GEOTECHNICAL INVESTIGATION

AND ANALYSIS REQUIREMENTS FOR

STRUCTURES

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MICHIGAN DEPARTMENT OF TRANSPORTATION

BUREAU OF BRIDGES AND STRUCTURES

GEOTECHNICAL SERVICES SECTION

Engineering Manual Preamble

This manual provides guidance to administrative, engineering, and technical staff. Engineering practice requires that professionals use a combination of technical skills and judgment in decision making. Engineering judgment is necessary to allow decisions to account for unique site-specific conditions and considerations to provide high quality products, within budget, and to protect the public health, safety, and welfare. This manual provides the general operational guidelines; however, it is understood that adaptation, adjustments, and deviations are sometimes necessary. Innovation is a key foundational element to advance the state of engineering practice and develop more effective and efficient engineering solutions and materials. As such, it is essential that our engineering manuals provide a vehicle to promote, pilot, or implement technologies or practices that provide efficiencies and quality products, while maintaining the safety, health, and welfare of the public. It is expected when making significant or impactful deviations from the technical information from these guidance materials, that reasonable consultations with experts, technical committees, and/or policy setting bodies occur prior to actions within the timeframes allowed. It is also expected that these consultations will eliminate any potential conflicts of interest, perceived or otherwise. MDOT Leadership is committed to a culture of innovation to optimize engineering solutions.

The National Society of Professional Engineers Code of Ethics for Engineering is founded on six fundamental canons. Those canons are provided below.

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform Services only in areas of their competence.
3. Issue public statement only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, reasonably, ethically and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

A. DESCRIPTION

1. The work performed by the consultant geotechnical engineer under these requirements shall consist of making a complete foundation investigation for the adequate design and construction of bridges and other associated structures.

   A complete foundation investigation and analysis shall consist of an adequate program of field sampling, laboratory testing, and engineering analysis and evaluation, with the results presented in report form. The investigation and analysis shall be performed in compliance with the procedures outlined in this document and generally accepted principles of sound engineering practice. The investigation and analysis shall be under the general supervision and subject to the approval of the M•DOT foundation analysis engineer. Unless otherwise subsequently noted, later references to as approved or directed will imply as approved or directed by the M•DOT foundation analysis engineer.

B. PERFORMANCE OF FIELD WORK ON PRIVATE PROPERTY

1. Entry Permission
   It is the responsibility of the consultant geotechnical engineer to obtain permission for entry from each property owner whose property must be entered for any reason.

2. Damages
   It is also the responsibility of the consultant geotechnical engineer acting as a representative of the Michigan Department of Transportation or local public agency to compensate the property owners for any damage incurred to their property because of the geotechnical investigation.

3. Railroad Expenses
   This item consists of the actual cost invoiced by the railroad for railroad permits, flagman, right of entry, etc. The consultant geotechnical engineer shall obtain the written approval of the State before incurring any railroad expense.

C. EQUIPMENT

1. The equipment used shall be hand operated or power drilling, and/or driving equipment, or other tools or equipment considered suitable or necessary for determination of the limits and conditions of the various soil strata, and for obtaining samples for examination, field classification, and laboratory analysis.

D. LOCATION AND DEPTH OF BORINGS

1. General
   This section is to be used as a guide in planning the boring program. It is not the intent that the location, boring interval, and depth specified herein be rigidly

adhered to. The consultant shall make use of available soils and geologic maps, water well records, reports, publications, aerial photographs, and other reference material which are available to prepare a preliminary boring program. Borings shall then be selectively located during a field check attended by the consultant geotechnical engineer and by the M•DOT foundation analysis engineer or his appointed representative.

The actual location, spacing, and depth of borings shall be dictated by the topography, geologic conditions, visible soil conditions, and design considerations, and in accordance with the practices set forth herein.

2. Depth of Exploration

Borings should extend through any unsuitable or questionable foundation materials and sufficiently deep into stable soils that the potential for settlement from compression of that layer or that the deeper underlying soils is determined. If deep excavations are required for building the structure, the explorations should be carried to at least 1.5 times the depth of the excavation in order to locate and determine groundwater levels in any aquifers that may exist below the level of excavation. This is necessary to design a dewatering system that may be required in such deep excavations and to avoid heave or disturbance to the bottom of the excavations.

