بسمه تعالی

تمرینات مکانیک سنگ سری ۵ (صفحات ضعیف در سنگ، تغییرشکل سنگ)

این تمرینات از فصل پنجم و ششم کتاب گودمن داده شده در صورت نیاز به جدول یا فرمول به این فصول کتاب مراجعه شود. هر دانشجو سه عدد تمرین بایستی حل کند که در زیر نام هر دانشجو و شماره تمرین مربوطه آمده است. به علت کمبود زمان (۳ جلسه دیگر مانده است) تمرینات از فصولی ارائه شده است که استاد در این هفته و هفته های بعد آنها را تدریس می‌کند. لیکن دانشجویان بایستی این تمریات را حل کرده و برای حل آنها در کلاس آمادگی کافی را داشته باشند. از تمریناتی که استاد موضوع آنها را تدریس نکند در امتحان سئوال داده نمی شود.

سئوالات فصل پنجم:

شماره تمرین		نام دانشجو	
۷،۱۱،۱	حسن	بهارلوئی	1
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سئوالات فصل ششم:

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سئوالات فصل پنجم:

Problems

1. Determine by mathematical calculation the mean orientation and the Fisher
   distribution parameter k_f for each of the joint sets represented by the follow-
   ing data collected in the field:

Joint or Other Plane	Strike (°)	Dip (°)	Joint or Other Plane	Strike (°)	Dip (°)
1	S40 E	35 NE	16	S38 W	62 NW
2	S42 E	35 NE	17	S36 W	63 NW
3	S40 E	39 NE	18	S38 E	41 NE
4	S30 W	60 NW	19	S25 E	38 NE
5	S35 W	61 NW	20	S30 W	58 NW
6	S41 E	34 NE	21	N30 E	30 SE
7	S32 W	59 NW	22	N35 E	32 SE
8	S35 W	62 NW	23	N22 E	28 SE
9	S38 E	37 NE	24	N45 E	60 NW
10	S40 E	37 NE	25	N55 E	58 NW
11	S33 W	61 NW	26	N50 E	59 NW
12	S33 W	64 NW	27	N30 W	90
13	S40 E	37 NE	28	N40 W	88 NE
14	S41 E	36 NE	29	N40 W	1 NE
15	S40 W	62 NW	30	N30 E	24 SE

2. Plot the normals to the joint planes of Problem 1 on an upper hemisphere
   stereographic projection and compare the calculated preferred orientations
   with what seem to be the points where the greatest density of normals
   occur.

3. A multistage triaxial test with a sawed joint oriented 45° with the axis of the
   core yielded the following data. Determine ϕ_μ.

Confining Pressure (p) (MPa)	Maximum Axial Stress (MPa)
0.10	0.54
0.30	1.63
0.50	2.72
1.00	5.45

4. A reverse fault in the rock of Problem 3 has a dilatancy angle of 5° and is inclined 20° with the horizontal. What is the maximum horizontal stress that could be sustained at a depth of 2000 m in this rock?

5. Trace the roughness profile of Figure 5.15a on a sheet of paper; then cut along it carefully with scissors to produce a model of a direct shear specimen. Slide the top to the right past the bottom, without rotation and without "crushing," and draw the path of any point on the top block. Compare this path to the constructed dilatancy curve of Figure 5.16b. Mark the locations of potential crushing at different shear displacements.

6. A normal fault that is partly cemented with calcite mineralization dips 65° from horizontal. The fault slipped when the water pressure reached 10 MPa at a depth of 600 m. If $S_j = 1$ MPa and $\phi_j = 35°$, what was the horizontal stress before the fault slipped?

7. $S_j = 0$ and $\phi_j = 28.2°$ for a sawed joint oriented 50° from vertical in a saturated triaxial compression specimen. The confining pressure is 1.5 MPa and the axial stress $\sigma_1 = 4.5$ MPa with zero joint water pressure. What water pressure will cause the joint to slip if σ_1 and σ_3 are held constant?

8. The following data were taken in a direct shear test conducted in the field along a rock joint, with area 0.50 m². The weight of the block above the joint is 10 kN.

