Exam 2020 spring

Problem 1, Design of Production casing

Data

9 5/8 in 53,5 lbs/ft P110

weight: 78,72 kg/m, Pburst: 752 bar Pcollapse: 547b

Ftension: 7590 kN, Mud weight: 1,60 sg

Inner diam: 216,8 mm

Setting depth: 2909 mMD, 2350 TVD

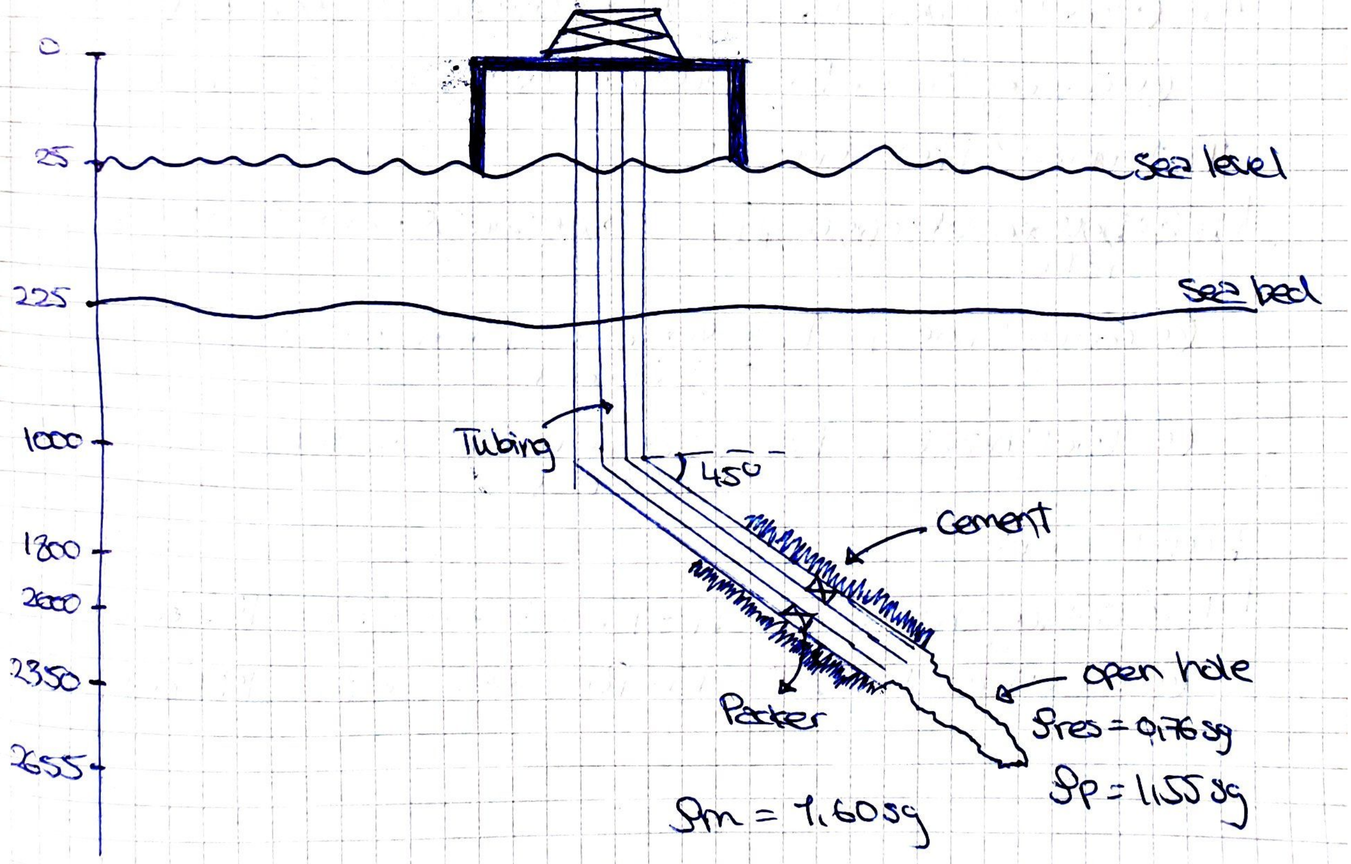
Depth next hole: 3341 mMD, 2655 TVD

cemented interval: 2131-2909 mMD, 1800-2350 TVD

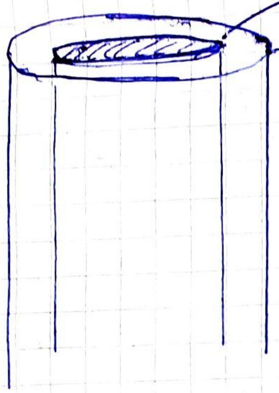
Production Packer: 2414 mMD, 2000 TVD

Pore Pressure grad: 1,55sg Pore fluid density: 0,76sg

a) Prepare a figure of the well and define two criteria for burst of the production casing, and determine the safety factor.



a)



Di = 216,8mm

Do = 244,5mm

Pburst = 752bar

Pcollapse = 547 bar

Ftension = 7590kN

$Do = 9,625'' \cdot 0,0254 \cdot 1000$

$= 244,475mm$

$\simeq \underline{244,5mm}$

① Oil filled casing scenario

- Assumptions
  - ↳ Sea bed at 225m depth
  - Riser air gap 25m
  - Sea water behind casing, ρw = 1,03sg
  - Riser and BOP installed
  - mud inside of casing

External Pressures

↳ @wellhead, $P_o = 0,098 \cdot 1,03 \cdot 225 = \underline{23\ bar}$

@casing shoe, $P_o = 0,098 \cdot 1,03 \cdot 2350 = \underline{237\ bar}$

Internal Pressures

↳ @Bottom of open-hole, $P_i = 0,098 \cdot 1,55 \cdot 2655 = \underline{403 bar}$

@casing shoe, $P_i = 403bar - (0,098 \cdot 0,76(2655-2350)$
$= \underline{380bar}$

@ wellhead, $P_i = 380bar - (0,098 \cdot 0,76(2350-225))$
$= \underline{222bar}$

Burst load

