A2L01: Committee on Exploration and Classification of Earth Materials
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Exploration and Classification of Earth Materials

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Engineering geologists and geotechnical engineers are concerned with the evaluation and application of all remote sensing, surface, and subsurface methods of exploration. In addition, they are interested in the application, evaluation, and correlation of all existing and proposed earth material classifications, surveys, and associated survey techniques.

STATE OF THE PRACTICE

During the latter part of the 20th century, conventional methods of exploring and classifying earth materials for transportation projects have evolved dramatically, and promising new technologies have been developed that have not yet been adopted as conventional methods. Traditional exploration consists of (a) direct observation of drilling or excavation progress (penetration rate, rig performance, returned cuttings) and exposures, and (b) collection, examination, and testing of samples of subsurface soil and rock materials and fluids. Individuals who make the field observations typically are trained and experienced engineering geologists or geotechnical engineers, or both.

Current state-of-the-practice exploration methods consist of both invasive and noninvasive procedures. The primary invasive equipment consists of drill rigs, excavators (backhoes), and bulldozers. Down-hole tools for drilling equipment developed during the past century have been improved to allow efficient advancement and collection of reasonably high-quality samples of soil and rock materials and subsurface fluids. The most common method of sampling soil is the Standard Penetration Test for disturbed samples and blow-count data. Relatively undisturbed samples of soft soils can be obtained with Shelby tubes. Core barrels are used to obtain samples of fresh and weathered rock. Core barrels that retain the orientation of the samples for rock structure analysis are available.

Drill rigs can be mounted on vehicles for use in areas where access is relatively easy, or on small platforms or even tripods where difficult access requires helicopter assistance or manual labor. Drill rigs can advance down-hole tools and return cuttings by the use of augers (flight or bucket) or circulating fluid (air, water, or slurry), depending on the nature of the formation to be sampled and the depth required. Inclined borings are used to intersect vertical rock structures or to obtain samples vertically beneath buildings or bridge foundations. Samples obtained with down-hole tools can be nearly undisturbed, but some disturbance often occurs. Additional down-hole tools, such as geophysical devices and cameras, are available for use in borings after they have been drilled, but these tools currently are not used routinely on transportation projects.

Excavators typically are mounted on tracked vehicles, although small backhoes are mounted on tractors with rubber tires. Bulldozers are usually equipped with simple blades for pushing soil and rock materials, but bucket-type blades (loader buckets) can be used for excavating large pits in soil materials. Samples obtained from excavations can be high-quality, undisturbed block-type samples of soil or bulk samples of soil or rock. Large pits allow direct observation of stratigraphic relationships and geologic structure.

The primary noninvasive equipment currently used widely on transportation projects consists of seismographs for shallow refraction surveys. Conventional stereoscopic aerial photographs commonly provide the basis for photogrammetric topographic maps of project sites. Aerial photographs also are used widely as the basis for geologic mapping.

STATE OF THE ART

A number of methods of exploring and classifying earth materials are currently available but not commonly utilized for transportation projects. These methods include cone penetrometers, dilatometers, pressure meters, electric piezometers, time-domain reflectometry (TDR), ground-penetrating radar, Global Positioning System (GPS) receivers, spectral analysis of surface waves, orthorectified aerial photographs (with and without superimposed topographic contours), remotely sensed images (airborne radar and infrared and satellite-based multispectral images), data loggers, direct computer links, telemetered data, and geographic information systems (GIS). The cone penetrometer, dilatometer, pressure meter, electric piezometers, and TDR tools are invasive, whereas the other methods are noninvasive.

Cone penetrometers can be pushed into the ground by conventional drilling equipment or from specialized trucks equipped specifically for cone penetration testing. Dilatometers and pressure meters are used in conjunction with conventional drilling. TDR allows measurement of moisture content in unsaturated soil.

Ground-penetrating radar has been demonstrated to be a useful tool for characterizing shallow profiles. Its use is growing, and it will soon become a standard tool on most projects. GPS receivers for differential surveys are used to locate borings and penetrometer soundings. Some specialized cone penetration testing trucks are equipped with GPS receivers and GIS software for rapid spatial-data analysis.

