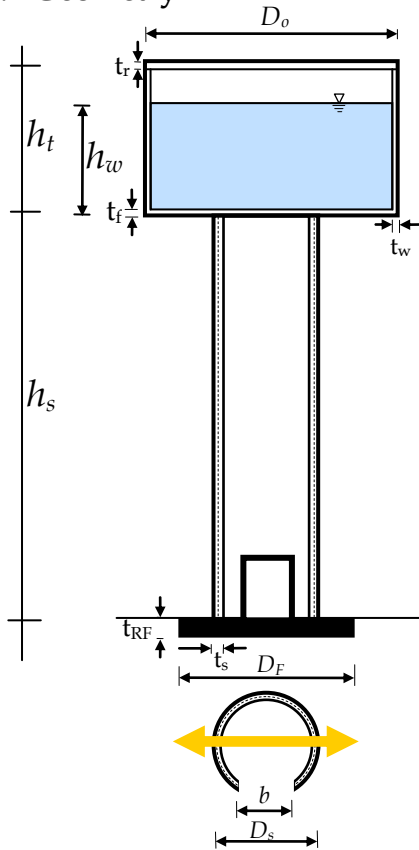


2. INPUTS

2.1 Basic Information

- | | | |
|-------------------------|------------------------|---|
| (1) Location | : Kasumpti (Shimla) | Seismic Zone as per Indian Seismic Code: IV |
| (2) Type of Staging | : Shaft | Site-specific horizontal acceleration Z_{SS} : 1g |
| (3) Importance Factor I | : 1.5 | Detailing Type: Ordinary / Special R = 1.8/2.5 |
| (4) Capacity | : 227.5 m ³ | |
| (5) Shape of Water Tank | : Circular | |

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

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

3.2 Natural Period of Tank

<p>Tank Full $T_{full} = C_T \sqrt{\frac{W_{s_full} h_s}{E_c A_s g}}$; Tank Empty $T_{empty} = C_T \sqrt{\frac{W_{s_empty} h_s}{E_c A_s g}}$</p> <p>where staging slenderness ratio $k = \left(\frac{h_s}{r_e}\right) = 17.25/1.88 = 9.175$; $C_T = 20.1$</p> <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th>k</th> <th>C_T</th> </tr> </thead> <tbody> <tr><td>5</td><td>14.4</td></tr> <tr><td>10</td><td>21.2</td></tr> <tr><td>15</td><td>29.6</td></tr> <tr><td>20</td><td>38.4</td></tr> <tr><td>25</td><td>47.2</td></tr> <tr><td>30</td><td>56.0</td></tr> <tr><td>35</td><td>65.0</td></tr> <tr><td>40</td><td>73.8</td></tr> <tr><td>45</td><td>82.8</td></tr> <tr><td>>50</td><td>1.8k</td></tr> </tbody> </table>	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	$T_{full} = 0.33$ 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)			
Soil Type	Spectral Acceleration (S_a/g)		
Type I	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \leq T \leq 0.4 \\ 1.00/T & 0.4 \leq T \leq 4.0 \end{cases}$	$(S_a/g)_{full} = 2.5$	$(S_a/g)_{empty} = 2.5$
Type II	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \leq T \leq 0.55 \\ 1.36/T & 0.55 \leq T \leq 4.0 \end{cases}$		
Type III	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \leq T \leq 0.67 \\ 1.67/T & 0.67 \leq T \leq 4.0 \end{cases}$		
Horizontal seismic coefficient $A_h = \frac{Z_{SS} I}{R} \left(\frac{S_a}{g}\right)$		$= \frac{1.0 \times 1.5}{1.8} (2.5) = 2.08$	$= \frac{1.0 \times 1.5}{1.8} (2.5) = 2.08$
Base Shear Filled $V_B = A_h W_{s_full}$; Empty $V_B = A_h W_{s_empty}$		$= 2.08 \times 6657 = 13,847$ kN	$= 2.08 \times 1377 = 2,864$ kN
Governing Shear force V_u is greatest of Full and Empty condition		$= 13,847$ kN	

3.5 Shear Demand on Shaft Staging

Shear Force due to Torsional Moment $V_T = V_B e / D_s$	$= \frac{13847 \times 0.263}{5.45} = 668$ kN	
Design Horizontal Shear Force on the staging cross-section	$V_d = 0.5V_b + V_T = 0.5 \times 13847 + 668 = 7,591$ kN	$V_d = 0.5V_b - V_T = 0.5 \times 13847 - 668 = 6,256$ kN

3.6 Shear Capacity of Shaft Staging

Area of cross section through the opening of the shaft staging A_c	$A_c = 0.8l_e t_s$ $= 0.8 \times 4.25 \times 0.125$ $= 0.43 \text{ m}^2$	$A_c = 0.8(l_e - b)t_s$ $= 0.8(4.25 - 0.75)0.125$ $= 0.35 \text{ m}^2$
Percentage of Longitudinal Reinforcement $\rho = \frac{100A_{t-st}}{A_s}$	$= \frac{100 \times 0.0234}{2.09}$ $= 1.12$	$= \frac{100 \times 0.0226}{1.99}$ $= 1.13$
For a percentage of Longitudinal Reinforcement ρ in shaft wall, from Table 19 of IS:456-2000, Design Shear Stress of Concrete τ_c	$= 0.62 \text{ MPa}$	$= 0.62 \text{ MPa}$
Shear Carried by Concrete $V_{uc} = \tau_c A_c$	$= 0.62 \times 0.43 \times 10^6 \text{ N}$ $= 267 \text{ kN}$	$= 0.62 \times 0.35 \times 10^6 \text{ N}$ $= 214 \text{ kN}$
Shear Carried by Steel V_{us}	$= 0.87 f_y A_{t-st} \frac{0.8l_e}{s_v}$ $= 0.87 \times 415 \times 113 \times \frac{0.8 \times 4250}{175}$ $= 793 \text{ kN}$	$= 0.87 f_y A_{t-st} \frac{0.8l_e - b}{s_v}$ $= 0.87 \times 415 \times 113 \times \frac{(0.8 \times 4250 - 750)}{175}$ $= 618 \text{ kN}$
Total Shear Capacity of Shaft Staging $V_{u,shaft} = V_{uc} + V_{us}$	$= 267 + 793$ $= 1060 \text{ kN}$ $< \text{Shear Demand } V_d$	$= 214 + 618$ $= 832 \text{ kN}$ $< \text{Shear Demand } V_d$

3.7 Check for Overturning Moment

Over Turning Moment $M_{OT} = V_B \left(h_s + \frac{h_t}{2} \right)$	$= 13847 \times (17.25 + 5/2)$ $= 2,73,478 \text{ kNm}$	$= 2864 \times (17.25 + 5/2)$ $= 56,564 \text{ kNm}$
Restoring Moment $M_R = (W_{tank} + W_{staging} + W_{foundation}) \left(1 - \frac{2}{3} A_h \right) \frac{D_F}{2}$ where D_F is diameter of the foundation	$= (6356 + 901 + 1105) \left(1 - \frac{2}{3} \times 2.08 \right) \frac{7.5}{2}$ $= -12,342 \text{ kNm}$	$= (1077 + 901 + 1105) \left(1 - \frac{2}{3} \times 2.08 \right) \frac{7.5}{2}$ $= -4,550 \text{ kNm}$
Factor of Safety = M_R / M_{OT}	$=$	$=$
Check	$\ll 1.5$	$\ll 1.5$