

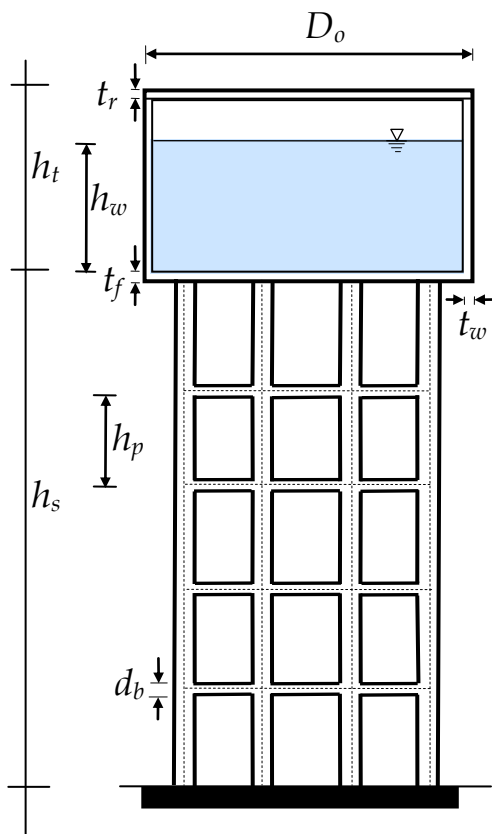
**Rapid Assessment of Seismic Safety of
Elevated Water Tanks with FRAME Staging**

2. INPUTS

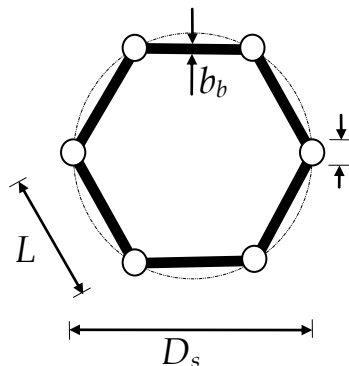
2.1 Basic Information

(1) Location	: Srinagar (J&K)	Seismic Zone as per Indian Seismic Code: V
(2) Type of Staging	: Frame	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	: 50 m ³	
(5) Shape of Water Tank	: Circular	Stirrups with : 90°/135° hooks

2.2 Geometry



Inputs	Units
N_p	= 4
h_s	= 12 m
h_t	= 3.3 m
D_o	= 5.05 m
t_w	= 0.20 m
t_f	= 0.20 m
t_r	= 0.12 m
h_w	= 3.00 m
D_s	= 4.85 m
N_c	= 4
b_b	= 0.30 m
d_b	= 0.45 m
d_c	= 0.45 m
D_F	= 6 m
t_{RF}	= 0.75 m



Beam size: 0.30×0.45 m×m	Cover: 20 mm
Longitudinal rebar ϕ : 16Y- 3 No.s (Top)	
	16Y- 4 No.s (Bottom)
$d_{b,eff} = 0.450 - 0.020 - 0.008 - 0.008 = 0.414$ m	
Transverse rebar ϕ : 8Y @ 150mm	
Column size: 0.45 m ϕ	Cover: 20 mm
Longitudinal rebar ϕ : 20Y- 16 No.s	
$d_{c,eff} = 0.450 - 0.020 - 0.008 - 0.010 = 0.402$ 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 $f_{ck} = 20$ MPa Modulus of Elasticity, $E_c = 5000\sqrt{f_{ck}} = 22360$ 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
$h_p = h_s / N_p = 12/4$	= 3.00 m
$D_i = D_o - 2 t_w = 5.05 - 2 \times 0.2$	= 4.65 m
$W_{T_empty} = \left(\frac{\pi}{4} \right) \left[(D_o^2 - D_i^2) h_t + D_o^2 (t_r + t_f) \right] \gamma_{concrete}$ $= \left(\frac{\pi}{4} \right) \left[(5.05^2 - 4.65^2) 3.3 + 5.05^2 (0.12 + 0.20) \right] 25$	= 411 kN
$W_{water} = \left[\left(\frac{\pi}{4} \right) D_i^2 h_w \right] \rho_{water} g = \left[\left(\frac{\pi}{4} \right) 4.65^2 \times 3 \right] 9.81$	= 500 kN
$W_{T_full} = W_{T_empty} + W_{water} = 411 + 500$	= 911 kN
$L = D_s \sin(\pi / N_c) = 4.85 \times \sin(\pi / 4)$	= 3.43 m
$W_{staging} = N_c \left(\pi (d_c / 2)^2 h_s + N_p b_b d_b L \right) \gamma_{concrete}$ $= 4 \left(\pi (0.45 / 2)^2 12 + 4 \times 0.3 \times 0.45 \times 3.43 \right) 25$	= 376 kN
$I_b = \frac{b_b d_b^3}{12} = \frac{0.3 \times 0.45^3}{12}$	= 0.00228 m ⁴
$I_c = \frac{\pi d_c^4}{64} = \frac{\pi \times 0.45^4}{64}$	= 0.00201 m ⁴
$K_r = \left(\frac{I_c}{I_b} \right) = \frac{0.00201}{0.00228}$	= 0.88
$W_{s_full} = W_{full} + \left(\frac{1}{3} \right) W_{staging} = 911 + \left(\frac{1}{3} \right) 376$	= 1036 kN
$W_{s_empty} = W_{empty} + \left(\frac{1}{3} \right) W_{staging} = 411 + \left(\frac{1}{3} \right) 376$	= 536 kN
$W_{foundation} = \left(\frac{\pi}{4} \right) D_F^2 t_{RF} \rho_{concrete} g = \left(\frac{\pi}{4} \right) \times 6^2 \times 0.75 \times 25$	= 530 kN

