necessary to resort to some of the exercises later described for obtaining stereovision without the stereoscope, using them, however, with the instrument.

For all purposes requiring very accurate observation of detail, such as map making, photos should be aligned carefully by the above procedure or its equivalent. For work of less exacting character, more rapid and approximate methods may be used after stereovision has become easy and natural. Due care must be exercised, however, for, even though fusion is obtained, any serious departures from correct orientation will cause unnecessary eye strain.

One method for rapid adjustment is first to place the photos approximately in position under the stereoscope by estimation, and then, seeing double, to locate any two complementary image points, and to slide the photos in such directions as to bring them into correspondence of position. A finger tip or other marker placed below each point may be helpful in doing this if no very sharply defined features are present on which to fix the attention. Another method for approximate orientation is to blink both eyes in rapid alternation, noting the relative position of some distinctive point which is shown on both the photos, and move the photos so that the point seems to jump less and less on shifting eyes, and finally remains in the same position. Stereoscopic fusion for that point should then be possible. The above procedure should be repeated for additional points in other parts of the overlap area, to make certain that the over-all adjustment is correct.

In orienting photos for stereoscopic examination, it is important always to separate them in the direction of the flight line. A common mistake of beginners is to separate the photos in some other direction. Although this may permit some degree of stereoscopic perception, it will make for distortion and eye strain, with a diminution of the relief effect.

STEREOVISION WITHOUT THE INSTRUMENT

Under many conditions, as in the field use of aerial photos, the stereoscope may be either unavailable or inconvenient to use. In such circumstances, and for the hasty examination of photos in general, it is extremely convenient to be able to see stereoscopically without the use of any instrument. This, of course, permits no magnification, and does not afford the comfort and stability of a stereoscope on the table. It is not to be recommended for sustained periods of exacting observation, and is best used to supplement standard instrumental methods rather than to replace them.

Stereovision with the unaided eye requires the disassociation of convergence and accommodation (or focus) of the eyes, which normally are coördinated instinctively. In other words, it is necessary to acquire voluntary control over a previously involuntary reflex. This, however, is less difficult than might be expected, and requires only the practice of certain simple exercises. The ones described below have been found by the writer to be particularly successful in teaching students. For some individuals, one method is easier than another, and for others, a combination of different methods may be most effective. If glasses are worn for ordinary reading, they should generally be worn for these exercises.

1. The simplest method requires only a stereo pair of photos and a plain white card, 5 x 8 in. or larger in size. The photos are first matched together, and then separated until complementary image

points are about 2 in. apart. The card is then placed upright between the photos, so that the right eye sees only the right-hand photo and the left eye only the left-hand photo. Attention is then concentrated on some well-defined feature common to both photos, and an effort is made to superimpose the images and to bring them into focus. If this can be done, fusion should be easy. If it cannot be done, however, the separation of the photos may be decreased to about half an inch or less, and the same procedure repeated. If this succeeds, and stereoscopic fusion is attained, the photos are gradually moved farther apart, while maintaining fusion. This, at first, will seem to strain the eyes, and at a certain stage the fused image will waver and then separate into two flat images. When this occurs, the eyes are rested for a few minutes and the exercise repeated. After a time, the card is dispensed with, and the eyes are trained to focus at will on two separate points some distance apart, and thus to bring the photos directly into position and into stereoscopic fusion. By practising this exercise several times a day for several days, it should be possible to attain stereoscopic fusion of points separated by a distance equal to that between the eyes, or about 2.5 in.—sufficient for viewing any of the stereoscopic illustrations in this book. With added practice, the distance of separation may be increased to 3 or 4 in. by many persons, and to as much as 6 in. at normal viewing distance by a few individuals. As proficiency is acquired, the sense of eye strain disappears, and this method of stereovision becomes easy and natural. 243

2. For those who find difficulty with the method outlined above, it is commonly helpful to substitute black dots on white paper for the photographic images. The sharper contrast and absence of interference or distraction makes for greater ease in focusing the eyes under the required conditions. The dots should be exactly alike, and are best made with a drop-bow compass and black india ink. Using the card as described under (1) above, it may be possible at the outset to obtain fusion for dots about 2 in. apart (Fig. 23 A). The convergence of the eyes should be nearly zero, as in looking at a distant object. The dots will probably be seen double at first, and an effort should be made to bring them together, even though they are blurred. When this is accomplished, a further effort is made to bring the fused dot into sharp focus. This is practised until it can be done at will, without the card.

If dots separated by the distance indicated above cannot easily be brought into fusion and focus, two dots on separate cards may be used, one near the edge of the card. These are placed close together for the first attempt, and the upright card used as before. After fusion is attained, the distance of separation is gradually increased, up to at least 2.5 in. A variant method is to use a series of paired dots, separated by regularly increased distances, as shown in Figure 23 B. Fusion is first obtained for the pair closest together, and then the gaze is made to progress to those of wider spacing by a series of small jumps. It will be noted that the various pairs of dots appear to be at different depths.

After proficiency in fusing the dots is attained, photos are placed with their edges close to the dots, and with complementary image points just below the dots. Then, after fusing the images of the dots, the gaze is shifted to the photos, and an effort is made to maintain

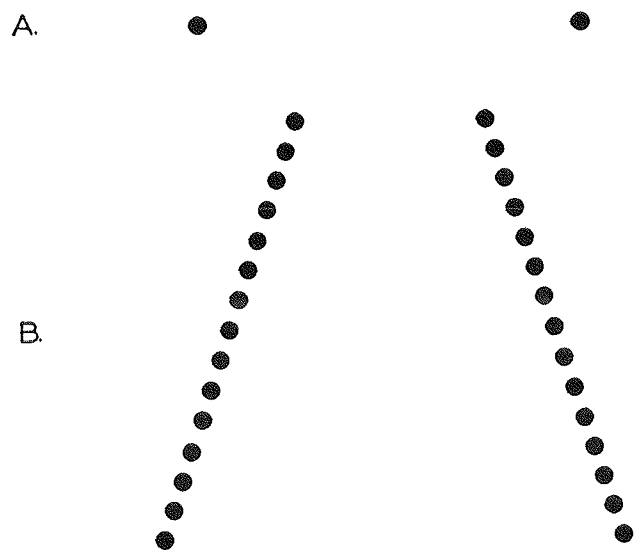

FIG. 23. Paired dots for practicing stereovision without the instrument. If it is not at first possible to fuse the pair in *A*, an effort is made to fuse successive pairs in *B*, starting at the top and proceeding downward, in the direction of increasing separation, by a series of small jumps. It may be helpful to cover all except the pairs nearest the one in fusion, with cards. An upright card between the right and left-hand rows aids in preventing interference between right and left images, particularly in the beginning.

fusion. Dots or small circles inked on complementary photo image points may be used as a further aid, if necessary.

3. A third exercise involves the use of two dots on a strip of transparent celluloid. The dots should be separated by a distance equal to or slightly less than the interpupillary distance. This strip is held at arm's length, and, looking through it, the eyes are focused on the sky. At the same time they should see, although somewhat out of focus, either three or four dots. If four are seen, the central dots will probably be close together, and should easily be superimposed, either by rotating the celluloid strip around an axis parallel to the line of sight, or by slightly changing the setting of the eyes. An effort is then made to change the focus of the eyes from the distant view to the central dot

without changing their convergence. After this is done, the dots are gradually brought nearer to the eyes, to within a distance of about 10 in. This is practised until it becomes easy, and then the gaze is shifted from the dots to photo image points as in (2) above.

By practising one or more of the above exercises, it should be possible for virtually all individuals having anything approaching normal vision in both eyes to obtain stereovision without the instrument. Some will acquire the faculty much more quickly than others, and some will achieve a much greater distance of separation than others, but all should find it a workable method.

CHARACTERISTICS OF THE STEREOSCOPIC IMAGE

The appearance of the stereoscopic image is that of a relief model or spatial model, giving the impression of solidity and depth. For vertical photos having 60 per cent overlap, the vertical scale of the "model" appears to be considerably exaggerated, and the impression of relief is far greater than that which an observer in the photographic airplane would have received visually. This is due to the much greater angular difference between the rays from any given ground point to two successive exposure stations, as compared to that between rays to the observer's eyes from the same ground point. This difference in relief effect may be likened to that between the images of objects viewed at distances of 8 in. and 1 mile, respectively. The strength of the relief effect is directly proportional to the ratio of air base (distance between exposure stations) to flight altitude. For photos made with the same camera, the strength is inversely proportional to the amount of overlap, as may be seen by comparing images of the same feature as viewed on the 60 per cent overlap area of successive photos in the flight strip and on the 20 per cent overlap area of alternate photos. If it be assumed that the size and scale of the photos and the amount of overlap remain the same, the strength of the relief effect varies directly with the angular coverage of the camera, and thus inversely with focal length.

In addition to the relief model, two satellitic images, without relief, may be seen on either side under certain conditions. This occurs when each eye not only sees the image directly beneath it,

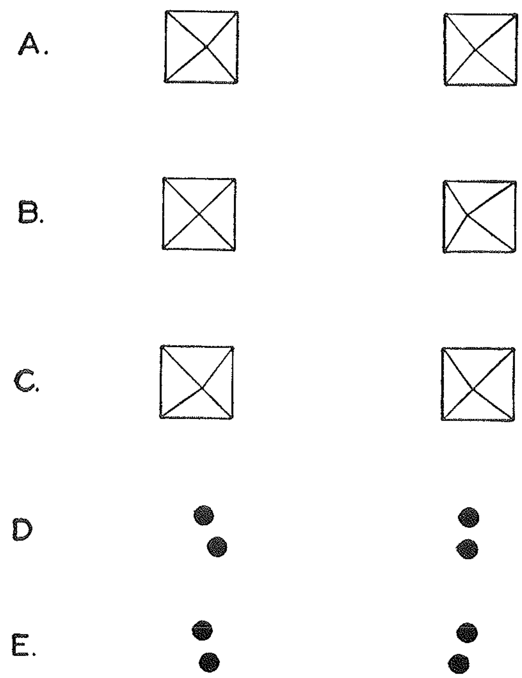

FIG. 24. Stereograms illustrating effects of distortion by parallactic displacement on the stereoscopic image. In *A*, the distortion on the two images is equal in amount but opposite in direction. In *B*, the distortion is zero on one image and 100 per cent on the other. In both *A* and *B*, the "*y*", or vertical component of distortion, is zero. In *C*, however, that component is large, and the other, or "*x*" component is the same as in *A*. Stereoscopic examination shows that the *x* component is averaged on the spatial model, while the *y* component is unaffected. *D* and *E* show two sets of dots having the same relative spacing but different position, and, viewed stereoscopically, show that the fused images appear to be halfway between the actual images. These stereograms may be viewed either with a simple lens type of stereoscope or with the unaided eyes.

but also has a marginal view of the image under the other eye. Thus the satellitic image at the right is the one seen by the left eye, and vice versa.

The effects of distortion by parallactic displacement on the stereoscopic image are different from those on any single photo.

The observed displacement, as measured parallel to the photo base, equals the algebraic mean of the displacements on each individual photo. Thus, if the displacements of a given point on the two photos are equal in amount but opposite in direction, they cancel one another, and the point or object shows no distortion along the one coördinate (Fig. 24 A). If the distortion is zero on one photo, the observed distortion will be half that seen on the other separately (Fig. 24 B). That component of distortion transverse to the photo base, however, is unaffected. For points lying close to the photo base, it will, of course, be inappreciable (Figs. 24 A and B), but for points lying well away from the photo base, it will be readily distinguishable, as shown in Figure 24 C. These effects are due to the simple fact that the apparent position of any point on the "spatial model" will be halfway between its complementary image points on the two photos, as may be seen in Figures 24 D and E.

FACTORS INTERFERING WITH STEREOVISION

Assuming that the observer has normal eyesight and has cultivated stereovision, there remain several factors, arising from the nature of the terrain, from the properties of individual photos, or from faulty procedure, which may interfere more or less seriously with depth perception.

1. Incorrect orientation. The effects of this factor have been noted in the preceding discussion. Suffice it to say that careless orientation of photos with respect to one another and to the eye base may allow some image points to be readily fused, while those in other parts of the overlap area are less easily fused. Other difficulties introduced by this factor in its various forms are eye strain, diminution of the relief effect, and increased distortion.

2. Marks on photos. Ink marks, such as sometimes used on photos to emphasize drainage lines or to record various data, detract seriously from the effectiveness of depth perception, particularly when on only one photo of a stereo pair. Injuries to the emulsion have the same effect.

3. Monotonously uniform color tone and texture. This condition, on one or both photos, may be due to the nature of the ground surface.

to faulty photographic processing, or to both. It makes stereovision unsatisfactory or even impossible for the areas affected. This is particularly well shown on bodies of quiet water, and may sometimes be seen also on grassland or on cultivated fields.

4. Scale difference. The effect of appreciable overall difference in scale between photos is to cause difficulty in obtaining stereovision in all parts of the overlap area without readjusting the photos. This difficulty may be dealt with, either by realigning the photos for examining different parts of the overlap area, or by bringing the photo of smaller scale closer to the eye, as by placing a book under it.

5. Tilt. This factor also necessitates readjustment of the position of one or both photos for viewing different parts of the overlap area. If very large in amount, it may make stereovision impossible for some parts of the overlap area. There is no simple way of compensating for tilt except rectification of the photo by projection printing.

6. Deep shadows. The effect of strong shadows may be such as to obscure photographic detail locally, and thus prevent stereoscopic fusion. Proper printing technique, however, may partially counteract this factor.

7. Cliffs and steep slopes. Steep, vertical, or overhanging slopes, particularly when facing away from the center of the photo, may either compress a part of the field of view, or cut it off entirely, and thus interfere with the two full views required for stereovision.

248 8. Large and abrupt local differences in elevation. The effect of this factor is to make it impossible to maintain fusion for adjoining high and low points at the same time. This is frequently true of tall smokestacks (Plate 5 A) or high, steep-sided buttes. A simple illustration may be had by looking down the end of a pencil held about 8 in. from the eyes. When the end is in fusion, the part farther away is seen double, and vice versa.

9. Changes in position of objects between exposures. This applies to such moving objects and features as cars, trains, and waves. Such objects cannot be viewed stereoscopically.

10. Reversal of photos. If the right- and left-hand photos are exchanged under the stereoscope, without rotation, the relief effect is reversed, with the streams appearing as ridges and the ridges as valleys. This effect is similar in appearance to that produced by incorrect shadow orientation, but is of physical rather than of psychological origin. It is termed the *pseudoscopic effect.* Generally this reversal of the topography is so abnormal in appearance as to be readily detected, but in certain types of hummocky terrain, where distinct points for comparison are lacking, it may pass unnoticed on casual observation. The pseudoscopic effect is likely to be seen only under the mirror stereoscope, for the distance of separation required is too great for the average lens stereoscope when photos of standard size are used.

AERIAL PHOTOGRAPHY

by

Jack Caraway

National Association of County Engineers
Action Guide Series

National Association of Counties
Research Foundation
July 1972

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APPENDIX C

MOSAICS

Mosaics are composite photographs made by assembling positive photographic prints of individual and adjoining consecutive aerial pictures to form one over-all picture of the total photographed area. These may be made using controlled, semi-controlled or uncontrolled photography.

A controlled mosaic is one which is controlled by a ground survey. A semi-controlled mosaic is usually defined as one which is controlled by features on a previously existing map. In the controlled mosaic, each photograph is rectified to remove the effects of camera tip and tilt and laid to a base map for control of azimuth, scale and position. Extensive ground control survey work is necessary to establish the horizontal coordinates of the points on the ground.

In a semi-controlled mosaic, each photographic print is indvidually ratioed and enlarged to produce matching of planimetric features. No ground control is necessary for the semi-controlled mosaic.

The uncontrolled mosaic is assembled by using photographic prints without any rectification or ratioing procedures. This type of mosaic is least costly and can be assembled without specialized equipment in the office in which it is to be used.

The photographic scale selected will depend upon the anticipated use of the mosaic, the funds available, the size of the mosaic area, and the space available for utilization. The scale should be large enough to afford recognizable images at a reasonable viewing distance.

The materials needed to construct an uncontrolled mosaic include the following items:

1. Photographic prints. A set of single-weight contact prints providing coverage of desired area
2. Mosaic board. A smooth, hard-surface and non-porous material such as masonite, should be used
3. Adhesive. An excellent adhesive for constructing mosaics is a mixture of gum arabic and water with a specific gravity of 20° Baume'
4. Sandpaper. A fine sandpaper rolled around a paper cylinder is usually used
5. Sanding block. A small block of wood in the form of a half-cylinder provides a support surface for the photograph while the edges are feathered with the sandpaper
6. China marking pencil
7. Masking tape
8. Sponges

9. Water container
10. Plastic squeegee

Begin by assembling *each* flight strip of photography by matching images along the flight line *only*, adjusting all assembled strips to the same length, and finally assembling strips by matching the images in the overlapping areas. Select an image in the overlap area of each adjacent pair and adjust the photographs so that when they are flipped back and forth the image does not appear to move. Fasten the oriented photographs along the flight line. The flight line, of course, is the trace across the photograph from the center of the photograph of concern to the image on the photograph corresponding to the center of each adjacent photograph in line of flight. The length adjustment must be made for all strips within an area to compensate for changes in ground elevation and for variations in the flight height of one strip of photographs in respect to another. It may be desirable to make the length adjustment in segments if local scale differences have been introduced by abrupt changes in height of the ground.

There are several techniques for assembling a mosaic. A method used by one road department is included for your information. With diagonal lines, locate the center of the mosaic board and mark it. Then draw a straight line across the mosaic board through the center point parallel to the direction that the flight lines are to be oriented. This line will serve as the controlling azimuth of the mosaic.

Disassemble the oriented center flight of photographs and carefully extend the line all the way across each photograph. Select the center photograph of the center flight and prepare it to be laid. Draw a line on the photograph enclosing the area to be used in the mosaic. Holding the photograph in one hand with image side up, use the other hand to tear off the portion not to be used. The tear should be done with a twisting motion away from the portion to be retained in such a manner that the edge of the portion to be used is left in a tapered fashion.

Lay the edge of the photograph over the cylinder shaped block with the picture side down and draw the sandpaper wrapped paper tube over it until a featheredge effect has been obtained. Be careful not to get the edge too thin as such exposed areas will appear darker after it has been laid. 253

Apply the adhesive to the mosaic board. Then lay the first print in the center of the board matching the line on the photograph to the line on the board. Remove excess adhesive by working the squeegee from the center of the photograph to the outer edge, forcing the photograph down and the excess adhesive from under it.

Allow the adhesive to set and select either of the adjacent photographs in the center flight. Orient it to the center photograph by matching detail in the overlap area and flipping to check for apparent movement. Draw a line on the second photograph along the area where the photograph is to be torn. Areas should be selected where adjoining photographs have the same tone. Avoid straight line tears except where the tear is parallel to straight, elongated images such as roads, railroads or fence lines. Then, using a very sharp blade cut through the emulsion along the marked line and tear away the portion to be discarded as previously explained.

After the torn edges have been feathered, re-orient the photograph in its proper position on the mosaic board, again matching detail and the lines of the photograph and mosaic board. Holding the photograph in its place, draw a series of match lines from points an inch or more from the edge of the photograph to be laid, across the edge of the photograph and onto the adjacent photograph or mosaic board for a distance of an inch or more. These match lines should be placed at intervals from two to three inches apart around the perimeter of the photograph.

Apply adhesive to cover the area where the photograph is to lay and then lay the photograph, matching up the previously drawn lines. Using the squeegee, remove the excess adhesive and then wipe the prints clean with a damp cloth.

Continue in this manner until all of the photographs in the center flight have been laid. Care should be taken to maintain the azimuth by matching the lines drawn on the photographs and mosaic board for that purpose. When the center flight has been completed, photographs in the adjacent flights should be laid by matching photographic detail in the overlap areas. Thereafter, each flight laid becomes the base for laying the next flight.

Severe erosion near La Paz, Bolivia.

HIGHWAY RESEARCH BOARD

Bulletin No. 28

SOIL EXPLORATION AND MAPPING

PRESENTED AT THE TWENTY-NINTH ANNUAL MEETING
1949

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING AND INDUSTRIAL RESEARCH
NATIONAL RESEARCH COUNCIL

Washington 25, D. C. November 1950

CONTENTS

DRAINAGE PATTERN SIGNIFICANCE IN AIRPHOTO IDENTIFICATION OF SOILS AND BEDROCKS

Merle Parvis, Research Engineer
and
Assistant Professor in Highway Engineering
Joint Highway Research Project, Purdue University

SYNOPSIS

This paper reports the analyses of drainage patterns for their use in the identification of regional soils and bedrocks by means of airphotos. The study is one of several concerning the interpretation of aerial photographs by the Joint Highway Research Project at Purdue University. The relative ease with which stream systems can be observed on aerial photographs facilitates the recognition of drainage patterns.

In the natural sciences, it has been accepted for a long time that certain basic drainage patterns such as the dendritic, trellis, radial, parallel, annular, and rectangular are associated with specific land surface materials. Airphoto interpretation has revealed several modifications of the basic drainage patterns. For example, some of these modified types are the reticular, phantom, and lacunate.

Drainage patterns, traced directly from representative airphotos of various physiographic regions throughout the United States, are presented as illustrations of patterns which develop in the soils and bedrocks typical of the regions. These examples have been selected to show noticeable differences in drainage patterns. For instance, drainage patterns in regions where the rocks are bare or are covered only with shallow soils, are decidedly different than those in regions of deep glacial drift. Likewise, drainage patterns develop differently in horizontal rocks than in tilted rocks.

It is concluded that surface drainage patterns can be relied upon in the airphoto identification of soils and bedrocks on a regional basis.

Drainage patterns have intrigued scientists over a long period of years. As a result of their findings, many patterns have been classified and incorporated into the literature of the natural sciences of geology, physiography, and geomorphology. Recently - probably within the last decade - engineers have been studying drainage patterns by means of airphotos. In the laboratories of the Joint Highway Research Project at Purdue University, highway research engineers have been using airphotos to construct detailed drainage maps of Indiana on a county basis. During the progressive stages in the compilation of these maps recurring drainage patterns were observed. This led to the investigation of drainage patterns on aerial photographs of areas of land surface materials, with known characteristics, which occur elsewhere in the United States.

The study of an area for the purpose of identifying its soils and bedrocks by means of airphotos is best effected by stereoscopic examination of the vertical aerial photographs of that area. By this means such "elements" of the terrain as landform, drainage pattern, erosion features, vegetative cover, and land usage are revealed on the airphotos in a most realistic manner. Photo tonality is another "element" vital to airphoto interpretation. Tonality can be observed without the aid of a stereoscope. Colors found in soil, rock, vegetation, or water are recorded on the airphotos in black, white, or tones of gray which vary according to the values of the respective colors and the reflection of incident light. While all the elements are correlative and are considered equally important in airphoto interpretation, only the drainage pattern element is herein set forth. In doing this, it is not to be assumed that the drainage pattern element can be relied upon alone in the identification of soils and bedrocks by the use of airphotos. It must be used in conjunction with the other elements.

It is known that the drainage of a region is affected by such factors as bedrock structure, soil textures, topography, artificial waterways, rainfall, vegetation, and evaporation. Since bedrocks on a regional basis.

The airphotos employed in the preparation of this paper were taken during 1937-1943 in connection with the United States Department of Agriculture mapping program. The prints were obtained from the Agriculture Adjustment Administration (now Production and Marketing Administration). They are standard 7-by 9-in. and 9-by 9-in. contact prints having an approximate

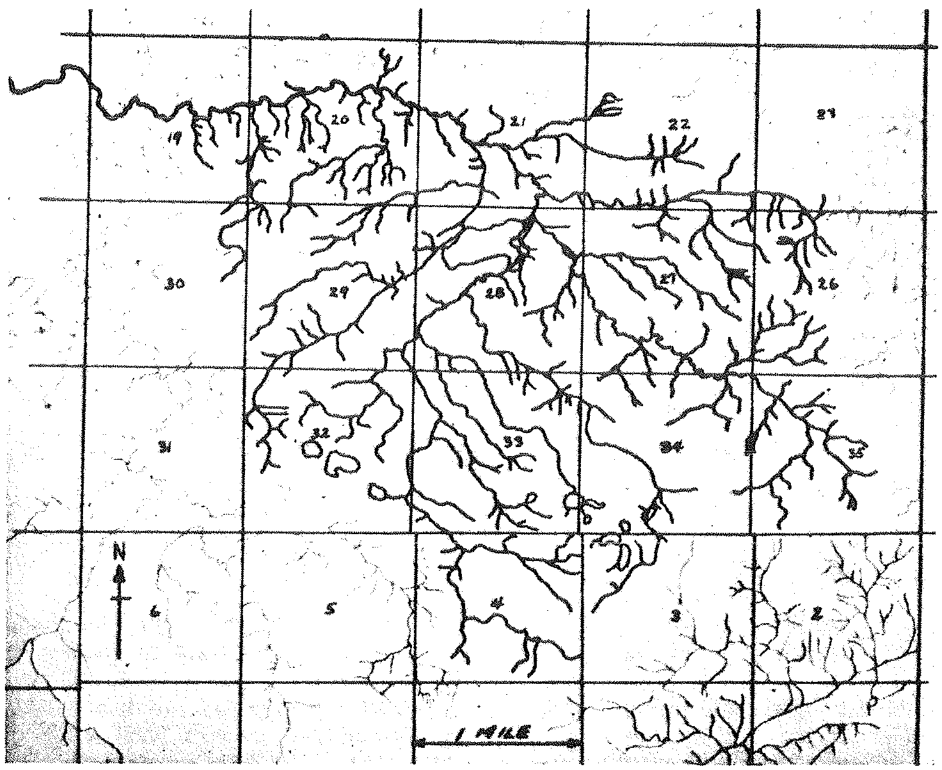

Figure 1. Drainage Pattern of the Headwaters of a Stream System Developed in Wisconsin Glacial Drift - Flint Creek, Tippecanoe County, Indiana - The areas bounded by dotted lines are infiltration basins. Numbers indicate Congressional land sections. (This pattern was traced directly from aerial photographs of the area. Original Scale : 1:20,000)

the drainage ways and landforms of a region are interdependent, they exist together as interrelated features of the region. Therefore, soils and bedrocks influence the evolution and character of the patterns of a region's many rivers and tributary streams. These facts lead to the premise that drainage patterns can be used to identify soils and scale of 1: 20,000 or 3 in. per mi.