↳ @casing shoe: $\Delta P = P_i - P_o = 380 - 237 = \underline{143\ bar}$

@wellhead: $\Delta P = P_i - P_o = 222 - 23 = \underline{199\ bar}$

a) Design factor

↳ $$DF = \frac{P_{burst}}{\Delta P@wellhead} = \frac{752\,bar}{199\,bar} = \underline{\underline{3,78}}$$

DF > Norsok requirement for burst, ok!

② Tubing leak

Assumptions

↳
- Production tubing is filled with formation oil and shut in
- Leak occurs in production tubing below wellhead
- Annulus is filled with completion fluid
  ↳ $\rho_{cf} = 1,1\,sg$
- Seawater outside
- TVD for Pressure calculations.

Internal Pressures

↳ @Bottom of open-hole, $P_i = 0{,}098 \cdot 1{,}55 \cdot 2655 = \underline{403\,bar}$

@ Below wellhead in casing annulus, $P_i = 403\,bar - (0{,}098 \cdot 0{,}76(2655-225)) = \underline{222\,bar}$

@ Packer, $P_i = 222 + (0{,}098 \cdot 1{,}1 \cdot (2000-225)) = \underline{413\,bar}$

External Pressure

↳ @wellhead, $P_o = 1{,}03 \cdot 0{,}098 \cdot 225 = \underline{23\,bar}$

@Packer, $P_o = 1{,}03 \cdot 0{,}098 \cdot 2000 = \underline{202\,bar}$

Burst Load

↳ @ Packer, $\Delta P = P_i - P_o = 413 - 202 = \underline{211\,bar}$

@wellhead, $\Delta P = P_i - P_o = 222 - 23 = \underline{199\,bar}$

a) Design factor

↳ $DF = \frac{P_{burst}}{\Delta P@packer} = \frac{752 bar}{211 bar} = \underline{\underline{3,56}}$

DF > Norsok requirement of 1,1 for burst, ok!

b) Design a criterion for collapse and calculate the factor of safety.

