Final Exam

Name:____________________________

1. True of false? (2 points × 15 = 30 points)

(1) Hoek-Brown failure criterion **cannot** usually be extended to deal with the failure of jointed rock mass since it does not provide with reliable results for poor rocks. ………………………… (**X**)

(2) Bieniawski's 1989 RMR classification is more conservative for the ground water condition than 1976 classification is. ……………………………………………………………………… (**O**)

(3) Hoek-Brown failure criterion is applicable **only to intact rock** since it is valid in homogeneous and isotropic media. ……………………………………………………………………… (**X**)

(4) To prevent rotations of rock wedge, rockbolt installation should be made to distribute the support elements uniformly about the wedge centroid. . …………………………………… (**O**)

(5) Since wedges require immediate support, the use of shotcrete for short term stabilization it clearly inappropriate. ……………………………………………………………………… (**O**)

(6) RSR classification is very crude, particularly for rockbolts and shotcrete, since it is based upon a relatively small number of case histories and very simplistic theoretical arguments. ……… (**O**)

(7) The value of **SRF** is related to the intended use of the excavation and to the degree of security which is demanded of the support system installed to maintain the stability of the excavation. ……………………………………………………………………………………… (**X**)

(8) Generally, surface roughness increases the **tensile** strength of the surface, and this strength increase is extremely important in terms of the stability of underground openings. ……… (**X**)

(9) The Gotthard Base Tunnel that connects between Zurich and Milan through the Swiss Alps is 57 km long one way. ……………………………………………………………………… (**O**)

(10) The significance of the stand-up time concept is that a **decrease** in the span of the tunnel leads to a significant reduction in the time available for the installation of support. …………… (**X**)

(11) The greatest difference between RMR and Q system is the lack of a stress parameter in the RMR system. ……………………………………………………………………………… (**O**)

(12) It is practically impossible to carry out triaxial or shear tests on rock masses at a scale which is appropriate for surface or underground excavations in mining or civil engineering. ……… (**O**)

(13) The most reliable values of both the uniaxial compressive strength σ_c and the material constant m_i are estimated from the results of **direct shear tests**. ………………………………… (**X**)

(14) Measurements of horizontal stresses at civil and mining sites around the world show that the ratio k tends to be **low** at shallow depth and that it **increases** at depth. …………………… (**X**)

(15) Measurements of vertical stress at various mining and civil engineering sites around the world confirm that the relationship $\sigma_v = \gamma z$ is valid although there is a significant amount of scatter in the measurements. ……………………………………………………………………… (**O**)

2. Rockbolts of 25 mm in diameter were systematically installed at the interval of 1 m × 1 m. Assuming that the elastic modulus (or deformation modulus) of the bolt and rock mass are 210 GPa and 1 GPa, respectively, calculate the increase of the deformation modulus of the rock mass due to the installation of the rockbolts. (15 points)
Hint: The total load acting on the block is the summation of the loads acting on the rock mass and rockbolt.

Solution

The total load acting on the block is the summation of the loads acting on the rock mass and rockbolt.

$$P_{total} = P_{bolt} + P_{rock}$$

Since $\mathrm{P} = \sigma \cdot \mathrm{A} = \varepsilon \cdot \mathrm{E} \cdot \mathrm{A}$ $(\varepsilon_t = \varepsilon_b = \varepsilon_r)$

$$\mathrm{E}_t \cdot \varepsilon_t \cdot \mathrm{A}_t = \mathrm{E}_b \cdot \varepsilon_b \cdot \mathrm{A}_b + \mathrm{E}_r \cdot \varepsilon_r \cdot \mathrm{A}_r$$

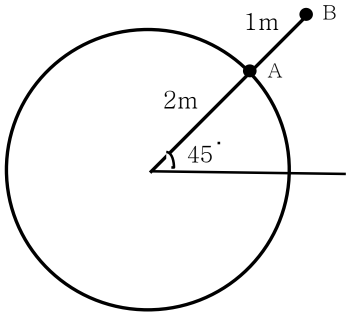
$$E_t = \frac{E_b \cdot A_b + E_r \cdot A_r}{A_t}$$

$$= \frac{210 \times 10^9 \times \left[\left(\frac{0.025}{2} \right)^2 \pi \right] + 1 \times 10^9 \times \left[1 - \left(\frac{0.025}{2} \right)^2 \pi \right]}{1}$$

$$\cong 1.103 \times 10^9$$

$$\therefore \Delta \mathrm{E} \cong 103\,\mathrm{MPa}$$

3. A circular horizontal tunnel is excavated at a depth of 2000m below the ground surface. Assume a K factor of 1.0.
   (1) Calculate the radial and tangential stresses at points A and B in the figure below. (5 points)
   (2) Would these points in the rock mass fail, assuming that Hoek and Brown rock mass failure criterion with q_u=110 MPa, m=0.7 and s=0.06 applies? (5 points)
   (3) If an internal pressure of 25MPa is applied to the inside of the hole in addition to the far field stresses, recalculate the stresses and possible failure at point A. (5 points)



