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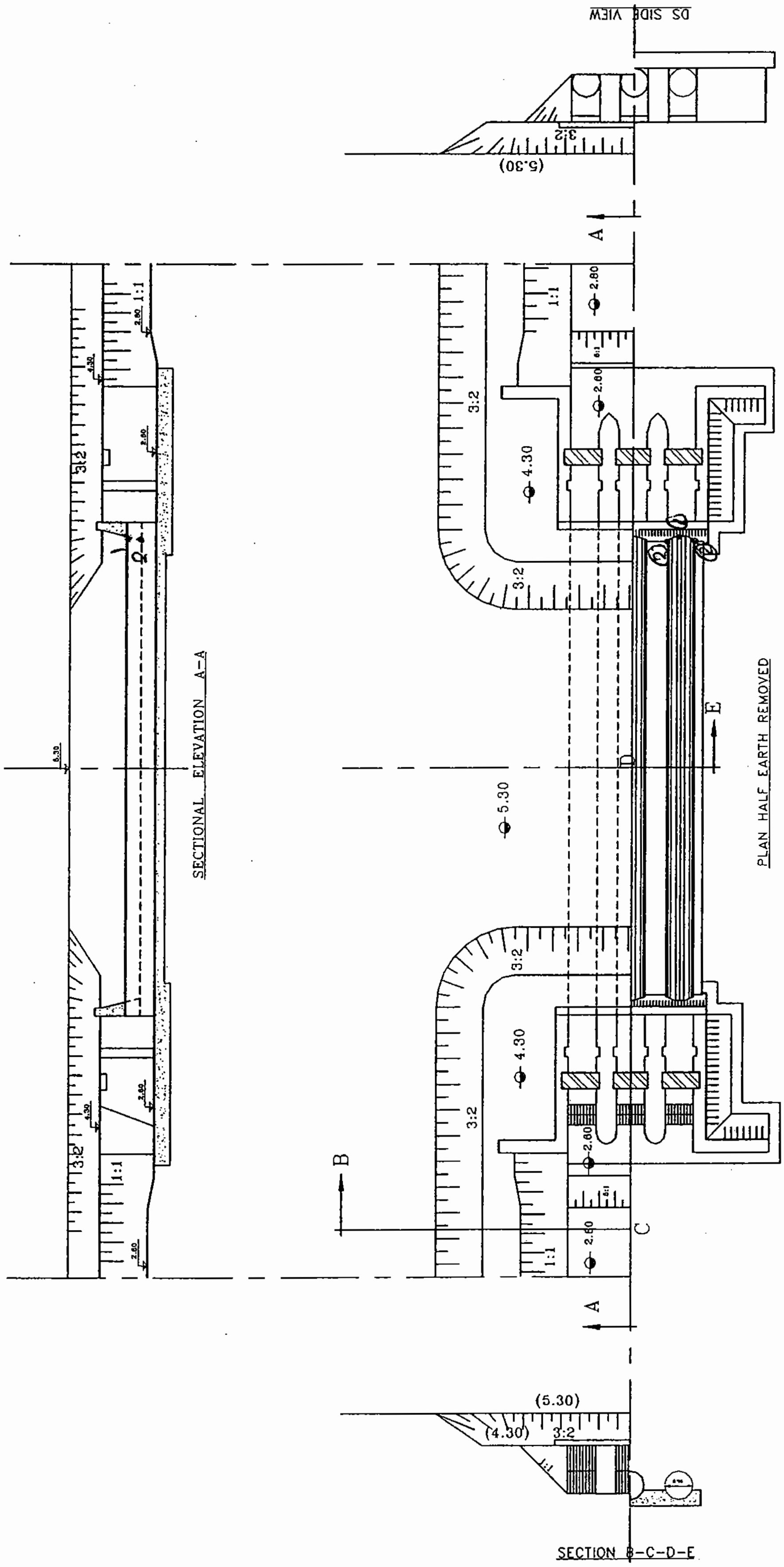
