PET 535 MODERN WELL DESIGN – MAY 2016

1. HYDRAULICS

1. REYNOLDS NUMBER DEFINES: INERTIAL / VISCOUS FORCES
2. BERNOULLI'S EQUATION IS A CONSERVATION OF: ENERGY
3. PIPE FRICTION FACTOR APPLIES FOR: TURBULENT
4. VISCOUS EFFECTS APPLIES FOR: LAMINAR
5. DRILLSTRING HYDRAULICS IS MOSTLY: TURBULENT
6. FLOW THROUGH BIT NOZZLES IS: TURBULENT
7. FLOW THROUGH THE MARINE RISER IS: LAMINAR
8. INCREASED FLOW RATE GIVES: MORE NOZZLE PRESSURE

2. WELLBORE FRICTION. THE ENCLOSED FIGURE SHOWS HOOKLOAD DATA FOR A DEVIATED WELL

a) BY INSPECTION OF THE FORCE PLOT, SUGGEST THE TYPE OF WELL GEOMETRY FOR EACH OF THE FOUR DISTINCT INTERVALS

THIS IS AN S-SHAPE WELL WITH 4 SECTIONS AS SPECIFIED IN THE FIGURE A VERTICAL SECTION WHERE THE FORCE IS DIRECTLY RELATED TO THE BUOYED WEIGHT, THEN A BUILD UP SECTION WHERE THE DOMINATING EFFECT IS FRICTION FOLLOWED BY A HOLD-UP SECTION WHERE AGAIN THE DOMINATING EFFECT IS THE BUOYED WEIGHT AND FINALLY AGAIN A CURVED SECTION OR DROP-OFF WHERE FRICTION DOMINATES THE HOOK-LOAD. FINALLY THE VERTICAL SECTION.

b) IN A LONG DEVIATED WELL, TITANIUM DRILLPIPE WILL BE USED FOR HALF OF THE WELL LENGTH. WOULD YOU USE THE TITANIUM PIPE IN THE TOP OR IN THE BOTTOM PART OF THE WELL? WHY?

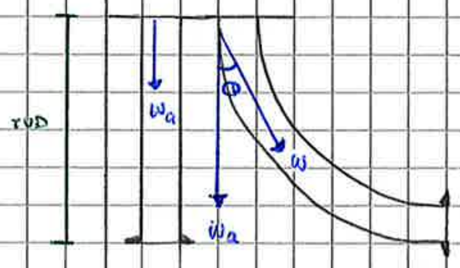
THE KEY HERE IS THAT THE APPLICATION IS ASSUMED FOR A LONG DEVIATED WELL WHERE THE TOTAL WEIGHT IS GIVEN BY THE PROJECTED HEIGHT PRINCIPLE AND IN THE CURVED SECTIONS THE FRICTION DOMINATES THE EFFECT ON THE HOOKLOAD AND HENCE THE RESISTANCE IN TENSION OF THE PIPE; SO CLEARLY TITANIUM BEING A MORE RESISTANT MATERIAL HAS TO BE PLACED IN THE UPPER PART OF THE WELL. THIS ASSESSMENT IS PURELY LOOKING AT THE MECHANICAL PROPERTIES, IF HIGH TEMPERATURES OR CORROSIVE GASSES ARE EXPECTED WE WOULD HAVE TO GET ADDITIONAL DETAILS

c) THE OIL INDUSTRY USES A STUCK PIPE MODEL THAT DOES NOT INCLUDE FRICTION. WILL THE DEPTH TO THE STUCK POINT BE TOO SHALLOW OR TOO DEEP USING THIS MODEL?

