GEOTECHNICAL INVESTIGATIONS, FOR NON-SEISMIC CONDITIONS, CONDUCTED FOR PLANNING, DESIGN, CONSTRUCTION AND MAINTENANCE OF TRANSPORTATION FACILITIES

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Abstract

In the majority of cases, geotechnical investigations for transportation facilities are conducted without consideration for seismic conditions, since the probability of seismic events is small. Included in this paper is a synopsis of current accepted practices for project planning purposes, for information leading to designs, for monitoring construction, for remedial studies and maintenance. Applications of standard testing methods are discussed for typical soil/rock profiles, site and project situations.

Laboratory and field testing methodologies, which may be applied during geotechnical investigations for transportation facilities, are discussed. Applicable published reports and standards for geotechnical investigations are discussed. The use of geophysical survey information, and how it can augment currently used methodologies is discussed.

The conclusions include a synopsis of current practice philosophy along with how geotechnical investigations can become more definitive using geophysical survey methodologies.

Introduction

The purpose of a geotechnical investigation is fact finding to support the process of analysis and design, no matter what the project situation. In particular, the facts to be found relate to earth materials which will influence and interface with or become part of the project under consideration. This paper is meant to contain an overview of the geotechnical investigation process, a synopsis of the available publications which can be used as resources for planning an investigation, and a discussion of how geophysical survey methodologies can be useful in better defining earth materials for transportation projects.

Transportation facilities are of such diversity that projects, which involve parts or all of them for purposes of feasibility studies, new construction, remedial corrections and maintenance, can include practically all kinds of construction attempted for civil works. These include, in part, slopes, cuts, fills, tunnels, pavements, bridges, bridge approaches, retaining walls and buildings for roadways. The listing becomes even larger when airports are added, with their parking facilities, aprons, taxiways and runways. In addition, railroad track systems, crossings, control structures and other supporting elements add to the listing. Finally, there are those associated with water transport such as docks, wharves, channels and other water control devices. With the possible exception of high-rise buildings, transportation projects include all types of constructed works.

Background

The process followed for geotechnical investigations, although project type specific, is well established and utilized by geotechnical engineers. The basis for engineering design, which will utilize the information obtained, is management of the risk of some kind of failure with the level of funding needed to prevent that failure. Although not absolutely true, it is possible in almost all cases to expend enough funding on information gathering and construction to essentially eliminate failure. The problem is that the level of funding to absolutely prevent failure is not practical or available for almost all transportation projects. Therefore, it is up to those engineers involved to manage the risk to acceptable levels and provide a failure safe and economical project.

The definition of a failure for a transportation facility includes far more than a materials strength failure of some sort. Displacement of part or all of the facility, when excessive, will constitute a failure. Cracking and buckling of pavements systems can render them useless. Erosion of materials either supporting or constituting parts of a transportation facility may eventually close the facility. The key to proper performance in the case of a lock and dam or channel may be that they be able to hold water. Whatever the definition of failure, the level of risk of that failure must be managed to the point that the facility be useful throughout it's design life, or far beyond since many are used indefinitely. Only with sufficient information about the materials to be used for construction is it possible to predict their behavior as utilized and thereby effect a design which will meet expectations.

It is well recognized that the variance and diversity of earth materials far exceed those of any other type. In addition, within the limits of a specific project the variance of properties and locations of earth materials types can be significant. It is imperative, therefore, that sufficient information be made available about these materials, from field and laboratory studies, to predict their behavior in such a way as to reduce the risks taken to acceptable levels. It is not possible to sample and test all materials that affect the project, or, in most cases, provide materials of known behavior, so that the performance and life of the project depend on the geotechnical investigation. Because of this it is recommended that those selected to conduct such investigations be chosen using Quality Based Selection procedures.

While there are those entities which own transportation facilities which continue to conduct geotechnical investigations, many have or are in the process of moving to out sourcing these services to be done. This means that the processes and methodologies used are those of the general engineering community, not those followed, necessarily, by the owners' investigating personnel. In both cases, in house and out sourced, the investigations must comply with the standard of care utilized for the local in which the project exists. For this reason the guidelines given by most publications are flexible and should not be taken as more than the least investigation needed.