T, Shear Force (kN)	0	1.0	2.0	3.0	5.0	6.5	6.0	5.5	5.4	5.3
u, Shear Displacement (mm)	0	0.5	1.0	1.5	3.0	5.2	7.5	9.5	11.5	≥12

Assuming that joint cohesion is zero, and that $\phi_\mu = \phi_{resid}$, determine the peak and residual friction angles, the shear stiffness (MPa/m), and the dilatancy angle at peak and post peak displacements.

9. A jointed shear test specimen is drilled at angle α with the normal to the shear plane and a model rock bolt is installed and tensioned to force F_B (see figure). Then a pair of shear forces T are applied until the joint slips.
   (a) What is the bolt tension F_B just sufficient to prevent slip under shear force T.
   (b) What is the value of α that minimizes the value of F_B required to prevent joint slip?
   (c) How are the answers to be changed if the joint tends to dilate during shear, with dilatancy angle i, and the bolt has stiffness k_b?
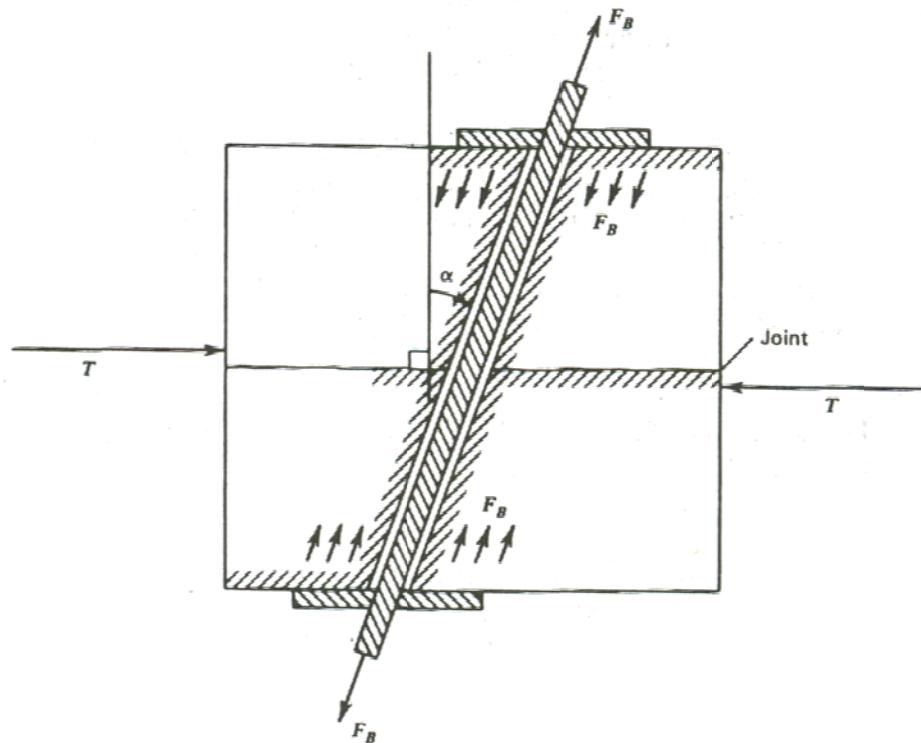
10. John Bray (1967) derived the following expression for the limiting effective stresses for joint slip:

$$K_f \equiv \frac{\sigma_3'}{\sigma_1'} = \frac{\tan |\psi|}{\tan(|\psi| + \phi_j)}$$

where ψ is the angle between the *direction* of σ_1 and the joint plane. (The derivation for this useful formula is given in Appendix 4 in the derivations to equations 7.11 to 7.16.) Draw a polar plot of the ratio σ_3'/σ_1' for limiting conditions as a function of $\psi(-\pi/2 \leq \psi \leq \pi/2)$ for values of (a) $\phi_j = 20°$ and (b) $\phi_j = 30°$. Label the regions on these diagrams corresponding to *slip* and *safe* principal stress ratios.

11. Use the expression given in Problem 10 to re-solve Problem 5-7. (*Hint:* Substitute $\sigma_1 - p_w$ and $\sigma_3 - p_w$ in place of σ_1', σ_3')

12. (a) Sedimentation is increasing the thickness of overburden (z) and the vertical stress (σ_v) in a rock mass. Assume the rock strength is given by $S_i = 1$ MPa and $\phi = 30°$. With $\nu = 0.2$, and $\gamma = 0.025$ MPa/m, draw the limiting Mohr circle that causes shear failure in the rock and determine the corresponding values of z, σ_v, and σ_h.

