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MEASUREMENT OF ROCK MASS DEFORMATION MODULUS USING GOODMAN'S JACK IN PONGKOR UNDERGROUND GOLD MINE, INDONESIA

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ABSTRACT

In situ measurement of rock mass deformation modulus has never been done in the Pongkor gold mine. Estimation of the rock mass deformation modulus was made by using the elasticity modulus of intact rock obtained in the uniaxial compression test in the laboratory. In situ measurement of rock mass deformation modulus is therefore required, which can provide important additional data.

In this research, a Goodman's Jack was used in bore holes with depths up to 7.5 m and diameters of 75 mm. The tests were carried out in the same depth for every bore hole and made in the part of borehole where no crack occurred. At each point the tests were conducted in four different directions.

The in situ tests revealed that the deformation modulus of the Au-Ag ore was 5.88 GPa and that of the footwall rock mass (breccia tuff) was 6.75 GPa and 5.63 GPa. The elasticity moduli of the Au-Ag ore and the footwall rock resulted from laboratory uniaxial compression tests were 10.45 GPa, 19.70 GPa and 13.78 GPa, respectively.

INTRODUCTION

Deformability is capacity of rock to strain under load or without load caused by an excavation that can be expressed quantitatively as elasticity or deformation modulus (Goodman, 1989). Being obtained through an in situ test, the rock mass modulus is one of the mechanical properties of the rock mass that represents loading condition experienced by the rock mass. Under equal stresses the stress-strain curve of a rock mass is dissimilar with that of an intact rock. The rock mass modulus and peak strength are lower compared to those of intact rock. It could therefore be said that approaches of predicting the rock mass modulus using laboratory test results still have limitation that leads to inaccuracy. Regarding this, in situ determination of rock mass modulus must be considered as a priority, especially in a large underground excavation project.

In this research, rock mass deformation modulus obtained through Goodman's jack test (E_{field}) was compared to rock mass deformation modulus estimated from rock mass classification (E_m) and elasticity modulus (E_{lab}) resulted from laboratory test. There is an expectation that the outcomes of this research can be utilised in determination of deformation modulus of Pongkor rock mass, which will be obviously of use in next stages of design and development of the underground mine.

RESEARCH LOCATION

This measurement of rock mass deformation modulus is the first research carried out in the Pongkor underground gold mine. The research was done in crosscut 6A that is located in the parallel ramp-up of Ciurug central at an elevation of 568 m at 3,100 m distance from the Level 500 portal, about a 300 m depth from the surface. In the location, the measurement was made in three horizontal drill holes that were two holes (i.e. left and right) on the footwall (breccia tuff) and one hole (i.e. front) on the vein (Au-Ag ore).

TESTING EQUIPMENT

A number of testing equipment to be used for direct measurement of rock mass reaction and determination of rock mass modulus through an application of pressure in the drill hole wall have been designed (Goodman, Van, and Heuze, 1972). One of the equipment is the borehole jack that gives one-directional pressure to the drill hole wall through two separate circular plates and one of the borehole jack types is the Goodman's jack or Goodman's probe. As illustrated in Figure 1, the length of the plate is 21.3 cm with the 2β angle of 60^0. The equipment was designed for a drill hole of 75-80 mm diameter.