3. Spacing and Number of Borings

Often borings are made in several stages. In the first stage, relatively few borings are made. Based upon these findings, additional borings may be made between the initial borings to define soil conditions in greater detail. The selection of sample type and frequency is determined by soil conditions and requirements of the structure. Where soil conditions are favorable, especially for small structures, all borings are often completed in the first phase of the investigation. If soil conditions are well known with fairly thick individual layers of consistent physical properties, relatively widely spaced borings may be sufficient. If, however, soil conditions vary appreciably from place to place, more closely spaced borings will be required. The number and spacing must be determined by engineering judgment as the work progresses. There should be a sufficient number to determine the stratification and interrelation of the soils to the extent economically feasible. The exploration should be conducted considering the requirements of the structure. All soil data necessary for the selection of the foundation and its design must be obtained.

4. Guidelines for Subsurface Investigations

With the above general concepts in mind, the following guidelines for location and depth of borings are to be followed. The boring frequency for most structures is one boring per substructure unit (such as a bridge pier) under 100 feet long and two borings for footings longer than 100 feet. For retaining walls and sewers, one boring every 300 feet, and for deep cuts and high fills, one boring every 200 to 500 feet depending on soil conditions. The sampling frequency for sands and

gravels is every 5 feet in depth where a standard penetration (resistance to driving) test (SPT) is obtained. If spread footings are proposed, the borings are extended until sufficient information has been obtained to complete the settlement analysis. If piles are anticipated, the boring is stopped 10 feet below the estimated bottom of the piling. The sampling frequency for cohesive (clay-like) materials is every 5 feet in depth to a depth of two times the footing width or 30 feet, whichever is greater, below the bottom of the proposed footing elevation. If the field consistency of the sample indicates an unconfined compressive shear resistance of less than 3,200 pounds/square foot, undisturbed samples are obtained for laboratory analysis. SPTs are taken in place of undisturbed samples if consistency is greater than 3,200 pounds/square foot. If piles are anticipated, the depth of boring is controlled by the estimated piling bottom as noted above. The strength testing for sands, gravels, and cohesive materials with consistency greater than 3,200 pounds/square foot is usually limited to in-place SPTs. For lower strength cohesive materials, undisturbed samples are collected for laboratory analysis. Groundwater table information is obtained at each boring location.

The above M•DOT guidelines are for routine foundation investigations. They are modified as necessary by the foundation analysis engineer to meet the needs of individual projects.

E. BORING AND SAMPLING

1. General

a. Standard Penetration Tests

Generally, all borings should be performed with split-spoon sampling. Samples should be taken at two-and-one-half-foot intervals for the upper ten feet and five foot intervals thereafter.

Split-spoon samples shall be obtained with the standard spoon of 2 inches O.D. and 1-3/8 inches I.D., driven with a 140-pound hammer, dropped 30 inches. The number of blows of the drop hammer to drive the spoon 18 inches, measured in 6-inch increments, shall be recorded. The penetration resistance, or N-value, shall be as defined in ASTM D 1586, and is normally the number of blows to drive the sampler the last 12 inches.

b. Split-Spoon Samples

Two jar samples approximately five inches long shall be obtained from each spoon for laboratory examination and/or testing. Care shall be taken to keep the jar samples as intact as possible. The samples shall be immediately placed in sealed glass containers to prevent loss of moisture.

c. Sample Handling

All of the samples should be delivered to the consultant geotechnical engineer's laboratory for representative classification tests and other tests

as required.

All samples shall be retained by the consultant geotechnical engineer for at least 90 days after final acceptance of the geotechnical report during which time the State may request that all or part of the samples be delivered to the Geotechnical Services Unit of the Michigan Department of Transportation.

d. Sample Identification

All laboratory samples shall be suitably marked up and identified to show sample number, project number, road number, county, structure number, depth below ground surface, boring number, and blow count for each 6-inch interval (if applicable). Undisturbed samples should, in addition, have a description of the soil. (Also see Sections E.3. and F.)

e. Groundwater Readings and Backfilling Bore Holes

After measuring the groundwater level at completion of the borings, the bore holes shall be suitably covered so that there will be no hazard to people, animals, or equipment. After the 24-hour groundwater level has been measured and all other observations, records, and information have been obtained, the holes shall be filled in such a manner as to prevent a hazard. Borings drilled through existing pavement should be suitably patched. Backfilling and plugging of all borings shall be in accordance with all Department of Natural Resources Regulations.

