Rock Mechanics in Underground Construction

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ISRM International Symposium 2006
4th Asian Rock Mechanics Symposium

Rock Mechanics in Underground Construction

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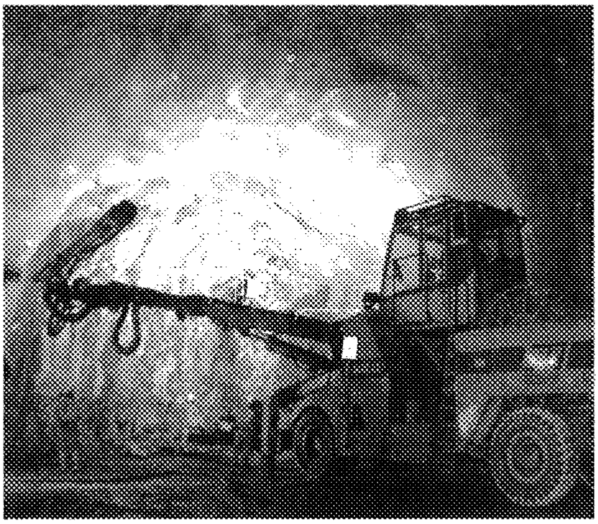

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PREFACE

The 4th Asian Rock Mechanics Symposium (ARMS) received overwhelming response for its call for papers in early 2006 with about 450 abstracts received by the Organising Committee. After a rigorous selection process, just over 300 papers were finally accepted for the proceeding, a record for ARMS. This is also the first time that the ARMS proceedings volume consists of printed copies of full papers of keynote lectures and extended abstracts of all the technical papers while the full technical papers are provided in a CD-ROM. This has enabled the Organising Committee to accept as many high quality technical papers as possible.

The theme of the Symposium is "Rock Mechanics in Underground Construction". Fittingly all the seven keynote lectures from Asia, Australia, Europe and North America deal with underground rock engineering topics. In fact, about half of the technical papers concern with underground construction such as tunnelling, rock caverns and underground mining. In addition, a large number of the remaining technical papers are directly or indirectly involved with rock mechanics in underground construction. Although the majority of the technical papers are contributed by rock engineers and researchers from Asia, the editors are glad to note that there are considerable number of contributions of high quality technical papers from many countries outside Asia.

The contributions of the technical paper reviewers and the ARMS 2006 award selection committee members are gratefully acknowledged. They play important roles to ensure that the papers in this proceedings volume are of high standard. The editors would like thank the able compilation and thorough checking of the scripts by Ms Chelsea Chin and her colleagues from World Scientific Publishing Company, and the diligent assistance of the staff from the symposium Secretariat, Meeting Matters International. With the efforts of all the above persons, the editors hope that this proceedings volume will serve as a useful reference for the engineers and researchers in rock mechanics and rock engineering.

C. F. Leung
Y. X. Zhou

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The editors gratefully appreciate the efforts of the following reviewers who have helped to maintain a high standard of the proceedings. The editors would like to apologise if some names have been left out or misspelled.

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CONTENTS

MEASURING ROCK MASS MODULUS OF DEFORMATION IN A STOPING-AFFECTED CROSS-CUT IN PONGKOR UNDERGROUND GOLD MINE

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This paper explains a rock mass deformation modulus measurement conducted in a cross cut at Pongkor underground gold mine, where there was an active stope underneath the cross-cut. It is revealed that the resulted rock mass deformation modulus was controlled by the stoping progress. The larger the dimension of the underneath stope, the higher the rock mass deformation modulus obtained, which was due to the higher induced stress in the test location. There was a 20-30% increase of rock mass modulus of deformation when the stope was advanced vertically from one mining slice to two mining slices, where the height of the slice was four metre.

Keywords: Rock mass; modulus of deformation; underground mine.

1. Introduction

Deformability is capacity of rock to strain under load or without load caused by an excavation that can be expressed quantitatively as modulus of elasticity or modulus of deformation (Goodman, 1989). Modulus of deformation of rock mass is one of the important factors required for design work within the rock mass, especially the design of an underground structure. It can be determined indirectly by applying a reduction factor to the rock elasticity modulus measured in laboratory or by using a number of formulas relating it with the rock mass quality or directly from *in situ* measurement.

In Pongkor underground gold mine, the first *in situ* measurement of rock mass modulus of deformation was carried out just recently. As the development and mining in Pongkor underground gold mine progress continuously, the measurement was conducted in an area that was affected by the stoping activities. The work reported in this paper is aimed at the investigation of the influence of stoping on the rock mass modulus of deformation measured in a cross-cut located above the stope.

2. Determination of Rock Mass Modulus of Deformation

2.1. *Determination from intact rock modulus of elasticity*

After reviewing a number of papers where laboratory and modelling properties were given, Mohammad, *et al.* (1997) found that if the Young's modulus results from laboratory tests (E) were plotted with those used in the model (E_m), the equation of the fitted straight line was:

$$E_m = 0.469\,E \qquad (1)$$

If the data were plotted as reduction factors, they also found a trend of increased reduction factors for low stiffness rock types and observed a number of very high reduction factors for very low stiffness rocks.

