CHAPTER 12

SOILS

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 12

SOILS

12–01 GENERAL

Earth materials —soils and rock— are the principal materials utilized in the construction of most highway projects and represent a very substancial portion of the project costs. Earthwork engineering —the art of the efficient utilization of earth materials for the construction of engineering works and foundation engineering— the art of the efficient utilization of the earth for the support of engineering works, play a most important role in highway design.

The engineering properties of soils are more variable than those of any other material used in highway construction. Therefore, the study of the soils along the highway corridor is an essential part of the highway design process from early route location phase through the final construction plans phase. Soil exploration, testing and evaluation should be performed under the direction of personnel trained in soils mechanics and foundation engineering who can provide to the highway designer recommendations compatible with the specific soil and rock conditions in the project corridor. It is the responsibility of the highway designer to solicit the necessary soils data and recommendations and to incorporate these into the development of an adequate, sound and economical design.

The Soils Engineering Division of the Department's Soils and Materials Office normally provides the necessary soils study services to the Survey and Design Area. This division is staffed with trained soils engineers and geologits, and has a number of field crews equipped for soil and rock exploration work. Testing services are provided by the materials Testing Division. The services of outside geotechnical consulting firms are used when autorized by the Director of the Design Area.

This chapter is intended to acquaint the highway designer with the role of soils in the design process including general information on soils investigations and reports, soil considerations in design, and plan and specifications requirements.

12–02 SOILS INVESTIGATIONS AND REPORTS

Soil and rock surveys are made to obtain data on the subsurface materials and conditions in a project corridor. The data obtained is evaluated and its engineering significance correlated to the design of the project and presented in a report.

The extent of investigation and the detail of the evaluation and report will normally be related to the stage of project development. As the project progresses through the various phases of planning and design, the investigations and reports will become more refined and definite in scope and will include more detailed recommendations on the engineering aspects of the soil conditions in the final highway location.

12–02.01 TERRAIN RECONNAISSANCE REPORT

The development of soils information should begin during the early planning stages when a corridor has been selected and the route location and geometrics are being studied. At this stage a terrain reconnaissance report should be requested. This initial report will normally be based on a field reconnaissance and on a survey of available soils data. Subsurface explorations are not normally performed at this stage unless needed for major problem evaluation.

Sources of existing terrain data include:

1. Geologic maps and surveys published by the U.S. Geological Survey.
2. Agricultural soil maps and surveys published by the U.S. Soil Conservation Service.

3. Topographic maps published by the U.S. Geological Survey.
4. Aerial photographs.
5. Construction materials resources maps and reports published by P.R. Department of Transportation and Public Works.
6. Previous soils studies made in the corridor area by the DTPW and other agencies.
7. Geologic literature of the area published in technical and professional publications.

The initial reconnaissance report concentrates on the engineering aspects of the geology of the area under study and normally includes a geologic strip map of the corridor. Major soil and rock deposits are identified and evaluated as to engineering significance affecting highway design, construction, performance and costs. The report will include general information on such items as methods of excavation, cut and fill slopes, probable sources of borrow and aggregates, groundwater conditions stability of foundations for embankments, foundations for structures, erosion control requirements, and expected problem areas (faults, underground caves, marshes, etc.). The report may be also include recommendations on subsurface explorations, including locations and methods, that should be made prior to or during the preliminary design stage.

An example of a geologic strip map is shown in Figure 12—A. The geologic strip map also may be plotted on a topographic map or an aerial photograph of the route corridor with the various formations identified by colors.

12—02.02 PRELIMINARY SOILS REPORT

A preliminary soils survey report shall be prepared during the highway preliminary design stage. Since this stage may involve the consideration and evaluation of more than one location or alignment within the corridor, the preliminary soils survey report shall include data and recommendations on each alternate.

The highway designer will furnish the Soils Engineering Division (or the geotechnical consultant) the tentative plan and profile, typical sections, key cross sections (if available) and location of proposed structures as soon as these are available. The designer may indicate areas or items for which specific evaluations and recommendations by the soils engineer are needed.