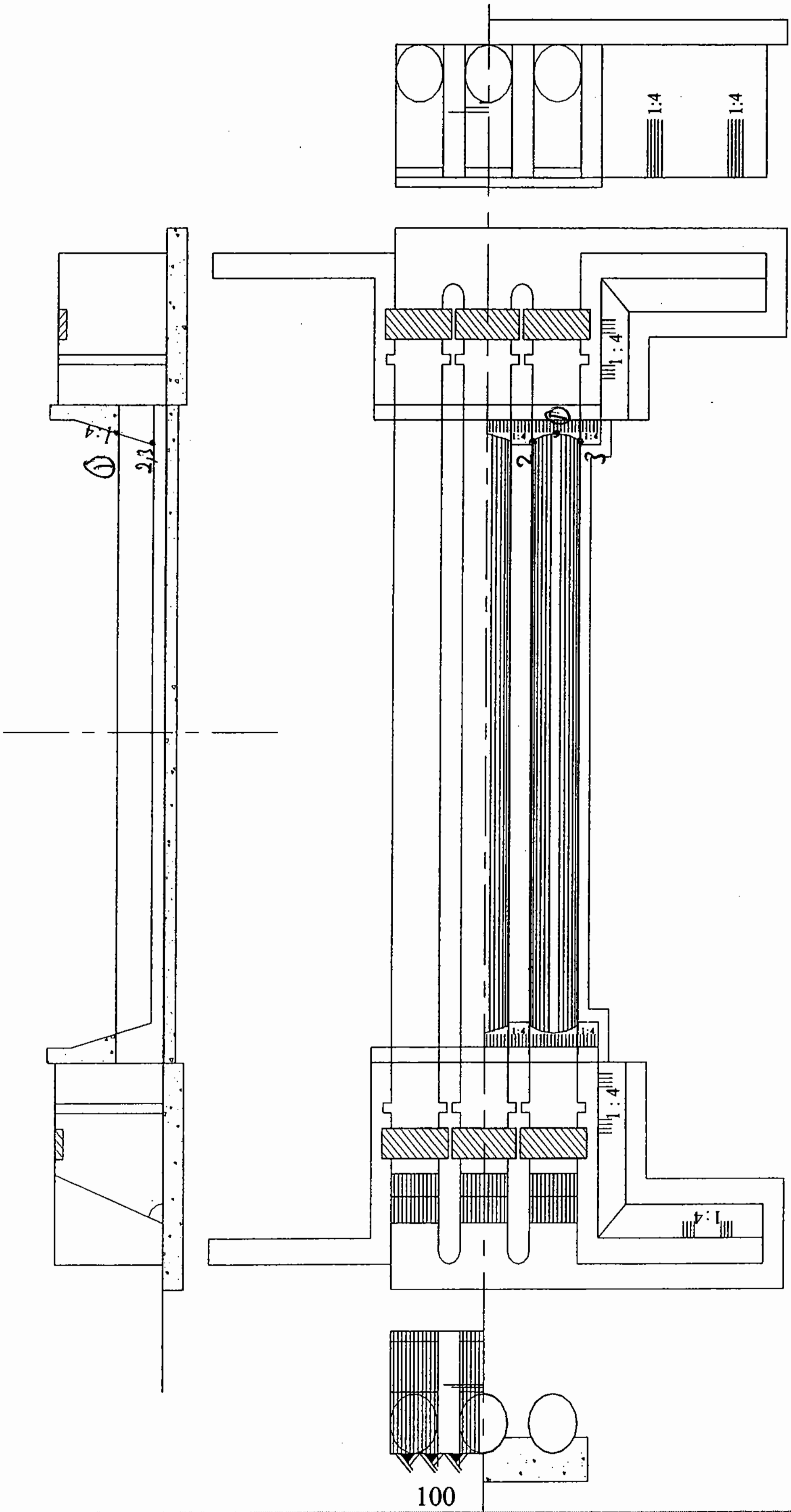
Drawing & Structural Design of Steel Pipe Culverts

