TU Delft

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AESB2341
Rock Mechanics and Rock Engineering

5^{th} July 2019
CT-IZ 3.98

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 11 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)

In an experimental study of 1970, Wawersik and Fairhust investigated the mechanical behaviour of Tennessee marble. The authors performed five triaxial compression tests at different confining stresses, ranging from 0 to 48.3 MPa. The corresponding experimental results are presented in Figure 1, where σ_a is the axial stress, σ_r is the radial or confining stress and ε_a is the axial strain.

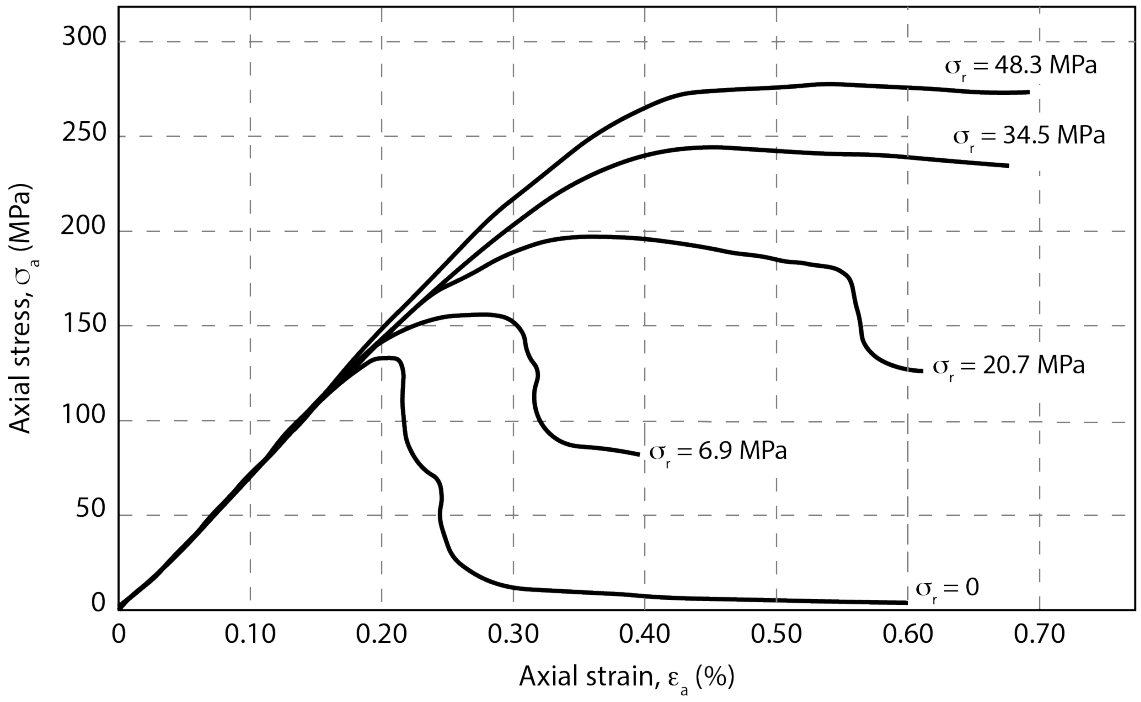


FIGURE 1 – Stress–strain curves of Tennessee marble.

