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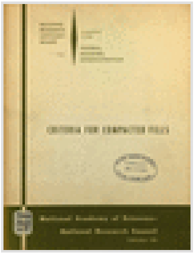

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CRITERIA

FOR

COMPACTED FILLS

Report No. 24 to the
FEDERAL HOUSING ADMINISTRATION

Prepared for the
National Academy of Sciences
by the
BUILDING RESEARCH ADVISORY BOARD
Division of Engineering and Industrial Research
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FOREWORD

The Academy-Research Council performs study, evaluation, or advisory functions through groups composed of individuals selected from academic, governmental, and industrial sources for their competence or interest in the subject under consideration. The members serve as individuals contributing their personal knowledge and judgments and not as representatives of other organizations with which they may be associated or of which they may be members.

This report represents the conclusions of the Building Research Advisory Board Special Advisory Committee on Criteria for Compacted Fills. The Committee which prepared this report is composed of recognized authorities on various technical aspects of the problem, who, at the request of the Academy-Research Council, gave freely of their time and knowledge on behalf of the advancement of building technology. The Committee's report was reviewed and approved by a review subcommittee of the Building Research Advisory Board acting for the Board.

BRAB appreciates the contribution that Committee members have made and takes this opportunity to acknowledge their efforts with gratitude. In addition, the Board thanks all who gave assistance to the Committee through either correspondence or personal contact.

Albert G. H. Dietz

ALBERT G. H. DIETZ, Chairman
Building Research Advisory Board

CONTENTS

I

INTRODUCTION

1.0 STATEMENT OF THE PROBLEM

Under a contract between the Federal Housing Administration and the National Academy of Sciences, the Building Research Advisory Board undertook a study to develop soil-compaction criteria for proposed and existing fills for single- and multi-story residential properties. This report of the results of that study treats:

a. The design and construction of proposed non-hydraulic soil fills, and the evaluation of underlying soils.

b. The evaluation of existing non-hydraulic and hydraulic soil fills, including underlying soils.

In addition, FHA requested answers to a number of specific questions; these are presented in Appendix A, p. 41.

2.0 SCOPE OF THE STUDY

This study is concerned with the problems encountered with man-made fills upon which single- or multi-family residential structures will be erected, and the effects of such fills on structure foundations, pavements and walks, utilities, and individual sewage disposal systems.

3.0 BACKGROUND

The Federal Housing Administration currently insures mortgages secured by properties where the foundations of the structures are to be supported in whole or in part on fill created to provide a site suitable for building. In order properly to protect FHA's interests, certain requirements have been established, including details of preliminary investigation, methods of construction, and slope stabilization.

It has been necessary to vary requirements in some FHA insuring offices because of local conditions and customs, but the basic requirements remain essentially the same. Presentation of engineering data to permit uniformly sound decisions on the acceptability of compacted fills, including effects of certain requirements in light of local conditions, is one purpose of this report.

4.0 AVAILABLE INFORMATION

Much is known about the engineering design and construction of earthworks. However, this kind of construction, usually for highways, airports, and dams, is relatively new to the housing industry. The fundamentals of soils engineering apply equally to all earthwork, but design details frequently differ according to whether highway or residential fills are being considered. The determinable experience, available data, and relevant published material have been utilized to formulate recommendations applicable to residential fills.

5.0 ORGANIZATION OF THE REPORT

This Section (I), Introduction, presents general information on the overall problem; Section II, Recommendations of the Special Advisory Committee, contains the specific recommendations of the Advisory Committee; and Section III, Supplementary Information, contains information intended to amplify and support the recommendations appearing in Section II.

In the Appendices are answers to the specific questions posed by FHA; technical references; and other clarifying information.

II

RECOMMENDATIONS OF THE SPECIAL ADVISORY COMMITTEE

The recommendations which follow, comprising the Committee's judgment based upon the most reliable information available, cover Site Investigation, Engineering Criteria, and Fill Placement Criteria, all for Proposed Fills; with an additional group of recommendations applicable to Existing Fills. It must be recognized, however, that there may be circumstances, not readily definable in terms of the criteria presented, which will require the engineering judgment of a qualified soils engineer[1] to provide problem solutions suited to individual site conditions.

Compacted fills for residential development sites are used most frequently in undulating or hilly terrain, to create reasonably level ground for the development and its landscape area. The most common and most serious resulting problem is interference with drainage channels of both surface and underground waters, frequently leading to a buildup of ground-water pressures in natural soils and fill, with consequent likelihood of instability and sliding. Thus, surface and underground drainage problems justify careful attention in every application of compacted fills, particularly wherever the natural terrain slopes are 10 percent or greater. The engineering studies recommended herein are intended to direct proper attention to these as well as other problems in the safe use of compacted fills.

The soil names and descriptions used are consistent with those of The Unified Soil Classification System [2] (which is used as reference throughout this report). Definitions of terms relating to soil mechanics appear in ASTM D 653-60[3]; relevant words or phrases not included in ASTM Standards are defined where they first appear in this report.

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[1] A qualified soils engineer is a graduate engineer, preferably with a graduate degree in soil mechanics and foundation engineering, properly licensed to perform engineering services in the state in which a particular project is located, with a minimum of four years' experience in engineering aspects of soil and foundation work, as defined in the resolution of the ASCE Board of Direction:

> Soil Mechanics and Foundation Engineering is defined as that branch of Civil Engineering which deals principally with soils and earth materials. As in other branches of the profession, engineering practice in this field includes evaluation of properties, analyses of behavior, economic studies, development of designs, and supervision of construction. [Reprinted from Civil Engineering December 1961 through courtesy of the American Society of Civil Engineers.]

[2] Item 15, Appendix B, p.48

[3] Item 1, Appendix B, p. 48

Recommendations

PROPOSED FILL

1.0 SITE INVESTIGATION

In order properly to evaluate a proposed fill, information about the physical conditions at the fill site is required.

1.1 General Site Information

It is recommended that the following site information be obtained in all cases:

a. Nature and origin of the natural soils.

b. Nature of potential and/or existing drainage problems.

c. Position, source, and the history of any fluctuations in ground water.

d. Types of foundation used in the general area.

e. Types of failure that have occurred in the area and the causes (include excessive building settlement, slides, and footing failures).

f. Probable thickness of fill.

g. Types of structure and foundation proposed.

1.2 Sites Which Require No Additional Investigation

It is recommended that no additional soil investigation (beyond that of 1.1 above) be required if the site presents all the following conditions:

a. Firm,[1] non-expansive existing soils.[2]

b. No evidence of ground- or surface-water problems.

c. Fill thickness not greater than 3 feet.

d. No footings or slabs supported on fill.

e. General overall fill slope of 10 percent or less.[3]

f. Only one- or two-family residential structures proposed.

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[1] Table I, p. 15

[2] In some areas, where there is a history of unfavorable soil reaction with cement or other building materials, the chemical composition of the soils will require study by a qualified soils engineer to determine the likelihood that such reaction would be critical.

[3] Page 16, and Fig. 1, p. 17

1.3 Soil Profile of the Fill Site

It is recommended that, except in the case of sites excluded by the conditions of 1.2 (above), a geologic cross-section, showing the horizontal and vertical extent and classification of soil strata, be provided by a qualified soils engineer. This will entail:

a. At least one boring to penetrate through all weak or compressible soils and at least 5 feet into rock, dense granular material, or hard clay.[1] This boring should be located where compressible material is likely to exist and should reflect conditions in the area of greatest superimposed load or thickest fill.

b. An additional boring at each building site. In the event that building sites are separated by less than 500 feet and uniform subsurface conditions are clearly indicated, borings may be spaced at intervals not greater than 500 feet in lieu of a boring for each building site. (A minimum of three borings will be needed to establish uniformity of subsurface conditions.)

c. All borings to penetrate at least 10 feet below existing grade, or at least 10 feet below final grade if in an area of cut (unless rock, dense granular soil, or non-expansive hard clay is encountered which is not underlain by weak or compressible soil), provided that the borings extend to firm soil not underlain by weak or compressible soil; no boring to stop in a compressible stratum, except when the geological cross-section is clearly established.

d. For each fill-site boring, a soil sample to be required for each 5 feet of penetration and for each different soil stratum encountered; a thin-walled sampler (ASTM D 1587-58T)[2] to be used for fine-grained soils, and the split-barrel sampler (ASTM D 1586-58T)[3] for other soils.

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[1] Appendix E , p.53

[2] ASTM Designation D 1587-58T, Tentative Method for Thin-Walled Tube Sampling of Soils, Philadelphia: American Society for Testing and Materials.

[3] ASTM Designation D 1586-58T, Tentative Method for Penetration Test and Split-Barrel Sampling of Soils, Philadelphia: ASTM

Recommendations

1.4 Laboratory Testing

It is recommended that laboratory tests be performed on samples representative of the various strata encountered in the borings, and that the following minimum information be obtained regarding the engineering properties of the fill soils and the natural soils existing at the site:

a. Visual classification of each sample by grain size and plasticity in accordance with The Unified Soil Classification System. Grain-size, liquid-limit, and plastic-limit tests on at least one sample from each stratum disclosed in the soil borings. Optimum moisture content and maximum dry density for proposed borrow material.

b. For all samples of existing fine-grained soils, water content and natural dry density.

c. Consolidation tests on at least one sample for each stratum, and for each 10 feet of depth in a particular stratum, for peat, organic clays and silts, and soft to medium clays. If the anticipated stress increase in the stratum as a result of the loads of fill and structures thereon is 2000 psf or more, then consolidation tests should be performed on stiff to very stiff inorganic clays and silts.

d. Shear strength of undisturbed representative samples of existing natural soil and suitable samples of compacted fill soil, except when the site presents all the following conditions:

   1) Firm, non-expansive existing soils.

   2) No evidence of ground- or surface-water problems.

   3) Fill thickness not greater than 10 feet.

   4) General overall fill slope of 10 percent or less.

   5) Only one- or two-family residential structures proposed.

   6) No slopes of cuts or fills steeper than 1 vertical to 2 horizontal.

   7) Clean sand (SW, SP) fill compacted to 95 percent of the maximum density obtainable in the ASTM D 1557-58T [1] test.

e. For shear strength determination, unconfined compression tests, direct shear tests, or triaxial compression tests for fine-grained soils.

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[1] ASTM Designation D 1557-58T, Tentative Methods of Test for Moisture-Density Relations of Soils Using 10-Lb Rammer and 18-In. Drop, Philadelphia: American Society for Testing and Materials.

2.0 ENGINEERING CONSIDERATIONS

To ensure adequate handling of the engineering problems of proposed compacted fills, the minimum requirements which follow are recommended.

2.1 Settlement

To cope with settlement problems of proposed structures on the fill, ultimate settlement, differential settlement, and time-rate of settlement of the fill should be determined from the results of consolidation tests on undisturbed samples of fine-grained existing soils and on suitable samples of compacted fill soils--including, wherever possible, field verification. No settlement calculations should be required when the site presents all the following conditions:

a. Firm, non-expansive existing soils.

b. No ground- or surface-water problems

c. Fill thickness not greater than 10 feet.

d. General overall fill slope of 10 percent or less.

e. Only one- or two-family residential structures proposed.

f. Compressibility of existing soils such that ultimate consolidation is less than 2 percent under a stress change from 500 to 3000 psf.

g. Proposed fill to consist of fine-grained fill soil compacted to 90 percent of the maximum dry density obtainable in the ASTM D 1557-58T test, or clean sand (SW, SP) fill compacted to 95 percent of the maximum dry density.

2.2 Shrinkage and Expansion

It is recommended that the potential for volume change of the existing soil and compacted fill soil be determined. When the existing soils or the compacted fill soils have an expansion or shrinkage potential, an engineering study should be conducted to determine necessary design and construction procedures.

2.3 Slope Stability

To prevent slope failures, it is recommended that an engineering analysis and design of fill slopes be made to provide a factor of safety against failure of 1.5 for slopes no steeper than 2:1, except that no engineering study should be required when the site presents all the following conditions:

a. Firm, non-expansive existing soils.

b. No ground- or surface-water problems.

c. Fill thickness not greater than 10 feet.

d. General overall fill slope of 10 percent or less.

e. Only one- or two-family residential structures proposed.

f. Slopes of cuts or fills not steeper than 1 vertical to 2 horizontal.

g. Fine-grained fill soil compacted to 90 percent of the maximum dry density obtainable in the ASTM D 1557-58T test, with clean sand (SW, SP) fill compacted to 95 percent of the maximum density.