DRAINAGE PATTERN CLASSIFICATION

A pattern has been defined by Webster as "an arrangement or composition that suggests or reveals a design". The term "drainage pattern" is used in this paper to apply to the manner, or "design", in which a given set of tributary streams arrange themselves within a given drainage basin (See Fig. 1).

Drainage patterns are classified on the basis of form and texture. The form of the pattern is its shape which may be described by comparing the pattern with a familiar object such as the branches of a tree. The texture (or density) of the pattern refers to the spacing of the tributaries in the stream systems. If the tributaries are closely spaced the texture is "fine", and if they are widely spaced it is "coarse".

Certain drainage patterns are considered as the basic patterns. Variations of the basic types are known as modifications of the basic patterns.

Basic Drainage Patterns - Of the many stream patterns which have been formed by natural forces acting upon the earth's land surface materials, six have been classified as the basic drainage patterns. Analyses of the more or less characteristic arrangement and repetition of the lines of these patterns have revealed significant relationships between the patterns and the soils and bedrocks of the regions in which they are found.

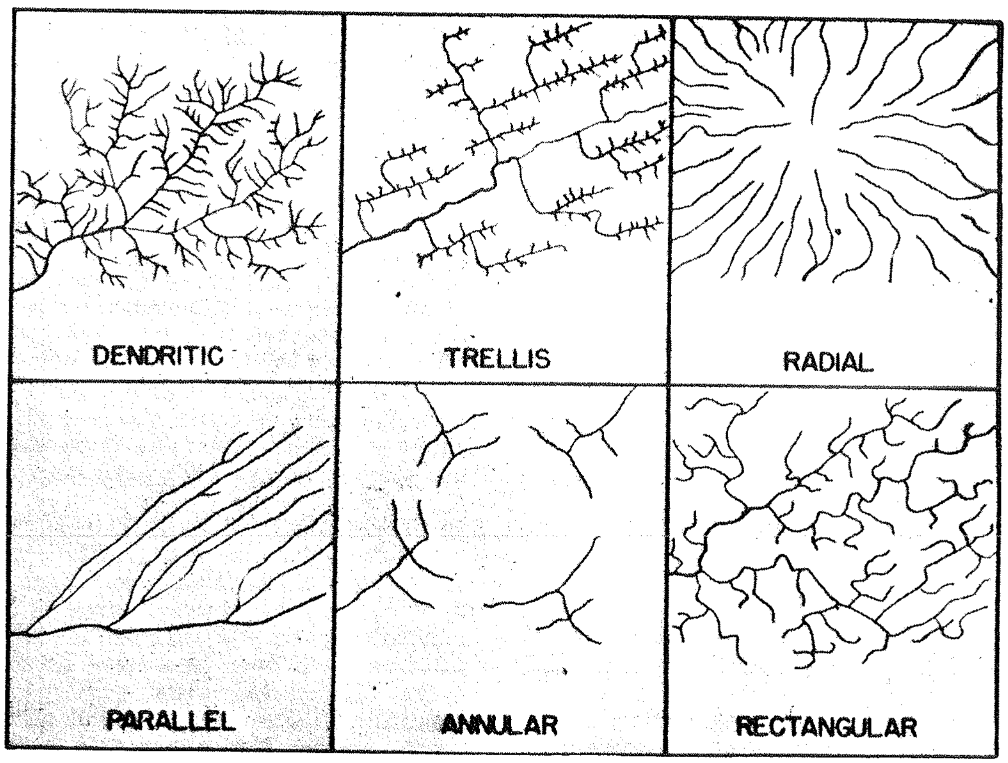

Figure 2. Sketches Illustrating Basic Drainage Patterns (20) (21)

Figure 2 illustrates the six basic drainage patterns. They can be described as follows:

1. A dendritic drainage pattern is tree-like in form; the main stream corresponds to the trunk of the tree and its tributaries resemble the irregularly subdivided branches, limbs, and twigs

of the tree (22: 127)[1]. Another term for this type pattern is "arborescent" (11: 300). It is the most common type drainage pattern. It is formed where the "rock structure does not interfere with the free development" of streams (15: 340).

2. A trellis type of drainage pattern may be compared to a vine on a garden trellis; the primary tributaries are long and straight and often parallel to each other and to the main stream. Numerous short, stubby secondary tributaries join the primary tributaries approximately at right angles (22: 127). This drainage pattern may be thought of as one "adjusted" to structure (2: 122). "Grapevine" is another name for this type pattern (26: 503).

3. A radial drainage pattern may be likened to the spokes of a wheel. The pattern may be either centrifugal or centripetal; that is, the streams may flow radially either outward from a peak or inward toward a basin (17: 175) (22: 127). Also, this term can refer to a group of drainage patterns originating at a common point (13: 350). Stream systems on isolated hills often take this form.

4. In a parallel drainage pattern the streams or their tributaries are parallel or nearly parallel to each other (22: 127). The way in which the streams are arranged might aptly lead to the naming of the pattern cauda equina - horse's tail.

5. In an annular drainage pattern "ring-like" tributaries flow into the radial streams (22: 127). This type pattern has been compared to the annual growth rings in a tree (17: 175).

6. A rectangular drainage pattern shows the influence of the angularity of rock joints; it is characterized by many "abrupt bends" in both the main streams and their tributaries (22: 129). This pattern is a "right-angle system of streams" (7: 130). The pattern is affected locally by horizontal rock strata of different composition.

Rock structure is a major factor in the development of these six patterns.

[1]Numbers in parentheses refer to references at the end of the paper.

Dendritic drainage patterns are normally formed by streams flowing in horizontal homogeneous rocks. Trellis patterns develop in folded or dipping rocks where there is a series of parallel faults. These also result from adjustment and are stream systems "aligned on a strike of the rock formations", the streams occasionally making "right-angled turns to cross strike ridges" (4: 86). Streams draining volcanic peaks assume the radial type of pattern. Drainage patterns in tilted rocks having parallel faults and in valley-fill materials often show striking parallelism. A parallel drainage pattern implies a "pronounced regional slope" (26: 510). Streams around a dome follow circular, or annular, courses. Streams following the faults and cracks in jointed rocks produce rectangular drainage patterns (17: 175). Fractures in the rocks of the earth's surface have "influenced the activities of running water". Sometimes a river's course is in "rectangular zigzags" - its walls are formed of joint planes" (12: 224). All these drainage patterns reflect details of relief that are characteristic of the materials from which the stream valleys have been carved.

Modifications of the Basic Drainage Patterns -There are several modifications of the basic drainage patterns. Figures 3, 4, 5, and 6 illustrate some of the modified types. A number of these patterns have been described in scientific literature. The author has identified others by means of aerial photographs.

Descriptions of the patterns in Figure 3 are as follows:

1. The pinnate drainage pattern is a modification of the dendritic type. The second order tributaries are arranged in a more or less parallel manner (parallelism indicates a nearly uniform slope). The rather evenly-spaced first order tributaries join the second order tributaries at acute angles (near right angles) much in the manner of a feather - hence the name "pinnate" (26: 512).

2. The deranged or disordered type

of drainage pattern has been applied to the drainage of drift-covered regions. It has been so termed because of the great irregularities of its pattern and the confused intermingling of lakes, marshes, and wide-open valleys (7: 503). Runoff water collects in the lakes, swamps, and marshes; and streams wander aimlessly about the landscape (8: 295). The numerous lakes and swamps depict the undeveloped character of the drainage. The terms "erratic" and "haphazard" may also be applied to this pattern (12: 300). Patterns of individual drainage systems within the area are usually dendritic.

3. The subparallel drainage pattern resembles the spire-like Lombardy poplar tree in its type of branching. The first order tributaries are usually nearly parallel to the second order tributaries. Again, in this type, parallelism denotes uniformity of slope (26: 513). This pattern is a modified type of parallel drainage, but "lacks the regularity of the parallel pattern" (26: 518).

4. The contorted drainage pattern type is a "response to rock structure" (7: 215). Streams flowing in one direction may be completely reversed in direction when they encounter resistant rock or granular barriers.

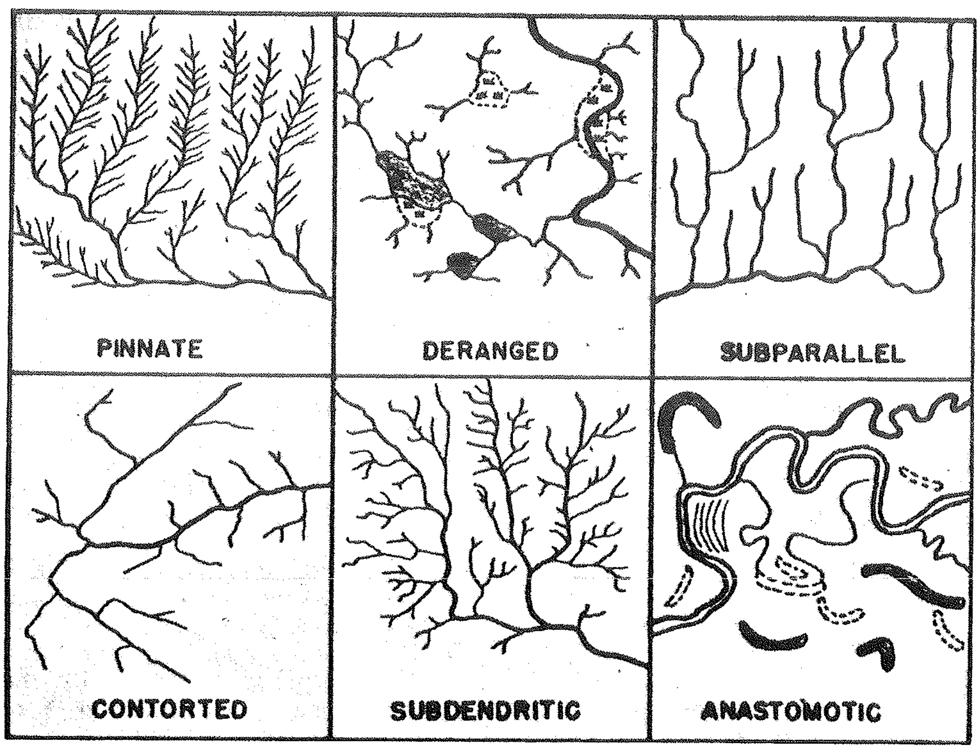

Figure 3. Sketches of Modified Basic Drainage Patterns (20) - Shaded areas are water filled basins - lakes, ponds, slough, bayous. Areas bounded by dotted lines are infiltration basins.

5. The subdendritic drainage pattern is a modification of the dendritic type. This type shows minor slope control of the second and third order streams (first order tributaries are the field gullies); other than that it closely resembles the dendritic type pattern (26: 513). It is a result of streams flowing from a non-resistant material area through another of slight structural control.

6. The anastomotic drainage pattern is characteristic of flood-plain drainage.

The meanderings of the main stream has produced sloughs, bayous, exbow lakes, and "interlocking channels". A network of anabranches may even be present. This type pattern is considered to be "a phase in the development of dendritic drainage" in restricted areas (26: 514).

Patterns illustrated in Figure 4 are described as follows:

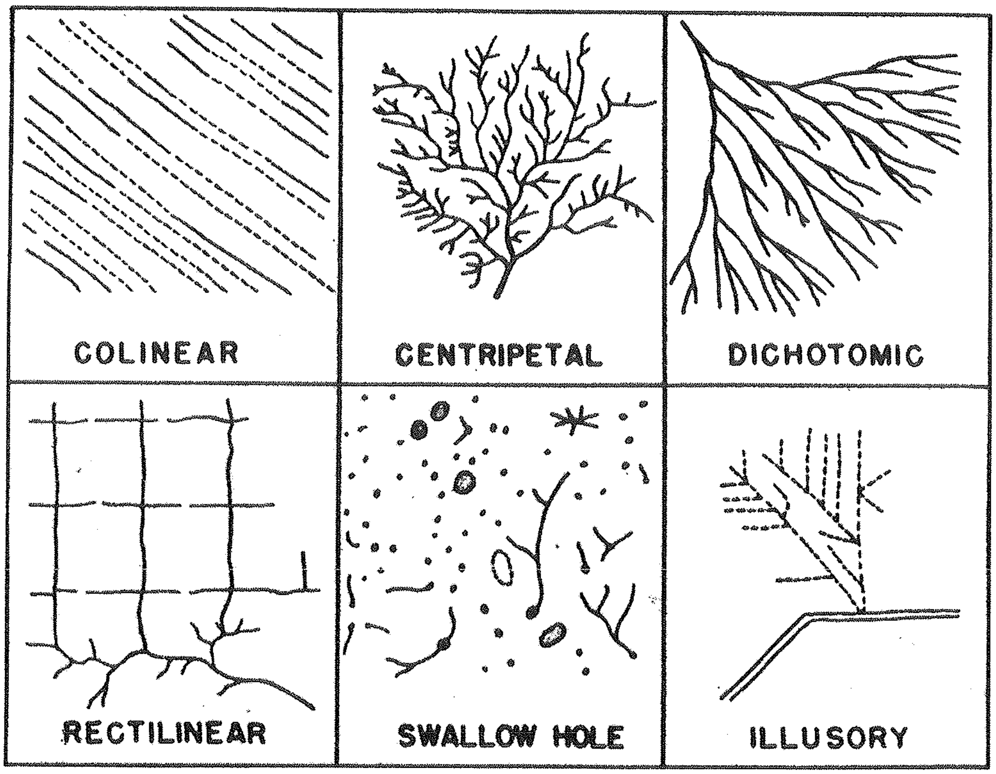

Figure 4. Sketches of Modified Basic Drainage Patterns (20) - Linear dotted lines indicate subsurface drainage ways. Shaded areas are water-filled basins. Dots are sinkholes. Areas bounded by dotted lines are infiltration basins.

1. The colinear drainage pattern is a modification of the parallel type. Parallel streams are alternately surface and subsurface. This is a recognized type of drainage pattern found in certain foreign countries (26: 519). It is a system of intermittent streams flowing in very straight lines through porous materials.

2. The centripetal drainage pattern is a modification of radial drainage. If the headwater divide of a drainage basin is "roughly an arc of a circle", and the inside surface is steep and evenly sloping, then tributaries from opposite sides of the basin will enter the main stream at nearly the same point (13: 350). This term can refer to a group of drainage patterns converging to a common point (13: 350) (26: 517). This pattern occurs frequently.

3. The branching pattern of the distributaries of a stream is the dichotomic pattern of alluvial fans (8). The end branches are called anabranches - branches which lose themselves in the valley fill. Also, this pattern may be applied to the arrangement of the streams in the birdfoot type of river delta.

4. In nearly level areas man has dredged ditches to drain swamps and low-lying soils. These ditches are fairly straight; they follow topograph-

ical depression channels or the section, half-section, and quarter-section lines. Often they do not "accord with the pattern of the soil and vegetation" of the area (6: 73). They have been grad-

pattern is common to regions of massive strata of limestone. The pattern of a youthful karst region might appropriately be called the "dot" pattern. In mature and old age limestone regions

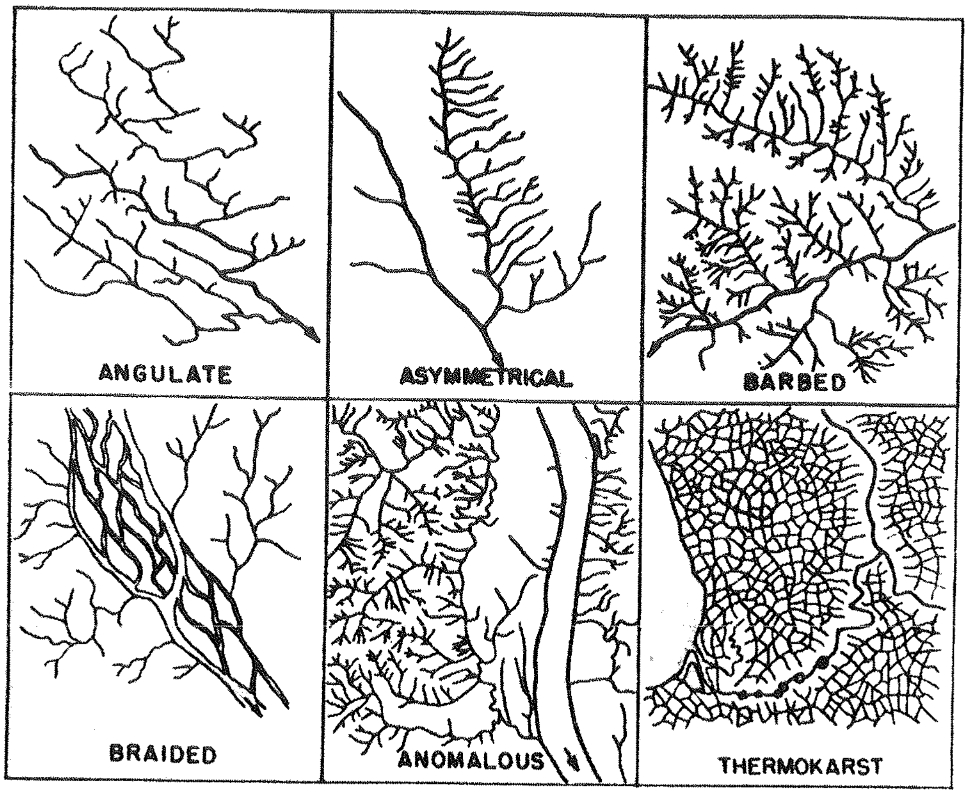

Figure 5. Sketches of Modified Basic Drainage Patterns - Shaded areas are water-filled channels and basins - rivers, lakes, sloughs.

ed so that low rises are traversed which would otherwise block the natural drainage. This pattern is identified as "rectilinear" in type (22). It is a form of artificial drainage. It is not to be confused with the pattern of irrigation ditches which is a distributary pattern (6: 73).

5. Drainage in horizontal limestone areas is both surface and subsurface. Where sinkholes predominate, small streams are "swallowed in holes" to continue under ground as subterranean streams. Sinkholes plugged with debris become ponds. This swallow hole

sinkholes, fensters, and solution valleys form "unsystematic" drainage patterns in that surface drainage is interrupted by the disappearance of the streams under ground (18: 116).

6. The illusory type drainage pattern is occasionally observed on airphotos of porous low-lying soils which are tiled for drainage. While this is subsurface drainage the network of tile drains is often "visible" on the airphotos because the soil above the tile has dried and there appears on the photos a sort of "X-ray near-white system of lines - formed by the trunk tiles and

their parallel laterals (14: 30). This is a form of artificial drainage. The lines appear somewhat spectral on the air-photos - they may be likened to the spreading of the ink in a line drawn on blotting paper. This pattern is depicted graphically by dashed lines - the accepted symbol for hidden lines. The pattern is an ovanescent one; as the soil dries the pattern becomes imperceptible. Also it is a deceptive pattern; a buried pipe line, a buried telephone cable, or an abandoned railway grade might easily be mistaken for a large tile.

The patterns shown in Figure 5 have the following descriptions:

1. The angulate pattern is a modified type of trellis drainage pattern. Parallelism in it is similar to the rectangular type but the tributaries join the principal streams at acute or obtuse angles (26: 517). Like the rectangular pattern it reflects the influence of rock joints.

2. An "asymmetrical" drainage pattern has more tributaries on the upslope side of a trunk stream than on the down slope side. This type is commonly found in mountainous territories (13: 352). It is often "pectinate" - shaped like a comb.

3. The barbed drainage pattern is a type of drainage pattern which results from stream piracy. Branching tributaries form obtuse angles with the trunk streams (11: 180). The pattern is "calcarate" - spurred. It is a form of "backhand drainage".

4. The braided drainage pattern is that of a graded stream. An intricate network of shallow channels forms "a complex pattern on the valley floor" (18: 69). Usually the materials deposited by a braided stream are granular, especially in the upper reaches of the stream.

5. An anomalous drainage pattern is the general irregular pattern of an area formed by the combination of dissimilar patterns in adjoining but different types of topography. This complex pattern indicates the existence of unlike materials in an area. The component pattern of the complex pattern can be studied individually.

6. The thermokarst drainage pattern is that produced by the surface thawing of permafrost (25: 2). It is formed by cave-in lakes which eventually become joined together by streams. The concatenate pattern of the "button" lakes is a singular feature. Usually the thermokarst pattern is found in areas of fine-grained alluvial sediments (9: 17).

Figure 6 presents other patterns which can be described as follows:

1. The lacunate type drainage pattern is formed by small "lakes" spaced at random over an area. Individual tributary systems may be dendritic. It is found where there is impervious substratum. This pattern occurs in areas where the erosion cycle is very young (2). It is a closed-basin type which is found in parts of the southern Great Plains region of the United States.

2. The Yazoo type drainage pattern pertains to larger stream systems than those which are usually considered. It is due to the inability of tributary streams to break through the natural levees of major streams. It is the pattern found on confluence plains - plains on which the tributaries unite before entering the main streams. This pattern develops in alluvial bottom lands.

3. The kettle hole type of drainage pattern is one of random-spaced depressions, with an occasional water-filled basin. Like the lacunate pattern it is a closed basin type, but it occurs where there is a porous substratum. It is the pattern found in granular moraines and outwash plains. Individual tributary systems may be dendritic.

4. The elongated bay type drainage pattern is one peculiar to coastal plain or delta areas. (The author believes the bays in the Carolinas and Texas to be cave-in lakes formed in permafrost during glacial times.) Rows of the bays follow the lows (troughs) in old beaches. This indicates that they have been formed in fine-grained sediments.

5. The reticular type drainage pattern is a network of stream chan-

nels. It is "canaliculated" - having many channels. It is a variation of the anastomotic pattern but is different in that it is found in tidal marshes and in youthful coastal plains (26: 514). At flood tide the water flows inward through the channels; at ebb tide, outward. It is a pattern of anabranches - the diverging branches of a large coastal plain stream which reenter that same stream.

6. The phantom drainage pattern is one of seepage ways. It is a network, also. The pattern is caliginous and arachnoid - dim, and cobweblike. It is found in "loose" (unconsolidated) fine-grained but well-drained soils on impervious subsoils.

ANALYSES OF REGIONAL DRAINAGE PATTERNS

The following illustrations which show airphotos paired with drainage maps are presented as examples of representative typical regional drainage patterns. The examples show noticeable differences in drainage patterns of materials common to various physiographic regions.

The patterns are classified according to the basic or modified types of drainage patterns. The forms and textures of the patterns are studied for the influences exerted on them by the soils and bedrocks in which they exist. The effects of peculiarities of topography and extraneous materials

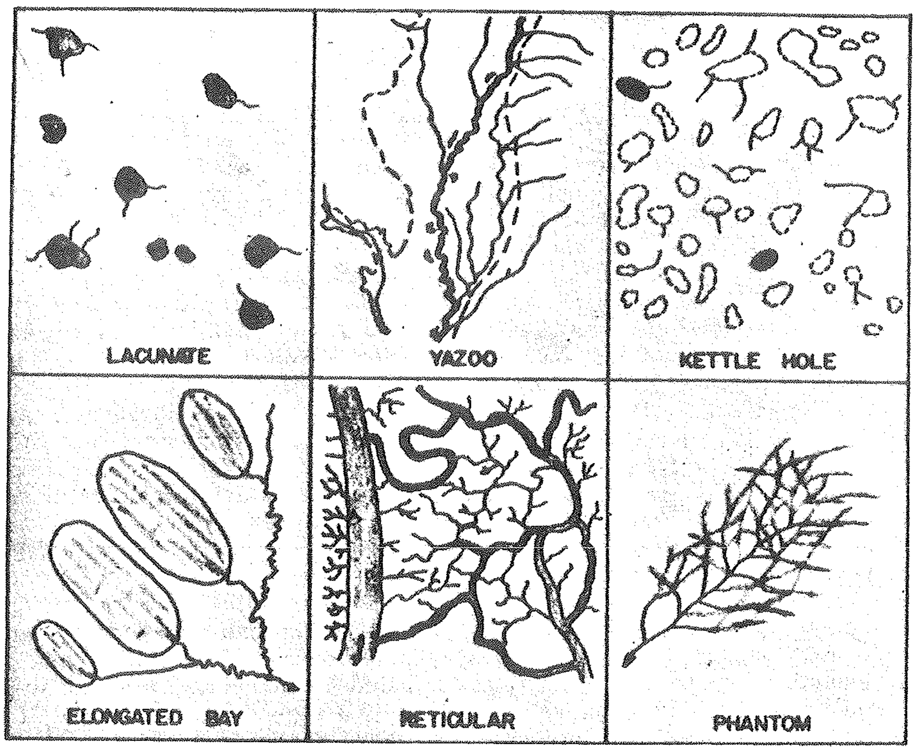

Figure 6. Sketches of Modified Basic Drainage Patterns - Shaded outlined areas are water-filled channels or basins - rivers, ponds, lakes. Shaded lines indicate high water table areas or seepage ways. Dotted lines bound infiltration basins.

on the patterns are noted also.