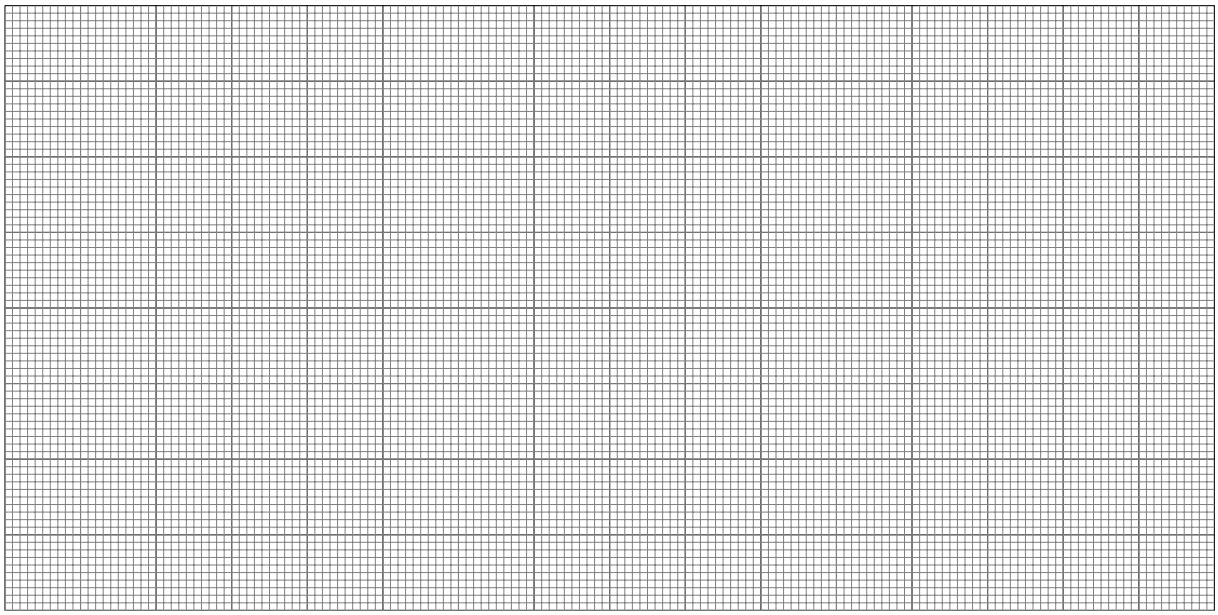
a Determine the Young's modulus of Tennessee marble. Refer to Figure 1 to explain your calculation. [**2 points**]

b Determine the unconfined compressive strength of Tennessee marble. [**2 points**]

c For each of the five stress–strain curves on Tennessee marble presented in Figure 1, mark in green the point at which failure occurred. [**4 points**]

d Name and explain two effects that the confining stress has on the mechanical behaviour of rocks. Refer to the stress–strain curves of Tennessee marble (Figure 1) to support your explanations. [**4 points**]

e Draw the Mohr's circles at failure for the five triaxial tests on Tennessee marble. Assuming a Mohr-Coulomb failure criterion, determine the cohesion and friction angle of Tennessee marble. [**8 points**]



f Calculate the tensile strength of Tenessee marble as predicted by the Mohr-Coulomb criterion. Explain your calculations and comment on the validity of the Mohr-Coulomb criterion for tensile stresses. [**5 points**]

g A sample of Tennessee marble is brought to a stress state such that $\sigma_r = 20$ MPa and $\sigma_a = 169$ MPa, before the water pore pressure of the sample is increased. Calculate the value of pore pressure that will cause failure of the sample. Explain how an increase in water pore pressure affects the Mohr's circle. [**5 points**]

Question 2 (25 points)

A circular tunnel is excavated at a depth of 250 m in granite. The diameter of the tunnel is 9 m. The vertical stress at a depth of 250 m is caused by the weight of the overlying rock. The average unit weight of the overburden is 26.0 kN/m^3 and its Poisson's ratio is equal to 0.37.

a Calculate the vertical *in situ* stress at a depth of 250 m before the excavation of the tunnel. Explain your calculations. [**2 points**]

b Calculate the horizontal *in situ* stress at a depth of 250 m before the excavation of the tunnel. Consider the theory of elasticity and assume conditions of uniaxial strain in the vertical direction with zero lateral strain. Explain your calculations. [**5 points**]

c Calculate the minimum and maximum tangential (orthoradial) stresses at the tunnel periphery using the Kirsch equations. Define the locations of the relevant points. [**6 points**]

d If the strength of the granite is defined by a maximum shear strength criterion, $\tau_{max} = 13$ MPa, estimate the extent of boundary failure, in terms of the angular range over the perimeter of the tunnel. [**7 points**]

e In sub-question b, you estimated the value of the horizontal stress using the theory of elasticity. Name one technique that can be used to measure the *in situ* horizontal stress and explain its principles. [**5 points**]

Question 3 (15 points)

a Explain the difference in mechanical behaviour between rock material and rock mass. **[6 points]**

b Figure 2 shows the outcrop of a sedimentary formation in the Belgian Ardennes. Point at 3 geometrical properties of discontinuities in the figure using arrows and label each of them. **[3 points]**

FIGURE 2 – Outcrop of a sedimentary formation.

c How does each of these geometrical properties of the discontinuities affect the stability of surface excavations (slopes) ? Explain your answer. **[6 points]**

Question 4 (30 points)

A rock slope is identified as being potentially unstable. The stability of the slope is critical because of its proximity to two blocks of apartments. The geometry of the slope is illustrated in Figure 3, which shows a 60 m high slope with an overall slope angle of 50°. An exfoliation joint surface dips at 35° and undercuts the slope as shown in Figure 3. It is assumed that the slope is completely dry and that the exfoliation joint has no cohesion.