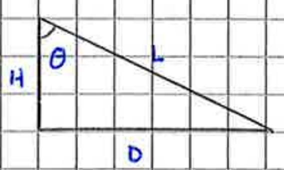
TOO SHALLOW, AS IT DOES NOT CONSIDER THAT THE FORCE EXERTED ON SURFACE IS NOT EFFECTIVELY TRANSMITTED DOWNHOLE AS PART OF IT IS TAKEN AS FRICTION, SO IT WILL CONSIDER THAT THE FREE POINT IS SHALLOWER.

d) STATIC PIPE WEIGHT WITHOUT FRICTION IS DEFINED BY "THE PROJECTED HEIGHT PRINCIPLE". PREPARE A FIGURE OF AN INCLINED PIPE ELEMENT, SHOW THE FORCES AND DERIVE THIS PRINCIPLE.

THE STATIC HOOK LOAD IS EQUAL TO THE BUOYED PIPE WEIGHT MULTIPLIED BY THE PROJECTED VERTICAL HEIGHT OF THE WELL, REGARDLESS OF WELLBORE INCLINATION. SO A VERTICAL WELL D1 HAS EQUAL STATIC LOAD AS A DEVIATED WELL WITH THE SAME PROJECTED HEIGHT D1.



WE CAN REPRESENT IT AS:



WHERE $H = \cos\theta \cdot L$

$D = \sin\theta \cdot L$

ALSO $\cos\theta = \frac{H}{L} = \frac{W_a}{W}$

HENCE

$$H = \left(\frac{W_a}{W}\right) \cdot L \rightarrow W_a = \frac{H \cdot W}{L}$$

WHERE $\frac{W}{L}$ IS THE NOMINAL WEIGHT OF THE PIPE

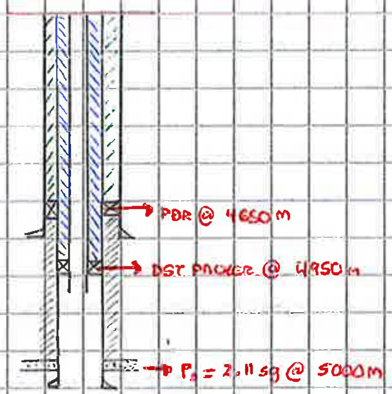
SUCH THAT

$W =$ (NOMINAL WEIGHT)(H) WHERE H IS THE PROJECTED HEIGHT OF THE PIPE SEGMENT

3. AN HTHP WELL IS DRILLED. THE FORMATION EVALUATION IS POSITIVE AND RECOMMENDS FLOW TESTING OF THE WELL. A TIE-BACK IS THEREFORE INSTALLED IN THE WELL. OTHER DATA ARE:

LINER INTERVAL:	4650 - 5100 M	LINER AND TIE BACK	7 5/8" SMC 110
TIE-BACK INTERVAL:	4650 - SURFACE	WEIGHT ON AIR:	625 N/m
TOL	4650	P_{BURST}:	1005 bar
DEPTH OF TEST PACKER:	4950	$P_{COLLAPSE}$:	959 bar
MW:	2.2 sg	TENSILE STRENGTH:	6846 kN
PORE PRESSURE:	2.11 sg AT 5000 M	DERATING DUE TO TEMPERATURE	0.91
$\rho_{RES\ FLUID}$:	0.547 sg		

a) PREPARE A FIGURE AND WRITE ALL ASSUMPTIONS



ASSUMPTIONS:

1. WELL IS DISPLACED TO INHIBITED SEAWATER PRIOR TO RUN THE TIE-BACK
2. THERE IS MUD IN THE HOLE BEFORE SETTING THE DST PACKER
3. DE-RATING FOR TEMPERATURE IS A LINEAR FUNCTION
4. THE LINER IS DESIGNED ONLY FOR WELL TESTING SO NO ALLOWANCE FOR LONG TERM CORROSION IS CONSIDERED
5. THE AXIAL LOAD IN THE LINER IS NEGLIGIBLE SO NO NEED TO CORRECT FOR BIAXIAL STRESSES FOR COLLAPSE CALCULATIONS

b) DEFINE A REALISTIC COLLAPSE SCENARIO FOR THE LINER. DERATE STRENGTH TO 85 % LEVEL BECAUSE OF HIGH TEMPERATURE. DETERMINE THE DESIGN FACTOR