2.4 Bearing Capacity

It is recommended that the allowable bearing pressure for foundations on fill be determined by an engineering study, except that no engineering study be required when the site presents all the following conditions:

a. Firm, non-expansive existing soils.

b. No ground- or surface-water problems.

c. Fill thickness not greater than 10 feet.

d. General overall fill slope of 10 percent or less.

e. Only one- or two-family residential structures proposed.

f. Fine-grained fill soil compacted to 90 percent of the maximum dry density obtainable in the ASTM D 1557-58T test, with clean sand (SW, SP) fill compacted to 95 percent of the maximum density.

2.5 Drainage and Erosion Control

It is recommended that adequate drainage and erosion control be provided; specifically, that:

a. Surface runoff be directed to streets, lined ditches, or pipes.

b. Flow of water through the ground be intercepted to prevent seepage into the fill, except when an engineering study indicates the fill can perform satisfactorily without water interception.

c. Vegetation or other appropriate cover be provided on slopes subject to erosion.

2.6 Sanitary Engineering

It is recommended that:.

a. Individual sewage disposal systems not be used, and that they be prohibited for multi-family housing.

b. If use of individual sewage disposal systems is unavoidable, on the ground that no other alternative exists, the following limitations should apply:

   1) Only clean gravel and sand (GW, GP, SW, SP) to be accepted as fill material, unless field or laboratory tests establish the acceptability of silty sands and gravels (GM, SM).

   2) Seepage fields or pits not to be used unless engineering studies indicate that liquid will not flow out of the boundaries of the fill.

   3) No portion of a seepage field to be located within 25 feet of the top of a fill slope.

   4) When a fill is 4 feet or more in thickness, a sewage absorption field to be designed on the basis of percolation tests performed on the underlying soil and on the fill material after placement.

   5) When a sewage absorption field is established in cut areas or areas with fill less than 4 feet thick, the seepage field to be designed in accordance with FHA Minimum Property Standards, including percolation tests on the natural soil.

   6) The highest probable ground-water level to be not closer than 4 feet below the surface of the fill.

   7) Wells drawing upon ground water that might be contaminated by seepage fields not to be permitted.

   8) The well head located in a fill to be continuously protected from surface water or contamination.

c. Utility lines and storm drains be so designed that anticipated settlement of the fill will not cause undesirable changes in slope of the lines, or breakage and separation.

3.0 FILL CONSTRUCTION

To assure that the fill conforms to the engineering requirements for the project, it is recommended that specifications, in addition to providing the usual items, also provide clear definition of the end results required, and that the earthwork be inspected and controlled by a qualified soils engineer, except when the site presents all the following conditions:

a. Firm, non-expansive existing soils.

b. No evidence of ground- or surface-water problems.

c. Fill thickness not greater than 3 feet.

d. No footings or slabs supported on fill.

e. General overall fill slope of 10 percent or less.

f. Only one- or two-family residential structures proposed.

EXISTING FILL

4.0 SITE INVESTIGATION

In order properly to evaluate an existing fill, information should be required concerning the physical conditions at the fill site in general, including soil profiles and determination of soil strength and compressibility.

4.1 General Site Information*

It is recommended that the following site information be obtained:

a. Nature and origin of the natural soils.

b. Nature of potential and/or existing drainage problems

c. Position, source, and history of any ground-water fluctuations.

d. Types of foundation used in the general area.

e. Types of failure that have occurred in the area, and the causes (include excessive building settlement, slides, and footing failures).

f. Probable thickness of fill.

g. Types of structure and foundation proposed

4.2 Soil Profiles of the Site

It is recommended that a geologic cross-section (soil profile) showing the horizontal and vertical extent and classification of soil strata be provided by a qualified soils engineer. This will entail:

a. At least two borings at the points of deepest fill and where the greatest superimposed load is to be applied.

b. An additional boring at each building site through the fill material. A sufficient number of these borings must be carried into the natural soils to establish the soil profile. In the event that building sites are separated by less than 200 feet and uniform subsurface conditions in the natural soil are clearly indicated, borings into the natural soil should be spaced at intervals, not greater than 200 feet.

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*Applicable before as well as after fill placement.

c. A minimum penetration for all borings into natural soils of at least 10 feet below original grade and 10 feet into firm material, or 5 feet into rock, very dense granular material[1] or hard clay.[2] Borings should be deeper if evidence indicates that these materials are underlain by weak or compressible soils. (No boring should stop in a compressible stratum unless the geologic cross-section is definitely established.)

d. For each fill-site boring, a soil sample to be required for each 2 feet of penetration in fill soils, for each 5 feet of penetration in natural soil, and for each different soil stratum encountered; a thin-walled sampler (ASTM D 1587-58T) to be used for fine-grained soils, and the split-barrel sampler (ASTM D 1586-58T) for other soils.

4.3 Laboratory Testing

It is recommended that the minimum information listed below be obtained regarding the engineering properties of samples representative of the various existing fill soils and the underlying natural soils.

a. Visual classification in accordance with The Unified Soil Classification System; grain-size, liquid-limit, and plastic-limit tests on at least one sample from each stratum disclosed in the soil borings. Optimum moisture content and maximum dry density to be reported for existing fill soils.

b. Water content and dry density for all samples of fine-grained soils.

c. Compressibliity, by consolidation tests, of the undisturbed samples of compressible soils, as described in 1.4c (p. 6).

d. Shear strength of undisturbed samples of existing fill and underlying natural soils.

e. For shear strength determination on fine-grained soils, unconfined-compression, direct-shear, or triaxial-compression tests to be used.

5.0 ENGINEERING CONSIDERATIONS

The recommendations in 2.0, p. 7 et seq, are considered appropriate for and applicable to existing as well as proposed fills.

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[1] As defined in Appendix F, p. 54

[2] As defined in Appendix E, p. 53

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III

SUPPLEMENTARY INFORMATION

There are numerous problems associated with man-made fills, particularly with fills supporting residential structures. In this report are presented means of recognizing potential problems at a site, procedures for improving the site, and minimum criteria by which the site can be evaluated for acceptance.

This Section (III), contains a discussion of the many aspects of man-made fills, and detailed information necessary to complement the Committee's recommendations. Each subject considered important to the design and construction of proposed soil fills, or the evaluation of existing soil fills, is treated, in the following sequence:

> Several site characteristics are identified as permitting separation of sites likely to cause few, if any, fill-construction problems, from those which must be examined more thoroughly or avoided entirely.
>
> The need for soil investigation and the required extent of such investigation are discussed in terms of conditions which may exist on the site. Reconnaissance, soil borings and samples, and laboratory tests are covered in some detail.
>
> Details of the criteria required to avoid or to treat engineering problems of settlement, slope failure, bearing-capacity failure, excessive seepage due to sewage absorption fields, and the like are discussed. The criteria for natural soils and existing man-made fills are consistent with those recommended for proposed fills. (Wherever a particular criterion is adequate to deal with only a single problem, whereas an alternative would effectively handle several problems, the latter is preferable and has been offered.)
>
> In the discussion are included the special requirements of site investigation in the presence of existing fills. The engineering considerations for existing fills are identical with those for proposed fills; therefore, reference is made to the appropriate section of the report, with no further discussion.

To clarify and supplement this report, examples of soils engineering calculations are included by reference to the literature. Excellent references on foundation engineering are the books authored by D.W. Taylor, Terzaghi and Peck, and G. Tschebotarioff.[1] In this report, examples of soils engineering are presented by reference to the book by Terzaghi and Peck. There are, of course, other publica-

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[1] Items 12, 13, and 14, Appendix B, p. 48

tions on soil mechanics which could equally well be used as a guide to necessary calculations.

The possible structures to be placed on fills have been, for purposes of this report, classified as one- or two-family residential structures of masonry or frame construction, as against structures of heavier construction or larger size.

1.0 SITE INVESTIGATION

The site investigation should provide information on the physical condition of the site. The extent of the investigation required depends upon the thickness of the fill, the proposed structure, and the soil, hydrologic water, and topographic conditions at the site.

For many of the site characteristics having particular significance as indicators of likely problems and of their extent, information is obtainable from a preliminary site investigation, including review of details of the proposed development. Such preliminary information may subsequently be supplemented by the results of a detailed soil investigation.

Such an investigation may require field studies, involving soil borings and sampling, laboratory tests, and analysis of all relevant information including the test results. A report should be prepared containing the data collected and presenting conclusions and recommendations.

Among significant considerations are: Character of existing soil; surface- and ground-water conditions; thickness of proposed fill; nature of foundation support— natural soil or fill; overall slope of completed fill; and type of proposed structures on the fill. These characteristics and the potential problems associated with them are discussed below.

With the character of the existing soil as the first salient matter for consideration, Table 1, p.15, has been prepared, listing, on the basis of The Unified Soil Classification System[1] those soils considered as firm—i.e., natural soils which are unlikely to contribute to potential problems, such as settlement or shear failure. Such "firm" soils normally have a design bearing pressure of at least 2000 psf—including a reasonable factor of safety—which is sufficient for the relatively lightly loaded footings typical of one- or two-family residences.

Should the soil at the site—natural or fill material—have more than a low expansion potential, there is likelihood of damage to light structures and pavements due to shrinkage or swelling; in such situations, an engineering study is required.

[1] Item 15, Appendix B , p. 48

TABLE I

DESCRIPTION OF FIRM SOILS

Soil Name	Soil Classification	Required Density, or Consistency [1]
Gravels or sand-gravel mixtures, little or no fines	GW, GP	All densities
Gravels or gravel-sand mixtures, with clay or silt	GM, GC	Medium-dense to dense
Sands with little or no fines	SW, SP	Medium-dense to dense
Silty or clayey sands	SM, SC	Medium-dense to dense
Silty or clayey fine sands	ML	Medium-dense to dense
Inorganic silts	ML, MH	Medium-dense to dense
Inorganic and silty clays of low to medium plasticity	CL	Stiff to hard

[1] For definition see Appendix E, p. 53, and Appendix F, p. 54

The significance of surface- and ground-water conditions lies in their ability to influence slope stability, soil expansion, bearing capacity, performance of subsurface sewage absorption systems, and frost action. If evidence of springs, seepage areas, flooding of part of the site, or similar water conditions is apparent from any site or soil investigation, recommendations for the provision of drainage and fill design should be based on an engineering study.

Thickness and areal extent of fill provide an indication of the magnitude of load and consequently of the problems potentially involved with compressibility in the existing soil and the fill itself. The nature of the foundation support also helps to determine the extent of the problems anticipated. When slabs or footings are supported on firm natural ground, some of the problems of fill construction are eliminated, such as differential settlements due to non-uniformity of fill, or shrinkage and expansion of expansive fill soils.

Supplementary Information

The overall slope of the completed fill is an indicator of potential for movement of large soil masses. The general overall fill slope is defined as either (1) the slope of a line connecting the line of contact of the natural ground surface at the uphill end of the fill with a point on the line of contact of the natural ground surface at the toe of the fill (Fig. 1, p.17); or (2) the flattest slope of a line connecting a point on the highest-level bench to a point on the lowest-level bench—whichever is the steeper. Provided that the slopes are underlain by firm non-expansive soils, a general overall fill slope of 10 percent (1 vertical: 10 horizontal) is considered a suitable dividing line between non-critical and potentially critical sloping sites. The latter may give rise to such problems as slides, and consequently require soil investigation and design recommendations based on engineering studies.

1.1 Preliminary Site Investigation

A preliminary site investigation (reconnaissance) is useful to provide general information about the site without the significant expense of a soil-boring and -sampling program. Also, this preliminary information can be used to judge the need for, extent of, and perhaps location of soil borings. Reconnaissance of the site should provide the following information:

a. Nature and origin of the existing natural soils.

b. Nature of existing and potential drainage problems.

c. Position, source, and history of any ground-water fluctuations.

d. Types of foundation used in the general area.

e. Types of failure that have occurred in the area and the causes (include excessive building settlement, slides, and footing failures).

