Management of geotechnical data and processes

Gestion des données et des procédés de géotechnique

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ABSTRACT

This General Report reviews the topic of Management of Geotechnical Data and Processes based on the papers submitted to the 17th International Conference on Soil Mechanics and Geotechnical Engineering, Alexandria, Egypt. The contributors agree that data standards are needed to allow interchangeability and sharing of geotechnical data. Hence, developments in data representation using XML are outlined that will allow the World Wide Web to become an international repository for geo-engineering information. XML provides the flexibility needed for representing heterogeneous data obtained from field monitoring. Geographical Information Systems (GIS) provide great opportunities for geotechnical engineers, particularly for the storage of large amounts of borehole data. The need for handling uncertainty and managing risk in geotechnical engineering is highlighted. Risk sharing should ensure that each risk is assumed by the party best able to control it, given their technical competence and contractual commitments. Risk mitigation measures need to be put in place when the risk level is high. Event Tree Analysis provides a useful way of assessing risk levels, and can incorporate expertise from different disciplines. Greater amounts of site investigation data will reduce the probability of under- or over-design of geotechnical structures, although there may be an optimum point beyond which further data will provide limited improvement. The degree of uncertainty in geotechnical engineering is evident from a benchmarking exercise for seismic site response analysis that showed variations of up to 4100% between participating teams, making assessments from the same input data sets. Specific examples and case studies are described in the application areas of Slopes & Landslides and Seismic Hazard Assessment.

RÉSUMÉ

Ce Rapport Général passe en revue les thèmes de la Gestion des Données et des Procédés de Géotechnique sur la base des documents soumis à la 17e Congrès International de Mécanique des Sols et de la Géotechnique, à Alexandrie, en Égypte. Les contributeurs conviennent que les normes de données sont nécessaires pour permettre l'interchangeabilité et de partage des données géotechniques. Ainsi, l'évolution de la représentation des données en utilisant XML sont décrites qui permettra à la World Wide Web à devenir un référentiel international pour l'information géo-ingénierie. XML fournit la flexibilité nécessaire pour la représentation des données hétérogènes obtenus à partir de la surveillance sur le terrain. Systèmes d'information géographique (SIG) offrent de grandes opportunités pour les ingénieurs en géotechnique, en particulier pour le stockage de grandes quantités de données de forage. La nécessité pour le traitement des incertitudes et de gestion des risques dans l'ingénierie géotechnique est mis en évidence. Le partage des risques devrait faire en sorte que chaque risque est assumé par la partie la mieux à même de contrôler, compte tenu de leur compétence technique et les engagements contractuels. Mesures d'atténuation des risques doivent être mis en place lorsque le niveau de risque est élevé. Event Tree Analysis constitue un bon moyen d'évaluer les niveaux de risque, et peuvent intégrer les compétences de différentes disciplines. De plus grandes quantités de données d'enquête sur site permettra de réduire la probabilité de sous-ou sur-conception des ouvrages géotechniques, bien que mai est un point optimal au-delà de laquelle des données fourniront amélioration limitée. Le degré d'incertitude dans l'ingénierie géotechnique est évident à partir d'un exercice d'étalonnage de la réponse sismique du site d'analyse a montré que les variations d'un maximum de 4100% entre les équipes participantes, les évaluations de la même entrée de données. Des exemples et études de cas sont décrits dans les domaines d'application des pentes et les glissements de terrain et l'évaluation des aléas sismiques.

Keywords : Data management; Uncertainty; Risk management; Slope; Landslide; Seismic Hazard; Site investigation

1 INTRODUCTION

This General Report reviews the topic of Management of Geotechnical Data and Processes based on papers submitted to Session 5B of the 17th International Conference on Soil Mechanics and Geotechnical Engineering, Alexandria, Egypt. Two key themes emerge from the papers presented: Data Management and Uncertainty & Risk Management. The geotechnical application areas cover Slopes & Landslides, Seismic Hazards, Site Investigation and Foundations. The report highlights some examples and case studies relating two of these topics: Slopes & Landslides and Seismic Hazard Assessment.

