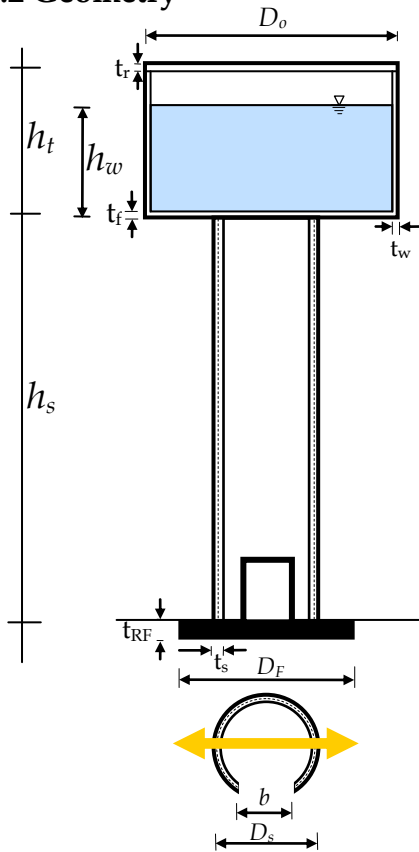


## 2. INPUTS

### 2.1 Basic Information

(1) Location	: Srinagar	Seismic Zone as per Indian Seismic Code: V
(2) Type of Staging	: Shaft	Site-specific horizontal acceleration $Z_{SS}$ : 0.36g
(3) Importance Factor I	: 1.5	Detailing Type: Ordinary / Special R = 1.8/2.5
(4) Capacity	: 75 m <sup>3</sup>	
(5) Shape of Water Tank	: Rectangular	

### 2.2 Geometry



Inputs	Units
$h_t$	= 3.300 m
$D_o$	= 6.000 m
$t_w$	= 0.200 m
$t_r$	= 0.120 m
$t_f$	= 0.120 m
$h_w$	= 3.000 m
$b$	= 1.250 m
$h$	= 2.500 m
$t_s$	= 0.200 m
$h_s$	= 12.000 m
$D_s$	= 4.250 m
$D_F$	= 6.500 m
$t_{RF}$	= 0.750 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 $f_{ck} = 20$ MPa	Modulus of Elasticity, $E_c = 5000\sqrt{f_{ck}} = 22,360$ 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
$D_i = D_o - 2t_w = 6.0 - 2 \times 0.2$	= 5.6 m
$W_{T\_empty} = \left[ \left( \frac{\pi}{4} \right) (D_o^2 - D_i^2) h_t + \left( \frac{\pi}{4} \right) D_o^2 (t_r + t_f) \right] \gamma_{concrete}$ $= \left[ \left( \frac{\pi}{4} \right) (6.0^2 - 5.6^2) 3.3 + \left( \frac{\pi}{4} \right) 6.0^2 (0.12 + 0.12) \right] 25$	= 184 kN
$W_{water} = \left[ \left( \frac{\pi}{4} \right) D_i^2 h_w \right] \rho_{water} g = \left[ \left( \frac{\pi}{4} \right) 5.6^2 \times 3.3 \right] 9.81$	= 797 kN
$W_{T\_full} = W_{T\_empty} + W_{water} = 184 + 797$	= 981 kN
$W_{staging} = \pi (D_s - t_s) t_s h_s \gamma_{concrete} = \pi (6 - 0.2) 0.2 \times 12 \times 25$	= 1093 kN
$I_s = \pi R_s^3 t_s = \pi \left( \frac{D_s - t_s}{2} \right)^3 t_s = \pi \times \left( \frac{6 - 0.2}{2} \right)^3 \times 0.2$	= 15.3 m <sup>4</sup>
$A_s = \pi (D_s - t_s) t_s = \pi \times (6 - 0.2) \times 0.2$	= 3.64 m <sup>2</sup>
$r_e = \sqrt{\frac{I_s}{A_s}} = \sqrt{\frac{15.3}{3.64}}$	= 2.04 m
$W_{s\_full} = W_{T\_full} + \left( \frac{1}{3} \right) W_{staging} = 981 + \left( \frac{1}{3} \right) 1093$	= 1345 kN
$W_{s\_empty} = W_{T\_empty} + \left( \frac{1}{3} \right) W_{staging} = 184 + \left( \frac{1}{3} \right) 1093$	= 548 kN
$W_{foundation} = \left( \frac{\pi}{4} \right) D_F^2 t_{RF} \rho_{concrete} g = \left( \frac{\pi}{4} \right) 6.5^2 \times 0.75 \times 25$	= 622 kN
Equivalent shear wall length $l_e = 0.78 D_s = 3.315$ m	
$\psi = \frac{b}{l_e} = 1.25 / 3.315 = 0.377$	
Eccentricity $e$ due to unsymmetrical opening	
$e = 0.5 D_s \left( \frac{\psi}{2 - \psi} \right) = 0.5 \times 4.25 \times (0.377) / (2 - 0.377) = 0.493$ m	

