1. Calculate the minimum required wall thickness of a watertube boiler tube 75 mm O.D. that is strength welded in place in a boiler drum. The tube will be in the furnace area of the boiler and have an average wall temperature of 350°C. The maximum allowable working pressure is 3500 kPa. The tube material is SA-192.

Use equation 1.1 (See Section I, paragraph 27.2.1.)

\[ t = \frac{PD}{2Sw + P} + 0.005D + e \]

where:

- \( P = 3.5 \text{ MPa} \)
- \( S = 87.8 \text{ MPa} \)
- \( D = 75 \text{ mm} \)
- \( e = 0 \)
- \( w = 1.0 \), since the operating temperature is below 427°C and carbon steel tubes are exempt from the requirements of (see Note 3, Table PG-26)

\[ t = \frac{PD}{2Sw + P} + 0.005D + e \]
\[ = \frac{3.5 \text{ MPa} \times 75 \text{ mm}}{2 \left( 87.8 \text{ Mpa} \times 1.0 \right) + 3.5 \text{ MPa}} + (0.005 \times 75 \text{ mm}) + 0 \]
\[ = \frac{262.5}{179.1} + 0.375 \]
\[ = 1.84 \text{ mm} \quad \text{(Ans.)} \]
2. Calculate the required shell thickness for a hydraulic cylinder with a design pressure of 62 000 kPa. The cylinder has an internal diameter of 36 cm, $S = 142$ MPa, and $E = 1.0$. Assume no corrosion allowance for this cylinder.

Since the cylinder is not a boiler, use Section VIII-I, UG-27 and Mandatory Appendix I, paragraph I-2:

a) Circumferential stress:

Since $P = 62$ MPa is > 0.385$SE$ (= 54.7MPa), use Equation 1 (Appendix 1):

Where:

$P = 62$ MPa  
$S = 142$ MPa  
$R = 180$ mm  
$E = 1.0$

\[
t = R \left( \frac{P}{S_{\text{SE}}} - 1 \right)
\]

\[
= 180 \text{mm} \left( e^{ \frac{62 \text{MPa}}{142 \text{MPa} \times 1} } - 1 \right)
\]

\[
= 180 \text{mm}(e^{0.43662} - 1)
\]

\[
= 180 \text{mm}(1.54747 - 1)
\]

\[
= 98.54 \text{mm}
\]

b) Longitudinal stress:

Since $P = 62$ MPa which is less than 1.25$SE = 177.5$ MPa, use UG-27 Equation 2:

\[
t = \frac{PR}{2SE + 0.4P}
\]

\[
= \frac{62 \text{MPa} \times 180 \text{mm}}{(2 \times 142 \text{MPa} \times 1.0) + (0.4 \times 62 \text{MPa})}
\]

\[
= \frac{11160 \text{mm}}{(284 + 24.8)}
\]

\[
= 36.13 \text{mm}
\]

Use the thickness specified by the larger, circumferential stress = 98.54mm (Ans.)
3. Calculate the thickness of a boiler steam header designed with a seamless, unstayed, full hemispherical head, with pressure on the concave side. The inside radius of the header and the radius to which the head is dished is 304 mm, MAWP is 6205 kPa, and the header and head material is SA-204-A. The average temperature of the header is 400°C. The header has a flanged-in inspection opening 100 mm diameter.

Use equation 2.3 to determine the thickness of the header. (See Section I, PG-27.2.2)

\[ t = \frac{PR}{SE - (1 - y)P} + C \]

Where
\[ P = 6.205 \text{ MPa} \]
\[ S = 128 \text{ MPa} \]
\[ L = 304 \text{ mm} \]
\[ y = 0.4 \text{ (see note 6)} \]
\[ E = 1 \]
\[ C = 0 \]

\[ t = \frac{6.205 \times 304}{128 - (1 - 0.4)6.205} + 0 \]
\[ = \frac{1886.32}{128 - 3.723} \]
\[ = \frac{1886.32}{124.277} \]
\[ = 15.18 \text{ mm} \quad \text{(Ans.)} \]

Use equation 3.2 to determine the thickness of the head.
(See Section I, paragraph PG-29-11.)

\[ t = \frac{PL}{2Sw - 0.2P} \]

Where
\[ P = 6.205 \text{ MPa} \]
\[ S = 128 \text{ MPa} \]
\[ L = 304 \text{ mm} \]
\[ w = 1.0 \text{ since the temperature is below } 427^\circ C \text{ minimum in Table PG-26} \]

But
In PG-44, access openings are listed as elliptical and circular manholes, handholes, inspection openings and washout openings. Manholes and handholes are specifically defined by dimensions, while “inspection openings” are not. The inspection opening in this question is 100 mm diameter, which is less than the 150 mm specified in PG-29.3 and, since it is not a manhole, the equation in PG-29.11 applies. (Note: If it were a “manhole”, then PG-29.12 would apply).

Also, PG-29.4 does not apply, since the opening is less than 150 mm in any dimension. Nor does PG-29.5 apply, since it not a flanged-in manhole.

Therefore:

\[ t = \frac{PL}{2Sw - 0.2P} + \text{additional thickness} \]

\[ = \frac{6.205 \text{ MPa} \times 304 \text{ mm}}{(2 \times 128 \text{ MPa} \times 1.0) - 0.2 (6.205 \text{ MPa})} + 0 \text{ mm} \]

\[ = \frac{1886.32 \text{ mm}}{254.76} \]

\[ = 7.4 \text{ mm} \quad \text{(Ans)} \]

4. An air receiver pressure vessel is constructed from SA-204-A with an inside diameter of 1830 mm. The design pressure is 1034 kPa at 200°C. The corrosion allowance is 4 mm, and the joint efficiency is 0.85. What is the required thickness of the hemispherical heads?

(See section VIII-1, paragraph UG-32 (f).)

The quantity \(0.665SE = 72.35 \text{ MPa}\); since this is greater than the design pressure of 1.034 MPa, use equation 3.4.

\[ t = \frac{PL}{2SE - 0.2P} + \text{corrosion allowance} \]
Where
\[ P = 1.034 \text{ MPa} \]
\[ S = 128 \text{ MPa} \]
\[ L = \frac{1830}{2} + 4 = 919 \text{ mm (fully corroded)} \]
\[ E = 0.85 \]

\[ t = \frac{1.034 \times 919}{2(128 \times 0.85) - 0.2(1.034)} + 4 \]
\[ = \frac{950.246}{217.394} + 4 \]
\[ = 4.37 + 4 \]
\[ = 8.37 \text{ mm (Ans.)} \]

5. Using the rules in Section VIII-1, determine the minimum required thickness of the flat end plate of a rectangular box header 200 mm by 400 mm with an internal pressure of 2500 kPa. The material used has a stress value of 103 MPa. The plate is integrally welded into place as per Fig UG-34(h). There is no corrosion allowance and no butt-welded joints in the plate.

Section VIII-1, UG-34 (a) applies to both circular and non-circular heads. Section VIII-1, Fig. UG-34 (h) has a value of \( C = 0.33 \). As there are no butt-welded joints in the plate, the value of \( E = 1 \). Section VIII-1, UG-34 (c)(3) provides the formula for square and oblong heads.

\[ t = d \sqrt{\frac{ZCP}{SE}} \text{ where } Z = 3.4 - \frac{2.4d}{D} \]

Therefore
\[ Z = 3.4 - \frac{2.4d}{D} \]
\[ = 3.4 - \frac{2.4 \times 200}{400} \]
\[ = 3.4 - 1.2 \]
\[ = 2.2 \]

\[ t = 200 \sqrt{\frac{2.2 \times 0.33 \times 2.5}{103 \times 1}} \]
\[ = 200 \sqrt{0.01762} \]
\[ = 200 \times 0.1327 \]
\[ = 26.55 \text{ mm (Ans.)} \]
6. Using the rules in Section I, calculate the reinforcement requirements for a 100 mm O.D. nozzle located in a cylindrical boiler drum. The nozzle abuts the vessel wall and is attached by a full-penetration weld. The I.D. of the drum is 780 mm. The thickness of the drum is 28.575 mm. The nozzle, made of tubing, has a wall thickness of 3.5 mm. The drum material is SA-516-55, and the nozzle material is SA-209-T1. The maximum allowable working pressure is 6000 kPa, and the design temperature is 250°C. All joint efficiencies \( E = 1 \). The reinforcement plate material (if required) is of SA-516-55 and 10 mm thick. Consider all outward welds to be 15 mm.

(See Section I PG-33.3.)

The allowable stress for both SA-516-55 and SA-209-T1 is 108 MPa at 250°C.

Solution

Therefore

\[
f_{rt} = \frac{S_n}{S_v} = \frac{108 \text{ MPa}}{108 \text{ MPa}} = 1
\]

Use equation 2.3 to find the minimum required thickness \( t_r \) of the drum (See PG-27.2.2.)

\[
t_r = \frac{PR}{SE - (1 - y)P} + C
\]
Where

\[ \begin{align*}
P &= 6.0 \text{ MPa} \\
R &= 780\text{ mm} / 2 = 390 \text{ mm} \\
E &= 1.0 \\
Y &= 0.4 \text{ (see PG-27.4 Note 6)} \\
S &= 108 \text{ MPa} \\
t &= 28.575 \text{ mm} \\
\end{align*} \]

\[ 
tr = \frac{6.0 \text{ MPa} \times 390 \text{ mm}}{(108 \text{ MPa} \times 1.0) - (1 - 0.4)6.0 \text{ MPa}} + 0 \\
= \frac{2340 \text{ mm}}{104.4} \\
= 22.41 \text{ mm} \\
\]

**Note:** PG-32.1.2 states that no calculation for compensation for a single opening is required when the diameter (d) of the finished opening does not exceed the larger of either:

(a) One fourth the inside diameter of the shell or head or (60 mm) or
(b) The value of \( d_{\text{max}} \) calculated in PG-32.1.2 for single openings not addressed in (a) above

Since the finished opening with the nozzle in place is 100 - (2 x 3.5) = 93 mm, it does not exceed 0.25 x 780 = 195 mm, as specified in (a) but it does exceed 60 mm.