THE MOST REALISTIC SCENARIO FOR LINER COLLAPSE WOULD BE DUE TO PLUGGED PERFORATIONS @ 5000 M

I. PRESSURE OUTSIDE: $P_o = (0.0981)(2.11)(5000) = 1035$ bar * ASSUMING PORE PRESSURE IN THE PERFORATIONS

II. PRESSURE INSIDE: $P_i = (0.0981)(0.547)(5000) = 268$ bar * ASSUMING A COLUMN OF CONDENSATE INSIDE

III. COLLAPSE LOAD: $= P_o - P_i = 1035 - 268 = 767$ bar

IV. DERATED STRENGTH: $P_{collapse} = (959 \text{ bar})(0.85) = 815$ bar * DERATED FOR TEMPERATURE

V. DESIGN FACTOR: $DF = \frac{815 \text{ bar}}{767 \text{ bar}} = 1.06$

c) DEFINE TWO BURST CRITERIA. DETERMINE THE DESIGN FACTOR FOR BURST, AND CORRECT FOR TEMPERATURE

* TUBING LEAKING CRITERIA

I. OUTSIDE PRESSURE
1. AT WELLHEAD $P_o = 0$
2. AT DST PACKER $P_o = (0.0981)(1.03)(4950) = 500$ bar

II. PRESSURE INSIDE
1. PORE PRESSURE $= (0.0981)(2.11)(5000) = 1035$ bar
2. AT WELL HEAD $= 1035 - (0.0981)(0.547)(5000) = 767$ bar
3. AT DST PACKER $= 767 + (0.0981)(2.2)(4950) = 1835$ bar

III. BURST LOAD
1. AT WELL HEAD $= P_i - P_o = 767 - 0 = 767$ bar
2. AT DST PACKER $= P_i - P_o = 1835 \text{ bar} - 500 = 1335$ bar

THE DST CANNOT BE PERFORMED WITH MUD IN THE ANNULUS, SO THE SOLUTION IS TO DISPLACE THE WELL TO 1.10 sg MEG-WATER

IV. NEW INSIDE PRESSURE

1. AT WELLHEAD $P_i = 767$ bar

2. AT DST PACKER $P_i = 767 + (0.0981)(1.10)(4950) = 1301$ bar * ASSUME 1.10sg MEG-WATER.

V. BURST LOAD

1. AT WELLHEAD = 767 bar

2. AT DST PACKER = 1301 − 500 = 801 bar

VI. CORRECTED BURST RESISTANCE $P_{burst} = (0.88)(1005) = 884$ bar * NEGLECTING THE 50m DIFFERENCE FROM THE PERFORATIONS TO THE PACKER.

VII. DESIGN FACTOR $DF = \frac{884 \text{ bar}}{801 \text{ bar}} = 1.10$

* BULLHEADING CRITERIA – PERFORATIONS ARE PLUGGED OFF WHILE BULLHEADING CAUSING PRESSURE BUILD-UP

I. PRESSURE OUTSIDE $P_o = (0.0981)(1.03)(5000) = 505$ bar * ASSUMING WATER BEHIND THE LINER

II. PRESSURE INSIDE ASSUMING A P_{FRAC} GRADIENT GIVEN BY THE MEDIAN LINE PRINCIPLE FOR MW SELECTION

$P_i = (0.0981)(2.29)(5000) = 1123$ bar

III. BURST LOAD $= P_i - P_o = 1123 - 505 = 618$ bar

IV. CORRECTED BURST RESISTANCE $P_{burst} = 884$ bar * SEE PREVIOUS SECTION

V. DESIGN FACTOR $DF = \frac{884 \text{ bar}}{618 \text{ bar}} = 1.43$

d) DEFINE A CRITERION FOR TENSION DESIGN. DETERMINE THE DESIGN FACTOR, INCLUDING THE TEMPERATURE DERATING

NEGLECTING TENSILE EFFECTS ON THE LINER AS THE AXIAL FORCE IS VERY SMALL, THE TENSION DESIGN IS PERFORMED ON THE TIE-BACK STRING

