PCI 559 MODERN WELL DESIGN - MAY 2015

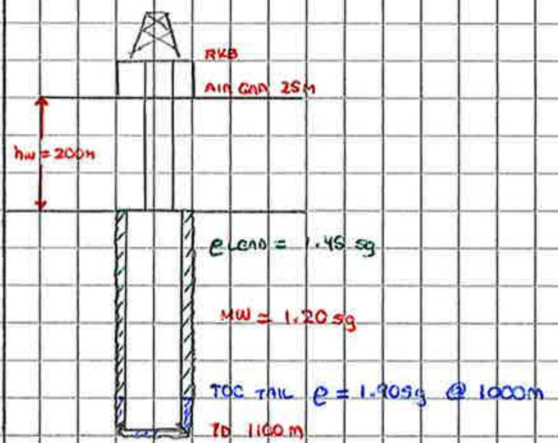
1. YOU ARE ASKED TO DESIGN A SURFACE CASING. THE DESIGN PARAMETERS ARE AS FOLLOWS:

DEPTH OF CASING	1100 m
DEPTH TO SEABED	225 m
DEPTH TO SEA LEVEL	25 m
DEPTH TO TOP OF TAIL CEMENT	1000 m
DEPTH TO TOP OF LEAD CEMENT	225 m
DEPTH NEXT OPEN HOLE	1820 m
P_{FRAC} AT CASING SHOE	1.57 sg
P_0 AT SHOE	1.03 sg
P_0 AT NEXT SECTION	1.40 sg
ρ FORMATION FLUID	0.70 sg
MW	1.20 sg
MW NEXT SECTION	1.50 sg
ρ LEAD CEMENT	1.45 sg
ρ TAIL CEMENT	1.90 sg

CASING DATA 18 5/8" X-70 84.5 #

WEIGHT	126 kg/m
D_i - CROSS SECTIONAL AREA	1527 cm^2
P_{BURST}	197 bar
$P_{COLLAPSE}$	43 bar
PIPE BODY YIELD STRENGTH	600 $\times 10^3$ daN

a) PREPARE A DRAWING OF THE SITUATION: THE CASING DURING INSTALLATION. DEFINE TWO CRITERIA FOR CASING COLLAPSE. COMPUTE THE DESIGN FACTOR FOR THESE SCENARIOS



ASSUMPTIONS:

1. DURING CEMENTING, DISPLACING FLUID IS WBM 1.20 sg USED IN THE SECTION

* COLLAPSE DURING CEMENTATION OF THE SURFACE CASING

- PRESSURE OUTSIDE
  1. AT WELLHEAD $P_o = (0.0981)(200)(1.03) = 20$ bar
  2. AT SHOE $P_o = 20 + (0.0981)(1000-225)(1.45) + (0.0981)(100)(1.90) = 149$ bar
- PRESSURE INSIDE
  1. AT WELLHEAD $P_i = (0.0981)(225)(1.20) = 26$ bar
  2. AT SHOE $P_i = 26 + (0.0981)(1100-225)(1.20) = 117$ bar DISPLACING WITH MUD
- COLLAPSE LOAD
  1. AT WELLHEAD $= P_o - P_i = 20 - 26 = 0$
  2. AT SHOE $= P_o - P_i = 149 - 117 = 32$ bar
- DESIGN FACTOR $DF = \frac{43}{32} = 1.34$

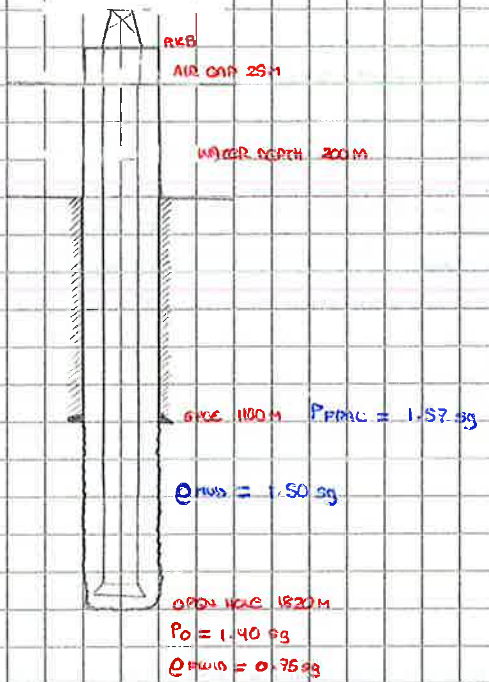
* COLLAPSE DUE TO A THIEF ZONE: THE ASSUMPTION IS THAT IN CASE OF MASSIVE LOSSES, THE LEVEL IN THE STRING WILL DROP UNTIL THE WELL PRESSURE EQUALIZES WITH A NORMAL PRESSURE GRADIENT