Similarly, calculating \( d_{\text{max}} \) (using the formula, where \( D = \text{OD} \), in PG-32-1.2 (2009b):

\[ d_{\text{max}} = 8.08[D t (1 - K)]^{1/3} \]

However, we need to find \( K \) from PG-32.1.1:

\[ K = \frac{PD}{1.82 St} \]

Where \( D = \text{OD of the shell} \)

\[ = 780 + (2 \times 28.575)\text{mm} \]

\[ = 837.15 \text{ mm} \]

\[ = \frac{6.0\text{MPa} \times 837.15 \text{ mm}}{1.82(108 \text{ MPa} \times 28.575 \text{ mm})} \]

\[ = \frac{5022.9}{5616.7} \]

\[ = 0.8942 \text{ (which does not exceed 0.99 as specified in PG-32.1.1)} \]
\[ d_{\text{max}} = 8.08 \left[ D t (1-K) \right]^{1/3} \]
\[ = 8.08 \times \left[ (780 + 57.15\,\text{mm}) \times 28.575\,\text{mm} \times (1 - 0.8942) \right]^{1/3} \]
\[ = 8.08 \times (837.15\,\text{mm} \times 28.575\,\text{mm} \times 0.1058)^{1/3} \]
\[ = 8.08 \times (2530.90)^{1/3}\,\text{mm} \]
\[ = 8.08 \times 13.628\,\text{mm} \]
\[ = 110.11\,\text{mm} \]

Since \( d_{\text{max}} \) is greater than 93 mm, case (b) is satisfied; however, the finished opening is greater than 60 mm, so further calculation for compensation is required.

Calculate compensation required by using PG-33.1 formulas.
Use equation 1.1 to find the minimum required thickness of the nozzle if the nozzle is tubing < 125 mm OD. (See PG-27.2.1)

\[ t_n = \frac{PD}{2S + P} + 0.005D + e \]

Where:
D = 100 mm OD
\( e = \) thickness factor for expanded tube ends. (Not used here) \( e = 0 \)
\[ t = \frac{6.0 \, \text{MPa} \times 100\,\text{mm}}{2(108 \, \text{MPa}) + 6.0 \, \text{MPa}} + 0.005(100\,\text{mm}) + 0 \]
\[ = \frac{600}{222} + 0.50\,\text{mm} \]
\[ = 3.202\,\text{mm} \]

Therefore,
\( t_{n} = 3.202\,\text{mm} \) and \( t_n = 3.5\,\text{mm} \)

To calculate whether reinforcement is required using Fig. PG-33.1:
Use larger of \( d \) or \( (R_n + t_n + t) \):
\[ d = 100 - (2 \times 3.5) = 93\,\text{mm} \]
\( (R_n + t_n + t) = (46.5 + 3.5 + 28.575) = 78.58\,\text{mm} \)
Use 93 mm

Use the smaller of 2.5t or \((2.5t_n + t_e)\) Note: \( t_e = 10\,\text{mm} \)
\[ 2.5t = 2.5 \times 28.575 = 71.438\,\text{mm} \]
\[ 2.5t_n + t_e = (2.5 \times 3.5) + 10 = 18.75\,\text{mm} \]
Use 18.75 mm

Reinforcement area required:
\[ A = dt_F \times F = 1.0 \, (\text{PG-33.3}) \]
\[ = 93 \times 22.41 \times 1.0 \]
\[ = 2084\,\text{mm}^2 \]
Reinforcement area available in drum shell:

\[ A = \text{larger of } d(t - F_t) \text{ or } 2(t + t_n)(t - F_t) \]

\[ = 93(28.575 - (1.0 \times 22.41)) \text{ or } 2(28.575 + 3.5)(28.575 - 1.0 \times 22.41) \]

\[ = 573 \text{ or } 395 \quad \text{ Use } 573 \text{ mm}^2 \]

Reinforcement available in nozzle wall:

\[ A_2 = 2(t_n - t_m)(2.5t f_{r3}) \quad (\text{since } 2.5t \text{ is the smaller value}) \]

\[ = 2(3.5 - 3.202)(18.75 \times 1.0) \]

\[ = 11.2 \text{ mm}^2 \]

For nozzles abutting the vessel wall, \( A_3 = 0 \) and \( A_{43} = 0 \)

Reinforcement available in outward weld:

\[ A_4 = (WL_f)^2 f_{r3} \text{ where } f_{r3} = 1.0 \]

\[ = (15)^2 \times 1.0 \]

\[ = 225 \text{ mm}^2 \]

Without reinforcing element added,

\[ A_1 + A_2 + A_3 + A_{41} + A_{43} \text{ must be } > A \]

\[ (573 + 11.2 + 0 + 225 + 0) \text{ mm}^2 \text{ must be } > 2084 \text{ mm}^2 \]

\[ 809.2 \text{ mm}^2 \text{ must be } > 2084 \text{ mm}^2 \]

Since 809.2 mm\(^2\) is NOT greater than 2084 mm\(^2\), a reinforcing element is required.

Calculate the size of reinforcement element if the thickness is 10 mm: As per PG-33.1 for a nozzle abutting the vessel wall, reinforcement elements \( A_{42} + A_5 \) must be added so:

\[ A_1 + A_2 + A_3 + A_{41} + A_{43} + A_{42} + A_5 > A \]

\[ A_{42} + A_5 > (2084 - 809.2) \text{ mm}^2 \]

\[ > 1274.8 \text{ mm}^2 \]

If \( A_{42} \) weld is the same as \( A_{41} \) at 15 mm,

\[ A_{42} = (WL_2)^2 f_{r3} = (15 \text{ mm})^2 \times 1.0 \quad (\text{assuming } f_{r3} = 1.0) \]

\[ = 225 \text{ mm}^2 \]

Therefore,

\[ A_5 > (1274.8 - 225) \text{ mm}^2 \]

\[ A_5 > 1049.8 \text{ mm}^2 \]

\[ A_5 = (D_p - d - 2t_n)t_c f_{r3} \quad (\text{PG-33.1}) \]

\[ D_p = \frac{A_5}{t_c f_{r3}} + d + 2t_n \]

\[ = \frac{1049.8 \text{ mm}^2}{10 \text{ mm} \times 1.0} + 93 \text{ mm} + 2(3.5 \text{ mm}) \]

\[ = (104.98 + 93 + 7.0) \text{ mm} \]

\[ = 204.98 \text{ mm or } 205 \text{ mm} \]

The reinforcing plate must be greater than 205 mm in diameter x 10 mm thick with 15 mm outward welds. (Ans.)
1. A flat plate is stayed with welded staybolts equally pitched both horizontally and vertically. The plate is 12.2 mm thick and is made of SA-285-B material. The maximum allowable pressure is 865 kPa, and the operating temperature is 250° C. Calculate the pitch of the stays.

Section I, paragraph PG-46.1

\[ t = 12.2 \text{ mm} \]
\[ P = 0.865 \text{ MPa} \]
\[ C = 2.2 \]
\[ S = 98.6 \text{ MPa} \]

\[
p = t \sqrt{SC \over P}
\]
\[
= 12.2 \times \sqrt{\frac{98.6 \text{ MPa} \times 2.2}{0.865 \text{ MPa}}}
\]
\[
= 12.2 \text{mm} \times \sqrt{250.77}
\]
\[
= 12.2 \times 15.836
\]
\[
= \textbf{193.2 mm (Ans.)}
\]
2. Determine the maximum allowable working pressure in kPa for a watertube boiler drum. The drum plate thickness is 50.8 mm with an inside radius of 500 mm. The longitudinal joint efficiency is 100%. The material is SA-516-55 and the operating temperature is not to exceed 300° C. The pitch of the boiler tube holes in the drum is 140 mm as shown in Fig 1. The diameter of the tube holes is 82.5 mm.

From Section I, paragraph PG-52.2

\[ E = \frac{p - d}{p} \]
\[ = \frac{140 - 82.5}{140} \]
\[ = 0.4107 \]

From Section I, paragraph PG-27.2.2

\[ P = \frac{SE(t - C)}{R + (1 - y)(t - C)} \]

\[ S = 107 \text{ MPa} \]
\[ E = 0.4107 \]
\[ t = 50.8 \text{ mm} \]
\[ R = 500 \text{ mm} \]
\[ y = 0.4 \text{ (PG-27.4, Note 6: ferritic steels below 480°C)} \]
\[ C = 0 \]

\[ P = \frac{SE(t - C)}{R + (1 - y)(t - C)} \]
\[ = \frac{107 \text{ MPa} \times 0.4107 (50.8 \text{ mm} - 0)}{500 \text{ mm} + (1 - 0.4)(50.8 \text{ mm} - 0)} \]
\[ = \frac{2232.4 \text{ MPa}}{530.48} \]
\[ = 4.21 \text{ MPa} \text{ (Ans.)} \]
3. A boiler is to be converted from burning pulverized semi-bituminous coal to natural gas. At maximum load the boiler burns coal at a rate of 5.5 tonnes per hour. What is the maximum amount of natural gas that can be burned per hour if the safety valves are re-rated to 3% above their present setting?