I. WEIGHT ON AIR $W = (625 \text{ N/m})(4650 \text{ m}) = 291 \times 10^3$ daN

II. BUOYED WEIGHT $W_b = \left(1 - \frac{2.20}{7.85}\right)(291 \times 10^3) = 209 \times 10^3$ daN

III. PRESSURE TEST ASSUMING THAT THE PRESSURE TEST WILL BE PERFORMED TO FULL WELLHEAD RATING TO ALLOW FOR ANY POTENTIAL ADDITIONAL OPERATIONS DURING DST

$P_{test} = 15\,000$ psi $= 1034$ bar

TO CALCULATE THE FORCE $A_i = \frac{\pi}{4}(17.15^2) = 231 \text{ cm}^2$ * ASSUMING ID = 6.75 in

HENCE

$F = P \cdot A = (1034 \text{ bar})(231 \text{ cm}^2) = 239 \times 10^3$ daN

IV. TOTAL TENSION NEGLECTING ANY BENDING EFFECTS

$T_{TOTAL} = W_b + F = (209 + 239) \times 10^3 \text{ daN} = 448 \times 10^3$ daN

V. CORRECTED TENSION RESISTANCE ASSUMING THE TEMPERATURE EFFECT IS ON BOTTOM AND A LINEAR FUNCTION TO SURFACE

INTERPOLATING $\frac{Y - Y_a}{Y_b - Y_a} = \frac{X - X_a}{X_b - X_a} \rightarrow \% P = \left(\frac{4650 - 0}{5000 - 0}\right)(0.91 - 1) + 1 = 0.916$

VI. DESIGN FACTOR $DF = \frac{(0.916)(681.6 \times 10^3 \text{ daN})}{448 \times 10^3 \text{ daN}} = 1.39$

4. BELOW IS A WELLBORE STRESS

$$\begin{bmatrix} \sigma_r & 0 & 0 \\ 0 & \sigma_\theta & \tau_{\theta z} \\ 0 & \tau_{\theta z} & \sigma_z \end{bmatrix}$$

a) EXPLAIN THE PHYSICS BEHIND THE ELEMENTS THAT ARE ZERO IN THE MATRIX.

THE ELEMENTS THAT ARE ZERO IN THE MATRIX REPRESENT THE SHEAR STRESSES WHERE THE INNER CONDITION IS P_w, THE PRESSURE EXERTED BY THE MUD COLUMN IN THE WELLBORE, SINCE FLUIDS AT REST CANNOT TRANSMIT SHEAR STRESSES, THESE ELEMENTS ARE CONSIDERED EQUAL TO ZERO.

b) SHOW THE 3 PRINCIPAL STRESSES EQUATIONS

- FOR FRACTURING

$$\sigma_1 = \sigma_r = P_w$$

$$\sigma_2 = \frac{1}{2}(\sigma_\theta + \sigma_z) + \frac{1}{2}\sqrt{(\sigma_\theta - \sigma_z)^2 + 4\tau_{\theta z}^2}$$

$$\sigma_3 = \frac{1}{2}(\sigma_\theta + \sigma_z) - \frac{1}{2}\sqrt{(\sigma_\theta - \sigma_z)^2 + 4\tau_{\theta z}^2}$$