### 3.2 Natural Period of Tank

<p>Tank Full <math>T_{full} = C_T \sqrt{\frac{W_{s\_full} h_s}{E_s A_s g}} = 15.3 \sqrt{\frac{1345 \times 10^3 \times 12}{22360 \times 10^6 \times 3.64 \times 9.81}}</math> ;</p> <p>Tank Empty <math>T_{empty} = C_T \sqrt{\frac{W_{s\_empty} h_s}{E_s A_s g}} = 15.3 \sqrt{\frac{548 \times 10^3 \times 12}{22360 \times 10^6 \times 3.64 \times 9.81}}</math></p> <p>where staging slenderness ratio <math>k = \left(\frac{h_s}{r_e}\right) = \frac{12}{2.04} = 5.88</math>; <math>C_T = 15.3</math></p> <table border="1" style="margin-left: auto; margin-right: auto; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #FFD700;"> <th><math>k</math></th> <th><math>C_T</math></th> </tr> </thead> <tbody> <tr><td>5</td><td>14.4</td></tr> <tr><td>10</td><td>21.2</td></tr> <tr style="background-color: #D3D3D3;"><td>15</td><td>29.6</td></tr> <tr style="background-color: #D3D3D3;"><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>&gt;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	$T_{full} = 0.07 \text{ s}$	$T_{empty} = 0.044 \text{ s}$
$k$	$C_T$																							
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 ( $S_a/g$ )			
<i>Soil Type</i>	<i>Spectral Acceleration (<math>S_a/g</math>)</i>		
Type I	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \leq T \leq 0.4 \\ 1.00/T & 0.4 \leq T \leq 4.0 \end{cases}$		
Type II	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \leq T \leq 0.55 \\ 1.36/T & 0.55 \leq T \leq 4.0 \end{cases}$	$(S_a/g)_{full} = 2.5$	$(S_a/g)_{empty} = 2.5$
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 $A_h = \frac{Z_{SS} I}{R} \left(\frac{S_a}{g}\right)$		$= \frac{0.36 \times 1.5}{1.8} (2.5) = 0.75$	$= \frac{0.36 \times 1.5}{1.8} (2.5) = 0.75$
Base Shear Filled $V_B = A_h W_{s\_full}$ ; Empty $V_B = A_h W_{s\_empty}$		$= 0.75 \times 1345 = 1,009 \text{ kN}$	$= 0.75 \times 548 = 411 \text{ kN}$
Governing Shear force $V_u$ is greatest of Full and Empty condition		$= 1,009 \text{ kN}$	

### 3.5 Shear Demand on Shaft Staging

Shear Force due to Torsional Moment $V_T = V_B e / D_s$	$= \frac{1009 \times 0.493}{4.25} = 117 \text{ kN}$	
Design Horizontal Shear Force on the staging cross-section	$V_d = 0.5V_b + V_T$ $= 0.5 \times 1009 + 117 = 622 \text{ kN}$	$V_d = 0.5V_b - V_T$ $= 0.5 \times 1009 - 117 = 388 \text{ kN}$

### 3.6 Shear Capacity of Shaft Staging

Area of cross section through the opening of the shaft staging $A_c$	$A_c = 0.8l_e t_s$ $= 0.8 \times 3.315 \times 0.2$ $= 0.53 \text{ m}^2$	$A_c = 0.8(l_e - b)t_s$ $= 0.8(3.315 - 1.25)0.2$ $= 0.33 \text{ m}^2$
Percentage of Longitudinal Reinforcement $\rho = \frac{100A_{t-st}}{A_s}$	$= \frac{100 \times 0.012}{3.64}$ $= 0.33$	$= \frac{100 \times 0.011}{3.39}$ $= 0.32$
For a percentage of Longitudinal Reinforcement $\rho$ in shaft wall, from Table 19 of IS:456-2000, Design Shear Stress of Concrete $\tau_c$	$= 0.39 \text{ MPa}$	$= 0.39 \text{ MPa}$
Shear Carried by Concrete $V_{uc} = \tau_c A_c$	$= 0.39 \times 0.53 \times 10^6 \text{ N}$ $= 207 \text{ kN}$	$= 0.39 \times 0.33 \times 10^6 \text{ N}$ $= 129 \text{ kN}$
Shear Carried by Steel $V_{us}$	$= 0.87 f_y A_{t-st} \frac{0.8l_e}{s_v}$ $= 0.87 \times 415 \times 113 \times \frac{0.8 \times 3135}{175}$ $= 585 \text{ kN}$	$= 0.87 f_y A_{t-st} \frac{0.8l_e - b}{s_v}$ $= 0.87 \times 415 \times 113 \times \frac{(0.8 \times 3135 - 1250)}{175}$ $= 293 \text{ kN}$
Total Shear Capacity of Shaft Staging $V_{u,shaft} = V_{uc} + V_{us}$	$= 207 + 585$ $= 792 \text{ kN}$ <b>&gt; Shear Demand <math>V_d</math></b>	$= 129 + 293$ $= 422 \text{ kN}$ <b>&gt; Shear Demand <math>V_d</math></b>

### 3.7 Check for Overturning Moment

Over Turning Moment $M_{OT} = V_B \left( h_s + \frac{h_t}{2} \right)$	$= 1009 \times (12 + 3.3/2)$ $= 13,772 \text{ kNm}$	$= 411 \times (12 + 3.3/2)$ $= 5,610 \text{ kNm}$
Restoring Moment $M_R = (W_{\text{tank}} + W_{\text{staging}} + W_{\text{foundation}}) \left( 1 - \frac{2}{3} A_h \right) \frac{D_F}{2}$ where $D_F$ is diameter of the foundation	$= (981 + 1093 + 622) \left( 1 - \frac{2}{3} \times 0.75 \right) \frac{6.5}{2}$ $= 4360 \text{ kNm}$	$= (184 + 1093 + 622) \left( 1 - \frac{2}{3} \times 0.75 \right) \frac{6.5}{2}$ $= 3070 \text{ kNm}$
Factor of Safety = $M_R / M_{OT}$	$= 4360 / 13772$ $= 0.32$	$= 3070 / 5610$ $= 0.55$
<b>Check</b>	<b>&lt;&lt; 1.5</b>	<b>&lt;&lt; 1.5</b>