MATES

MICHIGAN DEPARTMENT OF TRANSPORTATION

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FOUNDATION ENGINEERING: SUBSURFACE INVESTIGATIONS FOR FOUNDATION DESIGN

All of our roads and structures ultimately rest upon the earth. This is a fact of highway construction that is so obvious that the public pays little attention to it. In the case of roads or small structures such as shallow drains or short retaining walls, the soil preparation is not as complicated as that required for massive and heavy structures such as bridges. If an error is made in judging the strength of the earth that supports a portion of the relatively thin slab of a roadway, the consequences are fairly minor, manifesting themselves as a crack or settlement in the road. These can be rehabilitated rather inexpensively and prove no great hazard to the public. In the case of something as massive as a bridge foundation, a misjudgment concerning strength of the earth beneath it could result in serious and expensive problems. Due to the complexity and variability of soils, foundation engineering can be one of the most difficult phases of a project. On a national level, geotechnical problems are the single largest cause of construction claims and litigation; and are estimated to total over 30 percent of all claims.

Geotechnical engineers have to deal constantly with uncertainty and variability on a scale that few can appreciate. While others are ordering materials to specification, the geotechnical engineer is busy trying to figure out what nature has seen fit to provide. There is little or no control over existing site conditions. To make matters worse, subsurface information is expensive to obtain and the geotechnical engineer must often ply his trade based upon limited information. He is often, for example, expected to predict the behavior of thousands of cubic yards of earth on the basis of information that he can glean from soil samples so small that he can carry them in one hand.

In order to design and construct a safe, functional, and cost-effective foundation, three key factors must be evaluated for every individual job. The first factor relates to the adequacy of the subsurface information. Are the locations, types, and depths of borings sufficient? Are soil descriptions satisfactory? Are the resistance of the soils to penetration by the sampler (blow count) and/or laboratory test data sufficient and adequate? Is there proper groundwater information?

The second factor deals with the type of foundation under consideration. Is the foundation type (such as spread footings, piles, drilled shafts) appropriate? Are temporary construction techniques such as dewatering or braced excavations required?

The third main factor addresses bearing capacity, general stability, and settlement analysis. Are loadings to be imposed, sufficiently less than the capacity of the soil to allow the foundation to function properly? Are structural settlement or instability a problem?

This article will be devoted to examining subsurface investigations in more detail. A later article will concentrate on the other key factors. Much of the following material has been condensed from the ASCE manual on subsurface investigation for design and construction of foundations of buildings. The subsurface conditions for structures, even modest ones such as small diameter culverts, should be investigated before their design is undertaken.

The purpose of a foundation exploration is to determine the extent, thickness, and location, both vertically and horizontally, of the soil under a site and the appropriate physical properties of each layer. The soil profile is determined by making borings, generally with a hand-operated or power auger, from which samples of soil are recovered for identification and testing. The appropriate physical properties of each layer include the soil's strength, compressibility, and permeability. These physical properties may be determined from direct tests on undisturbed samples recovered from the ground, or from indirect tests, where no soil sample is recovered. Indirect tests include resistance of soils to penetration by a sampler, vane shear tests, pumping tests, plate bearing tests, and pile load tests. The number, depth, spacing, and types of tests to be made in any individual investigation are dependent upon site conditions, type of structure, and its requirements. Thus, no firm rules can be established, though general principles for guidance can be outlined.

Planning a soils or foundation exploration program includes determining the depth and location of borings, and establishing the methods of soil sampling and tests to be employed. Usually, the total extent of the work must be established as it progresses, unless knowledge of foundation conditions is available from existing geological studies, earlier investigations, or records of the existing or adjacent structures.

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 of 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.

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.

Soils Classification and Testing - In determining the type of soils, the basic group—gravel, sand, silt, clay, or organic (peat, muck, etc.)—to which they belong must be given. Further, terms describing the soil in greater detail, such as consistency, degree of compaction, color, odor, shape of grains, presence of minor constituents, and other factors, should be noted. Stratification, interbedding, etc., should always be noted. A soil description should cover all soil components contained in the samples. A driller may sense, though the action of the drilling tools, the probable presence of gravel, cobbles, boulders, or even rock, but with no recovery of such materials. A note to this effect should be included.

Groundwater - Knowledge of groundwater conditions and the effect of the proposed construction upon groundwater levels are frequently of importance. Factors to be considered include groundwater levels and their seasonal variations, means of dewatering for construction, the effects of dewatering on existing structures or other nearby facilities, the effects of dewatering upon adjacent water supplies, hydrostatic pressures on the structure, etc.