2 DATA MANAGEMENT

The issue of data standardisation concerns a number of contributors. Engel et al. (2009) note that in Germany separate data pools of geotechnical laboratory results are used by different institutions and companies. There is no common standard in use to provide a framework for sharing such data.

The heterogeneity of data required in geotechnical practice and the variety of data structures is another concern. Knitsch et al. (2009) outline the management of data from field monitoring of geotechnical processes. They highlight the heterogeneous nature of such data that can comprise 3D geodetic measurements, geotechnical measurements including pressure, stress or strain parameters or data from multi-sensor systems

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such as liquid cells or tilt meters. The data sets can include multiple parameters for a discrete time interval.

Another common problem for geotechnical engineers is the management of large data sets of borehole information. Auvinet et al. (2009) used a geographical information system (GIS) to store more than 7000 borehole profiles for Mexico City. However, much of the data was stored as scanned documents (images) which cannot be used for analysis. Therefore, significant pre-processing was needed to convert the data into digital form to allow geo-statistical modelling.

Possible solutions to some of these issues are identified by Toll (2009), who describes current efforts to define internationally agreed data standards for geotechnical engineering data. The focus is on using XML (eXtensible Markup Language) to define flexible data structures for geo-engineering applications.

International data standards for geo-engineering are the remit of Joint Technical Committee JTC2 (www.dur.ac.uk/geo-engineering/jtc2) of the Federation of International Geo-Engineering Societies (FedIGS) that includes ISSMGE, ISRM and IAEG. The aim of JTC2 is to oversee the development of an internationally agreed form of representation of geo-engineering data that can be used to store such data on the World Wide Web and transfer data between computer systems.

The development of international data standards would overcome the problem identified by Engel at al. (2009). Geotechnical data, in whatever form it was stored in, could be output in a standard format to provide interchangeability and sharing of data. As Toll (2009) notes, the use of a standardised XML data representation scheme will make the World Wide Web into an international repository for geotechnical information, available to the whole community.

Engel et al. (2009) have proposed a data structure for soil tests including shear strength, compressibility, permeability and compaction. For each test they propose storing the test method, boundary conditions, procedures, sample quality and state (i.e. intact/compacted) and the interpretation criteria for the test. This has common elements with the data exchange format developed by the Association of Geotechnical and Geoenvironmental Specialists (AGS, 2004).

Engel et al. also note the importance of storing a reliability measure with geotechnical test data and propose some reliability levels. This echoes the suggestions of Tegtmeier et al. (2007) to store quality information together with the data itself.

XML data structures for rock testing are under development by a Joint Working Group of the ISRM Commission on Testing Methods and JTC2. Standard data tables are being developed based on the ISRM Suggested Methods for rock testing (Chen, 2009).

The use of XML also provides the flexibility to store heterogeneous monitoring data, as identified by Knitsch et al. (2009). A data exchange format for monitoring data was developed by AGS (2002) which was extended to an XML format (AGS, 2005; Chandler et al., 2006). Currently, this is being revisited in the development of the Data Interchange for Geotechnical and Geoenvironmental Specialists: DIGGS (Bray, 2007). Suggestions have been put forward by Toll (2008) on the potential use of a generic mark-up language for sensor data (SensorML, 2005) in geotechnical engineering. It is vital that these efforts continue to be pursued by the entire international geotechnical community, to facilitate the management and exchange of geotechnical data.

The development of large datasets of borehole profiles, as reported by Auvinet et al. (2009) presents great opportunities for geotechnical engineers. GIS technologies provide essential tools for geotechnical engineers to assimilate and visualise these large amounts of data. GIS approaches have been advocated for many years (e.g. Giles, 1992; Adams and Bosscher, 1995; Parsons and Frost, 2002), but are only now finding general acceptance in the geotechnical community.

We now have a further opportunity to make these data sets available on the World Wide Web. An example of this is the Geotechnical Virtual Data Center developed for California (Swift et al., 2004; Stepp et al., 2006). This provides a common web portal to access borehole data from a range of data providers. Data are exchanged between the databases holding the information and the web portal using XML.