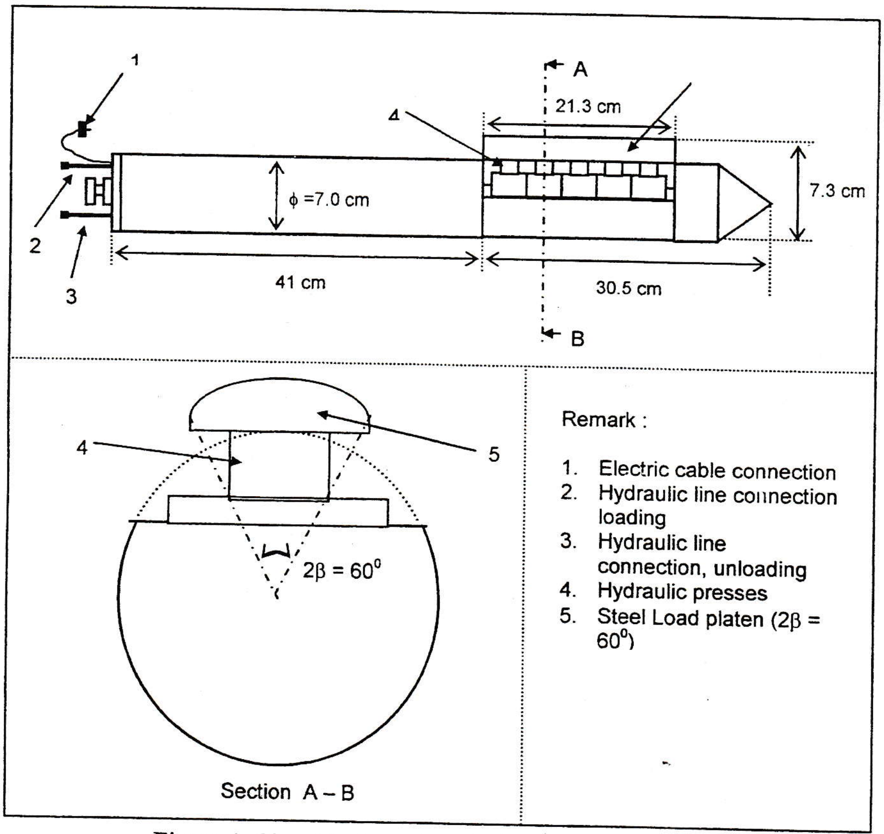


Figure 1. Simplified section of the Goodman's jack

Using the Goodman's jack, the rock mass will be pressed diametrically perpendicular to drill hole axis. Generally, the pressure is applied in cycles where the loading is kept for about 2 minutes and the unloading is kept for around 1 minute. The displacement is recorded continuously during the loading and the unloading in every cycle. The maximum pressure in the particular cycle should be adjusted according to the rock stress or the requirements of the proposed structure. The maximum is achieved if the maximum jack capacity is reached or there is an indication that the rock mass has failed (Fecker, 1998).

The test result can be used for rock mass classification and characterisation and calculation of deformation modulus. The characterisation based on elasticity theory is deformation modulus during loading and unloading (Goodman, Van, and Heuze, 1972; de la Cruz, 1984; Fecker, 1998). The results are stress-strain graph, table of measurement data, and characteristic value calculated from the data. The deformation modulus can be calculated using the following equation (Goodman, Van, and Heuze, 1972):

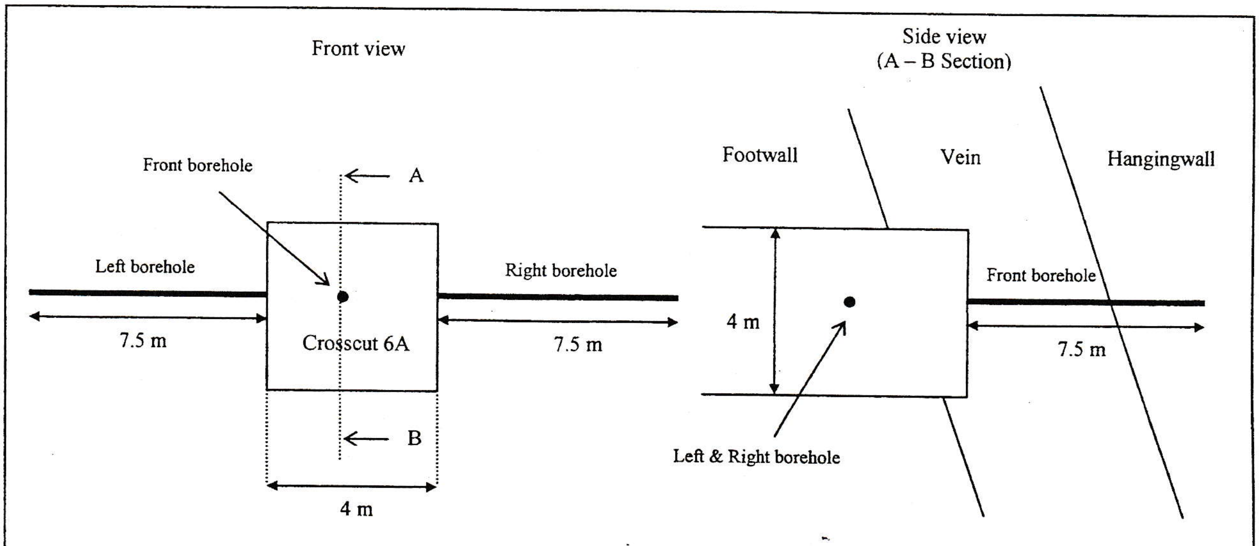
$$E = \frac{\Delta Q}{\Delta u_d / d} K(v, \beta) \qquad (1)$$