① Thief zone

Assumptions

↳ • Losses that occur due to the thief zone may stabilize at a depth equal to the hydrostatic sea water pressure.

- Mud on the outside
- Using TVD for pressure calculations.

Mud loss level

↳ $\rho_m g h_m = \rho_w g h_w$

$\gamma_m h_m = \rho_w h_w$

$1,60(2350-h) = 1,03(2350-25)$

$3760 - 1,6h = 2394,75$

$\Rightarrow h = \frac{3760 - 2394,75}{1,6}$

$h = 853,28 m \simeq \underline{853 m}$

External Pressure

↳ @wellhead, $P_o = 1,60 \cdot 0,098 \cdot 225 = \underline{35 bar}$

@h, $P_o = 1,60 \cdot 0,098 \cdot 853 = \underline{134 bar}$

@casing shoe, $P_o = 1,60 \cdot 0,098 \cdot 2350 = \underline{368 bar}$

b) Internal Pressure

↳ @wellhead, $P_i = 0$ } Because we have air inside.

@h, $P_i = 0$

@casing shoe, $P_i = 1{,}6 \cdot 0{,}098(2350-853) = \underline{235\,bar}$

~~Design factor~~

↳ ~~$Df = \frac{P_{collapse}}{\Delta P}$~~

Collapse Load

↳ @wellhead, $\Delta P = P_o - P_i = 35 - 0 = \underline{35\,bar}$

@h, $\Delta P = P_o - P_i = 134 - 0 = \underline{134\,bar}$

@casing shoe, $\Delta P = P_o - P_i = 368 - 235 = \underline{133\,bar}$

Design factor

↳ $Df = \frac{P_{collapse}}{\Delta P@h} = \frac{547\,bar}{134\,bar} = \underline{\underline{4{,}08}}$

Pcollapse will be derated due to biaxial forces, So a correction has to be made later. As of now Df > 1,1 Norsok requirement for collapse, Df is OK.

c) Determine the total weight in air of the casing string, and the buoyed weight in the well. Determine the factor of safety, bending may be neglected.

① Weight in air:

↳ $W_c = \text{Weight} \cdot g \cdot \text{Length (MMD)}$

$= 78{,}72\,kg/m \cdot 9{,}81\,m/s^2 \cdot 2909\,m$

$= 2246455{,}47\,N$

$= \underline{2246{,}45\,kN}$

c) ② Buoyed weight

$$W_B = W_C\left(1 - \frac{\rho_m}{\rho_s}\right)$$

Assuming $\rho_s = 7{,}85$ sg,
$\rho_m = 1{,}60$ sg and W_C from ①

$$W_B = 2246{,}45\,\text{kN}\left(1 - \frac{1{,}60}{7{,}85}\right)$$
$$= \underline{\underline{1788{,}6\,\text{kN}}}$$

③ Pressure test

P110 casing ⇒ Assuming that the casing can handle strength of ~~1~~10 000 psi or:

$$\frac{10\,000\,\text{psi}}{14{,}5} = \underline{690\,\text{bar} = P_{test}}$$

$$P = F/A \Rightarrow F_{test} = P_{test} \cdot A$$
$$= P_{test} \cdot \pi \cdot \left(\frac{D_i}{2}\right)^2$$
$$= 690 \cdot 10^5\,\text{bar} \cdot \pi \cdot \left(\frac{216{,}8 \cdot 10^{-3}}{2}\right)^2 \text{m}$$
$$= 2547167{,}635\,\text{N}$$
$$= \underline{\underline{2547{,}2\,\text{kN}}}$$

Total Tension:

$$\hookrightarrow T_{tot} = W_B + F_{test} + \text{Bending} \leftarrow 0$$
$$= 1788{,}6\,\text{kN} + 2547{,}2\,\text{kN}$$
$$= 4335{,}76 \simeq \underline{4335{,}8\,\text{kN}}$$

c) Design factor

$$\hookrightarrow DF = \frac{F_{tension}}{T_{TOT}} = \frac{7590\,kN}{4335{,}8\,kN} = \underline{\underline{1{,}75}}$$

DF > Norsok requirement of 1,25 for tension

ok!