Drwaing of steel pipe culvert:



the same as the box culvert exactly in the earth projections but the different is only in the cross section of the culvert itself as shown below



Structural design of Pipe Culvert

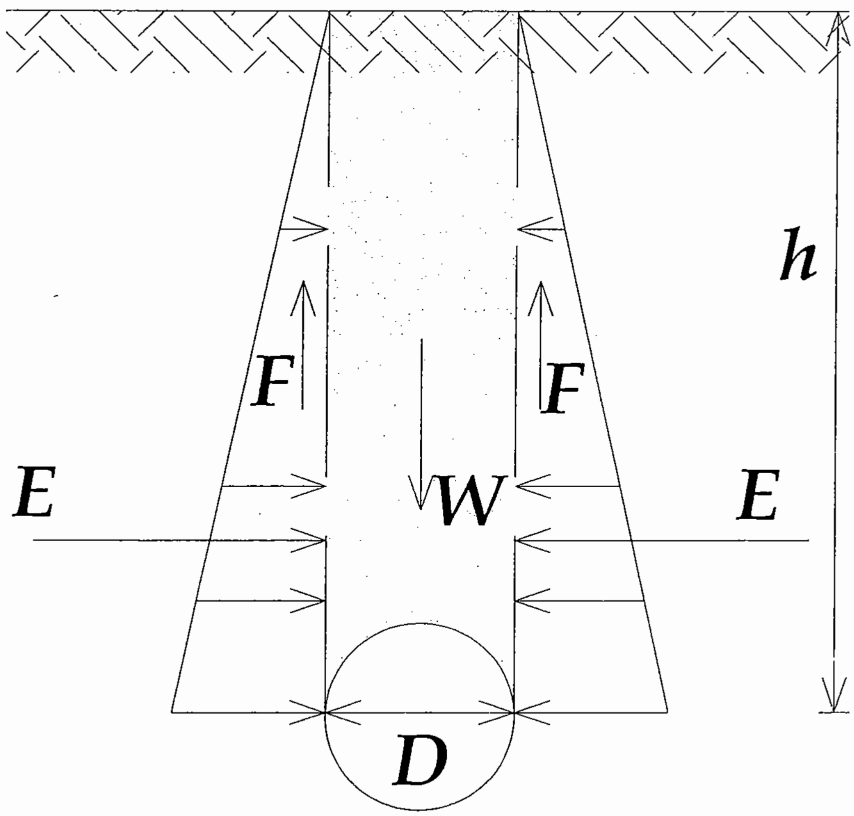
Loads can be classified into 2 types

1) **Vertical loads:**
    a) *Weight of embankment over culvert (L.L.)*
    b) *Own weight of culvert (D.L.)*
    c) *Live Load*
2) **Horizontal Loads:**
    a) *Earth pressure*
    b) *Side pressure due to surcharge*

Vertical loads:

1) Weight of embankment over culvert

The weight of the earth fill above the pipe is not acting with its full value as it is resisted by the effect of the lateral earth pressure.



W = weight of earth = $\gamma_e D h$

F = resistance acting at each side of the wedge of earth = μE

Where $\mu = \tan\varphi$

φ = *angle of internal friction*

$$F = \mu\left[\frac{k\gamma_e h^2}{2}\right]$$

$$F = \tan\varphi\left[\frac{\gamma_e h^2}{2} * \frac{1-\sin\varphi}{1+\sin\varphi}\right]$$

Where $\varphi = 30^o \rightarrow F = 0.192\left[\frac{\gamma_e h^2}{2}\right]$

$g_1\ (t/m')$ = *net load on pipe* = $W - 2F$

$$= \gamma_e D h - 2 * 0.192\left[\frac{\gamma_e h^2}{2}\right]$$

$$g_1 = \gamma_e D h\left[1 - 0.192\frac{h}{D}\right] \ldots\ldots t/m'$$

For $h \geq 5.2D \rightarrow g_1 = zero$

Then at a depth exceeding five times the diameter of the pipe there will be no effect of the weight of the earth fill.

$$g_1(t/m^2) = \frac{g_1(t / m')}{D} = \gamma_e\, h\left[1 - 0.192\frac{h}{D}\right]$$

2) __*Own weight of culvert:*__

$g_2\ (t/m') = $ *half weight of culvert* $/ m'$

$$g_2 = \frac{\pi}{8}\left[(D+2t)^2 - D^2\right]\gamma_{steel} \ldots\ldots (t/m')$$

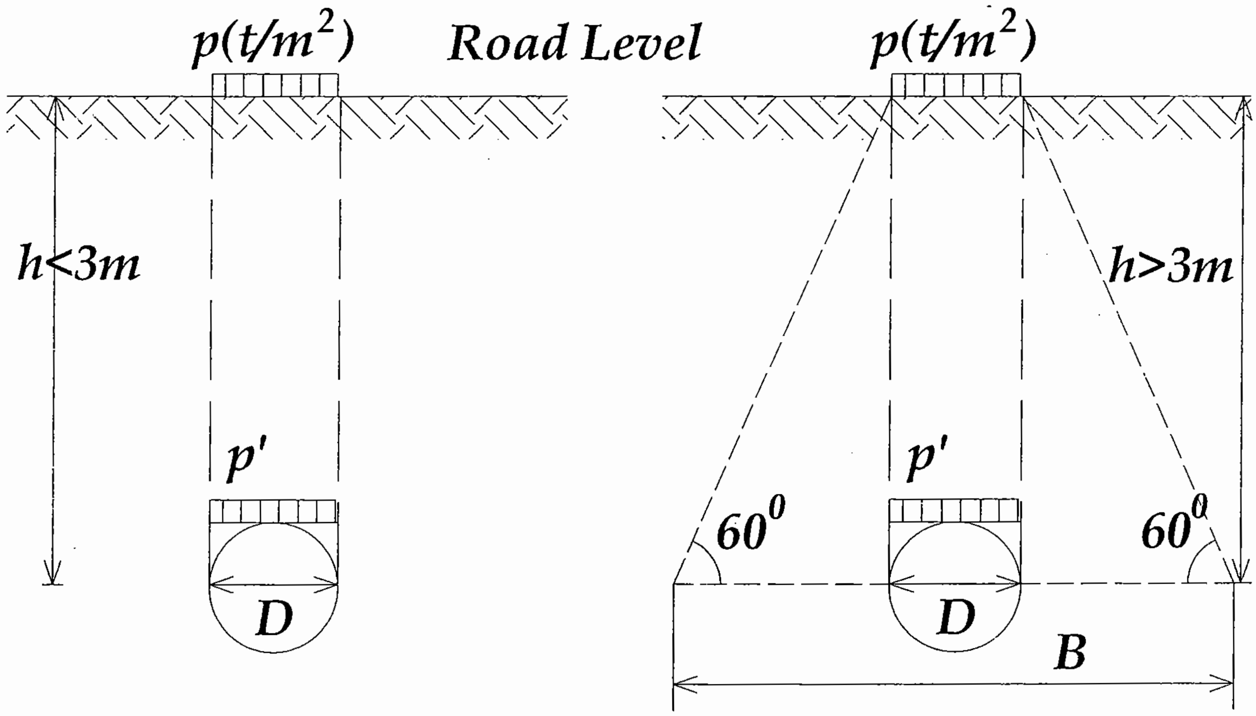
$$g_2\ (t/m^2) = \frac{g_2(t\ /\ m')}{D}$$