The preliminary soil survey involves amplifying and refining the data developed in the soils reconnaissance report. At this stage subsurface explorations, if not previously made, are undertaken to the extent that all major soil and rock deposits for each alternate are identified and their basic engineering characteristics determined. Special attention is also given to any major problem areas so that possible solutions may be evaluated the preliminary soils report will cover all items previously indicated for the reconnaissance report but usually in more detail and will include the boring logs. It may also include a soils profile for each alternate under consideration on major projects.

A separate subsurface exploration report is normally prepared for each bridge and major structure site. The Bureau of Structural Design or the consultant developing the design submits a special request including a layout of the structure showing the locations of boring desired and indicating items and questions for which specific data and recommendations are desired (See Chapter 6). However, the soils engineer may alter the location and number of borings in line with his experience and judgement of the site conditions, and will include such other items in his study and report that he considers to have significance in the design of the structure and its foundations.

The preliminary soils report is made a part of the highway preliminary location and/or design report. It is one of the key factors considered in the final selection of the highway alignment, both horizontal and vertical.

TABLE 12-1

CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES

GENERAL CLASSIFICATION	GRANULAR MATERIALS (35% OR LESS PASSING 0.075 mm)							SILT-CLAY MATERIALS (MORE THAN 35% PASSING 0.075 mm)			
GROUP CLASSIFICATION	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5, A-7-6
SIEVE ANALYSIS: PERCENT PASSING: 2.000 mm (No. 10) 0.425 mm (No. 40) 0.075 mm (No. 200)	50 MAX. 30 MAX. 15 MAX.	— 50 MAX. 25 MAX.	— 51 MIN. 10 MAX.	— — 35 MAX.	— — 35 MAX.	— — 35 MAX.	— — 35 MAX.	— — 36 MIN.	— — 36 MIN.	— — 36 MIN.	— — 36 MIN.
CHARACTERISTICS OF FRACTION PASSING 0.425 mm (No. 40): LIQUID LIMIT PLASTICITY INDEX	— 6 MAX.		— N.P.	40 MAX. 10 MAX.	41 MIN. 10 MAX.	40 MAX. 11 MIN.	41 MIN. 11 MIN.	40 MAX. 10 MAX.	41 MIN. 10 MAX.	40 MAX. 11 MIN.	41 MIN. 11 MIN.*
USUAL TYPES OF SIGNIFICANT CONSTITUENT MATERIALS	STONE FRAGMENTS, GRAVEL AND SAND		FINE SAND	SILTY OR CLAYEY GRAVEL AND SAND				SILTY SOILS		CLAYEY SOILS	
GENERAL RATING AS SUBGRADE	EXCELLENT TO GOOD							FAIR TO POOR			

* PLASTICITY INDEX OF A-7-5 SUBGROUP IS EQUAL TO OR LESS THAN LL MINUS 30.
PLASTICITY INDEX OF A-7-6 SUBGROUP IS GREATER THAN LL MINUS 30.

12–02.03 FINAL SOILS REPORT

After agreement is reached on the preliminary design the preparation of the project construction plans is initiated. Advance detail plans are first prepared and these are subsequently developed into final construction plans.

During the development of the advance detail plans the soils engineers will be requested to amplify the preliminary soils report and furnish more specific data and recommendations. The Soils Engineering Division or the geotechnical consultant shall be furnished plans, profiles, typical sections and cross sections.

At this stage, additional subsurface explorations, laboratory testing and analyses will be made to refine all subsurface information affecting the design and construction. This will include such items as embankment foundations, cut and fill slope design, top of slope ditches, benching, structure foundations, subsurface drainage, removal of unsuitable material, undercutting or special treatment of unstable materials, slope protection treatment, subbase and pavement design, topsoil sources, granular material sources, borrow sources, earthwork factors (shrinkage and swell) erosion control measures, and additional ROW requirements.

As the preparation of the final construction plans progresses, it is desirable to consult with the soils engineer on the action taken on his recommendations and suggestions, particularly on the solutions proposed for problem areas. It is recommended that the soils engineer be called on to assist in the drafting of any special construction procedures and specifications for earthwork items that may be required. The soils engineer shall furnish the final soils profile (if warranted), boring locations and data, and results from any special type subsurface explorations made for inclusion in the final plans.