2. Boring Methods

a. Mobilization

This work shall consist of mobilization of all necessary equipment, tools, and supplies to, and demobilization, from the drilling site. It shall be the responsibility of the consultant geotechnical engineer to determine the equipment needs of each site and to mobilize equipment needed to perform the necessary work. Payment will be made per each approved mobilization. Mobilization of barge equipment is excluded from this item as it is a separate pay item.

b. Remobilization

Remobilization shall be paid only after having received authorization prior to equipment removal from the project site, or if an unforeseen change in the scope of work is made after the initial demobilization. Payments for the remobilization will be made per remobilization, which are previously authorized in writing.

c. Hand Borings

This work shall consist of using and hand auger of minimum 1-1/2-inch-diameter, 1-inch-retraction piston sampler, peat sampler, 3-inch-

minimum-diameter, post-hole-type auger, or a hand guide power auger for obtaining samples for determining the geotechnical profile. This work shall be performed in accordance with AASHTO T 203. The increment of advance of hand augers shall not exceed six inches. Payments shall be made from the ground surface to the maximum depth of auger penetration.

d. Truck Drilling

(1) Truck-Mounted Borings with Split-Spoon Sampling

This work shall consist of using a truck-mounted drill rig to advance a hole of sufficient diameter for the purpose of taking 2-inch-O.D. split-spoon samples and making standard penetration tests at two-and-one-half-foot intervals for the first ten feet and at five-foot intervals thereafter, including a sample at the bottom of the boring with the possibility of taking 3-inch-O.D. Shelby tubes and 2-1/8-inch-diameter rock cores. This work shall be performed in accordance with AASHTO T 206, and as stated in Sections E.1.a. and E.1.b. Payment will be made from the ground surface to the maximum depth of penetration of the last split spoon.

A maximum of two wraps of rope around the cathead shall be used to minimize reduction of the energy due to frictional resistance of the falling hammer. Other precautions shall be exercised to insure a free-falling hammer.

Drilling fluid or other authorized practices shall be used in circumstances where sand heaves into the casing, or as previously approved. Any unusual sampling procedures or results shall be noted on the boring log.

Driving of the split-spoon will be discontinued when blow counts reach 100 for a penetration of 12 inches or less.

If a sample is not recovered upon retraction of the sampler, one attempt with an appropriate entrapment device shall be made in order to retrieve a sample for visual classification.

(2) Truck-Mounted Rock-Core Borings

This work shall consist of using a truck-mounted drill rig for rock-core drilling. Standard diamond core bits and series "X" or "M" double-tube core barrels to obtain 2-1/8-inch-diameter cores shall be required for making rock core borings. The maximum length of core barrels, and the maximum length of each core run, shall be five feet, unless otherwise approved. All rock cores recovered shall be retained and protected.

Rock cores shall be placed securely in suitable compartmented

wooden boxes with wooden lids, in the order in which removed from the boring, with dividers between core runs, with the top and bottom depths of each run suitably labeled. Suitable labeling shall also be done on the outside end of the core box. Payment will be made for the actual number of lineal feet cored.

e. Skid Drilling

The following item is to be used when site conditions are such that a skid-mounted, dozer-mounted, all-terrain-vehicle drill rig or any other type mount previously approved is required to obtain the borings. Borings where the consultant geotechnical engineer is required to use a dozer to get a rig to the boring location shall also be considered under this item. If the consultant geotechnical engineer chooses to use a skid-mounted, dozer-mounted, or all-terrain-vehicle rig to obtain borings which could have been obtained by a truck rig, they shall be considered as truck borings.

(1) Skid-Mounted Borings With Split-Spoon Sampling

This work shall be the same as described in E.2.d.(1), except for the drilling equipment required.