(b) Now assume that shear fractures have formed, in the orientation deter-

mined by the shear failure in (a). The new shear joints have $\phi_j = 20°$. Draw the new Mohr circle after the failure and determine the new value of σ_h (no change in σ_v has occurred).

(c) Assume additional sedimentation increases the value of σ_v to 1.5 times its value in (b). What are the corresponding values of z and σ_h. Draw the corresponding Mohr circle.

(d) Now erosion begins, reducing σ_v. Assuming the corresponding reduction in σ_h is given by $\Delta\sigma_h = [\nu/(1 - \nu)] \Delta\sigma_v$, draw a series of Mohr circles and determine the value of z when $\sigma_h = \sigma_v$.

(e) With further erosion, the shear joints formed in (a) are no longer relevant to the stress circles since the major stress is now horizontal. New joints form when the Mohr circle contacts the rock strength envelope. Draw this circle and determine the corresponding values of z, σ_h, and σ_v.

(f) Assume the Mohr circle is now limited by the new joints. Find the appropriate new value for σ_h (no change in σ_v).

(g) Draw graphs showing the variations of σ_v and σ_h with z increasing to the max found in (c) and then decreasing to zero.

13. The average fracture frequency (λ) across a rock core is the total number of natural fractures divided by the total length drilled.

(a) Suppose there is only one set of joints and that λ is the fracture frequency measured in a direction normal to them. Derive an expression giving λ in a direction θ with respect to the normal.

(b) There are two orthogonal sets of fractures with λ values, respectively λ_1 and λ_2. Derive an expression for λ measured in a direction θ from λ_1.

(c) Given $\lambda_1 = 5.0$ and $\lambda_2 = 2.0$ fractures per meter. Find the values of θ and λ such that the fracture frequency is a maximum. What is the average fracture *spacing* in this direction?

14. Barton (1973) proposed an empirical criterion of peak shear strength for joints:

$$\tau = \sigma_n \tan[JCR \log (JCS/\sigma_n) + \varphi_b]$$

where JCS is the compressive strength of the wall rock, and JCR is the joint roughness coefficient. (In this expression, the argument of tan is understood to be expressed in degrees.) Compare this equation with Equation 5.8.

Problems

1. Show that the stress-strain relationship connecting deviatoric strain e_{ij} and deviatoric stress τ_{ij} consists of six uncoupled identical statements:

$$\tau_{ij} = 2Ge_{ij}$$
$$i, j = 1, 3$$

("Deviatoric strain" is discussed in Appendix 2.)

2. Suppose a triaxial compression test is conducted by simultaneous change in σ_1 and p; derive expressions for E and ν in terms of the axial and lateral strains and the stresses σ_1 and p.

3. Describe a procedure for triaxial testing that raises the deviatoric stress while the nondeviatoric stress remains constant.

4. The following forces and displacements were measured in an unconfined compression test of a cylindrical claystone specimen 5.0 cm in diameter and 10.0 cm long.

Axial Force (N)	Axial Shortening (mm)	Lateral Extension (mm)	Axial Force (N)	Axial Shortening (mm)	Lateral Extension (mm)
0	0	0	0	0.080	0.016
600	0.030		2,500	0.140	
1000	0.050		5,000	0.220	
1500	0.070		6,000	0.260	
2000	0.090		7,000	0.300	
2500	0.110	0.018	7,500	0.330	0.056
0	0.040	0.009	0	0.120	0.025
2500	0.110		7,500	0.330	
3000	0.130		9,000	0.400	
4000	0.170		10,000	0.440	0.075
5000	0.220	0.037	0	0.160	0.035

Compute E and ν corresponding to elastic deformation and their counterparts M and ν_p for permanent deformation from the above data.

5. A triaxial compression test is performed as follows: (a) An all-around pressure is first applied to the jacketed rock specimen. Nondiviatoric stress $\bar{\sigma}$ is plotted against nondeviatoric strain ε and the slope $D_1 = \Delta\bar{\sigma}/\Delta\bar{\varepsilon}$ is determined. (b) Then deviatoric stress is increased while nondeviatoric stress is held constant and the axial deviatoric stress $\sigma_{1,\text{dev}}$ is plotted against the axial deviatoric strain $\varepsilon_{1,\text{dev}}$. The slope $D_2 = \Delta\sigma_{1,\text{dev}}/\Delta\varepsilon_{1,\text{dev}}$ is determined from the graph. Derive formulas expressing E and ν in terms of D_1 and D_2.