As a first step, the site should be given a thorough examination including observation of nearby structures for evaluation of the types of foundation previously used, and examination of evidence of apparent settlement or expansion (such as cracks in walls or pavements). The site examination should also note the topography, including: Probable thickness of fill; indications of recent (active) and ancient slide areas; drainage patterns; ground roughness and slope; erosion possibilities; flooding potential; and possible dangers to or from adjacent properties.

A review of information on the design and performance of existing foundations should be made. Such information is often available from city building departments or from the local FHA office.

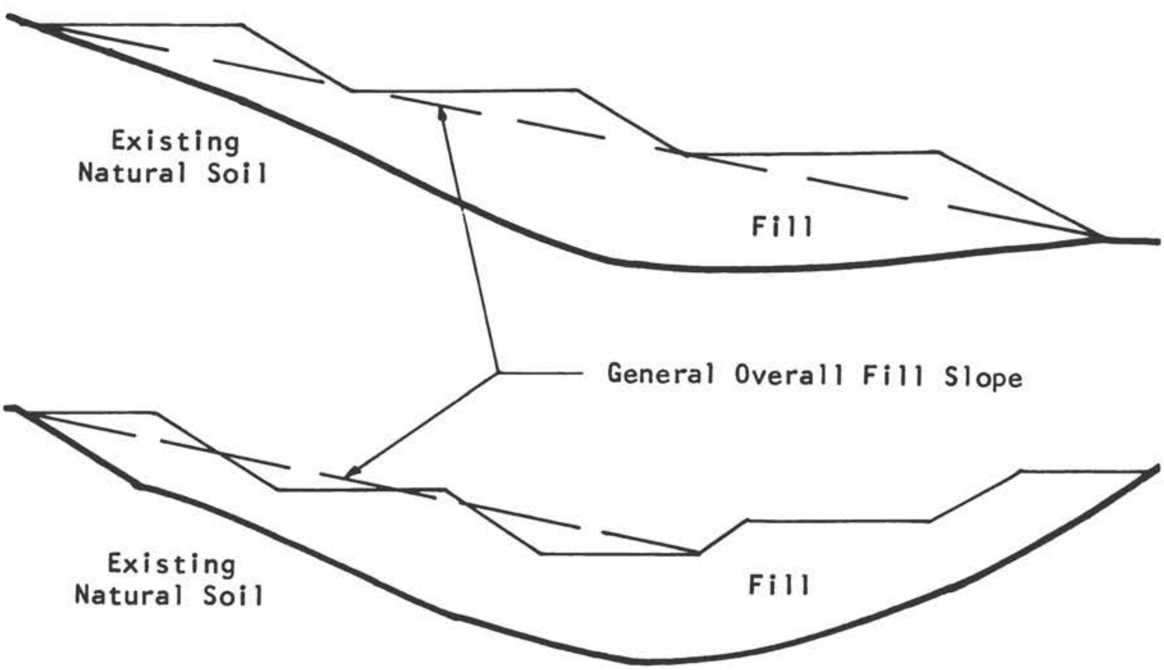

Fig. 1 DETERMINATION OF GENERAL OVERALL FILL SLOPE

Geologic, pedologic, and airphoto maps of the area should be examined for the nature, origin, and distribution of soil types, for ground- and surface-water information, and for drainage patterns and general topography. The location of springs and other seepage zones are of importance. Indications of deposits of compressible or weak materials, or of potentially unstable slope conditions—such as the presence of slickensided or fault-gouged materials, unfavorably inclined formations, or seams of weak soils—should be noted, since these conditions require a complete soil investigation, including borings, undisturbed sampling, and laboratory testing.

The preliminary site investigation will provide information which permits development of a reasonable program of subsurface soil sampling for further investigation; it also can guide the developer in his choice of building sites and project designs.

1.2 Soil Investigation

No additional soil investigation is required when the preliminary site investigation clearly indicates the site has natural soils consisting of firm non-expansive material,[1] evidences no ground- or surface-water problems such as springs or flooded areas, does not involve a fill thickness greater than 3 feet, has or will have no footings or slabs supported on the fill, has or will have a general overall fill slope of not more than 10 percent, and will have only one- or two-family residential structures located on the fill. For all sites with any condition other than those listed, there should be a soil investigation, since the potential exists for failure (by settlement, sliding, etc.).

Soil investigation procedures cannot be standardized; the detailed field investigation will vary with conditions. The boring-and-sampling program should provide reliable information on the vertical and horizontal variations in the subsoils. Active or potential slide areas, seepage areas, deposits of soft or loose soil, and other potential trouble spots should be given particular attention in planning boring-and-sampling locations. Maximum use should be made of the preliminary site investigation, of airphoto maps, and of geologic and pedologic maps in selecting optimum boring locations, so that all soil types and formations are covered, with particular caution to include both high and low topographic areas.

When a soil investigation is required because of conditions indicating potential problems, there should be at least one boring at the site, at the point of deepest fill or where the greatest superimposed load is to be applied. There should also

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[1] As defined in Table I, p.15

be an additional boring at each building site, except that when building sites are separated by less than 500 feet and uniform subsurface conditions are clearly indicated, borings may be placed at intervals not greater than 500 feet in lieu of a boring at each building site. Additional borings and other investigations (probings) should be used to define the strata in soil profiles of the site, with particular attention given to weak or compressible soils. This work should be done under the supervision of a qualified soils engineer. Soils which may be considered weak or compressible include peat, organic clays and silts, soft to medium inorganic clay and silt, and granular soils for which 6 or fewer blows are required per foot of penetration in the ASTM D 1586-58T[1] test procedure. Even stiff or very stiff inorganic clays may be considered compressible when the fill and structure loads increase the stress in a stratum of such soil by 2000 psf or more.

To assure an adequate investigation, at least one boring should penetrate through all weak or compressible soils such as organic clays and silts (OL, OH), soft inorganic clays and silts (ML, MH, CL, CH), and loose sands, to rock or very dense hard soil. This deep boring should be one of the first made, should be located where compressible material is likely to exist, and should reflect conditions in the area of heaviest loads. This will permit evaluation of the deeper soils and the need for additional deep borings.

All borings should penetrate at least 10 feet below existing grade, or 10 feet below final grade if in an area of cut, unless rock, very dense granular soil, or very hard clay is encountered, with sufficient evidence that such soil is not underlain by weak or compressible soil; provided that the borings also extend to firm soil[2] not underlain by weak or compressible soil. No boring should stop in a compressible stratum, except when the geological cross-section (soil profile) is clearly established.

For each boring, a soil sample is required for each 5 feet of penetration and for each different soil stratum encountered. To limit sample disturbance, a thin-walled sampler (ASTM D 1587-58T)[3] should be used for fine-grained soils; however, the split-barrel sampler (ASTM D 1586-58T) can be used for other soils.

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[1] ASTM Designation D 1586-58T, Tentative Method for Penetration Test and Split-Barrel Sampling of Soils, Philadelphia: American Society for Testing and Materials.

[2] As defined in Table I, p. 15

[3] ASTM Designation D 1587-58T, Tentative Method for Thin-Walled Sampling of Soils, Philadelphia: ASTM. Also Appendix D, p. 51

These minimum sampling requirements are intended to provide sufficient information from a borehole to evaluate the underlying soils. When evidence clearly indicates that fewer samples and penetration tests can define the soil strata, it should be within the soils engineer's discretion to direct that fewer samples be taken and fewer penetration tests be performed.

The results of soil sampling should be included on boring logs, with soils classified according to The Unified Soil Classification System. The logs should include the results of standard penetration tests (ASTM D 1586-58T) as well as results of any laboratory tests.

1.3 Laboratory Testing

Upon completion of the field investigation, a qualified soils engineer should examine the soil samples and plan the laboratory testing program, the magnitude of which will depend upon the types and variety of soils encountered. For all fine-grained soils, the water content and natural dry density should be determined. The strength of fine-grained soils can best be determined by use of the unconfined-compression test, direct-shear test, or triaxial-compression test. For peat (PT), organic silt and clay (OL, OH), and soft to medium inorganic or silty clays (CL, CH), consolidation tests should be performed on representative samples. Where the proposed increment of load on the formation is 2000 psf or greater, consolidation tests should be performed on inorganic clays (CL, CH) of even stiff to very stiff consistency, since significant settlement can occur in such soils when the stress increase in the stratum is of this magnitude.

In addition to the above minimum requirements, tests on representative samples of each stratum encountered should be performed to aid in classifying the soil under the Unified Soil Classification System. Classification tests which may be useful are grain-size analysis, liquid-limit tests, and plastic-limit tests. Additional laboratory tests may be required, depending on the findings from the field investigation. Specific additional required tests are recommended as necessary in a subsequent section of this report under Engineering Criteria. Some of the laboratory tests frequently required or useful are listed in Appendix C, p. 49

2.0 ENGINEERING CONSIDERATIONS

To ensure design of a fill adequate for a particular project, special consideration should be given to such soils engineering problems as volume change, slope stability, bearing capacity, drainage (including the effect of seepage fields, and surface- and ground-water flow), and slope erosion. Except under nearly ideal conditions, the variables involved with respect to soil characteristics such as compressibility, strength, and optimum moisture content, coupled with the wide variation in possible site characteristic combinations, preclude standardization of engineering criteria for compacted fills. Except when conditions virtually preclude the likelihood of problems, each fill will require specific evaluation by a qualified soils engineer in order to assure successful performance over the long term. For example, the results of compressibility and strength tests, when evaluated in light of the need to limit volume change, may require fill placement at other than optimum moisture content.

The requirements for compaction of the fill are specified as a percentage of the maximum density obtainable in the ASTM D 1557-58T test procedure. Although some engineering organizations use relative density for the control of fills constructed with free-draining sand and gravel soils (GW, GP, SW, SP), no standard procedure is at present widely used, and there is no wide background of experience based on any such test procedure. The American Society for Testing and Materials is currently evaluating a suggested method of test for relative density of soils. When a standard test procedure is established and becomes widely accepted, it would be practicable for FHA to convert to this method for non-plastic granular soils.

2.1 Settlement

Soil movement can result from compression or consolidation due to load application; shrinkage due to drying; and expansion due to moisture absorption. In some less common cases, old fills and natural deposits may experience a loss of volume due to leaching action or decomposition of organic materials. Frost action, common in certain areas, also produces a volume change problem. The tolerable limits of vertical movement caused by volume change depend upon the type of structure, types of utility line and joint, types of utility connection into the structure, and the design slope of sanitary and drain lines. The most common problems are those that involve differential movements. Most residential structures can withstand small differential settlements; it should be the obligation of the engineer responsible for the design of the structure, or for the design of the sanitary and utility lines, to comply with established tolerable settlement limits, or, in the absence of such established limits, to indicate what movement can be tolerated together with the basis for his recommendations.

Compressibility characteristics of the compacted fill and underlying natural soil should ensure that the settlement (total and differential, including effects of fill and natural ground) of the fill and structure thereon does not exceed the capability of the structure and utility lines to tolerate the resulting potential displacement. The important settlement is that which occurs after construction of the structures and utility lines. The Committee believes that only limited settlement of a fill surface (and probably of light structures on the fill) will occur if the fill is uniformly well compacted, of limited thickness, and possessing no characteristics contributing to potential problems. The combined effect of structure and fill loading—for fills up to 10 feet in thickness—is expected to produce differential settlement or swelling movement of a fill surface not exceeding either a smooth-curved hump or sag of 1 inch in 50 feet, or a uniform slope of 2 inches in 50 feet, provided that all the following conditions are fulfilled:

a. The natural underlying soils at the site are firm and nonexpansive.

b. No ground- or surface-water problems, such as springs or flooded areas, exist at the site.

c. The fill thickness is not greater than 10 feet.

d. The general overall fill slope is 10 percent or less.

e. Only one- or two-family residential structures are to be constructed on the fill.

f. The ultimate compressibility of the natural underlying soils is such that they are not subject to a compression strain of more than 2 percent under a stress change of 500 to 3000 psf.

g. For fills of fine-grained soils, the fill is compacted to a dry density at least 90 percent of the maximum obtainable in the ASTM D 1557-58T[1] test; for fill of cohesionless sands (SW, SP), densities of 95 percent of maximum are readily obtainable and are required to eliminate undesirable deformations.

