A Review of Artificial Intelligence Systems for Underground Construction

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Abstract: The paper reviews the development of artificial intelligence systems for underground construction. A total number of 16 knowledge-based (expert) systems and 11 neural network systems have been reported in the literature. These include systems for underground openings in rock, rock mass classification systems for tunnelling and systems for soft ground tunnelling. Systems for considering roof stability in mining are also reviewed. Many systems are only simple developmental prototypes, with much more work needed before they would prove useful in practice. Nevertheless, they do demonstrate the potential of both knowledge-based systems and neural networks in this field.

Key words: knowledge-based systems, neural networks, artificial intelligence, underground construction, rock engineering

Introduction

Artificial intelligence applications in geomechanics are still relatively new. Nevertheless a number of systems have been developed for underground construction and these are described in this paper. Knowledge-based (expert) systems for geotechnical engineering applications generally were reviewed by Moula et al (1995). However, that review concentrated on soil engineering applications. Toll (1996a) updated and extended that review to include other artificial intelligence approaches (neural networks) and also discussed systems for rock engineering. Details of systems for geotechnical engineering applications other than underground construction can be found in the review by Toll (1996a).

A total number of 16 knowledge-based (expert) systems and 11 neural network systems for underground construction have been reported in the literature. These include systems for rock mass classification as well as more specific systems relating to tunnels and underground openings. Other systems for ground control in mining have also been developed.

Rock Classification and Parameter Assessment

Rock mass classification systems make use of a set of reasonably well defined rules and are therefore ideally suited for implementation as knowledge-based systems. A number of systems have been developed, some of which have been reviewed by Coulthard (1995). These include Zhang et al (1988) based on Gu’s qualitative classification scheme; Juang & Lee (1989) and Madhu et al (1995) based mainly on Bieniawski’s rock mass rating (RMR) system, and using fuzzy logic; Butler & Franklin (1990) using Barton’s Q and Bieniawski’s RMR systems.

Neural networks have also been used for rock classification. Millar & Hudson (1994) describe the use of neural network methods for performance monitoring of rock masses for mining geomechanics. They describe an application for the collection of data relating to the condition and subsequent classification of rock masses. They have also used neural networks to predict the likely future performance of rock masses, particularly when they have been perturbed from
their natural condition by mining engineering activity. Cai (1995) has used neural networks to classify rocks for the purposes of blast design and Yi & Lindqvist (1995) have used neural network models for predicting rock quality parameters.


**Tunnels and Underground Openings**

Many of the systems for rock mass classification described above have an application in design of tunnelling support (Zhang et al, 1988; Juang & Lee, 1989; Madhu et al, 1995; Butler & Franklin, 1990). In addition, Fairhurst & Lin (1985) have discussed the use of a fuzzy methodology in the design of tunnel support systems.

Feng & Lin (1992) also present a knowledge-based system (OSDES) for tunnel support design. The system considers rock mass classification, groundwater, type, span and service time of opening, depth of overburden, dynamic, swelling and rheological properties of the rock. The system suggests a suitable type of support and also quantitative values for factors such as thickness of sprayed concrete, reinforcement details and diameter, length and spacing of rock bolts. The knowledge has been gained from more than thirty Chinese experts. The system has been tested against sixty case histories, and the support patterns suggested agree well with the solutions adopted.


Lee & Sterling (1992) describe a neural network for identification of probable failure modes for underground openings from prior case history information. The neural network forms part of a knowledge-based system for assisting with tunnel design (Sterling & Lee, 1992) and is used to identify similar cases to that being designed. The case histories can then be extracted for the the user to examine. Moon et al (1995) have also used a neural network approach integrated with a knowledge-based system for preliminary design of tunnels.

Gökay (1993) has made use of Hudson’s (1992) systems approach to rock engineering to develop a knowledge-based system to assist in rock engineering decisions relating to mine excavation. The system deals with rock mass type and structure; in situ stress state; hydrogeology; mining methods and assists with excavation stability, location and orientation.

**SIMSECTION** (Halabe & Einstein, 1994) is a knowledge-based system that acts as the user interface for DAT (Decision Aids for Tunnelling). The knowledge-based system assists the user with the definition of the problem and provides consistency checking before performing
an analysis. Coulthard & Ciesielski (1991) describe SAGA, a knowledge-based system to assist with the selection of a stress analysis program for rock excavation design. This can assist with choosing between ten different stress analysis packages.

Zhang et al (1993) present a knowledge-based system for prediction of potential disaster due to excavation of tunnels or underground structures within carbonate rock areas. It is based on the knowledge of Chinese experts in karst science and in underground engineering.