From a logical standpoint, the examples of drainage patterns found in residual materials are considered first; then, those in transported materials. The examples from different regions of residual materials are drainage patterns found in both horizontal and tilted rocks; and the examples from regions of transported materials are drainage patterns found in glacial drift, and water-laid and windblown soils.

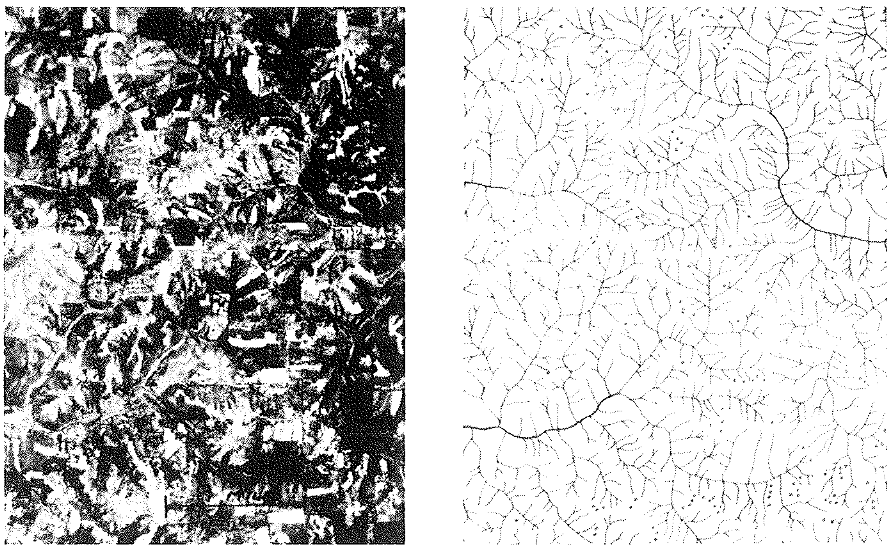

Figure 7. Drainage Pattern of Limestone-Shale (Ordovician) (20) (21) - Left - Airphoto of Area in Southwestern Switzerland County, Indiana - Right - Drainage Map of Same Area - Small circles are sinkholes.

Figure 8. Sloughing of Colluvial Hillside - Eastern Ohio County, Indiana (10) - Rock and soil break away from the hill to produce landslides.

Limestone-Shale - The intricately dendritic drainage pattern shown in Figure 7 compares closely to the basic dendritic pattern shown in Figure 2. It has some of the characteristics of the subdendritic pattern shown in Figure 3 but hardly enough for it to be classified as subdendritic. However, the presence of two materials, nearly horizontal thinly-bedded strata of limestone and shale of different textures, does lend the pattern an irregularity which indicates slight structural control. The primary tributaries flowing in shale are deflected, sometimes sharply, when they contact the more resistant limestone. Sinkholes are found on the ridges where a limestone layer is sufficiently thick to permit their development. These sinkholes affect the drainage pattern only to the extent of occasional surface depressions, for most of the runoff water flowing through them finds its way immediately into adjacent streams. The density of the pattern is great (or

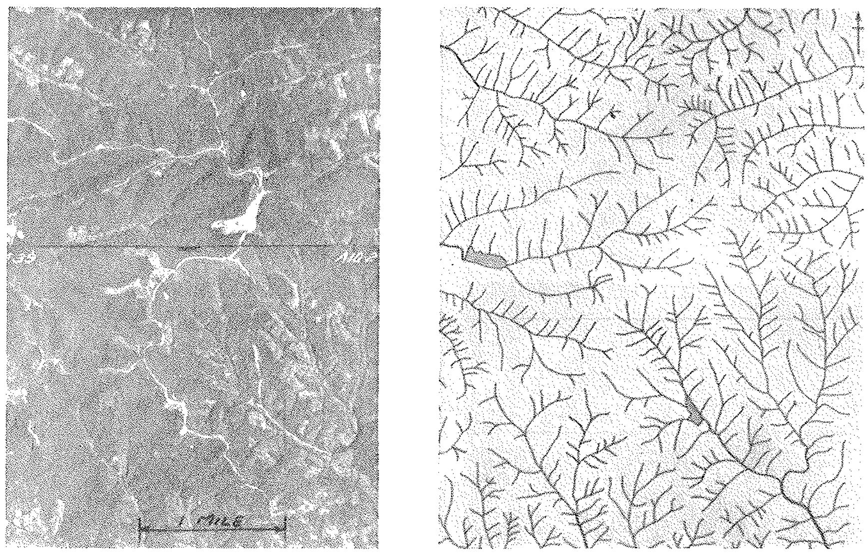

Figure 9. Drainage Pattern of Sandstone-Shale (Mississippi) (20) (21) - Left - Airphoto of Weed Patch Hill Area in Brown County, Indiana - Right - Drainage Map of Same Area - Artificial lakes are indicated by shaded spots.

fine) because of the presence of imperviousshale as well as because of a great difference in elevation between the ridges and the valleys.

This region was once covered with Illinoian glacial drift but the drift has been removed by erosion until now only traces of it are found on the highest ridges. The presence of the Illinoian drift apparently does not affect the drainage pattern. The pattern has resumed its primitive, or pre-glacial development.

Colluvial slopes found throughout the region cause many landslides in highway construction (See Fig. 8).

Figure 10. Gully in Residual Soils Formed from Sandstone-Shale (Mississippian), East-Central Brown County, Indiana (10) - In the foreground, fragments of sandstone may be seen in the bottom of the gully.

Sandstone-Shale - Figure 9 illustrates the slightly modified dendritic drainage pattern - somewhat subdendritic - developed in an area of laminated sandstone and shale. The area is especially known for the "perfection and symmetry of its drainage lines" (11: 90-94). The sandstone-shale has eroded to produce a "rangy" dendritic drainage pattern of which the branching of the smaller tributaries is confined mostly to their "tip ends". The sandstones are more or less pure, are usually rather soft, and are intercalated with sandy shales. Soils weathered from them are plastic clays which erode in V-shaped gullies because of steep slopes (See Fig. 10). Forests cover most of the hills as shown by the botryoidal texture of the airphoto in Figure 9.

The region is mature and the interfluves have been reduced to knife-like ridges. The ridges are clearly defined by the spaces between the tip ends of the first order tributaries (field gullies).

Weathering sandstone breaks down into small flat fragments; stream deposits of this material are known as "brown gravel". Although this gravel is used locally for road building material it is not very durable. It is detrimental as an aggregate for concrete.

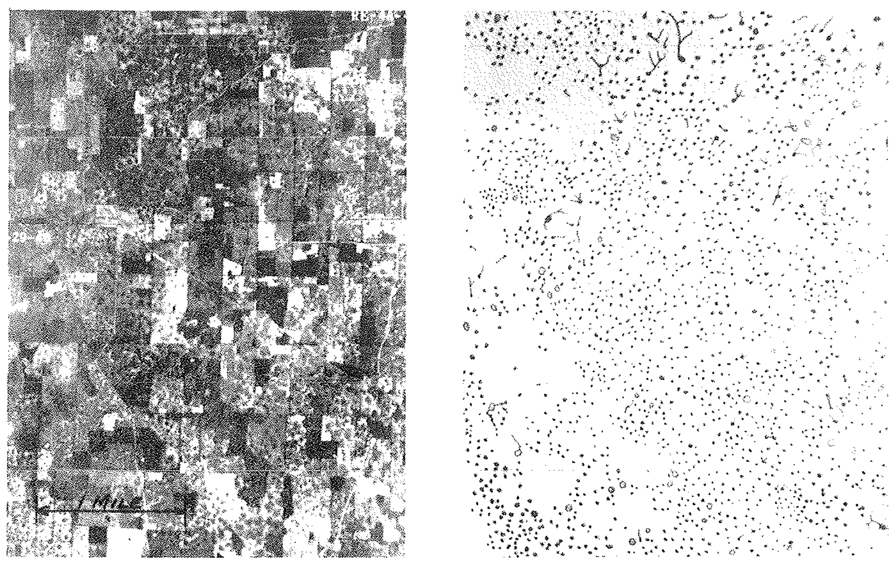

Figure 11. Drainage Pattern of Young Karst Topography (Mississippian Limestone) (20) - Left - Airphoto of Sinkhole Area in Washington County, Indiana - Right - Drainage Map of Same Area - Dots indicate sinkholes, some of which have small dendritic drainage systems. Shaded areas are water-filled basins - plugged sinkholes.

The influence of the shale is seen in the additional subdivisions of the smaller tributaries. Angularity in the pattern occurs because the sandstones are resistant to erosion. The density of the pattern indicates that immediate runoff is less than for limestone-shale regions (Fig. 7). The medium density is due to the somewhat pervious nature of sandstone and to the considerable difference in the elevation between the ridges and the valleys. The pattern is influenced very little by the general slope of the region.

Massive Limestone - Figure 11 illustrates the "swallow hole" drainage pattern of a youthful karst plain. Such plains are distinctive because their surface features are the "result of the solvent work of underground water" instead of surface streams (8: 321). In the area represented by this illustration there are no small streams although small streams are occasionally present in similar areas. The surface of a young karst plain is undulating, often rolling, and sometimes rough; it is known as sinkhole topography. The sinkholes are identified on the airphoto portion of Figure 11 by dark-centered circular light gray spots.

In the formation of young karst plains, water first flows through a fissure in the underlying limestone and begins dissolving the rock. When the surface depression has become approximately five feet in diameter it is known as a "ponor"; it has steep vertical slopes as a result of initial erosion but is "asymmetrical in both plan and profile". After the depression is deepened and widened it is then called a "doline"; its slopes are regular and its outline is symmetrical - it is circular if the fissure is short and oval if the opening is long. A "basin" is a filled doline; if the bottom outlet has become plugged with clay and other debris, swamps, temporary ponds, and even permanent lakes form (5: 713) (See Fig. 12).

Figure 12. Topography of Limestone Area, North-Central Harrison County, Indiana (10) - Roads constructed across plugged sinkholes give poor performance because of water-logged subgrades. Flooded conditions during wet weather result in the roads being impassable for periods of several days at a time.

The clays that develop from the weathering limestone have a peculiar "nutty" structure. They are well-drained "in situ", but they are very impervious and plastic when reworked by highway construction machinery (See Fig. 13).

Clay Shale -A most minutely (very fine) dendritic drainage pattern, shown in Figure 14, is that produced by eroding clay shale. Because the shale is completely impervious, the runoff is almost equal to the total rainfall. Surface drainage is developed fully. Streams flowing in shale usually do not reflect lineal control. An intricate stream system is formed which resembles the venation of a broad leaf of a deciduous tree. This pattern approaches the true

Figure 13. Concrete Pavement in Central Lawrence County, Indiana - Pavements often break up in shallow road cuts in the clays of limestone regions.

dendritic pattern illustrated in Figure 2. Where the general level of the upland is nearly flat - one to two mi. from the river - the gullies have "rounded" slopes; this is especially noticeable in the lower center of the airphoto in Figure 14. This is a characteristic of clay shale topography. The "smooth" areas outlined in white in the airphoto - left center and lower left - are remnants of the Great Plains mantle which is granular in texture; they do not contribute to the drainage pattern. Gravel is a material resistant to erosion; therefore, it "holds up" the hills. Near the river the drainage pattern is influenced by slope control of the streams. Some of the smaller tributaries are straight and the angles of their junctions with the larger tributaries are very acute. Another cause for this slight change in the pattern is the presence of thin layers of weak sandstones. These can be detected in the airphoto by the "bands" around some of the knolls, and by the presence on these bands of vegetation - shrubs and bushes. Steep slopes cause

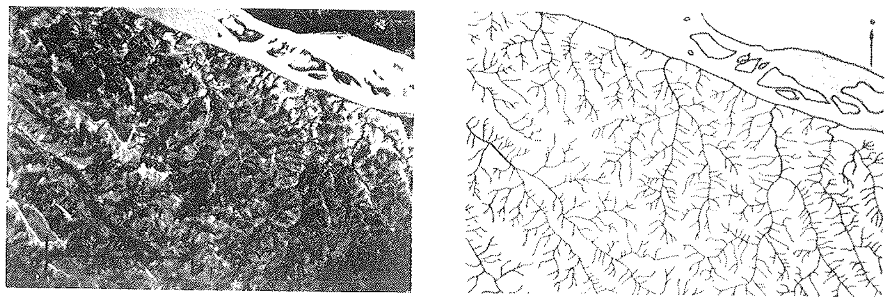

Figure 14. Drainage Pattern of Pierre Shale - Left - Airphoto of Area in Stanley County, South Dakota - Right - Drainage Map of Same Area - Shaded Area is Missouri River.

270

Figure 15. Poor Performance of Flexible Pavement Constructed on Clay Shales of the Northern Great Plains, Near Glendive, Montana - Lebo shales are similar to those illustrated in Figure 14.

V-shaped gullies; therefore, the cyma-curve cross sections of the upland gullies are extremely modified or lacking in the gullies near the river. The

Flexible pavements, like the one shown in Figure 15, suffer considerable distress when placed directly upon plastic clay subgrades.

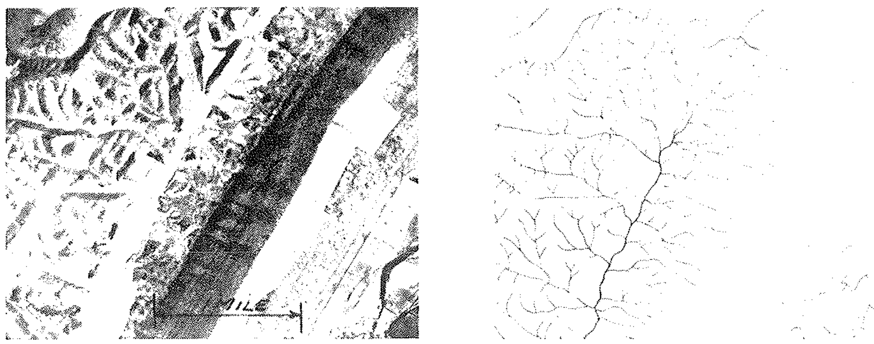

Figure 16. Drainage Pattern of Tilted Sandstone and Sandstone-Shale - Left - Airphoto of Area in Hampshire County, West Virginia - Right - Drainage Map of Same Area - Shaded area is a river.

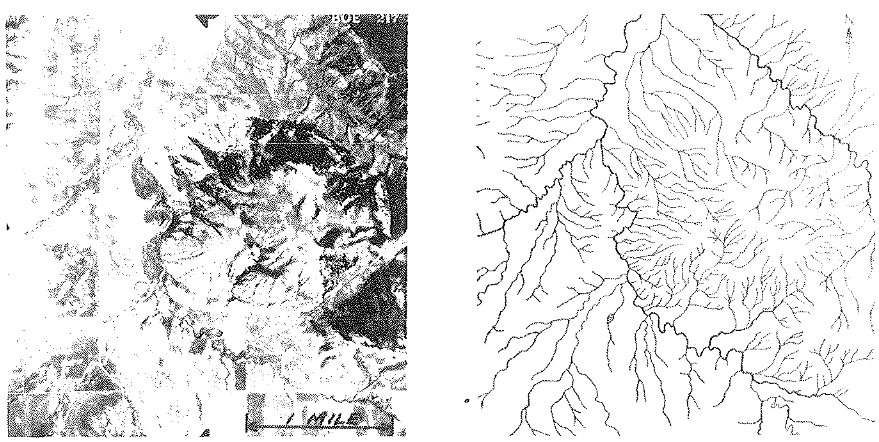

Figure 17. Drainage Pattern of Granite Dome - Left - Airphoto of Area in Lawrence County, South Dakota - Highways are straight white lines - Right - Drainage Map of Same Area - Shaded area is an artificial pond.

main tributaries have almost reached base level, in the vicinity of the river; here their courses have many full-curved meanderings. Parallelism may even be detected in the larger tributaries.

Clay shales weather to fine-grained, plastic, poorly-drained clay soils.

Tilted Sandstone and Shale - Figure 16 is the drainage pattern of an area of folded and tilted sandstones and shales. The drainage pattern, where the shales predominate, is dendritic (See the upper left half of the airphoto in Fig. 16). Resistant strata - probably sandstones - in the shale area give lineal control to some of the streams in that area. Streams are absent along the crest of the sandstone ridge (See lower right half of the drainage map in Fig. 16). Small "parallel" streams are spaced at "regular" intervals along the steep slopes of the sandstone ridge and form a subparallel drainage pattern on the left side of the ridge. The stream collecting the run-off waters from both the shale and the sandstone areas is flowing in shale.

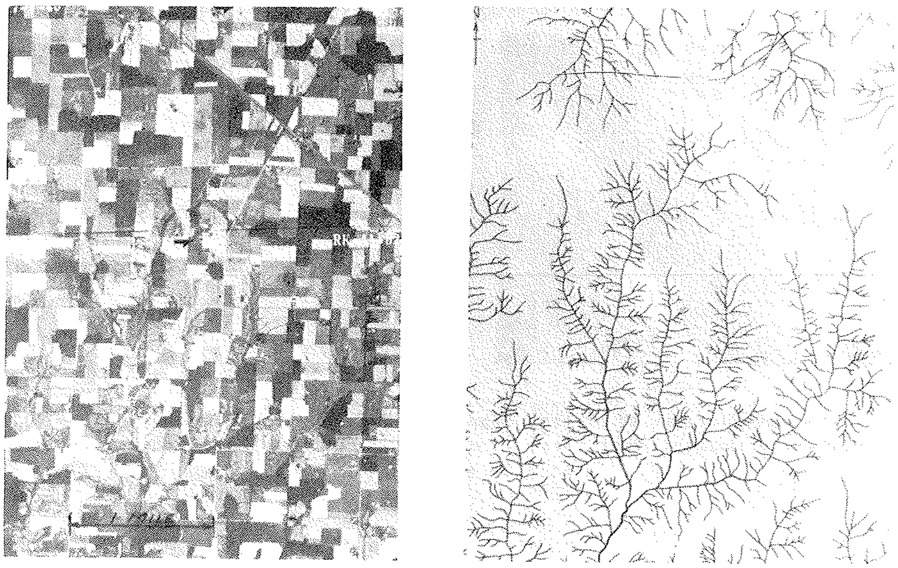

Figure 18. Drainage Pattern of Illinoian Glacial Drift (20) (21) - Left - Airphoto of Area in Ripley County, Indiana - Right - Drainage Map of Same Area

Figure 19. Erosion Control in Illinoian Glacial Drift Region, Jennings County, Indiana - At the extreme right-center, the very light tones of gray mark the silty edges of a lateral gully.

This stream is a part of a regional trellis drainage pattern which can not be shown by a single airphoto. The weakly developed subparallel drainage pattern on the right of the sandstone ridge has formed partly in shale since the river is flowing in shale, also.

In regions of sedimentary rocks slope control plays an important part in the development of the drainage pattern - the more resistant the material, the steeper the slopes. Consequently, the lines of the pattern are more nearly straight on steep slopes for fast-moving water tends to flow in straight lines. Sandstone is more resistant to erosion than shale. The drainage pattern in shale has a "roundness" contrasted to the "angularity" of the stream patterns in sandstone areas.

Granite Dome - Figure 17 illustrates the radial and annular drainage patterns of a granite dome. The streams of the plain have been forced to go around the bulging mass of granite, some of them making right-angle turns in the process. Radial streams course down the dome. These streams unite at lower elevations with sharp entrant angles. Near the base of the dome the runoff waters are collected in annular streams inside the rim of upturned sedimentary rocks.

the "B" horizon usually consists of 8 to 10 ft. of "expansive silty-clay" (3: 187). Much of the surface is so nearly level that it is imperfectly drained. The subsoil is impervious and is very poorly drained internally. Surface drainage furnishes a particularly significant air-photo identification element which is the "white-fringed" gully. The broad flat bottom of this type of gully is formed by erosion removing the top soil (silt) from the impervious clay subsoil (See

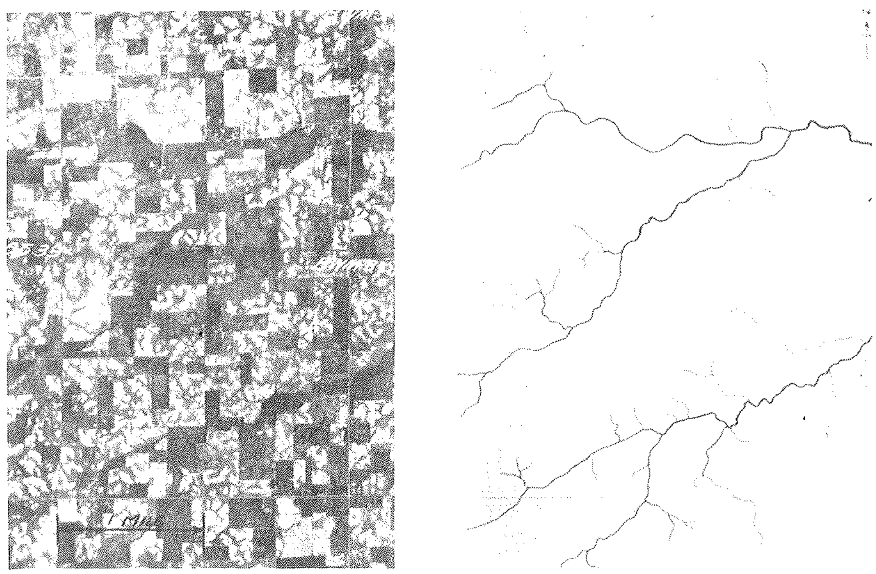

Figure 20. Drainage Pattern of Wisconsin Glacial Drift (20) (21), Tipton County, Indiana - Left - Airphoto of Tipton Till Plain - White lines are roads which follow land section boundaries - Right - Drainage Map of Same Area

Illinoian Glacial Drift - Figure 18 is a typical drainage pattern of the Illinoian drift region in southeastern Indiana. The drainage pattern is "subdendritic", a modification of the dendritic type with long, nearly parallel tributary systems. The pattern has a pronounced "lacy" appearance. Illinoian drift is the oldest surface drift in Indiana. Its topographical features are subdued. It is free from swells and ridges. It shows the effects of age and weathering, for the soil has a developed profile of approximately 10 ft. (3: 187). The "A" horizon consists of about two ft. of silt and

Fig. 19). Long shallow tributaries indicate low velocity of the runoff water. Where the gradient becomes steep and the runoff water cuts into the clay, the gullies become V-shaped. Secondary tributaries show minor slope control. Wide expanses show no developed drainage pattern; here the terrain is nearly flat and headward erosion has not cut into the silty "A" horizon.

Wisconsin Glacial Drift -Figure 20 is representative of a typical drainage pattern of the Tipton Till Plain which is an irregular, undulating sheet of till.