For sites with conditions other than those above, potential problems such as settlement or slides may occur; therefore, thorough engineering study is required. This includes situations where fills are thicker than 10 feet; the proposed fill density is less than the 90 percent recommended for fine-grained soils above; the site has drainage problems; expansive soils or compressible soils underlie the proposed fill; the general overall fill slope is greater than 10 percent; or there are similar variations from the conditions outlined above. The engineering study should include consolidation tests on suitable samples of both compacted fill soil and the undisturbed natural underlying soils; it should result in recommended degrees of compaction for the

[1] ASTM Designation D 1557-58T, Tentative Methods of Test for Moisture-Density Relations of Soils, Using 10 Lb Rammer and 18-In. Drop, Philadelphia: American Society for Testing and Materials.

fill, evaluation of the time-rate of settlement of the fill and natural soils, and of the anticipated settlements for the conditions involved. The settlement and its time-rate for structure foundations and the fill surface can be determined from calculations of the change in stress in the soil mass and its accompanying compression.[1]

When a building site is partly on fill and partly on natural soil, differential movements may be critical. For sites that have natural soil consisting of firm non-expansive materials, with no evidence of ground- or surface-water problems, with fill thickness not greater than 10 feet, overall fill slope of less than 10 percent, and only one- or two-family residential structures proposed for construction on the fill, the differential settlement of a building site partly on fill and partly on existing soil should not exceed that detailed previously, provided that the fill has been placed to a density at least 90 percent (95 percent for clean sand, SW or SP) of the maximum density obtainable in the ASTM D 1557-58T test, since the fill and existing soils will have like strength and compressibility. In areas of expansive soils, no structures can be placed partly on cut and partly on fill. On other soil types, structures can be placed partly on cut and partly on fill, provided that the natural undisturbed soil and the compacted fill have similar characteristics and that a thorough engineering study justifies the design.

When the total settlements and differential settlements are expected to exceed the tolerable limits specified for the structure, an analysis should be made, including evaluation of the time-rate of settlement, to provide suitable design and construction procedures. In the case of natural soils and existing fills, the degree of consolidation of the soil and the time-rate of settlement can be determined by conventional soils engineering calculations.[2] In some cases, a satisfactory degree of consolidation may already exist in soil at the site; that is, the settlement which may occur after initiation of structural construction on the fill is less than the structure can tolerate, and therefore no settlement problem will exist. At other sites, the consolidation under existing loads may be progressing at a sufficiently rapid rate so that no settlement problem exists, since again the settlement that remains after the start of construction of buildings on the fill is not excessive for the structure involved. Data from observation of piezometors or settlement plates may be used in addition to engineering studies in ascertaining the progress of consolidation of fill areas. In some cases the consolidation of the fill,

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[1] Articles 13, 35, 36, and 41, Item 13, Appendix B, p. 48

[2] Item 13, Appendix B, p. 48

and/or underlying natural soil, proceeds at a rate too slow for construction to be practicable; then, surcharging with high fills, use of sand drains to expedite consolidation, or a combination of such special construction techniques may be used, so that differential movements in a structure after the start of its construction will be kept within tolerable limits.

No undesirable settlement of sidewalks and roadways is anticipated when the entire fill is compacted to at least 90 percent of the maximum density obtainable in the ASTM D 1557-58T test. To prevent settlement of the walks, steps, and driveways adjacent to structures or traversing utility trenches, the backfill around structures or in trenches should be placed in layers and compacted with suitable mechanical tamping equipment to a uniform density, not less than that specified for the general area fill.

2.2 Shrinkage and Expansion

Shrinkage or expansion of soils is usually of significance only near the ground surface, where changes in moisture-content occur and where a differential movement of structures and utility lines will result. Such movement can occur only with expansive soils, and only when there is an opportunity for soil-moisture change.

The factors which effect the magnitude of volume change (shrinkage and expansion) in an expansive clay include: The amount and type of clay mineral, initial density, change in moisture, load conditions, soil structure, and time. The recognition of potentially expansive soil and the conditions for change of soil moisture which combine to create an expansion potential is a major problem. An estimate may be made of the expansive potential of a soil from knowledge of the plasticity index and clay content. Table II, p. 25, provides information generally applicable. The fourth column of Table II presents the volume change probably under the most severe conditions, as data are based on change from an air-dry to saturated condition under low surcharge load. The last column of Table II includes an allowance for the moisture present in natural soils.

Expansion and shrinkage problems will not be significant where the compacted fill and the underlying soil have a plasticity index less than 10, or contain less than 5 percent of material finer than the 0.002-mm size. Soils that cannot be clearly identified as non-expansive by the above criteria, or by falling within the "low" category of Table II, require additional engineering studies and tests to determine the degree of volume change which may occur. One method of determination is a volume-change test[1] on compacted samples of the fill soil and on un-

[1] Appendix C, p. 49

disturbed samples of the underlying natural soils. The engineering study should develop design and construction provisions which will determine whether and how specific soils may be utilized in the particular project.

There has also been development work by FHA on a swell-index device,[1] designated Potential Volume Change Meter, which permits recognition of some expansive soils. A rating system, called Potential Volume Change (PVC), has been developed. The swell-index device, in addition to yielding PVC values, can be used to estimate the plasticity index and the expansion and shrinkage behavior of some soils. Limited use to date indicates the device is helpful.

TABLE II

DATA FOR MAKING ESTIMATES OF PROBABLE VOLUME CHANGES FOR EXPANSIVE MATERIALS

Data from Index Tests*			Probable Expansion** and Total Volume Change (Dry to Saturated Condition) (Percent)	Degree of Expansion
Colloid Content (Percent Minus 0.001 mm)	Plasticity Index	Shrinkage Limit (Percent)		
28	35	11	30	Very high
20-31	25-41	7-12	20-30	High
13-23	15-28	10-16	10-20	Medium
15	18	15	10	Low

After Holtz

*All three index tests should be considered in estimating expansive properties.

**Based on a vertical loading of 1.0 lb per sq. in.

The expansion potential is greater for a dense than for a loose clay because more particles are included per unit of volume. The expansion process can occur only when an expansive soil receives a critical amount of additional moisture. Water is often supplied by sources other than rainfall—e.g., action of lawn sprinklers. In addition, moisture accumulation under covered areas, such as concrete floor slabs, can induce excessive swelling of the soil even in an area of continuous dry climate. The effect of climate is most important in working

[1] Item 6, Appendix B, p. 48

with expansive soils, since moisture content, density, and consistency will vary with the season, especially near the surface. The amount of expansion of a compacted soil depends on the surcharge pressure resisting expansion. If sufficient external load is applied, the expansion pressure developed in a clay may be balanced and expansion forestalled. Lesser loads will permit some expansion to occur, with maximum expansion under zero loading.

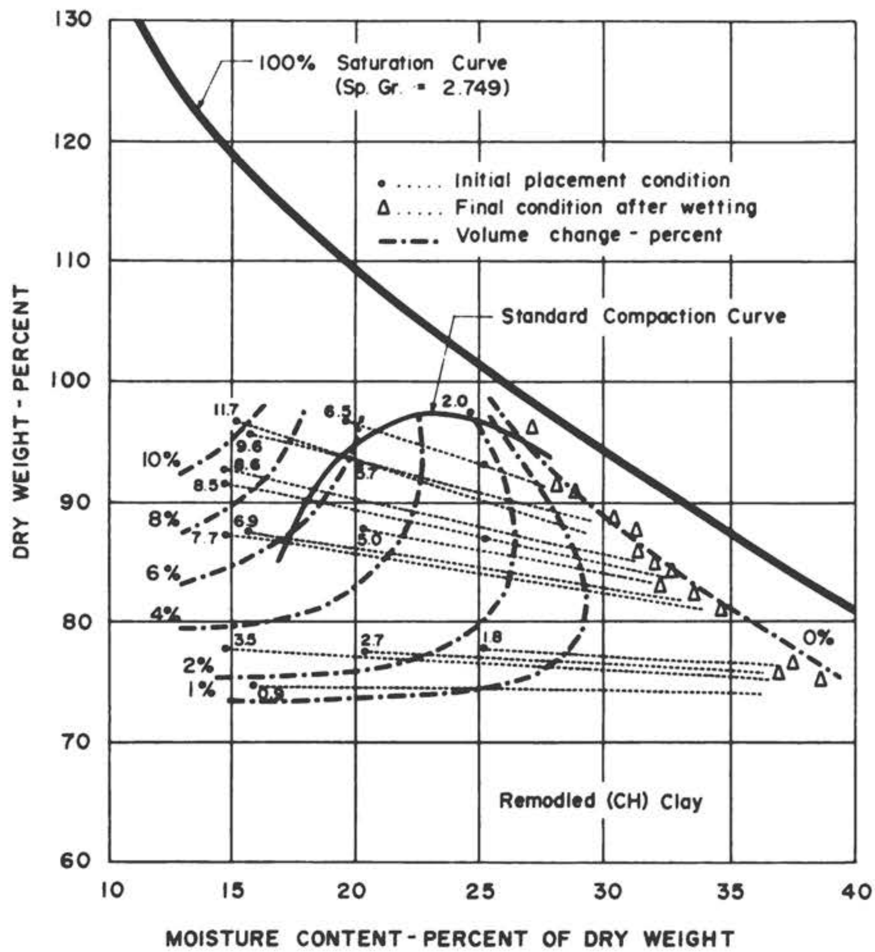

Fig. 2 PERCENTAGE OF EXPANSION FOR VARIOUS PLACEMENT CONDITIONS WHEN UNDER UNIT PSI LOAD (after Holtz and Gibbs).

The above figure, shows the influence of density and moisture on the expansion of a compacted expansive clay under unit psi loading. It can be seen that these soils expand very little when compacted to low density at high moisture content, but much more when compacted to high density at low moisture content. The swell pressures developed by a clay soil are affected in a similar manner by density and moisture.

Several methods can be used to counteract the difficulties presented for construction on expansive soils. The most suitable method can be determined only by the soils engineer making the study, and may entail a combination of techniques. Covering expansive soils with non-expansive materials can limit expansion to a tolerable amount. In some cases, a removal of the expansive soil to a suitable depth, and replacement with non-expansive soil (to limit moisture change effects or to provide surcharge pressure),is the best solution. Drainage procedures to control moisture changes in the fill and subsoils may also be used to limit expansion.

Compaction of expansive soil at relatively high water content (at or above the "optimum" water content in the ASTM D 1557-58T test) often eliminates detrimental volume changes should soil moisture content increase after construction. Consideration must be given to the fact, that the higher the water content at placement, the greater is the potential volume change due to shrinkage. It is advisable to compromise between placement water content producing low swell and that producing low shrinkage. This condition is usually approximated by the water content corresponding to a degree of saturation of about 85 percent in the compacted soil. Another procedure the soil engineer may recommend to limit expansion is placement of the fill soil at a low density. When a fill is being constructed in expansive soils at densities lower than 90 percent of the maximum obtainable in the ASTM D 1557-58T test, settlement should be computed by use of procedures recommended in Appendix B, reference 12, based on consolidation tests performed on samples prepared at placement water content.

When it is not possible economically to treat expansive soils so as to use shallow spread footings, a practical solution is the use of a pier foundation, with the structure between the piers supported by beams (normally of reinforced concrete and tied to the foundation piers with reinforcing steel). The piers should, by design, penetrate to a depth providing adequate support below the expansive material, without tendency to lift out of the ground through swelling of the expansive surface soil. The beams should be designed so that swelling of the soils beneath does not tend to lift the beams off the piers or to pull the piers out of the ground.

Fill placement procedures for expansive soil are no different from the procedures generally used and outlined in 3.0, p. 33. One specific requirement is accurate control of water content to limit shrinkage or swelling problems; consequently, climatic conditions can be troublesome during construction.

2.3 Slope Stability

In designing and constructing slopes, the shear strength of soils, the presence of surfaces of weakness, and the control of ground and surface water, which may cause undesirable seepage pressures or reduce the shear strength of soil, are all of importance. In some cases, catastrophic failure may occur because of a slide. The failure may pass through the fill only, through both the fill and the underlying soil or rock, or along the contact surface between the fill and the natural soil.