Satellite imagery has been available for use in mapping and interpretation for the last quarter-century. It is not used widely on transportation projects in part because of cost and in part because of copyright restrictions. The entire United States is covered by LANDSAT Thematic Mapper images with seven spectral bands. The visible and infrared bands provide 30-meter resolution, whereas the thermal band provides 120-meter resolution. This information is best suited to land-cover studies, but has limited value for site-specific studies. LANDSAT 7, operated by the National Oceanic and Atmospheric Administration and the U.S. Geological Survey, was launched in April 1999 and will provide public-domain imagery. SPOT (a French Company) has 10-meter panchromatic and 20-meter multispectral imagery, and IRS-C (an Indian Company) has 5-meter panchromatic imagery. Neither SPOT nor IRS-C images are used widely on transportation projects because they are expensive and restricted by copyright.

GEOTECHNICAL DATA MANAGEMENT AND UTILIZATION

The availability of electronic data has increased dramatically because of the proliferation of computers, data communications, and data processing capabilities. Engineering analyses are expected to be faster, better, and more efficient. Large datasets require planning and database design so the data required for all types of analyses will be available in a useful format. The quality of geotechnical data is critical in spatial information systems. Data must flow from the field to the office and laboratory in a useable format. Data and computational results must be archived for future retrieval and use on a variety of undesignated projects. Departments of transportation do not work on isolated projects. They work on the planning, design, construction, and maintenance of systems, and the reuse of available information is a major factor enabling functionality in the system. For example, highways and bridge structures often require widening or additional spans that need to be designed on the basis of available subsurface geotechnical information.

Increasing sophistication in geotechnical site characterization with greater amounts of digital data will create a growing demand for data management. The need for improved data management has been identified by the Federal Highway Administration (FHWA), but significant advances in data management are still needed at most departments of transportation. A 1996 report prepared for the Office of Engineering at FHWA, entitled *The National Geotechnical Engineering Improvement Program,* contains a number of recommendations and action items based on a survey of geotechnical sections in U.S. departments of transportation. The report includes the following findings:

> The survey noted wide disparities in the site investigation procedures employed by various highway agencies. In particular, weakness was evident in the areas of in-situ testing, automation of data collection and reproduction, and quality control of contract drilling operations. These findings are of concern as past FHWA geotechnical reviews had identified potential benefits for highway agencies that would adopt in-situ testing techniques and FHWA had completed several efforts to improve current practices. However, the 1995 survey shows a decrease in in-situ testing nationwide and a need for further FHWA efforts.

According to the report, FHWA’s short-term goals include dissemination of existing in situ testing information to encourage trial use of new equipment. Model programs are to be disseminated that will demonstrate the utility of high-quality databases and the techniques of recording, reproducing, and retrieving subsurface characterization data. FHWA’s long-term goals involve major initiatives by the National Highway Institute to demonstrate the benefits of in situ testing and to conduct research on new methods. Future FHWA training courses will cover modern techniques for dealing with large volumes of digital data in well-planned databases utilizing GIS.

Some common format or structure that facilitates digital data exchange and electronic handling is needed for recording geotechnical data. Perhaps another standard for engineering practice will be required to ensure that digital data are collected and stored in the optimum way. It is clear that formalization of some of these digital data issues is required. More resources must be invested in data management standards. There is also a need for data collection and management guidelines in geotechnical engineering derived from an industry-driven consensus process.

The volume of geoenvironmental and geotechnical data generated by transportation projects is increasing as new and better sensors and data loggers become available. Processing of these data requires advanced two- and three-dimensional computational tools, such as geostatistics, volume rendering, and voxel-based modeling. GIS and spatial analysis programs currently provide an excellent platform for data analysis, visualization, and presentation. The graphical products of these systems are sufficiently impressive that the appearance of the maps and graphs may impede their utility in decision making. The engineering community must produce clear graphics to promote rational decisions based on high-quality data. Subsurface data must be integrated with surface information, such as that available with aerial photographs and satellite-based multispectral images. Conventional color or panchromatic aerial photographs must be digitized and orthorectified for integration with digital subsurface data.

