

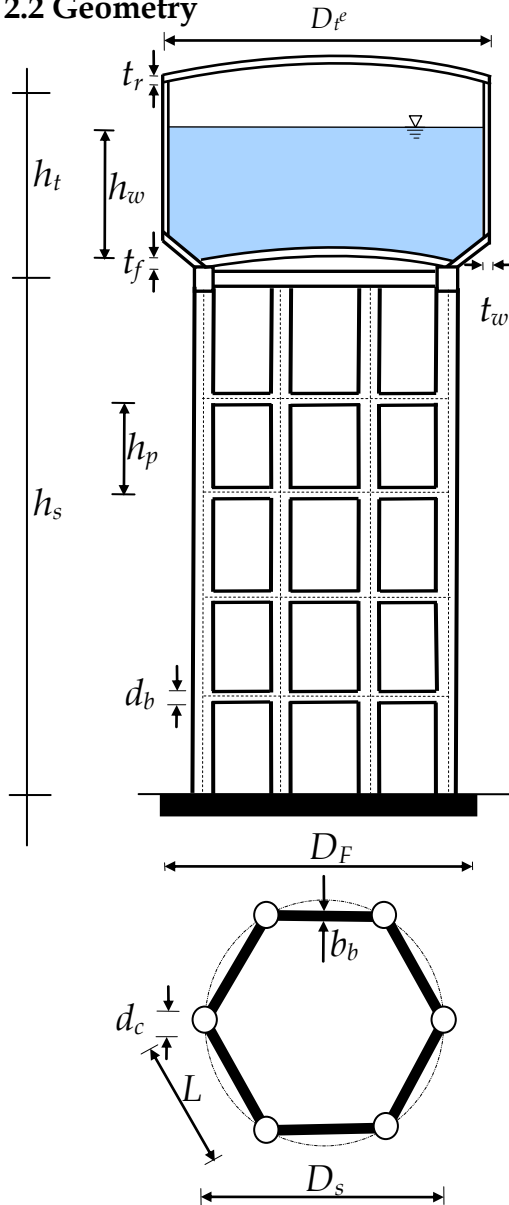
**Rapid Assessment of Seismic Safety of
Elevated Water Tanks with FRAME Staging**

2. INPUTS

2.1 Basic Information

- | | | |
|-------------------------|----------------------|---|
| (1) Location | : Chandigarh | Seismic Zone as per Indian Seismic Code: IV |
| (2) Type of Staging | : Frame | Site-specific horizontal acceleration Z_{SS} : 1g |
| (3) Importance Factor I | : 1.5 | Detailing Type: Ordinary / Special R = 1.8/2.5 |
| (4) Capacity | : 454 m ³ | |
| (5) Shape of Water Tank | : Circular (Intze) | Stirrups with : 90°/135° hooks |

2.2 Geometry



Inputs	Units
N_p	= 6
h_s	= 26 m
h_t	= 6 m
D_t^e	= 11.5 m
Dome ϕ	= 80 m
t_w	= 0.20 m
t_f	= 0.20 m
t_r	= 0.20 m
h_w	= 5.5 m
D_s	= 8 m
N_c	= 8
b_b	= 0.3 m
d_b	= 0.45 m
d_c	= 0.6 m
D_F	= 10 m
t_{RF}	= 1 m

Beam size: 0.30×0.45 m×m	Cover: 25 mm
Longitudinal rebar ϕ : 16Y- 3 No.s (Top)	
16Y- 4 No.s (Bottom)	
$d_{b,eff} = 0.450 - 0.025 - 0.008 - 0.008 = 0.409$ m	
Transverse rebar ϕ : 8Y @ 150mm	
Column size: 0.60 m ϕ	Cover: 30 mm
Longitudinal rebar ϕ : 20Y- 16 No.s	
$d_{c,eff} = 0.600 - 0.030 - 0.008 - 0.0010 = 0.552$ m	
Transverse rebar ϕ : 8Y @ 150mm	

