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Development of a web-based information system for shield tunnel construction projects

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A B S T R A C T

The development of a web-based information system for managing, visualizing, and analyzing shield tunnel construction data is presented. A data model is first proposed to define the geometries and attributes of shield tunnel structures. The data model is intended to enable effective construction data collection and database design. Then, a web-based system architecture is presented. The system is developed based on a Web Geographic Information System (Web-GIS) software, ArcGIS Server. The functionalities implemented in the system include data management, 2D and 3D visualizations, geospatial analysis functions, and tunnel analysis functions. The geospatial analysis functions provide spatial analyses of soils, tunnels, and the relationships between them. Tunnel analysis functions include face stability analysis, face pressure analysis, and tunnel load analysis. The Shanghai Yangtze River Tunnel project is selected as a case study. Construction data on the two shafts, 7473 segmental rings, eight cross passages, and various inner structures of the project are stored in the system. Examples of applying the software to the project are presented, including simultaneous visualization of construction data on a geographic map and a longitudinal view, analysis of the soil and water pressures applied to the TBM face, analysis of TBM face stability, soil excavation analysis along the longitudinal tunnel profile, and 3D visualization of construction data. As a result, the efficiency of construction data management is improved through the use of the system.

1. Introduction

Shield tunneling has become an attractive method in the development of underground spaces for transportation and utility networks in soft soils. In developing countries like China, large numbers of shield tunnels are being built, and many more will be built in the near future. Tunnel engineers are under increasing pressure to meet the demands of improved safety, lower operation costs, improved maintenance and increased product quality for tunnel projects. To assist in meeting the present and future challenges of this industry, the construction of tunnels can be dramatically improved through the use of a comprehensive information system.

The use of a comprehensive information system has long been recognized as a key to increasing productivity and improving the quality of underground projects. In 1972, a computer database for Greater London was created to evaluate tunneling conditions for potential underground roads and rail routes. Rosenbaum and Warren (1986) concluded that databases and computer technologies for processing these data are particularly valuable during the feasibility stage of a project and that continuous updating of these databases facilitates a rapid evaluation of the new data and thus improves the efficiency of the design operation. Maurenbrecher and Herbschleb (1994) discussed the potential uses of geotechnical information systems in the planning of tunnels in Amsterdam, Netherlands. The information system has been shown to produce thematic maps that can be used in tunnel planning and design. Using a geographic information system (GIS) as a platform, Parsons and Frost (2000) described a system that provides the analysis of the adequacy of geotechnical and geoenvironmental site investigation data sets. Yoo et al. (2006) developed a tunneling risk management system (IT-TURISK) in a GIS environment with the capability of performing preliminary assessments of tunneling-induced impacts on the surrounding environment. van der Poel et al. (2006) reported on the employment of a GIS for the storage, interpretation and visualization of measurement data in the construction of the North/South metro line in Amsterdam and concluded that monitoring, in combination with an intelligent GIS and adequate interpretation, can serve as an early warning system. Li et al. (2008) developed a 3D visualized lifecycle information system (3D-VLIS) for shield tunnel projects. The system can be used effectively for organizing and representing tunnel lifecycle information. Such efforts have greatly improved information management and facilitated analyses of underground works.

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The rapid development of the Internet has also provided a new opportunity to redesign the architecture of information systems to satisfy increasing user requirements for accessing and processing real-time engineering data. Web-based information systems are convenient and cost-effective tools to promote the accessibility, efficient distribution, effective administration, and cross-platform flexibility of engineering information. This trend has also been introduced in the fields of geotechnical engineering and underground projects. Chang and Park (2004) developed a web-based geographic information system for the management of borehole and geological data. Kunapo et al. (2005) proposed a web-based geotechnical information system that can perform online spatial queries, generate professional borelogs, and carry out various geotechnical analyses. Degebrodt et al. (2008) proposed a web-based information and monitoring platform for risk assessment and management of geotechnical engineering projects. Chmelina (2010) reported a web-based tunnel information system to integrate tunnel project data over the lifecycle of construction and to make these data more accessible, exchangeable and usable. The system was implemented in European metro sites, such as Budapest and Thessaloniki, where the system was mainly used as an alarm and reporting tool.

Despite such efforts, many important problems remain to be solved for a web-based information system for shield tunnel construction projects. One problem comes from the absence of a model for data collection, database design, and data sharing between the different departments and organizations in a shield tunnel construction project. Another problem is how to present the construction data to meet the requirements of tunnel engineers. In previous web-based applications, these functions and analysis tools are limited to simple plan views of geotechnical information using data layers and map (Chang and Park, 2004; Degebrodt et al., 2008). Another problem is construction simulation and visualization of the data over the Internet, especially 3D visualization (Chang and Park, 2004; Kunapo et al., 2005).