Geomedia include materials that are mixtures of earth (soils), nonsoil constituents, and fluids (e.g., fiber-reinforced soils, mechanically stabilized earth, soils mixed with vehicle tires or refuse, soil-cement, chemically stabilized soils, and contaminated soils). These materials require special characterization efforts. Geomedia are the result of human interaction with the earth either for the purpose of modifying ground conditions to improve strength or as an incidental byproduct of an industrial operation. Geotechnical engineers have focused on characterizing the properties of soils and rock and have moved toward using similar methods for the more complex geomedia. New instruments being developed in research institutions capture data by methods not familiar to the geotechnical engineer (e.g., ground-penetrating radar, imaging, chromatographs, and spectrographs). These methods require collecting, storing, and manipulating large amounts of data and correlating them with the traditional geotechnical properties for use in the exploration and classification of geomedia.

VISION FOR THE 21st CENTURY

In the new millennium, currently available state-of-the-art techniques that are not used routinely will become widely accepted. Acceptance of these more expensive techniques will grow with increased awareness that they yield valuable, high-quality information that can be applied at a variety of levels in transportation planning, design, construction, and maintenance. Probes that return digital data will become the primary invasive tools for transportation projects. These probes will evolve to contain numerous miniaturized sensors that return a suite of complementary digital data. Among the sensors on these probes will be dilatometers, optical cameras, electrical resistivity devices, chromatographs, and spectrographs. If a hard layer or fragment inhibits penetration, high-power lasers in the probe tips will be used to vaporize the impeding material. Field-developed digital data will be transmitted from the probe to the ground surface using sonic, infrared, or other noncable methods.

The primary noninvasive tools for transportation projects will be digital surface systems, such as ground-penetrating radar, electrical resistivity, seismic refraction and reflection, and surface waves, and remotely sensed systems, such as airborne and satellite-based multispectral and radar images. Locations of borings, soundings, ends of radar and seismic profiles, and observation points of any kind will be determined with differential GPS receivers and recorded on waterproof, pen-based computers. Surface observations of all types, including geologic mapping, will be recorded on pen-based computers and documented with digital images obtained with hand-held cameras. Miniaturization of sensors will allow laboratory-type data to be collected in the field. Multisensor meters will be used to collect digital geoenvironmental and geotechnical data. These meters will be connected directly to the serial ports on pen-based computers or will transfer data using infrared ports.

Shallow excavations will be done with more efficient equipment. Load cells on the buckets of excavators and blades or rippers of bulldozers will be used to monitor excavation progress. Exposures will be recorded with digital cameras, electrical conductivity meters, chromatographs, and spectrographs. Digital images will be analyzed with computer programs that return grain-size distributions, clay mineralogy, and pore-fluid chemistry.

Digital data developed in the field will be input directly into computers and simultaneously transmitted by satellite to offices and laboratories regionally, nationally, or even globally. As fieldwork progresses, detailed automated analyses of the data, based on neural networks and fuzzy logic, will be used to optimize further field activities. Ratios and products of multispectral and multisensor data will be computed and plotted to produce a new generation of geotechnical results. Three-dimensional tomographic analyses of large datasets will become common. Computer-aided analyses will be used to identify critical depths and locations where samples are needed for laboratory testing. The suite of down-hole and surface sensors will produce adequate data for computer-aided determination of the optimum method for obtaining the highest-quality samples.

The 21st century promises challenges and opportunities for the exploration and classification of earth materials, including geomedia. The utility and power of computers to collect, store, and manipulate digital data pose a particular challenge to engineering geologists and geotechnical engineers. If acceptable geotechnical data management standards and practices are not developed and adopted by engineering geologists and geotechnical engineers, they will be developed by database managers who have little or no knowledge of geotechnical issues and imposed on the geotechnical community. Exploration and classification of earth materials remain the foundation of all transportation projects. The future will be dominated by the collection, display, and utilization of digital data.