Total vertical dead load $g\ (t/m^2) = \dfrac{g_1 + g_2}{D}$

3) __*Live Load:*__

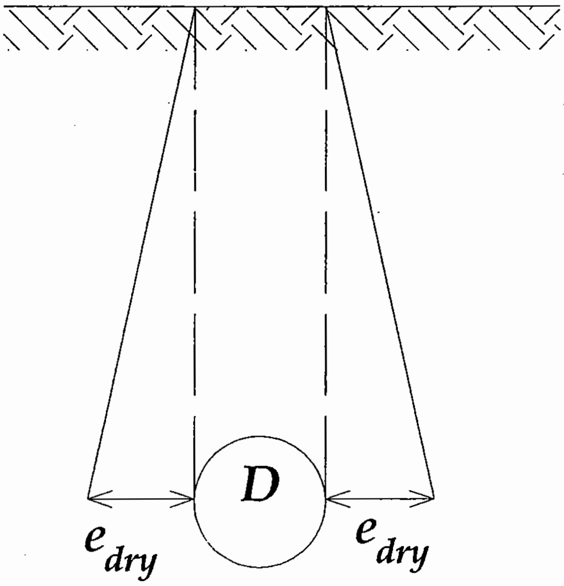
for $h < 3m \rightarrow p' = p$ *(live load intensity at ground level)*

for $h > 3m \rightarrow p' = \dfrac{pD}{B}$

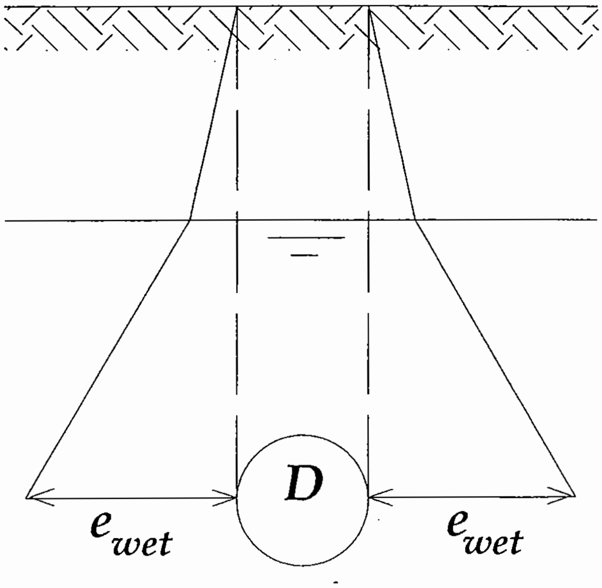


Horizontal loads:

1) Lateral earth pressure:

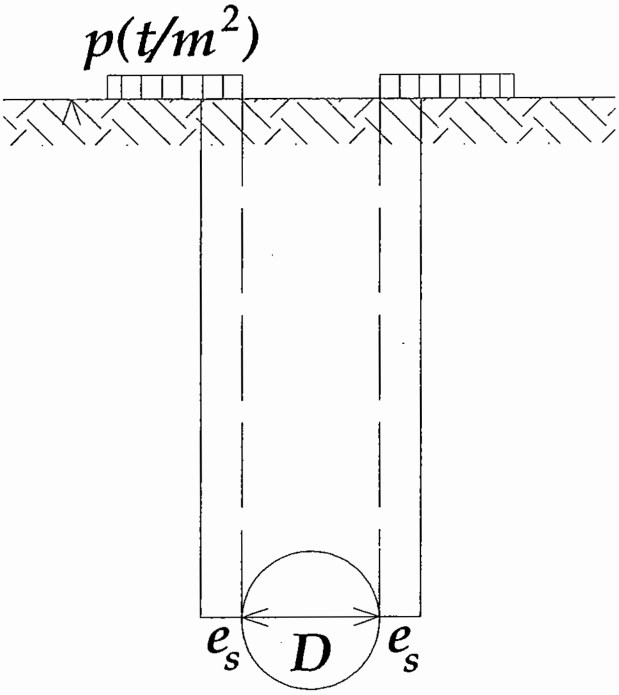


Case of dry earth pressure



Case of wet earth pressure

2) Side pressure due to surcharge:



$$e_s = p\,k$$

Vertical and horizontal loads:

