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AESB2341
Rock Mechanics and Rock Engineering

10th April 2019
CT-IZ 1.95 / 1.98

Exam

Name	
Student number	
Exam completion time	
Signature	

— The duration of the exam is 3 hours (13 : 30 – 16 : 30).
— There are 4 questions carrying a total of 100 points.
— The exam consists of 12 pages.
— Answer all questions.
— Indicate your name and student number on each page.
— Write your answers in a clear and comprehensible way.
— Do not use red pen or pencil.
— Good luck!

Question 1 (30 points)

An unconfined compression test was performed on a cylindrical sample of granite. The initial height of the sample is equal to $l_0 = 110$ mm and the initial radius is equal to $r_0 = 25$ mm. The changes in height Δl and in radius Δr are recorded as a function of the applied axial force F (Table 1). Δl is taken positive for a decrease in height, while Δr is positive for an increase in radius.

F (kN)	Δl (mm)	Δr (mm)	**Axial stress** (.....)	**Axial strain** (.....)	**Radial strain** (.....)
0.0	0.000	0.000			
170.0	0.185	0.011			
370.0	0.400	0.024			
471.5	0.480	0.028			
589.2	0.590	0.041			
0.1	0.620	0.045			

Table 1 – Experimental results from an unconfined compression test on granite.

a The experimental results from mechanical tests are generally represented under the form of stress – strain curves. Give the definitions and units of the axial stress, axial strain and radial strain. [**6 points**]

b Explain why stresses and strains are used instead of forces and changes in dimensions. [**3 points**] c Fill in Table 1 by calculating the axial stress, axial strain and radial strain. Draw below the axial stress – axial strain curve and the axial stress – radial strain curve of the tested specimen. [**5 points**]

d Determine the secant Young's modulus and the Poisson's ratio of the tested granite. Refer to the stress – strain curves drawn above to explain your calculations. [**4 points**]

e Determine the unconfined compressive strength of the tested granite. [**2 points**] f Draw the Mohr circle at failure and explain what the Mohr circle represents. [**4 points**]

g Determine, analytically and graphically on the Mohr circle, the state of stress at failure on a plane inclined of an angle of $30°$ to the horizontal. [**6 points**]

Question 2 (15 points)

The *in situ* state of stress in a granitic rock mass was measured at a depth of 500 m by the hydraulic fracturing technique. Assume the ground is saturated continuously from the surface and that the water pressure in the ground is hydrostatic. The water pressure was first raised 3.5 MPa above the original groundwater pressure and then it was not possible to raise it further. When pumping was stopped, the water pressure fell to a value 0.5 MPa above original groundwater pressure. Two days later, the pressure was raised again, but it could not be pumped to a value higher than 1.0 MPa above the previous pressure.

a Calculate the breakdown pressure P_f and the shut-in pressure P_s. Use $\gamma_w = 1000$ kg/m^3 and $g = 9.8$ m/s^2. [**3 points**]

b Give the mathematical expressions and calculate the minor and major horizontal stresses. [**5 points**]

c Calculate the tensile strength of the rock. [**2 points**]

d How many hydraulic fracturing set-ups are required to determine the 3D state of stress in a rock mass? Explain your answer. [**3 points**] e The *in situ* state of stress needs to be determined for a project of deep geothermal energy. Explain the advantage of the hydraulic fracturing technique over the flat jack technique. [**2 points**]

Question 3 (15 points)

Trona is a non-marine evaporite mineral, which is mined as the primary source of sodium carbonate in the United States. It is found as a sub-horizontal stratiform orebody in the Green River Formation in Wyoming. The Green River Formation is found at a depth of 450 m and has a thickness of 4 m. The average density of the overlying shale is equal to 2110 kg/m^3.

The lateral extension of the Green River Formation makes it particularly suitable for room-and-pillar mining. The foreseen design considers 5.0-m rooms ($w_0 = 5.0$ m) and 7.0-m square pillars ($w_p = 7.0$ m), and extraction of the full stratigraphic thickness of 4 m.