3.2 Lateral Stiffness of the Staging

Soft Soil	Intermediate and Hard Soil	Calculation
<p>Top panel</p> $k_{panel} = \frac{12 E_c I_c N_c}{h^3} \left[\frac{1}{1 + K_r \left(\frac{L}{h} \right)} \right]$	<p>Top and bottom panels</p> $k_{panel} = \frac{12 E_c I_c N_c}{h^3} \left[\frac{1}{1 + K_r \left(\frac{L}{h} \right)} \right]$	$= \frac{12 \times 22360 \times 10^3 \times 2.01 \times 10^{-3} \times 4}{3^3} \left[\frac{1}{1 + 0.88 \left(\frac{3.43}{3} \right)} \right]$ = 39,828 kN/m
<p>All other panels</p> $k_{panel} = \frac{12 E_c I_c N_c}{h^3} \left[\frac{1}{1 + 2 K_r \left(\frac{L}{h} \right)} \right]$	<p>Intermediate panels</p> $k_{panel} = \frac{12 E_c I_c N_c}{h^3} \left[\frac{1}{1 + 2 K_r \left(\frac{L}{h} \right)} \right]$	$= \frac{12 \times 22360 \times 10^3 \times 2.01 \times 10^{-3} \times 4}{3^3} \left[\frac{1}{1 + 2 \times 0.88 \left(\frac{3.43}{3} \right)} \right]$ = 37936 kN/m
<p>Lateral Stiffness of staging $K_{staging} = 1 / \sum_{j=1}^{N_{panels}} \left(\frac{1}{K_{panel}} \right)$</p>		$= 1 / \left(\frac{1}{39828} + \frac{1}{26525} + \frac{1}{26525} + \frac{1}{26525} \right)$ = 7235 kN/m

3.3 Natural Period of the Tank

Tank Full $T_{full} = 2\pi \sqrt{\frac{W_{s_full}}{gK_{staging}}}$; Tank Empty $T_{empty} = 2\pi \sqrt{\frac{W_{s_empty}}{gK_{staging}}}$	$T_{full} = 2\pi \sqrt{\frac{911}{9.81 \times 7235}}$ = 0.71 s	$T_{full} = 2\pi \sqrt{\frac{411}{9.81 \times 7235}}$ = 0.47 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	$\frac{S_a}{g} = \begin{cases} 2.5 & 0 \leq T \leq 0.4 \\ 1.00/T & 0.4 \leq T \leq 4.0 \end{cases}$	$(S_a/g)_{full} = 1.67/T$ = $1.67/0.71 = 2.35$	$(S_a/g)_{empty} = 2.5$
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 $A_h = \frac{Z_{SS} I}{R} \left(\frac{S_a}{g} \right)$		= $\frac{0.36 \times 1.5}{1.8} (2.35)$ = 0.71	= $\frac{0.36 \times 1.5}{1.8} (2.5)$ = 0.75
Base Shear Filled $V_B = A_h W_{s_full}$; Empty $V_B = A_h W_{s_empty}$		= 0.71×911 = 647 kN	= 0.75×411 = 308 kN
Governing Shear force V_u is greatest of Full and Empty condition = 647 kN			