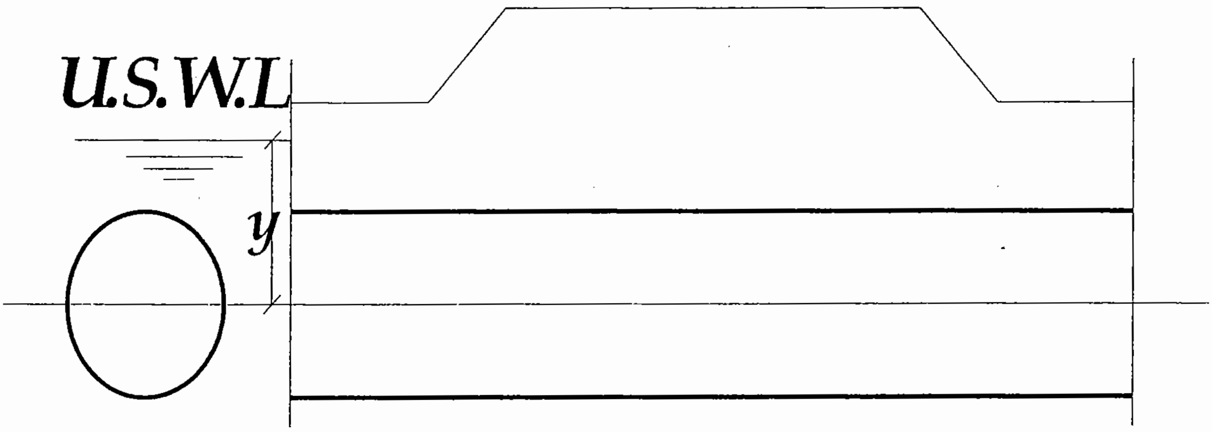
1. ***Internal water pressure:***

Internal pressure is considered to be uniformly distributed on both vertical and horizontal culvert side.

$P = y * \gamma_w$

y = U.S.W.L. – center line level

U.S.W.L. = D.S.W.L. + h_{up}

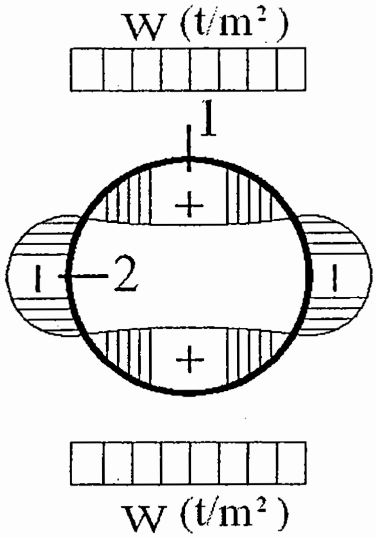


Calculation of straining actions:

1. *For Vertical load (w):*

$$M_1 = \frac{wD^2}{16} \qquad N_1 = zero$$

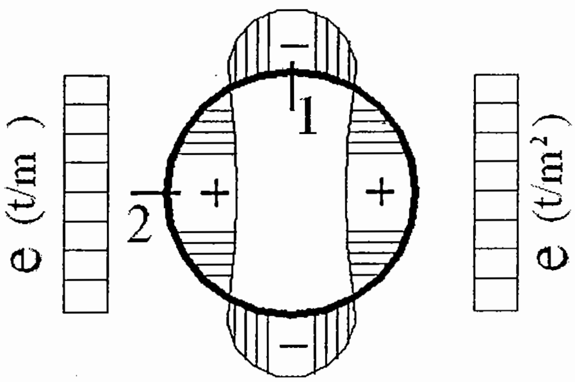
$$M_2 = -\frac{wD^2}{16} \qquad N_2 = \frac{wD}{2}$$



2. *For horizontal load (e):*

$$M_1 = -\frac{eD^2}{16} \qquad N_1 = \frac{eD}{2}$$

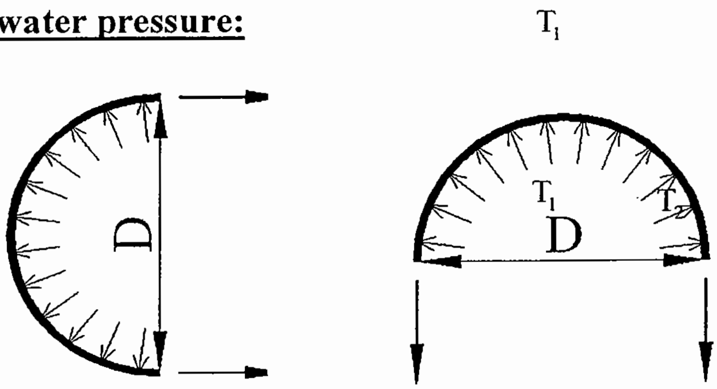
$$M_2 = \frac{eD^2}{16} \qquad N_2 = zero$$



