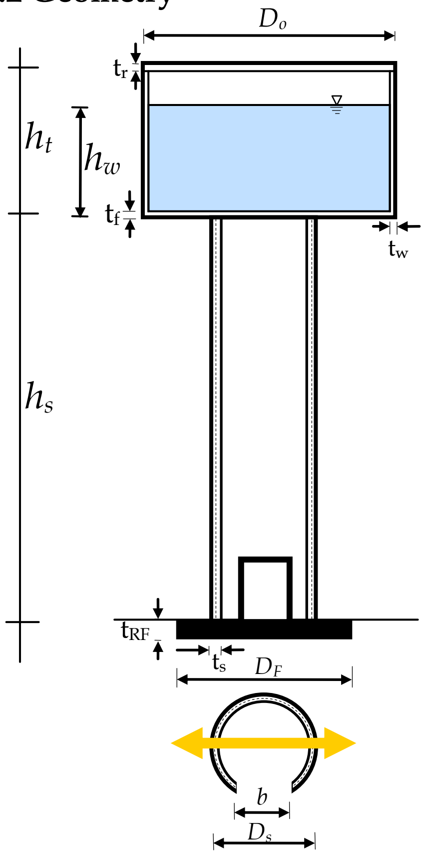
2. INPUTS

2.1 Basic Information

(1) Location : Panchkula
(2) Type of Staging : Shaft
(3) Importance Factor I : 1.5
(4) Capacity : 454 m^3
(5) Shape of Water Tank : Rectangular

Seismic Zone as per Indian Seismic Code: IV
Site-specific horizontal acceleration Z_{SS} : 1g
Detailing Type: Ordinary / Special R = [✓ 1.8] / 2.5

2.2 Geometry



Inputs	*Units*
h_t	= 4.25m
D_o	= 12.5m
t_w	= 0.15 m
t_r	= 0.15 m
t_f	= 0.15 m
h_w	= 3.9 m
b	= 0.9 m
h	= 2.0 m
t_s	= 0.15 m
h_s	= 26 m
D_s	= 10 m
D_F	= 12 m
t_{RF}	= 1.00 m
Vertical Reinforcement: Y16 @ 200 c/c *Transverse Reinforcement:* Y12 @ 175 c/c	

Figure 2.1: Elevated Water Tanks- Shaft Staging

2.3 Materials and Structural System

(1) Grade of Concrete f_{ck} = 15 MPa   Modulus of Elasticity, $E_c = 5000\sqrt{f_{ck}}$ =19,365 MPa

(2) Type of Soil **(Tick ONE)**

(i)	*Rocky and Hard Soil*	**N>30**	**:**	Type I
[✓ (ii)]	*Medium Soil*	**30>N>10**	**:**	Type II
(iii)	*Soft Soil*	**10<N**	**:**	Type III

3. BASIC SAFETY CHECKS

3.1 Section Properties

Derived Quantities	*Units*
$D_i = D_o - 2t_w = 12.5 - 2 \times 0.15$	= 12.2 m
$W_{T\_empty} = \left[\left(\pi/4\right)\left(D_0^{\,2} - D_i^{\,2}\right)h_t + \left(\pi/4\right)D_0^{\,2}\left(t_r + t_f\right)\right]\gamma_{concrete}$ $= \left[\left(\pi/4\right)\left(12.5^2 - 12.2^2\right)4 + \left(\pi/4\right)12.5^2(0.15 + 0.15)\right]25$	=1501 kN
$W_{water} = \left[\left(\pi/4\right)D_i^{\,2}h_w\right]\rho_{water}g = \left[\left(\pi/4\right)12.2^2 \times 3.9\right]9.81$	= 4470 kN
$W_{T\_full} = W_{T\_empty} + W_{water} = 1501 + 4470$	= 5971 kN
$W_{staging} = \pi\left(D_s - t_s\right)t_s h_s \gamma_{concrete} = \pi\left(10 - 0.15\right)0.15 \times 26 \times 25$	= 3016 kN
$I_s = \pi R_s^{\,2} t_s = \pi \times 5^2 \times 0.15$	= 11.775 m⁴
$A_s = \pi\left(D_s - t_s\right)t_s$	= 4.639 m²
$r_e = \sqrt{\dfrac{I_s}{A_s}} = \sqrt{\dfrac{11.775}{4.639}}$	= 1.593 m
$W_{s\_full} = W_{T\_full} + \left(1/3\right)W_{staging} = 5971 + \left(1/3\right)3016$	= 6976 kN
$W_{s\_empty} = W_{T\_empty} + \left(1/3\right)W_{staging} = 1501 + \left(1/3\right)3016$	= 2506 kN
$W_{foundation} = \left(\pi/4\right)D_F^{\,2} t_{RF} \rho_{concrete} g = \left(\pi/4\right) \times 12^2 \times 1 \times 25$	= 2826 kN
Equivalent shear wall length $l_e = 0.78D_s$ = 0.78×10 = 7.8 m $\psi = \dfrac{b}{l_e} = \dfrac{0.9}{7.8}$ =0.115	
Eccentricity e due to unsymmetrical opening $e = 0.5D_s\left(\dfrac{\psi}{2 - \psi}\right)$ = 0.305	