Available Publications

Considering the experience level of readers and the availability of information in many forms, the author chooses to provide a listing of the most prominent and modern publications found available on this subject. This listing is considered to include the most applicable found using Web search and library search techniques. The organizations whose members are most active in setting standards for transportation facilities include AASHTO, the Transportation Research Board, ASCE, ASTM and ASFE. In addition, agencies such as departments of transportation and the U.S. Army Corps of Engineers have standards. There are available, also, reference texts on the subject. These publication listings may be found at the end of this paper.

The author has decided to provide these listings because of the reality of standard of care practice varying from agency to agency, and especially between economic and geologic regions. The following discussion will provide a general overview of what is believed minimal for adequate fact gathering.

The Investigation Process

Whether an investigation is done with agency personnel or by a firm out side the agency, the process followed is similar. The largest difference is how the contracts are set up to do the investigation and the relationships between agency and those conducting the investigation. If done by those employed by the agency or owner, the initial steps are those of internal contacts and planning to utilize the resources of manpower and equipment. Communication of information should be simplified and interactions eased by the fact that all involved are working for the same entity. When a firm outside the agency performs the investigation, the first steps involve initial contacts to contractual agreements, before coordination and conduct of the investigation.

Agencies and owners of transportation facilities contractual matters are not within the scope of this paper; however, the ways in which outside firms are contacted and contracted are dependent on agency rules and laws which apply in each case. The consensus within the engineering community is that a process of selection should include quality-based information and not be based on a process of bidding for work. The nature of the importance of the quality of investigation to the future of the facility cannot be overemphasized.

Geotechnical investigations can be made at several stages during facility planning, design, construction and operation. They can be part of the planning/discovery process for a project in the site-selection phase on one extreme or they can be conducted because of maintenance problems well after the facility is in use in the other extreme. The size of the study and the time required to complete it are dependent on the size of the project for which it is done, the level of detail needed for the purpose done, and the real or imposed deadlines when information must be available. The expense of the investigation is directly related to the amount of information needed, the difficulty of obtaining it and the time constraints placed on the investigation. It is a reality of the situation that investigations for remedial purposes are generally more problematic and include a shorter time frame for completion. For these reasons it is wise and economical to have investigations done early in project planning and design, and done so as to preclude the need for remedial actions later.

Preliminary investigations are used for corridor studies and route selection studies. They may also be conducted before more detailed studies to determine the general subsurface situation for planning purposes. Time constraints are generally not a problem for preliminary investigations. Pre-design investigations are the most generally utilized type. When properly timed they can be economical and provide information to reduce risks. Investigations taking place during design are generally more rushed and may well result in more risk being accepted. During construction the need for an investigation causes delays in project progress, thereby making it difficult to achieve an economical or comprehensive investigation. Depending on the after construction or during operation problem that prompts the need for an investigation, the type done can either have severe time constraints or not. Most of the time, however, these types of investigations have severe time constraints and are expensive. After all of this is said, it is important to note that the information needed is very much situation dependent for all investigations and must conform to the ideas of the risks which can be taken versus the time and funding available to do the investigation.

Every investigation begins with communication of project information. This information includes the type, size and location of the project, the time constraints on the investigation, the material properties already known and the location of utilities and other things present that would have to be avoided. If the investigation will involve operating transportation facilities, arrangements must be made for access and safety. Although this is just the start of the communication process, it is important that as much project and safety information as possible be transmitted.

Before anyone of the investigation team goes to the field a review of existing information that may apply to the project is undertaken. This “literature” review will include available reports of earlier investigations or projects, journal articles or reports written covering the same or similar geologic situation, geologic and roadway maps, USDA soils reports, and topographic maps. In addition, available aerial photos or remote sensing information may be consulted. Other sources of local information gathered by talking to people or looking at public records, such as well drilling logs, will aid in the process, as well. Finally, personal phone conversations and available in-house records, such as previously done geophysical survey information, will assist in this process. The concept is to gather as much information about the geologic constraints, soil conditions and access to sampling sites as possible. Following this step the plans for the tentative field exploration program are formulated.

The next activity is a field reconnaissance trip. This trip should based on formal objectives, such as determining the nature and a real extent of major geologic units, to gain appreciation of their engineering characteristics and to develop site region geologic information. This trip should verify the information already gathered and further assist in the planning of the field exploration plan. The questions of locations of utilities and other barriers to the investigation present and the access to sampling sites will be answered during this trip. The results of this effort will include a compilation of a preliminary geologic map of the estimated conditions, a scope of estimated field exploration activities and a means for conducting a briefing for the planning/design/environmental impact team.