Although the main streams in the illustration are "roughly parallel, with few

Figure 21. Low Altitude Oblique Airphoto of a Wisconsin Glacial Drift Area, Tipton County, Indiana - The Brookston-Crosby soil pattern is easily identified even though the field has a cover crop. Faint near-white lines in some of the dark areas show a tendency toward gully development.

and only short tributaries" the general drainage pattern of the till plain is broadly dendritic - very coarse textured (15: 390). It has the appearance of the forked ends of chain lightning (Also see Fig. 1). The topography of the Tipton Till Plain is featureless - differences in elevation being from 2 to 20 ft. It has been referred to as a region of "little relief and meager modification by dissecting streams" (24: 17). The drift is recent in age - it is unconsoildated and, therefore, pervious. This reduces the amount of small gullies, for part of the runoff becomes subsurface drainage. Besides the drainage pattern, an outstanding identifying airphoto element is the "marbleized" or "black-and-white mottled" pattern often referred to as the Brookston-Crosby pattern (23: 39) (See Fig. 21). The drainage of the till plain is connected through the darker, lower-lying depressions. These dark areas indicate the presence of moisture, silty clays, clay, and organic matter in the soil (14: 27). Gentle gradients of these depressions prevent any but sheet erosion over extensive areas. The divides are flat and the streams sluggish. Wherever the gradient becomes steep enough for gullies to form these gullies are like "grooves" in the plain

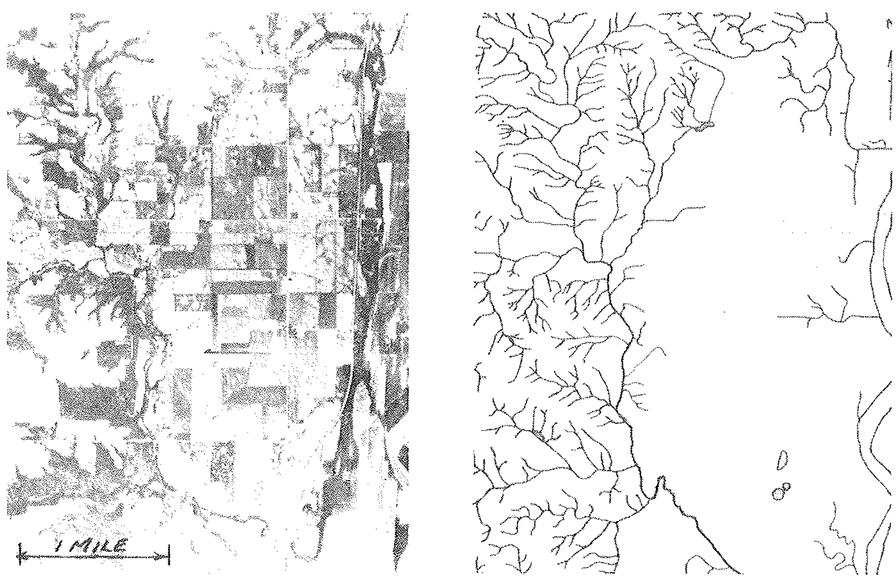

Figure 22. Drainage Pattern of Granular Terrace (20) - Left - Airphoto of Area in Vermillion County, Indiana - Right - Drainage Map of Same Area - Shaded spots are water-filled gravel pits.

and they empty into creeks which flow in shallow, wide "valleys". The drainage of a glaciated region has been described as "glacially disturbed" for drift deposits have obscured pre-glacial stream systems and new drainage systems have developed (26).

Granular Terrace - Figure 22 is the weakly developed dendritic drainage pattern characteristic of granular terraces found in the Wabash River valley in western Indiana. The almost total absence of surface drainage in the right half of the map in the illustration is a significant feature of the pattern. Internal drainage through infiltration basins provides an escape for nearly all runoff water. A few drainage ways follow depressions which are abandoned channels of the post-glacial braided stream that deposited the gravel. Occasional short, steep, V-shaped gullies are found along the terrace face next to the river. Gravel because of its porosity and permeability to water resists erosion. A most striking feature is the inability of the upland streams to cut across the terrace. The stream collecting the drainage of these upland streams flows in a slack water trough to a point where it can enter the river. The complete lack of relationship of the upland subdendritic drainage pattern of medium density to that of the terrace gives the entire area an "irregular" drainage pattern (26) (See sketch of anomalous drainage pattern in Fig. 5).

Terraces such as the one illustrated are composed of granular materials transported by glacial melt waters draining Wisconsin drift areas and are important sources of gravel and sand throughout Indiana. Figure 23 shows excellent highway performance on a

Figure 23. Flexible Pavement Constructed on an Ohio River Granular Terrace, Switzerland County, Indiana (20) - Only very shallow side ditches are required because of good internal drainage of the terrace materials. Highways on granular terraces usually give excellent performance.

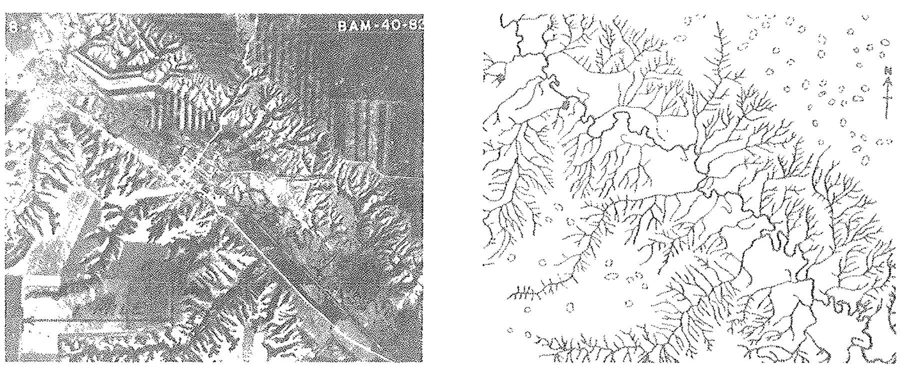

Figure 24. Drainage Pattern of Glacial Lakebed - Left - Airphoto of Glacial Lake Souris Area in Ward County, North Dakota - Right - Drainage Map of Same Area - Basins are outlined by dotted lines.

similar granular terrace.

Glacial Lakebed - Figure 24 illustrates the anomalous drainage pattern of an area in a glacial lakebed region. The gullies in the walls of the valley of the

These lakebed sediments cover the uneven glacial drift of the inner border of a granular moraine which is a short distance southwest of the area illustrated. Lakebed silty clays are stratified and impervious to water. They

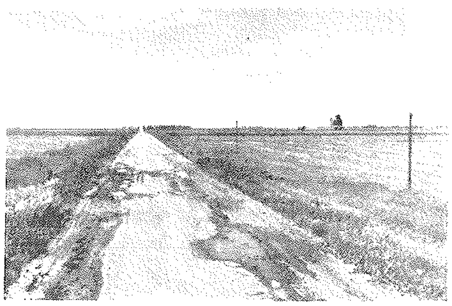

Figure 25. Poor Highway Performance on Glacial Lakebed Soils of Ward County, North Dakota

Figure 27. Topography of Altamont Moraine in Ward County, North Dakota - Left - Organic Soils of Infiltration Basin

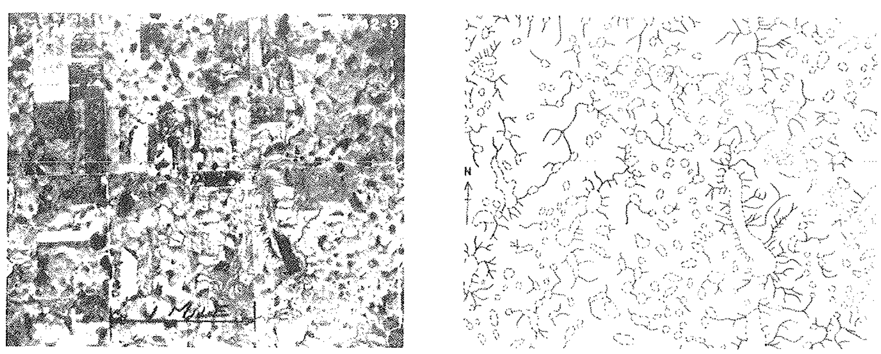

Figure 26. Drainage Pattern of Kettle-Kame Moraine - Left - Airphoto of a Portion of the Altamont Moraine in Ward County, North Dakota - Right - Drainage Map of Same Area - Infiltration basins are bounded by dotted lines.

river are typical lakebed gullies. The pattern of the shorter gullies is subdendritic and that of the longer stream systems is pinnate. The pinnate drainage pattern is found in eroding silty soils. The upland areas - the even floor of the lakebed itself - contain small basins. These give the overall pattern its irregularity. The lakebed sediments are "comprised largely of sand, silt, and clay" (1: 59).

are generally plastic and poorly drained internally (See Fig. 25).

Kettle Kame Moraine - Figure 26 illustrates the "kettle hole" drainage pattern of a granular moraine. Granular knolls of various sizes and shapes are scattered over the area without orderly arrangement; these consist of unconsolidated gravels, sands, and boulders "with minor amounts of finer sediments"

(1: 58). Numerous depressions called kettle holes are found among the knolls throughout the area. It is difficult to say whether the knolls or the depressions predominate. There is no developed surface drainage in the area. Short, V-shaped gullies having steep gradients can be seen on some of the knolls; this is an identifying characteristic of a granular deposit. Drainage from the kettle holes is through the underlying gravels. Many of the depressions have very small dendritic tributary systems. Some of the depressions are partly filled with organic accumulations while others have more or less ephemeral lakes. The smaller depressions are nearly circular while the larger ones are elongated. The depressions are closed basins from a few yards to a mile or more in extent. The floors of some of the larger basins are level and are cultivated since the soils hold moisture for a period of time (See Fig. 27).

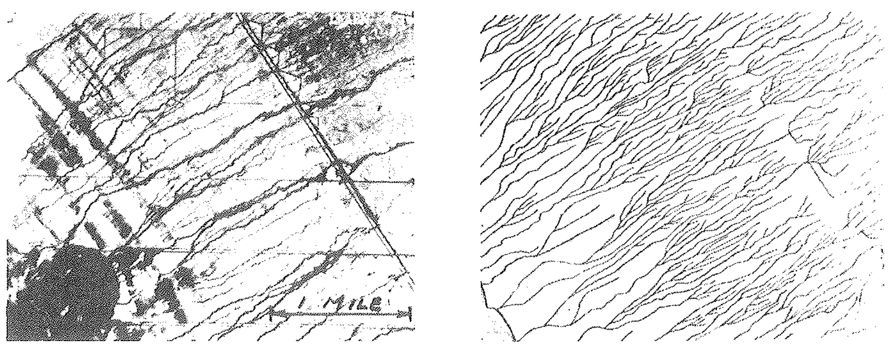

Figure 28. Drainage Pattern of Valley Fill Material - Left - Airphoto of Area in Imperial County, California - Dark bands in lower left corner of airphoto are beach lines - have fine-grained sediments - Right - Drainage Map of Same Area - Shaded area is water-filled basin (lake).

Valley Fill Material - Figure 28 illustrates the parallel drainage pattern of valley fill materials. This area is the gently sloping apron of erosional debris accumulated from the nearby mountains. The texture of the material is predominately coarse, although dark bands in the airphoto portion of Figure 28 indicate beach lines where finer sediments (clays) have collected. These "bands" support vegetation for they retain moisture (See Fig. 29). Straight streams having box-like cross sections are formed by flash floods.

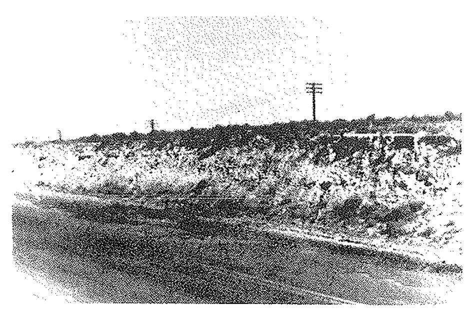

Figure 29. Poor Highway Performance in Valley Fill Materials - Northeastern Nevada - Construction operations removed granular materials - highway rests on fine-textured sediments.

Great Plains Mantle (Ogallala) - Figure 30 illustrates the lacunate drainage pattern of an Ogallala area in the southern Great Plains region. The relief of the area is gently undulating. There are no streams other than the small dendritic systems of individual basins. Many of the depressions contain water for days and even weeks after a period of wet weather. The term "poly basin" might aptly be applied to this area because of the depressions. The subsoil is impervious; it is probably a "marl". Erosion is controlled by contour farming (See the airphoto portion of Fig. 30).

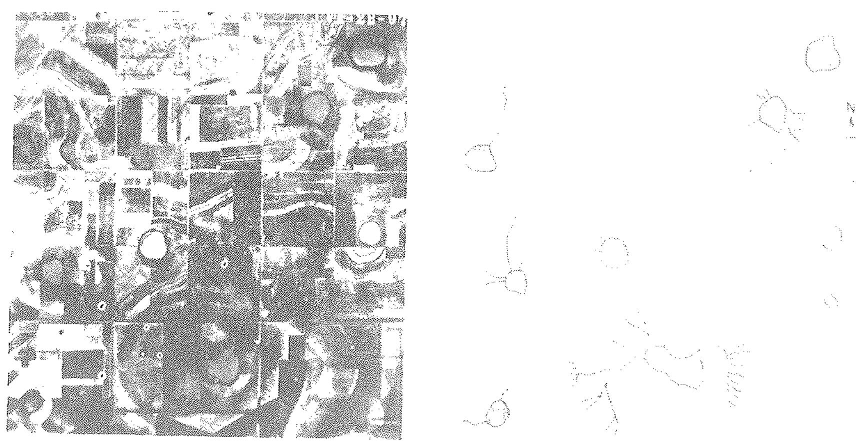

Figure 30. Drainage Pattern of Great Plains Mantle (Ogallala) - Left - Airphoto of Area in Lamb County, Texas - Right - Drainage Map of Same Area - Water-filled basins are shaded.

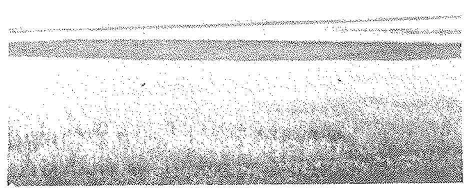

Figure 31. ''Buffalo Wallow'' in Eastern Colorado Near Kansas State Line - These slight depressions are closed basins.

In the inter-depression ridges the soils are silty and in places contain a large percentage of sand. The clay content of the soils increases toward the centers of the depressions. Locally these depressions are called "buffalo wallows" (See Fig. 31).

Loess - The drainage pattern in deep loess deposits, illustrated by Figure 32, is a modified dendritic pattern referred to as pinnate because of the feather or frond-like appearance of individual tributary systems. The lateral gullies are short and spaced at "regular" intervals along both sides of the principal tributaries which they enter at nearly right angles (See Fig. 33). The gully cross sections are hyoid shaped - like a "U"; and their gradients are compound - very steep at the headward end. Figure 32 is a striking example of eroding wind-blown silt found in parts of the Great Plains Region. The density of the pattern indicates large scale erosion in this area. Great Plains loess areas are generally nearly level tracts with very long, parallel, low, and fairly broad ridges which are not easily detected on single airphotos. Loess has a peculiar structure in that internal drainage is vertical. Where slopes are steep enough for erosion to start and where there is sufficient rainfall, the region soon becomes badly dissected. The ridges and valleys of deep loess deposits fix the direction of the trunk streams

(16: 98). The principal tributaries are long and often nearly parallel to each other.

The ridges of river valley loess are more pronounced than those in the Great Plains (See Fig. 34).

the drainage map of the county (See Fig. 35).

It is easily seen that the dendritic drainage pattern at "A" is repeated in a band 5 to 10 mi. wide along the right bank of the Ohio River. It is possible,

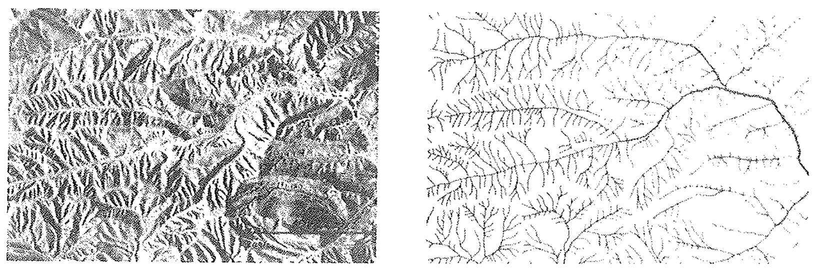

Figure 32. Drainage Pattern of Loess - Left - Airphoto of Area in Lincoln County, Nebraska - Right - Drainage Map of Same Area

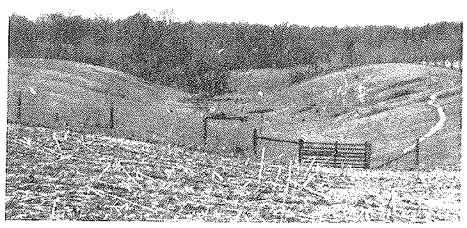

Figure 33. Gully System in Loess-Covered Area, Posey County, Indiana - Lateral gullies to the right and left of the main gully form the pinnate drainage pattern by which loess-covered regions can be identified.

Figure 34. Highway Constructed Through Ridges of Loess, North of Vicksburg, Mississippi - Road cuts are vertical.

THE APPLICATION OF DRAINAGE PATTERNS IN THE IDENTIFICATION OF REGIONAL SOILS AND BEDROCKS

Drainage patterns can be used in the identification of soils and bedrocks of an area. This statement is verified by the compilation from airphotos of a detailed surface drainage map of Switzerland County, Indiana (19). Three drainage patterns may be recognized readily in

then, to state with reasonable accuracy that bedrock materials (Ordovician limestones and shales) similar to those found at "A" will be found throughout this band.

It is observed, also, that the subdendritic drainage pattern at "B" is repeated in an area, centering about "B", of 35 to 40 sq. mi. in extent. It is possible to state, with assurance, that one material (Illinoian glacial drift) is the surface soil throughout this entire area.

The weakly developed dendritic

drainage pattern at "C" identifies a granular terrace. Similar patterns are detected about five mi. to the right of "C", and about five mi. to the left of "C". Knowing that a granular terrace exists at "C", it is within reason to predict that granular terraces are to be found in the other two areas.

application of keen observation on the part of the airphoto interpreter. The correlation of the salient characteristics of drainage patterns with known types of land surface materials is dependent upon his ability to understand the significance of the form and texture of the developed drainage patterns. This

Figure 35. The drainage map of Switzerland County, Indiana, exhibits the following drainage patterns: ''A'' - Dendritic drainage pattern of Ordovician limestone-shale regions (See Fig. 2 and 7). ''B'' - Subdendritic drainage pattern of Illinoian glacial drift regions (See Fig. 3 and 18). ''C'' - Weakly developed dendritic drainage pattern of river valley granular terraces (See Fig. 22). (This map was compiled from aerial photographs in the laboratories of the Joint Highway Research Project at Purdue University, Lafayette, Indiana. Scale: Typical square of grid system equals one sq. mi.)

SUMMARY AND CONCLUSIONS

The recognition, on aerial photographs, of the patterns of stream systems of an area is essentially the understanding makes possible the drawing of tentative conclusions regarding the identity of regional soils and bedrocks.

Drainage patterns are formed of

straight and curved lines. Where there is no structural control stream channels are curved. In regions of residual materials the drainage network depends upon the distribution of bedrock, and its surfaces of weakness. If the plan of a drainage system conforms with the structure of the bedrock, the same repeating pattern of uniformly-spaced fractures in that rock may be expected to appear in the lines of the drainage pattern. If the bedrock fractures are straight the streams will be straight between angular bends. Streams with steep gradients tend to be straight also.

Since most streams have their beginnings in soils or thinly mantled bedrocks, the patterns of streams of lower order (first, second, third, etc.) furnish clues by which those soils or bedrocks can be identified. It is the streams of higher order that show the influence of the structural control of the bedrocks.

Drainage patterns are coarse-textured in regions where the bedrock or soil mantle is resistant to erosion; e. g., sandstones, granular deposits, unconsolidated glacial drift. Fine-textured drainage patterns are associated with materials non-resistant to erosion; e. g., clay shales, silts, sand clays.

In other words, the drainage pattern reflects the porosity of the soil or bedrock in which it is found. Likewise, the relative depth of the soil mantle and the dip of the bedrock may be inferred.

Drainage patterns are classified for convenience of describing and comparing them. However, regardless of the name assigned to a regional drainage pattern, once it is established for a particular type of soil or bedrock, similar drainage patterns recognized within the region indicate the presence of materials similar to those associated with the established pattern.

By studying first the particularly conspicuous features of the overall drainage lines of a region it is possible to make deductions concerning bedrock structural control of the streams of the area. Moving, then, from the general to the specific, the details of the patterns formed by the headwater tributaries are the means by which repetitive drainage patterns within the region are classified. Accidental localized variations in those recurring patterns are disregarded. Recurring patterns are similar but rarely identical.

On the basis of observations made during the analyses of recurring drainage patterns in various physiographic regions throughout the United States, the following conclusions have been reached:

1. Drainage patterns may be classified according to the basic types or modifications of them.
2. There is a high degree of correlation between the drainage patterns and the soils and bedrocks of regions.
3. Drainage patterns recognized in the aerial photographs of a region can be relied upon to aid in the airphoto identification of the soils and bedrocks of that region.

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All airphotos used in connection with the preparation of this report automatically carry the following credit line: "Photographed for Field Service Branch - PMA - USDA". Other photographs taken by Joint Highway Research Project staff photographers.

Active landslide area in Bolivia.

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Chapter Five

Airphoto Interpretation

Ta Liang and Donald J. Belcher

Airphoto interpretation, one of the many tools for recognition of actual or potential landslides mentioned in the preceding chapter, warrants treatment in a separate chapter. This is because the interpretation of aerial photographs for engineering purposes is a relatively new and growing field. It is one, moreover, whose techniques and possibilities are perhaps less known to most than are most other engineering and geologic techniques.

Highway engineers have long been familiar with the use of topographic maps, both in planning and in ground reconnaissance. It was natural, therefore, that when aerial photographs became available, the engineer should make use of them as an additional tool. Aerial photographs present a complete map, as well as a three-dimensional model of the area covered. When properly interpreted, they reveal not only the topography but also considerable information concerning soil, geology, and other natural, as well as manmade, features.

Use of airphoto interpretation in various phases of highway engineering has increased rapidly during recent years. The fact that almost all of the United States and a good part of the world is already covered by aerial photography of suitable scales is an important stimulant. New photography is being added rapidly.[5] In addition, new techniques in production and interpretation processes have continued to extend the advantages of aerial photography.

Advantages

The advantages of using airphotos in the investigation of landslides are summarized as follows:

1. Airphotos present an over-all perspective of a large area. When examined with a pocket or mirror stereoscope, overlapping airphotos give a three-dimensional view.
2. Boundaries of existing slides can be readily delineated on airphotos.
3. Surface and near-surface drainage channels can be traced.
4. Important relationships in drainage, topography, and other natural and manmade elements that seldom are correlated properly on the ground become obvious in airphotos.
5. A moderate vegetative cover seldom blankets details to the photointerpreter as it does to the ground observer.
6. Soil and rock formations can be seen and evaluated in their "undisturbed" state.
7. Continuity or repetitions of features are emphasized.
8. Routes for field investigations and program for surface and subsurface ex-

[5] Detailed information as to availability of existing airphotos may be obtained from: Map Information Service, U. S. Geological Survey, Washington 25, D. C. Prevailing scales of photographs: 1:15,000 to 1:30,000. Price for each photograph, covering 6 to 9 square miles: $0.50 to $0.65. Airphotos taken specifically for highway projects are usually of much larger scale and may be procured through the highway authority concerned.

ploration can be effectively planned.

9. Recent photographs can be compared with old ones to examine the progressive development of slides.

10. Airphotos can be studied at any time, in any place, and by any person.

11. Through airphotos, information about slides can be transmitted to others with a minimum of ambiguous description.

Limitations

Although aerial photography proves a very useful tool for the study of both existing and potential landslides, the highway engineer should be aware of its limitations. Some of these follow.

Personal Experience. — The usefulness of airphotos increases with the individual's experience in interpretation and with his knowledge concerning the area under study. An inexperienced interpreter should be particularly careful in a new, complex area in which he has little background knowledge.

Scale. — The scale of ordinary existing photography (1:15,000 to 1:30,000) is adequate for the study of most terrain and slide problems. However, in geologically complex areas or in areas where landslides are rather small, a scale of 1:5,000 to 1:10,000 would be desirable. Pictures within this range of scale are commonly available when the route has been photographed for photogrammetric mapping purposes. Photography of scales even larger than this is good for detailed examination, but the area covered in each photograph is then limited and, therefore, the over-all perspective is more difficult to grasp.

City Development. — In well built-up areas, natural conditions are altered or concealed by human activities. There, air photography may have special merits in city planning and related purposes, but its usefulness in landslide investigation is greatly handicapped, especially when the landslides are small.

Ground Investigation. — It should be emphasized that the use of airphotos cannot and should not replace ground investigation entirely. Through careful planning with airphotos, however, the surface and subsurface exploration necessary for a landslide study can be profitably reduced to a minimum.

Principles of Airphoto Interpretation

The interpretation of airphotos includes three major steps: (a) examination of airphotos to get a three-dimensional perception, (b) identification of ground conditions by observing certain elements appearing in the photographs, and (c) interpretation of photographs with respect to specific problems by association of ground conditions with one's background experiences. The quality and reliability of any interpretation is, of course, enhanced in direct ratio to the interpreter's knowledge of the soils and geology of the area under study. The acquirement of such knowledge, either by field examination or by study of available maps and reports, should, therefore, be considered an essential part of any photointerpretation job.

Three-dimensional perception can be acquired with a little practice by any person having normal vision. Ability in the identification of ground conditions and the interpretation of them in terms of specific engineering problems grows with one's experience in the use of aerial photographs and in his specific field.

There are several major elements that can be seen in air photographs that indicate ground conditions accurately. They are: landform, drainage and erosion, vegetation, soil tones, and manmade features. These features are discussed briefly hereafter; more thorough treatments appear in the papers of Belcher (1943, 1946) and Liang (1952). A bibliography on airphoto interpretation in general was compiled by Colwell (1952) and should be consulted.

Landform

The term landform as used by photointerpreters indicates a mappable unit of the earth's surface that appears on the aerial photograph to be made up essentially of a single kind of geologic material, which together with similarity in overburden and in topographic expression give a recognizable homogeneity to the unit. Because the underlying geology tends to be the key factor in determining the appearance of a unit in aerial photographs, most of the landforms described in this chapter are given geologic terms.

