A2K01: Committee on Soils and Rock Instrumentation
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Soils and Rock Instrumentation

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The field of soils and rock instrumentation encompasses instrumentation for site investigation, laboratory testing, and field monitoring; for pavements; for environmental monitoring; and for determining the response of infrastructure to natural hazards. Data acquisition, transmission, and management are key areas of interest. Within this broad scope, developments in sensors and in computer hardware and software have influenced instrumentation and data communication and continue to offer new possibilities.

SOIL–STRUCTURE INTERACTION

A number of factors drive both short- and long-term demand for new, innovative devices and methods for measuring the behavior of soil–structure interaction. The construction of transportation facilities within limited rights-of-way in congested urban areas necessitates careful monitoring of adjacent structures. Increasingly complex and integrated structural-geotechnical projects have been undertaken that require measurement of performance in the field. There is an increasing need for detailed, quantitative monitoring during project construction and over the life span of important facilities. The need for observation and process control is intensified by the use of unconventional geotechnical methods.

Measurement at soil–structure interfaces can be particularly difficult because of the potentially large contrast in interacting material properties and challenges presented by the in situ environment. New devices and systems for monitoring force, acceleration, deformation, pore pressure, and temperature changes with depth need to be developed or adapted from other fields. There is also a need to monitor the condition and rate of degradation of buried structures. Future devices are likely to be smaller, easier to deploy, and capable of monitoring remotely without physical connections. New sensors and measurement technologies, such as optical and acoustic devices, will likely play pivotal roles in future applications.

GEOPHYSICAL METHODS

Geophysical techniques have shown great promise in the broad field of infrastructure engineering, and have led to the development and application of nondestructive evaluation and testing tools. In addition to applications involving geotechnical and environmental site investigation, geophysical techniques can provide an excellent means of performing construction quality control, monitoring the behavior and degradation of infrastructure, determining the effectiveness of major rehabilitation and maintenance projects, and diagnosing problems in complex systems. In the last decade, significant progress has been made toward rapid and almost real-time measurement of properties in situ. Hardware and software have been developed for ground-penetrating radar and seismic methods. Such technologies have found application in locating buried structures and characterizing existing foundations.

Lack of ruggedness and difficulties associated with equipment portability have thus far limited the application of geophysical techniques. Further work is needed to reduce costs and develop miniature sensors, recording devices, and data communication systems.

VISION TECHNOLOGIES

Vision technologies have been used for geotechnical engineering research for some time. Progressive failure in plane strain models has been investigated using colored soils. X-ray photography has been used to study three-dimensional soil models, and microscopy has been valuable for studies of soil fabric and behavior. Cone penetrometers have been outfitted with cameras to allow for visual characterization of penetrated soils. Progressive movements of very large areas are also being monitored using aerial and satellite photography.

Laboratory uses of vision technologies in geotechnical applications are concerned primarily with soil characterization and experimental modeling. Grain size distribution, void ratio, and soil fabric can be characterized. Three-dimensional soil–structure interaction and flow problems can be modeled with synthetic materials to represent the macroscopic behavior of natural soils. Advanced optical techniques that use interferometry, holography, and lasers may eventually have application in structural response and condition assessment.

ENVIRONMENTAL MONITORING

Subsurface contamination at transportation facilities may result from chemical spillage, leaky storage tanks, leaching from material stockpiles, and miscellaneous debris. Plume migration can threaten local and regional water resources and must be properly characterized prior to remediation efforts. Conventional techniques for characterizing subsurface contamination include drilling, sampling, and testing. The major drawbacks to these techniques include the variability and cost of sampling, the generation of secondary waste from drilling, and the potential cross-contamination of soil strata. There is a need for better means of characterizing site conditions and the extent of plume in a cost-effective manner while reducing secondary waste.

Innovative subsurface contamination sensors can minimize secondary waste, reduce disturbance of the waste, and lower the cost of site characterization. The future of subsurface environmental characterization depends on technologies that combine geophysical techniques with geo-information systems. The primary challenge to the use of innovative subsurface contamination sensors is the verification of observations, as many new methods do not directly measure the desired parameter.

DATA TRANSMISSION

Data communication systems continue to be hampered by high costs, as well as problems associated with reliability and physical security. Costs for sensors are decreasing, and their variety and capabilities are increasing. To best exploit this new capability, more reliable and cost-effective data communication alternatives are needed. The World Wide Web and radio transmission offer two promising near-term improvements in wireless geotechnical data transmission.

The Web is a flexible and reliable way to retrieve data from an instrumentation system. The communications backbone and the user interfaces are well established and rapidly evolving. The missing link is a low-cost, efficient way to connect the sensor to the Web at the sensor end. Major work is under way on developing such low-cost links for consumer products and appliances, and inexpensive and efficient low-cost links between a remote geotechnical sensor and the Web should be available in the near term.