2.2. *Determination based on rock mass quality*

In the last 30 years, a number of authors have proposed formulas that can be used to estimate the rock mass modulus of deformation (E_m) from the Rock Mass Rating (RMR) and some of the formulas are given in the followings.

Bieniawski (1978) proposed that for fair to very good qualities rock masses with RMR greater than 50, the following formula could be applied:

$$E_m = 2\,RMR - 100 \text{ [GPa]} \tag{2}$$

whereas Serafim and Pereira (1983) suggested that the relation is not linear but follows the following formula:

$$E_m = 10^{\frac{RMR - 10}{40}} \text{ [GPa]} \tag{3}$$

For covering all qualities of rock mass, from very poor to very good qualities, the values in Table 1 were suggested by Chappel (1984).

Table 1. Modulus of Deformation Based on RMR (Chappel, 1984)

Rock mass quality	Description	RMR	E_m (GPa)
V	Very poor	0 – 20	0.05 – 0.5
IV	Poor	20 – 40	0.5 – 4
III	Fair	40 – 60	4 – 5
II	Good	60 – 80	5 – 25
I	Very good	80 – 100	25 – 50

As a result from his work with very poor to fair qualities rock masses with RMR less than 52, Stille (1986) introduced the following formula:

$$E_m = 0.05\,RMR \text{ [GPa]} \tag{4}$$

Other non-linear relations between RMR and E were put forward by Mehrotra, *et al*. (1991), Iasarevic and Kovacevic (1996), and Berardi and Bellingeri (1998) as given respectively in Equations (5), (6), and (7) below.

$$E_m = 10^{\frac{RMR - 30}{50}} \text{ [GPa]} \tag{5}$$

$$E_m = e^{(4.407 + 0.08RMR)} \text{ [GPa]} \tag{6}$$

$$E_m = 0.87\,e^{0.0455RMR} \text{ [GPa]} \tag{7}$$

Following the introduction of the Geological Strength Index (GSI) by Hoek (1994) and Hoek, *et al*. (1995) as a replacement of RMR in their failure criterion, Hoek and Brown (1997) modified the Sarafim and Pereira (1983) equation for rock mass with intact rock uniaxial compressive strength σ_{ci} less than 100 MPa, as follows:

$$E_m = \sqrt{\frac{\sigma_{ci}}{100}}\, 10^{\frac{GSI-10}{40}} \quad [GPa] \tag{8}$$

Furthermore, taking into account the blast damage and stress relaxation, Hoek and Brown (2002) introduced the disturbance factor D and modified Equation (8) as follows:

$$E_m = \left(1 - \frac{D}{2}\right)\sqrt{\frac{\sigma_{ci}}{100}}\, 10^{\frac{GSI-10}{40}} \quad [GPa] \tag{9}$$

and for σ_{ci} greater than 100 MPa, the following equation was suggested:

$$E_m = \left(1 - \frac{D}{2}\right) 10^{\frac{RMR-10}{40}} \quad [GPa] \tag{10}$$

2.3. *In situ measurement*

In the last few years, there are three types of *in situ* tests are mostly used to determine the rock mass modulus of deformation (Palmström & Singh, 2001): Plate jacking test, plate loading test, and Goodman's jack test. In this work, rock mass modulus of deformation was determined by the Goodman's jack test. The Goodman's jack (see Figure 1) consists of a curved rigid bearing plate which can be forced inside an NX size borehole by a number of pistons. The displacement is measured with LVDT.

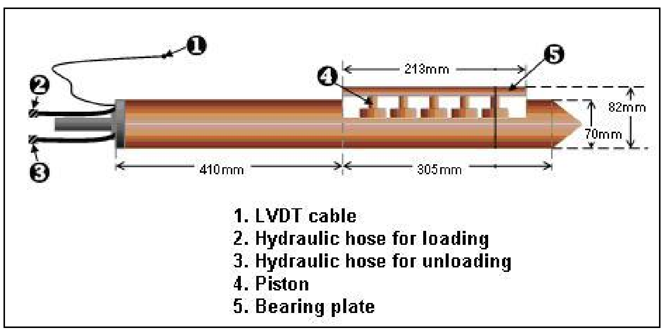

Fig. 1. Goodman's jack

The Goodman's jack test is conducted by applying pressure to the borehole wall in a number of loading-unloading cycles, and the rock mass modulus of deformation (E_m) is calculated using the following formula (Goodman, *et al*., 1970):

$$E_m = \frac{\Delta Q}{\Delta u_d / d} K(\beta, \nu) \tag{11}$$

ΔQ = Pressure increment
d = Hole diameter
Δu_d = Change in hole diameter
K = Stress factor as a function of the central angle β of the load and of Poisson's ratio ν

3. Data Collecting

3.1. *Test location*

The Goodman's jack test was conducted in the Cross-Cut 6A Ciurug, Level 570, Pongkor Underground Gold Mine. Underneath the test location there was an active stope which was advancing towards the test location (see Figure 2). Three boreholes were used for the test, namely left, right, and front boreholes. The left and right boreholes penetrate the footwall (Andesitic breccia rock mass) whereas the front borehole was drilled into the Au-Ag orebody. In each borehole, three tests were conducted. In each test, eight measurements were conducted at eight different depths from the collar and at each depth four different loading directions were applied.