Certain landforms are more susceptible to landsliding than are others, hence the identification of landform is highly important. By observing the topographic expression and the boundary of a unit area, and by comparing it with known sample photographs, a landform can often be identified on airphotos. For areas where geologic or soil maps are available, such identification can, of course, be checked against the facts shown on those maps.

The following major landforms (in the airphoto-interpretation sense) are classified according to differences in their physical composition: consolidated sedimentary rocks, intrusive and extrusive igneous rocks, metamorphic rocks, glacial deposits, unconsolidated sedimentary deposits, and windlaid materials. Each of these groups, together with the normal weathering products of each one, poses relatively distinct problems for the engineer, particularly from the standpoint of landslide susceptibility. Each one, moreover, can be more or less easily identified on aerial photographs. Numerous examples of each of the foregoing landforms, and of subtypes of each, are described and illustrated in the references previously cited.

Drainage and Erosion

The density and pattern of drainage channels in a given area reflect directly the nature of the underlying soil and rock. The drainage pattern is obvious in some cases, but more often it is necessary to trace the channels on a separate sheet of paper in order to study the pattern successfully.

Under otherwise comparable conditions, a closely spaced drainage system denotes relatively impervious underlying materials; widely spaced drainage, on the other hand, indicates that the underlying materials are pervious. Generally speaking, a treelike drainage pattern develops in flat-lying beds and relatively uniform material; a parallel stream pattern indicates the presence of a regional slope; rectangular and vinelike patterns, composed of many angular drainageways, are evidence of control by underlying bedrock, and a disordered pattern, interrupted by haphazard deposits, is characteristic of most glaciated areas. Indeed, disordered pattern of a much smaller scale is common in landslide deposits. There are other patterns developed in response to special circumstances. A radial pattern, for instance, is found in areas where there is a domal structure in the rocks, and a featherlike pattern is common in areas where there is severe erosion in rather uniform material, such as loess.

The shape of gullies appearing in airphotos gives valuable information regarding the characteristics of surface and near-surface materials. Thus, long, smoothly rounded gullies should indicate clays, U-shaped gullies indicate silts, and short, V-shaped gullies indicate sands and gravels.

Soil Tones

Soil tones are recognizable in photographs unless there is a very heavy vegetative cover. Black-and-white, rather than color, photography is commonly used in present-day engineering projects. Thus, the color tones examined are merely different shades of gray, ranging from black to white. Because gray tones are highly respondent to soil-moisture conditions on ground, they are an important airphoto element in landslide investigations.

A soil having high moisture content normally registers a dark tone and low moisture a light tone. The moisture condition is a result of the physical properties of the soil or the topographic position of the ground, or both. The degree of sharpness of the tonal boundary between dark and light soils aids in the determination of soil properties. Well-drained coarse-textured soils show distinct tonal boundaries whereas poorly-drained fine-textured soils show irregular, fuzzy boundaries between tones.

Vegetation

Vegetative patterns reflect both regional and local climatic conditions. The patterns in different temperature and rainfall regions can be recognized in airphotos. Locally, a small difference in soil moisture condition is often detected by a corresponding change of vegetation. A detailed study of such local changes is very helpful in landslide investigations. For instance, wet vegetation, represented by dark spots or "tails," is a clue to seepage in slopes. Cultivated fields, as well as natural growths, are good indicators of local soil conditions. Thus, an orchard is often found on well-drained soils; the sparseness of vegetation in nonproductive serpentine soils, where landslides are common, is very conspicuous and revealing.

Manmade Features

The identification of manmade features such as highway, railroad, and airport locations; dams, canals, and irrigation systems; sand and gravel pits, stone quarries, mining and other industrial operations, is obviously important in the investigation of landslides. With a little practice, an engineer who is familiar with these items on the ground should have no difficulty in recognizing them in airphotos. Some old, overgrown manmade features are actually easier to see in photos than on the ground.

Interpretation of Landslides in Airphotos

Having obtained a general understanding of a given area through airphoto examination of the major elements discussed in the preceding section, the engineer may proceed to a study of the specific features that are related to landslides.

Landslide Indications

An engineer already familiar with the appearance of landslides on the ground should orient himself to the airphoto view of landslides by examining photographs of some known examples. The difference between an air view and a ground view results chiefly from the fact that the former gives a three-dimensional perspective of the entire slide area, but at a rather small scale. Ground photos, on the other hand, show only two dimensions but on a larger scale. The indications of a landslide in airphotos are: the sharp line of break at the scarp; the hummocky topography of the sliding mass below it; the elongated, undrained depressions in the mass; and the abrupt differences in vegetative and tonal characteristics between the landslide and the adjoining stable slopes. Inclined position of trees in landslides is often observable in photographs.

Where a highway is built on unstable soil, the irregular outline and nonuniform tonal pattern of broken or patched pavement are often visible, even in relatively small-scale photography. Failures due to improper fill or inherently weak soil are also registered.

Vulnerable Locations

Many slides are too small to be readily detected in small-scale photography. In addition, the highway engineer often must cover an extended territory. Consequently, it is very important for him to locate and to examine closely all of the areas where the visible signs of slides may not be apparent, but in which there are special conditions that are conducive to slides. Typical vulnerable spots are as follows:

Cliffs or Banks Undercut by Streams. — Banks that are subject to attack by streams commonly fail by sliding. Where the banks are made up of soil or other unconsolidated material the weakest, hence most favorable slide position, is often located at the point of maximum curvature of the stream, where the bank receives the greatest impact from the water. In areas of rock outcrops, on the other hand, the section at and near the point of maximum stream curvature is often occupied by hard rock and the weak spots are to be found on both sides adjacent to that section.

Steep Slopes. — In stereo-examination of airphotos, it is reasonably easy to observe and compare the different hill slopes within a land unit. In a potentially dangerous area, large earth masses standing on the steepest slope are naturally the most vulnerable to landslides and should be examined closely. Comparison of slopes for this purpose should, of course, be confined to slopes of similar materials. Thus, a slope cut in earth or talus should not be compared with a rock cliff in an adjacent land unit.

Contributing Drainage. — Water contributes greatly to many slides. Careful examination of existing slide scars often indicates that a line connecting the scars points to some drainage channels on higher ground. Such drainage may appear on the surface or go underground and reappear as seepage water causing the damage. This drainage-slide relationship can frequently be detected in airphotos.

Seepage Zones. — Seepage is likely to occur in areas below ponded depressions, reservoirs, irrigation canals, and diverted surface channels. Such circumstances are sometimes overlooked on the ground because the water sources may be far above the landslide itself, but they become obvious in airphotos. The importance of recognizing the potential danger in areas below diverted surface drainage, especially in jointed and fractured rocks, needs particular emphasis. It has been proven repeatedly, through extensive field experience, that within an unstable area one of the most dangerous sections is the lower part of an interstream divide through which surface water seeps from the higher stream bed to the lower one. The recognition of seepage is sometimes aided by the identification of near-surface channels (appearing in airphotos as faint, dark lines), wet, tall vegetation on the slope (shown as dark dots or "tails"), and displaced or broken roads adjacent to the slope.

OLD LANDSLIDES

An investigation of existing landslides in any area gives an excellent basis for evaluating the possibility of future landslides (see Fig. 47). The indications of an old slide are similar to those of new slides except that they are not as fresh or as striking. Thus, the scarp may not appear sharp; the hummocky ground surface, although still present, may be subdued topographically; drainage and vegetation may have become established on the mass; and the change of gray tones between the landslide mass and the adjacent areas may be gradational rather than abrupt. As a matter of fact, the degree to which the vegetation and drainage are established on the mass helps determine the relative age and stability of the moved land.

Once an old landslide is found on the photographs it serves as a warning that the general area has been unstable in the past and that new disturbances may start new slides. However, such a warning should not discourage construction unconditionally. The unstable condition of the past does not necessarily exist today. In some western states, for example, railroads built in extensive old landslide areas have been stable for a long time.

In addition to the registration of unstable slopes, the airphoto also furnishes an excellent reference for the engineer to judge the attitude of slopes that are

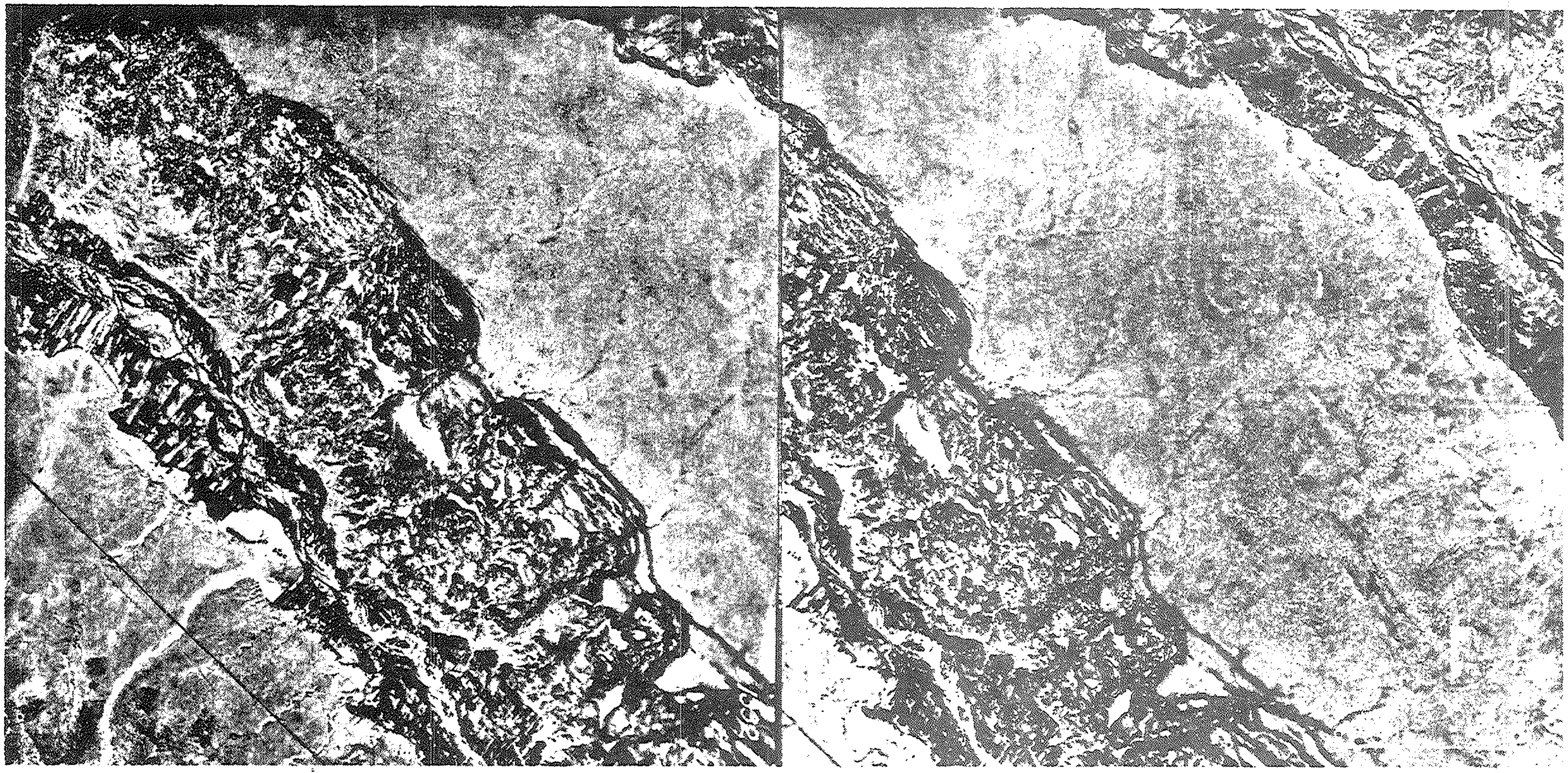

Figure 47. Old landslide, Rio Arriba County, N. Mex. This is one of the largest slide areas in the country. The slide is of such magnitude that it can be readily spotted even in the photo-index sheet. The characteristic sharp cliff at the scarp, hummocky surface and ponded depressions are well illustrated. Slides which the engineer ordinarily encounters are generally of much smaller magnitude, although they may assume similar forms.

The combination of basalt and the underlying sediments provided a favorable condition for the slide in this area; the once actively downcutting and laterally eroding river precipitated the movement. The well-established vegetation (shown in dark gray tones) and drainageways in the moved mass indicate that the general area is now stabilized. The currently critical spots are (a) where the river or artificial construction has cut into the toe of the lower slopes; (b) areas immediately below ponded depressions; and (c) areas along the cliff where imminent rockfall is indicated by breaking marks. The linear cliff above the slide indicates that the fracture pattern of the caprock is in coincidence with the horizontal axis of the slide. (Aerial photograph by U. S. Department of Agriculture) generally stable. Within the photo coverage, there is always a wide choice of combinations of circumstances, such as drainage, topographic position, and association with a gully or stream. For guidance in the design of new slopes the engineer often can find some existing slopes having conditions similar to the ones he is to build.

Landforms Susceptible to Landslides

Landslides are rare in some landforms and common in others. Most of the forms susceptible to landslides are readily recognizable in airphotos. The identifying elements and significant facts about them are summarized and illustrated in the following sections.

It should be noted that the order of presentation hereinafter follows a sequence based on origin and character of the materials rather than on the order of their importance in landslide occurrence. In general, the forms most susceptible to landslides are basaltic lava flows, serpentine, clay shale, and tilted sedimentary rocks; other forms are susceptible occasionally, depending on local circumstances.

Consolidated Sedimentary Rocks and Their Residual Soils. — The discussion of rocks and their residual soils is combined in this and in the following two sections because the recognition of types of residual soils depends primarily on the recognition of the landform developed in the parent rocks. The determination of depth of residual soil requires considerable judgment. However, the engineer working constantly in his own region should have no difficulty in estimating the depth once he is familiar with local conditions.

Generally speaking, rounded topography, intricate drainage channels and heavy vegetation are indicators of probable deep soils, in contrast to the sharp, steep, resistant ridges and rock-controlled channels commonly found in areas of shallow soil. The local climatic and erosion pattern should be considered in the interpretation.

A very high percentage of all slides occurs in residual soils and weathered rocks. They are usually in the form of slumps or flows. Rockfalls and rockslides, by definition, occur only in bedrock terrain.

In horizontal positions, massive sandstone is little likely to slide. Clay shale, especially if interbedded with sandstone or limestone, is highly susceptible to landslides (Figs. 48, 49, 50, and 51). Landslides are uncommon in thickly bedded limestone unless it is interbedded with shale or other soft rocks. In steeply tilted positions, any sedimentary rock may fail by sliding (Fig. 52). Depending on the dip angle, joint system, and climate, slides may take one or a combination of the forms of rockfalls, rockslides, debris falls, debris slides, and earthflows. River undercutting and artificial excavation are important factors in initiating landslides in both horizontal and tilted rocks.

Methods of identification of sedimentary rocks in airphotos are well established. Hard sandstones are noted for their high relief, massive hills, angular drainage, and light tones; clay shales are noted for their low rounded hills and well-integrated treelike drainage system; and soluble limestones are characterized by their sinkhole development in temperate humid areas and by rugged karst topography in some tropical regions. Interbedded sedimentary rocks show a combination of the characteristics of their component beds. When horizontally bedded, they are recognized by their uniformly dissected topography, contour-like stratification lines, and treelike drainage; when tilted, the parallel ridge-and-valley topography, the inclined but parallel stratification lines, and the trellis drainage are evident.

The identification of landform as a means of detecting associated landslides is important in the flat-lying sedimentary group because the slides there are often small and, therefore, not very obvious in the photographs. This is particularly

Figure 48. Clay shale, Monongalia County, W. Va. This stereo pair shows an area where clay shales predominate and landslides are active. There are very few competent beds in the general area as evidenced by the rounded, soft slopes and dull, uniform, gray tones. Minor irregularities as signs of movement are seen in most of the steep slopes. Even without artificial disturbances, nature is actively reducing the relief of the area by creeps, flows, and slides. At area (A), both the railroad and highway have experienced continuous landslide troubles. The irregular outline of the bank along the river and the patchwork on the road pavement are clearly seen in the photos. The steep slope and active attack by the river provides a favorable condition for landslides. Furthermore, surface drainage in the back of the slope is blocked by a hill and water is seeping through the hill toward the river. Such a circumstance is conducive to slides. (Aerial photograph by U. S. Department of Agriculture)

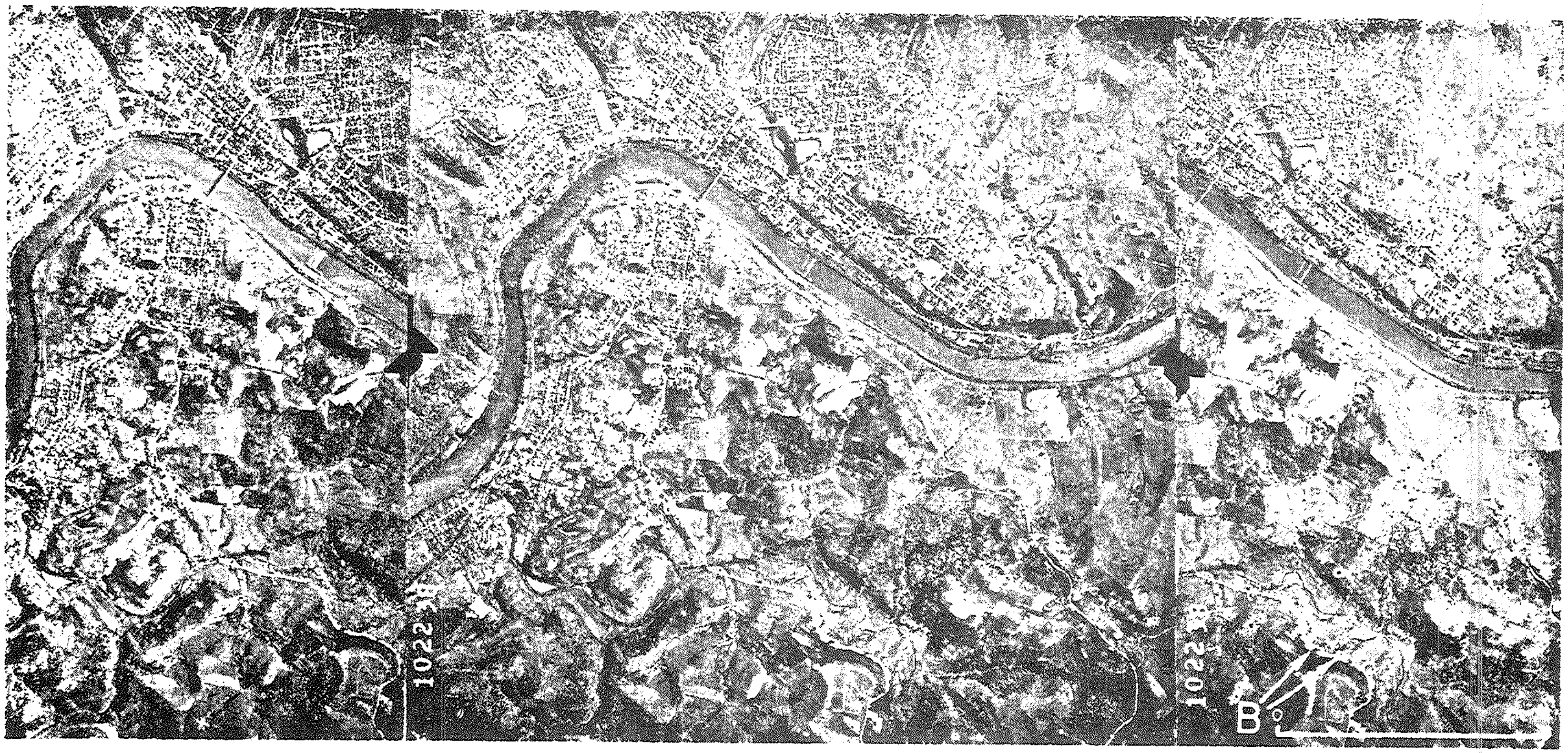

Figure 49. Shale in same general area as shown in Figure 48, Monongalia County, W. Va. Area (B) shows one of the most unstable slopes in the area. The disordered, hummocky forms on the hillside indicate that flows and slides are active. The irregular outlines of the road is a sign of continuous refilling and repatching because of slides. Slide scars are also prominent on the opposite side of the valley, particularly on the steeper slopes. (Aerial photograph by U. S. Department of Agriculture)

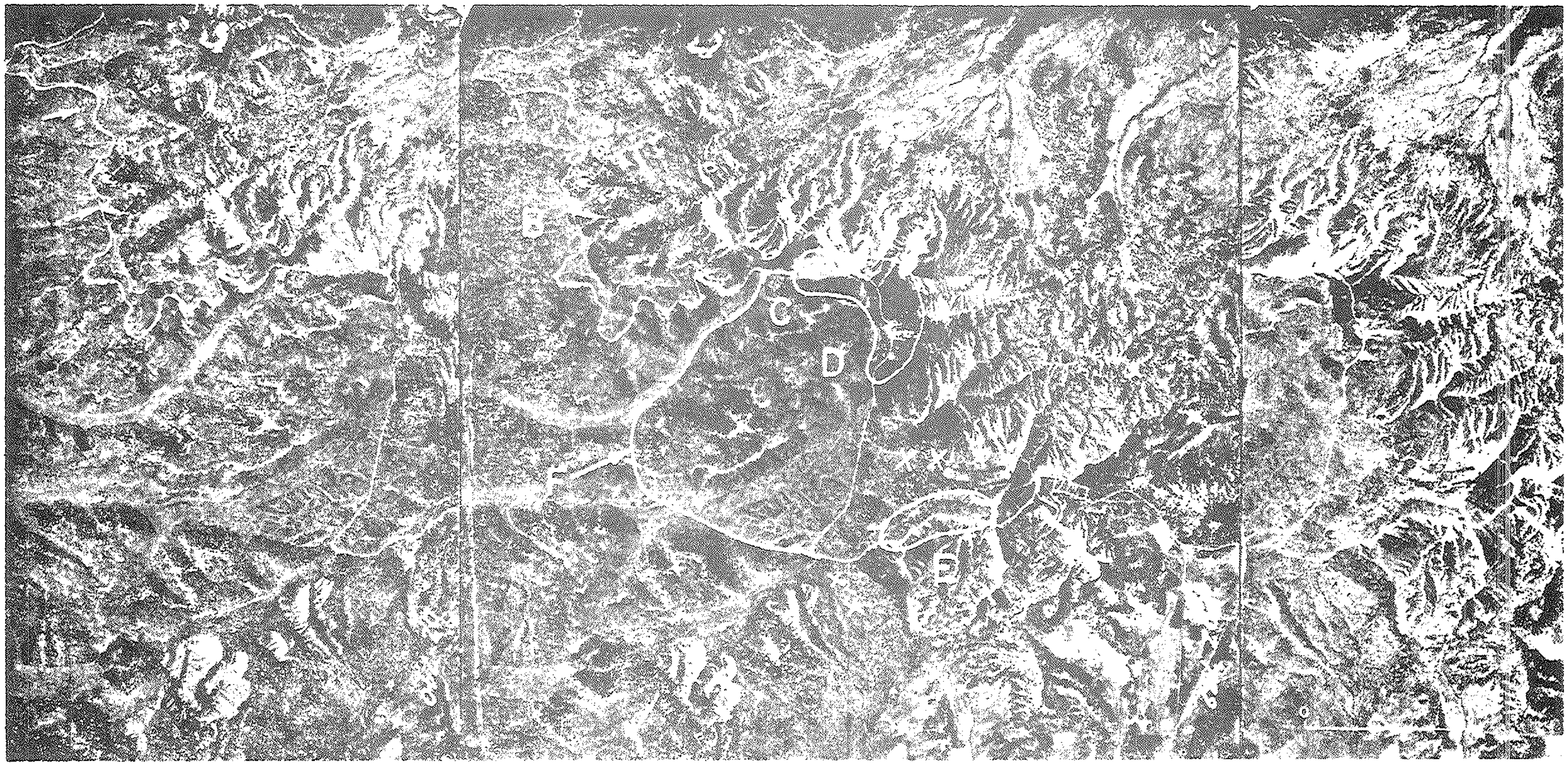

Figure 59. Flat-lying sedimentary rocks, Mesa Verde National Park, Montezuma County, Colo. The interbedded competent sandstones and soft shales are nearly horizontal, as indicated by the contour-like stratification lines on hills. The numerous landslides and erosional scars, seen as white patches, are striking throughout the area. Serious slides are marked (A), (B), (C), (D), and (E). (C) indicates where caprock fails, (D) indicates slumps where shale is primarily involved. Drainage condition in back of (C) helped to promote the mass movement.

