Roll No											

PRESIDENCY UNIVERSITY
BENGALURU

SET A

SCHOOL OF ENGINEERING
END TERM EXAMINATION - JAN 2024

Semester : Semester V - 2021

Course Code : PET3001

Course Name : Geomechanics for Wellbore Stability Analysis
Program : B.Tech.

Date : 08-JAN-2024
Time : 9:30AM - 12:30 PM
Max Marks : 100
Weightage : 50%

Instructions:
(i) Read all questions carefully and answer accordingly.
(ii) Question paper consists of 3 parts.
(iii) Scientific and non-programmable calculator are permitted.
(iv) Do not write any information on the question paper other than Roll Number.

PART A

ANSWER ALL THE QUESTIONS **5 X 2M = 10M**

1. Recall the four chief physical factors that control the type of deformation of rocks at depth.
(CO1) [Knowledge]

2. Fill in the blanks with the appropriate answer:
During drilling, if (a) _____ is found to be increasing or (b) _____ is found to be decreasing, then that indicates the presence of an overpressure zone beneath the surface.
(CO2) [Knowledge]

3. **Select the correct answer:**
Geomechanical analysis assesses the behavior of rocks under the influence of _____.
(A) Magnetic fields
(B) Gravitational forces
(C) Electrical currents
(D) Stress and strain
(CO3) [Knowledge]

4. **Select the correct answer:**
Assuming a coefficient of sliding friction of 0.6, an overburden stress of 11000 psi, a minimum horizontal stress of 8000 psi, which of the following stress states is possible?
(A) Reverse faulting only
(B) Normal faulting only
(C) Strike-slip faulting only
(D) Normal and/or strike-slip faulting
(E) Any faulting regime is possible

(CO4) [Knowledge]

5. **Select the correct answer:**
The leak-off pressure is a reasonable approximation of the magnitude of the least principal stress because _____.
(A) the slight decrease in the rate of wellbore pressurization is caused by a decrease in the system volume as a result of the onset of hydraulic fracturing.
(B) the pressure-volume curve has reached its summit where the pressure is high enough to propagate a hydraulic fracture.
(C) the noticeable change in the rate of wellbore pressurization is caused by propagation of a hydraulic fracture, which increases the system volume.

(CO5) [Knowledge]

PART B

ANSWER ALL THE QUESTIONS **5 X 10M = 50M**

6. Field photos of different geological faults are displayed in Figures A through C. Identify the faults and classify all with the block diagrams as per E. M. Anderson's Stress Classification Scheme.

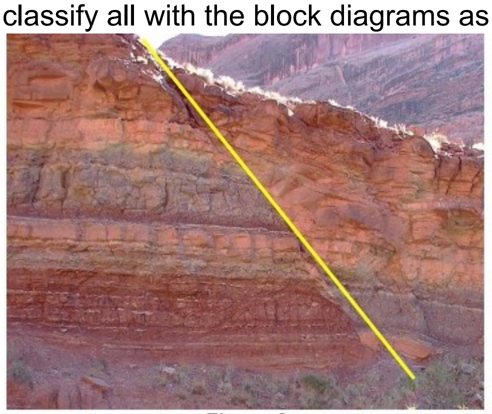


Figure A

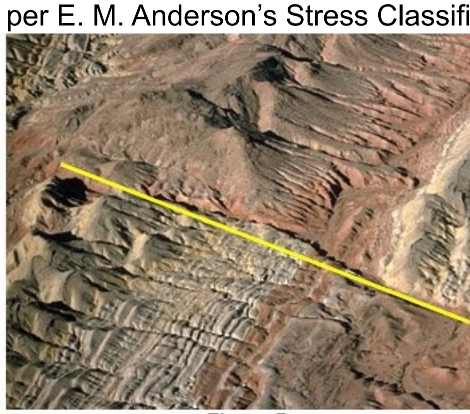


Figure B

Figure C

(CO1) [Comprehension]

