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A STUDY OF UNDERGROUND TUNNEL STABILITY & ROCK MASS FAILURE CRITERION

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ABSTRACT

The assessment of tunnel stability is a critical topic, especially when it is necessary to construct through complex geological settings. In practice, surface surcharge loadings may arise when tunnels are dug beneath pre-existing buildings through fine-grained soil overlain by granular material Although the weights of the overlying coarse-grained materials are readily taken into consideration when analyzing tunnel stability. Since the founding of the International Society for contribution to tunnel stability in terms of strength and stiffness is frequently overlooked or too complex to quantify.

Rock Mechanics (ISRM) in 1962, one of the most active study topics in the engineering of rock structures has been rock failure. In rock mechanics and engineering, a rock failure criterion is critical for predicting the failure of rocks or rock masses.

The study of the stability and rock mass failure criterion briefly discuss the considerable point of making underground tunnel. A detailed discussion has been carried out relevant theories and mathematical concepts which relate to tunnel stability and the failure criterion.
The literature review has found useful application especially in giving guidance on those areas needing further investigation. The author discusses mathematical theories in relation to the research undertaken. The major area of investigation has been done with the necessity of underground tunnel constructions focusing on after careful consideration.

The overall discussion has focused what influence mine tunnel failing criteria and essentiality of stability. Which helps to choose support type. In particular, the merits of standing support types such as square sets, steel arches and concrete linings are discussed in relation to the results of the research.

The thesis draws attention to the importance of study Stability and Rock mass failure criterion in tunneling aspect for a successful tunnel design.

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INTRODUCTION

The underground tunnels, which provide access to the mine area and are used to transport the ore, are essential to underground mine projects. Their stabilities are of great importance because it ensures the safety of the working people and operating equipment as well as successful ore production.
Stability conditions around underground tunnels can be affected by a number of factors, either internally or externally. Basically, the type of intact rock, whether it is competent or soft, determines the capability of the material. As a natural geological material, the rock mass contains pre-existing defects such as fissures, fractures, joints, faults, shear zones, dikes and so forth. These discontinuities could significantly weaken the rock mass strength, increase the rock mass deformability and make the rock mass mechanical behavior complicated. The failure modes of the rock masses are closely related to the geometry pattern and conditions of the discontinuities. As far as the underground situation is concerned, in-situ stress field caused by the overburden strata and the lateral stress system needs to be taken into account. Problems around excavations may arise as the stress exceeds the rock strength or as high differential stresses are encountered.

The design configurations of the excavations, such as orientations, sizes and shapes, are also critical factors. For instance, the favorably driven direction of the tunnels is that parallel to the maximum principal stress and that perpendicular to the strike of the discontinuities; the circular tunnel shape is ideal to suffer less stress concentrations and failures. After excavation, the support system has to be installed to help the rock mass support itself. The interactions between the rock mass and the support system depend on the factors including the rock mass properties, the geometry and properties of the supports, the geological condition and so forth. Additionally, the response of rock masses is sensitive to the unloading and loading processes.

Different excavation and supporting sequences could result in totally different reactions in the rock masses. Thus, under different combinations of the aforementioned factors, the assessment of rock mass stability for an underground mine is extremely challenging and difficult. Due to the fact that geological conditions and engineering disturbances may differ from one project to another, a study considering the specific factors to a given site is necessary.

The Hoek-Brown failure criterion was developed in the late 1970s to provide input for the design of underground excavations. Bieniawski's RMR was originally used to link the criterion to engineering geology input from the field but a more specific classification system called the Geological Strength Index (GSI) was introduced in 1995. Both the Hoek Brown criterion and the GSI classification have evolved and continue to evolve to meet new applications and to deal with unusual conditions encountered by users.

Failure criterion has developed into the most widely used system for estimating rock mass strength in rock engineering. The reason lies in its unique framework for integrating the strength properties of intact rock and geological observations in the field. While the determination of intact rock properties from laboratory tests is relatively straightforward, quantifying the relevant geological characteristics remains challenging. Strength degradation relations play a central role in the Hoek–Brown failure criterion by downgrading the strength properties of intact rock, based on quantitative measures of rock mass quality and disturbance, to estimate the strength properties of the rock mass.

In this independent review, the origin and evolution of the Hoek–Brown failure criterion and the associated strength degradation relations and rock mass characterization methods are discussed. Common methods for estimating rock mass cohesion, friction angle and deformation modulus are presented. The effect of parameter uncertainty on the reliability of estimated rock mass properties is investigated. Understanding the basis and development of the Hoek–Brown failure criterion is essential for proper use of the system within its limits of applicability and with realistic expectations of reliability.