While the subsurface investigation equipment and personnel are being readied, field geologic mapping can begin to answer requirements identified during the field of reconnaissance stage and those are to develop during meetings. The rate at which geologic maps can be produced is directly related to the level of detail and complexity of local geology. Plans for test pits and boring locations will be set to determine the maximum of information about the variability and extent of assumed subsurface materials.

Drilling, probing, and trenching should be undertaken only on the basis of a formalized plan. The plans should be based on geologic interpretations gathered at the time of initiation of field work, and should be reviewed and updated according to findings during field geologic mapping and as a result of the subsurface investigation program as it proceeds.

Subsurface investigations should be reviewed on a daily basis by the field supervisor in brief discussions held between geologists and geotechnical engineers assigned to drilling rigs and other excavation equipment and the mapping geologic team. All should come away from the meetings with improved field plans.

The number, frequency and depth of borings are the major variables that must be decided as the investigation is planned and conducted. There are guidelines available from the sources previously given, but these must be taken as minimum levels based on general situations. Local standards of practice must also be taken into account, since they are based on experience with similar subsurface and project situations. The following discussion about these variables will be based on a mix of published information and experience gained by the author and others. It has been found that the frequency of boring and sampling may well be more affected by economic factors or local practice than the materials investigated or the needs for information. These factors will be discussed further later as reasons for applications of more geophysical survey methodologies.

When considering a single unit of a transportation facility, such as a bridge abutment, there are those who would consider one boring as sufficient. However, the smallest statistically significant number would be three. This could be considered as an important fact, considering the horizontal and vertical variance of subgrade materials.

Also, it appears that many times the pattern of boring used places them in a straight line in alignment with the major axis of the plan of the abutment. If this is done, however, the variance of materials in the direction perpendicular to this line is unknown. There have been cases where this sort of sampling has lead to tipping of the abutment during or after construction, an unacceptable and expensive occurrence. It would have been much better to spend a bit more on borings to save the cost and embarrassment of such an occurrence. Of course, the same argument can be made about the depth of borings and the number of samples taken or field tests done. The answer is to do enough borings and tests, and take enough samples to be reasonably sure the variance of materials, both horizontally and vertically, is known. This is one of the concepts which supports local practice, because this sort of situation should have been encountered before, so long as the reason for local practice is the amount of information needed not just economic considerations. One of the strongest arguments for geophysical surveys is that they can provide information on the variance, which will normally reduce the number of borings needed.

Examples of the frequency and depth of borings can be characterized broadly by facility type. For two lane highways the borings should be spaced at 500 feet intervals and at changes in material types, while multi-lane highways this is normally at 250 foot spacing on alternate lanes or when materials change. Fills that are 10 to 20 feet high normally call for boring spacing of 350 feet and at changes of materials. Higher fills of 20 to 40 feet would call for 250 foot spacing and this would reduce to 200 feet for fills over 40 feet high. Borrow areas are normally sampled on a 250 foot spacing grid. Borings should extend to 10 foot depth for pavements, while embankment borings are about as deep as the fill is high and borrow areas should be sampled to 20 feet or depth of borrow expected, or the depth to the ground water table. Rock encountered should be carefully traced out and should be penetrated at least 2 ½ feet below the expected finish grade of subgrades for pavements. The penetration depths are similar for airfield pavements, and fills and cuts are generally less than 10 feet. Runways should be have borings spaced along two lines parallel to the centerline and 125 feet either side of it. These boring should be spaced at 250 foot intervals along the lines. Parking aprons and taxiways call for borings to be spaced on 250 foot intervals or 250 feet apart along the centerline.