3.5 Shear Beams

Over strength shear in beams at level j, $V_{bj} = \frac{1.4V_b h_p}{N_c R_s} \operatorname{cosec} \left(\frac{\pi}{N_c} \right)$	= $\frac{1.4 \times 647 \times 3}{4 \times (4.85/2)} \operatorname{cosec} \left(\frac{\pi}{4} \right)$ = 396 kN
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3.6 Shear Columns

Top panel, $V_c = \frac{2.8V_b}{N_c} \left[\cos^2 \left(\frac{\pi}{N_c} \right) + \frac{K_r}{3} \right]$	= $\frac{2.8 \times 647}{4} \left[\cos^2 \left(\frac{\pi}{4} \right) + \frac{0.88}{3} \right]$ = 359 kN
Other panels, $V_c = \frac{1.4V_p h_p}{N_c R_s} \cos \left(\frac{\pi}{N_c} \right) \cot \left(\frac{\pi}{N_c} \right)$	= $\frac{1.4 \times 647 \times 3}{4 \times (4.85/2)} \cos \left(\frac{\pi}{4} \right) \cot \left(\frac{\pi}{4} \right)$ = 198 kN

3.7 Shear Capacity of Beam

Percentage of Longitudinal Reinforcement $\rho = \frac{100A_{t_st}}{A_c}$	= $\frac{100 \times 200.96 \times 7 \times 10^{-6}}{0.3 \times 0.414} = 0.11$
For a percentage of Longitudinal Reinforcement ρ in shaft wall, from Table 19 of IS:456-2000, Design Shear Stress of Concrete τ_c	= 0.28 MPa
Area of concrete $A_{bc} = b_b d_{b,eff}$	= 0.3×0.414 = 0.124 m ²

Shear Carried by Concrete $V_{uc} = \tau_b A_{bc}$	= $0.28 \times 0.124 \times 10^6$ N = 35 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 kN
If hooks are 90° Total Shear Capacity of Beam $V_{u,beam} = V_{uc} + V_{us}$	= 35 + 0 = 35 kN < Shear Demand for Beams
If hooks are 135° Total Shear Capacity of Beam $V_{u,beam} = V_{uc}$	= 35+109 = 144 kN < Shear Demand for Beams

3.7 Shear Capacity of Columns

Percentage of Longitudinal Reinforcement $\rho = \frac{100A_{t-st}}{A_c}$	= $\frac{100 \times 314 \times 16 \times 10^{-6}}{0.45 \times 0.402} = 2.7$
For a percentage of Longitudinal Reinforcement ρ in shaft wall, from Table 19 of IS:456-2000, Design Shear Stress of Concrete τ_c	= 0.82 MPa
Area of concrete $A_{cc} = \frac{\pi}{4} d_{c,eff}^2$	= $\frac{\pi}{4} \times 0.402^2$ = 0.127 m ²
Shear Carried by Concrete $V_{uc} = \tau_c A_{cc}$	= $0.82 \times 0.127 \times 10^6$ N = 104 kN
Shear Carried by Steel $V_{us} = 0.87 f_y A_{t-st} \frac{d_c}{s_v}$	= $0.87 \times 415 \times 101 \times \frac{450}{150}$ = 110 kN
If hooks are 90° Total Shear Capacity of Column $V_{u,column} = V_{uc} + V_{us}$	= 104+0 = 104 kN < Shear Demand for Columns
If hooks are 135° Total Shear Capacity of Column $V_{u,column} = V_{uc}$	= 104+110 = 214 kN < Shear Demand for Columns

3.8 Check for Overturning Moment

Over Turning Moment $M_{OT} = V_B \left(h_s + \frac{h_t}{2} \right)$	= $911(12+3.3/2)$ = 12,435 kNm	= $411(12+3.3/2)$ = 5,610 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	= $(911+376+530) \left(1 - \frac{2}{3} \times 0.71 \right) \frac{6}{2} =$ = 2,858 kNm	= $(411+376+530) \left(1 - \frac{2}{3} \times 0.75 \right) \frac{6}{2} =$ = 1,886 kNm
Factor of Safety = M_R/M_{OT}	= 2858 / 12435 = 0.23	= 1886 / 5610 = 0.34
Check	<< 1.5	<< 1.5