3. **Stress due to internal water pressure:**

$$p_w \times D = 2 \times T$$

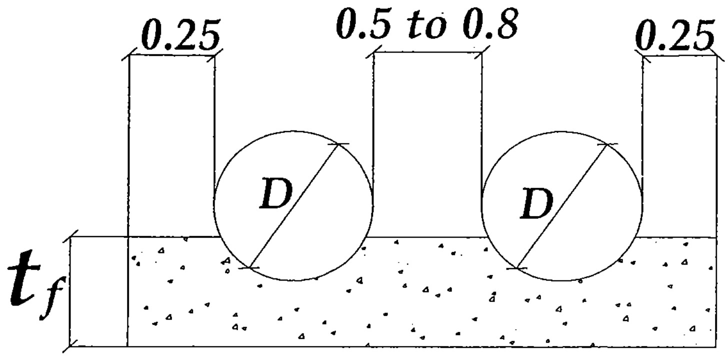
$$T_1 = T_2 = +\frac{p_w \times D}{2}$$



Empirical dimensions:

Pipe thickness $t_{cm} = 0.35(D_m + 1) \geq 15\ mm$

Thickness of foundation $t_f = 0.2\ D + 0.3$



Check Stresses:

Sec (1) is critical for maximum +ve moment

Sec (2) is critical for maximum -ve moment

Sec (1) Max. +ve:

$W_{max} = g_1 + g_2 + P$ *(live load)*

$e_{min} = e_{dry}$

$$M_{max} = \frac{(W_{max} - e_{min})D^2}{16}$$

$$N_{max} = (P_w - e_{min})\ \frac{D}{2}$$

$$f_{max} = \frac{N_{max}}{t} + \frac{6M_{max}}{t^2} \leq \text{maximum allowable tensile stresses for steel}$$

Sec (2) Max. -ve:

$W_{max} = g_1 + g_2 + P$ *(live load)*

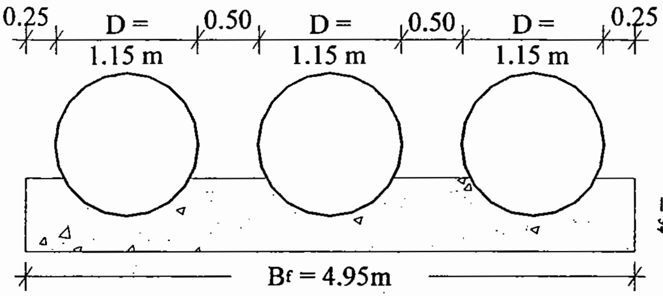
$e_{min} = e_{dry}$

$$M_{max} = \frac{(W_{max} - e_{min})D^2}{16}$$

$$N_{max} = -\ W_{max}\ \frac{D}{2}$$

$$f_{max} = \frac{N_{max}}{t} + \frac{6M_{max}}{t^2} \leq \text{maximum allowable compressive stresses for steel}$$

Example:



Empirical Dimensions:

Pipe thickness:

$$t_{cm} = 0.35(D_m + 1) = 0.35\ (1.15 + 1) = 0.75\ cm = 7.5\ mm$$

$$\therefore \textbf{Take } t = t_{min} = 15\ mm$$

Spacing bet. Pipes = (0.50 – 0.80) m

Take Spacing = min. = 0.50 m

Thickness of foundation:

$$t_f = 0.2\ D + 0.3 = 0.2 \times 1.15 + 0.3 = 0.53\ m$$

$$\therefore \textbf{Take } t_f = 0.60\ m$$

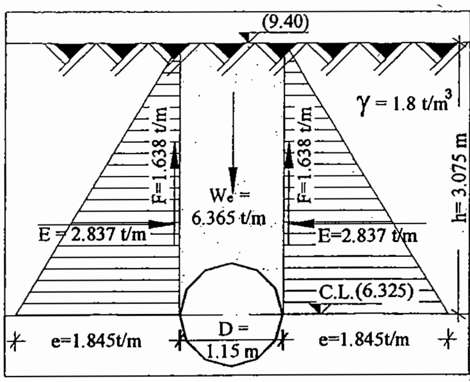
Levels:

Lip level = water level – 0.30 = (7.20) – 0.30 = (6.90)

Centerline level = Lip level – D/2 = (6.90) – (1.15/2) = (6.325)