A similar project has provided a web portal for accessing borehole data across national boundaries. The eEarth project (http://www.eearth.eu/) was a European funded project that links the Geological Surveys of six European countries. The project makes available borehole data from several countries and in multiple languages. Again XML is used as the linking tool to make the data available on the web.

GIS technologies are now being widely used in hazard assessment, where geo-spatial information is vital to the evaluation. Ansary et al. (2009), Murakami & Yasuhara (2009) and Wilding & Luna (2009) all report on the use of GIS in seismic hazard. This requires the storage of borehole profiles. Ansary et al. had 167 boreholes (SPT profiles), Murakami & Yasuhara used 700 boreholes and Wilding & Luna report on a study using 106 boreholes. Similarly, Trauner & Boley (2009) consider landslide hazards using GIS and identify the need to develop 3D models of geological conditions based on borehole profiles, ground water levels, and laboratory tests (Breunig et al., 2009).

Therefore, an important aspect of the development of geotechnical data formats is to ensure compatibility with GIS. This can be achieved by the use of Geography Markup Language (GML, 2004), an XML application that can be used to represent geo-spatial data. The DIGGS project (http://www.diggsml.org/) is using GML for geo-spatial referencing (Styler et al., 2007) and therefore can provide a linkage to GIS, satisfying a variety of users.

The ability to store 3D models of geological structures (as noted by Trauner & Boley, 2009) has been addressed in the XMML project aimed at mining and exploration information (https://www.seegrid.csiro.au/twiki/bin/view/Xmml). It has now been subsumed by GeoSciML (http://www.geosciml.org/) which aims to represent geoscience information associated with geologic maps and observations, as well as being extensible in the long-term to other geoscience data. Toll (2007a) identifies the importance of ensuring consistency between geo-engineering schemes (such as DIGGS) and geosciences schemes (such as eEarth and GeoSciML).

3 UNCERTAINTY AND RISK MANAGEMENT

Any civil engineering project is in many respects a prototype, having high complexity, and often involving unfavourable geotechnical conditions (Robert, 2009). Since the geotechnical works (earthworks, retaining structures, foundations) are constructed first, before the superstructure, they pose a particular problem. Robert notes that the management of geological hazards must be effective, dynamic and traceable. Risk sharing should ensure that each risk is assumed by the party best able to control it, given their technical competence and contractual commitments. He identifies that geotechnical studies must be sufficient for, and in advance of, each stage of the design and construction so that the geological risks can be appropriately managed.

Chin & Chao (2009) define risk as the combination of uncertainties and consequences of adverse events. They point out that risks can be dealt with by avoidance, mitigation, transfer or reserve but in any case, the risks should never be ignored. They report on a case study of risk management for the Mass Rapid Transit (MRT) system which connects Taiwan Taoyuan International Airport with Taipei city. They show Event Tree Analysis (ETA) for some construction operations to identify probabilities for failure events. Where the rank of risk was judged to be third level (e.g. the likelihood of the risk event had a frequency level of III (occasionally occurs) and a consequence level of 3) then risk mitigation measures were put in place.

Eidsvig et al. (2009) also used event tree analysis (ETA) as part of hazard and risk assessment of a massive rockslide at Åknes in western Norway. Verbal descriptors of uncertainty were used ranging from "Virtually impossible", through "Unlikely", "Likely" to "Virtually certain" to identify the likelihood of particular events. This approach allowed the views of a variety of scientists with expertise in geoscientific, political, social and public arenas, to quantify the probability of occurrence of a catastrophic rockslide and tsunami. This could be extended to an examination of the required parameters for effective early warning of a slide and possible mitigation measures.