where; E is the deformation modulus, MPa, Δu_d is the average diametral displacement, mm, for a given increment of pressure ΔQ, MPa, and d is the borehole diameter. Value of $K(v, \beta)$ are given table 1.

Table1 : Stress factor of $K(v, \beta)$

β \ v	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50
25^0	1.154	1.143	1.127	1.105	1.078	0.045	1.007	0.963	0.914
30^0	1.227	1.217	1.201	1.179	1.152	1.119	1.080	1.035	0.985
35^0	1.271	1.262	1.247	1.226	1.200	1.168	1.129	1.086	1.036
40^0	1.290	1.282	1.269	1.250	1.225	1.195	1.159	1.117	1.069
45^0	1.288	1.282	1.271	1.254	1.232	1.204	1.170	1.131	1.087
50^0	1.270	1.266	1.257	1.243	1.224	1.199	1.169	1.133	1.092
55^0	1.240	1.238	1.232	1.221	1.204	1.183	1.156	1.125	1.088

Poisson's ratio (ν) is obtained from the mechanical test of the rock samples from the drill hole where the test is performed. In this research, the tests were carried out in different depths in each holes (see Figure 2), where no cracks was observed by the borehole camera. The Goodman's jack plate were positioned at the top, bottom, left and right.



Borehole	Depth of test (m)					
Right	1.4	2.5	3.5	5	5.5	6.9
Left	2	3	5	6	6.5	-
Front	0.75	3.1	3.9	4.3	-	-

Figure 2. Sketch of the test

TEST RESULTS

Laboratory Test and Rock Mass Classification

The physical and mechanical properties of the rock samples obtained from the left, right, and front drill holes were determined in the laboratory. The average intact rock properties and the geomechanics classification (Bieniawski, 1989) of the rock mass are listed in Table 2.

Tabel 2. Properties of intact rocks and rock mass classification

No.	Borehole	Lithology	γ (gr/cc)	σc (MPa)	E_{lab} (GPa)	υ	Vp (m/dt)	RMR
1.	Left	Breccia tuff	2.61	87.52	19.70	0.27	5,852	53.04
2.	Right	Breccia tuff	2.51	72.10	13.78	0.25	5,075	52.74
3.	Front	Au-Ag ore	2.59	60.30	10.45	0.25	4,502	52.69

Where; γ is the natural density, σc is the uniaxial strength, E is the elasticity modulus, υ is the Poisson's ratio, Vp is the ultrasonic velocity and RMR is the rock mass rating according to geomechanics classification system.

In situ Test Using the Goodman's Jack

Goodman's jack tests were conducted in different depth using different plate positions. Every test was made in 5 cycles. Figure 3 depicts one example of the Goodman's jack test result.

