Overview

The potential for geotechnical applications of remote sensing and remote data transmission is rapidly increasing as the techniques and equipment for obtaining, transmitting, and interpreting data are improving and becoming more commonly available. Aerial photography has been used for a variety of engineering projects for more than 40 years, while satellite images have been available only since the launch of Landsat 1 in 1972. Remote sensing scanning systems now allow recording at ranges of the electromagnetic spectrum outside the range of photography, and active systems function regardless of weather. Digital data processing and image enhancement techniques provide recognition of contrasts at orders of magnitude better than the human eye.

ASTM Committee D-18 on Soil and Rock recognizes a general need for defining the requirements for remote sensing data which will allow the geotechnical engineering profession to access, interpret, and apply the data. Without these requirements being defined from the user's point of view, there may be gaps in knowledge between remote sensing specialists and practicing engineers which can hinder the full potential use of remote sensing techniques. This recognition and emphasis on application is consistent with international trends, as expressed, for example, in the United Kingdom by the Report on Remote Sensing and Digital Mapping published by a Select Committee of the House of Lords in 1983.

To provide interdisciplinary communication between remote sensing and data transmission specialists and users of geotechnical data, an International Symposium on Geotechnical Applications of Remote Sensing and Remote Data Transmission was held on 31 Jan. 1986 at Cocoa Beach, Florida. The symposium was organized by ASTM and the International Committee on Remote Sensing and Data Transmission (ICRSDT) of the International Association of Hydrological Sciences. The purpose of the symposium was to develop information that could be used to prepare guidelines for the use of remote sensing and data transmission techniques. The symposium topics were limited to those techniques using satellite or airplane sensor platforms. The following is an overview of the information presented in this volume.

Data Sources and Processing

U.S. Government programs that are potentially useful to geotechnical engineers and geohydrologists include the U.S. Geological Survey's National High Altitude Photography Program (NHAP) and Side-Looking Airborne Radar (SLAR) Program, and the Shuttle Imaging Radar (SIR) Program of the National Aeronautics and Space Administration (NASA). Such data can provide an inexpensive regional analysis that will serve as a basis for the planning and execution of detailed site-specific studies. The Geosat Committee's 1979–1984 Joint NASA/Geosat Test Case Project was developed to assess, in known geological areas, the value of existing and potential satellite remote sensing methods for oil/gas and mining exploration and for engineering geology and environmental applications. One result of the study was the recognition that a number of techniques that could be used in an interactive manner with each other and with field checking and computer processing techniques were needed to obtain optimum interpretation. The study also resulted in recommendations that shortwave infrared (IR) thematic mapper (TM) spectral bands, higher spatial resolution, and synthetic aperture radar (SAR) in present and planned systems, when combined with the Landsat/multispectral scanner (MSS) system, will substantially improve these systems as a whole for more efficient geologic mapping and improved exploration success worldwide.

A geographic information system (GIS) contains the basic data and the analysis software for registration and analyses of the spatial information from remote sensing and other sources. The GIS can be considered a basis for digital image processing and map automation. Land use and land cover data are the important data in a GIS. The land use and land cover condition often change as a result of natural causes as well as the activities of man. Appropriate ways for capturing and analyzing data are needed. Space-borne remote sensing, owing to its periodicity, speed, scanning scope, and economic benefit in providing synoptic information, is becoming the main data source for updating land use and land cover data.

The critical activity in the updating procedure is the combining of the remote sensing system and GIS by means of a digital image processing system. Accuracy in locating and classifying geographical data is considered the crucial problem in image processing.

The development and operation of remote sensing systems with improved resolution and dynamic range has lessened interest in archived data. However, archived data sets with recognized contrasts in system and operational parameters are available in many areas. When utilizing the capabilities of systems generating such contrasting imagery, data may emerge that are not available in imagery produced by a single system. Not only may unique data be provided, but information can be revealed as a result of strong contrast in the system and operational parameters of the sensors with which the imagery was generated.