The unit weight of the rock is 26.0 kN/m^3, and the unit weight of water is 9.8 kN/m^3.

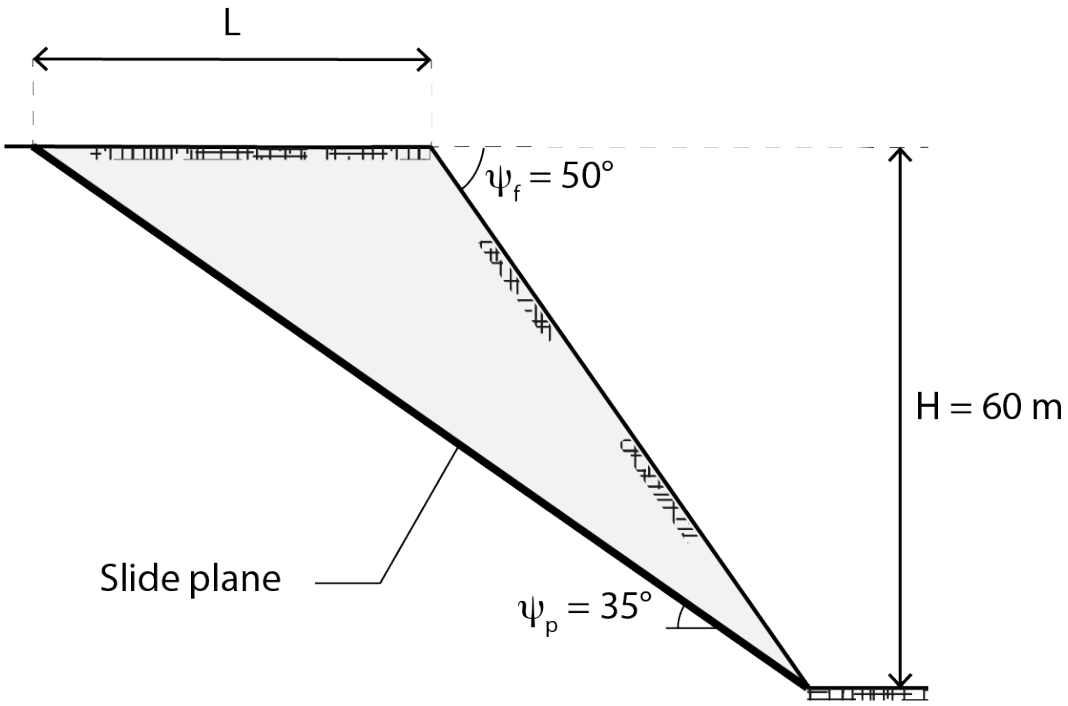


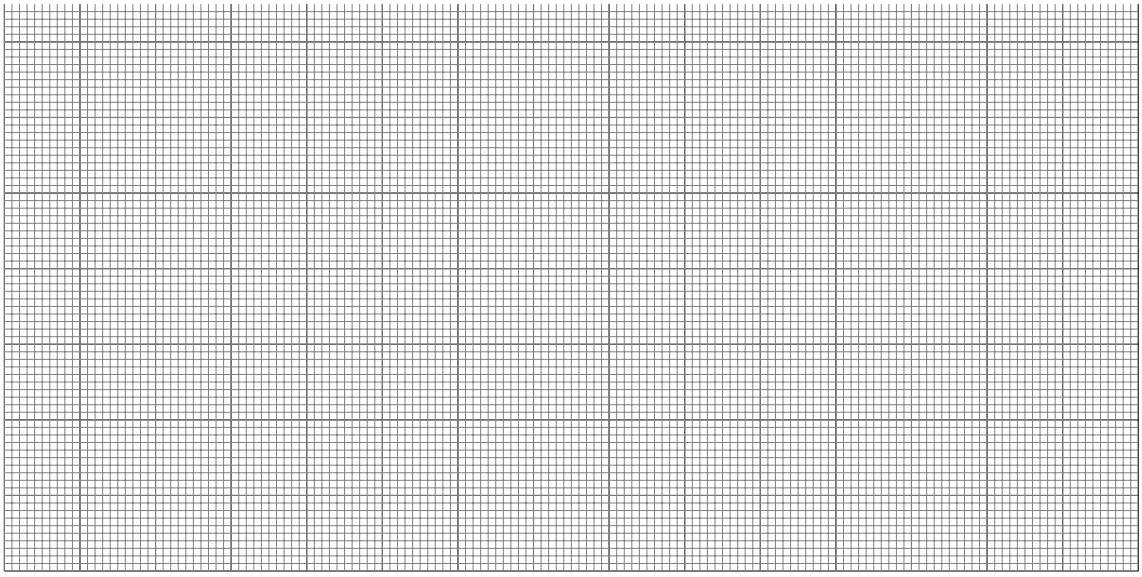
FIGURE 3 – Slope geometry.