TUNNEL STABILITY PROBLEMS FACING THE COAL INDUSTRY

Mining activities have posed various kinds of rock mechanics problems. In the process of a tunnel design, the stability of tunnel is always a focus of discussion. The assessment on tunnel stability needs first to take into account the required length of service life of the tunnel under consideration. According to the length of service life, tunnels may be classified in three categories, namely short term tunnels, medium term tunnels and long term tunnels. Short term tunnels are those often encountered in association with longwall mining, namely the gateways. The length of service life of these tunnels may be as short as a couple months and up to 1-2 years. Such tunnels are usually subject to heavy loading effects due to the mining induced stress redistribution. As a consequence of short term service, these tunnels can tolerate tunnel closure of up to 30% of the original dimensions, generally without the need for repair.

Medium term tunnels refer to those with a service life span being between 2- 10 years. Such tunnels are usually found to be accesses linking panels and pit major tunnels. Unlike short term gateways driven along seams, the medium term tunnels are often required to be designed and excavated in comparatively competent strata underneath or occasionally above coal seams. Such tunnels are likely to be subject to the mining induced stress effects. However, the influences that the tunnels can permit are less severe than those in gateway cases. Particularly, the deformations of the tunnels at the early stage of their service should be minimized. Long term tunnels are those having life durations of several tens of years or even accompanying the operation of the whole mine to the end. Long term tunnels need to be located in more stable rock formations. Since they tolerate less instability disturbance, the tunnels require more intensive and effective support systems to be employed. No matter which kind of tunnel is considered, the design of the tunnel must satisfy the requirements for the stability although the degree of stability and the duration of maintaining stability may vary from one case to another. In modern coal mining operations there are two notable features :

(1) Excavation depth is increasing. In the British coal mining industry, the greatest depth has reached 1100 metres below the surface, with deeper excavations being considered. In China, coal mine tunnels have also been driven to depths of over 1000 metres below the surface. In Germany, the depth has reached 1400 metres. Gradual increases in mining depth would result in gradual increases in the ground stresess, at least in the vertical component of stress. This indicates that the rocks around the tunnels at greater depths would suffer greater loading effects. Consequently, more instability problems would be encountered. As another result of the increase in driving depth, the properties of the rocks may be subjected to changes The failure mode of the same kind of rock may also differ. Yielding zones around the tunnels at greater depths may develop into a wider scope and thus the tunnel closure may become more apparent. Rock mechanics problems which have been encountered so far in association with the increase in mining depth are rock bursts occurring mainly in brittle rock formations characterised by high mechanical strength, and floor heaves occurring largely in soft ground formations.

(2) Coal mining activities are moving towards more difficult ground conditions in terms of strata control. Having been won for a considerable time, the number of seams which are easy to be extracted are becoming less and less. Many remaining seams for the future will exhibit various difficulties in respect of ground control of excavations. For example, mining in small interval multiseams would pose a number of potential problems to the extraction and excavation in the remaining underlying seams, due to the fact that a large quantity of remnant pillars have been left in the mined-out areas in upper seams, which have attracted high roof pressures and given rise to stability problems in the undercut tunnels in the remaining seams. In particular, if the remnant coal pillars in upper seams have not been recorded in detail, tunnels for the underlying seams in the future are likely to be designed and driven in those adverse areas of stress concentration. It seemed necessary at this stage to examine the rock mechanics problems occurring in association with tunnel stability and support design, before the research objectives of this thesis was identified. This has enabled the significance of the objectives to be highlighted.
If we carefully examine the most primary source of the above mentioned problems associated with tunnel stability, it is not difficult to find that the instability problems always arise from changes in the stress field. Excavation of a new tunnel removes the confinement on the surface of the profile and induces a stress concentration zone around the tunnel. The original equilibrium condition is thus disturbed and destroyed The inequilibrium in the stress field triggers the deformation and closure of the tunnel, with the exceptions of those owing to the dilation nature of soft rocks. The mining induced instability problems can also be attributed to the effects of the change (increase in this case) in stress field.

If various detailed reasons which cause the change in stress field are overlooked in order to find the core of these problems, the investigation into tunnel stability problems may be reasonably simplified, and the research focus may thus be thrown onto the effects of the most basic factor, namely the change in stress field, on the tunnel stability. This consideration formed the major research objectives of this thesis.

