Recent Developments in Support Desing Philosophy with Reference to UK Coal Mines

İngiltere Kömür Madenlerinde Tahkimat Tasarımı Felsefesindeki Güncel Gelişmeler

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Abstract

The paper reviews recent design procedures available and utilised for underground coal mine drivage development. The potential application of new technologies in geotechnical data collection and processing is discussed. Contemporary support methods are presented and current trends towards the application of roof bolting in British Coal Measures are also discussed.

Özet

Bu bildiride yeraltı kömür madenlerindeki hazırlıkların sürülmesinde kullannan güncel tasarım yöntemlerinde izlenen yollar gözden geçirilmektedir. Ayrıca, jeoteknik veri toplanması ve değerlendirilmesindeki yeni teknolojilerin uygulama olanağı tartışılmaktadır. İlave olarak, çağdaş tahkimat yöntemleri sunulmakta ve IngStere'de kömür cevheri kayaçlanndaki kaya saplaması uygulamasına yönelik mevcut yaklaşımlar tartışılmaktadır.

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1. INTRODUCTION

In response to the recent economic climate, UK coal mines have been involved in extensive cost reduction exercises. One of the principal areas identified for attention has been in the support of tunnels. These have involved high development costs in association with coal mining projects. This paper provides an overview of the excavation design processes utilised in UK coal mines. It also highlights the significant advances which have been made in approaches to monitoring, data collection, current design processes and support selection.

2. DESIGN PROCEDURES

The main objective of a design approach is to indicate whether an underground opening will be stable. In addition it should establish procedures to enable decisions to be made on the required support specifications. Currently there are three main approaches to the design of excavations in UK coal mines: empirical, analytical and dynamic design methods. These are reviewed within the context of UK mining conditions.

2.1 Empirical Design Methods

The principal empirical design approaches are Rock Mass Classification systems which have for a number of years provided one of the primary methods of empirical design in rock engineering. They have been applied to a variety of projects ranging from tunnel design to dam and foundation construction. Bieniawski (1988) identifies several aims and attributes that a rock classification should possess:

AIMS:

(1) Identify the most significant parameters influencing the behaviour of a rock mass.
(2) Provide a basis for understanding the characteristics of each group.
(3) Provide quantitative data for effective design.
(4) Provide a common basis for communication.

ATTRIBUTES:

(1) Simple, readily understandable, remembered and applied.
(2) Terminology widely accepted.
(3) The most significant properties of the rock mass included.
(4) Based upon measurable parameters, rapidly determined in the field.
(5) Based upon a rating system.

Several classifications have been developed which are used with the above guidelines, the most notable being the Rock Structure Rating (RSR), the Q System (Barton et al 1974) and the Geomechanics Classification (Bieniawski 1973).

In all of the above examples, the classifications were produced from the analysis of many case studies to produce a ranking system for various geotechnical parameters. These case studies were generally taken from shallow excavations where the principal mechanism of instability is the movement of detached blocks when the gravitational loading exceeds the resistance to movement provided by joint shear resistance. However in the deep coal excavations that typify UK conditions, other mechanisms of instability are introduced that are generally stress related. This has the tendency to render the classifications unreliable under certain conditions.

One key area where the application of classification becomes marginal is in discontinuity determination at depth. Often geotechnical investigations have featured the measurement of the natural joint system in the rock mass in order to provide joint spacing information and potentially the identification of unstable roof blocks using kinematic analysis techniques. In deep soft rock excavations, however, the joint system developed is dominated by a series of stress induced fractures. These fall into three principal categories:

(1) Fractures associated with the redistribution of stress as the heading advances.
(2) Fractures associated with the development of yield zone conditions around the excavation.
(3) Fractures associated with the interaction of adjacent workings.

The presence of these stress induced fractures, in addition to any natural joint planes, makes the task of defining joint characteristics important to stability, difficult. Several of the other factors are poorly represented by existing classifications. Most joint surfaces seen within deep coal mines have little separation, may be shckensided and are seldom infilled and these conditions are poorly dealt with in most schemes. In addition the water conditions described are excessive for Coal Measures strata where 10-15 litres per minute would be considered a high rate of inflow.

As a consequence of the non-sensitivity of these classifications to the values expected under the high stress conditions of deep coal excavations, the results they provide will often be at best poorly resolved and at worst non-applicable. **

2.2 Dynamic Design Approaches

Dynamic approaches base support selection on actual monitoring of ground movement during excavation. Although these developments have not resulted in useful design calculation methods in the sense of established methods; they signal an increasingly evident change in philosophy to mine support design. This has led to a greater necessity for integration of the procedures involved in a major excavation construction project. The two most utilised and popular approaches are the New Austrian Tunnelling Method (Rabcewicz 1964) and the Rock/ Support interaction analysis methods (Daemen 1975).