12–02.04 SUBSURFACE EXPLORATION METHODS

Subsurface explorations and sampling are made by a variety of methods depending on the nature of the terrain and the intended use of the data. The methods currently in use in Puerto Rico include:

1. SIMPLE BORINGS—This is the most common method. It involves driving a pipe casing to a desired depth while recording the driving blows count, removing the loosened material from inside the casing, and sampling the material below the casing with any one of a variety of tube-like samplers. This method produces a distubed sample and is generally used for soil identification and classification purposes. The blow counts are evaluated as an indication of the properties of the soil.

2. UNDISTURBED SAMPLE BORINGS—This method is similar to simple boring except that the sample is obtained by pressing a tube into the soil to be sampled and then sealing it for transportation to the laboratory in as near an undisturbed condition as possible. The sample is can then be tested to determine the density and moisture content, strenght properties and consolidation characteristics of the soil being investigated. This method is used primarily in deposits of cohesive soils.

3. ROCK CORE DRILLING—Rock coring is performed with rotary drilling. A cylindrical sample of the rock is obtained using a sampler fitted with a cutting bit. The core sample can be examined to determine the type of rock and its condition.

4. AUGER HOLES—This involves advancing, either manually or mechanically, an auger intthe ground and then extracting a disturbed sample for identification and classification. The depth of auger exploration is limited by the material encountered and the ground water level.

5. TEST PITS—A test pit is an open excavation large enough to permit access for a man to examine the subsurface materials in their natural condition. It is used to investigate the

subsurface strata, determine groundwater conditions and sample material sources. Test pits are expensive and usually limited in depth.

6. GEOPHYSICAL METHODS—The basic principle of geophysical exploration is that changes in subsurface conditions can be detected by the nature of the physical characteristics of the material. The two methods in current use are "seismic refraction" and "electrical resistivity". These methods allow remote determination of depth to various subsurface materials and are well suited for use in areas inaccessible to other equipment. However, their use requires a good knowledge of the geology of the area and its formations, and some borings are needed for monitoring and verification due to the parameters and assumptions involved.

a. Seismic Refraction — Consists of introducing sound or vibration waves within the earth and measuring the travel time of these waves from their point of origin to detectors located at known distances from the source. The velocity of the waves is related to the various earth strata traversed.

b. Electrical Resistivity — This method is based upon the difference in electrical conductivity or resistivity of subsurface materials. It is performed by measuring the resistance of the various strata and the underlying rock to the flow of electricity.

Geophysical methods are primarily used for area surveys, to determine the presence and depth to rock, to help plan a boring program, and to supplement data obtained from drill holes.

12—02.05 SOIL PROFILE

A soil profile is a graphical representation of the subsurface materials found along the project survey or center line. A portion of a typical soil profile is illustrated in Figure 12—A.

A soil profile is really definite only at the individual boring, test pit or other point explored. The remainder is developed by the soils engineer or engineering geologist by interpolation and interpretation of the available soils and geologic data. Since subsurface explorations are time consuming and expensive, a soil profile should be developed by detailed subsurface investigations only when a determination of the continous relationship of the depth and locations of the various types of soils and rocks to the design of the project is economically justified.

Soil profiles are warranted on all major highway projects. However, the extent and spacing of subsurface exploration performed to develop the necessary data will depend on the geologic complexity of the project area, the presence of particular problem areas, and the importance of soil and rock continuity to the project design. The extent and depth of subsurface exploration and the detail of the soil profile should be enough to develop the engineering data needed to allow analysis of the items listed under Section 12—02.