To provide some quantification to the problem identified in qualitative terms by Robert (2009), Aryad et al. (2009) consider the amount of ground investigation that can be justified for piled foundations using a site investigation reliability framework introduced by Jaksa et al. (2003). They considered the ground investigation to comprise CPT testing only. They found that designing the foundation based on a single CPT, for the scenarios considered, resulted in a probability of under-design of 11-22%. This could be reduced to 3-5% by carrying out 16 CPT tests, the maximum number considered in the study. However, for low values of the scale of fluctuation (SOF), a measure of the distance over which properties exhibit strong correlation, there was little benefit in carrying out more than 5 CPT tests.

Interestingly, Aryad et al. show that a greater number of CPTs was needed if the SOF increased. This might seem counter-intuitive but they argue this is due to the fact that soil profiles with higher SOFs, while being less erratic, can exhibit large pockets of material with very similar soil properties. If a CPT encounters one of these pockets, but the pile is located in a region outside of the pocket, the properties recorded by the CPT may be significantly different from the values adjacent to the pile. As a consequence, higher SOFs result in higher probabilities of under- and over-design.

Barvashov & Naidenov (2009) attempted to quantify Pareto-Jordan ratios that characterize the influence of input data (causes) on output data (effects) for a geotechnical problem. They did this for shallow foundations by analyzing the sensitivity of soil parameters such as deformation modulus, Poisson's ratio, unit weight, cohesion and angle of friction, as well as geometric parameters such as the depth of a compressible zone and depth of a plastic zone. They considered effects such as settlements, deflections, tilts, bending moments and shear forces. They conclude that the average ratios are close to 80/20 as suggested by the Pareto rule: "80% of effects are due to 20% of causes, 80% of causes generate 20% of effects".

Park & Kim (2009) report on a benchmarking exercise (what they call a round robin test) for seismic site response analysis in Korea. The purpose was to evaluate the dispersion of calculated responses. All participants were given profiles of SPT N-values together with limited CPT profiles and boring logs from three selected sites. The 12 participating teams were asked to estimate the shear wave velocity, the dynamic properties of respective layers and the depth of the bedrock for the given site profiles.

The submitted site response analyses showed significant variation among the teams. The maximum shear strain profile showed the highest variation (up to 4100%), while the discrepancy between the calculated peak ground accelerations was up to 700%. The wide dispersion was due to the combined effect of variations in the estimated shear wave velocity, dynamic curves and the type of analysis. These high values of variation confirm the large degree of uncertainty we are dealing with in geotechnical engineering.

4 SLOPES AND LANDSLIDES

A major part of research in data management and data processing relates to slopes and landslides. Toll (2009) describes XML representations of slopes and the use of Scalable Vector Graphics (SVG) to produce graphical images of slope cross-sections in a web browser. This was based on the data structure proposed by Toll (2007b) where the intention was to develop data structures that could suit a variety of usages from different professionals: geotechnical engineers, geomorphologists, geologists and planners.

This work on data standards for slopes can be further extended to incorporate work emerging from other projects, such as the Multinational Andean Project: Geosciences for the Andean Community (http://www.pma-map.com/en/gac/) or the Landslide Database Interoperability Project in Australia (Osuchowski, 2006).

Three papers submitted to the conference address the development of early warning systems for slope failures. Trauner & Boley (2009) report on a coupled GIS and finite element analysis tool for an early warning system for landslides. A 3D finite element mesh can be generated automatically from the GIS topographic data at a specified location. The system has been trialled for the Isar valley, south of Munich, Germany where it has been calibrated based on past landslide events. The authors suggest the system can analyse failures due to ground acceleration, over-steepening due to erosion and rainfall infiltration.

Lin et al. (2009) have attempted to establish a probability-based early warning criteria for landslides in Taipei City by performing statistical analyses using the rainfall intensity and effective cumulative rainfall from 63 landslides. These cases were selected from the 426 landslides that occurred when Typhoon Nari struck Taiwan in 2001 and a further 100 landslide events in Taipei City in 2004 due to Typhoons Aere, Haima, and Nock-Ten. The data were used to divide Taipei city into three sub-regions of rainfall characteristics, with further subzones taking into account the geomorphological conditions, geological formations, characteristics of the precipitation records and the resources available for disaster management.