Solution

$$\sigma_v = 0.025\,\text{MPa/m} \times 2000\,\text{m} = 50\,\text{MPa}$$
$$\sigma_h = K \cdot \sigma_v = 1.0 \times \sigma_v = 50\,\text{MPa}$$

Kirsch's solution

$$\sigma_r = \frac{1}{2}(S_x + S_y)\left(1 - \frac{a^2}{r^2}\right) + \frac{1}{2}(S_x - S_y)\left(1 + \frac{3a^4}{r^4} - \frac{4a^2}{r^2}\right)\cos 2\theta$$
$$\sigma_\theta = \frac{1}{2}(S_x + S_y)\left(1 + \frac{a^2}{r^2}\right) - \frac{1}{2}(S_x - S_y)\left(1 + \frac{3a^4}{r^4}\right)\cos 2\theta$$
$$\tau_{r\theta} = -\frac{1}{2}(S_x - S_y)\left(1 - \frac{3a^4}{r^4} + \frac{2a^2}{r^2}\right)\sin 2\theta$$

(1) At point A,

$$\sigma_r = \frac{1}{2}(50+50)(1-1) = 0$$
$$\sigma_\theta = \frac{1}{2}(50+50)(1+1) = 100\,(\text{MPa})$$

At point B,

$$\sigma_r = \frac{1}{2}(50+50)\left[1 - \left(\frac{2}{3}\right)^2\right] = 28\,(\text{MPa})$$
$$\sigma_\theta = \frac{1}{2}(50+50)\left[1 + \left(\frac{2}{3}\right)^2\right] = 72\,(\text{MPa})$$

(2) $q_u = 110\,\mathrm{MPa},\ m = 0.7,\ s = 0.06,\ \sigma_1 = \sigma_3 + \left(m\sigma_c\sigma_3 + s\sigma_c{}^2\right)^{1/2}$

At point A $(\sigma_3 = \sigma_r = 0)$, $\sigma_1 = \left(0.06\times 110^2\right)^{\frac{1}{2}} \cong 27\,(\mathrm{MPa})$

Therefore, $\sigma_\theta > \sigma_1 \rightarrow$ Fail

At point B, $\sigma_1 = 28 + \left(0.7\times 110\times 28 + 0.06\times 110^2\right)^{\frac{1}{2}} \cong 81\,(\mathrm{MPa})$

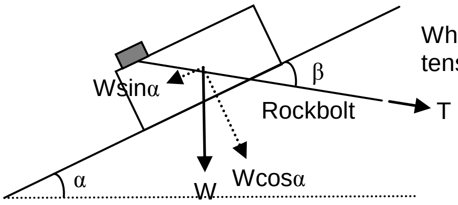
Therefore, $\sigma_\theta < \sigma_1 \rightarrow$ Not Fail

(3) At point A, $\sigma_r = 0 + 25 = 25\,(\mathrm{MPa}), \sigma_\theta = 100 - 25 = 75\,(\mathrm{MPa})$

$\sigma_1 = 25 + \left(0.7\times 110\times 25 + 0.06\times 110^2\right)^{\frac{1}{2}} \cong 76\,(\mathrm{MPa})$

Therefore, $\sigma_\theta < \sigma_1 \rightarrow$ Not Fail

4. A rock block of weight W is bolted to a plane inclined at angle α to the horizontal. Develop an expression for the bolt tension, T, in terms of the angle, β, at which the bolt is installed relative to the plane, the angle of inclination of the plane and Mohr-Coulomb friction properties, c and ϕ, of the block/plane interface. Hence, by differentiation, find the rockbolt angle at which the bolt tension is minimized. (20 points)



What is the angle, β, such that the tension in the rockbolt is minimized?