The New Austrian Tunnelling Method (NATM) is a philosophy based upon the mobilisating and conserving of the strength of the rock mass with the aim being to form a ring of self supporting or reinforced rock around the tunnel. This approach is often associated with the use of rock bolts and shotcrete. The NATM relies heavily on the implementation of a successful and well designed monitoring programme and an integrated approach to the utilisation of data. An excellent example of the successful application of the NATM was for the construction of two drifts through water bearing strata at Barrow-upon-Soar, by British Gypsum (Deacon & Hughes 1988). The use of the NATM allowed flexibility while a balance was obtained between rate of progress, and the requirement for caution and quality under difficult ground conditions.

The Rock/Support interaction methods of analysis enable calculation of load applied to the support by considering the intersection of two characteristic curves of loads as a function of deformation.This approach is a way of considering the process of stress redistribution around a supported tunnel as the head end effect diminishes during tunnel advance. The principle, like the NATM, is to conserve and mobilise the available ro$k strength thereby minimising the loads acting directly upon the tunnel lining.

With the improved data communication methods and on line monitoring methods which are becoming available, dynamic approaches will play a greater part in mining excavation design processes in the future. However the ability to have a continually changing support pattern as the conditions change is currently limited by UK mining legislation.

2.3 Analytical Design Approaches

Analytical'design approaches involve mathematical, numerical and physical modelling techniques which are used for analysing the stress distribution and for observing deformation around an opening (see Table 1)

Table 1 : Principal Analytical Design Approaches to Tunnelling

Mathematical Modelling	
	Finite Element Method
Numerical Modelling	Boundary Element Method
	Discrete Element Method
Physical Modelling	

Closed form solutions obtained in mathematical techniques are based on stress and continuum analysis. They provide information on stress distribution in certain ideal elastic situations and can be used in specific cases within an integrated approach to give initial guidance. They are, however, of limited value in most coal mine tunnelling situations.

Numerical modelling is one of the principal tools of design engineers and is suited to an integrated approach utilising interactive graphics and rapid communication of up to date, on site information. Due to the considerable interest in numerical modelling in the previous 25 years, a variety of modelling techniques have been developed. The principal techniques of relevance to rock tunnelling are the Finite Element Method, the Boundary Element Method and the Distinct Element Method. Excavation structural analysis can be systematically broken down into elements each of which is assigned behavioural qualities in terms of load, stiffness and displacement.

The Finite Element Method constructs matrices representative of the stiffness of the whole structure allowing solution of load displacement relationships. This method has been well proven for predicting elastic material behaviour and by alteration of the technique non-linear material behaviour of a number of forms can be analysed. This has particular relevance to coal mine excavation design. A major research interest at the University of Nottingham, Department of Mining Engineering is the influence of the nature of the stress field and the shape of the roadway in relation to stability. This research has concentrated upon the adaptation and utlisation of a non-linear Finite Element package (Reddish 1989) for differing conditions and comparison of underground sites.

The Boundary Element Method is used to describe a class of numerical solution methods that involve formulating a given elasticity problem in terms of boundary data. The common factor throughout this class of methods is the use of fundamental singular solutions distributed around the boundaries of the problem. Input data requirements using this method are considerably less than using the F.E.M and consequently can be adapted to provide rapid on site analysis of a particular solution.

The Distinct Element Method introduced by Cundall et al (1975) is a computer based analysis which utilises interactive graphics in which the behaviour of discrete semi rigid blocks which constitute the roof of an opening can be simulated. Consequently it has application to the design of tunnels through hard blocky rock ground. Each block may undergo rotation and displacement while progressive failure is modelled. This method holds potential for further development and is characterised by relatively simple principles and associated mathematical calculations.

Physical modelling techniques offer a solution to modelling specific cases where jointed rock masses are being excavated. However, they are of limited value where parameter variation is required in a design process and are often prohibitively expensive.

Currently the major restrictions associated with analytical methods of design are the difficulties in determination of in situ stresses and the verification of the validity of results.

3. MONITORING FOR DESIGN

Modern excavation engineering projects utilise an interactive procedure involving collection of data underground for input to design processes. It is in this context that in situ field measurements are of major importance and it is imperative to correctly plan monitoring procedures. Figure 1 shows the necessary procedure for the implementation of a successful monitoring programme and has been developed by the authors as a result of previous shortcomings in approaches to geotechnical monitoring.