It is difficult to maintain the highway on the shale slopes because they are already oversteepened and do not provide a good foundation; further disturbance would hasten the slide. Because of the difficulty in maintaining the roads on the steep slopes, several routes (X) have been abandoned in the general area. A plan of relocating the scenic highway that passes the hazardous area (C) and (D) is now under consideration. The new route will follow the valleys and go through a 1,400-foot tunnel (F). (Aerial photograph by U. S. Department of Agriculture)

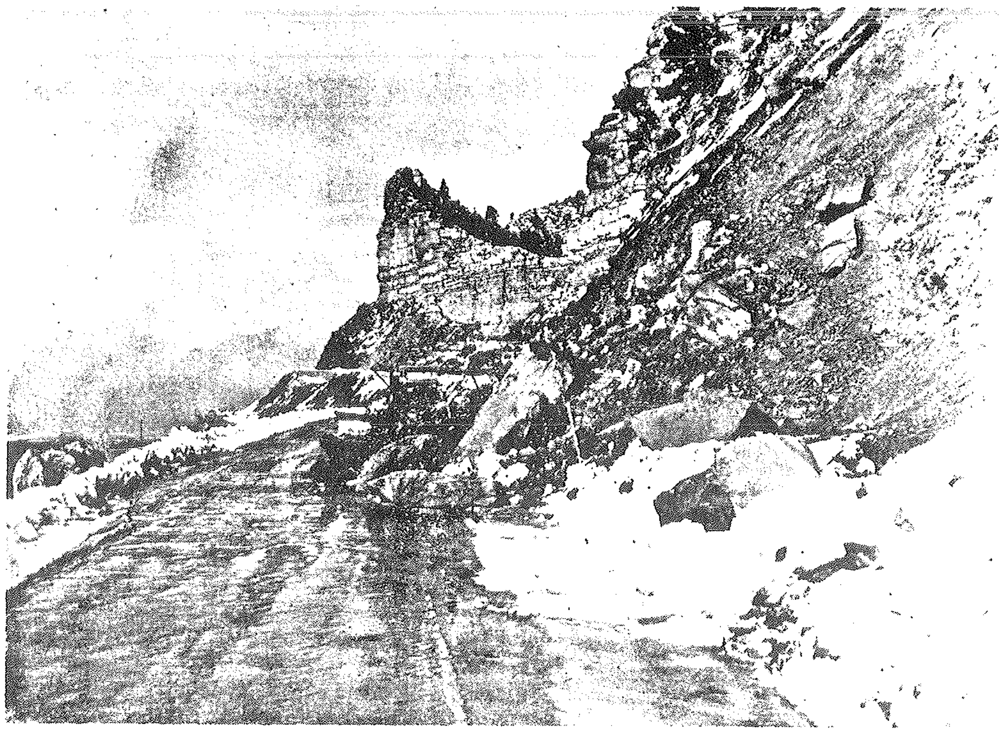

Figure 51. Ground view of rockslides and rockfalls in shale and sandstone, shown in Figure 50. (Photograph by National Park Service)

true for slides in colluvial deposits at the base of flat-lying beds. Furthermore, sedimentary rocks are the most widespread of all surface rocks and their conditions are to be met everywhere.

Intrusive and Extrusive Igneous Rocks and Their Residual Soils. — *Basaltic lava flows* are one of the most common representatives of the extrusive igneous rocks. They are readily identifiable in airphotos. Basalt is highly susceptible to different types of landslides (Fig. 53). Basalts often form the caprock in a plateau, with sharp, jagged cliff lines clearly visible in photographs. Surface irregularities or flow marks, sparseness of surface drainage, and dark tones are confirming airphoto characteristics.

If a basaltic flow is underlain by or interbedded with soft layers, particularly if it occupies the position of a bold escarpment, a very favorable condition for large slumps is present. The joints and the cracks in basalt give rise to springs and seepage zones and greatly facilitate movement. Rockfalls and rockslides along rim rock are usually favored by vertical jointing of basalt and by undercutting of basaltic cliffs. Talus accumulations of various magnitudes are found at the foot of cliffs. Disturbance of talus slope during road construction has caused some large slides of talus materials. Old slides and breaks indicating incipient slides often can be seen in photographs.

In areas of relatively deep weathering the landscape is somewhat modified. A more rounded topography and heavier vegetation develops, although dark tones still predominate. Slumps of both large and small size are common in basaltic soils.

Granite and related rocks are the most widely occurring intrusive igneous rock types. The landslide potential of granitic rocks varies widely, depending on

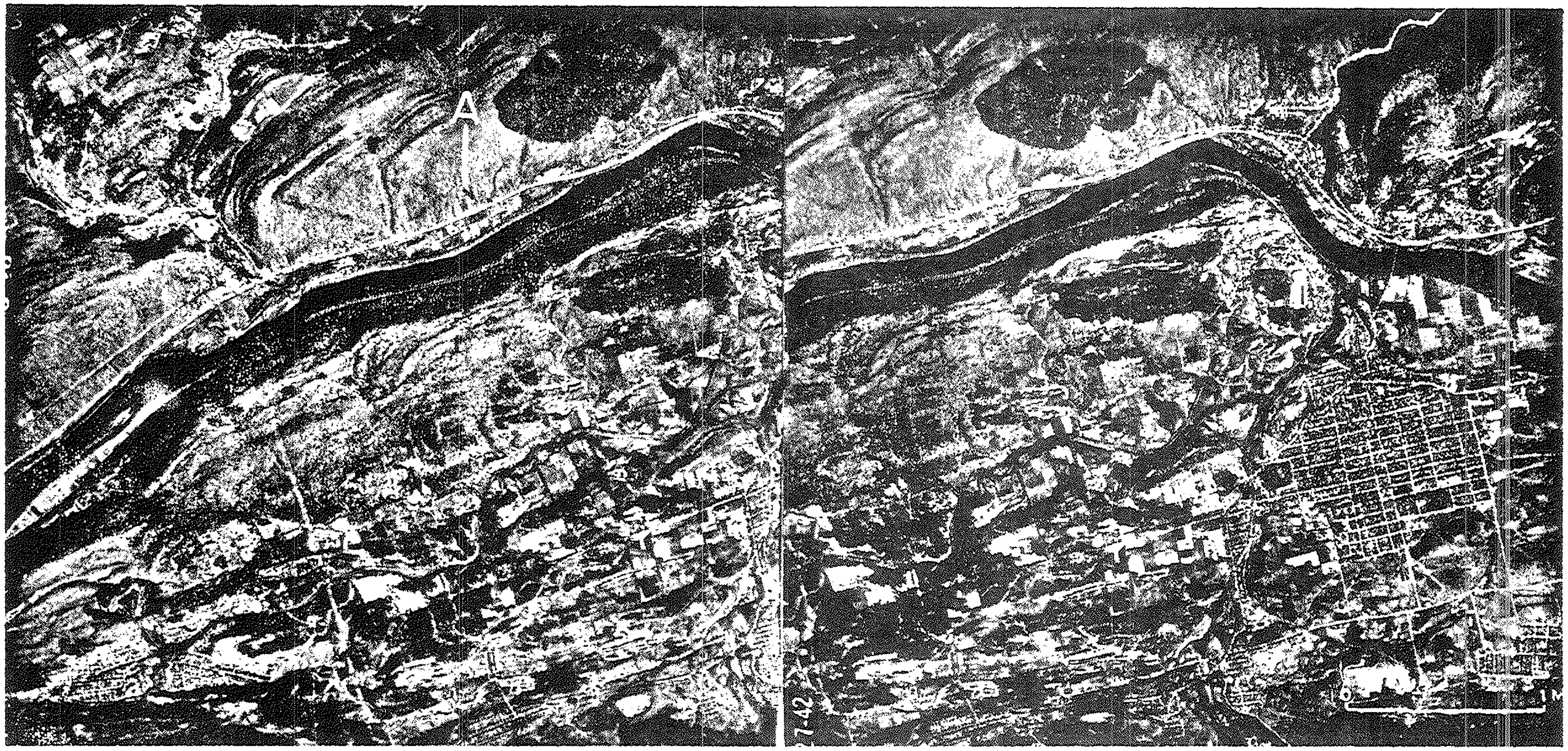

Figure 52. Tilted sedimentary rocks, Luzerne County, Pa. This stereo pair shows how an airphoto interpreter might predict the exact location and magnitude of a future slide. That this is an area of dangerously dipping sedimentary rocks is self-evident. Along the major highway, the most critical spot is at (A), where there is a clearly defined breaking line. Such an incipient break, although striking in the photo, is not obvious on the ground. Five years after this photograph was taken, when the highway below the break was being widened, the whole block of 400,000 cubic yards came down during an unusually heavy rain. (Aerial photograph by U. S. Geological Survey)

Figure 53. Basalt flow, Gooding County, Idaho. The basaltic plateau on the far side of the river is recognizable in the photo by its sharp cliff, minor surface marks, and dark tones. It is underlain by beds of tuff and clay, creating a favorable situation for landslides. There is a belt of talus accumulation and landslide deposits along almost the entire bottom of the cliff. Landslides are distinguished from talus slopes by the presence of a sharp break on the upland and the hummocky topography of the mass. An incipient slide is indicated at (A). Here, the partial breaking of a block of basalt from the mass is clearly shown; the slide can be precipitated by a slight disturbance. Smaller and less distinct breaks often appear in basalts along the cliff edge and can be detected by a careful inspection of airphotos. (Aerial photograph by U. S. Department of Agriculture)

the composition of the rock and its fracture pattern, the topography, and the moisture conditions. In granites that are highly resistant to weathering or of low relief, there is generally no slide problem. In hilly country where the granite is deeply weathered, slumps in cut slopes, as well as in natural slopes, are common. Fractures in the rock and high moisture condition undoubtedly are favorable factors in producing landslides.

Granitic masses are identified in airphotos by the rounded (old) to A-shaped (young), massive, uniform hills, and by the integrated treelike drainage pattern with characteristic curved branches. The presence of fractures and the absence of stratification and foliation aid to confirm the material.

Metamorphic Rocks and Their Residual Soils.— Landslides in metamorphic rocks vary greatly. The interpretation problem is rendered even more difficult because the criteria for identification of different metamorphic rocks in airphotos are not well established. Although the airphoto characteristics of major types of gneiss, schist, slate, and serpentine have been worked out, these rocks do not often have exposures of sufficient extent to be recognized by their topographic expression.

Within the metamorphic group, many slides are associated with *serpentine.* Serpentine areas are identified in airphotos by their sinuous ridge, smoothly rounded surface, short steep gullies, very poor vegetative cover, and dull gray tones.

There are, however, many serpentine areas where stable slopes prevail. Low relief and low rainfall are among the factors responsible for the stability of some of those serpentine slopes. A close examination of airphotos to detect existing scars is necessary before the instability of a serpentine area can be concluded. Within a general area, local conditions, such as vegetation, moisture, and slope, may create special, favorable circumstances for landslides.

Glacial Deposits. — Landslides are common in some glacial and glacio-fluvial deposits. Although most of the distinct glacial forms are easily identified in airphotos, there are complex areas which require a high degree of skill for their identification.

Moraines are found in nearly all glaciated areas. They are identified in airphotos by their jumbled, strongly rolling to hilly terrain. In moraines, particularly in the semiarid areas, there is a large proportion of waste, untilled land. Disordered drainage pattern, irregular fields, and winding roads are confirming clues.

Minor slumps, debris slides, and earthflows are common in cut slopes in moraines as the result of the presence of undrained depressions and seepage zones in the mass. Because morainic hills are usually small, these slides are not very extensive. They are, nevertheless, large enough to cause continuous trouble to many highway maintenance engineers (Figs. 54 and 55).

Slides in shallow *glacial mantle* overlying bedrock often take the form of slumps, debris slides, and debris falls, and often contribute to failures in artificial fill. They usually occur along valley walls that have been oversteepened by glaciation. The topography of such areas is basically that of the underlying bedrock with slight local modifications, depending on the thickness of the mantle. These cases are commonly found in the northern and northeastern United States where sedimentary beds predominate (Fig. 56). Slides seldom occur in other kinds of glacial deposits, such as kames, eskers, outwash plains, and till plains.

Unconsolidated Sedimentary Deposits. — Within this group, which includes such diverse forms as flood plains, alluvial fans, beach ridges, and swamps, most landslide problems are associated with dissected coastal plain deposits, river terraces, and lake beds.

Coastal plains are among the well-established forms that can be definitely recognized in airphotos. An undissected coastal plain is identified by its low, flat topography; its association with tidal

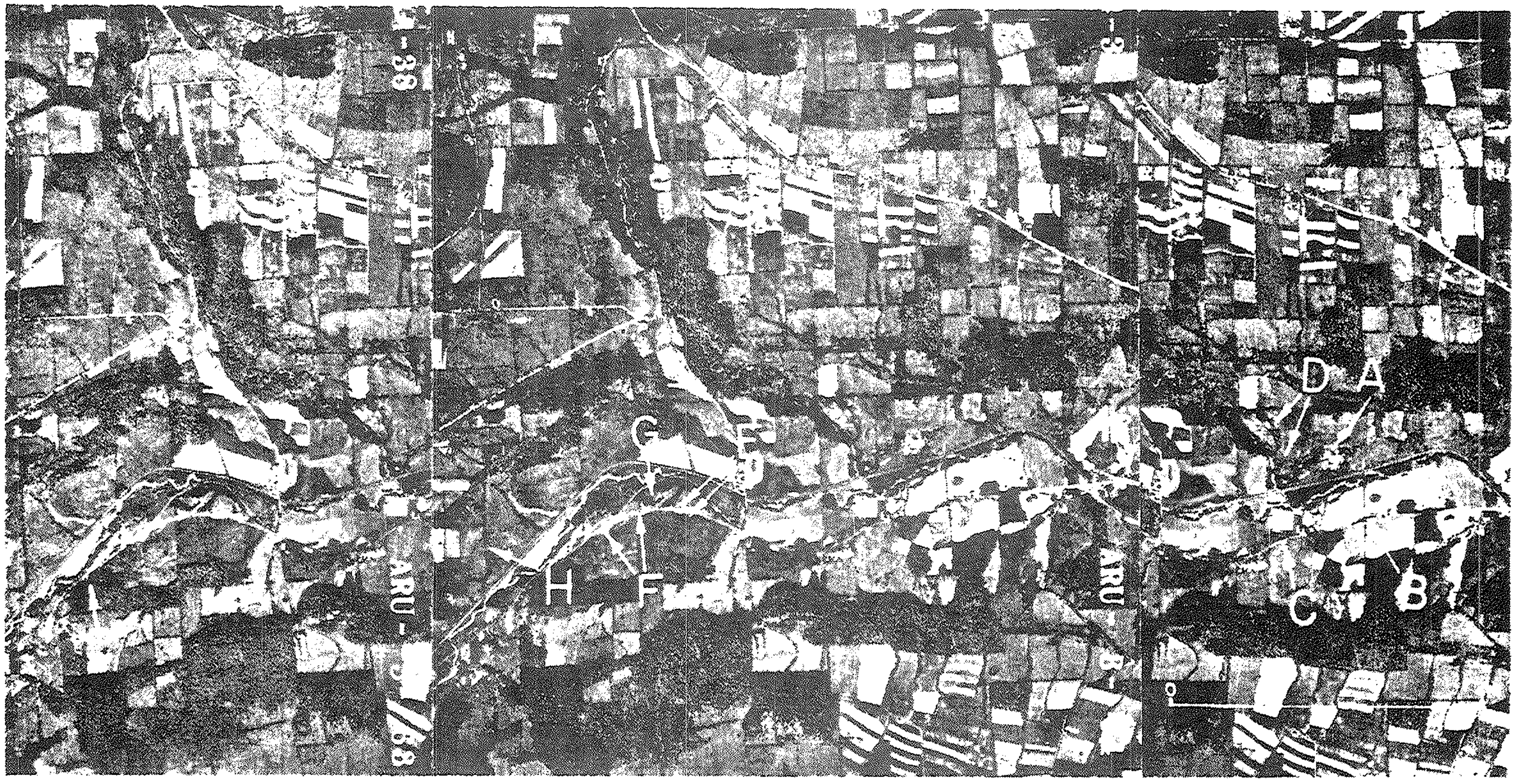

Figure 54. Moraine and lake bed, Tompkins County, N. Y. New slumps and debris slides, as well as old slide scars, are common occurrences in this glaciated valley where post-glacial erosion has dissected the moraines and the overlying lake deposits. Morainal areas are recognized by their hummocky topography. Lake deposits are usually distinguished by their flat, horizontal disposition. However, when lake clays are dissected, such a criterion no longer holds. Rather, the clues for clay identification, such as the characteristic smooth slopes, high degree of dissection, and gradual change of color tones, are more applicable.

A close inspection of the photo reveals that there are many old landslides, (A) being a prominent example. Other old slides, such as (D), (G), and (H), are common throughout the valley. All of them have been more or less stabilized, as indicated by the established vegetative pattern. Most highway cuts of moderate depth have experienced landslides, as in (B), (C), (E), and (F). Although deep-seated and large-scale slides are not likely to occur in such an area, continuous maintenance work in clearing the sliding material and in protecting slopes from erosion is necessary. (Aerial photograph by U. S. Department of Agriculture)

Figure 55. Ground view of a typical slide on a cut slope shown in Figure 54. (Photograph by Donald J. Belcher)

flats, marshes, and swamps; and the presence of broad, shallow, tidal stream channels. The dissected coastal plain is identified by its rolling to rugged topography and integrated drainage system. It is also associated with coastal features and appears on airphotos to be somewhat similar to areas underlain by consolidated sedimentary rocks.

In undissected plains, landslides offer a problem only in the construction of canals or similar structures that require deep excavation in flat lands. In dissected plains, however, slumps in natural hill slopes, as well as in road cuts, are common (Figs. 57 and 58). The stratified and unconsolidated nature of the sands, silts, and clays that characterize most coastal plains have provided a favorable situation for landslides.

Terraces are easily recognized in airphotos as elevated flat land along major or minor valleys. Terraces of gravel and sand are usually stable, maintaining a clean slope on the face. However, where terraces are composed of interbedded silts and clays, or where the natural equilibrium is disturbed by artificial installations, slumps will occur. Slumps in terraces naturally start on the unsupported slope facing the low land. The presence of slide scars along the terrace front is a reliable indicator of instability (Fig. 59).

Lake bed deposits generally display flat topography unless they are dissected. Although generally composed of clays, lake beds have little chance to slide except when exposed at valleys or at deep cuts. There have been slides of considerable magnitude in lake clays under each of the following circumstances: (a) where lake clays are interbedded with or, especially, are overlain by granular deposits, and (b) where lake clays overlie bedrock at shallow depth and the base level of erosion of the general area is greatly lowered. The former situation is common in some glaciated regions of New York. The latter combination has produced slides of extraordinary magnitude in western Canada.

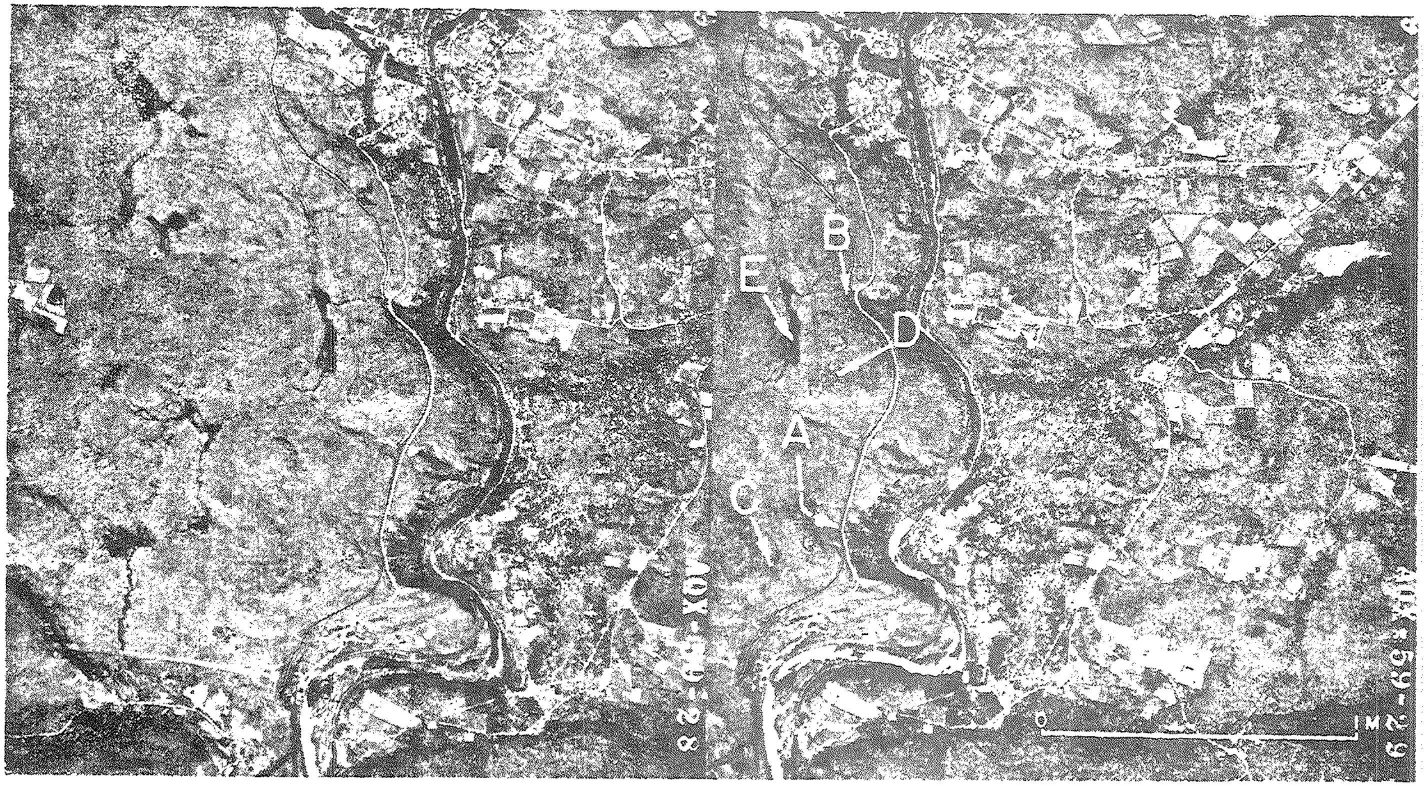

Figure 56. Glacial mantle over bedrock, Pike County, Pa. Thin deposits of unconsolidated materials on bedrock often develop landslides along stream valleys where undercutting is prevalent and the bank slopes are progressively steepened. Glacial deposits are usually unequally distributed over the bedrock — thinner on the hills and thicker over the valley. They tend to smooth the original bedrock topography. In the picture, at (A), the slide is shown to progress toward the road, threatening the road and the pipeline of a hydroelectric plant behind the road. A similar threat, though of lesser degree, exists at (B).

In examining the airphotos, it is clear that sandstone and shale outcrop at places like (C) and (D). On the basis of the general configuration of the sedimentary rock hills, the relative depths of unconsolidated deposits at various points can be estimated and a systematic, instead of haphazard, program for subsurface investigation can be planned.