<u>Solution</u>

The force F_n, acting normal to the plane is the sum of the resolved block weight and rockbolt tension components, $F_n = W\cos\alpha + T\sin\beta$. The force, F_s, acting along the plane is similarly given by $F_s = W\sin\alpha - T\cos\beta$. The limiting condition of the block/plane interface having reached peak strength gives

$$W\sin\alpha - T\cos\beta = cA + (W\cos\alpha + T\sin\beta)\tan\phi$$

where c is the cohesion and A is the basal area of the block. Rearranging gives the required answer of

$$T = \frac{W(\sin\alpha - \cos\alpha\tan\phi) - cA}{\cos\beta + \sin\beta\tan\phi}$$

To find the minimal rockbolt tension, we set the particl derivative of T with respect to β to zero and solve the resulting equation for β. Recognizing that the expression for T will be minimized when the denominator is maximized, we have

$$\frac{\partial}{\partial\beta}(\cos\beta + \sin\beta\tan\phi) = 0, \text{ or } -\sin\beta + \cos\beta\tan\phi = 0$$

$$\tan\phi = \frac{\sin\beta}{\cos\beta} = \tan\beta$$

$$\therefore\ \beta = \phi$$

* This problem is extracted from “J.P. Harrison & J.A. Hudson, 2000, Engineering Rock Mechanics: Part 2 – Illustrative Worked Examples, Pergamon, pp. 267-268”.

5. A mudstone rock mass at a depth of 200 m contains three fracture sets. One set comprises bedding planes; these are highly weathered, slightly rough surfaces, and are continuous with an orientation of 180/10. Another set is jointing; these joints are slightly weathered, slightly rough, and have an orientation of 185/75. The third set is also jointing; again, the joints are slightly weathered and slightly rough, and have an orientation of 090/80. The strength of the intact rock has been assessed as 55 MPa, and values for RQD and mean fracture spacing are reported as 60% and 0.4 m, respectively. Use RMR system to classify this rock mass, and assess the stability of a 10 m wide excavation being driven from east to west. (20 points)

Solution

In the problem, we have three sets of fractures, and so we need to apply RMR system to each set in turn, and hence identify the set that is most critical for this particular excavation. The classification parameters of intact rock strength and groundwater conditions relate to the rock mass as a whole, rather than to specific fracture set, and are applied identically to each set. The value of RQD and mean fracture spacing are reported generally, rather than for specific sets, and so these are applied equally. We assess all of these parameters first, and then move on to the parameters that are specific to the fracture sets.

Overall rock mass

The strength of the intact rock has been assessed as 55 MPa, and so a conservative value for the strength rating is 6. The excavation is situated at a depth of 200 m, and the rock mass is a mudstone. At a depth of 200 m, the vertical stress component is in the region of 5 MPa (assuming a unit weight of rock of 25 kN/m^3), and this stress is probably sufficient to the fractures tightly closed. Taken together with the fact that mudstones have very low primary and secondary permeability, we can infer that the groundwater conditions are probably in the range of damp to wet, with rating values ranging from 7 to 10.

For an average RQD value of 60%, the rating value is 12, and for a mean fracture spacing of 0.4 m the rating value is 10. Adding these four ratings together gives a total rating value of 6+(7 to 10)+12+10=35 to 38.

Classification using Set 1

These bedding planes are highly weathered, with slightly rough surfaces, and are continuous. The rating values for these specific attributes are 1, 3, and 0, respectively. An assessment of aperture can be made on the basis of the in situ stress state at the location of the excavation: a stress of 5 MPa will mean that the aperture is low, and so a reasonable rating value is 5. We have no information regarding infilling but, as there is no evidence to suggest the presence of any, we can assume a rating value of 6. The total rating value for these fractures is then 1+3+0+5+6+15. The dip direction of the bedding is 180°, and so the excavation is being driven along the strike. This is considered to result in 'fair' conditions, with a corresponding rating adjustment value of -5.

Thus, the overall RMR value based on Set 1 is (35 to 38)+15=50 to 53, which is classified as 'fair rock'. Taking into account the orientation rating adjustment of -5, the RMR value is reduced to 45 to 48, but this does not alter the classification.

Classification using Set 2

We know that this jointing is slightly weathered, slightly rough, and has an orientation of 185/75. We can therefore assign rating values of 5, 3, and -12 to these attributes. Knowing that the fractures are joints in a mudstone, their persistence is probably in the range of 1 m to 2 m, and an appoproate rating value for this is 2. As with Set 1, we can assign rating values for the aperture and infilling of 5 and 6, respectively. The total rating value for these fractures is then 5+3+2+5+6=21, giving an overall RMR value of (35 to 38)+21=56 to 59. Again, this is classified as 'fair rock'. Taking the orientation rating adjustment of -12 into account reduces the RMR value to 44 to 47.

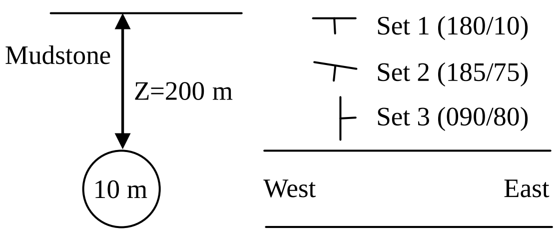
Classification using Set 3

The jointing representing Set 3 has identical mechanical characteristics to Set 2, and so has rating value of 21, giving an overall RMR value of 56 to 59 and a classification of ‘fair rock’. The orientation rating adjustment is now -5 (the strike is perpendicular to the excavation axis, and we are driving against the dip which is classified as ‘fair’), which reduces the RMR value to 51 to 54.