This paper describes the development of a web-based information system in which shield tunnel construction data are structured, archived, visualized, and analyzed. The development of the system includes (1) a data model for shield tunnel construction data management; (2) design of a web-based system architecture; (3) implementation of database design; and (4) the development of web-based 2D and 3D visualization tools. Finally, a case study is presented on the developed system in the Shanghai Yangtze River Tunnel Project to demonstrate the functionalities of the system and to provide guidance for further improvements.

2. A data model for shield tunnel construction

Developing standard data models is an important task to support the implementation of an integrated system for architecture/engineering/construction (A/E/C) projects (Halfawy and Froese, 2007). In recent years, there have been increasing efforts to develop data models for geotechnical engineering projects. For instance, Chang and Park (2004) suggested a borehole data standard for developing a GIS for the management of the geological data in a local urban area. Kunapo et al. (2005) used the Association of Geotechnical and Geoenvironmental Specialists (AGS) data standard in designing the geotechnical database for a web-based geotechnical information system. Halfawy (2010) proposed a Geography Markup Language (GML)-based municipal infrastructure data model for the development of an integrated municipal infrastructure management system. However, data models for shield tunnel projects have rarely been reported in previous studies.

A data model that defines the geometries and attributes of shield tunnel structures is proposed. The basic ideas behind the data model are spatially decomposing shield tunnel structures, abstracting the structures into a class hierarchy, and attaching construction information to appropriate classes. Shield tunnel structure elements, such as shafts, cross-passages, and segmental rings, are defined as feature classes that consist of spatial data and their inherent properties. Construction data are defined as general classes and associated with feature classes. The class diagrams are illustrated using the Unified Modeling Language (UML).

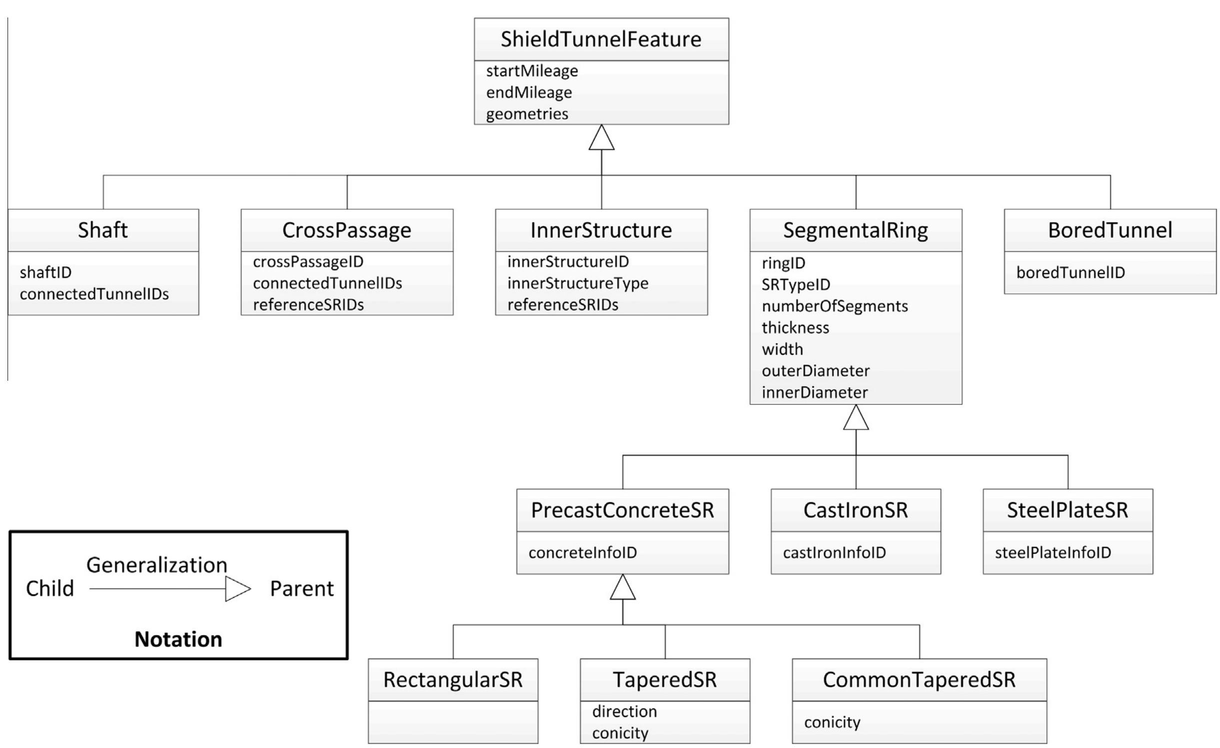

Fig. 1. Class diagram of the shield tunnel feature data model.