- Since WB is calculated in c) we can ~~f~~ now do the biaxial correction for assignment b).

Biaxial correction

$$\hookrightarrow \%T = \frac{W_B}{F_{tension}} = \frac{1788{,}6\,kN}{7590\,kN} = 0{,}2356$$

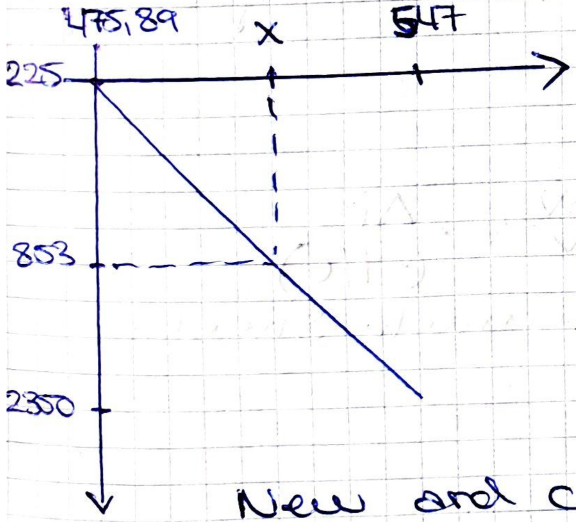
$$\simeq \underline{23{,}6\,\%}$$

%C is found in the formula sheet given in the exam by using %T.

$\%C \approx \underline{-87\%}$

$P_{collapse\ new} = 0{,}87 \cdot 547 = \underline{475{,}89\ \text{bar @ top}}$

Interpolating to find collapse strength at h = 853m.



$$\left(\frac{547-475{,}89}{2350-225}\right) = \frac{(x-475{,}89)}{\left(\cancel{853-2350}\ 853-225\right)}$$

$$\Rightarrow x = \left(\frac{547-475{,}89}{2350-225}\right)\left(853-\cancel{2350}\ 225\right)$$

$$+ 475{,}89$$

$$x = \underline{496{,}90}$$

New and corrected design factor is now:

$$DF = \frac{496{,}90\,bar}{134\,bar} = \underline{\underline{3{,}70}}$$

d) Where is the weak point in the well if any?

↳ Placing maximum allowable burst strength at the wellhead and calc pressure at the casing shoe.

Assuming fracture gradient @shoe = 1,78sg.

$P_{shoe} = 752 bar + (0{,}176 \cdot 0{,}098 \cdot 2350) = \underline{927 bar}$

Gradient at casing shoe:

↳ $\frac{927}{0{,}098 \cdot 2350} = \underline{4{,}025}$

$4{,}025 > 1{,}70$

⇒ <u>weak point is the casing shoe</u>

<u>Problem 2, Temperature induced pressures.</u>

a) Show the relationship between pressure increase and temperature increase. Explain the conditions for the equation

① $\frac{\Delta V}{V} = \frac{1}{2}\alpha \Delta T$

② $\Delta P = \left(\frac{-1}{c}\right) \cdot \frac{\Delta V}{V} \Rightarrow \frac{\Delta V}{V} = \frac{\Delta P}{(-1/c)}$

eq ① and ② found in formula sheet.
set ① = ②:

$$\frac{\Delta P}{(-1/c)} = \frac{1}{2}\alpha \Delta T$$

$$\Delta P = \frac{1}{2}\alpha \Delta T \cdot \left(\frac{-1}{c}\right)$$

$$\underline{\underline{\Delta P = -\frac{\alpha}{2c} \cdot \Delta T}}$$

a) Conditions for the equation

↳ Annulus is considered closed

Compressibilities of casing and rock is neglected.