7. The observation that a given reservoir can sometimes be compartmentalized and hydraulically isolated

from surrounding formations has received a lot of attention over the past decades. The economic reason for this interest is obvious as production from distinct compartments has a major impact on the drilling program required to achieve reservoir drainage. Ortoleva (1994) presents a compilation of papers related to the subject of reservoir compartmentalization. The easiest way to think about separate reservoir compartments is in the context of a series of permeable sands separated by impermeable shales (Figure AB) assuming, for the moment, that the lateral extent of each sand is limited. The case shown in the Figure is from a well in Egypt (Nashaat 1998). Interpret the importance of the Figure being a reservoir geomechanical engineer from the oil and gas industry.

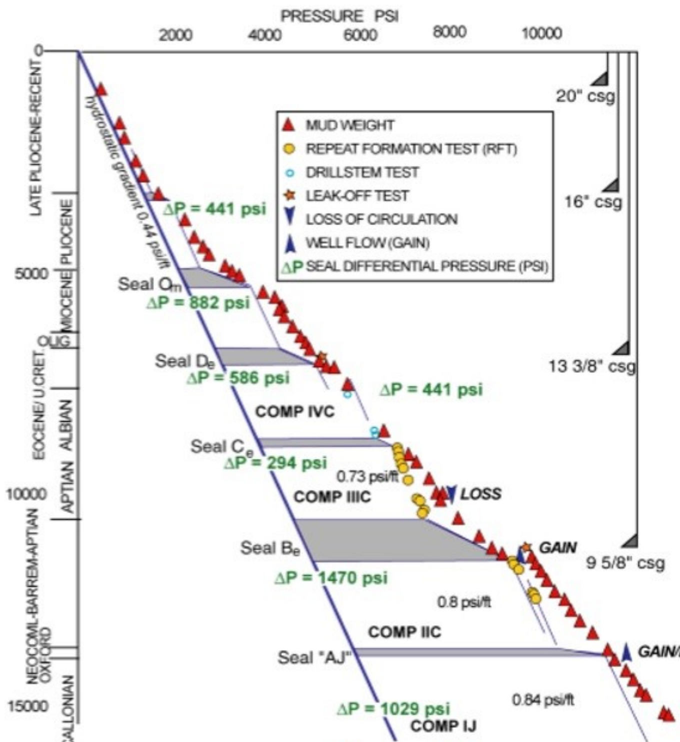
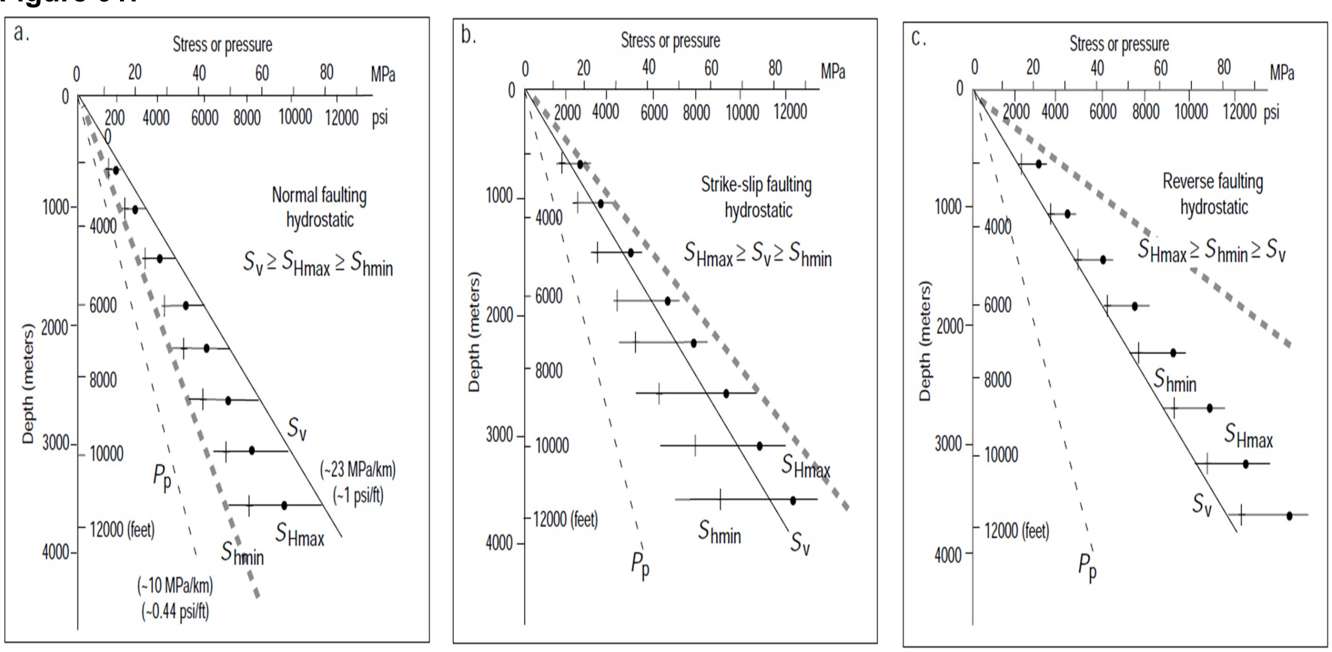