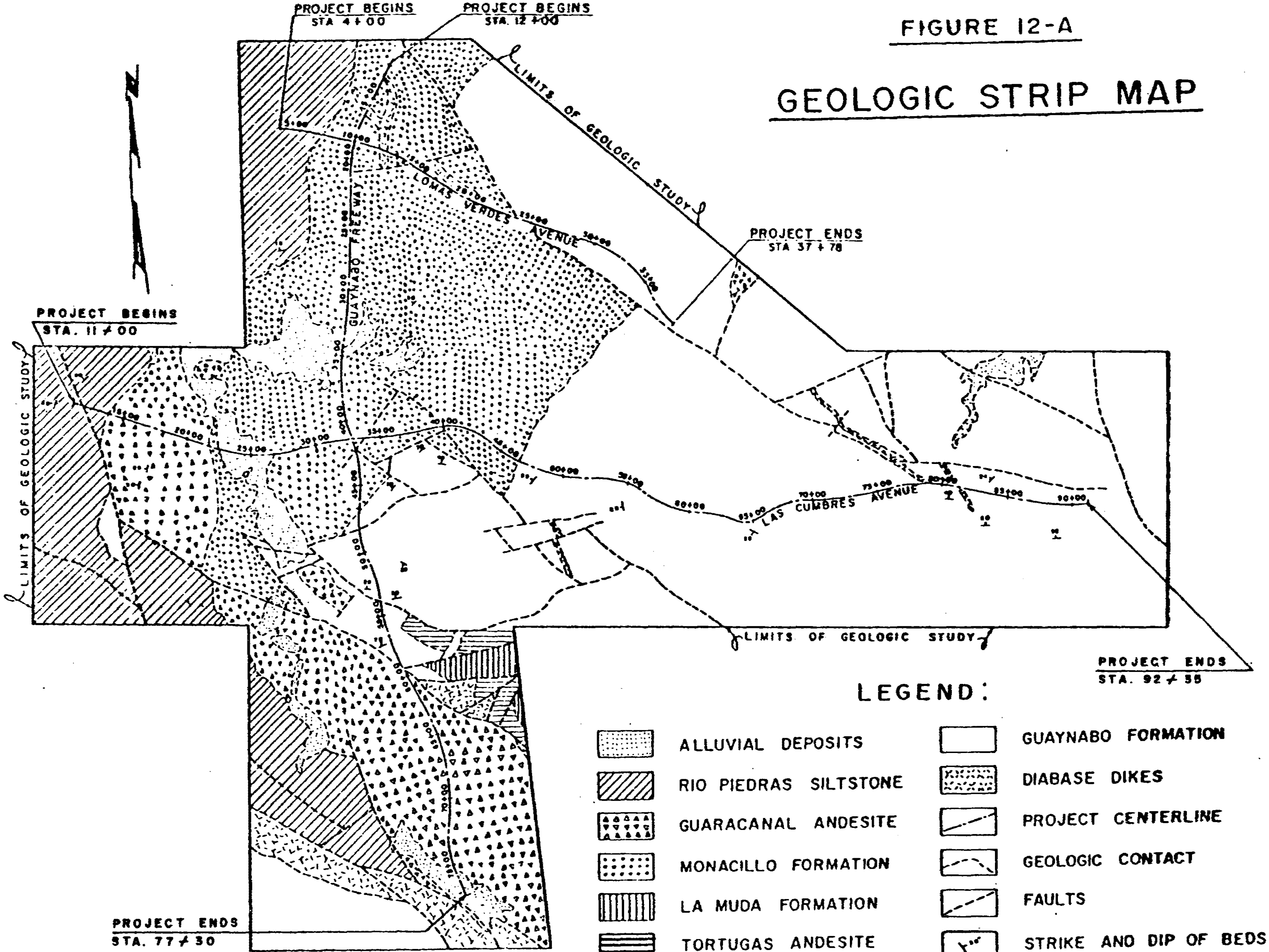
12—03 SOIL CLASSIFICATION

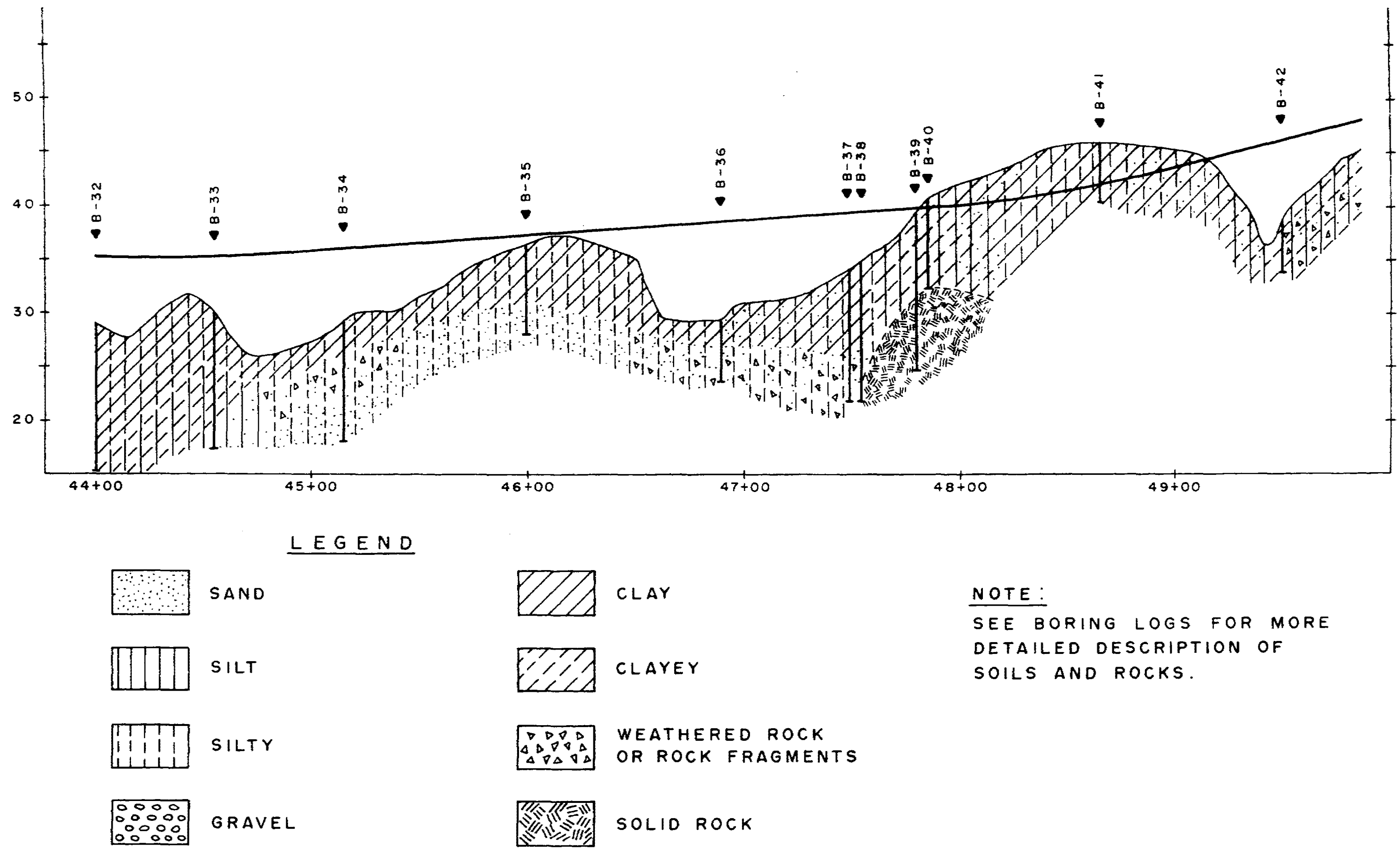
There are several soil classification systems for engineering purposes including the Unified Soil Classification System used by the U.S. Corps of Engineers and the U.S. Bureau of Reclamation, the FAA method used by the FAA for airport pavement design, and the AASHTO system which is widely used by highway engineers.

The AASHTO system, used by the Department, is based upon the observed field performance of soils under highway pavements and is described in AASHTO Specification M 145. The procedure classifies soils into seven groups based on particle-size distribution, liquid limit and plasticity index. The seven basic groups are further subdivided into twelve subgroups for more detailed classifications as shown in Table 12—1.

FIGURE 12-A

GEOLOGIC STRIP MAP





PORTION OF A SOIL PROFILE

FIGURE 12-8

Highly organic soils (peat or muck) may be classified on the basis of a visual inspection into an A–8 group not included in Table 12–1. These materials, composed primarily of partially decayed organic matter, are highly compressible and have low strength which makes them unsuitable for use in embankments and subgrade.

Evaluation of soils within each subgroup is further made by means of a group index value which is calculated from an empirical formula. A chart for graphically estimating the group index is included in AASHTO Specification M–145. The group index value of a soil is normally shown in parenthesis after its group classification. Group index values are useful in determining the relative quality of a soil material for use in embankments, subgrades and bases. Values range from O for good subgrade materials to over 20 for very poor materials.

12–04 SOIL CONSIDERATIONS IN DESIGN

The geophysical investigations previously described are made to define soil and rock conditions along the project so that adequate and economic solutions may be incorporated in the design. The ideal is to identify, evaluate and apply the proper solution to all soil conditions during the design stage so as to avoid, as much as possible, encountering unexpected problems during the construction stage when their solution is usually more difficult and expensive.