There is a wide variety of geotechnical questions that require on site underground investigation when monitoring tunnel stability. The prime purpose of tunnel monitoring is to provide the maximum amount of information about the changing geotechnical environment that can be readily translated into support specifications. Other considerations are the evaluation of the effectiveness of support measures, comparison of real performance with theoretical predictions, safety control measures and the evaluation of specific problem areas. The principal physical quantities which can be monitored are shown in Table 2. A monitoring programme encompassing the above physical quantities provides the best overall picture of a coal mine tunnelling project from a stability point of view.

Table 2 Principal Features of Tunnel Stability Investigation

Strain
Relative Displacement
Absolute Displacement
Changes in Curvature
Stresses in Linings and Rock Mass
Rock Pressures on Linings
Stresses in Rock Bolts
Water (if of significance)

As the realisation of the economic importance of data collection in the various stages of a

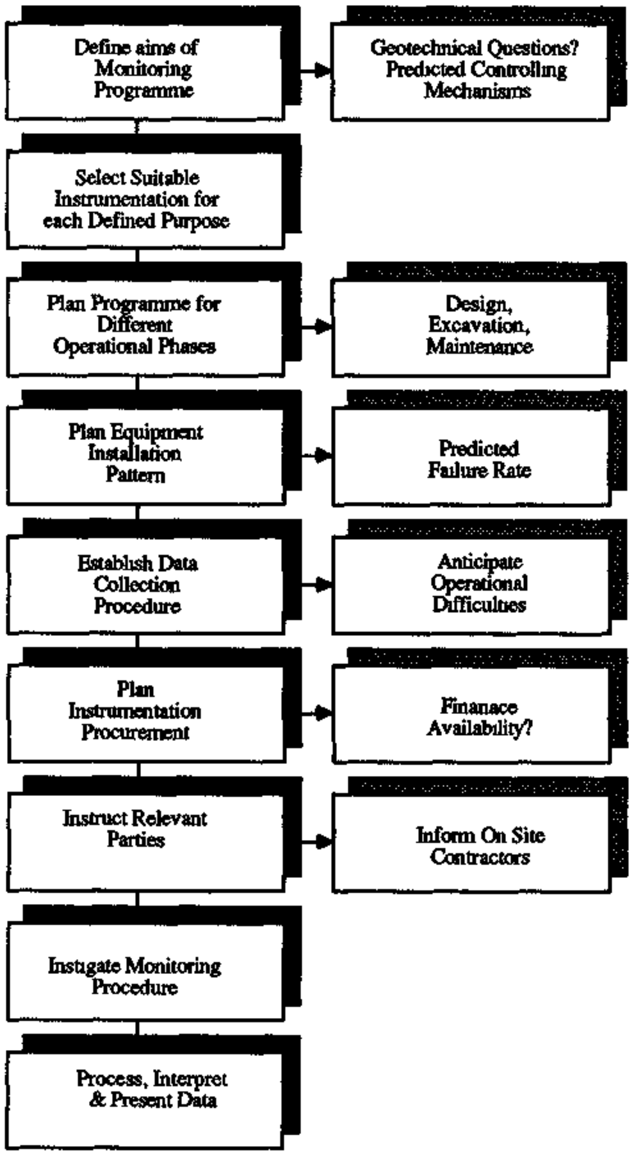

Figure 1: Structure of Monitoring Programme

project has increased, advances in data collection techniques have rapidly occurred. Much of the information derived is poorly handled resulting in task duplication. Developments in technology are enabling a wide range of in situ transducers to be remotely monitored although problems are encountered due to the hazardous nature of excavation work. The utilisation of continuous monitoring systems can provide a steady stream of information as events occur although there are still serious limitations due to the necessity for monitoring systems to be rugged and flameproof.

Another notable advance in computer technology and its application to geotechnical monitoring is the use of automatic image analysis in the interpretation of photographs from deformation surveys which enables rapid and extensive surveys to be carried out. Image analysis systems function by converting a photograph of an arch into a digital array of pixcels (picture points) and storing the data. By overlaying survey photographs over an original the system can automatically measure changes in area and curvature as well as height and width reductions.

Image analysis systems have great potential for improved deformation surveying. They provide a rapidly accessible visual record and it is possible to automate the whole survey thereby reducing human errors and increasing efficiency.

4. DATA INPUT TO DESIGN PROCESSES

Having produced a quantity of geotechnical information, the efficient utilisation of these data is imperative. Recent advances in Information Technology ensure easy analysis, presentation and transfer of information thus allowing a central data source to feed a number of problem areas.