Fluid mass remains constant.

b) Assume that

$\alpha = 3 \cdot 10^{-4} \left[\frac{1}{C°}\right]$

$C = -3 \cdot 10^{-5}$ [1/bar]

Compute the pressure increase if bottom-hole temp remains constant but surface temp has increased to 150°C.

$$\Delta P = -\frac{\alpha}{2C}\Delta T$$

$$\Delta P = -\frac{(3 \cdot 10^{-4})\left[\frac{1}{°C}\right]}{2 \cdot (-3 \cdot 10^{-5})\left[\frac{1}{bar}\right]} \cdot 150°C$$

$$\Delta P = \underline{\underline{750 \text{ bar}}}$$

F

C = compressibility factor

α = Thermal expansion coefficient

ΔT = Change in Temperature

ΔP = Change in Pressure

Problem 3, Casing strength

a) Compute the burst strength of each casing. List the casings from strongest to weakest.

$$P_{burst} = 2\sigma_{tensile}\left(\frac{Thickness}{D_o}\right) \quad , \quad \frac{Psi}{145} = bar$$

$$Thickness = \frac{D_o - D_i}{2}$$

$\sigma_{tensile}$ = casing yield strength.

By inserting our given data into the equations above we will get the following numbers:

Size	Grade, weight	Do	Di	$\sigma_{tensile}$ [Psi]	$\sigma_{tensile}$ [bar]	Thickness	P_{burst} [bar]
20"	P110, 133	508	457.7	110 000	7586,2	16.15	482,3
13 3/8"	K55, 88.2	346.1	314.3	55 000	3793,1	15.9	348,5
10 3/4"	N80, 60.7	273	245.4	80 000	5517,2	13.8	557,78
7"	L80, 20	177.8	164	80 000	5517,2	6.9	428,2

So, the strongest to weakest casings would be

① 10 3/4" - N80 casing
② 20" - P110 casing
③ 7" - L80 casing
④ 13 3/8" - K55 casing

b) Are these casings suitable for use in the same well? Which could be replaced, indicate if they should be stronger or weaker.

↳ One would expect to see an ~~burst~~ increase in burst resistance as we went deeper into the well. This is particulary important for the intermediate casings, as they ~~should~~ need to be capable of withstanding the formation pressure in the next hole section. From the data we can see that the 13 3/8" < 10 3/4" -casing, so I would suggest to increase the 13 3/8" casing strength by replacing it.

If we now consider the well cased and perforeted, then the production liner should also be able to withstand at least the same amount of resistance as the 10 3/4" casing. This is because it should be able to handle pressure test, a gas filled case etc. Since this is not the case here, I would recommend a stronger replacement for the 7" liner.

c) A closed pipe is pressurized from the inside. Define two failure modes, and show which failure mode is dominating

The two failure modes are axial and tangential failure modes.

- Tangentially the force applied onto the object across its surface area is given by

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

- And the axial force applied onto the object is given by

② $$\sigma_a = \frac{1}{4} P_i \left(\frac{D_i}{t}\right)$$

D_i = Inner diameter
t = Pipe Thickness
P_i = Internal Pressure

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

$$② \quad 4\sigma_a = P_i\left(\frac{D_i}{t}\right)$$

c) From looking at ① and ② its clear that $\sigma_t = 2\sigma_a$. Therefore, we can conclude that the most dominating failure mode is the tangential one.

Problem 4 Hydraulics

Please define the most correct answer:

① Reynolds number defines : Inertial / Viscous forces

② Bernoullis equation is a conservation of : Energy.

③ Pipe friction factor applies for : Turbulent flow

④ Viscous effects apply for : Laminar flow

⑤ Drillstring hydraulis is mostly : Turbulent

⑥ Flow through bit nozzle is : Turbulent

⑦ Flow through marine riser is : Laminar

⑧ Increased flow rate gives : More nozzle pressure.