(2) Skid-Mounted Rock-Core Borings

This work shall be the same as described in E.2.d.(2), except for the drilling equipment required.

f. Floatation Equipment

The following item is to be used when floatation equipment is required to make borings over water. Floatation equipment is described as a barge, raft, boat, or platform of sufficient size to properly and safely support the drilling equipment and have sufficient area for working and storage of the necessary tools and supplies required to make water borings. The barge and drilling equipment shall be of sufficient size to operate on any body of water within or bordering the state of Michigan, and be able to penetrate to depths as required. The equipment shall also be capable of obtaining 3-inch-O.D. Shelby tubes at depths requested by the consultant geotechnical engineer with prior approval. Water borings shall be generally defined as those where water is to a depth where it is not feasible to drill with equipment resting on a stream bed or earth ramp, all subject to prior approval. It shall be the consultant geotechnical engineer's responsibility to determine the elevation and depth of the water at the time the drilling is performed.

g. Floating Equipment for Machine Borings

This item shall consist of mobilization, demobilization, equipment rental, and setting up of equipment required for barge machine boring at a drilling site. This item shall also consist of the rental support equipment required

to perform barge machine borings on nonnavigable and navigable water. A quantity of one lump sum will be paid for the project, if required.

h. Soundings

This work shall consist of making continuous-flight auger borings with a truck-mounted rig, skid-mounted rig, barge-mounted rig, a powered hand auger, or a hand auger for the purpose of determining the depth to rock or the depth through surficial peat, other unstable soils, man-made waste deposits, etc. Samples do not need to be obtained.

This item shall also include borings advanced through soil for the express purpose of making core borings in rock or obtaining undisturbed samples at a certain depth in which a casing or drilling fluid is not used to keep the hole open. Measurement shall be from the ground surface to the depth augered.

i. Casing

This shall consist of furnishing and installing either hollow-stem auger or driven casing, as previously approved, through air, water, soil, shale, and/or weathered rock to a specified elevation for the purpose of obtaining Shelby tubes, rock cores, installing field instrumentation, etc., if required. Measurement shall be from the water surface (if casing is placed through water) or the ground surface (for land borings).

j. Field Geotechnical Engineer

This work shall consist of furnishing a qualified consultant geotechnical engineer for field work for all time in excess of one day per week per rig. The payment will be made at the price per work day, which payment shall include costs for travel and living expense at the site. Any time in excess of one day per week per rig must first be authorized.

3. Soil Sampling

a. Undisturbed Samples

Undisturbed samples, if required, shall be obtained by methods and equipment previously approved. This work shall consist of obtaining undisturbed samples by pressing 3-inch-O.D., thin-walled tubes into the soil with a continuous punch. In soils which are too soft to obtain good recovery by conventional means, a 3-inch-O.D., stationary-piston sampler may be used. An attempt shall be made to push the tube a maximum of 24 inches. Tube length shall be that recommended in Table 1 of AASHTO T 207 or longer to avoid overfilling of the tube during sampling. Payment will be made per each undisturbed sample only when recovery is 50 percent or greater, with a minimum of 6 inches unless otherwise approved. Smaller, testable samples may be used if previously approved. This work shall be performed in accordance with AASHTO T 207, except where

superseded by the following.

Immediately after trimming and cleaning the ends, the samples shall be sealed with approved expanders or by pouring petrowax or comparable materials into each end, placing suitable filler in the remaining void space to prevent movement of the sample, and covering each end with a metal or plastic cap. Bolt holes in the tube shall be covered with tape and both ends of the tube shall be dipped into petrowax or comparable material. Samples shall be kept in a vertical position with the top always up during transportation and storage. Samples shall not be jarred or vibrated and should be properly marked and identified. Tubes should be protected from temperature extremes and under no circumstance should tube samples be allowed to freeze.

b. Additional Split-Spoon Samples

This item shall consist of obtaining additional 2-inch-O.D., split-spoon samples as specified above by the Standard Penetration Test Procedure in accordance with AASHTO T 206. Payment shall be for split-spoon samples obtained in addition to those required in Items E.2.d.(1) and E.2.e.(1).

F. FIELD RECORD

1. All material encountered in each boring shall be carefully examined and visually classified at the time of boring, and a written record (boring log) should be prepared. The boring log shall be on a sheet 8-1/2-by-11 inches in size, and shall show the following information: (a) project designation and project location; (b) boring number; (c) final location of boring by reference to station, offset, and survey line; (d) method of boring, type drill rig and sampling; (e) date of boring and weather; (f) ground elevation measured utilizing a transit or level instrument and referencing to a USC&GS Benchmark or other points of known elevation; (g) numerical thickness and depth of various soil layers to be shown in feet below ground surface or by elevation; (h) a complete description of each soil layer including color, moisture, consistency or density, and visual grain-size classification; (i) the elevation of free water during the drilling, at completion of drilling and 24 hours later; (j) any additional information obtained during the boring shall be shown; (k) blows per 6-inch increment of drive of split-spoon sampler, sample number, and depth of top and bottom of samples taken; (1) percent recovery on split-spoon and undisturbed samples, rock cores, etc.; (m) county; (n) driller; (o) inspector.