From Section I, Appendix A, paragraph A-12

Where:

\[ W = \text{mass of steam generated} \]
\[ C = \text{mass of fuel burned} = 5500 \text{ kg/h} \]
\[ H = \text{calorific value from A-17} = 34000 \text{ for coal and 35700 for natural gas} \]

\[ W = \frac{C \times H \times 0.75}{2558} \]
\[ = \frac{5500 \times 34000 \times 0.75}{2558} \]
\[ = 54827.99 \text{ kg of steam/h} \]

At the new rating \( W = 54827.99 \times 1.03 = 56472.83 \text{ kg of steam/h} \)

\[ W = \frac{C \times H \times 0.75}{2558} \]
\[ C = \frac{W \times 2558}{H \times 0.75} \]
\[ = \frac{56472.83 \times 2558}{35700 \times 0.75} \]
\[ = 5395.2 \text{ m}^3 \text{ of natural gas per hour} \quad \text{(Ans.)} \]

The maximum amount of natural gas that can be burned per hour is 5395.24 m³.
4. A furnace is produced using the Fox corrugation system. The furnace has a mean diameter of 1118 mm, a maximum working temperature of 370°C, and a maximum allowable working pressure of 1375 kPa. The corrugations are 152.4 mm centre to centre and have a suspension curve depth of 38 mm. The length of the furnace is 2.5 m. The furnace material is carbon steel with a minimum yield strength of 207 MPa.

(a) What is the minimum thickness of the furnace tube?

(b) What is the calculated allowable external pressure of a plain furnace tube with the same dimensions (2.5 m long and 1118 mm outside diameter) and the same minimum required thickness?

(a) From Section I, paragraph PFT-18.1

\[
P = \frac{Ct}{D}, \quad \therefore \quad t = \frac{PD}{C}
\]

Where:
- \(C\) = 97
- \(D\) = 1118 mm
- \(P\) = 1.375 MPa

\[
t = \frac{PD}{C}
\]

\[
= \frac{1.375\text{MPa} \times 1118\text{mm}}{97\text{MPa}}
\]

\[
= 15.85\text{mm} \quad \text{(Ans.)}
\]

(b) From Section I, paragraph PFT-51.1.2

**Step 1:** Calculate the ratios

\[
\frac{D_o}{t} = \frac{1118\text{mm}}{15.85\text{mm}} = 70.5
\]

\[
\frac{L}{D_o} = \frac{2500\text{mm}}{1118\text{mm}} = 2.236
\]

**Steps 2 & 3:** Using Section II, Part D, Chart Fig. G, the value of \(A\) = 0.0001.
Step 4 & 5: Since the minimum yield strength is above 207 MPa, use Section II, Part D, Fig. CS- Applying the value of $A = 0.001$ and the $370^\circ$C line2, the value of $B = 56$

Step 6:

$$P_a = \frac{4B}{3\left(\frac{D_o}{t}\right)} \text{MPa}$$

$$= \frac{4 \times 56}{3 \times 70.5} \text{MPa}$$

$$= 1.059 \text{MPa} \quad (\text{Ans.})$$

Note: This is the calculated allowable external working pressure of the plain circular furnace with a wall thickness of 15.85mm. This plain circular furnace could not be operated at the design working pressure (1375MPa) of the Fox furnace unless the wall thickness was increased.
1. (a) In your own words, briefly describe constitutional law.

(b) Where is the constitutional authority found for your Province to create municipal institutions?

(c) Where is the authority for municipal governments found?

(d) State two unique characteristics of our Constitution.

(a) Constitutional law is the law prescribing the exercise of power by the organs of a state, and which organs can exercise legislative power (making laws), executive power (implementing the law), and judicial power (adjudicating disputes).

(b) Section 92(8) of the Constitution Act, 1867.

(c) Municipal institutions possess only those powers which they have been expressly granted by provincial legislation or are necessarily incidental to those expressed powers.

(d) Two unique characteristics of our Constitution are:

1) The Constitution is the supreme law of the country to which all other laws must be subordinate.

2) The Constitution is the most difficult legislation to change; it is said to be "entrenched."

   (a) What are the three primary classifications of courts in Canada?

   (b) Why is the jurisdiction of the Court of Queen’s Bench of interest to the Safety Officer (Inspector)?

2. (a) **What are the three primary classifications of courts in Canada?**

   (a) The three primary classifications of courts in Canada are: Provincial Courts, Superior Courts and Federal Courts.
3. Why is the jurisdiction of the Court of Queen’s Bench of interest to the safety officer (inspector)?

The jurisdiction of the Court of Queen's Bench of interest to Safety Officer (Inspector) includes the following:

a) indictable offences under section 469 of the Criminal Code of Canada;"
b) indictable offences by election (jury or judge alone);
c) appeals of summary conviction offences;`
d) all civil matters in excess of $4,000;
e) appeals from Small Claims Court; and
f) administrative law jurisdiction in respect of applications for judicial review or statutory rights of appeal of administrative decisions."

4. (a) In your own words define “statutory delegate.”
(b) State the difference between “mandatory” and “discretionary” powers.
(c) Governments may delegate which three general types of functions?
(d) In your own words describe “standard of care” as applicable to a Safety Officer (Inspector).

(a) A statutory delegate is any entity that receives federal or provincial powers.

(b) Mandatory delegated powers impose a duty on statutory delegates, whereas discretionary delegated powers allow statutory delegates to use their discretion in the exercise of the delegated powers.

(c) 1. legislative
2. judicial
3. administrative.

(d) The “standard of care” is that care given by the “reasonable man” or “reasonable Safety Officer (Inspector)”.
5. (a) Is there any legal responsibility for Power Engineers to retain a Log Book.
(b) If a Power Engineer knowingly makes a false statement concerning matters under the Boiler and Pressure Vessels Act, describe the penalty allowed.

(a) Yes, failure to do so would result in the person being guilty of an offence.
(b) For the first offence the person is liable for a fine of $15,000 and an additional $1,000 per day during which the offence continues; or imprisonment for a period not exceeding 6 months; or both fines and imprisonment. (The candidate’s numbers may reflect his/her own provincial legislation).

6. A new piping system which is part of the boiler external piping is to be examined. Explain in your own words who is required to inspect this piping system and under what Code requirement(s).

Boiler external piping must be inspected by an Authorized Safety Officer (Inspector). The requirements are provided in Section I of the ASME Boiler and Pressure Vessel Code. The qualifications of the Authorized Safety Officer (Inspector) are stated in Section I. Paragraph PG-91. The duties of the Authorized Safety Officer (Inspector) are summarized in Section I. Paragraph PG 9O.

ASME B31.1 requires that examination of the piping be performed by the piping manufacturer, fabricator, erector, or a party authorized by the Owner as a quality control function. These examinations include visual observations and nondestructive examination, such as radiography, ultrasonic, eddy-current, liquid-penetrant, and magnetic-particle methods.

Inspection is the responsibility of the Owner and may be performed by employees of the Owner or a party authorized by the Owner except in the case of boiler external piping, which requires inspection by an Authorized Safety Officer (Inspector). The Authorized Safety Officer (Inspector) is responsible for ensuring, before the initial operation, compliance with the engineering design as well as with the material, fabrication, assembly, examination, and test requirements of ASME B31.1.

Note that the process of inspection does not relieve the manufacturer, fabricator, or erector of his or her responsibilities for complying with the Code. ASME B31.1 does not specify qualifications for the Inspector.
Requirements for the examination processes are described in Section V of the Boiler and Pressure Vessel Code, with limited exceptions and additions. Section V is referenced by ASME B31.1. The required degree of examination and the acceptance criteria for the examinations are provided in ASME B31.1. Chapter VI.
1. What does ASME stand for? List the ASME Codes used for the design and construction of pressure equipment in Canada.

ASME stands for the American Society of Mechanical Engineers. The applicable codes used for design and construction of pressure equipment are listed below.

- Section I, Power Boilers, contains the requirements for the field assembly of power boilers and external piping.
- Section II Materials
  - Part A- Ferrous Materials Specifications
  - Part B- Nonferrous Material Specifications
  - Part C- Specifications for Welding Rods, Electrodes and Filler Metals
- Section IV- Heating Boilers
- Section V - Nondestructive Examination
- Section VI- Recommended Rules for the Care and Operation of Heating Boilers
- Section VII- Recommended Guidelines for the care of Power Boilers
- Section VIII - Unfired Pressure Vessels, contains the requirements for the remainder of the plant pressure piping and pressure vessels.
- Section IX - Welding and Brazing Qualifications
- ASME B31.1, Power Piping, contains requirements for the installation of boiler external piping, and makes reference to ASME Code, Section I
- ASME B31.3 - 1999 Process Piping
- ASME B31.4 - 1998 Transportation Systems for Hydrocarbons
- ASME B31.5 - 2000 Refrigeration Piping
2. **Briefly describe the steps involved in developing specifications and contracts for new plant installations.**

The first step is the feasibility study. This is to determine if it is feasible to build the new plant. The study is used to determine the plant size and to estimate costs. The primary emphasis of the engineering feasibility study is economics. The study is used to determine the cost of the new plant and to ascertain its economic viability – whether the plant can make a profit.