Figure 2.1: Elevated Water Tanks with Frame Staging

2.3 Materials and Structural System

- (1) Grade of Concrete $f_{ck} = 25$ MPa Modulus of Elasticity, $E_c = 5000\sqrt{f_{ck}} = 25000$ 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 |

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3. BASIC SAFETY CHECKS

3.1 Section Properties

Derived Quantities	Units
$h_p = h_s / N_p = 26/6$	= 4.33 m
$D_t^i = D_t^e - t_w = 11.5 - 0.2$	= 11.30 m
Arc length of the Dome $L_D = \left[2 \left(\sin^{-1} \left(\frac{D_t^e}{\phi} \right) \right) \right] \frac{\phi}{2}$ $= \left[2 \left(\sin^{-1} \left(\frac{11.5}{80} \right) \right) \right] \frac{80}{2}$	= 11.54 m
$W_{T_empty} = \left[\pi D_t^e t_w h_t + \pi \left(\frac{D_t^e}{2} \right)^2 (t_f + t_r) \right] \gamma_{concrete}$ $= \left[\pi \times 11.5 \times 0.2 \times 6 + \pi \left(\frac{D_t^e L_d}{2} \right) (0.2 + 0.2) \right] 25$	= 3167 kN
$W_{water} = \left[\pi \left(\frac{D_t^i}{2} \right)^2 h_w \right] \rho_{water} = \left[3.14 \times \left(\frac{11.3}{2} \right)^2 \times 5.5 \right] 10$	= 5513 kN
$W_{T_full} = W_{T_empty} + W_{water} = 3167 + 5513$	= 8680 kN
$L = D_s \sin(\pi / N_c) = 8 \times \sin(\pi / 8)$	= 3.06 m
$I_b = \frac{b_b d_b^3}{12} = \frac{0.3 \times 0.45^3}{12}$	= 0.00228 m ⁴
$I_c = \frac{\pi d_c^4}{64} = \frac{\pi 0.6^4}{64}$	= 0.00636 m ⁴
$K_r = \left(\frac{I_c}{I_b} \right) = \frac{0.00636}{0.00228}$	= 2.79
$W_{staging} = N_c \left(\pi \left(\frac{d_c}{2} \right)^2 h_s + N_p b_b d_b L \right) \gamma_{concrete}$ $= 8 \left(\pi \left(\frac{0.6}{2} \right)^2 \times 26 + 6 \times 0.3 \times 0.45 \times 3.06 \right) 25$	= 1965 kN
$W_{s_full} = W_{full} + \left(\frac{1}{3} \right) W_{staging} = 8680 + \left(\frac{1}{3} \right) 1965$	= 9335 kN
$W_{s_empty} = W_{empty} + \left(\frac{1}{3} \right) W_{staging} = 3167 + \left(\frac{1}{3} \right) 1965$	= 3822 kN
$W_{foundation} = \left(\frac{\pi}{4} \right) D_F^2 t_{RF} \rho_{concrete} g$	= 1962 kN

3.2 Lateral Stiffness of the Staging

Soft Soil	Intermediate and Hard Soil	Calculation
Top panel $k_{panel} = \frac{12 E_c I_c N_c}{h^3} \left[\frac{1}{1 + K_r \left(\frac{L}{h} \right)} \right]$	Top and bottom panels $k_{panel} = \frac{12 E_c I_c N_c}{h^3} \left[\frac{1}{1 + K_r \left(\frac{L}{h} \right)} \right]$	$= \frac{12 \times 25000 \times 10^3 \times 6.36 \times 10^{-3} \times 8}{4.33^3} \left[\frac{1}{1 + 2.79 \left(\frac{3.07}{4.33} \right)} \right]$ $= 63134 \text{ kN/m}$