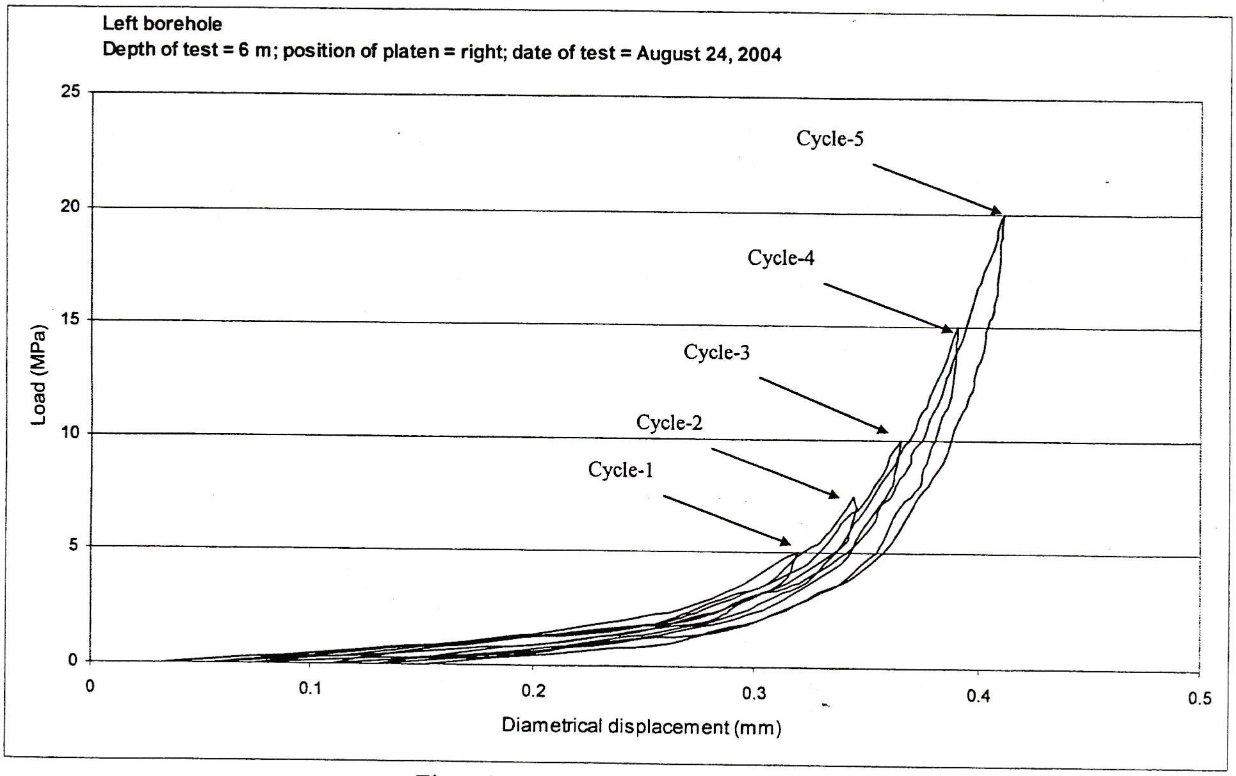


Figure3. Graph of Goodman jack test

The complete results of deformation modulus measurements in the three boreholes for different depths and different plate positions are given in Table 3. Deformation moduli reported in the table were calculated using the total displacements and total pressures from cycles 1 to 5.

Table 3. Results of Goodman jack tests

Borehole	Lithology	Depth of test (m)	Deformation modulus (GPa), E_{field}			
			Position of platen Goodman jack			
			Top	Right	Bottom	Left
Left	Breccia tuff	0.5	4.76	3.76	3.43	5.72
		2.0	-	5.63	5.22	6.85
		3.0	-	10.88	8.78	7.32
		5.0	7.27	-	10.36	11.42
		6.0	4.42	4.78	5.74	6.87
		6.5	-	8.34	9.91	7.32
		Average	5.84	6.68	7.24	7.58
		Total average	6.75			
Right	Breccia tuff	1.4	4.35	3.81	4.26	3.90
		2.5	6.01	4.93	4.57	4.94
		3.5	6.35	-	7.07	7.64
		5.0	6.11	5.62	4.70	6.02
		5.5	7.02	7.00	3.26	5.27
		6.9	7.59	6.43	6.07	6.62
		Average	6.24	5.56	4.99	5.73
		Total average	5.63			
Front	Au-Ag ore	0.75	5.45	6.03	4.34	4.82
		3.1	6.66	-	4.89	8.37
		3.9	-	7.44	5.45	7.93
		4.3	4.51	5.08	4.29	-
		Average	5.54	6.18	4.74	7.04
		Total average	5.88			