If the plant proves to be viable during the feasibility study, the process then moves to the next stage. During this phase, the detailed design and specifications are produced. The engineering company produces drawings and specifications, with the amount of detail required for construction companies to create competitive bids. Contracts are then written to build the plant as laid out in the drawings and specifications.

3. **Explain the difference between an engineering study and detailed plant engineering.**

The engineering study includes a report used to obtain capital funds for plant construction. It includes outlays for such items as operations, maintenance, depreciation, insurance, interest, taxes, and a budget. It includes recommendations for such items as: capital required, operating costs, and fixed costs. The engineering study often includes economic alternatives. Such alternatives could include different plant locations, various plant output sizes, or use of different fuels.

Detailed plant engineering follows the engineering study and the decision to proceed. The detailed design builds upon the work accomplished in the engineering study but contains much more detail. Items included in the detailed design include: Detailed drawings such as P& Ids, detailed specifications for all engineering disciplines including material specifications and construction drawings including isometric piping drawings.
4. **How can change orders affect the price of a project? When is the least expensive time to make changes in the design drawings?**

Change orders add to the cost of the project, as the changes must be re-engineered and changes made to the drawings and specifications. The least expensive time to make changes is before the drawings and specifications have been finalized.

5. **List five duties of operations personnel during the construction phase of a new plant construction project.**

Some of the duties of operations people during the construction phase of the project include:
- Learning the piping details of the new plant and the punch listing. Punch listing lists the construction deficiencies of a piping system.
- Line blowing or trash blowing. This process cleans the debris out of a piping system. The debris items include welding slag, rags, rust, debris, and liquids used to pressure test the piping.
- Leak testing of piping systems, such as vacuum systems. Often the flanges are wrapped and a small air pressure is put on the system to detect leaks.
- Test running motors and pumps, checking for proper rotation
- Steam blowing of the piping that supplies turbines and processes

6. **Explain the difference between the Design – Bid – Build method for plant construction and the Design- Build method.**

In design-bid-build the owner gets a scope definition with 5% basic engineering complete. An engineering company completes the detailed engineering. When working drawings and designs are completed, bids are sent out for the construction of the plant. Construction is contracted out to a general contractor. The plant scope is not finalized until late in the project. The cost of the project cannot be finalized until all changes in scope have been completed.

In design-build, with the basic design engineering about 20% complete, the owner selects a company to complete the detailed design, order the equipment, and construct the plant. The entire project is done based on a final, lump sum payment. The final payment is often made after the performance run of the plant has been completed. This type of arrangement combines the roles of the designer and the general contractor.
1. **State and describe the four functions of management.**

   Planning is a higher level activity that involves establishing organizational goals, establishing a strategy for achieving the goals and developing plans to integrate and coordinate activities at all levels.

   Organizing refers to the organizational structure or the manner in which people are grouped to determine what activities are accomplished, how they are to be done, by whom and when.

   Leading is the function whereby managers direct, coordinate and motivate employees in their work. Whenever necessary, the manager serves to resolve conflicts among members.

   Controlling consists of monitoring the performance of activities by comparing them to previously set goals and objectives. If there are significant deviations, management must evaluate what has to be done to close the gap and correct the deficiencies.

2. **Explain the traditional way of setting objectives and compare this to management by objectives.**

   The traditional way for setting objectives is for top-level managers to state the overall objectives and essentially impose them on the organization. The next level of managers takes these objectives, interprets them for applicability to their part of the organization and passes them down to the next level. Finally, the lowest level of management receives the objectives and attempts to meet them.

   Management by objectives (MBO) is a system whereby objectives are jointly developed by those involved and progress is periodically reviewed. Rewards may be tied directly to performance as it relates to agreed to objectives.
3. **List the eight steps to making a decision.**

The decision-making process consists of:
1. Identifying a problem
2. Identifying decision criteria
3. Allocating weights to criteria
4. Developing alternatives
5. Analyzing alternatives
6. Selecting an alternative
7. Implementing the alternative
8. Evaluating decision effectiveness.

4. **List four items that will maximize the effectiveness of a job interview.**

The following items will maximize the effectiveness of an interview (choose any four):
1. Prepare a fixed set of questions for all candidates.
2. Agree on detailed job requirements prior to interviews and make this available to the applicant.
3. Minimize knowledge of the background, experience, etc. of the applicant before the interview.
4. Ask behavioural questions that show how the person behaved in similar applicable situations.
5. Use a standardized evaluation form.
6. Take good notes during the interview.
7. Allow sufficient time and avoid short interviews that will lead to quick decisions.

5. **List four steps that should be taken to set up a training program for employees.**

These are the steps that should be taken to set up a training program for employees (choose any four):
1. Fully understand the job functions of the work unit. A typical team in which a power engineer may be employed might be responsible for the operation and routine maintenance of machinery. Examples of job functions will be logging and monitoring of the equipment, startup and shutdown and routine maintenance such as a filter changeout.
2. List the skills required to accomplish these job functions. These skills will include ones such as safety procedures, work procedures, operating procedures, maintenance procedures and documentation.
3. Determine the specific training required to support the skills needed for the job functions. This will include both on-the-job and off-the-job training.
4. Using the skills from step 2, perform a skills inventory which documents the current level of skills for each employee.
5. Identify gaps in training that need to be addressed for each employee based on the job functions they are required to perform.
6. Prepare an individual training plan for each employee taking into account constraints in time (not all training can or needs to happen at once) and budget (only so much money will be available).

6. What are four ways a manager can motivate an employee?

The successful manager and supervisor can motivate employees by (choose any four):
1. Enlarging the work scope to provide variety
2. Using realistic goals
3. Allowing people or small groups to complete and be responsible for larger tasks instead of portions of tasks
4. Providing flexibility for the employee in how and when a task is done
5. Recognizing extra effort
6. Having rewards that employees can strive for
7. Providing feedback, especially positive
8. Matching jobs and tasks to individual strengths and desires
9. Ensuring that there are no inequities between employees and with others outside the group.

7. Describe the four elements of the “hot stove” rule to applying discipline.

The way discipline is applied is sometimes called the “hot stove” rule because of the similarity with touching a hot stove. This leads to four aspects of discipline:

1. Immediacy: with a hot stove, the pain is felt immediately. The effectiveness of discipline decreases with the amount of time between the offence and the penalty.
2. Advance warning: from a young age, people know what happens when a hot stove is touched. Managers need to be clear about what standards have to be followed and what the consequences are.
3. Consistency: the results of touching a hot stove are very consistent and the response to an infraction needs to be the same.
4. Impersonal nature: the stove does not differentiate between people. The manager must be impersonal as well and not favour some people over others. The penalty is directed at the rule violation and not the person.
8. Describe four important aspects of writing a formal report.

For the report to effectively communicate, the following aspects should be carefully considered (choose any four):

1. The purpose of the report must be clear and stated at the beginning of the report.
2. The contents of the report need to be structured properly.
3. The report must contain enough information to meet the needs of the reader but should be as short and succinct as possible. If a greater level of detail is required, these should be contained in appendices.
4. Good grammar and spelling are essential to clear communication. Simple grammar and well-structured sentences are preferred over complicated sentence structure.
5. Before issuing the report, ask someone else to read it over and offer suggestions for improvement.
6. Find examples of good reports and learn from them.
7. Use standard report formats if they are available.
1. Identify and describe three components of the definition of maintenance.

Choose any three from the following.

This definition has a number of components:

- item: this term includes all hardware and associated software such as equipment, components, devices, systems, and other physical assets.

- perform a required function: maintenance is concerned with ensuring that equipment can perform required functions. These functions are a combination of design (which defines the limits of use) and operation (which describes its actual use).

- to retain an item in, or restore it, to a state: the purpose of maintenance is either to perform actions that keep equipment performing as required by doing preventive maintenance (to retain), or to repair it when it has failed by doing corrective maintenance (to restore).

- combination of all technical and administrative actions, including supervision actions: maintenance is not only the execution of maintenance tasks, but also administrative actions (such as planning and scheduling) and supervisory actions (such as hiring and training skilled personnel).

2. Explain the difference between preventive and corrective maintenance.

Preventive maintenance covers all pre-planned maintenance activities that are always performed before failure occurs. Corrective maintenance, on the other hand, is done after a failure.
3. **List four items that might need to be identified during planning of maintenance.**

Any four of the following items apply.

Planning is needed to identify some or all of the following items:
- Description of tasks to be performed and their sequence (if important)
- Length of downtime required (equipment, system, or plant)
- Number of staff and hours needed for each type of maintenance trade or specialty
- Types of spare parts and materials and where they are to be sourced (inventory or purchase)
- Specialized tools and support equipment
- Lifting equipment (e.g., a crane)
- Special safety and environmental procedures
- Special maintenance procedures
- External contractors and services
- Financial account codes to which the costs are to be charged
- Cost breakdown and total cost for the task

4. **Describe what is meant by the critical path.**

The critical path is defined as all the tasks that will increase project completion time if they take longer than planned. If there is some way to shorten the duration of any of these tasks, then the overall completion time will be decreased.

5. **List four types of information that might be recorded in a CMMS.**

Any four of the following items apply.