The following sections cover some of the soil related items that the highway designer and the soils specialists shouls be cognizant of and that should be resolved early in the development of the project plans.

12–04.01 EARTHWORK FACTORS

The highway alignment and grade line is established primarily on the basis of the applicable geometric design standards. Obtaining a balanced earthwork is a desirable secondary consideration which should be practiced provided geometric design criteria is not violated.

To complete the mass diagram and plan the earthwork movements the designer must have an estimate of the shrinkage or swell factors for excavated materials. Most soils decrease in volume when excavated and then placed in compacted fills. The shrinkage factor is the difference between the original soil volume in cut and the final volume in fill. On the other hand, rock usually increases in volume when excavated and then placed in the embankments because of the high percentage of voids; the difference is called the swell factor.

For earthwook calculations, the earthwork factor is used. This is the number by which the cut volume of a material must be multiplied to determine the embankment volume obtained. In general the earthwork factor for soils in Puerto Rico ranges from 0.70 to 0.90 while for rock it ranges from 1.00 to 1.20. However, for the same soil the earthwork factor is, as a rule, lower in value for a shallow fill than for a high fill. The designer should request the advice of the soils engineer on the earthwork factors for the various soils in the project area if these have not been included in the soils report.

12–04.02 CUTS

Because of our mountainous terrain, most rural projects in Puerto Rico, other than in the coastal plains, involve extensive cut excavation. Some of the most troublesome problems in highway construction and maintenance are encountered in cut slopes, particularly erosion and slides. Although all possible problems can not be anticipated, the soils report should include recommendations on the cut slopes that should be used for the various soils in the project and any special measures that should be incorporated in the design such as benching or serrated slopes and groundwater interception.

Locations involving sidehill cuts must be frequently used in mountainous terrain. On such locations, the direction of the inclination of the soil and rock strata should be observed and preference should be given, whenever feasible, to locating the highway where the cut will be such that any movement of the strata will tend to be into the hill rather than down the side towards the cut.

The combination of sidehill fill is generally troublesome, particularly on very steep terrain, and should be avoided to the extent possible. It is normally preferable to locate the entire roadway on the sidehill cut and avoid having it partially on a sidehill fill. Where sidehill cut and fill design must be used, benching of the natural ground should be employed to key the sidehill fill to a firm foundation and adequate drainage provisions incorporated in the design to prevent the accumulation of surface water and groundwater within the embankment.

Rock excavation is more difficult and expensive than soil excavation. However, there are some advantages to rock excavation that the designer should consider. Rock cut slopes can be steeper than soil slopes and thus rock cuts will normally require less right-of-way. In addition sound rock cuts will generally be more stable and less suceptible to erosion than soil slopes and the excavated rock may be used for the production of aggregates for the project. The design of rock cut slopes is dependent on the composition and structure of the rock which is very variable in Puerto Rico. Benches in rock cut slopes should be used only when necessary and designed according to the rock type and structural conditions. Therefore the advice of the soils engineers should be obtained for the design of the rock cut slopes and any special treatments that may be required if not included in the soils report. The use of presplitting excavation methods is very desirable but should not be specified without prior consultation with the Soils Engineering Division.

12—04.03 EMBANKMENTS

Embankment performance is associated with the stability and the deformation of both the embankment and the underlying foundations materials. Embankment failures fall into two general categories —failure within the embankment itself or failure due to poor foundation conditions. The first may be due to use of unsuitable fill materials, unsatisfactory construction methods or ineffective quality control procedures. The foundations failures are caused primarily by inadequate consideration of foundations soils, sidehill locations, cut-fill transitions and groundwater conditions.

The soil survey should provide information on which cut soils are inadequate for embankment construction and should be wasted, and which soils, although poor, may be used but requiring special treatment. It should also identify those locations where foundation problems should be expected and recommended corrective measures to avoid embankment failure.

One of the most frequent type of embankment failure is the settlement or distortion of the fill resulting from a shear failure or lateral displacement of soft foundation soils such as peats, muck and organic and inorganic silts and clays. The most common treatments used in improve soft foundation are the complete or partial removal of the unsuitable material when economically feasible. Another method is the consolidation of the soft soil layer. Consolidation can be obtained by preloading for a given length of time, if a greater shear strength is required in the same length of time or with a shorter waiting period a surcharge should be used. Sand draing may also used for this purpose and may be combined with a surcharge load.

