Engineering Geology

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Engineering geologists are concerned with the distribution and relevance of earth materials; potentially dangerous naturally occurring and human-induced geologic hazards; and assessment of the risks of damage and injury associated with those hazards as they can be quantified for application to the planning, location, design, construction, and maintenance of transportation systems. During the 20th century, these concerns have been addressed in part by landmark publications in the Transportation Research Board's Special Report series on landslides, first published in 1958, updated in 1978, and appearing most recently in 1996 as Special Report 247, *Landslides: Investigation and Mitigation*. Similar efforts are expected to serve engineering geologists in the new millennium.

STATE OF THE PRACTICE

Conventional methods of documenting and mapping earth materials for transportation projects are based on direct observation, with notes being made directly onto maps and aerial photographs. Current state-of-the-practice exploration techniques include mapping regional features at small scale and detailed features at large scale. Mapping done directly on aerial photographs can be transferred to planimetric maps using plotting devices that are rapid and accurate. Low-sun-angle aerial photographs are being used to enhance the definition of fault and landslide scarps for field identification. Interpretations of earth material distribution and evidence of relevant geologic processes, along with effective communication of these interpretations, remain among the most significant of challenges for engineering geologists.

Many transportation systems face a variety of potentially hazardous natural processes. In their attempts to deal with these hazards in a responsible way, state departments of transportation are using engineering geologic procedures to identify and rank specific hazards so that cost-effective remediation plans can be formulated. Litigation is a driving force in some cases as natural processes are being more closely scrutinized, and the public expects departments of transportation to be able to control the associated hazards. Rockfalls and scour at bridge sites are two such processes that have been addressed systematically in the 1990s.

Remedial measures applied to soil and rock slopes and facilities for containing or controlling sediment discharge from stream channels and on alluvial fans are being evaluated in terms of their effectiveness and longevity. The performance of steel rock bolts applied to improve the stability of some highway slopes since the 1960s is being assessed relative to the long-term maintenance of the slopes and corrosion of the rock bolt elements. Slope treatment measures, such as wire and cable drapery systems, and corridor protection measures, such as flexible barrier systems, are being evaluated for their performance and long-term maintenance. Sediment-control basins and berms used to protect transportation facilities are being assessed with regard to maintenance and appropriateness of location.

STATE OF THE ART

Global Positioning System (GPS) satellite receivers are being used to locate field observation sites so that geographic information system (GIS) data manipulation and presentation techniques can be used for rapid and efficient map display. Digital data acquisition systems for seismic refraction, ground-penetrating radar, and electrical resistivity profiles are becoming available for use with computer programs that provide automated interpretations of subsurface data. Digital cameras are available for documenting surface exposures and test pit excavations in formats that can be archived easily and inexpensively and transmitted by modem.

Repetitive photographic documentation of slope conditions is being done in such a way that changes in the slope between photographs can be quantified for use in hazard and risk analyses. Photogrammetric techniques are being applied to rock slopes and cliff faces in the same way that they are applied to conventional vertical aerial photographs. Low-sun-angle photography of faults is being quantified for use in computer-aided analyses of scarp height and slope angle in engineering evaluations. Multiple functions of many remedial measures are being explored; an example is rockfall mitigation barriers, which are being used for debris flow control, landslide mitigation, and erosion protection.

MANAGEMENT AND UTILIZATION OF ENGINEERING GEOLOGICAL DATA

Use of electronic data has increased dramatically because of the general availability of computers, data communications, and data processing. Engineering analyses based on geological data are expected to be faster, better, and more efficient. Planning and design of databases must be done carefully and consistently so that the results of all types of analyses will be available in a universally useful format. Data must be transmitted from the field to the office and laboratory in a directly useable format. Basic data and computational results must be archived for future retrieval and use on a variety of as-yet undesignated projects. Available engineering geological information may be required for use in the design of highway-widening or bridge-improvement projects.