Borings for bridge support structures have been discussed somewhat already. The normal spacing along the transverse profile should be at the quarter points. It is suggested that consideration be given to some spread in the lateral direction as well. The depth is as is needed to penetrate and sample materials that will support the structure foundation system. If rock is encountered it should be penetrated to a depth of at least 20 feet. Foundation systems must be placed adequately below expected scour depths and boring should extend at least 1-½ times the least dimension of foundation system elements. Scour has been noted to a depth of three times the maximum height of rise of floodwaters. One suggested frequency of borings per pier is based on pier size. If less than 500 square feet in plan one boring is sufficient. For piers between 500 and 1000 square feet in size at least 2 are recommended and for larger piers at least 4 borings are recommended. The foregoing are mentioned to assist the reader and not as a standard for use, even a minimum standard. Previously discussion concerning risk versus investment in borings should be noted.

When investigating materials to be cut the borings should extend the depth of the cut below the level of the finish elevation of the cut section. Retaining walls are major structures that call for a boring every 10 feet of wall length with minimum penetration of 10 feet into the subgrade. For other rigid frame structures the suggested spacing of borings is one for every 2500 square feet of plan, which is a conservative spacing, normally. In each case the borings should extend at least 1-½ times the least dimension of any supporting element. The discussion concerning the variability of materials applies to the spacing of borings for all structural facilities as it does for bridge abutments.

Sampling of materials for the purpose of identification can be done by many methods, so long as it is reasonable to identify the depth from which the materials came. Sampling for the purpose of testing is done differently if only depths to differing layers are wanted or if the continuity of layers is needed. It is important to collect samples of the correct type for the tests to be done at each layer of material and is normally done at intervals from 2 ½ to 5 feet in depth. Continuous sampling is done to determine the continuity of layers or the material properties continuously with depth. Rock cores are generally done continuously to determine the Rock Quality Designation of the materials. Because of it's importance to the long term stability of facilities founded on soil materials, the depth of the ground water table is always determined, and the effects of the seasonal variations of it are inferred from the date when the determinations are made.

Field testing may be done as a necessity, since samples of the materials of interest cannot be sampled and returned to the laboratory for testing, or may be done to replace or supplement testing done in the laboratory. The use of field-testing should be part of the planning and scheduling of the investigation, as remobilization to conduct these tests is usually prohibitive in cost. The most frequently used field test in cohesionless materials is the Standard Penetration Test (SPT). Some have applied it to cohesive soils, but it is not recommended for use in these soils because of excessive disturbance and pore pressure unknowns. The Cone Penetrometer Test (CPT) is the next most widely used field test. It has been applied to nearly all types of soils and gives both an end resistance and side shear resistance as it is pushed into the subgrade. There are available extensive correlations between SPT and CPT results and correlations to soil properties and capacities of foundation elements. Some states, such as Texas, have developed and correlated results of their own differing cone penetrometer tests to material properties, as well. Information of how these tests are conducted is available in the ASTM standards, and Texas D.O.T. testing manuals.

Less utilized, yet still significant, other field testing methods include dynamic penetration tests, pressuremeters, stress or shear devices and permeability tests. Pressure meter tests, such as the Menard Pressuremeter Test, the Self-Boring Pressuremeter Test and Dilatometer Test, have been utilized a good deal and there have been correlations developed for their applications to design. Stress and shear device tests include the Hydraulic Fracturing Test, the Vane Shear Test and the Borehole Shear Test. Correlations of the results of these tests to design parameters are also available. Field permeability tests include percolation tests, water pressure tests, pump tests and hydraulic conductivity tests, which have all been used extensively. Although field tests provide information without laboratory testing and are believed superior by some to better represent in situ subgrade conditions, they are normally done in conjunction with the normal boring and sampling process described above and, therefore, provide information about materials only where utilized.

Test conducted in the laboratory to determine the properties of subgrade materials are aimed at predicting behavior to enable design. The types of tests used include those to establish the basic identity and enable classification of materials, such as grain size distribution tests and Atterberg Limits tests, to those used to evaluate strength and durability under expected field conditions. Project type and materials being tested determine the specific tests applied. There are available through ASTM and most transportation agencies testing standards to cover all situations. Tests that are generally used include sieve tests, hydrometer tests, liquid limit tests, plastic limit tests, compaction tests, consolidation tests, unconfined compression tests, California Bearing Ratio (CBR) tests, swell tests of differing kinds, and sometimes triaxial shear and permeability tests. Resistances to wetting and drying situations are tested, as well as resistance to freezing and thawing. Many times local practice will indicate widely accepted tests and will be followed.