With the above general concepts in mind, a review of MDOT practice is appropriate. Presently, most subsurface foundation investigations are conducted by M&T's Central Office Foundation Design and Analysis Unit. They are responsible for borings, sampling, testing, soil mechanics analysis, and foundation recommendations. In those instances where the Department contracts the work to be done, M&T or the Design Division are generally responsible. The boring frequency for most structures is one boring per substructure unit (such as a bridge pier) under 100 ft long and two borings for footings longer than 100 ft. For retaining walls and sewers, one boring every 300 ft, and for deep cuts and high fills, one boring every 200 to 500 ft. The sampling frequency for sands and gravels is every 5 ft 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 ft below the estimated bottom of the piling. The sampling frequency for cohesive (clay-like) materials is every 5 ft in depth to a depth of two times the footing width or 30 ft, 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 3200 lb/sq ft, undisturbed samples are obtained and sent to the laboratory for testing. SPTs are taken in place of undisturbed samples if consistency is greater than 3200 lb/sq ft. 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 3200 lb/sq ft is usually limited to in-place SPTs. For lower strength cohesive materials, undisturbed samples are collected and returned to the laboratory for testing. Groundwater table information is obtained at each boring location.

The above MDOT guidelines are for routine foundation investigations. They are modified as necessary by the Foundation Analysis Engineer to meet the needs of individual projects. Paying close attention to the earth upon which our highways and structures rest is one of the most basic—yet crucial—elements in the design of modern transportation facilities.

–J. M. Ritchie

TECHADVISORIES

The brief information items that follow here are intended to aid MDOT technologists by advising or clarifying, for them, current technical developments, changes or other activities that may affect their technical duties or responsibilities.

NEW MATERIALS ACTION

The New Materials Committee recently:

Approved

Pentaseal Dust Palliative - Astro Oil Company
Superb Grout 611 - Specco Industries, Inc.
Brick Gasket Liner Sound Barrier Facing - Scott Systems, Inc.
Mountain Grout - Specco Industries, Inc.

It should be noted that some products may have restrictions regarding use. For details please contact Don Malott at (517) 322-5687.

MDOT RESEARCH PUBLICATIONS

Development of A Computer Program For Design of Pavement Systems Consisting of Layers of Bound and Unbound Materials, by R. S. Harichandran, G. Y. Baladi, and M. S. Yeh. This study, sponsored by the Michigan Department of Transportation in cooperation with the Federal Highway Administration, was performed by Michigan State University's Civil Engineering Department. It resulted in the development of a nonlinear finite element program (MICH-PAVE) for use on personal computers to aid in the routine design and analysis of flexible pavement structures. Three major achievements have been accomplished in this research. First, a new concept of utilizing a flexible boundary in pavement analysis has been introduced, and its characteristics fully investigated. Second, an extremely 'user-friendly' nonlinear finite element program for pavement analysis and design has been implemented on personal computers. Third, two empirical equations to predict fatigue life and rut depth have been developed for use with nonlinear finite element analysis. In the MICH-PAVE program, the pavement is represented by an axisymmetric finite element model, and the resilient modulus model together with the Mohr-Coulomb failure criterion is used to characterize the nonlinear material response of granular and cohesive soils. Extrapolation and interpolation techniques have been used to improve stresses and strains at layer boundaries. Results from a variety of analyses have been compared with exact solutions (when available), and with the results from existing computer programs. Extensive sensitivity analyses have also been performed to explore the capabilities and limitations of the program.

Legibility and Visibility of Retroreflective Sign Materials, Research Report No. R-1304, by R. E. Nordlund, D. C. Long, G. M. Smith, and V. C. Andrews. This report covers the investigation of the relative effectiveness of major retroreflective sign materials. Three white legend materials (demountable characters with reflector buttons, Type III encapsulated lens high intensity retroreflective sheeting, and Type II enclosed lens engineering grade retroreflective sheeting) and three green background materials (Type III sheeting, Type II sheeeting, and non-reflective paint) were used in various combinations of legend and background. A group of 11 observers were driven through a test area where both an overhead and a roadside sign were displayed with the legend/background combinations, and the observers rated the combinations for legibility and visibility under both day and nighttime conditions. The study found that demountable characters with reflector buttons were the preferred legend material for night and day. Type III and Type II sheeting were equally preferred background materials for the above legend material. Type III legend on Type II background was the favored sheeting-on-sheeting sign combination. The report recommends that the Department further investigate the use of demountable characters with reflector buttons, and that a follow-up investigation be initiated to study the effectiveness of signing combinations of newly available materials.

This document is disseminated as an element of MDOT's technical transfer program. It is intended primarily as a means for timely transfer of technical information to those MDOT technologists engaged in transportation design, construction, maintenance, operation, and program development. Suggestions or questions from district or central office technologists concerning MATES subjects are invited and should be directed to M&T's Technology Transfer Unit.

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