The construction of embankments on soils of a low or poor shear strength require careful consideration. The initial inadequate shear strength of the foundation soil to carry the total embankment load will require a time-loading sequence of fill placement so as to progressively build up the soils shear strength. A toe berm should be considered in some cases to provide an additional stability during or after construction.

Excavation and replacement with a good material is the most satisfactory solution and usually the most economical when the depth of the unsuitable material does not extend more than 4 to 6 meters. The economical depth for a given site will depend on the soil type, groundwater condition and availability of replacement material. A cost comparison with other methods should be made in doubtful cases.

Consolidation in place of the poor foundation soil is a time-dependent process which requires waiting period between completion of the embankment and the construction of the pavement. The rate of settlement may be accelerated by applying a surcharge load which also helps in eliminating post-construction settlement. On certain soils the rate of settlement can be further accelerated by improving the drainage of the compressible layer by the use of sand blankets and vertical sand drains. These methods of solving settlement problems by consolidation procedures require detail laboratory testing and analysis of the soils and the design procedures and construction requirements should be developed in close coordination with the soils engineer.

12—04.04 GROUNDWATER CONTROL

Because of its erosive action and softening effects, the penetration of water into the subgrade is one of the principal causes of pavement failure. Surface waters can be satisfactorily handled through the design of adequate storm drainage systems (See Chapter II). The control of groundwater is just as important and should be given consideration during the preliminary and final design stages. Failure to provide for adequate handling of subsurface waters can prove to be disastrous and very costly in the long run.

Much less is normally known about the location of groundwaters than surface waters in the project area. However, the soils investigations should include the study of existing and potential groundwater conditions.

The soils engineer can provide valuable assistance in identifying potential problem areas and suggesting groundwater control measures.

Groundwater problems are usually encountered in cut sections, sidehill fills and cut-fill transitions. They can also develop at the low point in vertical curves, in sections with shallow ditches, on the low side of superelevated section, and/or roads underlaid with retentive subsoils.

Groundwater is normally controlled through the introduction of a subsurface drainage system. The basic purpose is to intercept and drain the groundwater away from critical areas. They are also used to intercept and lower the water table, and prevent the accumulation of groundwater in the subgrade under the pavement.

The most common subdrain systems consist of pervious blankets and/or perforated pipe underdrains. Whenever pipe underdrains are installed they must be surrounded by a pervious material which must also be capable of protecting the pipe from infiltration by the surrounding soil. When large quantities of ground water are involved, a continous pervious blanket may be more effective and economical than a pipe underdrain system.

The specific design of a subdrain systems may vary considerable as to cost and complexity depending on the topography, depth of waterbearing strata and amount of groundwater flow. The major problem is the identification of the specific problem sites and the severity of the groundwater conditions so that an effective and economical solution be designed prior to construction.

Once the grade line has been established a thorough review should be made of all locations where groundwater problems may be expected using the soil survey data and consulting with the soils engineer. The subsurface drainage system for each location should be individually designed taking into consideration the type of soils, the location of the various strata, the presence of water in such strata and the direction of flow of the groundwater.

12–04.05 EROSION CONTROL

Cuts and fills with their exposure of bare ground present an erosion problem which can be quite serious when highly erodible soils are exposed in cuts and used in embankments.

Environmental and practical considerations require that erosion control measures be incorporated in the design for implementation during the construction phase which is normally the most critical stage for the development of erosion and pollution problems. The soils study should identify the highly erodible soils along the route location that warrant special attention by the designer.

The highway construction contracts include special provisions for temporary erosion control measures during construction aimed at protecting the project and preventing water pollution, sedimentation and ecologic damage to adjacent land and water bodies. However, much can be done by the designer to minimize erosion and related pollution if adequate consideration is given to this problem during the location and design stages.

Erosion control measures fall into two general categories —vegetative and mechanical. Vegetative refer to the seeding and planting to provide a protective cover of vegetation to the soil in place and slow down the water runoff. Vegetative measures are discussed in Chapter 14.

Mechanical erosion control measures are basically those aimed at controlling the surface water runoff, through other than vegetative measures, to minimize their damaging action. These measures normally contribute to the development of a vegetative cover.