The purpose of the overall investigation is to determine information to allow design and construction of the project with acceptable risk of unknowns. When laboratory testing is utilized there are at least two very important principles which should be followed. The first is based on the expected variability of earth materials. To establish a property of a given layer of material at least three tests of any type should be done for this purpose, since three is the least statistically significant number. The second principle has to do with testing materials for prediction of field behavior. Each test should be conducted with materials prepared in such a way to best represent field conditions and should be tested using the worse case scenario to predict material behavior under those conditions. Illustrations of what is meant by this are large diameter specimens compacted using field gradation specifications, soaked CBR and Unconfined Compression Tests, and the use of a residual strength direct shear test for slope design information in clay soils. The experience records of transportation agencies are filled with examples of material failures that could have been prevented by such testing.

The sum result of geotechnical investigations conducted without the use of geophysical survey methods is a document containing the probable location, vertically and horizontally, of earth materials based on fairly widely spaced columns or excavated volumes of these materials. Each individual having much experience at all can relate how much remains unknown about the materials that will actually be involved in the project. There are the stories of how a filled-in stream was encountered which was unknown, or how the top of rock was so erratic in a limestone residual material that it was either missed altogether or was there near the surface in borings but no where else. These, among the many other examples, support the use of geophysical survey methods to reduce the unknowns and thereby reduce the risks taken.

Geophysical Survey Methodologies

Geophysical techniques applied to geotechnical investigations can be characterized the two general groups: investigations conducted from ground surface and those conducted in boreholes. Each group is further separated in the two basic modes of data generation, those using measurement of existing earth fields and those using measurement of fields induced deliberately for the purpose of the investigation. Investigations conducted from ground surface typically provide information about the subsurface both laterally and to some depth, while most of the borehole investigations, with some exceptions, provide detailed information about materials only in the intermediate vicinity of the borehole or between boreholes. The testing energy fields and the induced energy fields pertinent to two adjacent hole investigations include:

Existing Fields (Passive)
Gravimetric
Electric
Magnetic
Thermometric
Nuclear

Induced Fields (Active)
Seismic
Acoustic
Electric
Electromagnetic
Nuclear
Ground Penetrating Radar (GPR)

Interest in existing energy fields occurs because the strength of the field of any particular point can reflect the geological conditions present between that point in the source of the field. Examples of what can be determined include proximity of bedrock, varying stratigraphic conditions, hydrologic conditions, or mineral changes indicative of the stratigraphy present. Interpretations of anomalies may be ambiguous since anomalies may be due to natural geological conditions or to the manner in which geophysical measurements were made.

Geophysical methods that rely upon the reaction of subsurface materials to energy introduced by some deliberate process are typically more much more versatile for geotechnical purposes. The appropriate equipment can be selected, the locations for investigation chosen, and parameters measured in accordance with the specific project requirements, provided that the measurements are within the ability of the geophysical techniques to be applied. Selection of the methods are methods appropriate to measure are derived needed parameters must be based on a knowledge of how the resulting data are to be used, and how the data should not be used.

A combination of several complimentary methods usually provides more information and detail than might be expected. The purpose and limitations of any particular investigation should be clearly understood before selecting the approach to be used. All potential aspects of investigation should be considered in terms of what the geophysical methods can provide. Because a moderate amount of additional effort in data collection may add a significant increase in the volume of additional information with somewhat broader application, a most cost-effective investigation can often be designed so that the need for later geophysical surveys can be avoided.

The data derived from geophysical investigations usually have to be interpreted by experienced geophysical analysts prior to use by engineering geologist by geotechnical engineers. In all but a few applications, such as reconnaissance investigations for example, the results of geophysical investigations should always be supported by direct observation of subsurface conditions by means of borings, tests pits, trenches, outcrops and other geological information. In this way geophysical data augment that found using these methods to assist in explaining what lies between other sampling sites.

Each geophysical technique has facets that, if not recognized, can cause serious misinterpretation or misuse of the results. Awareness of the potential for error must be recognized and anticipated so that proper calibration of the results is possible. The potential for helpful information is great, utilizing these methods, but it is essential that properly trained people with experience be involved to achieve the maximum from these methods.

Measurements of existing geophysical fields and resulting interpretations range from detailed gravimetric plan maps showing relative depth of bedrock, to the identification of zones and flow rates of moving groundwater penetrated by boreholes. In each case, the density of surface observation stations or frequency of borehole recording or measurement points establishes the resolution level of the data collected.