Figure AB

(CO2) [Comprehension]

8. The pressure in a liquid at a given depth is called the hydrostatic pressure and pore pressure is the pressure of the fluid in the pore space of the rock. When pore pressure exceeds the hydrostatic pressure, an overpressure situation occurs. Describe the significance of Figure 01 in line with the above statement.

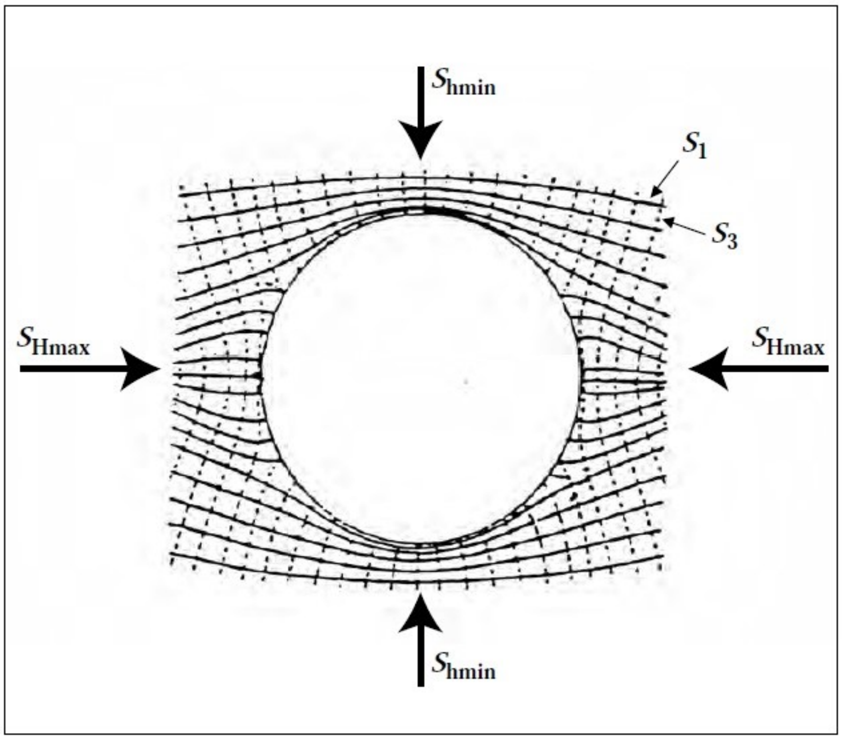
Figure 01:



(CO3) [Comprehension]