The stability of a slope depends on the minimum strength of the soil that may be expected during its useful life. It is necessary to consider the strength of the fill and underlying soil (1) during and immediately after construction; and (2) over the long term, when all changes in water content and density have taken place regardless of cause. The effect of possible changes in ground-water conditions must be considered. Even at constant water content, strength decrease in cohesive soils may result from increased pore-water pressure due to compression under superimposed loads. The Committee believes that for fills of limited thickness placed on relatively flat, strong, and dry sites, the problem potential associated with slope stability is significantly reduced. Specific limiting conditions are required to justify such confidence, e.g., no slope stability problems will exist if the fill is placed on relatively level sites underlain by firm soils; if there are no ground- or surface-water problems such as springs or flooded areas; if the fill thickness is not greater than 10 feet; if the general overall fill slope is 10 percent or less; if slopes of cuts or fill are not steeper than 1 vertical to 2 horizontal; and if only one- or two-family residential structures are to be constructed on the fill.

All sites with cuts or fills higher than 10 feet, weak sub-soil conditions, or other features different from those described in the paragraph above, require soils engineering studies. The studies should include a stability analysis using the results of laboratory tests on suitable undisturbed soil samples as well as on compacted samples of the fill soil. Consideration should be given to the strength of the fill and underlying soils under all service and construction conditions, analysis of driving forces, evaluation of resistance to sliding of the earth mass, effect of seepage forces, and design of appropriate drainage elements.[1] A factor of safety against failure of at least 1.50 should be provided, considering all possibilities of loading and potential changes in soil and ground-water conditions during both construction and the life of the fill and structures thereon. The factor of safety is required to allow for possible un-

[1] See Articles 31 and 41, Item 13, Appendix B, p.48

anticipated variations in loading and soil properties; for inaccuracies in the methods of analysis; and for many unknown factors in the behavior of soils and in environmental conditions.

Some general statements on strength of compacted soils are pertinent. The strength of clays as compacted is related to the water content: The strength is low for water content above optimum, increases rapidly near the optimum water content, and continues to increase slightly for water content on the dry side of optimum, even though the dry density is decreasing. Change in soil water content after compaction may affect the soil strength and must also be considered. The strength of compacted cohesionless soil is essentially independent of water content, provided there are no changes in effective pressures within the soil mass (as might occur with a rise in ground-water level). However, in cohesive soils, an increase in water content will cause a decrease in strength, with conditions at placement of the compacted cohesive soil influencing the amount of strength loss. Soils placed at water content above optimum show small loss of strength if saturated after placement; if placement water content is near optimum, a somewhat larger loss in strength occurs; when placement water content is below optimum and the compacted soil is subsequently saturated, a large loss in strength occurs. The strength loss in expansive soils, for both the natural and the compacted state, is particularly large with increases in water content.

2.4 Bearing Capacity

The strength of the compacted fill soil as well as the soil underlying the fill must be considered in evaluating bearing capacity, so that bearing failure of footings or mat foundations under structures can be avoided.

In general, the bearing pressures imposed by one- and two-family residential structures on conventional foundations are less than 2000 psf. For fills composed of inorganic soils, the bearing capacity stated above (2000 psf) will be provided if the fill is placed in accordance with the density and compaction requirements described earlier (90 percent compaction for fine-grained soil, 95 percent for sand) and if the underlying soil is firm as defined in Table I, p. 15. Local experience records may be helpful in estimating the design capacity of natural soils at the site.

For site and soil conditions other than those listed in the second paragraph of 2.1, p. 21, evaluation of the bearing strength of the soil requires an engineering study utilizing the results of laboratory strength tests on suitable undisturbed samples of natural soil and appropriately prepared compacted-soil samples.

The Terzaghi bearing-capacity equations and charts[1] will be found useful. A factor of safety against failure of about 3.0 should be provided to allow for possible unanticipated variations in loadings and soil properties. Plate bearing tests[2] may also be utilized to evaluate the bearing properties of the fill and natural soils; however, these tests provide information on the bearing capacity of the soil to a very shallow depth, and the test results are not directly usable in predicting either long-term settlement or stability of slopes.

2.5 Drainage and Erosion Control

In order to ensure the adequate drainage and erosion control necessary for slope stability and maintenance, surface drainage should be positive, to prevent ponding of water, cutting, fissuring, or erosion, surface run-off should be directed to the street or a lined drainage ditch (Fig. 3, p. 31). No water should run over the slopes except the rain which falls on them. Where seepage from higher ground is expected to soak down into or pass through a proposed fill, a thorough engineering study to evaluate the consequences of such seepage should be made. Provision should be made to intercept the flow with drainage ditches, unless the engineering study gives assurance that ground- or surface-water passage through the fill will not result in weakening of the fill sufficient to cause excessive settlement or slope failure. The effect of ground- and surface-water flow on the strength of a fill is of greater consequence for cohesive soils than for granular soils. The engineering criteria presented in 2.3, p. 28, should be satisfied under all conditions of change in water content and seepage pressures.

Ground-water conditions and the permeability of the fill are of particular importance when seepage fields are to be used. Possible reduction of soil strength which reduces slope stability is one problem; another is the adverse effect on adjacent property due to lateral flow of seepage from subsurface absorption fields if a pervious fill is placed on impervious natural soil. This problem is discussed in more detail in 2.6, p. 31.

Vegetative or other appropriate cover should be provided on slopes subject to erosion. The surface soils should be selected and prepared where landscape planting is proposed for erosion control. The experience of state highway departments and county and city agencies in planting for erosion control should be

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[1] ASTM Designation D 1194-57, Standard Method of Test for Bearing Capacity of Soil for Static Load on Spread Footings, Philadelphia: American Society for Testing and Materials. Article 54, Item 13, Appendix B, p. 48.

[2] Article 29, Item 13, Appendix B, p. 48

utilized, particularly data on the types of plant suitable to serve the purpose of erosion control. The planting should obviously be consistent with the soil and climatic conditions at the site in order to assure permanent or long-term growth.

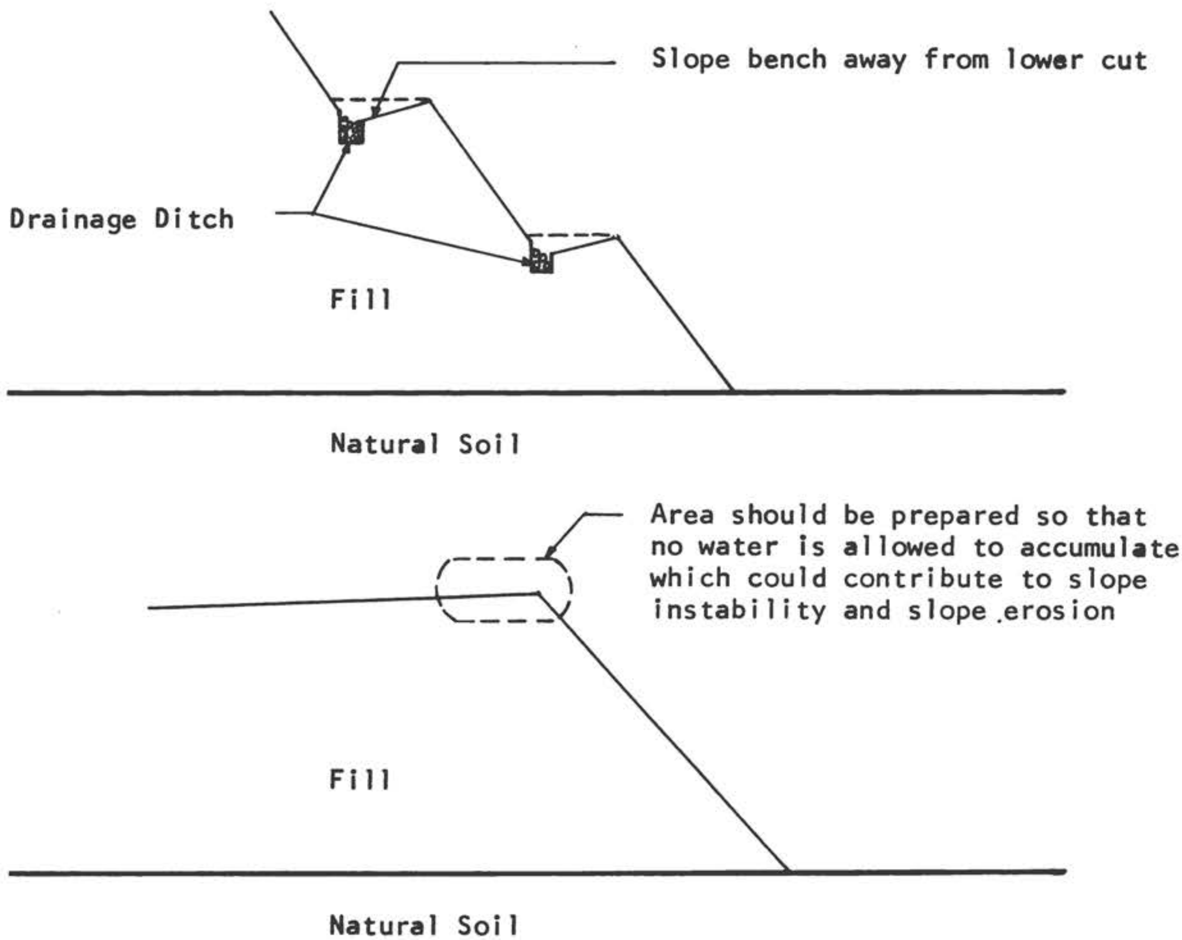

Fig. 3. POSSIBLE DRAINAGE METHODS FOR EROSION CONTROL

2.6 Sanitary Engineering Aspects

Utilization of individual sewage disposal systems should be prohibited for multi-family housing and should be considered for single-family housing only after the impracticability of public or community sewerage facilities is established. When use of such individual systems is unavoidable, both the fill and the facilities should be designed and constructed in accordance with the criteria stated in this report. Also, the Minimum Property Standards of FHA for such facilities (in other than filled areas) should be satisfied.

Individual Sanitary Facilities

Special attention should be given to problems of ground slope, subsurface flow of liquid, and distance separation of individual sanitary facilities; the large volume of sewage (about 150,000 gallons per house per year) disposed of into the fill may cause serious problems if not properly provided for. Absorption fields or pits should not be utilized where liquid will adversely affect the structural stability of the fill, cause unacceptable expansion of soils, or flow out at the boundaries of the fill. No portion of a seepage field should be located within 25 feet of the top of a fill slope.

Seepage pits should not be utilized unless sufficient area of suitable soil (per MPS[1] requirements) exists beneath the fill. The seepage pit should be built into the soil beneath the fill and walled off within the fill. This should protect against undesirable seepage and contamination through the fill.

Normally, individual sewage-disposal facilities utilizing subsurface absorption fields in fill should be used only when clean gravels and sands (GW, GP, SW, and SP) comprise the fill material. However, if test or field data demonstrate that silty sands and gravels (GM and SM) will perform adequately, they may also be used. Use of other soils in such fills could cause unsatisfactory performance of the seepage field, as may be revealed by erratic values of percolation rate. With clean gravels and sand, the percolation characteristics will be relatively uniform and will permit design in accordance with FHA Minimum Property Standards. The type of soil to be used and criteria for its placement should be contained in the specifications.

Percolation tests should be performed on the fill material after placement in the fill. The design of the absorption field should be based upon the percolation rate obtained, with a minimum acceptable percolation rate of 1 inch per 30 minutes. For an absorption field to be established in fill, there should be at least 4 feet of fill, with percolation tests performed in natural soil as well as fill, and design should be based on the lowest rate obtained. For absorption fields in cut areas or areas with fill less than 4 feet thick, the absorption field should be designed in accordance with FHA Minimum Property Standards, including percolation tests on the natural soil.

A high ground-water level can seriously limit the adequate functioning of subsurface absorption fields; consequently, the probable water level should be at least 4 feet below the ground surface for proper performance. The site grading and sewerage facilities should be so designed that a seasonal rise in the water-table does not bring it closer to the surface than 4 feet.

[1] Item 4, Appendix B, p. 48.

Differential movements due to volume change of the soil may cause changes in elevation of utility lines, resulting in rupture of lines or undesirable changes in slope. The initial alignment and slope of gravity-flow lines (for example, from septic-tank outlet to seepage-field inlet) should be designed to ensure satisfactory performance even after anticipated settlement occurs. Special joints, as well as special cradling, bridging, or extra-strength pipe, may be required for water or sewer lines constructed in fills subject to differential movements. Applicable data on volume-change problems are discussed in 2.2, pp. 24-27. The tolerable differential movements for septic tanks and seepage-pit structures should be considered when applying volume-change criteria. In general, the procedures and requirements concerning differential movements are the same as those required for unfilled sites of similar nature.