Most CMMS’s record these types of information:
- Facility and equipment information
- Work management (work requests and work orders)
- Planning and scheduling
- Preventive maintenance
- Spare parts and materials
- Equipment tracking
- Analysis and reporting
6. **What are the two approaches used for preparing a maintenance budget?**

Two approaches are used for budgeting:

- **Zero-based budgeting:** budget amounts are determined by identifying and estimating all activities to be carried out. For maintenance budgets, this works well for routine and major inspections although it takes a considerable amount of time to prepare.

- **Historical budgeting:** costs are estimated based on past history with actual expenditures, usually those of the previous year. This is the most efficient way to budget for miscellaneous expenses and minor work, as well as unscheduled work due to failures.
1. **Explain the difference between a hazard and a risk.**

Hazard is a source or situation with the potential for causing harm to a person or property.

Risk is a function of the potential severity of the hazard and the likelihood of the hazard occurring.

2. **What is the purpose of an Initial Status Review?**

An Initial Status Review is used when implementing a new health & safety program. It establishes how the existing health & safety program, processes and procedures compare to the desired program and highlights where improvement action needs to be taken.

3. **Why is involvement of top management in the health & safety program essential and where should they be involved?**

Top management involvement in the overall health & safety program is essential to demonstrate their commitment to safe operation and to provide the necessary resources for implementing the program.

They need to be involved in:
- Setting the health & safety policy and objectives
- Providing the necessary resources
- Demonstrating their support by personal involvement in safety audits and face to face briefings on safety

4. **Explain the purpose of operational controls and their relationship to power plant safety related work instructions.**

Operational controls are safety processes or procedures that are put in place to control plant wide hazards. Work instructions, which may incorporate safety requirements, are detailed procedures that apply to specific tasks or parts of the plant and do not have plant wide application.
5. **Compare the purposes of safety checklists, safety inspections and safety audits.**

Safety checklists are used by on-shift personnel as a memory aid and to record the current state of the plant.

Safety inspections are carried out by supervisors in order to satisfy themselves that the risks are under control and that the safety related procedures are being followed in their area of responsibility.

Safety audits are used by management to evaluate the effectiveness of each element of the overall health & safety program with a view to identifying areas for continuous improvement.

6. **Explain the relationship between the plant’s risk reduction plan and its safety training program.**

No plant has either the time or limitless resources that can be used for training. The risk reduction plan for the plant will identify those hazards that have the greatest associated risk. Training resources can then be focused on the high risk hazards.

7. **Discuss the advantages and disadvantages of computer based training.**

Computer-based training advantages:
- CBT is the most cost-effective way to train for companies that have facilities on a national or even international scale. Training employees by the conventional means (classroom instruction) requires that the company pay high travel expense costs for the trainer
- CBT is very flexible in that it does not interrupt the trainees' work schedules to train them. CBT optimizes the time available for training, and affords flexibility since training can be taken by most employees on a 24 hr. basis without leaving the work site
- CBT is self-paced instructional program that allows for mastery of the material because time is not a constant

Computer-based training disadvantages:
- CBT does not allow for real-time training
- CBT type of training lacks the face to face contact that classroom instruction allows. Without the face to face with the instructor, the trainee cannot have their questions answered on the spot when they need help
Chapter 8
Linear Motion

1. A body, moving at 10 m/s, accelerates uniformly at 5 m/s² for 20 seconds. What is the final velocity and the total distance traveled?

The final velocity is calculated from the equation:

\[ u = 10 \text{ m/s} \quad a = 5 \text{ m/s}^2 \quad t = 20 \text{ s} \]

\[ v = u + at \]
\[ = 10 + (5 \times 20) \text{ m/s} \]
\[ = 110 \text{ m/s} \quad \text{(Ans.)} \]

The distance is determined using the equation:

\[ s = \left( \frac{u+v}{2} \right) t \]
\[ = \left( \frac{10+110}{2} \right) 20 \text{ m} \]
\[ = 1200 \text{ m} \quad \text{(Ans.)} \]

2. What force is required to accelerate a 10 kg mass at 5 m/s²?

The accelerating force is determined by equation

\[ m = 10 \text{ kg} \quad a = 5 \text{ m/s}^2 \]
\[ F = ma \]
\[ = 10 \times 5 \]
\[ = 50 \text{ kg m/s}^2 \]
\[ = 50 \text{ N} \quad \text{(Ans.)} \]
3. (a) Define momentum.
   (b) Calculate the momentum of a 50 kg mass moving at a velocity of 10 m/s.

   (a) Momentum is the product of the mass of a body and its velocity.

   (b) Using the equation:

   \[ m = 50 \text{ kg} \quad v = 10 \text{ m/s} \]

   \[ p = mv \]

   \[ = 50 \times 10 \]

   \[ = 500 \text{ kg m/s} \text{ (Ans.)} \]

   Note that the distance is not relevant in this question.

4. What is the kinetic energy of a vehicle of mass 1000 kg travelling at 36 km/h?

   \[ m = 1000 \text{ kg} \quad v = 36 \text{ km/h} \]

   \[ E_k = \frac{36 \text{ km} \times 1000 \text{ m/km}}{\text{h} \times 60 \text{ min/h} \times 60 \text{ sec/h}} \]

   \[ = 10 \text{ m/s} \]

   The kinetic energy is then calculated as:

   \[ E_k = \frac{1}{2}mv^2 \]

   \[ = \frac{1}{2} \times 1000 \times 10^2 \]

   \[ = 50,000 \text{ J} \]

   \[ = 50 \text{ kJ} \text{ (Ans.)} \]
5. A four cylinder 2 stroke diesel engine runs at 210 rpm and has a mean effective pressure of 1000 kPa. The stroke of each cylinder is 1200 mm. The total indicated power for the engine is 6000 kW. Calculate the diameter of each cylinder.

With a two stroke engine, there is one power stroke per revolution, so the number of strokes per second is:

\[
N = \frac{1 \text{ power stroke/rev} \times 210 \text{ rpm}}{60 \text{ sec/min}} = 3.5 \text{ power strokes per second}
\]

Total indicated power/cylinder = \( \frac{6000}{4} \)

\( = 1500 \text{ kW} \)

Because one Pa (Pascal) is equivalent to one N/m\(^2\) (Newton/metre squared), the indicated power produced by each cylinder is calculated using the following equation:

Given:

\[ P_i = 1500 \text{ kW} \]
\[ p = 1000 \text{ kPa} \]
\[ L = 1.2 \text{ m} \]
\[ N = 3.5 \]

Calculate cylinder area

\[ P_i = pLAN \]

\[ A = \frac{P_i}{pLN} \]

\[ = \frac{1500}{1000 \times 1.2 \times 3.5} \]

\[ = 0.357 \text{ m}^2 \]
Calculate diameter of each cylinder:

\[ A = \pi r^2 \]
\[ \pi r^2 = A \]
\[ r^2 = \frac{A}{\pi} \]
\[ r = \sqrt{\frac{A}{\pi}} \]
\[ = \sqrt{\frac{0.357}{3.1416}} \]
\[ = \sqrt{0.1136} \]
\[ = 0.337 \text{ m or } 337 \text{ mm} \]

_Cylinder diameter = 674 mm_ (Ans.)
1. What is the angular velocity of a flywheel rotating at 200 rpm?

The angular velocity is

\[ \omega = \frac{2\pi \times n}{60} \]

\[ = \frac{2\pi \times 200}{60} \]

\[ = 20.94 \text{ rad/s} \quad \text{(Ans.)} \]

2. Define the moment of inertia and describe what is meant by the radius of gyration.

The moment of inertia is a combination of the mass and the distance of each part of that mass from the axis of rotation. It is dependent on the shape of the object and its axis of rotation. Once the moment of inertia has been determined, it is convenient to define an equivalent radius at which the mass can be assumed to be concentrated. This is called the radius of gyration.

3. A force of 50 N is applied to a wheel with a diameter of 2 m. What is the torque?

The torque is calculated as

\[ T = F \times r = 50 \times 1 = 50 \text{ Nm} \]
4. The mass of a flywheel is 125 kg and its radius of gyration is 400 mm. Calculate the kinetic energy stored when rotating at 150 and 350 rpm, respectively.

Convert rpm to rad/s:
\[ \omega (\text{rad/s}) = \frac{2\pi}{60} \times n \]
\[ = \frac{2\pi}{60} \times 150 \]
\[ = 15.71 \text{ rad/s} \]

Kinetic energy at 150 rpm:
\[ K = \frac{1}{2} m\omega^2 k^2 \]
\[ = \frac{1}{2} \times 125 \times 0.4^2 \times 15.71^2 \]
\[ = 2468.04 \text{ kJ} \] (Ans.)

Kinetic energy at 350 rpm:
\[ K = 2468.04 \times \left( \frac{350}{150} \right)^2 \]
\[ = 2468.04 \times 2.33^2 \]
\[ = 13399 \text{ kJ} \] (Ans.)

5. A crane engine lifts a 420 kg mass to a height of 10 m in 1.74 minutes. The indicated power of the engine is 416 W. What is the mechanical efficiency of the engine?

\[ W = Fs \]
\[ = 420 \text{ kg} \times 9.81 \text{ m/s}^2 \times 10 \text{ m} \]
\[ = 41202 \text{ J} \] (Ans.)

Brake Power = \[ \frac{41202 \text{ J}}{1.74 \times 60 \text{ s}} \]
\[ = 394.7 \text{ W} \] (Ans.)