9. In vertical wells, the occurrence of tensile fractures in a wall usually implies that (i) Shmin is the minimum principal stress, and (ii) there are large differences between the two horizontal principal stresses, SHmax and Shmin. The occurrence of tensile fractures is also influenced by high mud weight and cooling of the wellbore wall. The processes that control the initiation of tensile wall fractures are important for understanding the initiation of hydraulic fractures. However, hydrofracs are distinguished from tensile wall fractures in that they propagate from the wellbore into the far field, away from the wellbore stress concentration. The importance of drilling-induced tensile fractures as a means of obtaining important information about stress orientation and magnitude as well as how hydraulic fractures yield extremely important information about the magnitude of the least principal stress. The stress concentration around a vertical well drilled parallel to the vertical principal stress, Sv, in an isotropic, elastic medium is described by the Kirsch equations. Explain the causes for the bending of stress trajectories due to the creation of a cylindrical opening (like a wellbore) with the help of Figure A.

Figure A:



(CO4) [Comprehension]

10. Natural fracture data interpreted from an FMI image log in a vertical well from the Barnett Shale has been presented in Table 1. This image log has been processed using the software GMI Imager, in which fractures were picked as abrupt contrasts in the electrical resistivity image of the borehole wall. Analyze the data presented in Table 1 and answer the following:

(a) Which of the following strike intervals contains the highest number of fractures?
(i) 0° to 90°
(ii) 90° to 180°
(iii) 180° to 270°
(iv) 270° to 360°

(b) Which of the following dip direction intervals contains the highest number of fractures?
(i) 0° to 90°
(ii) 90° to 180°
(iii) 180° to 270°
(iv) 270° to 360°

(c) Which of the following aperture intervals contains the highest number of gently dipping fractures of which the dip is less than 45°?
(i) 0 mm to 4 mm
(ii) 4 mm to 8 mm
(iii) Greater than 8 mm

(d) Which of the following aperture intervals contains the highest number of nearly north-south striking fractures of which the strike is either between 0° and 15°, or between 75° and 105°, or between 345° and 360°?
(i) 0 mm to 4 mm
(ii) 4 mm to 8 mm
(iii) Greater than 8 mm

[2.5 + 2.5 + 2.5 + 2.5]

Table 1:

Depth (ft)	Strike (degree)	Dip (degree)	Dip Direction (degree)	Aperture (millimeter)
5200.82	228.25	76.41	318.25	4.31
5200.97	207.80	86.11	297.80	5.87
5205.07	233.97	84.07	323.97	7.22
5208.82	206.68	82.67	296.68	5.52
5221.97	214.65	77.20	304.65	5.44
5232.42	211.99	79.37	301.99	9.95
5248.54	214.61	79.88	304.61	12.24
5252.68	226.41	84.78	316.41	10.21
5269.20	245.50	80.63	335.50	8.22
5280.63	238.08	81.70	328.08	2.67
5290.00	226.76	83.85	316.76	5.28
5298.56	212.76	82.34	302.76	2.28
5422.93	220.49	75.45	310.49	2.21
5480.59	235.58	78.23	325.58	2.79
5486.79	203.03	80.78	293.03	1.92
5541.47	228.51	78.70	318.51	0.25
5629.33	190.00	82.13	280.00	0.79
5654.14	162.75	18.04	252.75	9.69
5691.06	7.48	15.89	97.48	9.44
5715.48	162.80	7.92	252.80	2.69
5857.44	224.46	85.04	314.46	1.15
5878.72	219.11	86.63	309.11	3.08

6000.14	5.74	11.19	95.74	11.29
6020.27	0.37	40.44	90.37	11.04
6114.42	201.54	56.87	291.54	5.53
6142.56	208.40	59.07	298.40	4.22
6154.56	200.38	56.88	290.38	0.25
6164.20	351.60	5.34	81.60	16.72

(CO5) [Comprehension]

PART C

ANSWER ALL THE QUESTIONS **2 X 20M = 40M**

11. Assume that you are associated with an E&P company as a Geomechanical Engineer. You have been assigned the task to estimate Unconfined Compressive Strength (UCS) for the formations encountered in a well drilled in Cambay Basin. Refer to the geophysical log data shared in Table 1 and answer the following:

(a) Name the geophysical log data required for the calculation of U
(b) Estimate the UCS of the formation encountered at 5160.50 ft using density-porosity data directly, if possible, and
(c) Predict the UCS of the formation encountered at 5168.50 ft using sonic travel time (Δt) data directly.