Overall assessment

We can see that Set 2 leads to the most critical classification, with a range of probable RMR values of 44 to 47. Using a chart linking RMR and excavation span to stand-up time shows an excavation 10 m wide in such a rock mass would suffer from immediate collapse, and so we can see that the engineering design will need to incorporate rock stabilization measures (i.e. support or reinforcement). In addition, some form of staged excavation may also be necessary, whereby a small pilot excavation is formed and then systematically opened out to the full size as the engineering behavior of the rock mass is steadily improved as the stabilization measures are applied.

<u>SUMMARY</u>



UCS = 55 MPa
RQD = 60%
Mean fracture spacing = 0.4 m

Set 1:	Highly weathered	UCS = 55 MPa	→ Rating = 6
	Slightly rough surfaces	RQD = 60%	→ Rating = 12
	Continuous	Spacing = 0.4 m	→ Rating = 10
	180/10	Discontinuity condition	→ Rating = 15
		Persistence: continuous	0
		Aperture: low (< 0.1 mm)	5
		Roughness: slightly rough	3
		Infilling: none	6
		Weathering: high	1
		Groundwater	→ Rating = 7~10
		Wet ~ damp	
		Orientation adjustment	→ Rating = -5
		Dip=10°, Strike//Tunnel axis, fair	
		<u>Overall RMR</u>	<u>= 45 ~ 48</u>

Set 2:	Jointing	UCS = 55 MPa	→ Rating = 6
	Slightly weathered	RQD = 60%	→ Rating = 12
	Slightly rough	Spacing = 0.4 m	→ Rating = 10
	185/75	Discontinuity condition	→ Rating = 21
		Persistence: 3 ~ 10 m (jointing)	2
		Aperture: low (< 0.1 mm)	5
		Roughness: slightly rough	3
		Infilling: none	6
		Weathering: slight	5
		Groundwater	→ Rating = 7~10
		Wet ~ damp	
		Orientation adjustment	→ Rating = -12
		Dip=75°, Strike//Tunnel axis, very unfavorable	
		Overall RMR	= 44 ~ 47

Set 3:	Jointing	UCS = 55 MPa	→ Rating = 6
	Slightly weathered	RQD = 60%	→ Rating = 12
	Slightly rough	Spacing = 0.4 m	→ Rating = 10
	090/80	Discontinuity condition	→ Rating = 21
		Persistence: 3 ~ 10 m (jointing)	2
		Aperture: low (< 0.1 mm)	5
		Roughness: slightly rough	3
		Infilling: none	6
		Weathering: slight	5
		Groundwater	→ Rating = 7~10
		Wet ~ damp	
		Orientation adjustment	→ Rating = -5
		Dip=80°, Strike⊥Tunnel axis, fiar	
		Overall RMR	= 51 ~ 54

Therefore, Set 2 is the most critical (RMR = 44~47). "Immediate collapse"

* This problem is extracted from "J.P. Harrison & J.A. Hudson, 2000, Engineering Rock Mechanics: Part 2 – Illustrative Worked Examples, Pergamon, pp. 194-196".

6. 발파공법을 사용하여 굴착하는 원유 비축용 지하 저장시설의 설계 및 시공과정에 대하여 아는 대로 서술하시오. (20 points)

<u>Solution</u>

설계과정: 지질도, 위성사진 등을 이용한 광역지질조사, 현장지질조사, 물리탐사, 시추공 영상자료 분석, 시추코어 분석 등을 통한 지질 정보를 획득 분석함. 초기지압을 측정하여 추후 구조물의 안정성 해석에 사용함. 비축기지에서 요구되는 지하수압력 등을 고려하고 초기지압과 구조물의 크기 형상 등을 고려하여 구조물의 위치 및 방향을 결정함. 지질조건 및 암반분류 결과를 반영하여 발파설계 및 시공 설계를 실시함.

시공과정: 시공은 기본적으로 천공, 발파, 환기, 버력처리, 지보의 순서로 이루어짐. 저장시설의 경우 국내 제원은 폭이 최소 10 m 이상, 높이가 약 15 m 이상이 되므로 전단면 발파를 수행하기 어렵고 벤치발파를 수행하므로 시공 관리 측면에서 정비 및 인력의 활용 면에서 효율을 극대화할 필요 있음. 또한 비축 터널 외 공사터널 및 시설 운용을 위한 수직터널의 굴착을 실시하여야 함.