Advances in data communication methods have produced a situation where information is rapidly disseminated from the .actual tunnel site in a manageable form to the decision making body. Presentations of a high standard can be rapidly produced through the use of quality graphics systems, reading information straight from the original analysis. Information can be accessed directly from the board room to the tunnel site on a real time scale. In particular, the advent of computer aided planning packages which incorporate three dimensional graphics facilities will become of great value to coal mine planning engineers, similar packages are used in many metal mining operations.

With the complete integration of the geotechnical information into a central data base, options are available for improved analysis techniques. A flow chart representing a completely integrated approach is presented in Figure 2. With the advent of computer expertise, both design and monitoring processes can be simplified and immediate distribution of results to relevant parties can be enacted. Decision support systems can be applied to the processes of data interpretation and analysis thereby producing savings in time and money whilst releasing competent engineers from tedious and repetitive procedures.

Expert systems are a notable development in decision support that has received much attention over the past few years. Their ability to mimic human expertise by the manipulation of data often of a non numerical form, has led to their development in a number of fields in mining engineering. The utilisation of a heuristic or rule based structure is seen as a logical step along the route from conventional algorithm based systems to the artificial intelligence applications of the future. The interpretation of underground information is a domain of expertise that can be readily computerised by the application of expert systems. For instance the interrogation of gçotechnical data by an expert system could readily convert raw information to meaningfully classified rock quality information. The basic design structure of an expert system is shown in Figure 3. The development of fuzzy methodologies has also enabled computer systems to deal with the interpretation of observations, that do not fall into distinct classes.

5. ASPECTS OF SUPPORT DESIGN DEVELOPMENTS IN UK COAL MINES

The principal types of support at present utilised in UK coal mines are included in Table 3. At present the support requirements of the majority of coal mine drivages are provided by steel arch support systems with the remainder being supported by other passive support systems such as concrete segmental linings. The use of bolting has been generally limited to a supplementary role with one of these systems. Several methods of improving support design including grout filled envelopes, TH arches and circular supports have been developed, especially for major drivages (Newson 1986). However, these methods have only really involved slight changes to the traditional methods of free standing supports. / '