Imagery from systems having diverse parameters (for example, X-band images generated by an airborne mapping system analyzed in concert with imagery generated by a satellite-borne L-band system) can provide otherwise unobtainable data when adjustments are made for the time lapse between the missions and when supporting ground data have been acquired. Included among such data would be information relative to man's activities, delineation of the drainage net, definition of surface roughness in cleared areas, and swamp identification.

The relatively low cost of archived imagery, such as Seasat-SAR, SIR-A, and SIR-B X-band imagery provided by the U.S. Geological Survey, and X-band imagery produced by Strategic Air Command systems, should prompt investigators to utilize such data in conjunction with mission-specific generated imagery.

Improvements in data processing techniques are needed whenever images from different sensors, or from different spectral bands within the same sensor, are collected for geotechnical interpretation. Image spatial statistics can potentially be used to improve the resolution of low-resolution digital images.

One experimental procedure involves degrading one of two digital images in adjacent spectral bands to simulate a low-resolution image. New samples within the sparse, low-resolution image are subsequently estimated using the spatial characteristics of the high- and low-resolution images. These spatial characteristics displayed in the variogram function are used to estimate the new high-resolution data. For cases where geotechnical decisions rely on accurate knowledge of image amplitudes, co-kriging may provide an accurate and flexible estimation technique. Moreover, co-kriging appears to be a promising technique for future automated image interpretation and feature extraction algorithms.

Classification and comparison of features such as fracture patterns in rock, surface drainage, and details of topography may be characterized by levels of subjectivity that are unacceptable for geotechnical applications. Optical diffraction analysis (ODA), and, in particular, image subtraction (IS) and joint-transform correlation (JTC), yield results that are far more objective than those obtained from visually observing pairs or series of photographs.

The basic methods of ODA have been shown to be useful in analyzing spatial geological data from the microscopic through the planetary scales. What is new is the application of a simple filtering technique to achieve subtraction of one image from another. The same technique can be applied to headward growth of gullies, crack propagation, meander migration, shore erosion, and the like. Image subtraction is most useful in work with "before and after" pairs of photographs, but it can also be effective in working with sequential series of photographs.

JTC provides a numerical measure of the similarity between the spatial information in pairs of photographs. JTC, IS, and other ODA methods have the capability of mining the abundant resources of spatial data recorded in geological and geotechnical photographs. The simplest and most easily obtained product of ODA is the Fourier optical transform, which is obtained in the course of doing JTC and IS work. It, too, can be used in working with "before and after" pairs and with sequential series.

The need for standardization of the format for digital recording of spatial data used in remote sensing and data transmission is evident from the papers in this volume. Several organizations are presently proceeding with such standardization efforts. An important function for geotechnical engineers and remote sensing and data transmission specialists active within ASTM would be to provide input regarding their needs and preferred data formats to these already active standardization groups, and to provide guidelines to the user community for adaption of digital remote sensing spatial data in practical applications.

Geotechnical Applications

Civil engineering projects require the systematic collection of geotechnical and environmental data. In the preliminary stages, topographic and geological maps and reports should be studied before field activities are begun. A variety of remote sensing data systems can provide valuable information for site evaluations, including geotechnical investigations and site monitoring during and after construction.

Remote sensing data can be analyzed and integrated with field data to determine the site conditions for design, assess environmental effects, and plan construction activities. The data include large-scale color-infrared aerial photography, and aerial video recordings. Digital analysis of Landsat data, as well as the interpretation of thematic mapper (TM) and Seasat SAR data provide information on regional terrain and land cover.

Interpretation of infrared imagery can provide geologic data prior to detailed mapping of a potential site. Lineaments can be delineated and faults identified from the interpretation of both thermal imagery and large-scale infrared photography. Additional photographic geological interpretation can provide an engineering map of the terrain and surficial deposits over the area.