Indicated Power = 416 W

\[ \eta_m = \frac{394.7}{416} \times 100 \]
\[ = 94.9 \% \] (Ans.)
6. A pulley, 300 mm in diameter, is driven at 350 rpm by a belt 14 mm thick. The tensions in the tight and slack sides of the belt are 1800 and 500 N respectively. Considering the thickness of the belt, find the power transmitted.

Given:

Radius of the pulley = 150 mm
Speed of the pulley = 350 rpm
Tension on right side = 1800 N
Tension on slack side = 500 N

With the addition of the belt thickness, the radius will be increased by half of the belt thickness. With a belt thickness of 14 mm, the new radius will be 157.0 mm.

Power transmitted:

\[ P = 2\pi(F_1 - F_2)r \frac{n}{60} \]
\[ = 2\pi(1800 - 500) \times 0.157 \times \frac{350}{60} \]
\[ = 7476.4 \text{ W} \]
\[ = 7.476 \text{ kW (Ans.)} \]

7. Describe centripetal and centrifugal force and indicate the difference between them.

Centripetal force acts toward the center of rotation due to acceleration caused by a change in velocity and is the one that produces the circular motion.

Centrifugal force tries to move the object away from the center of rotation. The two forces are equal in magnitude but opposite in direction.
8. Find the change in height of a Watt governor when it changes speed from 80 to 120 rpm.

For the 80 rpm:

\[
\frac{80 \text{ rpm} \times 2\pi}{60} = \frac{8}{3}\pi \text{ rad/s}
\]

For the 120 rpm:

\[
\frac{120 \text{ rpm} \times 2\pi}{60} = 4\pi \text{ rad/s}
\]

Height = \(\frac{g}{\omega^2}\)

\[
h_1 = \frac{g}{\left(\frac{8}{3}\pi\right)^2}
\]

\[
= \frac{9.81 \times 3^2}{8^2 \times \pi^2}
\]

\[
= 0.1398 \text{ m}
\]

\[
h_2 = \frac{g}{(4\pi)^2}
\]

\[
= \frac{9.81}{(4 \times \pi)^2}
\]

\[
= 0.0621 \text{ m}
\]

Change in height = \(h_1 - h_2\)

\[
= 0.1397 - 0.0621
\]

\[
= 0.0776 \text{ m}
\]

\[
= 77.6 \text{ mm (Ans.)}
\]
9. A shaft is found to have an unbalance of 0.5 kg at a radius of 100 mm from the center of rotation. At what radius and position in the same plane should a mass of 1 kg be placed for balance?

Taking moments about the center of rotation, the solution will be

\[ 0.5 \times 100 = 1 \times r \]
\[ r = 50 \text{ mm} \]

The compensating mass is placed in the opposite direction to the unbalance mass.
1. Define static and sliding friction and indicate which is greater.

Static friction is the force exerted between two bodies that are not moving relative to each other.

Sliding friction is the force acting against the direction of motion and parallel to the two surfaces while they are moving relative to each other. The coefficient of kinetic friction is less than the coefficient of static friction. This means that it takes more force to start a body sliding than it does to keep the body sliding.

2. Define the coefficient of friction by stating the equation and illustrate the forces with a diagram for a simple block moving on a horizontal surface.

The coefficient of sliding friction $\mu$ (mew) is defined as

$$\mu = \frac{F}{N}$$

$F$ is the friction force that balances the force acting on an object while it slides at a constant velocity. $N$ is the normal force that presses the two surfaces together.
3. A mass of 100 kg slides along a horizontal plane at uniform velocity. If the coefficient of friction is 0.1, what force is required to move the mass?

The normal force is calculated by the equation

\[ N = mg \]
\[ = 100 \times 9.81 \]
\[ = 981 \text{ N} \]

The force required to move the object at constant velocity will be

\[ F = \mu N \]
\[ = 0.1 \times 981 \]
\[ = 98.1 \text{ N} \]

4. Using the standard equation for the coefficient of friction, derive the equation for an upwards force acting on a sliding object as shown in the diagram below and illustrate the forces on the diagram.

![Non-Parallel Forces](image)

The vectors for the forces are shown on the diagram as follows

![Non-Parallel Forces Vectors](image)
The vector equations for the applied force become

\[ F_y = F \sin \theta \]
\[ F_x = F \cos \theta \]

The basic equation for the coefficient of friction is

\[ \mu = \frac{F}{N} \]

In this case, \( F = F_x \) and \( N = W - F_y \). Substituting these in the basic equation for the coefficient of friction, we derive as follows

\[ \mu = \frac{F}{N} \]
\[ \mu = \frac{F_x}{W - F_y} \]
\[ \mu = \frac{F \cos \theta}{W - F \sin \theta} \]
\[ F = \frac{\mu W}{\cos \theta + \mu \sin \theta} \]

5. Define the angle of repose and state the equation that relates it to the coefficient of friction.

The angle of repose is the angle of the incline at the point that an object will start to slide. The coefficient of friction is defined by the angle of repose through the equation

\[ \mu = \tan \alpha \]
6. Using the diagram below, derive the equation for the horizontal force required to move a jack screw upwards.

Forces Applicable to a Screw Jack

The horizontal force to move the screw jack upwards is the sum of the frictional and gravitational forces, which results in the equation:

\[ F = W \tan(\alpha + \varphi) \]
1. A simply supported beam is loaded as shown below. What are the required supporting forces $R_1$ and $R_2$ to maintain the beam in equilibrium?

Moments around $R_1$:

\[
\text{clockwise moment} = \text{anticlockwise moment}
\]
\[
(1000 \text{N/m} \times 2) + (3000 \text{N/m} \times 7) = R_2 \times 10 \text{ m}
\]
\[
R_2 = \frac{(1000 \text{ N/m} \times 2) + (3000 \text{ N/m} \times 7)}{10 \text{ m}}
\]
\[
= \frac{2000N + 21000N}{10}
\]
\[
= 2300 \text{ N} \quad \text{(Ans.)}
\]

Moments around $R_2$:

\[
\text{clockwise moment} = \text{anticlockwise moment}
\]
\[
R_1 \times 10 \text{ m} = (1000 \text{ N/m} \times 8) + (3000 \text{ N/m} \times 3)
\]
\[
R_1 = \frac{8000 + 9000}{10 \text{ m}}
\]
\[
= 1700 \text{ N} \quad \text{(Ans.)}
\]
2. Define a centroid. Define the first moment of areas and explain how it relates to the location of a centroid.

The centroid for a shape is the center of the areas that make up the object. If the shape is irregular, it is more difficult to find the centroid and a method called the first moment of areas can be used to find it. The first moment of area is defined as

First moment of area = area \times distance

The centroid is established for irregular shapes by dividing the shape into areas whose centroids are known and then taking moments around a common plane.

3. A circular column with a diameter of 40 cm carries a compressive load of 200 kN. What will be stress on the column?

The area of the column is

\[ A = \pi r^2 \]
\[ = \pi (0.2)^2 \]
\[ = 0.1257 \text{ m}^2 \]

The stress will be

\[ \text{Direct stress} = \frac{\text{load}}{\text{area}} \]
\[ \text{Direct Stress} = \frac{P}{A} \]
\[ = \frac{200}{0.1257} \]
\[ = 1591.09 \text{ kPa} \quad \text{(Ans.)} \]
4. A steel bar with a diameter of 6 cm and a length of 5 m is subjected to a tensile load of 250 kN. If the factor of safety is 5.8 and E is 225 GPa, calculate the following:
   (a) Stress
   (b) Strain
   (c) Increase in length
   (d) Elastic limit

The area of the bar is
\[ A = \pi r^2 \]
\[ = \pi (0.03 \text{ m})^2 \]
\[ = 0.0028 \text{ m}^2 \]

a) The stress is:
   
   Direct stress = \( \frac{\text{Load}}{\text{Area}} \)
   \[ = \frac{250 \text{ kN}}{0.0028 \text{ m}^2} \]
   \[ = 89.286 \text{ MPa} \] (Ans.)

b) The strain:
   
   Direct strain (\( \varepsilon \)) = \( \frac{\text{Stress}}{E} \)
   \[ = \frac{89.286 \times 10^6 \text{ Pa}}{225 \times 10^9 \text{ Pa}} \]
   \[ = 3.968 \times 10^{-4} \] (Ans.)

c) The increase in length is:
   \[ \varepsilon = \frac{\Delta l}{L} \]
   \[ \Delta l = \varepsilon L \]
   \[ = 3.968 \times 10^{-4} \times 5 \text{ m} \]
   \[ = 1.984 \times 10^{-3} \text{ m} \]
   \[ = 1.984 \text{ mm} \] (Ans.)
d) The elastic limit is:

\[
\text{Factor of safety} = \frac{\text{Elastic limit}}{\text{Maximum working stress}}
\]

\[
\text{Elastic limit} = \text{Factor of safety} \times \text{Maximum working stress}
\]

\[
= 5.8 \times 89.286 = 517.86 \text{ MPa (Ans.)}
\]

5.

a) Calculate the safe load in kN that can be carried by a stud of 645.16 mm\(^2\) cross-sectional area allowing a safe working stress of 30 MN/m\(^2\).

\[
\text{Safe load/stud} = \text{Safe stress } \times \text{ area}
\]

\[
= 30 \times 645.16 \text{ mm}^2
\]

\[
= 1.935 \times 10^4
\]

\[
= 19.35 \text{kN (Ans.)}
\]

b) Calculate the number of studs required to hold the cylinder cover of a diesel engine where the maximum pressure in the cylinder is 4.5 MPa and the diameter of the cover is 400 mm.

\[
\text{Total load on cover} = \text{pressure } \times \text{ area}
\]

\[
= 45 \times 10^5 \text{ N/m}^2 \times 0.7854 \times 0.4 \text{ N}
\]

\[
= 565488
\]

\[
= 19350
\]

\[
= 29.22
\]

\[
= 30 \text{ Studs (Ans.)}
\]
6. A steel bar is covered by a copper sheath over its entire length. This sheath is firmly affixed to the bar so that one cannot expand more than the other. The cross-sectional area of the steel bar is twice the cross-sectional area of the copper sheath. If there is zero stress in the bar, then its temperature is increased by 150ºC, what now are the stresses in the steel and the copper?