FACTORS INFLUENCING TUNNEL STABILITY

Underground coal mining operations in the UK coalfields are virtually entirely confined to Carboniferous Coal Measures rock formations. Although, in other countries, the mining activities also take place in the Jurassic, Permian, Triassic and even Tertiary Periods of sedimentary rock formations. The rock settings encountered in these coal fields are frequently those of sediments such as conglomerates, sandstones, limestones, clays and shales in addition to the coal itself. They commonly exhibit typical sedimentary characteristics in their rock structures and their physical and mechanical properties. Moreover, each rock also has its own features different from those of the others due to variations in the early sedimentary circumstances and the later geological processes. The differences in the features of rocks make the rocks respond differently to the excavation formation and, thereafter, the stability of the tunnel. The fact that the ease of excavation in these rocks varies indicates the need for a proper choice of excavation method in a given strata circumstance since the approaches to excavation have a varied effect on the degree of disturbance and can result in damage or even destruction of the surrounding rocks. Obviously a review of the factors from both geological and operational points of view, which influence the stability of tunnels, is necessary before the extent of the problem can be properly appreciated and identified for study in detail. This is discussed later in the thesis.

ROCK MECHANICS PROBLEMS AND ROCKMASS FAILURE THEORIES

As stated in the previous chapter, upon excavation, rocks surrounding a tunnel sustain effects of stress concentration. These rocks will fail when the absolute stresses in some zones near the tunnel are so high as to be able to overcome the relevant rock strength. Alternatively, some soft and weak rocks will be destroyed under not very high ground pressures, due to the weak nature of the rocks themselves. Ground conditions, where tunnels are hardly maintained and rock failures occur extensively, are identified as adverse tunnelling conditions.

They have become a major concern of the tunnel designer. In particular, tunnelling in soft ground at increasing depths is often subject to a series of rock mechanics problems in terms of tunnel deformation, support torsion and damage, rock failure and collapses. The main causes of these problems are usually attributed to:

(i) increasing ground pressure;
(ii) poor rock properties;

(iii) improper use of support with regard to support characteristics, support installation time and support structure;
(iv) lack of understanding of the interaction between support system and surrounding rock;
(v) inadequate design of tunnel cross-section, etc.

As coal mining turns towards deeper and deeper ground below the surface, more and more tunnels require to be excavated at increasing depths in the modem world's coal industries. Both in China and the United Kingdom tunnelling at a number of collieries has been carried out at over 800 or even 1000 metres below the surface.

Increased ground pressure due solely to an increase in overburden thickness makes the above mentioned problems become outstanding. Lack of proper understanding of the ground pressure characteristics may give no basis on which support systems are effectively designed and installed, on which tunnels are properly designed in terms of shape and cross sectional area, and on which the mechanism of interaction between the support system and the surrounding rocks may be well understood.

Rock formations within the fields where Coal industry mainly comprise mudstones, claystones, siltstones and sandstones. The majority of these rocks are weak or medium in strength with UCS ranging from 20 to 80 MPa. Poor rock properties result in tunnel floor heave by virtue of the effects of plastic flow and rock creep.
The complex nature of tunnelling sites and rock structures often gives rise to difficulties in finding analytical solutions to these rock mechanics problems.

Strains and deformations of rock around tunnels prior to occurrence of rock failure. Such an analysis requires some criterion to be used for identifying if the rocks have failed in some region. This indicates the need for selecting a proper failure criterion. Various rock failure theories need to be reviewed before the selection is made.Obviously, all of these required field will be discussed breifely in the final thesis.

RESEARCH OBJECTIVE

According to the above discussion, the research objectives of this thesis have been focussed on the following points:

(1) The concept of stress concentration in the vicinity of a tunnel due to the effect of stress field has been first studied prior to the occurrence of rock failure or yielding. Based on this study, the potential failure zones around the tunnel have been identified in relation to the stress field environment.

(2) The dimensional characteristics of the tunnel that copes well with the stress field condition in respect of tunnel stability has been studied. The relation between the tunnel dimensional feature and stability in the relevant stress field conditions has been developed, which is hoped to improve the current concept on tunnel design and construction.

(3) The currently prevailing prediction theories regarding the tunnel stability and the yielding radius have been studied and developed. The study aimed at correlating the available rock properties with the tunnel yielding radius and gathering them into a prediction theory on tunnel stability.

(4) The influence of the stress field environment on the fracture development around the tunnel with various profiles has been intensively investigated. A detailed comparison on the fracture orientation and scope and the effect of the stress field features has been conducted, in order to give a clear picture regarding the effect of stress field on tunnel stability.

(5) The fracture and stability of tunnels in stratified rock conditions and rock mass failure criteriterion has been another study focus of this thesis. This has been hoped to outline the typical failure and deformation features of underground tunnels in association with sedimentary rocks. The study covered the necessary theory regarding tunnel stability and rock mass failure criterion for underground construction.

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