Table 2.1 through Table 2.3 may be referred to for finding out the most suitable equation to calculate USC.

[4 + 8 + 8]

Table 1: Geophysical Log data.

Depth (ft)	Density (g/cc)	Δt_compressional (μs/ft)	Δt_shear (μs/ft)	Formation Name	Formation Type
5160.00	2.5969	73.9180	134.3668	X	Sandstone
5160.50	2.7472	72.9881	134.6025		
5161.00	2.6879	70.6541	131.0170		
5161.50	2.6363	70.3154	126.5105		
5162.00	2.6322	68.2713	125.3421		
5162.50	2.6090	64.2715	118.7308		
5163.00	2.7408	57.9452	112.7404		
5163.50	2.5913	54.2315	106.4179		
5164.00	2.7339	49.3006	101.1393		
5164.50	2.7363	48.6093	98.2395		
5165.00	2.7862	46.7769	98.5376		
5165.50	2.7409	47.6919	95.0032		
5166.00	2.7210	47.0965	92.3078		
5166.50	2.7204	47.2167	95.9393		
5167.00	2.7264	46.8250	96.0021		
5167.50	2.7233	47.4132	94.2504	Y	Limestone
5168.00	2.7221	48.2833	94.1394		
5168.50	2.7153	47.7699	95.3368		
5169.00	2.7395	48.9384	93.4016		
5169.50	2.7152	48.2850	95.4636		
5170.00	2.7017	47.7034	95.4235		

Additional Information:
- Assume full saturation of 1.12 g/cc water in the pores.
- Use matrix density of 2.88 g/cc, which is a reasonable value for matrix of quartz, feldspar, mica and clay.
- Assume hydrostatic pore pressure of 0.44 psi/ft
- Use 9.8 m/s2 to approximate g, the acceleration due to gravity.

Table 2.1: Equations for estimating UCS of Sandstone.

Equation No.	UCS, MPa	Region where developed	General comments	Reference
1	$0.035\ V_p - 31.5$	Thuringia, Germany	–	(Freyburg 1972)
2	$1200\ \exp(-0.036\Delta t)$	Bowen Basin, Australia	Fine grained, both consolidated and unconsolidated sandstones with wide porosity range	(McNally 1987)
3	$1.4138 \times 10^{7}\ \Delta t^{-3}$	Gulf Coast	Weak and unconsolidated sandstones	Unpublished
4	$3.3 \times 10^{-20}\ \rho^2 V_p^2\ [(1+\nu)/(1-\nu)]^2(1-2\nu)\ [1+0.78V_{clay}]$	Gulf Coast	Applicable to sandstones with UCS >30 MPa	(Fjaer, Holt *et al*. 199
5	$1.745 \times 10^{-9}\ \rho V_p^2 - 21$	Cook Inlet, Alaska	Coarse grained sands and conglomerates	(Moos, Zoback *et al*.
6	$42.1\ \exp(1.9 \times 10^{-11}\ \rho V_p^2)$	Australia	Consolidated sandstones with $0.05 < \phi < 0.12$ and UCS > 80MPa	Unpublished
7	$3.87\ \exp(1.14 \times 10^{-10}\ \rho V_p^2)$	Gulf of Mexico	–	Unpublished
8	$46.2\ \exp(0.000027E)$	–	–	Unpublished
9	$A\ (1-B\phi)^2$	Sedimentary basins worldwide	Very clean, well consolidated sandstones with $\phi < 0.30$	(Vernik, Bruno *et al*. 1
10	$277\ \exp(-10\phi)$	–	Sandstones with 2 < UCS < 360 MPa and $0.002 < \phi < 0.33$	Unpublished

Units used: V_p (m/s), Δt (μs/ft), ρ (kg/m^3), V_{clay} (fraction), E (MPa), ϕ (fraction)

Table 2.2: Equations for estimating UCS of Shale.