Individual Water-Supply Systems

Current distance-separation criteria for locating wells in relation to sources of pollution may not be adequate for wells constructed in fills, since the studies of this problem have been made on virgin soil, whereas compaction of a fill may provide more serious conditions for pollution. Therefore, wells drawing upon ground water that might be contaminated by sewage effluent should not be permitted in filled areas. Wells constructed in filled areas should be cased and adequately grouted into an impervious layer (rock or clay) above the aquifier drawn upon. Provision should be made to ensure that settlement of the fill around the well does not displace the well structures or the seal, pump, and take-off facilities at the well head. The well head should be continuously protected from surface wash or contamination.

3.0 FILL CONSTRUCTION

Adequate specifications are necessary to assure that the fill conforms to the engineering criteria for the project. Sites with natural soils of firm non-expansive material, with no evidence of ground- or surface-water problems, with fill thickness not greater than 3 feet, with no footings or slabs supported on fill, with the overall fill slope not over 10 percent, and with only one- or two-family residential structures proposed, do not require inspection during fill placement but do require specifications to define the quality of fill required.

For all sites other than those meeting the conditions above, progress of the work should be inspected and controlled by a qualified soils engineer to ensure compliance with the specifications. Where there are few potential problems, as in sites with all the conditions in the paragraph above except that the fill may be up to 10 feet thick with foundations supported on fill, field inspection by subprofessional technicians under the direction of the soils engineer is feasible if only the performance of specified tests and observation of procedures is needed. It is recognized that the soils engineer will visit the job site regularly. The inspection and control responsibilities of the soils engineer include recognition of conditions disclosed during construction that were not previously anticipated, and the initiation of procedures to deal with such new conditions; for example, discovery of lenses of soft or loose soil, or a seam of weak clay may require a revised design.

The soils engineer has the responsibility for verifying and reporting whether or not the fill and site conforms to the specifications for the project. In detail, this includes recommending approval of: Site preparation before placement of any fill; drainage methods employed during and after construction; materials for use as fill; placement and compaction of the fill to ensure a specified end product. The specifications should thoroughly cover all the above items.[1]

3.1 Site Preparation

Site preparation is for the purpose of providing a support for the fill consistent with the engineering design and assumptions. Unsuitable material such as logs, stumps, and major roots attached thereto, and soft, compressible, loose, or organic soils should be located and removed; otherwise, unexpected or localized settlement of the fill and structures thereon may occur. On some projects where fill is to be placed over marsh areas, support for construction equipment can only be provided if the marsh grass is not removed prior to fill placement; but compressible material must be considered in making settlement calculations.

3.2 Drainage

The soils engineer should ascertain that all surface and ground water is carried through the site by permanent or temporary drains, as shown on the engineering design drawings, or diverted during construction by a method that will not channel water over embankments and thereby cause objectionable erosion.

3.3 Fill Material

For all sites that require inspection during fill placement (3.0, p. 33), only fill material approved by a qualified soils engineer should be used. This is to assure that the engineering criteria for the project are satisfied by use of fill soil con-

[1] Appendix G, p. 55, presents a typical check list for specifications for placement of compacted fills.

sistent with the conditions under which the fill will function. The materials used should not contain brush, roots, sod, frozen lumps, rubbish, or other deleterious substance. No rocks or lumps with a dimension greater than the compacted thickness of the layer in which it is placed should be permitted. If only occasional rocks are present in the fill material, the largest dimension should be no greater than 6 inches; but if more than 10 percent by weight of the fill material consists of rocks, the maximum size permitted should be about 3 inches. Such limitation permits uniform compaction of the layers.

In the special case where acceptable fill material is available, but where large quantities of rocks 6 inches or greater in dimension must be disposed of economically, practice has demonstrated that such larger-sized rock material can be included in a fill successfully if placed under continuous supervision and strict control. Specifically, the rock must be laid in windrows with the normal compacted earth fill brought up along either side; granular soils are then flooded, jetted, and occasionally vibrated into the voids. The tops of the windrows must be kept at least 10 feet below finished grade to avoid future excavation problems.

In the use of man made materials, such as slag, for construction of fills, inert materials should comply with specifications for naturally occurring soils of similar type. However, when active ingredients are present, such as calcium oxide or iron sulfide, use should be permitted only if the materials satisfy a critical evaluation by a qualified person (engineer or chemist). The contractor should expose sufficient area of the borrow site to permit an accurate determination of the extent and character of the fill material. Samples should be carefully selected to be representative of the borrow site. Laboratory tests, such as grain-size determination, Atterberg limit, compaction, strength, and swelling should be performed as needed for the engineer to determine acceptability of the soil.

3.4 Fill Placement

The approved fill material should be placed in accordance with the specifications and in such manner that the fill will perform satisfactorily. For uniformity of compaction, the fill material should be spread evenly and blade-mixed in approximately horizontal layers of not more than 9 inches of uncompacted thickness. Then the layer should be uniformly compacted to the specified density with a sufficient number of passes of suitable equipment.

When the borrow is variable or comes from several sources, the soils engineer should report the degree of compaction from a compaction test for material similar to that for which the field density determination is made.

At the time of compaction, the material in each layer of fill should have a moisture content near the optimum value for compaction, or, alternatively, a value specified by the soils engineer to obtain the required fill density and quality.

Ponding or jetting of fills should not be permitted except with coarse-grained materials containing less than 2 percent of material finer than the #200 mesh sieve (GW, GP, SW, SP), and then only when the water can be drained downward through the fill to a relatively low water table.

During cold weather, attendance by the soils engineer may be required to control fill placement. Additional lifts of fill may be placed on compacted fill which has been frozen, provided it has not suffered a loss of density. Satisfactory densities cannot be obtained in compacting soil which is frozen at the time of compaction.

3.5 Inspection and Control

The need for engineering supervision during fill placement depends on such factors as rate of placement, characteristics of fill material, topography of fill site, and climatic conditions. Topography with slopes of more than 1 vertical to 3 horizontal, or with gullies and ditches,for example, requires continuous inspection during fill placement. The soils engineer or an inspector under his supervision should be present at the site during placement of each lift; the rate of fill placement will dictate the continuity of inspection and the need for attendance by the soils engineer. Here the concern is to assure and verify that the fill is placed uniformly to the density required by the engineering design as stated in the specifications.

The number of required fill-density determinations on compacted layers depends upon the uniformity of the operation and the uniformity of the results obtained. The measurement of the density of soil in place can be made by sand-cone[1] or similar methods. Although nuclear methods of determining moisture and density have not yet entered ASTM standards, nuclear procedures can be considered suitable for the purpose if, on any individual project, results are correlated with those obtained by ASTM D 1556-58T. The nuclear methods can be particularly useful in granular soils where sand-cone tests are difficult.

[1] ASTM Designation D 1556-58T, Tentative Method of Test for Density of Soil in Place by the Sand-Cone Method, Philadelphia: American Society for Testing and Materials.

The minimum number of field density determinations for areal fills should be determined by the soils engineer; an average may be one for about each 50,000 sq. ft. or less of 9-inch uncompacted lift thickness, provided that at least three tests are performed on a fill site. More density tests should be taken in critical areas, such as ravines or building areas, than would be otherwise required, with at least three tests per lift.

Density tests should be performed in trenches during backfilling at intervals not greater than 200 feet in each layer, in order to assure uniformity with fill. A final report should be compiled at the completion of the earthwork. The report should include the results of all field and laboratory tests, all fill-density determinations, descriptions of procedures and equipment used by the contractor, descriptions of unusual occurrences and conditions, and the conclusions of the engineer regarding the adequacy of the fill. On large projects, interim reports may be required.

4.0 EXISTING FILLS

A widely varying risk is involved in any method of evaluating an existing fill, since the extent of site preparation, the procedures used in fill placement, and the uniformity of the operation are usually unknown. Without engineering records, a thorough soil investigation is essential in evaluating any existing fill; the underlying material needs study from the standpoint of both stability and potential settlement. Since the original terrain is no longer visible, the soil investigation should be considerably more comprehensive than one made before the fill is placed. An existing fill should never be accepted unless the results of a comprehensive investigation made by a qualified soils engineer indicate adequacy for the project. Such fills should be evaluated in accordance with the engineering considerations for proposed fills presented in 2.0, pp. 20-33 *et seq.*

4.1 Site Investigation

When an existing fill is to be utilized, the first step in the investigation should be a preliminary site investigation as detailed in 1.1, p. 16. In addition, all existent engineering records pertaining to the construction of the fill and investigation of the original site should be located and studied—particularly any site investigation comparable to that detailed in 1.1 and 1.2, pp. 16-20 . The records should include data on compaction characteristics for the fill soils used and the recommended degree of compaction for the fills. The quality of inspection and control should be evaluated partly through the completeness of the records. Engineering judgment is required to determine what additional investigation and tests are needed to ascertain whether the fill will satisfy the requirements of the project.

The detailed method of investigating the quality of an existing fill will vary with the material involved and the findings during the course of the investigation. The sampling techniques will be much the same as those for evaluating a fill in the process of placement or for investigating the site of a proposed fill. The most direct investigation would be the digging of test pits and performing of field density tests at various depths. For adequate examination by this method, considerable destruction of the fill is necessary; therefore, it is reasonable to utilize boring-and-sampling operations, with considered judgment applied to the results of the borings and samplings.

As a minimum requirement, soil borings in the fill should be made at each building site. A sufficient number of these borings must be carried into the natural soils to establish the soil profile. In the event that building sites are separated by less than 200 feet and uniform subsurface conditions in the natural soil are clearly indicated, borings into the natural soil should be spaced at intervals not greater than 200 feet. In-place density should be determined at 2-foot intervals in the fill material. Results of compaction tests (ASTM D 1557-58T) on the fill soil should be utilized to evaluate a fill in terms of the percent of compaction, which should be listed on the boring logs. Where weak or compressible soils, such as organic clay and silts (OL, OH), or soft to medium inorganic clays and silts (ML, MH, CL, CH), are encountered, consolidation tests should be performed as for proposed fills (1.2, p. 18). For fine-grained soils the soil classification and results of laboratory tests should be included on the boring logs; for coarse-grained soils, the result of standard penetration tests (ASTM D 1586-58T), results of laboratory tests, and the soil classification should be included on the boring logs.

Other requirements of 1.1 and 1.2, pp. 16-20 , also apply to the investigation of existing fills. It should be emphasized that in the preliminary site investigation particular attention should be given to any evidence of the existence of creeks or sloughs in the area. If the terrain is rough, including steep slopes, stream beds, and the like, it should be ascertained whether proper site preparation has been performed and whether drainage systems were needed and have been installed. Additional evaluation problems arise when the existing fill is located adjacent to a bay or river, because of the likelihood of a high water table and possible erosion due to wave action. It is necessary to determine whether required riprap has been placed along the edge of the fill and also whether the elevation of the fill is sufficient to prevent flooding under present or likely future circumstances.

4.2 Engineering Considerations

The engineering considerations presented in 2.0, pp. 20-33, *et seq.* are considered appropriate and adequate for the evaluation of existing fills, since the engineering problems of proposed and existing fills are alike once the fill is in place.

APPENDIX A

ANSWERS TO SPECIFIC QUESTIONS POSED BY FHA

In this appendix are included answers to specific questions developed by FHA. These answers are excerpts from the more complete information of Section III, Supplementary Information, and should be used only for general guidance.

1. What sampling and testing methods, either field, laboratory, or both, are appropriate and reasonable for evaluation of controlled and uncontrolled soil fills and fill materials? For example, compaction requirements for controlled fills are 90 percent of maximum density in accordance with AASHO Test No. T99-49 Modified. Is this a practical degree of compaction to use for housing development? Under what conditions (depth of fill, soil characteristics, etc.), should other standard test methods that give lesser degree of density be used?

   a. Compaction requirements should be stated as a percentage of the maximum dry density obtainable in the ASTM D 1557-58T test.

   b. The density of the fill soil in place can be determined by any one of a number of widely used procedures, such as the sand-cone method (ASTM D 1556-58T), rubber-baloon method, the drive-cylinder method, or the nuclear method.

   c. For other appropriate tests, see 4.3 p. 11, see also pp. 18-33.