6. (a) Derive a relationship between E, the modulus of elasticity computed from the reloading curve of stress and strain; M, the modulus of permanent deformation; and E_{total}, the modulus of deformation computed from the slope of the loading curve of stress and strain. (b) Show how M varies with axial strain throughout the complete stress-strain curve.

7. In a full seismic wave experiment, the compressional and shear wave velocities were measured as $V_p = 4500$ m/s, $V_s = 2500$ m/s. Assuming the density of the rock is 0.027 MN/m³, calculate E and ν.

8. What physical phenomena could explain a plate-bearing pressure versus displacement curve like that of Figure 6.9?

9. A rock mass is cut by one set of joints with spacing $S = 0.40$ m. (a) If the joint normal and shear deformations are assumed to be equal to that of the rock itself, express k_s and k_n in terms of E and ν. (b) Assuming $E = 10^4$ MPa and $\nu = 0.33$, calculate all the terms of the strain-stress relationship for an equivalent transversely isotropic medium, (corresponding to Equation 6.9).

10. Modify Equations 6.23 and 6.24 accordingly for a rock mass with three mutually perpendicular sets of joints.

11. Show that for rock cut by one set of joints with spacing S, the normal strains and normal stresses referred to n, s, t coordinates are related by

$$\begin{pmatrix} \varepsilon_n \\ \varepsilon_s \\ \varepsilon_t \end{pmatrix} = \frac{1}{E} \begin{bmatrix} p & -\nu & -\nu \\ -\nu & 1 & -\nu \\ -\nu & -\nu & 1 \end{bmatrix} \begin{pmatrix} \sigma_n \\ \sigma_s \\ \sigma_t \end{pmatrix}$$

where $p = 1 + E/k_n S$ and where E and ν are Young's modulus and Poisson's ratio of the rock, k_n is the normal stiffness of the joints, and n is the direction perpendicular to the joint planes.

12. A jacketed rock cube, with edge length 50 cm, is subject to an all around pressure p. The pressure versus volumetric strain curve recorded is given in the figure. Assume the rock contains three mutually perpendicular joint sets all spaced 5 cm apart. Calculate the normal stiffness of the joints k_n at each of the normal pressures corresponding to the start of unloading paths (2.4, 4.8, and 10.3 MPa).
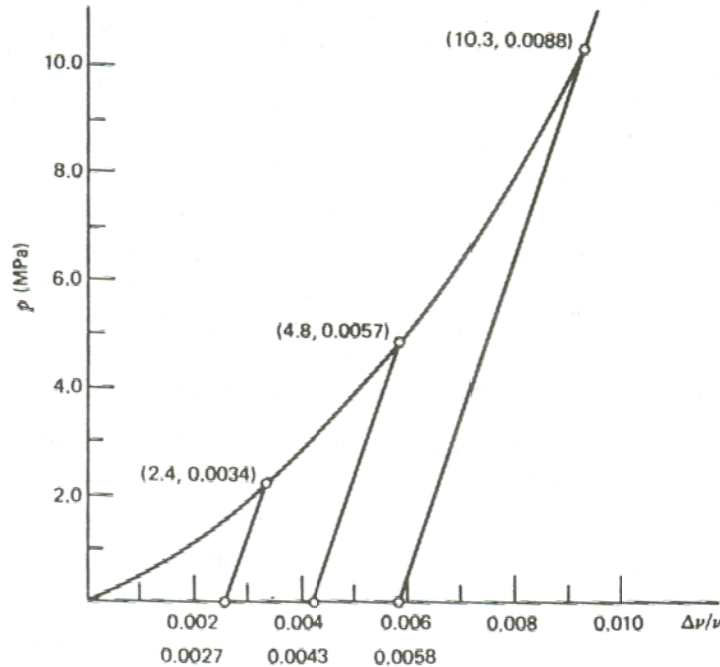
13. Let ν_p, ν_t, and ν be respectively the Poisson's ratios for plastic, total, and elastic strain; that is, for strain applied in the x direction, $\nu = -\varepsilon_y/\varepsilon_x$, etc. Derive a formula expressing ν_t as a function of E, M, ν, and ν_p.