Radio and acoustic methods offer alternatives for wireless data transmission. Acoustic methods are limited by transmission interference in geotechnical settings. Radio frequency transmission is more promising for geotechnical instrumentation. A transceiver at the sensor end would communicate with another transceiver located at some point that could be connected to an established communications link, typically the telephone system. Data would be transmitted from the sensor to the central transceiver and then over the established communications link to the desired receiving location. The technology for accomplishing this has existed for some time, but the radio equipment has been too costly to permit widespread use. The electronics industry is now beginning to produce low-cost radio transceivers with a range of 100–300 m. Repeaters and other modifications to the system can expand this distance. Better and lower-cost spread-spectrum systems can expand the range to 15–25 km, but at higher cost.

DATA MANAGEMENT AND FEEDBACK

Although relatively new to the construction industry, real-time data management and feedback is widely used in high-cost research and operational systems designed for military, space, and aviation applications. The technique involves the use of four essential components: sensors, a data acquisition system, devices for data communication and computer-based data processing, and a visual display. In some applications, real time is measured in micro- or nanoseconds, so high-cost components are necessary. In construction monitoring, however, a response time of seconds or even minutes is often sufficient.

Driven in part by recent advances in affordable microelectronics and microcomputers, the use of data management and feedback in construction is emerging. Recent applications of real-time monitoring in transportation-related construction include settlement monitoring and control (e.g., using compensation grouting) for urban tunneling or deep foundation excavation, safety monitoring during highway slope rehabilitation, and railway track settlement and twist monitoring. The data management and feedback technique automates the processes of data acquisition, processing, and presentation. The parameters being monitored are displayed graphically against time and over plans or sections with respect to multilevel alarm thresholds. The aim is to provide the data in an easily understood and consistent format to aid the engineer in charge in making prompt and correct decisions.

It is anticipated that in the next 10 to 25 years, integration with the Internet and with smart sensors and structures will strongly impact trends in the development of instrumentation. Advances in sensors and in real-time monitoring and feedback technologies could lead to the development of a system with the ability to sense and react to the environment. Such a system would be ideal for nondestructive health and damage assessment of infrastructure and even for the automation of damage-control responses.

FIBER-OPTIC SENSORS

Fiber-optic sensors are small, rugged, and immune to electromagnetic noise, and can survive in harsh chemical environments. Fiber-optic chemical sensors, consisting of a light source and sensor and detector elements, can be used for environmental monitoring. The optical properties of the sensor adjust to ambient chemical changes, and the detector switches the sensor output to an electrical signal. Fiber-optic sensors for monitoring of physical change operate through modulation of light due to disturbance in the ambient field. Changes in strain, pressure, temperature, acoustics, or vibration induce a phase change between the source and the detected light signals. A grating is used as a narrow-band filter. The grating period and characteristics of the reflected light change with the ambient field.

Installation of individual fiber-optic sensors can be time-consuming and difficult to accomplish in a construction environment. Alternatively, prefabricated panels containing multiple sensors can be embedded within soil or concrete masses. Time and frequency domain techniques have been used to simplify communication with individual sensors by multiplexing several sensors onto a single transmit/receive fiber.

Fiber-optic sensors are new and rare in the domain of soil and rock instrumentation. With further refinements and increased production, costs will decrease, and a much broader range of applications is likely in the coming decades.

SMART SENSORS

Smart sensors, characterized by embedded intelligence and microcontrollers, can monitor parameters and process data internally, and can use the processed data to identify thresholds and activate alarms. Sensing and controlling elements are integrally linked. Thus the need for large wiring harnesses and full-time data acquisition systems is eliminated. Smart sensor networks provide a useful means of performing extended observation without an extensive hardware investment for data acquisition and processing, and can communicate by modem automatically or on command.

The software embedded in smart sensors can be upgraded while in service. Continuous autocalibration of the offset and gain of the complete system can be performed through use of a reference signal. These features address a variety of current limitations in soil and rock instrumentation.

MICROELECTROMECHANICAL SYSTEMS

Microelectromechanical systems are micro devices that have both mechanical and electrical components. They are fabricated using integrated-circuit manufacturing techniques and can range in size from micrometers to millimeters. Microfabrication enables production of large arrays of devices that individually perform simple tasks, but in combination, can accomplish complex functions. The concept is analogous to the development and operation of digital computers. Near-term applications are envisioned to include accelerometers; pressure, chemical, and flow sensors; micro-optics; fluid pumps; and position, rotation, and other physical variable controls. Miniaturization of mechanical systems promises unique opportunities for new applications in many fields, such as instrumentation. This technology is in its infancy, however, and the possibilities for geotechnical applications are not yet clear.

CONCLUSION

The technology revolution is enabling more sophisticated modeling, increased flexibility in implementing design revisions, closer sequencing of design and construction, and real-time monitoring of field conditions. Uncertainties in knowledge of site-specific geologic conditions and hazard forecasting will remain. Instrumentation and data communication will become more indispensable for diagnosis and observation, as justified by cost and utility. The sorting and deciphering of information from instruments will be performed by intelligent systems that can prioritize and interpret data. Results will be archived and channeled to users and decision makers. In the end, it will still be necessary to build on or with geologic materials at varying scales and level of detail. Future advances in instrumentation will help improve the ability to build and maintain smart transportation infrastructure systems and conserve resources more rationally.