Although most artificial intelligence applications in tunneling have been developed for rock engineering applications, Mi and Jieliang (1989) report on a knowledge-based system for soft ground tunnelling. It has been developed to predict the value of surface settlement and the degree of damage to buildings caused by shield-driven tunnelling. The buildings considered can be brick structure, filled frame structure or infilled frame structure having either shallow foundations or pile foundations. The knowledge base stores information about the class of soil, ratio of tunnel depth/diameter, stability ratio of soil, type of shield, condition of underground water, level of working quality etc.

Another soft-ground application is that by Russell & Alhammad (1993) who describe a knowledge-based system framework for selection of appropriate construction methods. The approach is illustrated using a prototype knowledge-based system, called CMSA (Construction Methods Selection Assistant), to select a shoring system for cut-and-cover tunnelling. A knowledge-based system has also been developed for providing assistance for the planning of support for trenches (Konkoly, 1986; Siller, 1987). The system is based on two soil classification systems developed by the US National Bureau of Standards in order to increase the safety of this type of excavation.

Yao et al (1992), Reddish et al (1994), Reddish et al (1995) present ESDAS (Expert Structural Damage Assessment System). This was developed to evaluate damage due to mining subsidence. The system uses a risk-assessment technique based on certainty factors to predict the likely damage to a particular structure that is subject to mining subsidence.

Yu & Vongpaisal (1996) describe a new blast damage criteria that has been developed with special reference to mining operations. It can be used for assessing damage by incorporating the vibration level, rock properties, site characteristics and the effects of ground support systems. The approach has been used within a ground control knowledge-based system module.

Discussion

Artificial intelligence systems for underground construction make up a significant proportion of the total number of systems developed for geotechnical applications. Fig.1 shows that underground openings and classification systems are two of the most extensively developed areas for geotechnical systems. Neural network applications have also been particularly well developed for these topics.

Rock mass classification systems are well suited to a rule-based approach, although neural networks have also been used for this purpose. Other systems have been developed specifically for preliminary design of tunnels and of tunnel support systems. Although most artificial
Fig. 1. Artificial intelligence applications in geotechnical engineering, classified according to the area of application (from Toll, 1996b)

Artificial intelligence applications in tunnelling have been developed for rock engineering, a small number of systems have been developed for soft-ground tunnelling.

Artificial intelligence systems have been used to assist in the prediction of failure modes for underground openings and to predict problems due to excavation of underground structures within carbonate rock areas. Knowledge-base systems have also been used to assist with the selection of stress analysis programs for rock excavation design.

Systems for considering roof stability in mining are also been developed. Since 1991 a number of neural network systems have been developed for monitoring mine roof stability, designing supports and predicting deformations.

Many of the systems described are simple prototypes i.e. they have been developed to show that the techniques could be useful. Relatively few are being used commercially at present. However, as the area develops, and more systems develop beyond the prototype phase, we should see an increase in the use of artificial intelligence systems in practice.

Conclusions

The paper discusses the development of artificial intelligence systems for underground construction. This has been an area in which a significant number of systems have been developed. Neural network applications have been particularly well developed for rock engineering applications.
The applications include rock mass classification; preliminary design of tunnels and of tunnel support systems; prediction of failure modes for underground openings; selection of stress analysis programs for rock excavation design; prediction of problems due to excavation of underground structures within carbonate rock areas; roof stability in mining. Although most artificial intelligence applications in tunnelling have been developed for rock engineering, a small number of systems have been developed for soft-ground tunnelling.

The application of artificial intelligence techniques in geotechnical engineering as a whole is still relatively new. Many systems are only simple developmental prototypes, with much more work needed before they would prove useful in practice. Nevertheless, they do demonstrate the potential of both knowledge-based systems and neural networks in this field.

References


Introduction

Mechanized tunneling technique using roadheaders or shuttle cars has become a predominant method of underground mining. Recently, tunneling machines have been used to an increasing extent in both mining and civil engineering projects. Compared to traditional methods, mechanized tunneling techniques offer major advantages such as a higher degree of mechanization and improved advance rates with reduced manpower. It also offers improved ground control and an environment leading to safer working conditions.

In underground coal mining, longwall mining method is the most productive in comparison to other methods but requires particular conditions for its effective use. One of these requirements is that the longwall gateways are driven rapidly and are also well supported in order to withstand high ground stress structures created by the advancing longwall face. In a mine using a high-production longwall mining system, gateways should be developed more rapidly and maintained effectively to achieve high levels of mine productivity and economy.

This paper discusses the influence of geological and mining factors related to the performance of coal mine tunnel drives by roadheaders and discusses some improvements in the heading drive operation in Japanese underground coal mines.

Geological and Rock Engineering Aspects

Detailed geological information is necessary in mine tunnel drives to adopt the most appropriate, efficient excavation technique and selection of ground control method. Properties of coal and coal-measure rocks have implications in the selection of drive and support method. In underground coal mines, geological discontinuities such as