Given:

Coefficient of linear expansion for the steel = \(12 \times 10^{-6} / ^\circ C\)
Coefficient of linear expansion for the copper = \(17 \times 10^{-6} / ^\circ C\)

\[\begin{align*}
E\text{ for steel} &= 210 \text{ GN/m}^2 \\
E\text{ for copper} &= 100 \text{ GN/m}^2
\end{align*}\]

a) Outward pull of copper = Inward pull of steel

\[
\begin{align*}
\text{Stress}_c \times \text{Area}_c &= \text{Stress}_s \times \text{Area}_s \\
\text{Stress}_c \times 1 &= \text{Stress}_s \times 2 \\
\text{Stress}_c &= \text{Stress}_s \times 2
\end{align*}
\]

\[
\text{Strain}_c + \text{Strain}_s = \text{Difference in free expansion/unit length}
\]

\[
\frac{\text{Stress}_c}{E_c} + \frac{\text{Stress}_s}{E_s} = (\alpha_c - \alpha_s) \Delta T
\]

\[
\begin{align*}
\frac{2 \times \text{Stress}_s}{100 \times 10^9} + \frac{\text{Stress}_s}{210 \times 10^9} &= (17-12) \times 10^{-6} \times 150 ^\circ C \\
0.02 \times \text{Stress}_s + 0.00476 \text{Stress}_s &= 150 ^\circ C \times (17-12) \times 10^{-6} \times 10^9 \\
0.02476 \times \text{Stress}_s &= 750 \times 10^3 \\
\text{Stress}_s &= \frac{750 \times 10^3}{0.02476} \\
&= 30290.8 \times 10^3 \text{ Pa} \\
&= 30.29 \text{ MPa} \text{ (Ans.)}
\end{align*}
\]

b) Stresses in the copper = \(2 \times \text{Stress}_s\)

= \(2 \times 30.29 \text{ MPa}\)

= \textbf{60.58 MPa} \text{ (Ans.)}
7. A cantilever 10 m long carries two concentrated loads, one at the free end and the other at the midpoint of the beam. The bending moment at the wall is 100 kN and at the midpoint of the beam it is 30 kN. Calculate the magnitudes of both loads.

Length of the beam = 10 m
Bending moment at the wall = 100 kN
Bending moment at the midpoint = 30 kN

Let \( W_1 \) = load at free end of beam
Let \( W_2 \) = load at midpoint

\[
W_1 \text{ kN} \times 5 \text{ m} = \text{Bending moment at midpoint of the beam}
\]
\[
W_1 \text{ kN} \times 5 \text{ m} = 30 \text{ kNm}
\]
\[
W_1 = \frac{30 \text{ kNm}}{5 \text{ m}}
\]
\[
= 6 \text{ kN} \quad \text{(Ans)...... load at free end}
\]

\[
W_1 \text{ kN} \times 10 \text{ m} + W_2 \text{ kN} \times 5 \text{ m} = \text{Bending moment at the wall}
\]
\[
6 \text{ kN} \times 10 \text{ m} + W_2 \text{ kN} \times 5 \text{ m} = 100 \text{ kNm}
\]
\[
60 \text{ kNm} + W_2 \text{ kN} \times 5 \text{ m} = 100 \text{ kNm}
\]
\[
W_2 = \frac{(100 - 60) \text{ kNm}}{5 \text{ m}}
\]
\[
= \frac{40}{5} \text{ kN}
\]
\[
= 8 \text{ kN} \quad \text{(Ans) ......load at midpoint}
\]
8. A 406 mm diameter solid steel shaft in a reciprocating engine develops 7150 kW. The maximum stress allowed is 60 MN/m² and the maximum to mean torque ratio is 1.75:1. Calculate the rpm of the engine.

The polar inertia is found using the equation \( J = \frac{\pi r^4}{2} \)

\[
J = \frac{\pi r^4}{2} = \frac{\pi \times 0.203^4}{2} = 0.0027 \text{ m}^4
\]

The torque is then obtained from the equation \( \tau = \frac{T r}{J} \):

\[
\tau = \frac{T r}{J} = \frac{60 \times 10^6 \text{ N/m}^2 \times 0.0027 \text{ m}^4}{0.203 \text{ m}} = 798 \text{ 030 Nm}
\]

\[
= 798.03 \text{ kNm}
\]

Since this is the maximum torque, the mean torque is:

\[
\text{mean torque} = \frac{\text{maximum torque}}{1.5} = \frac{798.03}{1.75} = 456.02 \text{ kNm}
\]
From equation, \( P = 2\pi T \frac{n}{60} \), the engine rpm power is:

\[
P = 2\pi T \frac{n}{60}
\]

\[
n = \frac{P \times 60}{2\pi T}
\]

\[
= \frac{7150 \times 60}{2\pi 456.02}
\]

\[
= 149.7 \text{ RPM (Ans.)}
\]

9. Two 450 mm solid shafts are connected by a coupling which has a 900 mm diameter bolt circle. The maximum allowable stress of the bolt material and the shaft is 50 MPa. If the diameter of each bolt is 90 mm, calculate the number of bolts required?

The polar inertia is found using the equation \( J = \frac{\pi r^4}{2} \):

\[
J = \frac{\pi r^4}{2}
\]

\[
= \frac{\pi \times 0.225^4}{2}
\]

\[
= 0.0040 \text{ m}^4
\]

The torque is then obtained from the equation \( \tau = \frac{T r}{J} \):

\[
\tau = \frac{T r}{J}
\]

\[
T = \frac{\tau J}{r}
\]

\[
= \frac{50 \times 10^6 \text{ N/m}^2 \times 0.0040 \text{ m}^4}{0.225 \text{ m}}
\]

\[
= 888889 \text{ Nm}
\]

\[
= 888.9 \text{ kNm}
\]
The force applied to the bolts is found by dividing the torque by the radius of the bolt circle:

\[
\text{Force} = \frac{\text{torque}}{\text{radius}} = \frac{888.9 \text{ kNm}}{0.45 \text{ m}} = 1975.33 \text{ kN} = 1975.33 \times 10^3 \text{ N}
\]

Since \( \text{Force} = \text{stress} \times \text{area} \), the total area required is:

\[
\text{area} = \frac{\text{Force}}{\text{stress}} = \frac{1975.33 \times 10^3 \text{ N}}{50 \times 10^6 \text{ N/m}^2} = 0.0395 \text{ m}^2
\]

Thus, the area of each bolt will be:

\[
A = \frac{0.0395 \text{ m}^2}{N}
\]

The number of bolts required:

\[
A = \pi r^2
\]

\[
\frac{0.0395 \text{ m}^2}{N} = \pi (0.045)^2
\]

\[
\pi (0.045)^2 N = 0.0395 \text{ m}^2
\]

\[
N = \frac{0.0395 \text{ m}^2}{\pi (0.045)^2} = \frac{0.0395 \text{ m}^2}{0.0064} = 6.17
\]

7 bolts required (Ans.)
1. A tank contains a 5400 kg mass of oil which has a relative density of 0.86. What is the volume of the oil?

Using equation \( RD = \frac{\rho}{1000} \), the density of the oil is:

\[
RD = \frac{\rho}{1000 \text{ kg/m}^3}
\]
\[
\rho = RD \times 1000 \text{ kg/m}^3
\]
\[
= 0.86 \times 1000 \text{ kg/m}^3
\]
\[
= 860 \text{ kg/m}^3
\]

Therefore, using equation \( \rho \left( \frac{\text{kg}}{\text{m}^3} \right) = \frac{m(\text{kg})}{V(\text{m}^3)} \), the volume of the oil is:

\[
\rho \left( \frac{\text{kg}}{\text{m}^3} \right) = \frac{m(\text{kg})}{V(\text{m}^3)}
\]
\[
\rho \frac{\text{kg}}{\text{m}^3} \times V \text{ m}^3 = m(\text{kg})
\]
\[
V = \frac{m(\text{kg})}{\rho \frac{\text{kg}}{\text{m}^3}}
\]
\[
= \frac{5400 \text{ kg}}{860 \text{ kg/m}^3}
\]
\[
= 6.28 \text{ m}^3 \text{ (Ans.)}
\]

2. What is the total force on the bottom and on each side of a tank 2 m by 3 m that contains water to a depth of 1 m?

The pressure at the bottom of the tank is found using equation \( p = h \rho g \):

\[
p = h \rho g
\]
\[
= 1 \text{ m} \times 1000 \text{ kg/m}^3 \times 9.81 \text{ N/kg}
\]
\[
= 9810 \text{ N/m}^2 \quad = 9.81 \text{ kPa}
\]
The force on the **bottom** of the tank is determined by equation $F = pA$:

$$F = pA$$
$$= 9.81 \text{kN/m}^2 \times (2 \text{ m} \times 3 \text{ m})$$
$$= 58.86 \text{kN} \text{ (Ans.)}$$

The average pressure on the sides of the tank is one half of the pressure at the bottom, or 4.905 kPa.