Mechanical erosion control measures include:

1. The selection of a cut and fill slopes apropriate to the soil.

2. The use of independent highway alignment on divided highways to reduce the height of cuts and fills.

3. The use of benched slopes to control the velocity of an channelize the runoff.

4. The use of serrated cut slopes at suitable locations, usually sites containing rotten or fragmented rock.

5. The use of curbs or berms on high fills to collect runoff water and guide it into inlets or slope pipes.

6. Adequate design of the ditches, particularly in steep terrain, to insure the capacity to carry the maximum flow and control of the flow velocity.

7. Providing channel protection such as riprap, paving of ditches, etc.

8. The rounding of the tops of cut and fill slopes.

12–04.06 MECHANICAL EROSION CONTROL MEASURES

There are a variety of mechanical erosion control measures that can be designed and used to control surface runoff, and as a result minimize soil erosion. They are usually constructed of concrete, rock, masonry, prefabricated metal or wood. Among them are:

Graded Chanels — across a slope to intercept the water and lead it an outlet where it can be safely discharged.

Berms or Benches — May also be used in the manner as diversious to reduce slope length and divide the runoff volume.

Chutes Flumes — channels of concrete to control runoff downslope.

Check Dams — To reduces or prevent excessive erosion by reduction of velocities.

Diversions Dike — constructed at the top of cut or fill slopes; erosion check, to prevent the formation of rills and gullies.

Gabions — a multi-celled, rectangular wire mesh box, filled with rocks used for erosion control structure.

Sandbag Sediment Barrier — used at storm drain inlets, across minor swales and ditches.

Sectional Downdrain — conduct storm runoff from one elevation to another without erosion of slope.

Sedimentation Retention Basins — It is a structure detains runoff water carrying heavy loads of silt, sand or gravel. It is usually consists of an earth embankment and a perforated pipe spillway. A large part of the debris settles out and the water automatically drawns out the spillway. The structure should be designed to store the expected debris for the life of the structure. The basin created should be periodically cleaned of eroded material.

Energy Dissipators — Used to prevent water erosion at the outlet of the pipe.

Stone Lining — Stone lining with a gravel foundation may be used for large diversion channels. On projects where rock excavation is encountered, ledge fragments should be stockpile for use in lining channels, ditches, pipe outlets and constructing haul roads across streams.

12—04.07 FILTER MEDIA

Filter Berm — Gravel or crushed rock constructed across a graded right of way. The berm retain the sediment on site by retarding and filtering runoff.

Filter Inlet — Gravel or crushed rock constructed at storm sewer curb inlet structure. The rock retain sediment on site by retarding and filtering runoff before it enters storm sewer system.

Plastic Filter Fabrics — On steep slopes, inaccessible to construction equipment, it will be necessary to surface the slope with filter cloth and crushed stone or other suitable material.

Plastic filter sheets are used as a replacement for graded filter systems and filter blankets in conjuction with many hydraulics structures. Filter fabrics have been used also in the construction of subsurface drains beneath roadway shoulders; roads and parking areas over soft soils; and siltation-control fences along superhighways. In general the material is rolled out unto the prepared surface. When in place the succeeding layer of material, can be places on the filter fabric where more than one sheet is required, they should be lap jointed to ensure continous converage of the area to be protected.

12—05 SELECTED REFERENCES

There are innumerable textbooks and publications which cover the application of geology and soils engineering to highway works. The following are some selected AASHTO and TRB references which can be particularly helpful to the highway designer.

1. AASHTO
   a. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. Volumes I and II. In particular — Specifications M-145, and Method of Sampling and Testing T-86.
   b. Manual of Foundation Investigations (1967).
2. Transportation Research Board — National Cooperative Highway Research Program

a. Synthesis of Highway Practice No. 8 -- Construction of Embankments (1971).

b. Synthesis of Highway Practice No. 18 -- Erosion Control on Highway Construction (1973).

c. Synthesis of Highway Practice No. 29 — Treatment of Soft Foundations for Embankments (1975).

d. Synthesis of Highway Practice No. 33 — Acquisition and Use of Geotechnical Information.

3. Transportation Research Board — Special Reports

   a. Landslides Special Report 29

   b. Soil Erosion Special Report 135