When rock is encountered and cored, the boring log shall also include the following remarks: (a) numerical thickness and depth of rock unit; (b) a complete description of each rock unit including color, texture, significant mineralogy, degree of weathering etc.; (c) percent recovery and RQD values (rock quality designation); (d) a description of joints, fractures, and bedding planes (i.e., degree

of openness, spacing, inclination, etc.); (e) location of core fracturing; (f) type and size of core barrel and depths where casing is used; (g) general descriptions of penetration rate, with significant changes in rate noted; (h) zones of drilling fluid loss; (i) zones of water gain (when air is the drilling fluid); (j) any unusual occurrences such as sudden drop of drill rods, change in color of return wash water, etc.

Fill or embankment material depth limits should be shown on all boring logs, as well as the classification of the soil comprising the fill or embankment. This information should be checked for accuracy by referring to original construction plans to determine the original embankment height.

The boring logs shall contain all necessary information required to plot the final geotechnical profile, and such information shall also serve as the basis for determining pay quantities.

G. LABORATORY TESTING

1. General

Boring samples shall be submitted from the soil strata for laboratory analysis as the work progresses.

All laboratory tests shall be performed in accordance with AASHTO and/or ASTM Standard Methods of Testing as listed herein, except as described below. Tests for which standard or tentative procedures have not been adopted by the above societies shall be governed by Standard Michigan Test Methods, by the publication "Soil Testing for Engineers" by T. William Lambe, or by other procedures previously approved.

When AASHTO or ASTM Specifications govern, the most current Standard or Interim Specification shall be used for reference.

2. Classification Tests

These tests shall be performed on samples that were obtained for verification of the field classification of the major soil types encountered during the investigation. The number shall be limited to that established by the agreement in effect unless prior approval is given, or to those necessary to reasonably establish the stratification without duplication. A minor soil type, if not critical, may be given a visual classification, instead of performing classification tests for reference.

a. Sieve Analysis

This work shall consist of determining the gradation of a sample in accordance with AASHTO T 88. Sieves used shall be U.S. Sieve sizes 3", 2", 1", and 3/8" and U.S. Sieve Nos. 4, 10, 40, and 200, decanted over the No. 200. A grain-size distribution curve shall be provided as a part of this

item.

b. Hydrometer Analysis

This work shall consist of performing the hydrometer analysis in accordance with AASHTO T 88, and includes a Specific Gravity Determination performed in accordance with AASHTO T 100. If 20 percent or more passes the No. 200 Sieve, a hydrometer analysis shall be performed. A grain-size distribution curve shall be provided and should include the combined results of the sieve analysis.

c. Liquid Limit

This shall consist of the determination of the liquid limit in accordance with AASHTO T 89, Method "A" only. Three points shall be determined and no payment will be made for nonplastic (N.P.) soil.

d. Plastic Limit and Plasticity Index

This work shall consist of the determination of the plastic limit and plasticity index in accordance with AASHTO T 90. If the soil is found to be nonplastic, then the liquid limit shall not be performed, and the AASHTO group index shall be reported as zero.

e. Shrinkage Limit

This work shall consist of the determination of the shrinkage limit in accordance with AASHTO T 92. No payment will be made for nonplastic (N.P.) soil. This test shall be performed only with prior approval.