Drainage conditions are clearly shown in the photographs. Ponded depressions, like (E), are obvious in the picture; but on the ground, it would take much time and effort to locate them in this tree-covered area. Drainage of such depressions would reduce the danger of impending slides below them. (Aerial photograph by U. S. Department of Agriculture)

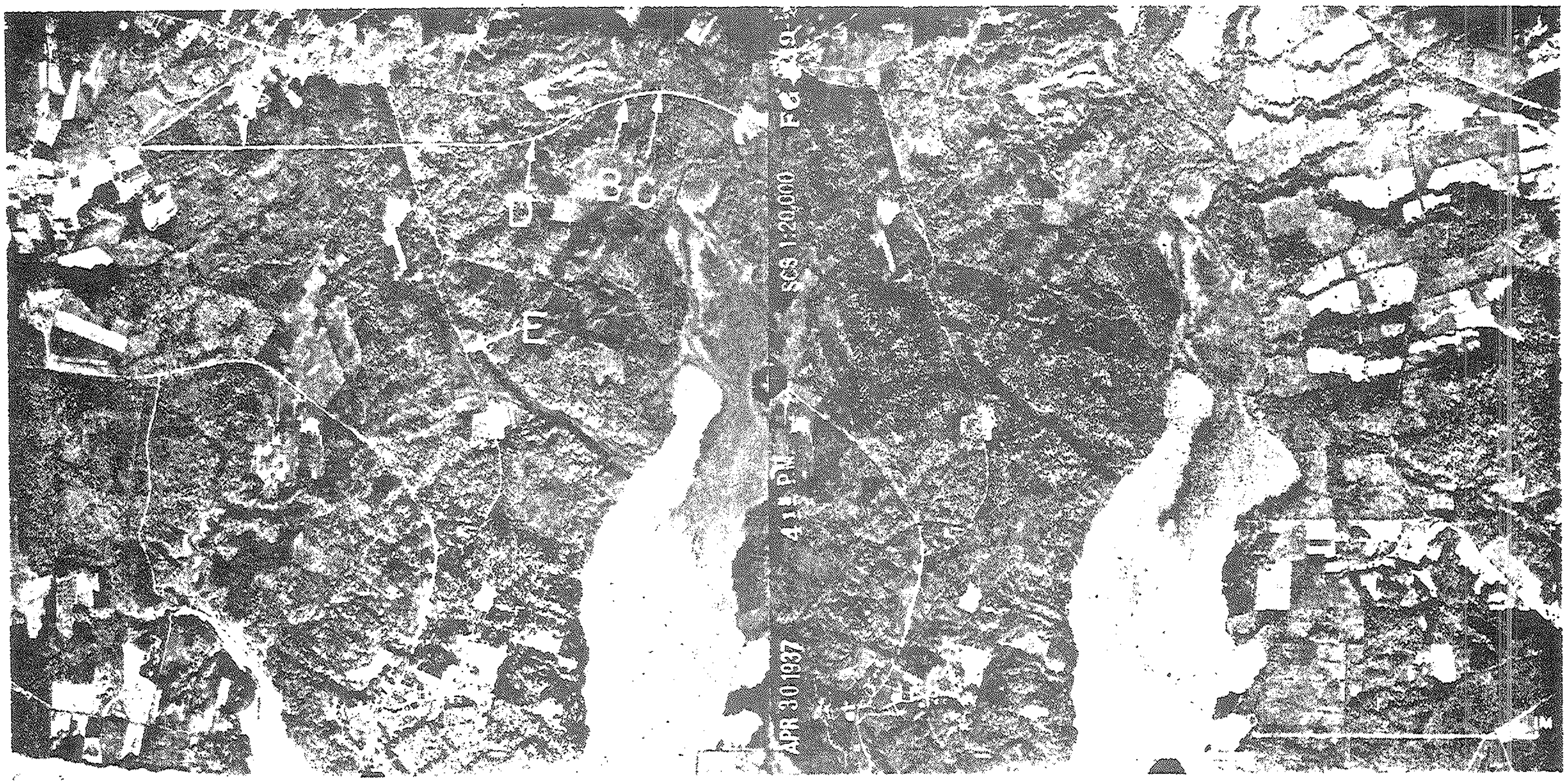

Figure 57. Coastal plain, Prince Georges County, Md. The stereo pair shows a proposed road (white line on left photo). The dissected plain is identified by its low, soft hills and the associated tidal channels. Cut slopes steeper than the natural slopes are susceptible to slides unless adequate precautions are taken. In highway location in an area like this, it would be better to set the grade line below dangerous clay layers so that even if a slide occurs, it would not affect the foundations of the road. At (A), a road constructed after the photos were taken was located above the clay. The subsequent slide not only damaged the upper slope but took away part of the pavement as well. At (B) and (C), the road cut into the toe of the natural slopes. Since the road was located below the clay layer, slides in both places occurred on the cut slope only. The cut slope at (D) also failed, but the drainage and topographic situation was more favorable there and the slide was stabilized shortly. At (E) is an old slide that can be easily recognized in the photograph; it is hidden by vegetation when inspected on the ground. (Aerial photograph by U. S. Department of Agriculture)

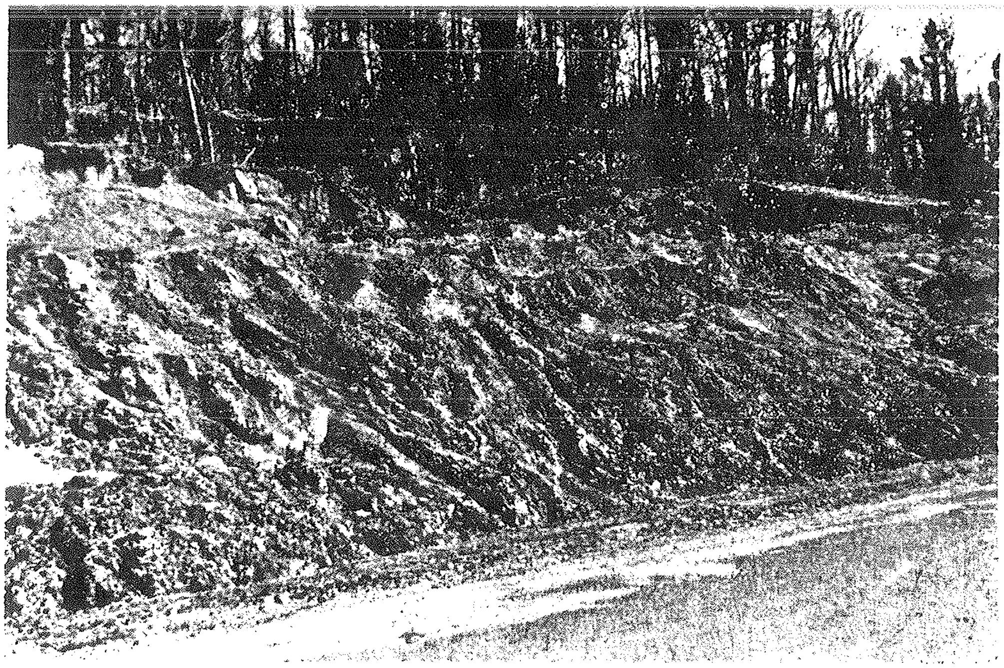

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Figure 58. Ground view of landslide at point (A) shown in Figure 57. Here, the gray clay layer lies underneath the pavement, which is damaged by the slide. (Photograph by Ta Liang)

Undissected lake clays are easily identified in airphotos by their characteristic broad, level tracts, dark gray tones, and artificial drainage practices. Dissected and complex lake bed areas are relatively difficult to identify, particularly for one that is not familiar with the local geologic conditions. Again, the presence of existing slides is the most reliable warning signal.

Windlaid Materials. — *Loess,* or wind-deposited silt, can be identified unmistakably in airphotos by its vertical-sided gullies, which are evenly spaced along wide, flat-bottomed tributaries to show a featherlike drainage pattern. Equal slopes on hills and valleys, an indication of uniform material, heavy vegetative cover, and soft gray tones serve to confirm the landform.

Loess is well known for its minor slumps, generally called catsteps. The catsteps are seen in airphotos as fine, roughly parallel, light tone contours (Figs. 60 and 61). On the ground, the individual steps of these small slumps are commonly 2 to 4 feet wide, and several inches to 2 or 3 feet high.

Complex Forms. — Most of the landforms previously described may be called simple forms because they consist predominantly of one type of material in each unit. In nature, however, complex or superimposed forms are numerous and of common occurrence. This is especially true in glaciated areas, as mentioned previously. They are further emphasized here because of their significance in landslide studies. Airphoto recognition of the basic simple forms is definitely helpful in the interpretation of complex forms.

A change of material vertically or horizontally in complex areas often affects the internal drainage characteristics and creates slope stability problems. The most common situation favorable to slides is when impervious formations

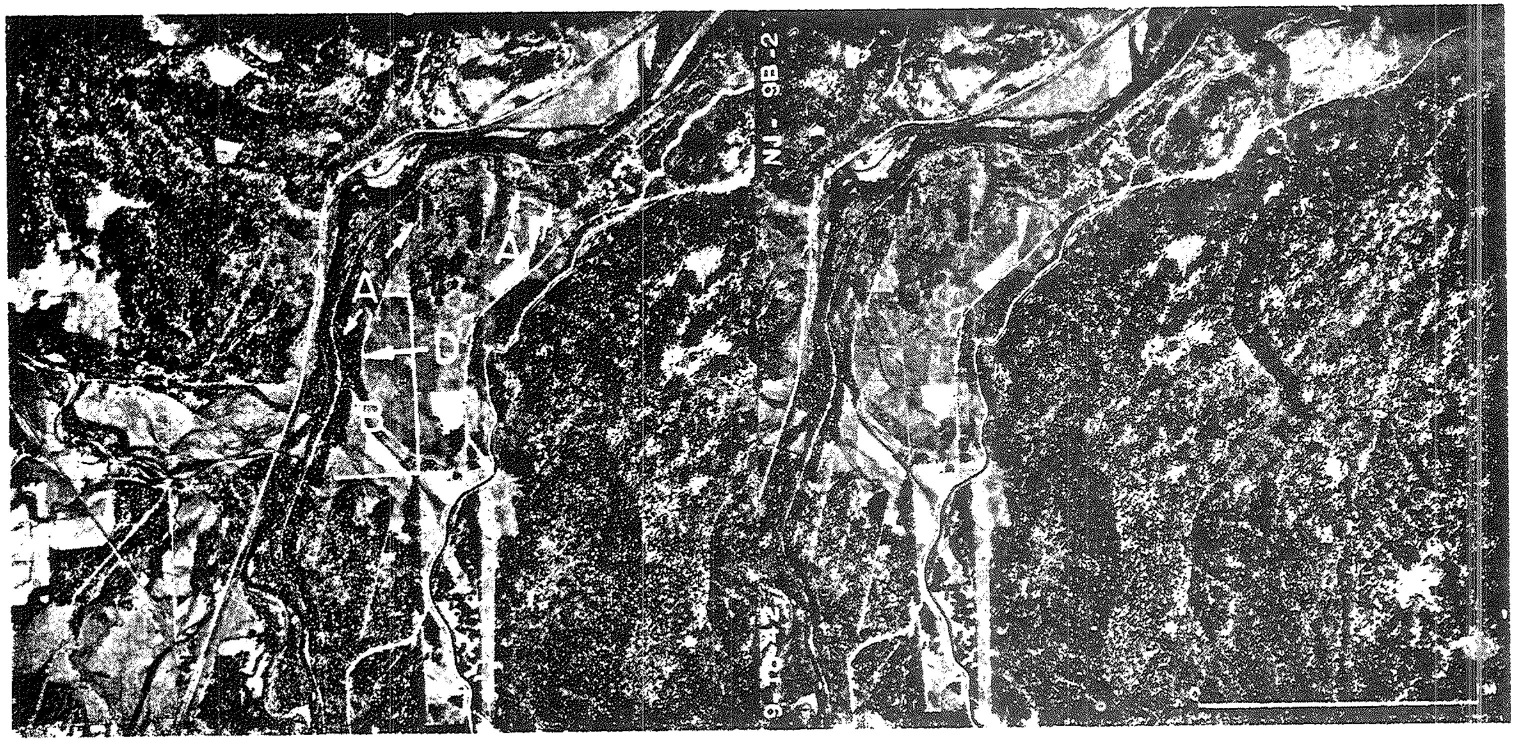

Figure 59. River Terrace, Kittitas County, Wash. The combination of pervious and impervious beds is a favorable condition for slides, often deep-seated ones. The instability of the land shown in this stereo pair is indicated by the numerous slide scars (A) along the terrace front. When the irrigation system of the farm (B) above the railroad was connected to the main canal (C) a new slide became imminent. The most probable next slide (D), which actually took place later, could be predicted in advance from air-photos as it is the steepest slope and is actively attacked by the river. (Aerial photograph by U. S. Department of Agriculture)

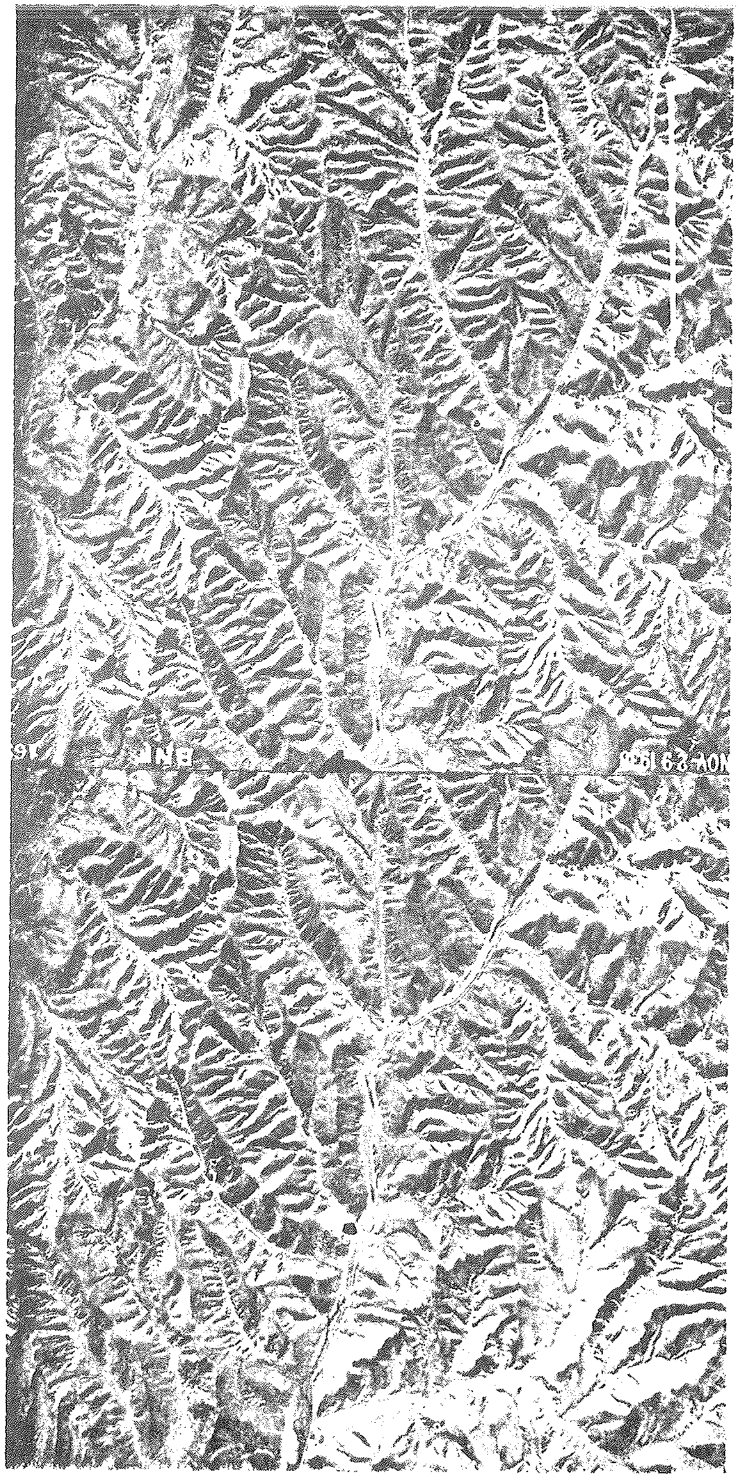

Figure 60. Loess, Lincoln County, Nebr. This stereo pair shows loess of great depth which is identified by steep-sided, flat-bottomed gullies, equal slopes in hills and valleys, and soft tones. The catsteps — small slumps — are seen as light fine contours all over the area. (Aerial photograph by U. S. Department of Agriculture)

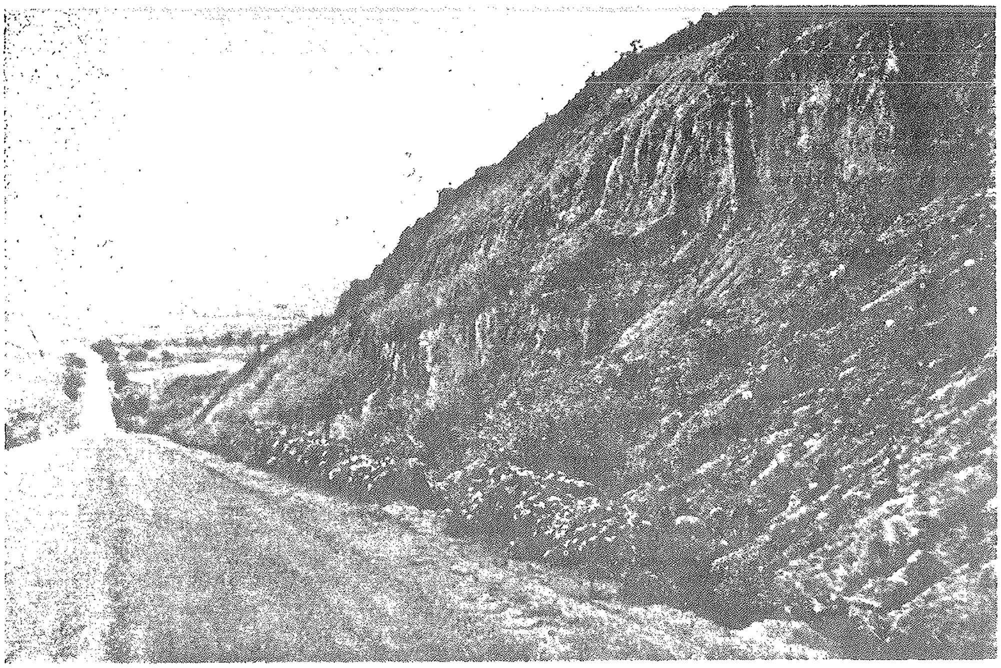

Figure 61. A ground photo showing catsteps in loess, such as those shown in Figure 60. (Photograph by Ta Liang)

are underlain by relatively pervious beds.

Actual failures are commonly detectable in airphotos in the following situations:

1. Glacial outwash or delta deposit over old lake bed. Photo pattern changes from that of light-toned, well-drained outwash at high ground to poorly drained lake clays exposed on the slopes. Old landslide scars are present in the slopes.
2. Glacial drift over shale. The photo is likely to show numerous landslides along river banks composed of shallow drift.
3. Valley fill over bedrock. The photo may show the landform characteristic of bedrock, but this is modified locally by fill deposits. Slides of fill material along steep hill slopes may be observed.
4. Sand over clay. This combination is common both in glacial and coastal plain areas. Slope failures along natural or cut slopes can be seen in many photos.

Procedure for Detecting Evidence of Landslides in Airphotos

A step-by-step procedure for landslide investigation by airphotos is outlined in the following:

1. Lay out locations of road or other planned structure on photos.
2. Take a quick survey, on the photographs, of all cliffs or banks adjacent to river bends, and of all steep slopes in the photo area, to see if landslide movements are evident.
3. Outline areas along the right-of-way that show consistent characteristics of topography, drainage, and other natural elements within the same unit.
4. Evaluate the general landslide potential of the areas with the help of Table 2.
5. Make a detailed study of all cliffs or banks adjacent to river bends and all steep slopes above and below the center line of the road. It is important to com-

TABLE 2

AIRPHOTO IDENTIFICATION AND LANDSLIDE EVALUATION OF LANDFORMS

Elimination Procedure	Supporting Characteristics	Probable Landform[1]	Landslide Potential[2]
I. Level terrain			
A. Not elevated:		Flood plain, etc.	(c)
B. Elevated:			
	Uniform tones	Terrace, lake bed	(b)
	Surface irregularities, sharp cliff	Basaltic plateau	(a)
II. Hilly terrain			
A. Surface drainage not well integrated:		Limestones, etc.	(c)
B. Surface drainage well integrated:			
1. Parallel ridges			
a. Parallel drainage	Dark tones	Basaltic hills	(a)
b. Trellis drainage	Ridge-and-valley topography, banded hills	Tilted or folded sedimentary rocks	(a)
c. Featherlike drainage	Vertical-sided gullies	Loess	(b)
2. Branching ridges			
a. Featherlike drainage	Vertical-sided gullies	Loess	(b)
b. Treelike drainage			
(1) Banding on slope		Flat-lying sedimentary rocks	(b)
(2) No banding on slope			
	Moderately to highly dissected ridges, uniform slopes	Clay shale	(a)
	Low ridges, associated with coastal features	Dissected coastal plain	(a)
	Winding ridges connecting conical hills, sparse vegetation	Serpentine	(a)
3. Random ridges or hills			
a. Treelike drainage			
	Low, rounded hills, meandering stream	Clay shale	(a)
	Massive, uniform, rounded to A-shaped hills	Granitic rocks	(b)
	Bumpy topography[3]	Moraine	(b)
b. Disordered drainage			
	Disordered, overlapping hills, associated with lakes and swamps[3]	Moraine	(b)

[1] The landforms listed are the most likely ones to represent the condition listed. It must be remembered, however, that other kinds of geology and terrain can give photographic representation similar to some of those listed. Only a high degree of skill in photo interpretation or knowledge of the local geology can be regarded as certain to avoid errors.
[2] (a) susceptible to landslides; (b) susceptible to landslides under certain conditions; (c) not susceptible except in dangerous locations discussed above.
[3] Glaciated areas only.

pare slopes within the same unit area rather than of different areas. For instance, slopes in bedrock would be more stable, even though steeper, than slopes in adjacent soil areas. Realize that slides usually appear small in photos, and so look carefully, inspecting slopes in minute detail. Look especially for:

a. Existing slides. Relatively new slides appear in white tones; vegetation and drainage are not well established on them. The reverse conditions are true for old slides.
   (1) Hillside scars and hummocky topography.
   (2) Parallel moon-shaped dark patches on hillside, likely to reflect vegetation in minor depressions. Draw a line through the axis of scars or crescents in the slides. This line often points to drainageways on higher ground that contribute to the landslide movement.
   (3) Irregular outline of highways and random cracks or patches on existing pavement.

b. Potential slides
   (1) Ponded depressions and diverted drainageways.
   (2) Seepage areas suggested by faintly dark lines, which may mean near-surface channels and fanshaped dark patches, probably reflecting wet vegetation.

6. Ground check some of the landslides that are recognized in airphotos.

7. Ground check all suspected spots, using methods and criteria described in Chapter Four.

References

Belcher, D. J., "The Engineering Significance of Soil Patterns." *Highway Research Board Proceedings.* v. 23, p. 569-598, 1943.

Belcher, D. J., et al., "The Origin, Distribution, and Identification of United States Soils, with Special Reference to Airport and Highway Engineering." Civil Aeronautics Administration Technical Report No. 52, 1946.

Colwell, R. N., "Bibliography (Photographic Interpretation)." American Society of Photogrammetry, Manual of Photogrammetry, p. 600-602, 1952.

Liang, Ta, "Landslides — An Aerial Photographic Study." Cornell University Ph.D. Thesis, 274 p., 1952.

Mountainside road gallery in 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.

(a) Reference number: This number gives the position of the reference within this particular bibliography. It is used in the compendium index but should ***not*** be used when ordering publications.

(b) Title: This is either the title of the complete publication or the title of an article or section within a journal, report, or book.

(c) Bibliographic data: This paragraph gives names of personal or organizational authors (if any), the publisher's name and location, the date of publication, and the number of pages represented by the title as given above. In some references, the paragraph ends

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Bibliografía

La siguiente bibliografía contiene dos series de referencias. La primera serie consiste en una referencia para cada texto seleccionado que apareció en la parte anterior de este compendio. La segunda serie consiste de referencias a publicaciones adicionales que fueron mencionadas en los textos seleccionados o que se asocian intimamente con el material que se presentó en la Vista General y los Textos Seleccionados. Cada referencia tiene cinco partes que se explican e ilustran abajo

(a) Número de referencia: Este número dá la posición de la referencia dentro de este bibliografía en particular. Se utiliza en el índice del compendio pero ***no*** deberá utilizarse al pedir publicaciones.

(b) Título: Este es el título de la publicación completa o el título de un artículo o sección dentro de una revista, informe, o libro.

(c) Datos bibliográficos: Este parágrafo dá los nombres de autores personales o organizacionales (si hay alguno), el nombre del editor y su direccion, la fecha de publicacion, y el numero de paginas representadas por el título en la parte (b). En algunas referencias el parágrafo termina con

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Bibliographie

La bibliographie qui suit contient deux catégories de références. La première catégorie consiste en une référence pour chaque texte choisi qui est inclus dans la partie précédente de ce recueil. La deuxième catégorie contient des références pour des documents qui ont soit été cités dans les textes choisis, ou soit sont étroitement associés avec des écrits qui sont présentés dans l'Exposé ou les Textes Choisis. Chaque référence est composée de cinq parties qui sont expliquées et illustrées ci-dessous

(a) Numéro de la référence: Ce numéro indique la position de cette référence dans cette bibliographie. Ce numéro est indiqué dans l'index du recueil mais ***ne doit pas*** être utilisé pour les commandes de publications.

(b) Titre: Cela indique ou le titre du livre entier, ou le titre d'un article ou d'une section d'une revue, un rapport, ou un livre.

(c) Données bibliographiques: Ce paragraphe indique les noms des auteurs personnels (quand il y en a) ou des auteurs collectifs (organisation), le nom de l'éditeur et son adresse, la date de l'édition, et le nombre de pages qui sont incluses sous le titre dans (b). Certaines with an order number for the publication in parentheses.

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(e) Abstract: This paragraph contains an abstract of the publication whose title was given in part (b).

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un número de pedido para la publicación en paréntesis.

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(e) Resumen. Este parágrafo es un resúmen de la publicación cuyo título se dió en la parte (b).

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références se terminent par un numéro entre parenthèses qui indique le numéro de commande.

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Illustration Ilustración Illustration

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(a) Número de referencia
(a) Numéro de la référence

(b) Title
(b) Título
(b) Titre

(c) Bibliographic data
(c) Datos bibliográficos
(c) Données bibliographiques

(d) Availability information
(d) Disponibilidad de la información
(d) Disponibilité des documents

(e) Abstract
(e) Resumen
(e) Analyse

The order should include all information given in parts (b) and (c) above.

El pedido deberá incluir toda la información dada en las partes (b) y (c).

L'ordre de commande doit inclure toutes les informations données dans les parties (b) et (c).

Reference 5
A REVIEW OF HIGHWAY DESIGN PRACTICES IN DEVELOPING COUNTRIES

Cron, Frederick W. Washington, DC: International Bank for Reconstruction and Development; 1975 May. 57 p.

Order from: International Bank for Reconstruction and Development, 1818 H Street, N.W., Washington, DC 20433.

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.

SELECTED TEXT REFERENCES

Reference 1
HIGHWAY DRAINAGE GUIDELINES; VOLUME I: GUIDELINES FOR HYDRAULIC CONSIDERATIONS IN HIGHWAY PLANNING AND LOCATION

American Association of State Highway Officials, Operating Subcommittee on Roadway Design, Task Force on Hydrology and Hydraulics. Washington, DC: American Association of State Highway Officials; 1973. 4 p.