IV. Loads on Culvert:

4. *Vertical Loads:*



1. *Weight of embankment over culvert:*

Check: h = Road level – Centerline level

= (9.40) – (6.325) = 3.075m < 5D

∴Weight of embankment is **not neglected**

$W_e = \gamma_e \times D \times h = 1.8 \times 1.15 \times 3.075 = \underline{6.635\ t/m}$

For $\varphi = 30°$ $K_a = \frac{1-\sin\varphi}{1+\sin\varphi} = \frac{1-\sin 30°}{1+\sin 30°} = \frac{1}{3}$ & $\mu = \tan\ \varphi = \tan 30°$

$E = e \times h/2 = (K_a \times \gamma_e \times h) \times h/2 = (1/3 \times 1.8 \times 3.075) \times 3.075/2 = 2.837\ t/m$

$F = \mu \times E = \tan 30° \times 2.837 = \underline{1.638\ t/m.}$

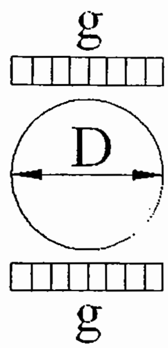
$\therefore g_1 = W_e - 2 \times F = 6.635 - 2 \times 1.638 = 3.089\ t/m$

2. *Own weight of culvert:*

g_2 = *half weight of culvert/m'*

$D_{out} = D + 2t = 1.15 + 2 \times 0.015 = 1.18\ m$

$$g_2 = \frac{1}{2} \times \frac{\pi}{4}\left[D_{out}^{\ 2} - D^2\right] \times \gamma_{steel} = \frac{\pi}{8}\left[1.18^2 - 1.15^2\right] \times 7.8 = 0.214 t/m'$$



∴ *Total vertical dead load:*

$$g = (g_1 + g_2)/D = (3.089 + 0.214)/1.15 = 2.872\ t/m'$$

3. *Live load:*

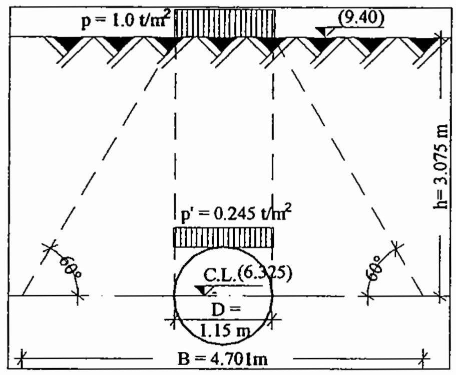
$p = 1.0\ t/m^2$ & $h = 3.075\ m > 3.0\ m$

$B = D + (2 \times h / \tan 60^o)$

$= 1.15 + (2 \times 3.075 / 1.732) = 4.701\ m$

$p' = (p \times D)/B = (1.0 \times 1.15)/4.701$

$\therefore p' = 0.245\ t/m^2$



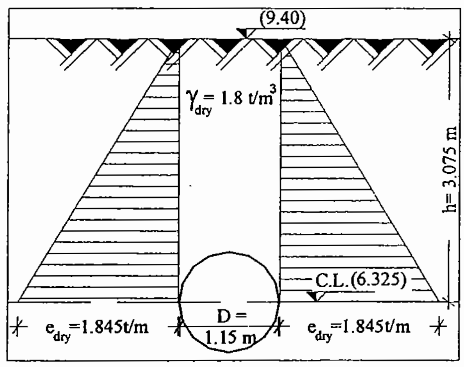
5. **Horizontal Loads:**

1. *Earth pressure:*

a. *Just after construction* (e_{dry})

$e_{dry} = K_a \times h \times \gamma_d$

$= 1/3 \times 3.075 \times 1.8 = 1.845\ t/m^2$



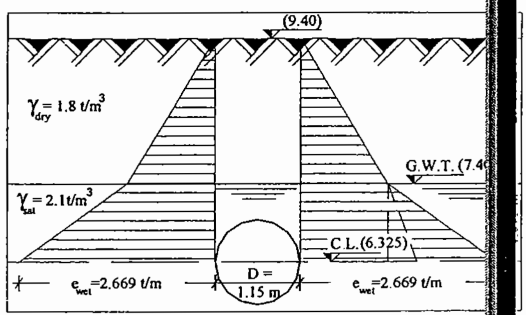
b. *During repair* (e_{wet})

$G.W.T = U.S.\ water\ level = D.S.W.L + h_{up}$

$= (7.20) + 0.20 = (7.40)$

$h_1 = (9.40) - (7.40) = 2.00\ m$

$h_2 = (7.40) - (6.325) = 1.075\ m$



$e_{wet} = K_a \times h_1 \times \gamma_d + K_a \times h_2 \times \gamma_{sub} + h_2 \times \gamma_{water}$