3. Special Tests

These are tests which are performed on bag samples, jar samples, undisturbed samples, and/or split-spoon samples to obtain additional information about the soils and their condition. This information is used in analysis of conditions and preparation of recommendations for design and construction.

a. Moisture Content Test

This work shall consist of the determination of moisture content in accordance with AASHTO T 265, on representative samples of soil from each major stratum in each boring, except sands or gravels. When this test is performed as part of a primary test, it will not be considered a pay item.

b. Unit Weight Determination

This work shall consist of the determination of the unit weight by measurement of the length and diameter as performed in accordance with the appropriate part of AASHTO T 234. When this test is performed as a part of a primary test, it will not be considered a pay item.

c. Consolidation Test

This work shall consist of performing the consolidation test in accordance

with AASHTO T 216, except the load increments shall be 1/16, 1/8, 1/4, 1/2, 1, 2, 4, 8, and 16 tons/square foot. This test also includes specific gravity, initial and final moisture content tests, initial and final degrees of saturation and unit weights (density). Time curves for all load increments and e-log-p curve shall also be furnished.

d. Unconfined Compression Test

This work shall consist of performing the unconfined compression test in accordance with AASHTO T 208. This test shall include initial and final moisture content test, unit weight determination, visual description of the soil, average strain at failure and average rate of strain to failure. This test shall be performed on 3-inch undisturbed samples unless other types are specifically approved in advance. This test shall not be performed on nonplastic soils.

e. Triaxial Test

This work shall consist of performing the triaxial test in accordance with AASHTO T 234. Each test shall consist of three points for plotting a Mohr failure envelope and determining the strength parameters. This test shall include initial and final moisture content tests, specific gravity, Atterburg limits, initial and final void ratio, initial and final degrees of saturation, initial and final unit weights (densities), visual textural description, cohesion, plot of Mohr circles and envelope, and sketch of failure. The test shall be one of the following:

(1) Unconsolidated — undrained (UU) test
(2) Consolidated — undrained (CU) test
(3) Consolidated — drained (CD) test

Pore pressure measurements may be required with the UU or CU tests and will be paid for in addition to this test.

f. Direct Shear Test

This work shall consist of performing the direct shear test of soils under consolidated — drained conditions in accordance with AASHTO T 236. Each test shall consist of three points for plotting of Mohr failure envelope and determining the strength parameters. This test shall include initial and final moisture content tests, initial and final degrees of saturation, sample thickness and void ratio before and after consolidation, dry unit weight (density), and plotted Mohr envelope.

g. Housel Transverse Shear Test

This work shall consist of the determination of the ultimate shearing resistance of cohesive soils by measuring the force required to cause the failure in double shear of a soil cylinder of 1-1/2-square-inch, cross-sectional area in accordance with Michigan Test Method 401-76.

h. Loss on Ignition Test

This work shall consist of the determination of the loss-on-ignition (organic content in accordance with AASHTO T 267.

4. Classification of Soils

The soil description and classification is to be based on the distribution and behavior of fine-grained (passing No. 200 sieve) and coarse-grained (retained on the No. 200 sieve) soil constituents, as described in ASTM D 2487 and D 2488.

a. Soil descriptions contained on exploration logs and in field/laboratory reports shall be consistent with the visual-manual procedure of ASTM D 2488. The visual-manual method employs visual observations and simple manual test (index tests) to estimate the size and distribution of the coarse-grained soil reactions and to indicate the plasticity characteristics of fine-grained fractions. These index tests should be performed on representative samples from each soil unit.

b. Soil classifications are determined based on soil descriptions and laboratory testing. Representative soil samples that are submitted for laboratory testing shall be classified using the procedure of ASTM D 2487, which generally requires grain size and plasticity testing (Atterburg limits).

H. GEOTECHNICAL REPORT

1. General

The geotechnical report shall be the presentation of all data obtained during the investigation, both in the field and laboratory, all engineering analyses, and recommendations for the use or satisfactory treatment of various soils and soil conditions encountered on the project. A maximum of ten copies of the geotechnical report will be required, with the actual number being requested by M•DOT.

2. Contents of Report

a. General Information

(1) A discussion of the location of the project (including the beginning and ending stations), project identification and background, scope of proposed construction, field and laboratory investigation procedures, etc.

(2) The date, month, and year when the field investigation was made.

(3) A general description of climatic conditions during field investigation.

(4) A general description of the geology and soils encountered on the project, and a description of the terrain, to include drainage, erosion patterns, high water elevation, flooding, and any other specific conditions which may be of value in the design of bridges, culverts, and other structures.