The force on the **long side** of the tank is determined by equation $F = pA$:

$$F = pA$$
$$= 4.905 \text{kN/m}^2 \times (3 \text{ m} \times 1 \text{ m})$$
$$= 14.715 \text{kN} \text{ (Ans.)}$$

The force on the **short side** of the tank is determined by equation $F = pA$:

$$F = pA$$
$$= 4.905 \text{kN/m}^2 \times (2 \text{ m} \times 1 \text{ m})$$
$$= 9.81 \text{kN} \text{ (Ans.)}$$

3. A tank of oil with a volume of 5 m$^3$ heats up from 20°C to 120°C. If the coefficient of volumetric expansion is $0.9 \times 10^{-3}$ per °C, what is the volume at 120°C?

The change in volume is found using equation $\Delta V = V \beta (T_2 - T_1)$:

$$\Delta V = V \beta (T_2 - T_1)$$
$$= 5 \text{ m}^3 \times (0.9 \times 10^{-3}/\text{°C}) \times (120 - 20)\text{°C}$$
$$= 5 \text{ m}^3 \times (0.0009/\text{°C}) \times (100)\text{°C}$$
$$= 0.0045 \text{ m}^3/\text{°C}\times100\text{°C}$$
$$= 0.45 \text{ m}^3$$

Therefore, the new volume is:

$$V_2 = V_1 + \Delta V$$
$$= 5 \text{ m}^3 + 0.45\text{m}^3$$
$$= 5.45 \text{ m}^3 \text{ (Ans.)}$$
4. A weir with a half notch is 3 m high. What is the maximum flow that it can measure?

The maximum flow is calculated as:

\[
Q = 2.3175H^{5/2}
\]

\[
= 2.3175 \times (3)^{5/2}
\]

\[
= 2.3175 \times 15.5885
\]

\[
= 36.13 \text{ m}^3/\text{s} \quad \text{(Ans.)}
\]

Note: The above question and answer are not appropriate to the 2013 printing and later, since the half notch is not included.

5. A rectangular notch is 7 m wide. The head of water over the rectangular notch is 0.85 metres. Calculate the amount of water it discharges per minute if the discharge coefficient is 0.62.

The head over the notch is calculated using equation \( \frac{2}{3}C_dB\sqrt{2gH^3} \):

\[
\text{Discharge} = \frac{2}{3}C_dB\sqrt{2gH^3}
\]

\[
= \frac{2}{3} \times 0.62 \times 7 \times \sqrt{2 \times 9.81 \times (0.85)^3}
\]

\[
= \frac{2}{3} \times 0.62 \times 7 \times \sqrt{19.62 \times 1.2750}
\]

\[
= \frac{2}{3} \times 0.62 \times 7 \times 4.4294 \times 1.2750
\]

\[
= 16.3401 \text{ m}^3/\text{s}
\]

\[
= 16.3401 \text{ m}^3/\text{s} \times 60 \text{ s/min}
\]

\[
= 980.41 \text{ m}^3/\text{min}
\]

\[
\text{Discharge} = 980.41 \text{ t/ min} \quad \text{(Ans.)}
\]
6.

a) **Describe the principle of flow continuity.**

b) A pipe of 20 cm internal diameter carries water with velocity of 2 m/s. What is the velocity if the pipe size is reduced to 10 cm?

a) The principle of continuity states that the mass flow must be the same at all points of a piping system as long as no junctions occur.

b)

The area of the 20 cm pipe is:

\[ A = \pi r^2 \]
\[ = \pi (0.1 \text{ m})^2 \]
\[ = 0.0314 \text{ m}^2 \]

The area of the 10 cm pipe is:

\[ A = \pi r^2 \]
\[ = \pi (0.05 \text{ m})^2 \]
\[ = 0.0079 \text{ m}^2 \]

The velocity in the 10 cm pipe will be:

\[ v_2 = \frac{A_1 v_1}{A_2} \]
\[ = \frac{0.0314 \text{ m}^2 \times 2 \text{ m/s}}{0.0079 \text{ m}^2} \]
\[ = 7.95 \text{ m/s (Ans.)} \]
7. Water flows through a horizontal pipe which varies in diameter. At one point, the pressure is 225 kPa and the velocity is 2.45 m/s. If the pressure is 30 kPa at another location, what is the velocity?

\[
\frac{P_1}{w} + \frac{v_1^2}{2g} = \frac{P_2}{w} + \frac{v_2^2}{2g}
\]

\[
v_2^2 = \left( \frac{P_1}{w} - \frac{P_2}{w} + \frac{v_1^2}{2g} \right) \times 2g
\]

\[
v_2^2 = \left( \frac{225 \text{ kN/m}^2}{9.81 \text{ kN/m}^2} - \frac{30 \text{ kN/m}^2}{9.81 \text{ kN/m}^2} + \frac{(2.45 \text{ m/s})^2}{2 \times 9.81 \text{ m/s}^2} \right) \times 2 \times 9.81 \text{ m/s}^2
\]

\[
v_2^2 = \left( 22.9358 \text{ m} - 3.0581 \text{ m} + \frac{6.0025 \text{ m}^2/\text{s}^2}{19.62 \text{ m/s}^2} \right) \times 19.62 \text{ m/s}^2
\]

\[
v_2^2 = (22.9358 \text{ m} - 3.0581 \text{ m} + 0.3059 \text{ m}) \times 19.62 \text{ m/s}^2
\]

\[
v_2^2 = 20.18 \text{ m} \times 19.62 \text{ m/s}^2
\]

\[
v_2 = \sqrt{395.93 \text{ m}^2/\text{s}^2}
\]

\[
= 19.90 \text{ m/s} \text{ (Ans.)}
\]

8. Water flows from a 20 cm diameter hole in the side of a tank 5 m from the surface. If the coefficient of discharge is 0.7, what will be the flow?

The area of the orifice is:

\[
A = \pi r^2
\]

\[
= \pi (0.1 \text{ m})^2
\]

\[
= 0.0314 \text{ m}^2
\]

The flow is obtained from the equation \( Q = C_d A \sqrt{2gh} \):

\[
Q = C_d A \sqrt{2gh}
\]

\[
= 0.7 \times 0.0314 \text{ m}^2 \sqrt{2 \times 9.81 \text{ m/s}^2 \times 5 \text{ m}}
\]

\[
= 0.2179 \text{ m}^3/\text{s}
\]

\[
= 217.9 \text{ L/s} \text{ (Ans.)}
\]
9. A venturi meter with a pipe diameter of 30 cm and a throat diameter of 16 cm is used to determine the flow rate of water. If the pressures are measured as 140 kPa and 120 kPa, respectively, and the flow rate is 7000 L/min, what is the coefficient of discharge?

Area of pipe, \[ A_1 = \pi r_1^2 \]
\[ = \pi (0.15\text{ m})^2 \]
\[ = 0.0707\text{ m}^2 \]

Area of throat, \[ A_2 = \pi r_2^2 \]
\[ = \pi (0.08\text{ m})^2 \]
\[ = 0.0201\text{ m}^2 \]

For use later in the flow equation, the ratio of the squares of the areas is:

\[ \frac{A_1^2}{A_2^2} = \left(\frac{\pi r_1^2}{\pi r_2^2}\right)^2 \]
\[ = \left(\frac{0.0707}{0.0201}\right)^2 \]
\[ = (3.5174)^2 \]
\[ = 12.372 \]

Flow rate \( (\text{m}^3/\text{s}) \) = \[ \frac{7000 \text{ L/min}}{1000 \text{ L/m}^3 \times 60 \text{ s/min}} \]
\[ = 0.1167 \]
Since the gravitational force on water, $w$, is 9.81 kN/m$^3$, the coefficient of discharge can be found using the general flow equation, as follows:

$$A_1 C_d \sqrt{\frac{2g (P_1 - P_2)}{w} \left( \frac{A_1^2}{A_2^2 - 1} \right)} = Q$$

$$0.0707 \times C_d \times \sqrt{\frac{2 \times 9.81 \text{ m/s}^2 \times (140 \text{ kN/m}^2 - 120 \text{ kN/m}^2)}{9.81 \text{ kN/m}^3 (12.372 - 1)}} = 0.1167$$

$$C_d \times \sqrt{\frac{19.62 \text{ m/s}^2 \times 20 \text{ kN/m}^2}{9.81 \text{ kN/m}^3}} = 0.1167$$

$$C_d \times \sqrt{\frac{19.62 \text{ m/s}^2 \times 20.039 \text{ m}}{11.372}} = 1.6506$$

$$C_d \times \sqrt{\frac{40 \text{ m}^2/\text{s}^2}{11.372}} = 1.6506$$

$$C_d \times \sqrt{3.517 \text{ m}^2/\text{s}^2} = 1.6506$$

$$C_d \times 1.875 = 1.6506$$

$$C_d = \frac{1.6506}{1.875} = 0.88 \text{ (Ans.)}$$