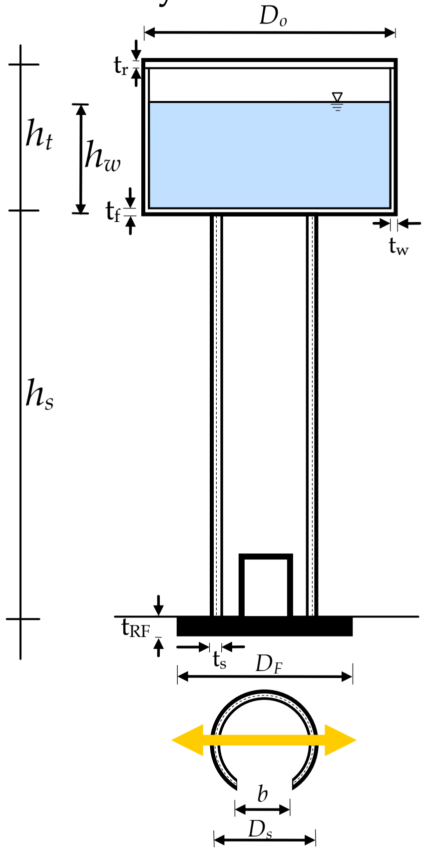
2. INPUTS

2.1 Basic Information

(1) Location : Kasumpti (Shimla)
(2) Type of Staging : Shaft
(3) Importance Factor I : 1.5
(4) Capacity : 227.5 m^3
(5) Shape of Water Tank : Circular

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	= 5.0 m
D_o	= 8.5 m
t_w	= 0.200 m
t_r	= 0.100 m
t_f	= 0.200 m
h_w	= 4.1 m
b	= 0.750 m
h	= 1.600 m
t_s	= 0.125 m
h_s	= 17.25 m
D_s	= 5.45 m
D_F	= 7.50 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, $E_c = 5000\sqrt{f_{ck}}$ = 19,500 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

Rapid Assessment of Seismic Safety of
Elevated Water Tanks with Shaft Staging

3. BASIC SAFETY CHECKS

3.1 Section Properties

Derived Quantities	*Units*
$D_i = D_o - 2t_w$ = 8.5 -2 × 0.2	= 8.1 m
$W_{T\_empty} = \left[\left(\pi/4\right)\left(D_0^{\,2} - D_i^{\,2}\right)h_t + \left(\pi/4\right)D_0^{\,2}\left(t_r + t_f\right)\right]\rho_{concrete}g$	= 1,077 kN
$W_{water} = \left[\left(\pi/4\right)D_i^{\,2}h_w\right]\rho_{water}g$	= 5,279 kN
$W_{T\_full} = W_{T\_empty} + W_{water}$	= 6,356 kN
$W_{staging} = \pi\left(D_s - t_s\right)t_s h_s \rho_{concrete}g$	= 901 kN
$I_s = \pi R_s^{\,3} t_s = \pi\left(\frac{D_s - t_s}{2}\right)^3 t_s$	= 7.40 m^4
$A_s = \pi\left(D_s - t_s\right)t_s$	= 2.09 m^2
$r_e = \sqrt{\frac{I_s}{A_s}}$	= 1.88 m
$W_{s\_full} = W_{full} + \left(1/3\right)W_{staging}$	= 6,657 kN
$W_{s\_empty} = W_{empty} + \left(1/3\right)W_{staging}$	= 1,377 kN
$W_{foundation} = \left(\pi/4\right)D_F^{\,2}t_{RF}\,\rho_{concrete}g$	= 1105 kN
Equivalent shear wall length $l_e = 0.78D_s$ = 4.25 m $\psi = \frac{b}{l_e}$ = 0.75/4.25 = 0.176	
Eccentricity e due to unsymmetrical opening $e = 0.5D_s\left(\frac{\psi}{2-\psi}\right)$ = *0.5× 5.45×(0.176)/(2-0.176) = 0.263* m	

3.2 Natural Period of Tank

Tank Full $T_{full} = C_T\sqrt{\frac{W_{s\_full}h_s}{E_c A_s g}}$; Tank Empty $T_{empty} = C_T\sqrt{\frac{W_{s\_empty}h_s}{E_c A_s g}}$ where *staging slenderness ratio* $k = \left(\frac{h_s}{r_e}\right)$ = 17.25/1.88= 9.175; C_T = 20.1	T_{full} = 0.33 s	T_{empty} =0.14 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

	Tank Full	Tank Empty
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 $V_B = A_h W_{s\_empty}$	= 2.08×6657 = 13,847 kN	= 2.08×1377 = 2,864 kN
Governing Shear force V_u is greatest of Full and Empty condition	= 13,847 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 on Shaft Staging

Shear Force due to Torsional Moment $V_T = V_B e/D_s$	$= \frac{13847\times0.263}{5.45}$ = 668 kN	
Design Horizontal Shear Force on the staging cross-section	$V_d = 0.5V_b + V_T$ = 0.5×13847+668 =7,591 kN	$V_d = 0.5V_b - V_T$ = 0.5×13847-668 = 6,256 kN

3.6 Shear Capacity of Shaft Staging

Area of cross section through the opening of the shaft staging A_c	$A_c = 0.8 l_e t_s$ = 0.8×4.25×0.125 = 0.43 m²	$A_c = 0.8(l_e - b)t_s$ = 0.8(4.25-0.75)0.125 = 0.35 m²
Percentage of Longitudinal Reinforcement $\rho = \dfrac{100 A_{t\_st}}{A_s}$	$= \dfrac{100 \times 0.0234}{2.09}$ = 1.12	$= \dfrac{100 \times 0.0226}{1.99}$ = 1.13
For a percentage of Longitudinal Reinforcement ρ *in shaft wall,* from Table 19 of IS:456-2000, Design Shear Stress of Concrete τ_c	= 0.62 MPa	= 0.62 MPa
Shear Carried by Concrete $V_{uc} = \tau_c A_c$	= 0.62 × 0.43×10⁶ N =267 kN	= 0.62 × 0.35×10⁶ N =214 kN
Shear Carried by Steel V_{us}	$= 0.87 f_y A_{t\_st} \dfrac{0.8 l_e}{s_v}$ $= 0.87 \times 415 \times 113 \times \dfrac{0.8 \times 4250}{175}$ =793 kN	$= 0.87 f_y A_{t\_st} \dfrac{0.8 l_e - b}{s_v}$ $= 0.87 \times 415 \times 113 \times \dfrac{(0.8 \times 4250 - 750)}{175}$ =618 kN
Total Shear Capacity of Shaft Staging $V_{u,shaft} = V_{uc} + V_{us}$	= 267 + 793 = 1060 kN **< Shear Demand V_d**	= 214 + 618 = 832 kN **< Shear Demand V_d**

3.7 Check for Overturning Moment

Over Turning Moment $M_{OT} = V_B \left(h_s + \dfrac{h_t}{2} \right)$	= 13847 ×(17.25+5/2) = 2,73,478 kNm	= 2864× (17.25+5/2) = 56,564 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	$= (6356 + 901 + 1105)\left(1 - \dfrac{2}{3} \times 2.08\right)\dfrac{7.5}{2}$ = -12,342 kNm	$= (1077 + 901 + 1105)\left(1 - \dfrac{2}{3} \times 2.08\right)\dfrac{7.5}{2}$ = -4,550 kNm
Factor of Safety = M_R / M_{OT}	=	=
Check	**<< 1.5**	**<< 1.5**