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A relationship-based and object-oriented software for monitoring management during geotechnical excavation

Hao Wang [a], Li Li [b], Yu-Yong Jiao [a,*], Xiu-Run Ge [a], Shu-Cai Li [c]

[a] State Key Laboratory of Geomechanics and Geotechnical Engineering, Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan 430071, PR China
[b] Wuhan Maritime Communication Research Institute, Wuhan 430200, PR China
[c] Geotechnical & Structural Engineering Research Centre, Shandong University, Jinan 250061, PR China

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ABSTRACT

The efficient management of monitoring data is necessary for large geotechnical engineering projects. The development of an information management, prediction and warning software system for geotechnical monitoring is presented in this study. Seven categories of property objects that describe the hierarchical relationships among the monitoring objects, as well as two objects that represent and manage the construction progress, are proposed based on the requirements of geotechnical monitoring, data flow and the monitoring objectives of the site. The corresponding data structure and database were established using the object-oriented method in the Visual C++ environment. The software integrated various types of information and document management schemes, including data input and processing, CAD drawing visualisation, data modelling and prediction, as well as an early warning function. The applied case studies indicate that the software system is highly flexible and reliable and can be widely applied to monitor the sites of various geotechnical construction projects, such as tunnels, underground caverns, slopes and foundation pits.

1. Introduction

The monitoring of the construction of large civil engineering projects, such as hydropower and metro projects, usually features long construction periods, complex geological conditions and busy sites. The efficient management of large amounts of monitoring data and construction information, including monitoring data acquisition and processing, safety assessment and feedback, is imperative to ensure the quality and safety of the construction project [1,2]. Determining the correlations between different monitoring variables, construction progress, geological conditions, environmental variables and the changes in these factors over time using extremely abundant monitoring information is essential. These correlations and trends are used to guide the construction and rectify problems. Accomplishing this task in time by manually collecting and analysing relevant documents without support from professional software is difficult. Currently, geotechnical engineering monitoring information can be managed via three types of methods:

(1) For small projects with a simple structure, geology and surrounding conditions, fewer monitoring data are needed. In these situations, contractors generally use common data processing software (e.g., Microsoft Excel) to manage the observation results, but some additional simple developments (such as Excel VBA) are occasionally needed tostore and compute data, plot charts, analyse trends andgenerate reports. Sometimes, the drawings are managed by common CAD software, and the documents are managed by word processing software. Professional software that integrates information management and analysis is seldom used in such projects.
(2) Self-developed or integrated monitoring software systems are generally adopted for projects that require higher levels of data analysis and timely feedback. These situations are often mid-size and large projects with relatively complicated structure, geology and surrounding conditions that produce extremely large quantities of monitoring data. A number of software systems with different functions are currently available. For instance, GDMS, a fully functional system for design and construction management, developed by the GeoData Corporation, Italy, supports remote automated data collection, automatic alarms, CAD drawing visualisations and tunnel

* Corresponding author. Tel.: +86 27 87198299; fax: +86 27 87197560.
E-mail address: yyjiao@whrsm.ac.cn (Y.-Y. Jiao).

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construction progress management based on a geographic information system (GIS) and web technology. However, this program is not convenient to use because of its complexity [3]. Vista Data Vision (VDV), another web-based geotechnical engineering data management system with full functions, features curve chart comparisons and vector drawing visualisations based in Google Maps. However, sometimes certain elements of this program are unsatisfactory, especially regarding construction progress, document management and information exchange among participants during construction [4]. GEOSCOPE, which is similar to VDV, was developed based on GIS and also cannot manage construction progress [5]. SYTGEOScop, a monitoring management software program, is characterised by remote data collection, alarms and charts, but does not include CAD drawing visualisations, document management or progress management [6]. Geo-Engrade, which is similar to SYTGEOScop in its major functions, is known for its small size [7]. The GGU GmbH Corporation also developed a series of independent software known as GGUs. They are GGUTIME GRAPH, GGUCAD and GGU-GEO GRAPH, which together satisfy various geotechnical engineering requirements. However, these programs were not integrated into one system, which represents a problem. Additionally, many other researchers have developed various software systems for the purpose of monitoring management [8–12]. All of these systems were essentially developed in GIS or CAD, and they achieve similar functions but still suffer from some of the shortcomings mentioned above.