Analysis of pillar failures in a nearby mine indicates that the pillar strength is defined by :

$$S \text{ (in MPa)} = 56.3 \cdot h^{-0.83} \cdot w_p^{0.5}$$

where h is the pillar height (in m) and w_p is the pillar width (in m).

a Calculate the pre-mining vertical stress. Use $g = 9.8$ m/s^2. [**2 points**]

b Calculate the stress in a pillar using the tributary area method. Explain your calculations. [**4 points**]

c Calculate the strength of a pillar. [**1 point**]

d Explain why the strength of pillars depends on their size. [**2 points**] e Calculate the factor of safety against compressive failure of the pillars. [**1 point**]

f Define, give the mathematical expression and calculate the corresponding extraction ratio. [**3 points**]

g Which failure mechanism other than compressive failure of pillars can happen in a room and pillar mine ? [**2 points**]

Question 4 (40 points)

A 12.0-m high rock slope has been excavated at a face angle of 60°. The rock in which this cut has been made contains persistent bedding planes that dip at an angle of 35° into the excavation (slide plane). A 4.35-m deep tension crack is 4.0 m behind the crest, and is filled with water to a height of 3.0 m above the slide plane (Figure 1). It is assumed that water escapes at atmospheric pressure where the slide plane daylights in the slope face.

The strength parameters of the slide plane are as follows :

— Cohesion, $c = 25$ kPa

— Friction angle, $\phi = 37°$

The unit weight of the rock is 26 kN/m^3, and the unit weight of the water is 9.8 kN/m^3.

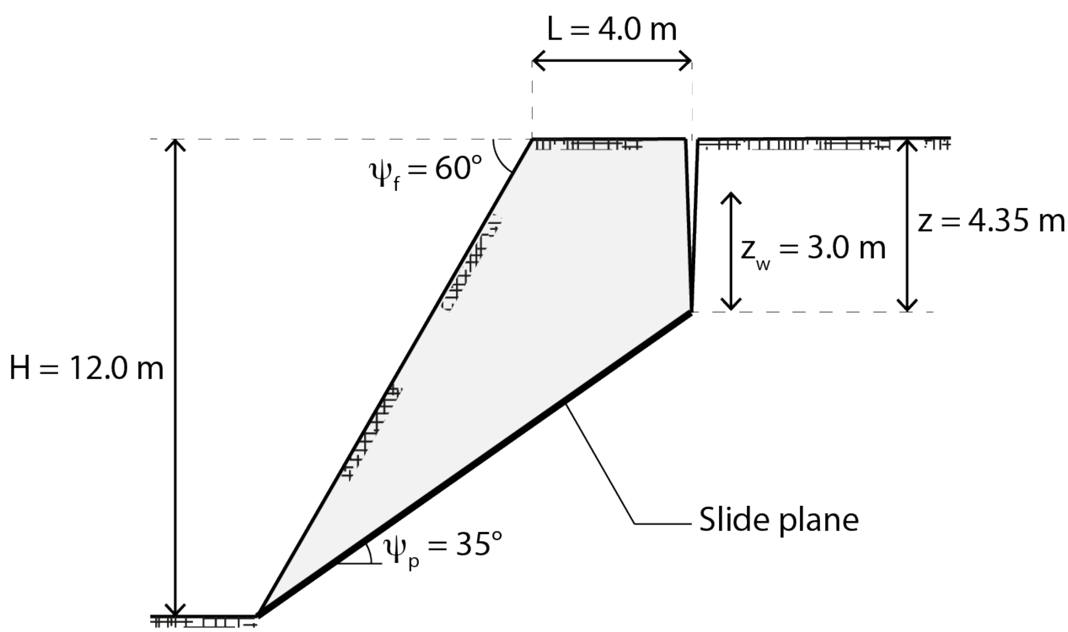

FIGURE 1 – Slope geometry.