DISCUSSION

Some researchers found that the deformation modulus of the rock mass was not constant but controlled by the stresses experienced by the rock mass. Generally, higher deformation moduli were found in the rock mass under higher stress. Clerici (1993) stated that rock mass deformation modulus obtained directly from in situ could not be reported as an absolute value but rather be used to estimate the magnitude of the modulus (Palmstrom and Singh, 2001).

Comparison of E_{field} and E_m

The deformation modulus of a rock mass can be calculated indirectly from the rock mass rating using the following relation:

$$E_m = 2RMR - 100 \quad \text{untuk } RMR > 50 \text{ (Bieniawski, 1989)} \qquad (2)$$

Comparisons of E_{field} and E_m are shown in Table 4.

Table 4. Comparisons of E_{field} and E_m

Borehole	Lithology	RMR	E_{field} (GPa)	E_m (GPa)	Difference E_{filed} - E_m
Left	Breccia tuff	53.04	6.75	6.08	9.93 %
Right	Breccia tuff	52.74	5.63	5.48	2.66 %
Front	Au-Ag Ore	52.69	5.88	5.38	8.50 %

The table shows that the deformation moduli determined using the Goodman's jack were close enough to those estimated using the RMR, with less than 10% difference. Although the rock mass deformation modulus can be predicted indirectly using the RMR, in the earlier stage the in situ measurement is still of importance to ensure the real value of the rock mass deformation modulus. In the later stages, provided that there is no equipment, time and money for in situ measurement, the indirect calculation can be taken into account. The determination of the RMR must be conducted very carefully however. This is due to the sensitivity of the predicted modulus caused by the change of the RMR.

Comparison of E_{field} and E_{lab}

Comparisons between rock mass deformation modulus (E_{field}) and elasticity modulus of intact rocks (E_{lab}) are given in Tabel 5.

Table 5. Comparison of E_{field} and E_{lab}

Borehole	Lithology	E_{field} (GPa)	E_{lab} (GPa)	E_{lab}/E_{field}
Left	Breccia tuff	6.75	19.70	2.92
Right	Breccia tuff	5.63	13.78	2.45
Front	Au-Ag Ore	5.88	10.45	1.78

Table 5 highlights that the elasticity moduli of intact rocks were up to 3 times of the deformation moduli of the rock mass. Rock mass has a variety of discontinuities whereas intact rock has a very little ore no discontinuities. The discontinuity is the main factor that causes the decrease in the deformation modulus for the rock mass.

Operation

The Goodman's jack test graph (Figure 3) shows that the initial displacement in loading and the final displacement in unloading is very close. This was caused by the imperfect pressing of the plate at the initial pressure of 0 MPa that made the diametrical displacement for 0 – 2 MPa pressure observed very large and very close. It is therefore recommended to start the reading at a pressure of 1.5 MPa. During unloading at a pressure of 1.5 MPa the diametrical displacement happened very fast because the plate did not press the wall perfectly. The unloading is therefore recommended to be stopped at a pressure of 1.5 MPa. This phenomenon was observed by previous researcher who suggested that the contact pressure earlier at the test was 1.5 MPa (Fecker, 1998). It is due to the limited observation that can be made on the Goodman's jack placed inside the hole that leads to an inaccuracy in defining the pressure of 0 MPa.

CONCLUSION

Deformation modulus of vein (Au-Ag ore) obtained from the Goodman's jack test was 5.88 GPa whereas those of footwall (Breccia tuff) were 6.75 GPa and 5.88 GPa for left and right walls respectively. The values were very close to those calculated using the RMR.

Elasticity moduli of intact rocks could be up to 3 times of rock mass deformation moduli.

Good results can be expected if the initial pressure is 1.5 MPa and the unloading is stopped at a pressure of 1.5 MPa.

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