2. What realistic compaction (maximum density) requirements can be made for widely divergent soil materials such as a (CH clay), as compared to an open sand (SW)? Can these requirements be geared to a specific soil classification system such as the Unified?

   a. <u>The Unified Soil Classification System</u> can be used to describe fill soils, but varying degrees of compaction for many different soils are not realistic, unless thorough engineering studies are performed which clearly indicate the feasibility of such practice. Such studies will require consideration of many factors which are interdependent and do not lend themselves to simple categorization.

   b. Only for certain site conditions, as set forth in 2.0, pp.20-33 can specific compaction requirements be stated; normally for clean sand fill (SW, SP), 95 percent of the maximum dry density obtainable in the ASTM D 1557-58T test, and 90 percent for all other fine-grained, non-expansive fill soils.

   c. For sites on which expansive soils are to be used as fill, a somewhat lower density than the 90 percent recommended in the text for all soils except SP and SW might be so high as to result in some expansion and deformation in the structures. Therefore, reduced densities for expansive soils may be required by the qualified soils engineer.

3. Sometimes field density tests of the compaction of each layer of fill are required by the developer's engineer. Should further requirements be made for the horizontal spacing of field density tests in regard to area covered? If so, what would be required?

   a. At least three field density tests should be performed for each 9-inch uncompacted-fill lift thickness, and for each site requiring inspection, provided that no one test be considered adequate for an area in excess of 50,000 square feet.

   b. More field density tests should be made in critical areas, such as ravines and building areas, than are required in the general overall area.

4. What is recommended as the maximum depth of layers in placing fill for various materials and placement methods?

   The uncompacted thickness of a lift of fill should not exceed 9 inches unless a field test section is used to demonstrate satisfactorily that a greater thickness can be used and still obtain the quality of fill and density specified.

5. Should the maximum size of rock be specified for placing in fills? If so, what size is recommended?

   a. No rocks or lumps with a dimension greater than the compacted thickness of the layer in which it is placed should be permitted.

   b. If only occasional rocks are present in the fill material, the largest dimension should be less than 6 inches; but if more than 10 percent by weight of the fill material consists of rocks, the maximum size permitted should be about 3 inches.

6. Should the developer's engineer supervise grading construction continuously, or is an inspection of the project once or twice daily sufficient?

   a. During fill placement the need for continuous attendance of the soils engineer depends on many factors, including topography and rate of fill placement. Continuous supervision is generally advisable, except when rate of fill placement is slow.

   b. When the existing topography includes slopes of more than 1 vertical to 3 horizontal, with gullies or ditches present, continuous inspection is required during fill placement.

   c. The soils engineer or an inspector under his supervision should be present during the placement of each lift.

d. When the borrow material varies, continuous inspection is required in order to assure that field density obtained correlates with the appropriate laboratory test results and the compaction specified for each of the various materials.

e. Prior to placement of any fill material, careful inspection of all initial stripping and of drainage provisions is required. This inspection can usually form the basis for establishing the need for and extent of construction supervision.

7. What variations of specifications for soil fill are needed where slag material is used for fill?

   a. When slag material is used for construction of fills, inert materials should comply with specifications for naturally occurring soils of similar type.

   b. When active ingredients, such as calcium oxide or iron sulfide, are present, the slag material cannot be used unless a critical evaluation by a qualified engineer or chemist assures the suitability of the material.

8. What variation from [field] optimum moisture content should be allowable in field compaction for various soil types including expansive soil?

   At the time of compaction, the material in each layer of fill should have a moisture content slightly below the optimum value for field compaction, or, alternatively, a value specified by the soils engineer to obtain the required quality and density of fill. For example, the engineer may require placement at water content above field optimum, to guard against expansion.

9. What specific methods of construction of fills should be established for general use in expansive soils in order to create suitable building sites?

   It is not possible to specify all of the techniques available for construction of satisfactory fills of expansive soils. However, some of the more commonly used procedures follow.

   a. Drainage procedures to control moisture changes in the fill and subsoils may be used to limit expansion.

   b. The covering of expansive soils with non-expansive materials can limit expansion to a tolerable amount.

   c. Removal of expansive soil to a suitable depth (which limits moisture changes or provides surcharge pressure) and replacement with non-expansive soil can be used.

d. Compaction of expansive fill soil at relatively high water content will limit volume changes should soil moisture increase after fill construction. Possible shrinkage problems should be considered.

e. The fill soil may be placed at a low density to limit expansion. The compressibility of the fill should be considered to ensure against unacceptable settlements.

10. Should different methods of construction of fills be used, dependent upon the degree of expansion?

A soils engineer should recommend the appropriate method of fill construction in the presence of expansive soils. The methods in 9 (above) may be used singly or in combination, or other methods may be suitable. No particular method can be specified universally for a particular degree of potential expansion.

11. Can highly expansive soils be placed in the lower parts of the fill, or must they be eliminated in creating fills for residential developments? If placed in the lower parts, what minimum distance below the finished surface is satisfactory? What depth of courses would be satisfactory? How should they be constructed?

a. The answer to Question 9 (above) indicates that expansive material can be placed in a fill.

b. Fill placement procedures for expansive soils are outlined in answer to Questions 8, 9, and 10.

c. Expansive soils can be placed in the lower parts of a fill, provided the thickness of non-expansive material overlying it is sufficient to prevent volume change in the expansive soil under all probable changes in moisture content.

12. For what range of fill depths and under what foundation construction designs should soil compaction requirements be established?

a. Criteria for soil investigation, engineering of the fill, and fill placement are required for all fills, except when the site has all the following characteristics:

1) Firm, non-expansive existing soils.
2) No evidence of ground- or surface-water problems.
3) Fill thickness not greater than 3 feet.
4) No footings or slabs supported on fill.
5) Overall fill slope of 10 percent or less.
6) Only one- or two-family residential structures proposed on the fill.

b. For sites with fills up to 10 feet thick, with firm, non-expansive existing soil, with no water problems, with overall slope less than 10 percent, and with only one- or two-family residential structures proposed, minimum criteria are provided in this report. For all sites that do not have all the above characteristics, specific recommendations can be made only on the basis of an engineering study.

13. What test procedures are necessary to determine acceptability of individual sewage disposal systems in fills with various soil-compaction characteristics?

a. Percolation tests (as described in the FHA Minimum Property Standards) should be performed on the underlying soil and fill material after placement in the fill. The design of the sewage absorption field should be based upon the poorest percolation rate obtained.

b. For sewage absorption fields in cut areas, or areas with fill less than 4 feet thick, the absorption field should be designed in accordance with FHA Minimum Property Standards, including percolation tests on the natural soil.

14. What control methods are needed to prevent stratification harmful to individual sewage disposal systems?

a. Sewage absorption fields should be used only when clean gravels and sands (GW, GP, SW, and SP; also SM or GM soils when percolation tests demonstrate their acceptability) are used as fill material, so that stratification in the fill is not a problem. Even thin layers of less pervious materials should not be permitted.

b. When fill is less than 4 feet thick, the percolation rate of the underlying soil will govern the design of a subsurface sewage absorption field.

15. What test and control methods are needed to prevent harmful differential settlement of utility lines and appurtenances or foundations in compacted fills?

a. The total and differential settlements and time-rate should be determined by a soils engineer for all sites except when the site has all the following characteristics:

1) Firm, non-expansive existing soils.
2) No ground- or surface-water problems.
3) Fill thickness not greater than 10 feet.
4) Overall fill slope of 10 percent or less.
5) Only one- or two-family residential structures on the fill.
6) Compressibility of existing natural soils of less than 2 percent under a stress change from 500 to 3,000 psf.

7) Fine-grained fill soil compacted to 90 percent of the maximum dry density obtainable in the ASTM D 1557-58T test, with clean sand (SW, SP) fill compacted to 95 per cent of the maximum dry density.

b. The engineer responsible for the design of the structures or the design of the sanitary and storm drains and utility lines should ensure that design conforms to established limits; or, in the absence of such limits, should define tolerable movements.

16. Under what conditions can a structure be placed partly on fill and partly on cut or natural ground without harmful differential settlement?

Only when the compacted fill and natural existing soil have comparable compressibility characteristics and similar expansion or shrinkage potential.

17. What investigations and tests are needed to determine whether existing filled ground and the original undisturbed ground under the fill are beyond any reasonable doubt equal to what would have been obtained had the fill been placed under proper engineering controls?

a. There should be a preliminary site investigation including a review of all engineering records pertaining to construction of the fill, to obtain the following information:

1) Nature and origin of the natural soils.
2) Nature of potential drainage problems.
3) Position, source, and the history of any fluctuations in ground water.
4) Types of foundation used in the general area.
5) Types of failure that have occurred in the area and the causes (include excessive building settlement, slides, and footing failures).
6) Probable thickness of fill.
7) Type of sturctures and foundations proposed.

b. At least one boring should be performed through the fill material at each building site. A sufficient number of these borings must be carried into the natural soils to establish the soil profile. In the event that building sites are separated by less than 200 feet and uniform subsurface conditions in the natural soil are clearly indicated, borings into the natural soil should be spaced at intervals not greater than 200 feet.

c. An existing fill should not be accepted unless the results of a comprehensive engineering study assures acceptable performance.

18. What criteria or engineering tests are necessary to determine suitability of existing fills and natural soil on which the fill is placed for use as individual sewage absorption systems?

    The same requirements apply as for Question 13 above.

19. What tests and criteria are needed to determine the possible adverse effects of disposal of septic-tank effluent in filled soil?

    When septic-tank effluent or other fluids pass into fill soils, there is a possibility of significant changes in the engineering properties of the soil. For example, from increased moisture there may possibly be a decrease in shear strength, and possibly a volume change due to expansion of fine-grained soils. The soils engineer should consider all consequences of such seepage into the fill.

20. What other considerations should be given to existing fills to determine suitability for residential developments?

    Existing fills should be evaluated on the basis of the criteria for proposed fills.

APPENDIX B

TECHNICAL REFERENCES

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APPENDIX C

METHODS OF SOIL SAMPLING AND TESTING

(See "ASTM Standards" and "Procedures for Testing Soils," ASTM, April 1962.)

1.0 SAMPLING METHODS

1. Split-Barrel Sampling - ASTM D1586-58T
2. Thin-Walled Tube Sampling - ASTM D1587-58T
3. Sampling by Auger Borings - ASTM D1452-56T
4. Core Drilling for Site Investigation - ASTM D2113-62T
5. Others (includes Bulk Sampling)

2.0 LABORATORY TESTING METHODS

1. Classification Tests

   a. Grain-Size Analysis - ASTM D422-54T
   b. Liquid Limit - ASTM D423-59T
   c. Plastic Limit - ASTM D424-59T
   d. Water-Content Determination by Oven-Drying at 105° C. ASTM D423-59T

2. Strength Tests

   a. Unconfined Compression Strength
   b. Triaxial Compression Strength
   c. Direct Shear Strength

3. Compressibility and Volume Change

   a. Consolidation of Soils (Reference 2, Appendix B)
   b. Volume Change of Soils
   c. Swell Index Test - using device developed by Lambe for FHA

4. Miscellaneous

   a. Moisture-Density Relations of Soils-ASTM D1557-58T (Modified Compaction Test)
   b. Permeability
   c. Organic Content
   d. Relative Density of Cohesionless Soils

3.0 FIELD TESTING METHODS

1. Density Determination

   a. Sand-Cone Method - ASTM D1556-58T
   b. Rubber-Balloon Method
   c. Nuclear Density Probe
   d. Drive-Cylinder Method

2. Moisture Determination

    a. Oven-Drying at 105°
    b. Nuclear Moisture Probe
    c. Quick Field Methods (pan frying, alcohol, etc.)

3. Plate Bearing Tests - ASTM D1194-57
4. Percolation Tests for Seepage Fields (Reference 4, Appendix B.)
5. Vane Shear Test for Determination of In-situ Strength
6. Settlement Plates (for observation of the effects of consolidating layers)

APPENDIX D
SOIL SAMPLING

Soil sampling involves two operations: First, advancing of the hole and, second, recovery of the sample. The hole can be advanced by any of a number of techniques; a brief description of general procedures (with relevant specific examples) may indicate the conditions of appropriateness.