Order from: American Association of State Highway and Transportation Officials, 444 North Capitol Street, N.W., Suite 225, Washington, DC 20001.

These guidelines present a design approach to drainage and hydraulic problems which brings together related disciplines in highway engineering. The effect of the highway construction on the existing drainage pattern and on the potential flood hazard, as well as the effect of floods on the highway must be assessed in the preliminary planning and design stages. Special studies and investigations (topographic maps, aerial photographs, streamflow records, historical highwater elevations and flood discharges) including consideration of the environmental and ecological impact should be made comensurate with the importance and magnitude of the project and the complexity of the problems encountered. Comments are made on potential construction and maintenance problems. The desirability of interagency coordination, and the need for information on existing and planned non-highway projects are noted. The requirement of permits, legal liabilities with regard to highway drainage construction, and the reporting and documentation of hydrologic and hydraulic data are discussed.

Reference 2
HIGHWAY DRAINAGE GUIDELINES; VOLUME II: GUIDELINES FOR HYDROLOGY

American Association of State Highway Officials, Operating Subcommittee on Roadway Design, Task Force on Hydrology and Hydraulics. Washington, DC: American Association of State Highway Officials; 1973. 23 p.

Order from: American Association of State Highway and Transportation Officials, 444 North Capitol Street, N.W., Suite 225, Washington, DC 20001.

Guidelines are given for a recommended approach to the hydrologic analysis for the design of highway drainage facilities. The need for the documentation of the design of highway drainage facilities is indicated, and the basic items that should be documented are noted . The need for familiarization with the factors affecting flood runoff is emphasized. These factors include drainage basin characteristics, stream channel characteristics, flood plain characteristics, and precipitation. Flood hazards must be evaluated; comments are made on historical flood records, flood data, flood history of existing structures, and methods of determining flood magnitudes. Factors in the selection of a design flood frequency (highway classifications, risk and economics) are outlined. The predicting of flood magnitudes and the development of the flood frequency curve are also covered.

Reference 3
SUBSURFACE SOILS EXPLORATION

Finn, Fred N. Washington, DC: National Association of Counties, Research Foundation; 1972 July. 36 p. (National Association of County Engineers Action Guide Series Volume XVI).

Order from: National Association of Counties, 1735 New York Avenue, N.W., Washington, DC 20006.

This manual attempts to give the county engineer a basic understanding of the need for subsurface soil exploration, a review of the techniques currently available, and proper field and office procedures for logging, recording and interpreting data. Pointers are given on planning the soil investigation process, followed by a brief review of the properties of soils and their strength values for design process. The conduct of the exploration is then detailed, this covers aspects such as locating and sampling borings, sampling procedures and techniques, field identification of soils, soil classification systems, and field identification of rock. Reporting of 6 types of subsurface exploration information is discussed: graphical presentations of soil borings; special use of materials or potential problems areas; photographs of land forms; profiles of surface and subsurface materials, properties, strength and grading; and unusual problems and recommended solutions.

Reference 4
FIELD IDENTIFICATION OF SOILS AND AGGREGATES FOR COUNTY ROADS

Shurig, D.G.; Hittle, Jean E. Lafayette, Indiana: Purdue University; 1971 December. 57 p. (Highway Extension and Research Project for Indiana Counties Engineering Bulletin, Engineering Experiment Station County Highway Series No. 13).

Order from: Highway Extension and Research Project for Indiana Counties, Engineering Experiment Station, Purdue University, West Lafayette, Indiana 47907.

Instruction on rating the quality of soils and pit-run materials used in the construction and maintenance of county roads is presented, and a system of soil classification for identifying soil types, properties and problems is outlined. Chapter II provides instructions on the identification of soil components, based on their physical properties as determined by visual examination and simple hand tests. Five soil components are defined, along with their size ranges, properties and simple hand tests for identification. The Unified Soil Classification System is presented in Chapter III: The classification recognizes 15 basic soil groups. Definitions, word descriptions and classification symbols are summarized in tabular form. Chapter IV outlines instructions and procedures for identifying each of the 15 soil groups, using visual examination and simple hand tests. The identification process is summarized in tabular form. Chapter V outlines additional field identification tests. These "indicator" tests are mainly for pit-run gravels and sands but can serve for both identification and general quality evaluation tests. Guide gradings are presented for gravel base and surfacing aggregates. Tests to indicate the relative amount of fines and relative plasticity of fines are also outlined. In Chapter VI, the 15 soil groups are rated with respect to their inherent properties as road-building materials. Each soil group is rated for its: (1) load-carrying properties as road-building materials, (2) drainage properties, (3) frost properties, and (4) compaction properties.

Reference 5
DESIGN MANUAL: SOIL MECHANICS, FOUNDATIONS AND EARTH STRUCTURES

U.S. Navy Department, Bureau of Yards and Docks. Washington, DC; 1963. Various paging. (Stock Number 0850-00075-9).

Order from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

This manual, which is part of a series of design manuals, provides direction and standards for procedures, methods, dimensions, materials, loads and stresses relating to soil classification, exploration and sampling, laboratory tests and properties, as well as field tests and measurements. The distribution of stresses and pressures, settlement analysis, stability analysis, seepage and drainage analysis, are covered in addition to compacted embankments, compaction procedures and hydraulic fills, and the analysis of walls and retaining structures. Spread foundations, deep foundations, pile foundations, pressures on buried structures, soil and rock stabilization are detailed and special problems relating to foundations in seasonal frost areas, vibrations and seismic effects are discussed. A bibliography of publications containing background information and additional reading on the subject is included.

Reference 6
THE IDENTIFICATION OF ROCK TYPES

Revised ed. Woolf, D.O.; U.S. Bureau of Public Roads, Division of Physical Research. Washington, DC: U.S. Government Printing Office; 1960 November. 17 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.

The method for identification of rock types presented here in simple terms, is intended for application to pieces large enough for the rock structure to be observed clearly. The method which follows that described by Pirrson and Knopf and which is based on that given by Geikie, uses a combination of simple physical and chemical determinations to identify the rock. The necessary equipment consists of a steel knife blade, a magnifying glass of 6 to 10 power, and dilute hydrochloric acid. A general classification of rock type, mineral composition of rocks, and a geologic classification are described. Rock structure, the identification of quartz, feldspar and other minerals are reviewed. Comments are made on the difficulties encountered with intrusive igneous rocks and on the engineering properties of rock.

Reference 7
THE ENGINEERING SIGNIFICANCE OF LANDFORMS

Belcher, D.J. The Appraisal of Terrain Conditions for Highway Engineering Purposes. Washington, DC: Highway Research Board; 1948 November; pp. 9-29. (Bulletin No. 13).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

Influences of the land unit or land form upon the design, construction, and maintenance of highways are described. Specific solid rock and moisture conditions existing in the land form are important. A given land form possesses a distinctive type of relief. The texture of the soil varies in a prescribed way and ground water and soil moisture follow typical trends. Land forms influence the quality and type of grading, pre-determine the drainage requirements and fix the soil or rock conditions. Emphasis is placed on the physical characteristics of the materials that compose the land forms, and the inter-relationship of the relief, soil, rock and ground water characteristics. Aerial and ground photographs have been used to illustrate individual forms as well as to identify the variations that occur within each unit area. Soil survey objectives are analyzed in the following land forms: (1) soluble limestones, (2) wind transported materials, (3) glaciated regions, (4) arid regions, and (5) landslides. Characteristics of the land form under study conditions of topography, soil, water and bedrock provide conditions to determine design methods and construction procedures.

Reference 8
TERRAIN EVALUATION FOR ROAD ENGINEERS IN DEVELOPING COUNTRIES

Dowling, J.W.F.; Beaven, P.J. Institution of Highway Engineers Journal, Vol. 16, No. 6, 1969 June; pp.5-15.

Order from: Institution of Highway Engineers, 3 Lygon Place, Ebury Street, London SW1W 0JS, U.K.

Some aspects of engineering planning are reviewed including route location, site investigation and surveys of engineering materials. The basic unit used for land classification is the land facet; land facets recur together in land systems which are usually identified by means of aerial photography. Examples of terrain evaluation studies from Northern Nigeria and Western Malaysia are illustrated. A discussion is appended in which Dr. Millard, Road Research Laboratory, took part.

Reference 9
LANDSLIDE INVESTIGATIONS; A FIELD HANDBOOK FOR USE IN HIGHWAY LOCATION AND DESIGN

Cleaves, Arthur B. Washington, DC: U.S. Bureau of Public Roads; 1961 July. 67 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.

The handbook is condensed in a deliberate effort to provide a work that may be used in the field. It is divided into four parts. The first is a very brief introduction to geologic processes, rocks and soil types, and geologic structures which provide the setting for landslides. The second involves the recognition of phenomena presaging the advent of slide movements, and those characteristic of the landslide itself. The third is devoted to methods of landslide prevention, control, and correction. The fourth discusses details of mapping and reporting landslides.

Reference 10
AERIAL PHOTOGRAPHS AND THEIR APPLICATIONS

Smith, H.T.U. New York, New York: D. Appleton-Century Company; 1943. 372 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 presentation of the elements of photographic mapping, photointerpretation and their various applications, emphasizes practical working procedures as well as outlines the underlying principles. The interdependence of aerial photographs and map-making procedure is emphasized, and the methods of study and the recognition of all important types of man-made and natural features seen on photos is covered. The topographic and geologic aspects of interpretation is based primarily upon photographic illustrations. The various chapters cover the details of characteristics of aerial photos, stereoscopic study of aerial photos, the general principles of photointerpretation, geographic and topographic interpretation, planimetric maps from vertical and oblique photos, photo-mosaics, contour maps from physiographic interpretation, aerial photos in economic geology, engineering and other fields, as well as, military applications. Problems are included in several chapters and laboratory exercises are included in the appendix.

Reference 11
AERIAL PHOTOGRAPHY

Caraway, Jack. Washington, DC: National Association of Counties, Research Foundation; 1972 July. 57 p. (National Association of County Engineers Action Guide Series Volume XIII).

Order from: National Association of Counties, 1735 New York Avenue, N.W., Washington, DC 20006.

This manual provides information that can lead to innovative changes in engineering and planning procedures. It is designed to assist engineers in providing the greatest amount of service possible for the minimum expenditure of funds. The broad aspects of available types, forms, and sources of aerial photographs are discussed. Details are given of how aerial photographs can be used to obtain information and data important to the county engineer. Detailed descriptions are provided of applications in highways, drainage and flood control, water supply, sewage and solid waste disposal, land use and development planning, and land evaluation. Some limitations of aerial photography are also pointed out.

Reference 12
DRAINAGE PATTERN SIGNIFICANCE IN AIRPHOTO IDENTIFICATION OF SOILS AND BEDROCKS

Parvis, Merle. Soil Exploration and Mapping. Washington, DC: Highway Research Board; 1950 November; pp. 36-60. (Bulletin No. 28).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This paper reports the analyses of drainage patterns for their use in the identification of regional soils and bedrocks by means of airphotos. The study is one of several concerning the interpretation of aerial photographs by the Joint Highway Research Project at Purdue University. The relative ease with which stream systems can be observed on aerial photographs facilitates the recognition of drainage patterns. In the natural sciences, it has been accepted for a long time that certain basic drainage patterns such as the dendritic, trellis, radial, parallel, annular, and rectangular are associated with specific land surface materials. Airphoto interpretation has revealed several modifications of the basic drainage patterns. For example, some of these modified types are the reticular, phantom, and lacunate. Drainage patterns, traced directly from representative airphotos of various physiographic regions throughout the United States, are presented as illustrations of patterns which develop in the soils and bedrocks typical of the regions. These examples have been selected to show noticeable differences in drainage patterns. For instance, drainage patterns in regions where the rocks are bare or are covered only with shallow soils, are decidedly different from those in regions or deep glacial drift. Likewise, drainage patterns develop differently in horizontal rocks than in tilted rocks.

Reference 13
AIRPHOTO INTERPRETATION

Liang, Ta; Belcher, Donald J. Landslides and Engineering Practice; Chapter Five. Highway Research Board, Committee on Landslide Investigations. Washington, DC: Highway Research Board; 1958; pp. 69-92. (Special Report 29).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This book, which is designed for practical use, brings together information useful in recognizing, avoiding, controlling, designing for, or correcting landslide movement. The first part of the book provides the tools and methods needed to solve an actual or potential landslide problem. The economic and legal aspects are covered here, as well as landslide types and processes, their recognition and identification, the use of airphotos in landslide investigation, and field and laboratory investigations. The second part of the book summarizes the methods known to have been applied to the prevention and control of landslides; it also discusses the methods of making stability analyses and of using them in the solution of design problems. Areas in which information on landslides and their control are needed are noted, and methods by which such information may be obtained are suggested.

ADDITIONAL REFERENCES

Reference 14
SOIL MECHANICS FOR ROAD ENGINEERS

Great Britain Road Research Laboratory, Department of Scientific and Industrial Research. London: Her Majesty's Stationery Office; 1952. 541 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 presents the collective experience of a large body of people concerning the use of soils and soil engineering techniques in road construction and maintenance. The information, which is equally applicable to road and airfield pavements, deals with the embankment, the foundation beneath the embankment, the cutting, and the road pavement. The nature of soil and the characteristics of its various components are reviewed, and the classification of soils on the basis of simple laboratory tests and plasticity tests is described. The methods for classifying subsoil drainage and moisture control, frost damage to road foundations, soil strength measurements, pavement design, and foundation failure investigations are descibed, as well as soil stresses, bearing capacity, and the consolidation of compressible soils. The construction of roads on swampy ground, the stability of clay slopes, and soil testing laboratory equipment requirements are also covered.

Reference 15
GLOSSARY OF PEDOLOGIC (SOILS) AND LANDFORM TERMINOLOGY FOR SOIL ENGINEERS

Highway Research Board. Washington, DC; 1957. 32 p. (Special Report 25).

Order from: University Microfilms International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.

This glossary defines terms used to describe soils and landforms and which are used in pedological and aerial photographic studies. The glossary also provides a means of understanding information from other technical and scientific fields and is an aid to consistency of terminology in reports and discussions. This compilation provides a reference for terms used in the soil survey maps. Terms describing the properties, types and classes of soil, and landform terms describing topographic features and geological aspects are included. Many sources were used in the preparation of this glossary of soil and landform terms.

Reference 16
MANUAL OF PHOTOGRAPHIC INTERPRETATION

American Society of Photogrammetry. Washington, DC; 1960. 868 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.

The development of photointerpretation is traced, the procurement of aerial photography is discussed, the fundamentals of photointerprētation are set forth, and the use of photointerpretation in various disciplines is covered. Contracting for new photography, and the parameters governing the selection of aerial photographic equipment and materials are discussed. Photointerpretation in geology, particularly geomorphism and stratigraphic interpretation, is described, as well as the factors affecting photointerpretation of soils. Photointerpretation in engineering, is discussed with reference to its application in highway traffic, power line, pipeline, damsite and flood control. Basic soil and geologic concepts, the identification of landforms and landslides are also covered. Applications in forestry are discussed with reference to the classification of forest stands, volume inventory timberland appraisals, sale and exchange of timber, forest roads and soils, forest protection and damage assessment, and reforestation. Wildlife and forest range management are also considered. Photointerpretation techniques in hydrology and watershed management, agriculture, and urban area analysis are detailed, as well as the use of such techniques in archaeology and geography. Comments are made on special forms of photointerpretation such as photomicrography, electron microscopy, fluorescence microscopy, radiography, radioantography, spectroscopy, high-speed photography, and photography in space.

Reference 17
TROPICAL SOILS: CHARACTERISTICS AND AIRPHOTO INTERPRETATION

Liang, Ta; Cornell University. Bedford, Massachusetts: U.S. Air Force, Cambridge Research Laboratories; 31 August 1974. 83 p. plus photographs and appendices. (Report #AD-613555).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

To facilitate engineering studies of tropical soils, and particularly their airphoto interpretation, a classification system is proposed which covers major groups of soils peculiar to the tropics, soils common in both tropical and subtropical regions, and soils common in all climates. The origin and formation of tropical soils and their relation to climate, parent material, topography, and age are reviewed. The physical and chemical characteristics, and engineering problems of each of the major soil groups are examined. A method of airphoto interpretation by direct recognition of soil features, and by inference gained from observation of soil-forming factors and circumstances is presented. Air and ground photographs from Central and South America, Tropical Africa, Southeast and South Asia, and Australia are included to illustrate a cross section of the major soil groups in the tropics. Recommendations are made for further study toward refining the airphoto interpretation of the major groups and subgroups of tropical soils, in addition to the supplementary use of other remote sensing devices.

Reference 18
PCA SOIL PRIMER

Portland Cement Association. Skokie, Illinois; 1973. 39 p. (Engineering Bulletin EB007.04S).

Order from: Portland Cement Association, 5420 Old Orchard Road, Skokie, Illinois 60076.

This publication was prepared to furnish engineers with basic information on soil with regard to its influence on the design, construction, and performance of concrete, soil-cement, and other types of pavement. Definitions of soil terms are given and tests commonly employed by soil technicians are described, with particular emphasis on the practical meaning and application of these terms and tests. The importance of a clear understanding of the relation of soil identification to soil classification is stressed, and the classification systems of the U.S. Department of Agriculture, the American Association of State Highway Officials (AASHO), the American Society for Testing and Materials (ASTM) and the Federal Aviation Administration are described. The engineering properties of soils (compaction, structural strength, elasticity and compressibility, permeability and capillarity) and related tests are outlined, as well as soil surveys and soil sampling. Examples are used to illustrate the engineering application of the information presented here. These examples include a soil reconnaissance survey for an airport, a detailed soil survey, sampling, testing, and classification procedure for the same airport, and the analysis of soil tests in terms of the design and performance of concrete, soil-cement, and granular-base pavements.

Reference 19
SOIL AS AN ENGINEERING MATERIAL

Holtz, Wesley G. Washington, DC: U.S. Bureau of Reclamation; 1974. 45 p. (Water Resources Technical Publication Report No. 17; stock number 2403-0091-4).

Order from: Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

This publication, which is derived from years of experience in sampling and testing materials and constructing earth dams, canals, foundations and other works, describes the forming processes of soils, the properties of soils, soil types, soil problems related to soil properties, construction control, soil sampling and testing and future research needs. The soils engineer's job is largely one of investigation to determine the physical properties of the material and the reactions of the soil mass to imposed conditions. To obtain meaningful data for the design of earth structures and foundations, consideration must be given to geological history, present conditions, construction sequences, and the anticipated operation conditions. Proper construction control procedures are important to assure that the properties assumed in the design are obtained. The complex nature of soils, the relatively short era of the science, and the increased engineering requirements indicate the need for extensive research in the future.

Reference 20
WORLDWIDE DIRECTORY OF NATIONAL EARTH-SCIENCE AGENCIES

Falk, Anne Lucas; Miller, Ralph L., comps. Washington, DC: U.S. Geological Survey; 1975. 32 p. (Geological Survey Circular 716).

Out of stock; may be consulted at U.S. Geological Survey Library, National Center, 12201 Sunrise Valley Drive, Reston, Virginia 22092.

This directory provides references to earth-science bureaus in America (North and South and Central), Europe, Africa, Asia and Australia. Thirty countries in Europe, 49 countries in Africa, and 44 countries in Asia are included. Agencies in Australia and New Zealand are also included. This directory lists only governmental institutions whose functions correspond to one or more divisions of the U.S. Geological Survey.

Reference 21
DESIGN AND CONSTRUCTION OF COMPACTED SHALE EMBANKMENTS. VOL. 1. SURVEY OF PROBLEM AREAS AND CURRENT PRACTICES

Shamburger, J.H.; Patrick, D.M.; Lutten, R.J.; U.S. Army, Waterways Experiment Station, Soils and Pavements Laboratory. Washington, DC: U.S. Federal Highway Administration, Offices of Research and Development; 1975 August. 292 p. (Report # PB253120).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

The first phase is reported of a three-phase study to develop design and construction methodologies that will enable shales causing settlements and slope failure in highway embankments in the past to be identified and used successfully in future construction. Information obtained from state and federal agencies on the extent and types of problems, possible causes, and problem formations is discussed, and current highway practices are summarized. Physical and chemical weathering of shale placed as rock fill is a primary cause of problems. Nine states do not permit shale to be placed as rock fill, and seven states allow placement as rock fill with special provisions. Corps of Engineers and Bureau of Reclamation experiences indicate that heavy compaction equipment and relatively thin lifts produce well compacted embankments having no problems. Data from 16 projects indicate that saturated compacted shale materials have low shear strengths. A review of shale composition, factors contributing to degradation, and laboratory testing emphasizes the importance of mineralogy and slake-durability characteristics. The natural variability of shales collected from formations in five geologic age groups is described.

Reference 22
DESIGN AND CONSTRUCTION OF COMPACTED SHALE EMBANKMENTS. VOL.2. EVALUATION AND REMEDIAL TREATMENT OF SHALE EMBANKMENTS

Bragg, G.H., Jr.; Zeigler, T.W.; U.S. Army, Waterways Experiment Station, Soils and Pavements Laboratory. Washington, DC: U.S. Federal Highway Administration, Offices of Research and Development; 1975 September. 235 p. (Report #PB-253121).

Order from: National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

The second phase is reported of a three-phase study to develop design and construction methodologies that will enable shales which have caused settlements and slope failure in highway embankments to be identified and used successfully in future construction. Techniques for evaluating the stability of existing embankments, and remedial treatments for distressed embankments were developed. Information obtained from State and Federal agencies and the literature was reviewed. Types and probable causes of distress, evaluation techniques, and remedial treatment measures are discussed. Evaluation techniques recommended are: instrumentation with piezometers, inclinometers, and settlement markers; undisturbed sampling and laboratory testing; in situ testing with borehole devices (Menard pressuremeter and Iowa shear test device); and back analyses of failed slopes. The primary considerations in remedial treatment should be subsurface drainage (mainly horizontal and vertical drains) and surface drainage (mainly paved ditches). Slope flattening, berms, retaining walls, cement grouting, and/or complete reconstruction should be considered in addition to drainage measures when extensive movements and/or shale deterioration have caused large reductions in shear strength. This is the second of two volumes.

Reference 23
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-267262).

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 tropical 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 pedalogical 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 24
ACQUISITION AND USE OF GEOTECHNICAL INFORMATION

Jones, Gay D., Jr. Washington, DC: Transportation Research Board; 1976. 40 p. (NCHRP Synthesis of Highway Practice 33).

Order from: Transportation Research Board, Publications Office, 2101 Constitution Avenue, N.W., Washington, DC 20418.

This report presents the results of a comprehensive review and assessment of the current practices of state highway and transportation agencies in the acquisition and use of geotechnical information in route selection, design, and construction of transportation facilities. Information is presented on such matters as planning, conducting, and presenting information from geotechnical investigations, the equipment, procedures, and selection of sampling locations for geotechnical investigations, and the structuring and positioning within the agency framework of the organization that must acquire and use geotechnical information.

Reference 25
SOILS MANUAL FOR DESIGN OF ASPHALT PAVEMENT STRUCTURES

3rd ed. The Asphalt Institute. College Park, Maryland; 1978 March. 248 p. (Manual Series No. 10).

Order from: The Asphalt Institute, Asphalt Institute Building, College Park, Maryland 20740.

This manual describes laboratory and field soil test procedures used for obtaining design information. The origin, composition and properties of soil and the significance of tests for soil materials are discussed, and a soil survey is presented because of its importance in obtaining accurate test results. The three commonly used soil classification systems and the three principal testing methods used in selecting pavement thickness are included: American Association of State Highway Officials (AASHO) Classification of Soils; Unified Soil Classification System; Federal Aviation Agency Methods of Soil and Subgrade Classification; California Bearing Ratio Method; Bearing Value Determination - Plate Bearing Test; and Hveem's Resistance Value Method. The importance and use of aerial photographs for highway location, drainage, soil studies and design are also briefly discussed. The AASHO procedures for several routine soil tests are included in an appendix.

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 may 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 or name ap-

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 el Vista General, Textos Seleccionados, o Bibliografía. Los vocablos del tema que se listean son aquellos básicos 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 están listeados como apellido seguido por las iniciales. Las organizaciones nombradas son las que han producido información sobre la materia del compendio y que siguen siendo una fuente de información sobre alguna parte o el alcance total del compendio. Por esta razón se dan las direcciones postales para cada organización listeada.

Los números que siguen a un vocablo del tema, nombre personal, o nombre de organización son los números de página del com-

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 cités 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 de personnes identifiées avec les sujets de ce recueil. Le nom de famille est suivi des initiales des prénoms. Les organisations citées sont celles qui ont écrit sur le sujet de ce recueil et qui continueront d'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 écrits en chiffres romains se rapporpears. Roman numerals refer to pages in the Overview, Arabic numerals refer to pages in the Selected Texts, and reference numbers (e.g., Ref.12) 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 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. 12) 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 compendio 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 indicadas bajo los términos que siguen a las palabras *see also*.

La explicación anterior esta subsiguientemente ilustrada.

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tent 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. 12) 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, les références qui les touchent se trouveront citées après les mots-clés qui suivent la notation *see also*.

Ces explications sont illustrées ci-dessous.