The Event Tree Analysis by Eidsvig et al. (2009) described earlier was used for an early warning system for the massive rockslide at Åknes, Norway. The area is characterised by frequent rockslides, usually with volumes between 0.5M and 5M m^3. There is enormous concern because of the possibility of a tsunami triggered by the slide endangering several communities around the fjord. Slope movements have been detected at Åknes down to 60 m depth with total annual displacements vary from less than 2 cm up to about 10 cm. The displacements appear to be increasing linearly with time.

Ohta et al. (2009) describe a trial of geotechnical asset management for highway embankments constructed on very soft clayey ground in Hokkaido, Japan. The embankment was constructed 30 years ago and continues to settle, requiring a considerable cost in maintenance. They conclude that coupled finite element analysis is reliable enough to be used in long-term prediction of settlement of highway embankments on soft clay foundations. The predicted life-cycle costs generated from the analysis agree well with the actual ones.

A novel use of data processing is reported by Jung et al. (2009) who describe a purpose-built information gathering vehicle used for mobile inspection of rock slopes. The vehicle was equipped with wireless Internet using CDMA for data transmission data between the vehicle and the Central Control Center. A GPS receiver was installed to allow location tracing and control of the vehicle. A video filming camera and two still video cameras were used for analysing the slope conditions and rock joint characteristics, providing visual observations for areas that are difficult to actually visit and inspect. The video equipment was capable of being raised about 7m above the ground surface.

The vehicle could also take measurements from sensors previously installed on the rock slopes (e.g. surface LVDTs, clinometers and earth pressure cells). In trials it was found that sensor data could be transferred seamlessly when the vehicle was travelling at approximately 30km/h and when sensors were within 100m distance of the vehicle.

5 SEISMIC HAZARDS

Seismic hazard assessment is now commonly carried out using GIS since geo-spatial information is vital to the analysis. Ansary et al. (2009), Murakami & Yasuhara (2009) and Wilding & Luna (2009) all report on the use of GIS in seismic hazard assessment.

Ansary et al. (2009) carried out a microzonation of Sylhet City, Banglasesh. Site amplification, liquefaction, and landslide microzonation maps for the city were developed as part of a comprehensive earthquake loss assessment for the city, using the 1918 Srimangal Earthquake as a scenario event. It was estimated that an event of this type would result in 25% of housing units collapsing and a further 40% being heavily damaged. Critical levels of ground motion values and regional estimates of surface peak ground acceleration were used in slope stability analyses to identify potential earthquake-induced landslides in the study area.

Murakami & Yasuhara (2009) performed liquefaction analyses for Yokohama and Kawasaki cities in the Tokyo Bay region of Japan. This study is of particular interest as the authors took account of rising ground water levels that could result from climate change. They based the assessment on a worst case scenario of a sea level rise of 0.88m in 2100 predicted by the Intergovernmental Panel on Climate Change (IPCC, 2001). They further assumed an increase in annual rainfall of 20% by 2100 (compared to current conditions) as predicted by the Japanese Meteorological Agency. A 2D model for unconfined groundwater flow in unsteady conditions was used to assess the rise in ground water level. They found that the area of high potential liquefaction increases severely with rising ground water level.

Wilding & Luna (2009) report on a pilot study for Poplar Bluff, Missouri, USA where "screening" analyses were run for liquefaction potential. The screening tool had the ability to interact with the user to display additional information with depth, for instance a distribution of factors of safety with depth. This allowed the user to examine where the lowest factor of safety was located within the soil profile and hence consider its importance relative to the structure being evaluated.

Wilding and Luna note that the GIS methodology is significantly simplified compared to a site-specific geotechnical analysis when a ground motion is propagated mechanistically through the profile. However, they note that a detailed site-specific analysis is rarely performed and hence the simpler GIS method has some merit, although it should be limited to use as a screening tool.