"Dry" methods of advancing a hole include augering and the use of bucket rigs. These are generally suitable when the hole will stand open without casing and are usually satisfactory above the water table. Augered holes are usually, but not necessarily, of small diameter (6 inches or less) and are relatively economical. Bucket rigs drill holes from 12 to 36 inches in diameter and are frequently used where the strata encountered are subject to visual inspection.

"Wet" methods include the use of wash borings and rotary drilling. These procedures utilize water to flush out cuttings, and are generally applicable where drilling extends well below the ground-water table and casings are used to maintain the hole. Wet methods should be used with care with soils subject to change of characteristics upon the addition of moisture—for example, loess—making sure that samples are taken in undisturbed soil ahead of the boring or drilling bit.

A third type of procedure for advancing a hole is "coring". This technique is used to recover continuous samples, usually of rock.

Although the primary purpose of advancing a hole is—emphatically—to reach a lower depth in order to obtain a representative or undisturbed sample, information of value in interpreting overall test results is frequently obtained in the process of advancing the hole. Therefore, all observations and occurrences during the field work must be recorded. For example, a loss of wash water in a boring may be of minor consequence to the drill crew but of vital importance to the engineer who later interprets the results of the exploration. The material recovered while advancing the hole with wet techniques is usually of little value. On the other hand, the dry methods, particularly the use of large-diameter bucket rigs, can yield disturbed samples of some value. Bucket rigs provide a good opportunity for visual examination of fairly large quantities of representative soil samples as the hole is advanced. Coring is a unique method in which the undisturbed sample is recovered at the same time as the hole is advanced. Whatever the method of sampling, the observations and comments of an experienced drilling crew and field engineer are invaluable.

After the hole is advanced to the desired depth and loose material removed, relatively undisturbed samples of the soil can be recovered. There are many ways of accomplishing sample recovery. The amount of disturbance of the sample is generally greater when the simpler methods are used and less with the more difficult and expensive methods. Fairly stiff clays, and other soils which are not particularly susceptible to loss of strength after sample disturbance, can be sampled by the simpler methods. Soft clays, and other soils which show a large loss of strength when disturbed, should be recovered by methods which cause the least disturbance, even though such methods may be slow and expensive. Granular soils present special problems in sample recovery, but in many cases undisturbed samples are not necessary in such soils.

The disturbance of a sample results from several factors, an important one being the amount of material displaced by the wall of the sampler (A thorough study of the subject is contained in "Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes" by M. Juul Hvorslev, Corps of Engineers, Waterways Experiment Station, November, 1949.)

One of the simpler devices for recovering relatively undisturbed samples consists of a hollow steel casing with a tapered end. A typical sampler of this type (sometimes referred to as a "spoon") has an inside diameter of 1-3/8 inches and an outside diameter of 2 inches. Thin brass liners are occasionally placed inside the steel casing. The sampler is pushed or driven into the soil and then pulled out with soil filling the hollow casings. If a liner is used, the liner containing the soil samples can be capped and sealed to prevent moisture change until tested, or the soil can be placed in tightly-capped jars. An example of this type is the split-barrel sampler, in ASTM method D-1586-58T; the split barrel (outside casing) allows easy removal of the soil, or of liners containing the soil samples.

To reduce sample disturbance, different techniques may be used. The most common approach is to increase the sample diameter and reduce the amount of soil displaced by utilizing thinner-walled samplers with tapered cutting edges. A typical example of a more refined sampling technique for use in soft soils is the Shelby tube method. A thin-walled tubing, often 3 inches or more in diameter, is pushed into the soil, then pulled out with the soil sample inside the tube, and the tube is sealed at each end. For testing, the sample may be extruded from the tube or the tube itself cut away. The latter method generally results in less sample disturbance. The thickness of Shelby tube samplers is only a fraction of an inch (see ASTM D-1587-58T). The Dennison sampler, fixed-piston samplers, and the Swedish Foil sampler provide excellent samples but are more complicated and more expensive than the Shelby tube. As a result, they are generally used only for comprehensive investigations for large and expensive structures.

Among other techniques that may be used in the field investigation, one of the most important is the use of test pits. In this method a pit into which a man can descend is dug into the ground; the soil can be examined, and an excellent undisturbed sample cut from the side or bottom of the pit. The vane shear test can be used to evaluate the <u>in-situ</u> strength of soft clays.

APPENDIX E

CONSISTENCY OF UNDISTURBED COHESIVE SOILS

Consistency	q_u (tsf)[1]	Field Guide
Very soft	0.25	Core (Height = twice diameter) sags under own weight
Soft	0.25 - 0.50	Can be pinched in two between thumb and forefinger
Medium	0.50 - 1.00	Can be imprinted easily with fingers
Stiff	1.00 - 2.00	Can be imprinted with considerable pressure from fingers
Very stiff	2.00 - 4.00	Can barely be imprinted by pressure from fingers
Hard	4.00	Cannot be imprinted by fingers

[1] q_u is unconfined compressive strength in tons/square foot.

Note: The field guides are only an indication of the consistency of soils as described in the left-hand column. The values of q_u, unconfined compressive strength, are given as the basic values of consistency by which field-guide classification can be verified. The values obtained from the field guide must not be used for design without laboratory verification. Unconfined compressive strength is not synonymous with ultimate bearing capacity.

APPENDIX F

RELATIVE DENSITY OF COHESIONLESS SOILS

Term	Field Guide [2]	Blows [1] per Foot
Very loose	---	0 - 4
Loose	Easily penetrated with 1/2-inch reinforcing rod pushed by hand	5 - 10
Medium	Easily penetrated with 1/2-inch reinforcing rod driven with 5-pound hammer	11 - 30
Dense	Penetrated a foot with 1/2-inch reinforcing rod driven with 5-pound hammer	31 - 50
Very dense	Penetrated only a few inches with a 1/2-inch reinforcing rod driven with 5-pound hammer	Over 50

[1] Blows as measured with 2-inch OD, 1-3/8-inch ID sampler driven 1 foot by 140-pound hammer falling 30 inches. See tentative Method for Penetration Test and Split-Barrel Sampling of Soils, ASTM Designation: D1586-58T. It should be borne in mind that the number of blows per foot required at any given depth is influenced not only by the density of the soil, but also, by its gradation (coarseness), the depth, the elevation of the water table above the point at which the measurement is taken, and the weight of the drill rod.

[2] The field-guide column is given merely as an example of one of numerous simple field procedures that are in current use for indicating density. Many other procedures are equally good, and this column is not intended to establish a preferred method. The results of the penetration test, as shown in blows per foot, are widely accepted as a standard for the terms shown.

APPENDIX G

CHECK LIST FOR SPECIFICATIONS FOR PLACEMENT OF COMPACTED FILLS

1.0 GENERAL

Compacted fills are to be placed at the site as shown on Drawings ________, attached to and made a part of these specifications.

The work includes clearing, grubbing, and stripping of the site, removal and disposal of unsuitable material, drainage during and after construction, supplying suitable fill material obtained either from the site or from the contractor's borrow pit, and the compacting of the fill material into place, all as shown and noted in these specifications and on the Drawings.

The inspection and acceptance of all work under this specification is by the architect and the designated soils engineer. The architect and the soils engineer shall have access to the work at all times.

2.0 WORK INCLUDED

The work to be done under this specification includes the following items:

1. Clearing the site of trees, shrubs and other growth, debris, etc., as shown on the Drawings.

2. Stripping topsoil and other compressible or unsuitable material below the existing grade, as shown on the Drawings and as directed by the architect or soils engineer.

3. Subsequent to stripping, making at least one pass over the stripped area with a heavy pneumatic-tired roller, to detect any soft spots.

4. Additional stripping in all soft areas revealed by the above proof-rolling—all stripping to be done in a manner that causes minimum disturbance to underlying soil, and surface water to be removed from all areas so that stripping operations are performed under dry conditions.

5. Removal of all stripped material from the site, or its stockpiling.

6. Filling with clean approved granular material to the planned footing grades within building areas, and to indicated grades in other areas designated on the Drawings. Above footing grade and outside building areas, approved clay fill can be used, with all fill compacted as specified in Section 8.0.

3.0 WORK NOT INCLUDED

The following items are not included under this specification:

1. Waterproofing and damp-proofing,
2. Finish grading and landscaping.

4.0 SOIL CONDITIONS

The soil conditions at the site are indicated by the boring logs shown on the Drawings. Neither the architect nor the owner guarantees that the soil conditions will not vary from those indicated. The contractor will be permitted to make his own additional soil investigation, but at no cost to owner or architect.

The soils engineer will have made an inspection and subsurface exploration at the site, and the report of his finding will be available at the architect's office.

5.0 UTILITY AND DRAINAGE LINES

The location of utility and drainage lines is indicated on the Drawings. However, the contractor should verify the location of any existing pipes or conduits within the area of his operations and satisfy himself that they are properly cut off from the service lines or rerouted.

6.0 SUBGRADE PREPARATION

The Contractor is to strip all topsoil, trees, stumps, bushes, and unsuitable material off the area to be graded, as shown on the Drawings. Unsuitable material includes soft compressible or loose soil, material that will decompose with time such as trash or cinder fill, or other material so designated by the soils engineer. All topsoil removed from the area to be filled should be stockpiled at the area designated on the Drawings for future use in areas to be planted.

After proof-rolling to locate any soft spots which require additional stripping, the area to be filled is to be scarified and compacted or compacted without scarifying, as directed by the soils engineer.

7.0 DISPOSAL OF UNSUITABLE MATERIAL

Trees, stumps, and other items that can be burned should be so disposed of. All stripped or excavated material which is unsuitable for use as fill soil should be stockpiled in the disposal area designated on the Drawings.

8.0 FILL PLACEMENT

Only fill material approved by the soils engineer is to be used; material is not to contain brush, roots, sod, frozen lumps, rubbish, or other decomposable matter.

The equipment used for compacting the fill may be sheeps-foot rollers, rubber-tired rollers, or other suitable equipment. It is the responsibility of the contractor to select and furnish equipment which will compact the fill uniformly to the required density.

The contractor is to spread the fill soil in approximately horizontal layers of not more than 9 inches in loose thickness over the area to be filled, each layer to be compacted as uniformly as practicable by suitable equipment, so that the completed fill will have a dry density of___ percent of the maximum dry density obtainable on the fill soils as determined by Moisture-Density Relations of Soils Using a 10-pound Rammer and 18-inch Drop (ASTM D 1557-58T), unless otherwise noted on the Drawings.

At the time of compaction the material in each layer of fill is to have a moisture content within___percent of the optimum value for compaction, as determined by the soils engineer using the ASTM D 1557-58T procedure for determining the moisture-density relationship of the fill soils. If the fill material is too wet, it should be spread and dried; if too dry, water may be applied uniformly to the borrow material. The soils engineer may permit a greater variation than ___ percent from optimum moisture if the fill cannot be placed satisfactorily within this limit of moisture content.

Each layer of fill is to be approved by the soils engineer before placement of an additional lift of fill. When a portion of the fill is found to be unsatisfactory, the soils engineer will instruct the contractor to continue compaction in an attempt to attain the required density. The soils engineer may require removal, replacement, and recompaction of the material in the unsatisfactory area, or he may require removal of the material and replacement with other compacted soil.

All backfill adjacent to foundations and walks and in trenches for utility lines should be placed in layers and compacted with suitable mechanical hand-tamping equipment, all backfill to be compacted to the density specified for the general area fill.

During construction, the surface of completed fill should be left in such condition and grade that rain and surface water will run off without ponding. Methods should be used to drain the job site that will not cause serious erosion, with natural water courses maintained or routed around the construction area as required.

Appendix G

9.0 CONTRACTOR'S PERFORMANCE

The contractor should include in his proposal the date on which work will begin, the date work will be completed, a list of equipment to be used, and the names of any subcontractors who will be used on the job.

The contractor is to furnish all supervision, labor, tools, earth-moving machinery, and other services and equipment, together with the fuels and lubricants required to perform the work.

The contractor is fully responsible for working under conditions as they exist at the site. He will be required, as far as economy permits, to complete work in the order requested by the soils engineer. He will be required to work harmoniously with other contractors on the job site.

Upon completion of the work, the contractor is to remove all equipment, supplies, and the like from the work area and leave the area in a neat and presentable condition.

APPENDIX H
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