a List two kinematic conditions for a plane failure to occur. [**3 points**] b List, label, represent and give the mathematical expression of the forces acting on the block shaded in Figure 1 at limit equilibrium conditions. [**10 points**]

c Develop a mathematical expression of the resultant force resisting failure along the slide plane. [**2 points**]

d Develop a mathematical expression of the resultant force driving failure along the slide plane. [**2 points**]

e Give the mathematical expression and calculate the factor of safety against plane failure along the slide plane. [**5 points**] f Is the rock mass stable or not ? Justify your answer. [**2 points**]

g Give the mathematical expression and calculate the factor of safety against plane failure if the cohesion were to be reduced to zero due to excessive vibrations from nearby blasting operations. [**2 points**]

h It is proposed the slope with zero cohesion be reinforced by installing tensioned rock bolts anchored into sound rock beneath the slide plane (Figure 2). If the rock bolts are installed at right angles to the slide plane, that is, $\psi_T = 55°$, and the total load on the anchors per lineal meter of slope (i.e. per 1-m thick slice of slope) is 400 kN, give the mathematical expression and calculate the factor of safety against plane failure. [**3 points**]

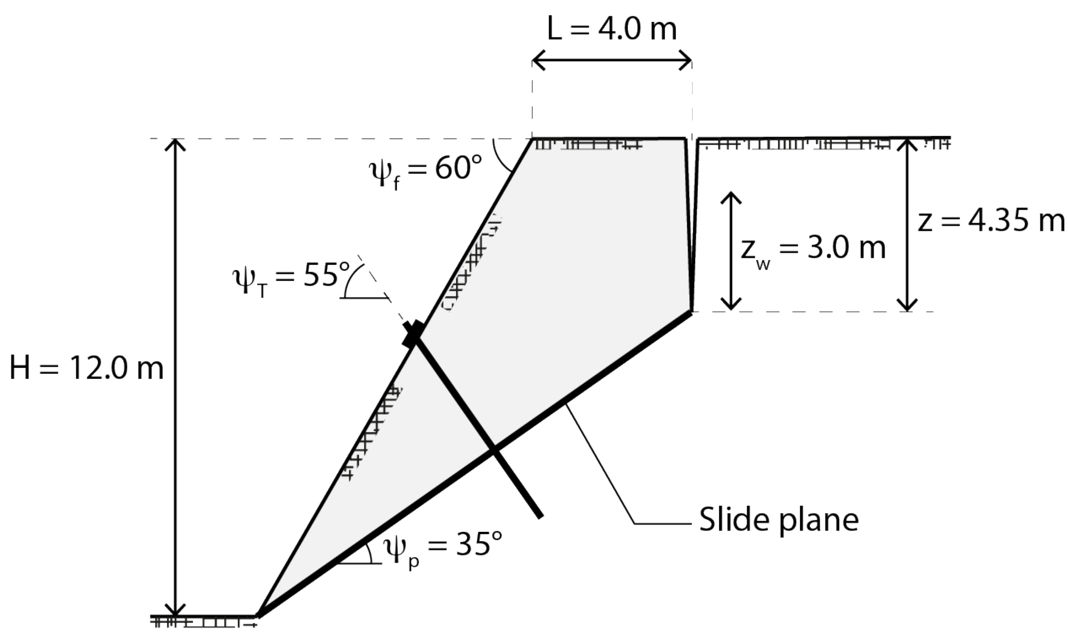

FIGURE 2 – Reinforced slope geometry.

i Explain how rock bolts installed at right angles to the slide plane increase the factor of safety of the slope against failure along the slide plane. [**3 points**]

j Based on the case described above, explain the difference between a risk and a hazard. [**3 points**]

k The limit-equilibrium analysis assumes that the strength of a discontinuity is described using the Mohr-Coulomb failure criterion. Comment on the validity of this hypothesis. [**5 points**]