- FLUID LEVEL $(0.0981)(1.03)(1100-25) = (0.0981)(1.20)(1100-h)$

$h = 177$ m

THIS LEVEL IS NOT IN THE CASING SO THE CASING LOAD IS ZERO

b) PREPARE A DRAWING OF THIS SITUATION: THE BURST DESIGN. DEFINE A BURST SCENARIO. COMPUTE THE DESIGN FACTOR.



ASSUMPTIONS:

1. THIS IS A POST-INSTALLATION SCENARIO, SO WELL HEAD AND RISER ARE INSTALLED
2. DRILLING WITH $17\frac{1}{2}$ HOLE, $5\frac{1}{2}$" DP
3. WE ASSUME SEAWATER BEHIND THE CASING

* OIL-FILLED CASING SCENARIO

- PRESSURE OUTSIDE
  1. AT WELLHEAD $P_o = (0.0981)(1.03)(225) = 23$ bar
  2. AT SHOE $P_o = (0.0981)(1.03)(1100) = 111$ bar

- PRESSURE INSIDE
  1. PORE PRESSURE $= (0.0981)(1.40)(1820) = 250$ bar
  2. AT WELL HEAD $P_i = 250 - (0.0981)(1820 - 225)(0.750) = 133$ bar
  3. AT SHOE $P_i = 250 - (0.0981)(1820 - 1100)(0.75) = 197$ bar

- BURST LOAD
  1. AT WELLHEAD $P_i - P_o = 133 - 23 = 110$ bar
  2. AT SHOE $P_i - P_o = 197 - 111 = 86$ bar

- DESIGN FACTOR $DF = \frac{197}{110} = 1.79$

  THE CASING RESISTS THE OIL-FILLED CASE, BUT TO ENSURE THAT THE WELL HAS FULL WELL INTEGRITY WE NEED TO INVESTIGATE THE PRESSURES THE SHOE

- ASSUMING THE MAXIMUM PRESSURE EXERTED AT THE CASING SHOE DURING AN OIL-FILLED CASING AND NEGLECTING ANY PRESSURE FROM BEHIND THE CASING

  PRESSURE AT THE SHOE = 197 bar = 1.83 sg

  SO THE SHOE CANNOT HANDLE AN OIL-FILLED CASING HENCE WE NEED TO CALCULATE A KICK MARGIN

- TO FIND THE KICK MARGIN

$$P_{FRACTURE} = P_{PORE} - (0.0981)(1.50)(1820 - 1100 - h) - (0.0981)(0.75)(h)$$
$$(0.0981)(1.57)(1100) = 250 - (0.0981)(1.50)(720 - h) - (0.0981)(0.75)(h)$$
$$169 = 250 - 106 + (0.0981)(1.50)(h) - (0.0981)(0.75)(h)$$
$$25 = (0.0981)\,h\,(1.50 - 0.75)$$
$$h = 340 \text{ m}$$

- CAPACITY $CAP = \frac{\pi}{4}(0.4445^2 - 0.1397^2) = 0.13985 \text{ m}^3/\text{m}$

- KICK MARGIN $V_{KICK} = 47.5 \text{ m}^3$

- TO ENSURE THAT THE WEAK POINT IS AT THE CASING SHOE

ASSUMING THAT THE SAFETY FACTOR IS 15%

$$P_{BURST\,MAX} = \frac{P_{BURST}}{1.15} = \frac{197}{1.15} = 171 \text{ bar}$$

THEN

$$P_{SHOE} = P_{BURST\,MAX} + (0.0981)(0.75)(1100 - 225) = 235 \text{ bar} = 2.18$$

IN THE UNLIKELY SCENARIO THAT THE MAXIMUM BURST PRESSURE IS REACHED IN THE WELLHEAD, THE PRESSURE IN THE CASING SHOE AT THAT POINT WOULD AN EQUIVALENT GRADIENT OF 2.18 sg > PROGNOSED FRACTURE GRADIENT HENCE THE WEAK POINT IS AT THE SHOE.