Park & Kim (2009) concluded from the benchmarking (round robin) exercise described earlier that cautious characterization of dynamic properties through site-specific geophysical and laboratory tests is of primary importance for evaluating site amplification effects. Use of empirical relationships and non-site-specific dynamic curves in a site response analysis may lead to unacceptable prediction of the dynamic response of the site.

García & Romo (2009) explored the use of the Hilbert-Huang Transform (HHT) for analysing earthquake recordings and the associated dynamic soil behaviour. This can be used to produce physically meaningful representations of data from nonlinear and non-stationary processes. In trials on the soft soil responses in Mexico City they found that the HHT was better than some conventional Fourier data processing techniques.

6 CONCLUSIONS

The review of the topic of Management of Geotechnical Data and Processes shows that there is a clear need for internationally agreed data standards that will allow interchangeability and sharing of geotechnical data. Developments in data representation using XML are progressing under the overall guidance of Joint Technical Committee JTC2 of the Federation of International Geo-Engineering Societies (FedIGS). Such developments will allow the World Wide Web to become an international repository for geo-engineering information. It is vital that efforts continue to be pursued by the entire international geotechnical community to facilitate the management and exchange of geotechnical data.

Data obtained from field monitoring can be particularly heterogeneous in nature. However, XML provides the flexibility needed for representing this type of data.

It is increasingly common for geotechnical engineers to make use of Geographical Information Systems (GIS) for storing and processing data as geo-spatial information is often vital to analyses. When large amounts of borehole data are to be stored it is important that these are available as digital data, rather than scanned images or pdf files, since image data will not allow geo-statistical manipulation of the information.

We now have a further opportunity to make borehole data sets available on the World Wide Web. Examples of web portals to provide access to these data have been developed for California and within the eEarth project, making borehole data available from several European countries and in multiple languages.

GIS technologies have been used for carrying out seismic hazard (liquefaction) and landslide assessments. Liquefaction assessments for the Tokyo Bay region of Japan have used GIS to take account of rising ground water levels that could result from climate change. It may be the case that GIS methodologies are significantly simplified compared to a site-specific geotechnical analysis and their use is likely to be limited to providing a screening tool. However, in another example, GIS was coupled with finite element analysis to provide detailed analyses at specified locations.

Handling uncertainty and managing risk in geotechnical engineering is essential. Risk sharing should ensure that each risk is assumed by the party best able to control it, given their technical competence and contractual commitments.

Examples are presented of risk assessment and management for the Mass Rapid Transit (MRT) system which connects Taiwan Taoyuan International Airport with Taipei city and a massive rockslide at Åknes in western Norway. Event tree analysis (ETA) provides a useful way of assessing risk levels, and can incorporate expertise from different disciplines. Risk mitigation measures need to be put in place when the risk level is sufficiently high.

A site investigation reliability framework provides a useful way of quantitatively justifying the amount of ground investigation data that is required to reduce the probability of under- or over-design. Greater amounts of site investigation data will reduce the probability, although there may be an optimum point beyond which further data will provide limited improvement.

The degree of uncertainty in geotechnical engineering is evident from a benchmarking exercise for seismic site response analysis carried out in Korea that showed significant variation among the teams. The maximum shear strain profile showed the highest variation (up to 4100%), while the discrepancy between the calculated peak ground accelerations was up to 700%. The wide dispersion was due to the combined effect of variations in the estimated shear wave velocity, dynamic curves, and the type of analysis.

A novel example of data processing is provided by a purpose-built information gathering vehicle used for mobile inspection of rock slopes in Korea. The vehicle continuously transmits data to a Central Control Center using wireless Internet. Video cameras are used for analysing the slope conditions and rock joint characteristics, providing visual observations for areas that are difficult to actually visit and inspect. The vehicle can also take measurements from sensors previously installed on the rock slopes.

The papers submitted to the Session on Management of Geotechnical Data and Processes provide a useful snapshot of the current state-of-the-art. The international geotechnical community is making good progress in addressing data management issues, but there is still much work to be done before we can make best use of our geotechnical data. Likewise, while explicit risk management and quantification of uncertainty is being used on some projects, it is still not the norm and could be adopted more widely.

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