Infrared and thermal imagery data can be used successfully to detect areas of instability in mines. Imagery can permit the mapping of subtle drainage and fracture patterns on the surface. Hydrogeological information derived from remote sensing techniques allows determination of safe mining areas when integrated with local seismic refraction surveys and underground observations.

Airborne thermography can also be used to delineate areas of near-surface aggregate, based on the relationship between the soil moisture and texture and on the sensitivity of thermal data to differences in the surface soil moisture content, determined in large part by surface drainage characteristics.

National Oceanic and Atmospheric Administration/advanced very-high-resolution radiometer (NOAA-AVHRR), Landsat/MSS, and shuttle imaging radar imagery have been analyzed to determine their utility in evaluating parameters of geotechnical interest in relation to problems encountered in large open-cut coal mines. The extent of this utility has been tested to determine the distribution, structure, and form of surficial deposits in the vicinity of large-scale mining operations. Data on geotechnically important parameters such as the density and orientation of regional fracture systems; the thermal conductivity of the surface; the distribution, movement, and discharge of ground water; and the roughness and moisture content of the surface have been acquired using these systems. These data can be interpreted from biological and physical indicators and used to predict mining conditions and to pinpoint regions of potential hazard.

The potential occurrence of subsidence and collapse dolines on soluble carbonate rocks is a frequent geotechnical hazard throughout the world. Such features pose serious geotechnical problems to engineering and building construction and also to public safety. Detection methods utilized during site investigations range from direct methods—for example, drilling—to indirect methods, such as ground geophysics and airborne remote sensing. The most favorable detection results will be obtained if remote sensing methods are used under optimum environmental conditions and in appropriate geological conditions.

Remote Data Transmission

Electronics, communications, and satellite technologies have enhanced collection and communication of environmental data from remote locations. While environmental data collection agencies have begun to employ these technologies operationally, hydrologic data collection agencies have made the greatest transition to their use. Most major hydrologic agencies in the United States and Canada have come to rely on satellite communications operationally to collect data directly from remote locations and provide the data in real time to central data processing and dissemination facilities. One communications technique is the "meteor-burst," which relies on ionized trails in the atmosphere left by micrometeors, as they plunge into the atmosphere, to reflect radio messages between a hydrologic station and an interrogation site.

Geotechnical monitoring has within the last five years entered the area of automatic and remote data telemetry. Civil engineers, especially geotechnical engineers, have recently begun to use communication lines, telephone modems, radio links, and satellites to convey monitoring data automatically from the field to the office. Initial projects involving instrumentation automation and data telemetry have been limited to either remote areas or large projects. Instrument data acquisition systems are of paramount importance to monitoring systems because they must accurately monitor the instrument and store the data. The monitoring data can now be automatically gathered at the site and transmitted to a central location efficiently and economically for essentially any size of project. A data collection system utilizing the Geostationary Environmental Operational Satellite (GOES) is being designed and implemented for underseepage monitoring of dams. The piezometer levels, water temperature, and conductivity will be monitored. The random reporting scheme of the GOES system will be utilized so that periods of particular interest will be more frequently monitored. This near-real-time data collection system will provide the necessary information concerning underseepage quantity and quality.

General Discussions

As noted in the summarizing discussion by Pincus, it is clear that geotechnical needs for remote sensing are real and that some of the capabilities are already available. Technology transfer between geotechnical and remote sensing specialists has been developing, as evidenced by this volume. However, the communication gaps in technical knowledge have not been closed between all the various groups that are concerned with remote sensing. These groups not only include geotechnical and remote sensing and telemetry specialists but also involve industrial equipment suppliers and system operators, government agencies, and academic institutions. Adequate facilities and educational programs must be provided by the universities and supported by adequate government and industry funding.

The editors conclude that ASTM's continued efforts to develop standardization in the areas of remote sensing and telemetry must start with the geotechnical engineers and scientists involved in studies, investigations, and monitoring programs for soil, rock, and water. ASTM will provide a forum for communication on these subjects through subgroups of ASTM Committee D-18 active in remote sensing and remote data transmission.

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