(5) Any other information which may be of value for the proper interpretation of the field survey data.

b. General Recommendations

The Geotechnical Report shall include general recommendations concerning design and construction procedures for bridges, retaining walls, culverts, and other structures, as applicable.

c. Detailed Geotechnical Conditions and Recommendations

The soils at the site shall be generally described; specific problems or conditions shall be explained; and recommendations with the results of engineering analyses (where applicable) shall be made relative to any special embankment construction; cut slope recommendations in soil or rock; subgrade removal, replacement, or treatment; removal of unsuitable soil; drainage installations; the use of channel change materials; and/or any other factors affecting design or construction of the project. Any investigation of channel relocations shall also be a part of the report.

Whenever it is recommended to install field monitoring equipment and/or devices such as piezometers, settlement plates, and shoulder stakes, the recommendations should include the purpose and/or objective, proposed locations, an approximate schedule as to the frequency of readings, controls which can be used during construction to assure proper performance based on the design assumptions, etc.

d. Borings Logs

Logs of all borings along with a location plan shall be included in the appendix of the report. The logs shall be based on the field logs and laboratory test data. The logs shall contain all the information recorded on field logs as specified in Section F., Field Record, and the grain-size classification based on laboratory test data, and each soil layer shall be referenced to a laboratory sample number.

e. Test Data

The results of all laboratory tests on various samples shall be tabulated and included in the appendix of the report. The tabulation shall identify each sample as to boring number, depth, and sample number, and shall include all results obtained under items G.2. and G.3., as set out under Section G., Laboratory Testing. Separate tabulations shall be included for

classification test results, strength test results, and other special test results.

f. Engineering Analysis

The work described herein shall include review and correlation of various test results as to embankment stability, material placement, and other geotechnical engineering considerations. Sketches, assumptions, calculations, etc., (where applicable) of all final engineering analyses shall be included in the appendix of the report. The source of the analysis, the input and output data (properly labeled) all shall be provided if computerized analysis methods are utilized. The consultant geotechnical engineer shall also attend all field checks, conferences, etc., as requested by the State. Methods of analysis shall be as approved in the proposed work plan.

(1) Settlement Analysis

This work shall consist of performing settlement analysis at a specific cross section based on consolidation test results in fine-grained soils or based on blow count and the soil gradation in granular soils. The consultant geotechnical engineer shall furnish computations for total estimated settlement, a plot of percent total estimated settlements vs. time assuming the most likely drainage conditions, etc. The analysis can be for the proposed structure, a proposed and existing structure, etc. A quantity of one will be paid for each point analyzed.

(2) Sliding Block Slope Stability Analysis

This work shall consist of making sliding block slope stability analyses at specific sections to analyze proposed or existing conditions. One analysis will be authorized for payment for each cross section analyzed.

Factor of safety computations shall be made for various assumed failure surfaces until an apparent minimum factor of safety has been established for each analysis. The model used shall be as approved in the proposed work plan.

(3) Rotational Slope Stability Analysis

This work shall consist of making rotational slope stability analyses at specific sections to analyze proposed or existing conditions. One analysis will be authorized for payment for each cross section. The model used shall be as approved in the proposed work plan.

(4) Bridge Foundation Analysis

This work shall consist of bridge foundation analysis, including

recommendations. This shall include all analyses and computations required to make complete recommendations for a satisfactory foundation to support the proposed loading conditions at each bridge support, such as bearing capacity, settlement, and stability and constructability, as required.

A separate generalized subsurface profile shall be prepared for each bridge foundation analysis and included as part of the calculations. The drawing shall show the existing ground line, the proposed grade line, the location of the structure and its supports, the estimated soil and rock stratification within the limits of the proposed structure, the location of each structure boring, hydrologic data, standard penetration values adjacent to the boring location, groundwater levels, etc., as applicable. Each bridge analyzed shall be considered as one analysis.

(5) Retaining Structure Analysis

This work shall consist of retaining structure analysis, including recommendations which shall include conventional retaining walls, bridge abutments, bin walls, or drilled-in piers. Separate pay items as defined below will be made for either (a) shallow foundation or (b) deep foundation or any other retaining-type structures. The analyses and recommendations shall include all computations necessary to assure the constructability; and the stability of the retaining structure, including bearing-capacity settlement and stability, as required.

The analyses and computations required shall include the determination of the lateral loads which will be imposed on the structural elements, the depth of embedment required for stability of a typical section, etc. The final recommendations shall include the station limits of the structural elements, their offsets, penetration depths, and the soil and/or rock stresses for which the elements of the retaining structure should be designed. Any other design parameters which are pertinent to the recommendations for such a retaining structure should also be included as part of this item.