C) DEFINE TWO SCENARIOS FOR TENSION DESIGN. COMPUTE THE DESIGN FACTORS.

- WEIGHT ON AIR $W = (186 \text{ kg/m})(9.81)(1100 - 225) = 160 \times 10^3 \text{ daN}$

- BUOYED WEIGHT $W_b = \left(1 - \frac{1.20}{7.85}\right)(160 \times 10^3) = 136 \times 10^3 \text{ daN}$

- NEGLECTING BENDING EFFECTS

- TEST PRESSURE THE SAFEST COURSE OF ACTION WOULD BE TO PRESSURE TEST THE CASING TO 85% OF ITS NOMINAL BURST RESISTANCE = 167 bar ONCE THE CEMENT IS SET

- TO CALCULATE THE FORCE $P_t = 167 \text{ bar}$

$$F_t = P_t \cdot A = (167 \text{ bar})(1527 \text{ cm}^2) = 255 \times 10^3 \text{ daN}$$

- TOTAL TENSION $T_{TOTAL} = (136 + 255) = 391 \times 10^3 \text{ daN}$

- DESIGN FACTORS

$$DF = \frac{800 \times 10^3}{391 \times 10^3} = 2.05$$

THIS DESIGN FACTOR ASSUMES THAT BOTH THE FORCE DURING THE PRESSURE TEST AND THE BUOYED WEIGHT ACT ON THE BODY OF THE PIPE SIMULTANEOUSLY, NAMELY THAT THE MECHANICAL AID OF THE CEMENT IS NEGLECTED

$$DF = \frac{800 \times 10^3}{136 \times 10^3} = 5.88$$

THIS DESIGN FACTOR ONLY ASSUMES THE BUOYED WEIGHT OF THE PIPE AND SHOULD BE USED FOR BIAXIAL CORRECTIONS IF REQUIRED

2. GEOMECHANICS

a) SHOW AN EXPRESSION FOR THE HORIZONTAL IN-SITU STRESS. HOW WOULD YOU SELECT THE MW RELATIVE TO THIS? WHAT DO WE CALL THIS CONCEPT?

$$\sigma_a = \frac{1}{2}(P_{wf} + P_o)$$

THE MW SELECTION SHOULD BE AS CLOSE AS POSSIBLE TO THIS VALUE SINCE IT WILL GIVE THE CLOSEST STATE TO THE IDEAL IN-SITU STRESSES. WE CALL THIS CONCEPT MEDIAN LINE PRINCIPLE

b) THREE LOT DATA SETS ARE GIVEN IN A WELL AS FOLLOWS

DEPTH (M)	LOT (sg)	PORE (sg)	OVERBURDEN (sg)	INCLINATION (°)
890	1.51	1.03	1.62	0
1124	1.36	1.21	1.76	30
1540	1.27	1.30	1.80	39

ESTIMATE THE LOT VALUES FOR VERTICAL HOLE SECTIONS

$$P_{wf}(0) = \frac{P_{wf}(\gamma) + \left(\sigma_o - \frac{1}{2}P_o\right)\sin^2\gamma}{1 + \frac{1}{2}\sin^2\gamma}$$

DEPTH (M)	P_{wf} (0°) sg
890	1.51
1124	1.46
1540	1.44

c) COMPARE THE HORIZONTAL STRESS LEVELS FROM THE ABOVE DATA (STATE ALL ASSUMPTIONS)

ASSUMING NO CHANGES IN THE PORE PRESSURE AND A RELAXED BASIN, WE WILL CALCULATE THE HORIZONTAL STRESSES (ASSUMING $\sigma_H = \sigma_h$) TAKING AS REFERENCE THE TRANSFORMATION DONE FOR VERTICAL WELLS.