	UCS, MPa	Region where developed	General comments	Reference
11	$0.77\ (304.8/\Delta t)^{2.93}$	North Sea	Mostly high porosity Tertiary shales	(Horsrud 2001)
12	$0.43\ (304.8/\Delta t)^{3.2}$	Gulf of Mexico	Pliocene and younger	Unpublished
13	$1.35\ (304.8/\Delta t)^{2.6}$	Globally	–	Unpublished
14	$0.5\ (304.8/\Delta t)^{3}$	Gulf of Mexico	–	Unpublished
15	$10\ (304.8/\Delta t - 1)$	North Sea	Mostly high porosity Tertiary shales	(Lal 1999)
16	$0.0528E^{0.712}$	–	Strong and compacted shales	Unpublished
17	$1.001\phi^{-1.143}$	–	Low porosity ($\phi < 0.1$), high strength shales	(Lashkaripour and Dusseault 1993)
18	$2.922\phi^{-0.96}$	North Sea	Mostly high porosity Tertiary shales	(Horsrud 2001)
19	$0.286\phi^{-1.762}$	–	High porosity ($\phi > 0.27$) shales	Unpublished

Units used: Δt (μs/ft), E (MPa), ϕ (fraction)

Table 2.3: Equations for estimating UCS of Carbonate.

	UCS, MPa	Region where developed	General comments	Reference
20	$(7682/\Delta t)^{1.82}$ / 145	–	–	(Militzer 1973)
21	$10^{(2.44 + 109.14/(t)}$ / 145	–	–	(Golubev and Rabinovich 1976)
22	$0.4067\ E^{0.51}$	–	Limestone with 10 < UCS < 300 MPa	Unpublished
23	$2.4\ E^{0.34}$	–	Dolomite with 60 < UCS < 100 MPa	Unpublished
24	$C\ (1-D\phi)^2$	Korobcheyev deposit, Russia	C is reference strength for zero porosity (250 < C < 300 MPa). D ranges between 2 and 5 depending on pore shape	(Rzhevsky and Novick 1971)
25	143.8 exp(-6.95ϕ)	Middle East	Low to moderate porosity (0.05 < ϕ < 0.2) and high UCS (30 < UCS < 150 MPa)	Unpublished
26	135.9 exp(-4.8ϕ)	–	Representing low to moderate porosity (0 < ϕ < 0.2) and high UCS (10 < UCS < 300 MPa)	Unpublished

Units used: Δt (μs/ft), E (MPa), ϕ (fraction)

(CO3) [Application]

12. The energy demand is continually increasing and with the decline of conventional reservoirs, the importance of understanding unconventional reservoirs is even greater. Within the last decade, the exploration and production of shale reservoirs has increased significantly, due to coupled horizontal drilling and hydraulic fracturing applications, along with other advancements in completion technologies. Estimation of the lower bound of the minimum horizontal stress, the upper bound of the maximum horizontal stress, and the range of possible magnitudes of the maximum horizontal stress given a magnitude of the minimum horizontal stress. Answer the following based on knowledge of the vertical stress, the pore pressure, and the coefficient of sliding friction.

(a) Assuming a coefficient of sliding friction of 0.6, an overburden stress of 42.52 psi, and a pore pressure of 18.96 psi at 5500 ft depth, (i) identify the faulting regime with explanation, and (ii) compute the upper bound of the maximum horizontal stress.

(b) Assuming a coefficient of sliding friction of 0.6, an overburden stress of 42.52 psi, and a pore pressure of 18.96 psi at 5500 ft depth, (i) identify the faulting regime with explanation, and (ii) identify the faulting regime and determine the lower bound of the maximum horizontal stress.

[10 + 10]

(CO4) [Application]