- FOR COLLAPSE

$$\sigma_1 = \frac{1}{2}(\sigma_\theta + \sigma_z) + \frac{1}{2}\sqrt{(\sigma_\theta - \sigma_z)^2 + 4\tau_{\theta z}^2}$$

$$\sigma_2 = \frac{1}{2}(\sigma_\theta + \sigma_z) - \frac{1}{2}\sqrt{(\sigma_\theta - \sigma_z)^2 + 4\tau_{\theta z}^2}$$

$$\sigma_3 = \sigma_r = P_w$$

c) RANK THE PRINCIPAL STRESSES FOR FRACTURING

$$\sigma_1 = \sigma_r > \sigma_2 > \sigma_3$$

d) RANK THE PRINCIPAL STRESSES FOR WELLBORE COLLAPSE

$$\sigma_1 > \sigma_2 > \sigma_3 = P_w$$

5. THE FOLLOWING CASING TYPES EXIST IN STOCK

SIZE (in)	GRADE	WEIGHT	D_o (mm)	D_i (mm)
20	P-110	133	508	475.7
13 3/8	K-55	88.2	346.1	314.3
10 3/4	N-80	60.7	273	245.4
7	L-80	20	177.8	164

a) COMPUTE THE BURST STRENGTH OF EACH CASING. LIST THE CASINGS FROM STRONGEST TO WEAKEST IN BURST

FIRST $P_{burst} = 2 \cdot \sigma_{tensile} \cdot \frac{t}{D_o}$

SO

SIZE (in)	$\sigma_{tensile}$ (psi)	t (mm)	D_o (mm)	P_{burst} (psi)
20	110 000	16.15	508	6994
13 3/8	55 000	15.90	346.1	5053
10 3/4	80 000	13.80	273	8088
7	80 000	6.90	177.8	6209

FROM STRONGEST TO WEAKEST

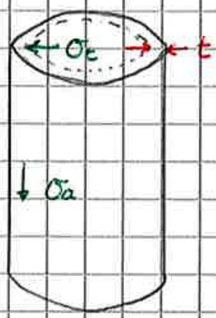
10 3/4"	8088 psi
20"	6994 psi
13 3/8"	5053 psi
7"	6209 psi

b) ARE THESE CASINGS SUITABLE FOR USE IN THE SAME WELL? EXPLAIN WHICH OF THE CASINGS COULD BE REPLACED, AND INDICATE IF IT SHOULD BE STRONGER OR WEAKER.

INTUITIVELY WE WOULD EXPECT TO SEE A BURST RESISTANCE INCREASE AS WELL GOES DEEPER, PARTICULARLY FOR THE INTERMEDIATE CASING 13 3/8" WE ASSUME THAT IS A SHORT SECTION USED TO ISOLATE MAINLY A WEAK ZONE AND HENCE THE DESIGN COULD BE A REDUCED WELL INTEGRITY CASE WHERE THE BURST RESISTANCE IS CONSIDERABLY HIGHER THAN THE FRACTURE PRESSURE AT THE SHOE, SO WE COULD USE IT WITHOUT FURTHER COMPLICATIONS. NOW, CONSIDERING THE WELL DESIGN AS A CASED AND PERF WITH A 7" LINER ACROSS THE RESERVOIR, THEN THE PRODUCTION LINER IS NOT SUITABLE FOR THE APPLICATION AS WE WOULD EXPECT AT LEAST THE SAME RESISTANCE AS THE 10 3/4" PRODUCTION CASING TO BE ABLE TO HANDLE WITH THE GAS-FILLED CASE, PRESSURE TESTING AND OTHER POTENTIAL OPERATIONS DURING WELL COMPLETION.

c) A CLOSED PIPE IS PRESSURIZED FROM THE INSIDE. DEFINE TWO FAILURE MODES, AND SHOW WHICH FAILURE MODE IS DOMINATING.

THERE ARE STRESSES ACTING IN TWO DIRECTIONS: AXIALLY AND TANGENTIALLY



TANGENTIALLY THE FORCE APPLIED ON THE VESSEL ACROSS ITS SURFACE AREA IS GIVEN BY

$$\sigma_t = \frac{1}{2} P_i \left(\frac{D_i}{t}\right)$$

AXIALLY THE FORCE APPLIED IS GIVEN BY

$$\sigma_a = \frac{1}{4} P_i \left(\frac{D_i}{t}\right)$$

HENCE $\sigma_t = 2\sigma_a$ THEREFORE THE FAILURE MECHANISM THAT DOMINATES IS TANGENTIALLY.