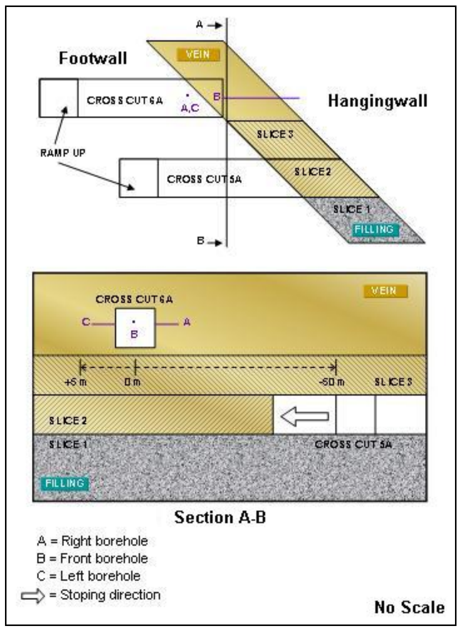

Fig. 2. Test location and boreholes configuration

3.2. *Measured rock mass modulus of deformation*

Table 1 shows the average values of the modulus of deformation of andesitic breccia rock mass and that of Au-Ag orebody. E_{GJ2} is modulus of deformation measured in a previous work (Hananta, 2005) that was conducted in the same boreholes, when the underneath stope was being mined in Slice 2 in Figure 2. E_{GJ3} is modulus of deformation measured in this work.

Table 1. Measured rock mass modulus of deformation

Rock mass	Measured modulus of deformation (GPa)	
	E_{GJ2}	E_{GJ3}
Andesitic breccia	5.58	6.67
Au-Ag orebody	5.28	6.96

4. Discussions

4.1. *Comparison with intact rock modulus of elasticity*

The uniaxial compressive strength tests conducted on andesitic breccia and Au-Ag samples revealed that the uniaxial compressive strength (σ_{ci}) of andesitic breccia was 63.35 MPa with Young's modulus (E) of 14.46 GPa. σ_{ci} and E for the Au-Ag ore were 57.83 MPa and 13.72 GPa, respectively. It means that the reduction factors are 0.46 for the andesitic breccia rock and 0.51 for the Au-Ag ore, which is generally in line with the findings of Mohammad, et al. (1997) described earlier in this paper.

4.2. *Comparison with values estimated using rock mass quality*

The Geotechnical Section of Pongkor Underoround Gold Mine reported that the RMR of the andesitic breccia rock mass at the test locations was 52 and that of Au-Ag orebody was 53. Using these values in the equations relating rock mass modulus with RMR given earlier, the rock mass modulus of deformation were estimated and they are given in Table 2.

Table 2. Estimated rock mass modulus of deformation

Formula	Estimated modulus of deformation (GPa)	
	Andesitic breccia	Au-Ag orebody
Bieniawski (1978)	4.50	5.78
Serafim & Pereira (1983)	11.38	11.81
Chappel (1984)	4.61	4.64
Stille (1986)	n.a.	n.a.
Mehrotra, et al. (1991)	2.78	2.86
Iasarevic & Kovacevic (1996)	5.36	5.64
Berardi & Bellingeri (1998)	9.37	9.65
Hoek & Brown (1997)	9.06	8.98
Hoek & Brown (2002) with D = 0.7	5.89	5.84

It can be observed from Table 2 that rock mass modulus of deformation measured in this work are relatively closed to those estimated using the equations proposed by Iasarevic and Kovacevic (1996) and Hoek and Brown (2002). The measured values are lower than those estimated by Serafim and Pereira (1983), Berardiand Bellingeri (1998) and Hoek and Brown (1997) formulas.

4.3. *Effect of the underneath stoping*

There was a 20-30% increase in rock mass modulus of deformation measured in this work compared to that obtained in the previous work. It is obvious that when the stope was mining in Slice 3 the excavation dimension was larger than the dimension when the stope was mining in Slice 2 which caused higher induced stresses to the rock mass in the test location. Consequently, due to the nature of the Goodman's jack test, to enlarge the borehole diameter by a particular length, higher pressure was required for larger stope dimension. Subsequently, the gradient of pressure-displacement curve used in the determination of the rock mass modulus of deformation was higher which gave a higher rock mass modulus of deformation.

5. Conclusions

Determination of rock mass modulus of deformation in the area that was affected by underneath stoping has been carried out. It was observed that the stoping activity affected the measurement results. Higher rock mass modulus of deformation was obtained for larger underneath stope.

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