The induced fields of geophysical techniques are more widely used and passive techniques. Joint use of both induced and existing Fields is common in some types of investigations. Selection of the method used in the induced case can be based upon the need for depth of coverage, in the case of traditional seismic and GPR seismic, electrical, or electromagnetic studies, versus the specific type of information needed as in seismic, acoustic, nuclear or electrical studies. Resolution capability is also selectable to some degree, with resolution increasing as the density of observation points or rate of observation is increased. The following table indicates which geophysical methods can be used to investigate geologic conditions that may be important in the signing of transportation facilities. An understanding of limitations of these methods is essential to understand their actual usefulness.

Seismic methods, refraction and reflection, involve measurement of the transmission velocity of mechanical waves in soil and rock units. Seismic wave velocities are controlled by the density of the materials and the presence of discontinuities such as joints and faults. The density measured for an earth material is affected by its mineralogy, velocity, moisture content, degree of saturation, and the degree of fracturing of the material. Seismic wave velocities are indicative of the gross or bulk nature of these combined material characteristics. During traditional seismic surveys energy is imported to the ground by striking a plate on the ground with a sledgehammer or by setting off an explosive charge of the ground surface or in a borehole. The travel times of the seismic waves from the energy source to the geophones are measured by a seismograph. The distances of the geophones from the energy source divided by the travel times indicate the seismic wave velocities of the materials through the mechanical waves traveled. Reflection methods utilize the reflection of mechanical waves at the interfaces of different materials. Reflection methods utilize a reflection of mechanical waves at the interfaces. Reflection methods are best suited for use on land.

Ground penetrating radar utilizes high frequency radio energy waves to conduct seismic surveys. Instead of mechanical wave velocities, GPR utilizes differences in the dielectric constant to develop a reflection data signature for specific geologic situations. Both transmitting and receiving antennas I moved across the top of the ground or are placed inside of boreholes to develop reflection data.

Electrical resistivity methods utilize the differences in the electrical resistivities at different earth materials. Since the resistivity of earth materials are affected by mineralogy, porosity, degree of saturation, moisture content, and the chemistry of pore fluids, electrical resistivity surveys can be used to define subsurface layering, locate cavities and gravel pockets, and locate the groundwater table. Electrical resistivity array consists of four electrodes that are pushed into the ground. Two of the electrodes transmit an electrical current to the ground and the other two electrodes measure the voltage drop in the earth materials between the current electrodes. The resistivity of earth materials can be calculated using a form of Ohm’s law.

Gravity methods involve the measurement of anomalies in the gravitational field of the earth, which are due to differences in the density of materials in the subsurface. For example, an air filled solution cavity would result in a gravity anomaly and a trough or pinnacle in the bedrock surface would also appear as an anomaly when compared to the gravity readings in surrounding terrain.

Magnetic surveys measure major changes in the magnitude in the total magnetic field of the earth which are due to the presence of earth materials which contain significant amounts of magnetite or hematite and therefore have high magnetic susceptibilities. Magnetic surveys may be performed with ground-based or airborne magnetometers. The primary use of magnetic surveying is locating potential iron ore deposits, but magnetic surveying can also be used to locate basaltic igneous intrusions.

Borehole logging can involve electrical, radioactive, mechanical, and thermometric measurements that can be made in a borehole. Borehole logs can be calibrated by comparing them with cutting logs are descriptions of cores taken from the borehole. Borehole logging of shallow holes can be used to identify stratified sedimentary deposits such as sands, clays, and organic materials. They can also be used to identify rock units containing radioactive material and to distinguish permeable sands from impermeable sands.

Nuclear methods involve measurement of natural gamma radiation in a formation, or the backscatter on radiation as the result of bombardment of the formation by gamma radiation or neutrons. The first of these provides data on the uranium content of a material, while the second can be interpreted to find the density of the material. Neutron water detection measures the moisture content of the material.

Two methods exist for the downhole sonic investigations of boreholes: the sonic borehole imagery method and the continuous sonic velocity method. In the sonic borehole imagery method, pulses of high frequency sound are emitted from a transducer and are reflected from the high impedance surfaces of the borehole wall. The transducer is rotated about the central axis of the borehole and the detected reflected waves are transformed into electrical pulses which are used to present an image of the borehole wall on a cathode ray tube. The continuous sonic velocity method measures the travel times of seismic waves along the borehole wall between two transducers on a tool that is lowered or raised in the hole. The seismic wave velocity in a material will indicate something about its density.