<p>All other panels</p> $k_{panel} = \frac{12E_c I_c N_c}{h^3} \left[\frac{1}{1 + 2K_r \left(\frac{L}{h} \right)} \right]$	<p>Intermediate panels</p> $k_{panel} = \frac{12E_c I_c N_c}{h^3} \left[\frac{1}{1 + 2K_r \left(\frac{L}{h} \right)} \right]$	$= \frac{12 \times 25000 \times 10^3 \times 6.36 \times 10^{-3} \times 8}{4.33^3} \left[\frac{1}{1 + 2 \times 2.79 \left(\frac{3.07}{4.33} \right)} \right]$ $= 37936 \text{ kN/m}$
<p>Lateral Stiffness of staging $K_{staging} = 1 / \sum_{j=1}^{N_{panels}} \left(\frac{1}{K_{panel}} \right)$</p>		$= 1 / \left(\frac{1}{63134} + \frac{1}{37936} + \frac{1}{37936} + \frac{1}{37936} + \frac{1}{37936} + \frac{1}{63134} \right)$ $= 7293 \text{ kN/m}$

3.3 Natural Period of the Tank

<p>Tank Full $T_{full} = 2\pi \sqrt{\frac{W_{s_full}}{gK_{staging}}}$; Tank Empty $T_{empty} = 2\pi \sqrt{\frac{W_{s_empty}}{gK_{staging}}}$</p>	$T_{full} = 2\pi \sqrt{\frac{9335}{9.81 \times 7293}}$ $= 2.27 \text{ s}$	$T_{full} = 2\pi \sqrt{\frac{3822}{9.81 \times 7293}}$ $= 1.45 \text{ s}$
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3.4 Design Horizontal Seismic Force

		Tank Full	Tank Empty
Spectral Acceleration (S_a/g)			
Soil Type	Spectral Acceleration (S_a/g)		
Type I	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \leq T \leq 0.4 \\ 1.00/T & 0.4 \leq T \leq 4.0 \end{cases}$	$(S_a/g)_{full} = 1.36/T$ $= 1.36/2.27 = 0.6$	$(S_a/g)_{empty} = 1.36/T$ $= 1.36/1.45 = 0.94$
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 $A_h = \frac{Z_{SS} I}{R} \left(\frac{S_a}{g} \right)$		$= \frac{1.0 \times 1.5}{1.8} (0.6)$ $= 0.5$	$= \frac{1.0 \times 1.5}{1.8} (0.94)$ $= 0.78$
Base Shear Filled $V_B = A_h W_{s_full}$; Empty $V_B = A_h W_{s_empty}$		$= 0.5 \times 9335$ $= 4668 \text{ kN}$	$= 0.78 \times 3822$ $= 2981 \text{ kN}$
Governing Shear force V_u is greatest of Full and Empty condition = 4668 kN			

3.5 Shear Beams

<p>Over strength shear in beams at level j,</p> $V_{bj} = \frac{1.4V_b h_p}{N_c R_s} \text{cosec} \left(\frac{\pi}{N_c} \right)$	$= \frac{1.4 \times 4668 \times 4.33}{8 \times 4} \text{cosec} \left(\frac{\pi}{8} \right)$ $= 2312 \text{ kN}$
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3.6 Shear Columns

<p>Top panel,</p> $V_c = \frac{2.8V_b}{N_c} \left[\cos^2 \left(\frac{\pi}{N_c} \right) + \frac{K_r}{3} \right]$	$= \frac{2.8 \times 4668}{8} \left[\cos^2 \left(\frac{\pi}{8} \right) + \frac{2.79}{3} \right]$ $= 2918 \text{ kN}$
<p>Other panels,</p> $V_c = \frac{1.4V_p h_p}{N_c R_s} \cos \left(\frac{\pi}{N_c} \right) \cot \left(\frac{\pi}{N_c} \right)$	$= \frac{1.4 \times 4668 \times 4.33}{8 \times 4} \cos \left(\frac{\pi}{8} \right) \cot \left(\frac{\pi}{8} \right)$ $= 1976 \text{ kN}$