Use of geological, geoenvironmental, and geotechnical data on transportation projects is increasing as new and better sensors and data loggers become available. Data processing requirements include advanced two- and three-dimensional computational tools, such as geostatistics; pixel and volume rendering; and pixel- and voxel-based modeling. Data analysis, integration, visualization, and presentation are being accomplished with GIS and spatial analysis programs. Maps and graphs produced with these systems are increasingly providing a basis for rational decisions by those without a geotechnical background. Surface geologic information, aerial photographs, and satellite-based multispectral images must be integrated with subsurface data. Conventional color or panchromatic aerial photographs must be digitized and orthorectified for integration with other digital geotechnical data. Earth processes such as rockfalls and rock slope configurations are being modeled for use in design and in hazard and risk analysis.

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. Geostatistical and spatial analysis programs that integrate digital subsurface data with digital surface data in GIS format will become the primary data analysis and communication tools for transportation projects. Miniaturized surface and subsurface sensors that return a suite of complementary digital data will become commonplace and standardized. Among the surface sensors will be optical cameras, electrical resistivity devices, chromatographs, and spectrographs.

Increasing demand and restrictions on transportation corridors will generate a greater need for utilization of the existing corridor network. The Federal Highway Administration (FHWA) is aware of the need for improved techniques to optimize corridor paths and maintain safety. This awareness is reflected in FHWA's research and workshop program addressing the need for more quantitative characterization of natural processes such as rockfalls.

Digital surface systems (e.g., ground-penetrating radar, electrical resistivity, seismic refraction and reflection, and surface waves) and remotely sensed systems (e.g., airborne and satellite-based multispectral and radar images) will provide the basis for integration and interpretation of relevant geological information for transportation projects. Interferometric analyses of repeated satellite-based synthetic-aperture radar images will be used to determine changes in ground-surface position for subsidence, landslide, and fault displacement evaluations. 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.

Landslide warning systems will be implemented with remote monitoring equipment that can transmit data on ground movement, groundwater pressure, rainfall, and ground vibrations. The transmitted measurements will be received continuously by a computer system that will verify incoming data and automatically page key personnel should a significant event occur. When paged, key personnel will access the World Wide Web to examine the events and recommend mitigation measures. The capability to access all available data at any time from any location will result in greater confidence in decision making and significant improvements in safety for transportation corridors.

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. Similarly, load cells will be installed on barrier structures to measure impact loads imparted by debris flows, rockfalls, and rockslides. Exposures will be recorded with digital cameras, electrical conductivity meters, chromatographs, and spectrographs. High-resolution digital video imaging with frame speeds of up to 3,000 frames per second will be used to classify and document the behavior of natural processes such as rockfalls and debris flows. Digital images will be analyzed with computer programs that return grain-size distributions, clay mineralogy, and pore-fluid chemistry. Time-domain reflectometry will be used to measure unsaturated soil moisture and monitor deformations of landslides and creep along faults. Vehicles, including railroad locomotives, will be equipped with digital cameras or multispectral sensors for automated repetitive photography of critical slopes to document movement and provide the basis for early warnings and risk assessments. Strong-motion accelerographs will be deployed on key railroad bridges and smart highway systems for real-time telemetry into the transportation operating systems. Strong motion exceeding a threshold value will result in shutting down the system until the key facilities can be inspected to determine that they have not been damaged, or until they are repaired.

Digital data developed in the field will be input directly into computers and transmitted simultaneously 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 locations where additional observations and measurements are needed for hypothesis building and model testing.

The 21st century promises challenges and opportunities for engineering geologists. The future will be dominated by the collection, utilization, and display of digital data. The utility and power of computers to collect, store, manipulate, and display digital data poses a particular challenge to engineering geologists who have the task of quantifying observations or uncertainties in interpretation. Appropriate standards and practices for management of engineering geologic data must be developed by geotechnical professionals and adopted for use in the transportation industry. Otherwise, database managers who have little or no knowledge of geotechnical issues or uncertainties associated with the geologists’ approach of multiple working hypotheses will develop those standards and impose them on the geotechnical community. Interpretation and communication of the relevance and distribution of earth materials and identification and quantification of hazardous geologic processes will remain critical for all transportation projects.