(3) Expert systems and decision support systems, e.g. the Decision Aids for Tunnelling (DAT), are well-known programs that focus on tunnel construction schedule arrangement, cost analysis and decision making. However, professional knowledge and skills are required to use these programs [13,14]. By using the fuzzy set theory and GIS, Cheng et al. developed a monitoring-data-based risk decision support system for foundation pit excavation [15].

Generally, the main shortcomings of the previously mentioned existing software systems can be summarised as follows:

(1) If tasks, including management, analysis and the querying of the collected multi-source information are not performed in the same software, good comparisons, correlation analyses and automation in the application are difficult to obtain. For instance, conducting comparative and consistency analyses among different types of monitoring data is difficult (i.e. generally, different types of nearby instruments should report similar information; if not, differences will exist). The correlation between the monitoring data and the construction progress (e.g. a chart of crown settlement vs. distance between settlement point and working face) also becomes difficult to compute. The above analyses are very important to quickly discern the main reasons for abnormal variations in the monitoring data.

(2) Geotechnical engineering monitoring is always poorly understood and a systematic design for the management of monitoring objects is always lacking. Thus, comprehensively and effectively demonstrating the complicated relationships between monitoring objects is not convenient, which leads to a poor flexibility in the software systems.

(3) Representing and managing construction progress is insufficient. This fatal defect needs to be solved because the principal purpose of a monitoring system is to analyse the correlation between monitoring data and construction progress. Additionally, insufficient attention is paid to document management, information exchange among participating construction organisations and other aspects.

(4) Many systems do not sufficiently support vector drawings that provide good visualisation experiences for users in practice. These systems also usually lack a bidirectional link to the property/data window from drawing windows (i.e. the ability to easily switch between these windows via a shortcut menu or right-click menu).

As mentioned above, current monitoring systems do not fully and effectively apply data collected at high costs. Thus, satisfying the strict requirements of the owners, designers and contractors is difficult [16–18]. In fact, site managers and engineers are eager to have a comprehensive monitoring software system rather than a system with a single function, as described above. In this context, the main functions of the monitoring software systems are listed as follows: ① database technologies can be used for various operations, such as management; the storing, sharing and querying of the monitoring data; relevant design; geological investigation; construction progress and other multimedia information; ② spreadsheet technology can be used to input, process and analyse monitoring data; generate curve charts and produce reports; ③ links between the monitoring data and relevant properties in CAD drawings for investigation, design and monitoring can be constructed; ④ statistical and numerical analytical algorithms can be used to predict trends, identify risk, evaluate projects and provide early warnings.

A comprehensive geotechnical engineering monitoring software program was developed in this study by integrating the above-mentioned four functions and a case application is presented. This software is convenient for users to gain a clearer and fuller understanding of the general situation of the whole project, construction progress, safety conditions and potential risks. Additionally, information querying, risk identification, online communication and information publishing are easily performed. This system has the advantage of closely connecting all construction participants to facilitate information search, exchange and feedback in a convenient and timely manner.

2. Concept and design method

2.1. Relationships between monitoring objects

For a geotechnical monitoring system to be easy to operate, its main function must be information management. This function depends on the efficiency of the database structure and the structure of the data, which describes the complicated relationships among various monitoring objects.

Monitoring points are the basic objects managed by the monitoring system. Each point is associated with several properties, including instrument types, instrument parameters and installation information, such as drilled borehole, coordinates, monitoring section, building or contract. These properties not only comprise the basic information of each monitoring point but also reflect the multiple relationships among various monitoring objects.

By analysing the logical relationships between monitoring procedures and monitoring objects in geotechnical engineering construction, seven types of objects were extracted in this study as the basic elements to organise the system data: engineering project, contract section, project unit, section, monitoring point type, monitoring points group and monitoring point (Fig. 1). These seven objects are briefly described below using a metro project as an example. This classification is also applicable to other similar geotechnical engineering projects.