a List, label, represent in Figure 3 and give the mathematical expression of the forces acting on the block shaded in Figure 3 at limit equilibrium conditions. [**5 points**]

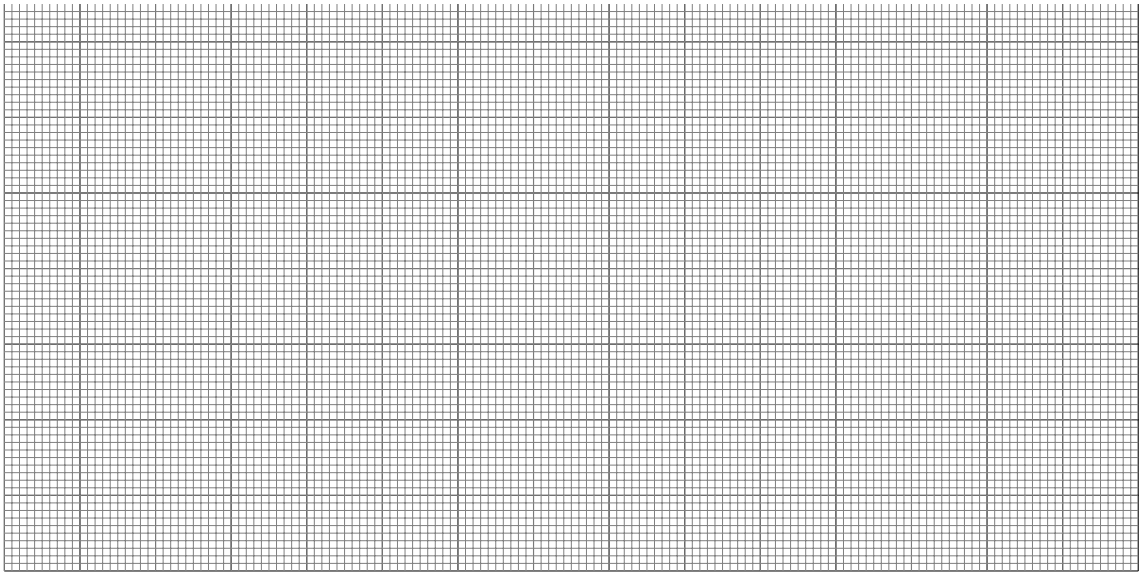
b In order to characterise the shear strength of the exfoliation joint, a direct shear test was conducted in the field along the joint. The average normal pressure on the sample was 250 kPa. The following table of results was obtained :

T, Shear stress (kPa)	210	250	290	280	265	257	250	243	230	230
u, Shear displacement (mm)	0.05	1.19	3.61	4.50	8.51	9.40	11.61	12.60	17.09	19.81

— Plot a graph of shear stress (on the vertical axis) against shear displacement. From the graph determine the peak and residual shear strengths of the surface. **[4 points]**



— Plot a graph of the peak and residual shear strengths (on the vertical axis) against the average normal stress on the surface. From the graph determine the peak and residual friction angles of the surface. **[6 points]**



c Give the mathematical expression and calculate the factor of safety against plane failure along the slide plane. Justify all your hypothesis. **[6 points]**

d Name two techniques that can be used to stabilise a surface excavation. Explain their principles and how they affect the factor of safety of a slope. **[6 points]**

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