3.2 Natural Period of Tank

Tank Full $T_{full} = C_T\sqrt{\frac{W_{s\_full}h_s}{E_s A_s g}} = 31.92\sqrt{\frac{6976\times10^3\times26}{19365\times10^6\times4.639\times9.81}}$; Tank Empty $T_{empty} = C_T\sqrt{\frac{W_{s\_empty}h_s}{E_s A_s g}} = 31.92\sqrt{\frac{2506\times10^3\times26}{19365\times10^6\times4.639\times9.81}}$ where *staging slenderness ratio* $k = \left(\frac{h_s}{r_e}\right) = \frac{26}{1.593}$ =16.32; C_T = 31.92	T_{full} = 0.456 s	T_{empty} = 0.274 s

k	C_T
5	14.4
10	21.2
15	29.6
20	38.4
25	47.2
30	56.0
35	65.0
40	73.8
45	82.8
>50	1.8k

3.4 Design Horizontal Seismic Force

Spectral Acceleration (S_a/g)	$(S_a/g)_{full}$= 2.5	$(S_a/g)_{empty}$= 2.5
Horizontal seismic coefficient $A_h = \frac{Z_{SS}I}{R}\left(\frac{S_a}{g}\right)$	$= \frac{1.0\times1.5}{1.8}(2.5) =$ 2.08	$= \frac{1.0\times1.5}{1.8}(2.5)$ = 2.08
Base Shear Filled $V_B = A_h W_{s\_full}$; Empty $V_B = A_h W_{s\_empty}$	= 2.08 × 6976 = 14,510 kN	= 2.08 × 2506 = 5,212 kN
Governing Shear force V_u is greatest of Full and Empty condition	= 14,510 kN	

Soil Type	*Spectral Acceleration (S_a/g)*
Type I	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \le T \le 0.4 \\ 1.00/T & 0.4 \le T \le 4.0 \end{cases}$
Type II	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \le T \le 0.55 \\ 1.36/T & 0.55 \le T \le 4.0 \end{cases}$
Type III	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \le T \le 0.67 \\ 1.67/T & 0.67 \le T \le 4.0 \end{cases}$

3.5 Shear Demand and Capacity of Shaft Staging

Shear Force due to Torsional Moment $V_T = V_B e/D_s$	$= \frac{14510\times0.305}{10}$ = 443 kN	
Design Horizontal Shear Force on the staging cross-section	$V_d = 0.5V_b + V_T$ = 0.5×14510+443 =7,688 kN	$V_d = 0.5V_b - V_T$ = 0.5×14510- 443 = 6,812 kN

3.6 Shear Capacity of Shaft Staging

Area of cross section through the opening of the shaft staging A_c	$A_c = 0.8 l_e t_s$ = 0.8×7.8×0.15 = 0.936 m^2	$A_c = 0.8(l_e - b)t_s$ = 0.8(7.8-0.9)0.15 = 0.828 m^2
Percentage of Longitudinal Reinforcement $\rho = \dfrac{100 A_{t\_st}}{A_s}$	$= \dfrac{100 \times 0.031}{4.64}$ = 0.67	$= \dfrac{100 \times 0.029}{4.51}$ = 0.64
For a percentage of Longitudinal Reinforcement ***ρ*** *in shaft wall,* from Table 19 of IS:456-2000, Design Shear Stress of Concrete τ_c	= 0.52 MPa	= 0.52 MPa
Shear Carried by Concrete $V_{uc} = \tau_c A_c$	= 0.52 × 0.94×10^6 N =489 kN	= 0.52 × 0.83×10^6 N =432 kN
Shear Carried by Steel V_{us}	$= 0.87 f_y A_{t\_st} \dfrac{0.8 l_e}{s_v}$ $= 0.87 \times 415 \times 113 \times \dfrac{0.8 \times 7800}{175} =$ 1455 kN	$= 0.87 f_y A_{t\_st} \dfrac{0.8 l_e - b}{s_v}$ $= 0.87 \times 415 \times 113 \times \dfrac{(0.8 \times 7800 - 900)}{175} =$ 1287 kN
Total Shear Capacity of Shaft Staging $V_{u,shaft} = V_{uc} + V_{us}$	= 489 + 1455 = 1944 kN **< Shear Demand *V*$_d$**	= 432 + 1287 = 1719 kN **< Shear Demand *V*$_d$**

3.6 Check for Overturning Moment

Over Turning Moment $M_{OT} = V_B \left(h_s + \dfrac{h_t}{2} \right)$	$= 14510(26 + 4.25/2)$ = 4,08,093 kNm	$= 5212(26 + 4.25/2)$ = 1,46,587 kNm
Restoring Moment $M_R = \left(W_{tank} + W_{staging} + W_{foundation} \right) \left(1 - \dfrac{2}{3} A_h \right) \dfrac{D_F}{2}$ where D_F, is diameter of the foundation	$= (5971 + 3016 + 2826)\left(1 - \dfrac{2}{3} \times 2.08 \right) \dfrac{10}{2}$ = -23,247 kNm	$= (1501 + 3016 + 2826)\left(1 - \dfrac{2}{3} \times 2.08 \right) \dfrac{10}{2}$ = -14,451 kNm
Factor of Safety = M_R / M_{OT}	=?	=?
Check	**<< 1.5**	**<< 1.5**