DEPTH (M)	P_{wf} (0°) sg	PORE (sg)	σ_a (sg)
890	1.51	1.03	1.27
1124	1.46	1.21	1.34
1540	1.44	1.30	1.37

3. FUNDAMENTALS

a) WHICH EQUILIBRIUM CONDITION DOMINATES GEOMECHANICS NEWTONS 2nd LAW

b) WHICH STATEMENT IS CORRECT? THE DLS IS A 3 DIMENSIONAL PARAMETER

c) STRESSES TRANSFORM IN SPACE ACCORDING TO: SQUARED TRIGONOMETRIC LAW

d) REPLACING THE MUD IN THE DRILL STRING WITH SEAWATER LEADS TO: INCREASE IN SURFACE PIPE TENSION

e) SURFACE CASING IS INSTALLED: BEFORE RISER IS INSTALLED

f) ON JACK-UP RIGS: HANG THE WEIGHT OF THE WELL ON MUD LINE SUSPENSION SYSTEM

g) WELLHEAD SYSTEMS: HORIZONTAL X-MAS TREES ARE MOSTLY USED SUBSEA

4. CASING DEPTH AND MUD WEIGHT SELECTION

a) USING THE GRADIENT CURVE BELOW PROPOSE THE DEPTH OF THE FOLLOWING CASINGS

CASING (in)	SETTING DEPTH (m)
30	300
20	650
13 3/8	1300
9 5/8	2100
7	2250

b) PROPOSE A MUD WEIGHT PROGRAM FOR THE WELL. DEFINE ASSUMPTIONS

CASING (in)	MUD WEIGHT (sg)
30	SW
20	1.10
13 3/8	1.18 - 1.30
9 5/8	1.32 - 1.50
7	1.40

THE MUD WEIGHT SELECTION IS BASED ON THE MID LINE PRINCIPLE

c) CONSIDER IMPLEMENTING A RISER MARGIN. IS THIS POSSIBLE? EXPLAIN

CASING (in)	Δ MUD WEIGHT (sg)
30	N/A
20	N/A
13 3/8	
9 5/8	✓
7"	✓

* ASSUMING 175 M WATER DEPTH + 25 M AIR GAP
THE 13 3/8 MIGHT BE A BIT PROBLEMATIC TO IMPLEMENT A RISER MARGIN BECAUSE THE WINDOW IS NARROWER HERE PLUS IT IS THE SHALLOWER SECTION; WE WOULD HAVE TO BE SLIGHTLY OVER THE DESIRED MID-LINE POINT.

5. YOU ARE PLANNING A SUBSEA INFILL WELL IN A PRODUCTION FIELD. YOUR DESIGN IS BASED ON DATA FROM THE PRODUCTION PLATFORM WHICH HAS A WELLHEAD ELEVATION OF 120M. YOU ARE GOING TO USE A JACK UP DRILLING RIG WITH AN AIR GAP OF 40M. THE WATER DEPTH IS 300M. THE DATA FROM THE PRODUCTION PLATFORM IS:

PORE PRESSURE GRAD (sg)	0.82	0.90	0.95	1.10	1.15	1.20
DEPTH (m)	500	700	900	1100	1300	1500

a) DEFINE THE NORMALIZATION EQUATIONS.

THE CONCEPT OF DATA NORMALIZATION IMPLIES THAT THE BHP IS THE SAME REGARDLESS OF THE REFERENCE POINT

$$BHP = (0.0981)(P_{o\ JACK\text{-}UP})(TD - 80) \rightarrow P_{o\ JACK\text{-}UP} = \frac{(P_{o\ PROD})(TD)}{(TD - \Delta AIRGAP)}$$

$$P_{o\ SEA\ LEVEL} = \frac{(P_{o\ PROD})(TD)}{(TD - AIR\ GAP\ PROD)}$$

b) NORMALIZE THE PORE PRESSURE GRADIENTS TO DRILL FLOOR AND SEA LEVEL. SHOW ALL THREE CURVES IN A PLOT

PORE PRESSURE GRAD (sg)	0.82	0.90	0.95	1.10	1.15	1.20	PRODUCTION PLAT.
DEPTH (m)	500	700	900	1100	1300	1500	
PORE PRESSURE (sg)	0.98	1.02	1.04	1.19	1.23	1.27	JACKUP
DEPTH (m)	420	620	820	1020	1220	1420	
PORE PRESSURE (sg)	1.08	1.09	1.10	1.23	1.27	1.30	SEA LEVEL
DEPTH (m)	380	580	780	980	1180	1380	