3.7 Shear Capacity of Beam

Percentage of Longitudinal Reinforcement $\rho = \frac{100A_{t_st}}{A_c}$	$= \frac{100 \times 200.96 \times 7 \times 10^{-6}}{0.3 \times 0.409} = 0.17$
For a percentage of Longitudinal Reinforcement ρ in shaft wall, from Table 19 of IS:456-2000, Design Shear Stress of Concrete τ_c	$= 0.30 \text{ MPa}$
Area of concrete $A_{bc} = b_b d_{b,eff}$	$= 0.3 \times 0.409$ $= 0.123 \text{ m}^2$
Shear Carried by Concrete $V_{uc} = \tau_c A_{bc}$	$= 0.30 \times 0.123 \times 10^6 \text{ N}$ $= 37 \text{ kN}$
Shear Carried by Steel $V_{us} = 0.87 f_y A_{t_st} \frac{d_b}{s_v}$	$= 0.87 \times 415 \times 101 \times \frac{450}{150}$ $= 109 \text{ kN}$
If hooks are 90° Total Shear Capacity of Beam $V_{u,beam} = V_{uc} + V_{us}$	$= 37 + 0$ $= 37 \text{ kN}$ < Shear Demand for Beams
If hooks are 135° Total Shear Capacity of Beam $V_{u,beam} = V_{uc}$	$= 37 + 109$ $= 146 \text{ kN}$ < Shear Demand for Beams

3.7 Shear Capacity of Columns

Percentage of Longitudinal Reinforcement $\rho = \frac{100A_{t_st}}{A_c}$	$= \frac{100 \times 314 \times 16 \times 10^{-6}}{0.6 \times 0.552} = 1.5$
For a percentage of Longitudinal Reinforcement ρ in shaft wall, from Table 19 of IS:456-2000, Design Shear Stress of Concrete τ_c	$= 0.74 \text{ MPa}$
Area of concrete $A_{cc} = \frac{\pi}{4} d_{c,eff}^2$	$= \frac{\pi}{4} \times 0.552^2$ $= 0.239 \text{ m}^2$
Shear Carried by Concrete $V_{uc} = \tau_c A_{cc}$	$= 0.74 \times 0.239 \times 10^6 \text{ N}$ $= 177 \text{ kN}$
Shear Carried by Steel $V_{us} = 0.87 f_y A_{t_st} \frac{d_c}{s_v}$	$= 0.87 \times 415 \times 101 \times \frac{600}{150}$ $= 146 \text{ kN}$
If hooks are 90° Total Shear Capacity of Column $V_{u,column} = V_{uc} + V_{us}$	$= 177 + 0$ $= 177 \text{ kN}$ < Shear Demand for Columns
If hooks are 135° Total Shear Capacity of Column $V_{u,column} = V_{uc}$	$= 177 + 146$ $= 323 \text{ kN}$ < Shear Demand for Columns

3.8 Check for Overturning Moment

Over Turning Moment $M_{OT} = V_B \left(h_s + \frac{h_t}{2} \right)$	$= 4668(26 + 6/2)$ $= 1,35,372 \text{ kNm}$	$= 2981(26 + 6/2)$ $= 47696 \text{ kNm}$
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	$= (8680 + 1965 + 1962) \left(1 - \frac{2}{3} \times 0.5 \right) \frac{10}{2}$ $= 41,918 \text{ kNm}$	$= (3167 + 1965 + 1962) \left(1 - \frac{2}{3} \times 0.78 \right) \frac{10}{2}$ $= 16,933 \text{ kNm}$
Factor of Safety = M_R/M_{OT}	$= 41918/135372$ $= 0.31$	$= 16933/47696$ $= 0.36$
Check	<< 1.5	<< 1.5