Television cameras lowered into boreholes can be used to visually inspect the conditions of the borehole walls and to make videotape records of observations for later analysis. The use our borehole television cameras requires that the borehole be dry or filled with clear water.

Geophysics Applied to Investigations for Transportation

Conditions to be Investigated	Useful Geophysical Techniques	
	Surface	Subsurface
Depth of Stratified Rock and Soil	Seismic Refraction GPR	Borehole Logging
Depth to Bedrock	Seismic Refraction, GPR, Electric Resistivity	Borehole Logging
Depth to Groundwater Table	Seismic Refraction, GPR Electric Resistivity	
Location of Highly Fractured Rock And /or Fault Zones	Electric Resistivity	Borehole TV Camera
Bedrock Topography	Seismic Refraction, Gravity, GPR	
Locations of Planar Igneous Intrusions	Gravity, Magnetics, Seismic Refraction, GPR	
Solution Cavities	Electric Resistivity, Gravity, GPR	Borehole TV Camera

Isolated Pods of Sand, Gravel, Or Organic Material	Electric Resistivity	Borehole Logging
Permeable Rock and Soil Units	Electric Resistivity	Borehole Logging
Topography of Lake, Bay, or River Bottoms	Seismic Reflection (Acoustic Soundings), Side-Scan Sonar	
Topography of Lake, Bay, or River Bottom Sediments	Seismic Reflection (Acoustic Soundings)	
Lateral Changes in Lithology of Rock and Soil Units	Seismic Refraction, Electrical Resistivity, GPR	

The use of geophysical survey methods during a geotechnical investigation has the potential to enhance the total knowledge of project earth materials. When properly applied, by experienced and knowledgeable people, and when their strengths and limitations are taken into account, the results provided by these methods can significantly reduce the risks taken during design and construction of facilities.

Summary and Conclusions

This report includes a general discussion of the purposes of geotechnical investigations, their planning and conduct. Emphasis has been placed on the understanding and reduction of risks associated with utilizing the limited information available from these investigations. In lieu of a bibliography, a listing of available references and organizations where information if available are given. The general review of standard practice is based on the reference materials available and the author's experience with investigations in Missouri, Texas and Oklahoma, and is not meant to be an exhaustive coverage of all local practices. The introduction of geophysical survey methods is a general overview.

The purpose of geotechnical investigations as part of the planning, design and construction of transportation facilities is to provide information about earth materials that will affect the project and enable prediction of their behavior. The amount of risk of failure related to earth materials taken during the design, construction and operation of these facilities is indirectly proportional to the extent of the knowledge available about these materials. A balance between necessary levels of knowledge and the cost of obtaining that knowledge must include consideration of the risks involved and the inherent variability of earth materials. The use of geophysical survey methods, in conjunction with a well planned drilling, sampling and testing program can significantly and economically reduce the risks that are ultimately taken.

Applicable Publications

Publications available from AASHTO:

Manual on Subsurface Investigations, 1988.

Interim Specifications and Methods of Sampling and Testing, Adopted by the AASHTO Subcommittee on Materials, 1989.

Publications available from ASCE:

Foundation Engineering: Current Principles and Practices: Proceedings of the Congress, Evanston, Illinois, June 25-29, 1989, Edited by Fred H. Kulhawy, Geotechnical Division, ASCE, 1989.

Advances in Site Investigation Practice, C. Craig, ASCE, 1996, 958 pages.

Soil Sampling, Technical Engineering and Design Guides as Adapted from the U.S. Army Corps of Engineers, No. 30, ASCE, 2000, 224 pages.

Publications available from ASFE and ASTM:

Members of ASFE can receive publications on this subject by contacting ASFE. Non-members can purchase publications on this subject.

Members of ASTM can purchase at reduced cost standards for testing earth materials by contacting ASTM. Non-members can purchase these standards also.

Recently published reference text:

Geotechnical Engineering Investigation Manual, Roy E. Hunt, Mc Graw-Hill, 1984, 983 pages.