If a tie-back system is required, the recommendations for the tie-back shall include the capacity of the tie-backs, the penetration required for resistance and stability, the spacing of the tie-backs, and any other design parameters pertinent to the tie-back system recommendations.

A separate generalized subsurface profile shall be prepared for each retaining structure analysis as described above for bridge

foundation analysis.

(a) Shallow Foundation
This item shall include all analyses and computations required to make complete recommendations for a satisfactory shallow foundation to support the proposed loading conditions at each section. Shallow foundations are defined as spread footings, reinforced concrete mats, etc. A quantity of one will be paid for each section of shallow foundation retaining structure analyzed.

(b) Deep Foundation
This item shall include all analyses and computations required to make complete recommendations for a satisfactory deep foundation to support the proposed loading conditions at each section. Deep foundations are defined as piles, drilled-in piers, tie-back systems, etc. A quantity of one will be paid for each section of deep foundation retaining structure analyzed.

g. Geotechnical Profile

(1) The geotechnical profile shall consist of the following:

(a) Sheet 1 — Title Sheet. This may be a reproducible of the title sheet used by the design consultant for the design plans, modified as necessary.

(b) Sheet 2 — Legend Sheet.

(c) Sheet 3 — Tabulation of Classification Test Data

Classification test data shall be tabulated on a separate sheet of the geotechnical profile. Such tabulation shall include laboratory sample number, field sample number, boring number, station, offset, depth of sample, color, textural or grain-size classification, ASTM classification and the test results obtained from mechanical analysis, liquid limit, plastic limit, plasticity index, and shrinkage limits.

(d) The geotechnical profile plan and profile sheets with the borings and data shall be plotted to a vertical scale of not more than 1" = 10', and to a horizontal scale of not more than 1" = 100'. Each sheet shall be identified by control section, structure number, and project and route number,

and the scale to which it is drawn.

(e) Elevation of subsurface water levels recorded during the boring, at completion of boring, and 24 hours later, shall be indicated by suitable symbols. The use of color as a symbol will not be permitted.

(f) Additional sheets as required shall be used to plot soil or rock cross sections, peat or unstable soil profiles, rock profiles, etc.

(2) The geotechnical profile shall be prepared in ink on linen, mylar, or other material with prior approval, to provide permanent originals which will not deteriorate or fade with age.

I. SUPERVISION

1. General

All phases of the geotechnical investigation, including boring and sampling, laboratory testing, analyses, and preparation of the geotechnical report, shall be under the direct supervision of the qualified geotechnical engineer.

2. Scheduling

After the preliminary field check, as previously mentioned, the scope of work for the project should be defined on a tentative basis. The consultant geotechnical engineer shall send in writing a work plan for the completion of the field work and the date when the complete geotechnical report and profile will be transmitted to the M•DOT foundation analysis engineer immediately after the preliminary boring location plan is approved. If it appears that the aforementioned schedule must be altered during the progress of the work, the consultant geotechnical engineer shall send in writing to the M•DOT foundation analysis engineer the revised schedule and a statement explaining the reasons for the schedule change.

3. Field Supervision

During the boring and sampling phase, the consultant geotechnical engineer shall so organize the work that the consultant geotechnical engineer can spend at least one day per week per rig (minimum) with the drilling crews. If more than one drill crew is used, they shall be so operated that the consultant field geotechnical engineer can supervise them with a minimum of travel from one crew to another. Prior authorization shall be obtained regarding field supervision in excess of one day per week per rig.

4. Maintaining Cost Records

The consultant geotechnical engineer shall maintain records to reflect the running total of work accomplished for all items of work, including testing, as the work progresses. These records shall be up to date and available for inspection at all times. As the work progresses, it may be advantageous for the consultant

geotechnical engineer to consult with the M•DOT foundation analysis engineer prior to executing certain laboratory tests and/or engineer analyses. The consultant geotechnical engineer may elect to proceed with the work using reasonable engineering judgment without consulting with the M•DOT foundation analysis engineer, as long as the actual quantities used do not exceed the estimated agreement quantities. If at any time, it appears that an overrun will be necessary, the consultant geotechnical engineer shall obtain approval prior to performing work which will be in excess of the estimated amounts.