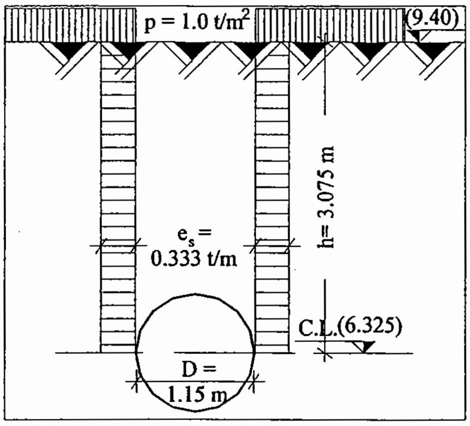
$= 1/3\ [(2.00 \times 1.8) + (1.075 \times 1.1)] + 1.075 \times 1.0$

$\therefore e_{wet} = 2.67\ t/m^2$

2. *Surcharge lateral pressure:*

$p = 1.0\ t/m^2$

$\therefore e_s = p \times K_a = 1.0 \times 1/3 = 0.333\ t/m^2$



6. *Internal water pressure:*

h_w = U.S.W.L. – Centerline Level = 7.40 – 6.325 = 1.075 m

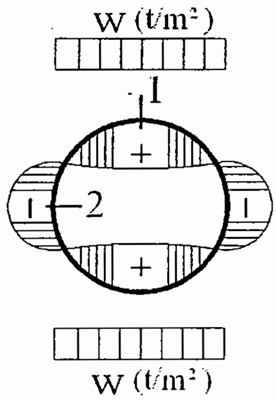
$p_w = h_w \times \gamma_w = 1.075 \times 1.0 = 1.075\ t/m^2$

V. Straining actions:

7. *For Vertical Loads: (w)*

$$M_1 = +\frac{wD^2}{16} \qquad N_1 = zero$$

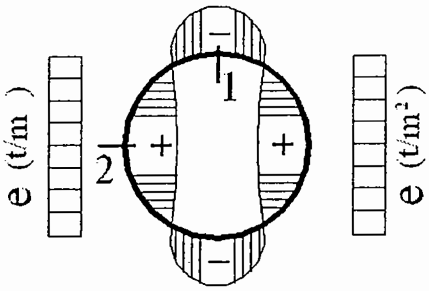
$$M_2 = -\frac{wD^2}{16} \qquad N_2 = -\frac{wD}{2}$$



8. *For Horizontal Loads: (e)*

$$M_1 = -\frac{eD^2}{16} \qquad N_1 = -\frac{eD}{2}$$

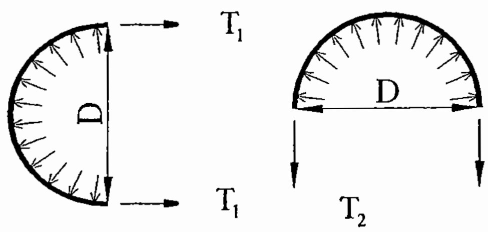
$$M_2 = +\frac{eD^2}{16} \qquad N_2 = zero$$



9. *Stress due to internal water pressure:*

$p_w \times D = 2 \times T$

$$T_1 = T_2 = +\frac{p_w \times D}{2}$$



VI. Check stresses:

Section 1:

$w_{max} = g + p = 2.872 + 0.245 = 3.117\ t/m^2$

$e_{min} = e_{dry} = 1.845\ t/m^2$

$$M_{max} = \frac{(w_{max} - e_{min})D^2}{16} = \frac{(3.117 - 1.845) \times 1.15^2}{16} = 0.105 mt$$

$$N_{min} = -\frac{e_{min} \times D}{2} + \frac{p_w \times D}{2} = -\frac{1.845 \times 1.15}{2} + \frac{1.075 \times 1.15}{2} = -0.443t$$

$t = 15\ mm = 0.015\ m$

Max. tensile stresses

$$f_{t\,max} = \frac{N_{min}}{t} + \frac{6M_{max}}{t^2} = \frac{-0.443}{0.015} + \frac{0.63}{0.000225} = 2770t/m^2 = 0.277t/cm^2$$

$$< f_{tall} = 1.4\ t/cm^2$$

Section 2:

$$M_{max} = \frac{(w_{max} - e_{min})D^2}{16} = \frac{(3.117 - 1.845) \times 1.15^2}{16} = 0.105 mt$$

$$N_{max} = -\frac{w_{max} \times D}{2} = -\frac{3.117 \times 1.15}{2} = -1.79t$$

$t = 15\ mm = 1.5\ cm$ $\quad$ $b = 1.0\ m = 100\ cm$

$A = b \times t = 150\ cm^2$ $\quad$ $Z = b \times t^2/6 = 37.5\ cm^4$

Max. compressive stresses

$$f_{t\,max} = \frac{N_{min}}{t} + \frac{6M_{max}}{t^2} = \frac{-1.709}{0.015} + \frac{0.63}{0.000225} = 2686t/m^2 = 0.268t/cm^2$$

$$< f_{call} = 1.2\ t/cm^2$$