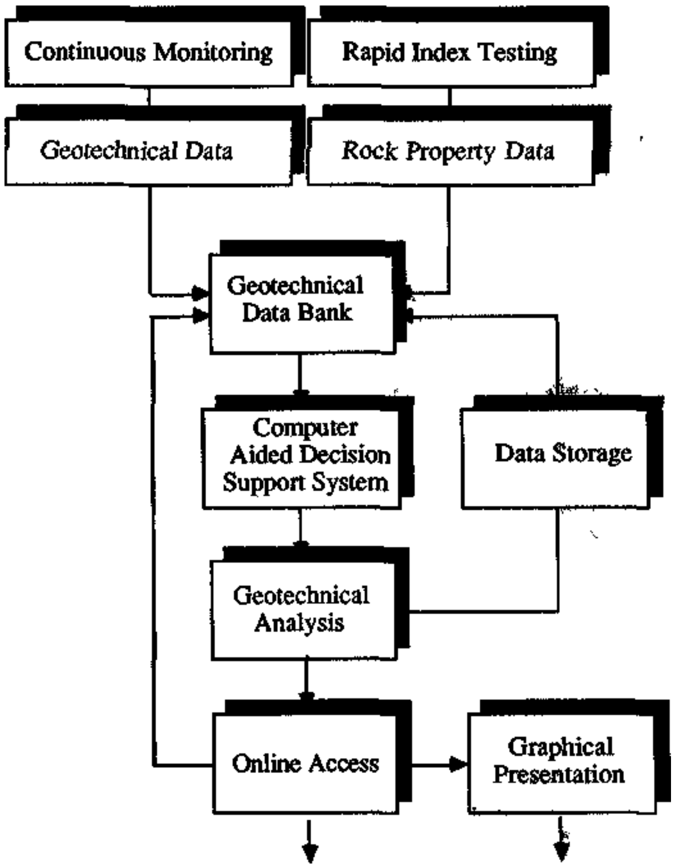

Figure 2 Geotechnical information: integrated approach

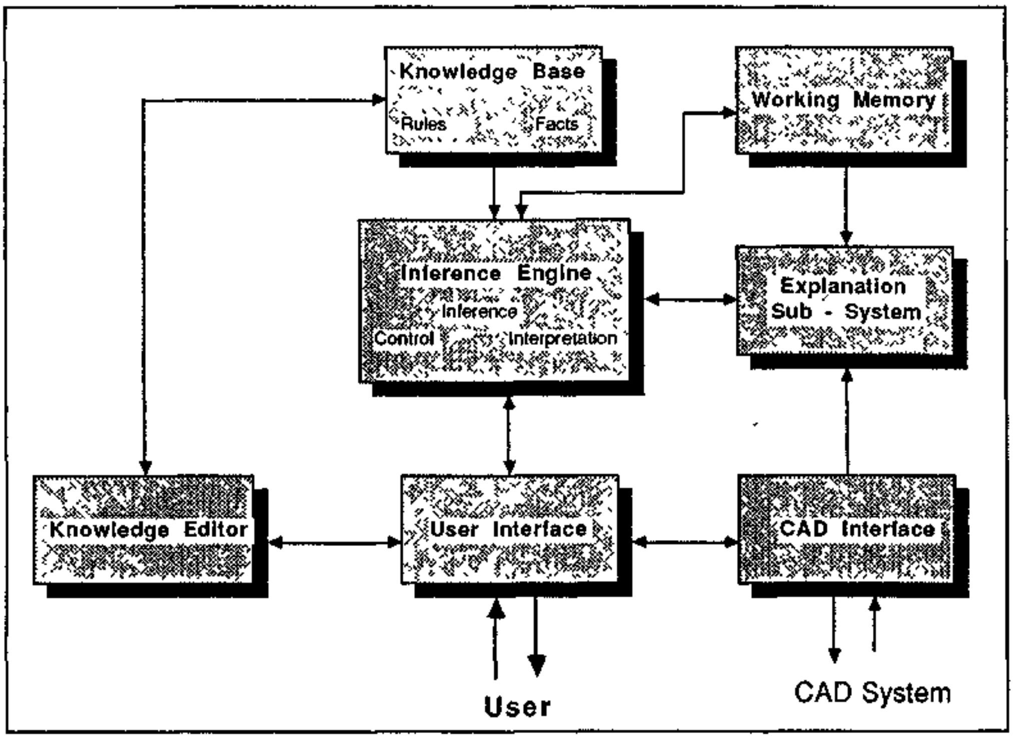

Figure 3 : Diagrammatic representation of the structure
of an Expert System (After Brown 1988)

Table 3: Contemporary Support Systems: UK coal mines

Rigid Steel Supports	Rigid Steel Arches Square Work Supports Circular Steel Supports
Yielding Steel Supports	Yielding Arches Yielding Square Sets
Concrete Supports	Monolithic Concrete Linings Sprayed Concrete Linings Prefabricated Concrete Supports Prefabricated Panel Supports
Rock Bolting	Mechanically Anchored Boks Grouted RockSotes Friction Anchored Roek Bolts Cable Bolts

Economic pressures have, however, produced renewed emphasis on efforts to change the main support type through the widespread application of roof bolting reinforcement a*, primas support systems. As a direct result it has been necessary to research:-

1) A satisfactory method of evaluation of sites where roof bolt reinforcement systems would be applicable.
2) A satisfactory method of designing the system wüfesafe »tandafds.
3) Improvements to bolt installation methods in association with mechanised tunnelling.

The assessment of the viability of roof bolting in coal mine tunnels and establishment of design procedures has posed a major problem. Research has concentrated on identifying the mechanism of reinforcement (see Table 4) which is most applicable to British Coal Measures conditions and assessing the performance of variations of types of support systems. These aims are being attained by a combination of effort including a major programme of underground site installations utilizing borehole extensometers, roof bolt extensometers and deformation surveys at the tunnel face.

Table 4 : Mechanisms of Reinforcement by Rock Bolts

Formation of a natural arch

lownation of a composite beam from several layatës

Reinforcement of laminated roof by friction astion

Suspension of weak layers to a steowgef taper

Prevention of movement along planes of weataets

Whilst the utilisation of roof bolting has resulted in a reduction in support costs in underground coal mining roadways, it requires careful design consideration prior to installation. For instance, the roof conditions encountered in UK Coal Measures rocks often consists of very weak rock (UCS <25MPa) such that the application of reinforcement techniques in these conditions can be limited unless a proper design is adopted to suit the particular conditions. Monitoring stability is highly desirable especially in conditions where there may be difficulties.

6. COMCLWSIONS

This paper has drawn attention to aspects of the underground monitoring, excavation design, and support selection procedures currently utilised in UK coal mines. The main conclusions are:

(1) The application of new technologies to data aqusition and processing can

improve efficiency in geotechnical monitoring operations.

(2) Roof bolting has been proven to be effective as a support system and shows potential for considerable cost reductions.

(3) Application of roof bolting support systems has required a change in emphasis towards greater flexibility in support design.

Roof bolting has a major role to play in giving stability and cost reductions in coal mine roadways and other underground excavations.

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