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

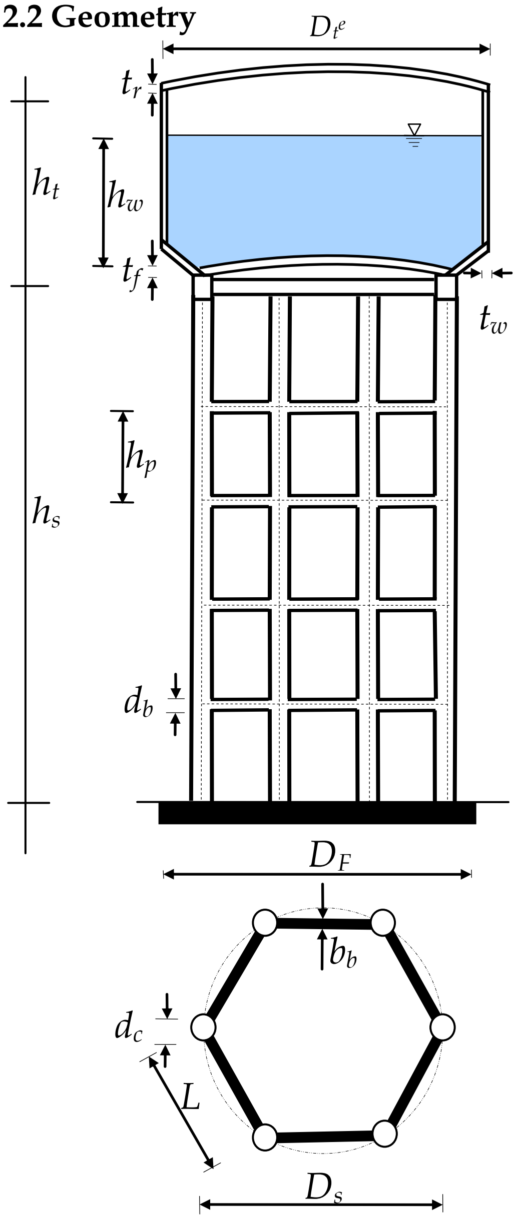

Figure 2.1: Elevated Water Tanks with Frame Staging

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

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

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

3. BASIC SAFETY CHECKS

3.1 Section Properties

Derived Quantities	*Units*
$h_p = h_s / N_p = 26/6$	= 4.33 m
$D_t^i = D_t^e - t_w = 11.5\text{-}0.2$	= 11.30 m
Arc length of the Dome $L_D = \left[2\left(\sin^{-1}\left(D_t^e/\varphi\right)\right)\right]\frac{\varphi}{2} = \left[2\left(\sin^{-1}\left(11.5/80\right)\right)\right]\frac{80}{2}$	= 11.54 m
$W_{T\_empty} = \left[\pi D_t^e t_w h_t + \pi\left(D_t^e/2\right)^2\left(t_f + t_r\right)\right]\gamma_{concrete} = \left[\pi \times 11.5 \times 0.2 \times 6 + \pi\left(D_t^e\, L_d/2\right)(0.2+0.2)\right]25$	= 3167 kN
$W_{water} = \left[\pi\left(D_t^i/2\right)^2 h_w\right]\rho_{water} = \left[3.14 \times \left(11.3/2\right)^2 5.5\right]10$	= 5513 kN
$W_{T\_full} = W_{T\_full} + W_{water} = 3167 + 5513$	= 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
$W_{staging} = N_c\left(\pi(d_c/2)^2 h_s + N_p b_b d_b L\right)\gamma_{concrete} = 8\left(\pi(0.6/2)^2 26 + 6 \times 0.3 \times 0.45 \times 3.06\right)25$	= 1965 kN
$W_{s\_full} = W_{full} + \left(1/3\right)W_{staging} = 8680 + \left(1/3\right)1965$	= 9335 kN
$W_{s\_empty} = W_{empty} + \left(1/3\right)W_{staging} = 3167 + \left(1/3\right)1965$	= 3822 kN
$W_{foundation} = \left(\pi/4\right)D_F^2 t_{RF}\, \rho_{concrete}\, g$	= 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 kN/m

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

3.3 Natural Period of the Tank

Tank Full $T_{full} = 2\pi\sqrt{\frac{W_{s\_full}}{gK_{staging}}}$; Tank Empty $T_{empty} = 2\pi\sqrt{\frac{W_{s\_empty}}{gK_{staging}}}$	$T_{full} = 2\pi\sqrt{\frac{9335}{9.81\times 7293}}$ = 2.27 s	$T_{full} = 2\pi\sqrt{\frac{3822}{9.81\times 7293}}$ = 1.45 s

3.4 Design Horizontal Seismic Force

	Tank Full	**Tank Empty**
Spectral Acceleration (S_a/g)		
Soil Type — *Spectral Acceleration (S_a/g)*		
Type I: $\frac{S_a}{g} = \begin{cases} 2.5 & 0 \le T \le 0.4 \\ 1.00/T & 0.4 \le T \le 4.0 \end{cases}$		
Type II: $\frac{S_a}{g} = \begin{cases} 2.5 & 0 \le T \le 0.55 \\ 1.36/T & 0.55 \le T \le 4.0 \end{cases}$	*(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 III: $\frac{S_a}{g} = \begin{cases} 2.5 & 0 \le T \le 0.67 \\ 1.67/T & 0.67 \le T \le 4.0 \end{cases}$		
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× 9335 = 4668 kN	= 0.78 × 3822 = 2981 kN
Governing Shear force V_u is greatest of Full and Empty condition = 4668 kN		

3.5 Shear Beams

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

3.6 Shear Columns

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

3.7 Shear Capacity of Beam

Percentage of Longitudinal Reinforcement $\rho = \frac{100 A_{t\_st}}{A_c}$	$= \frac{100 \times 200.96 \times 7 \times 10^{-6}}{0.3 \times 0.409} = 0.17$
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 MPa
Area of concrete $A_{bc} = b_b d_{b,eff}$	= 0.3×0.409 = 0.123 m^2
Shear Carried by Concrete $V_{uc} = \tau_b A_{bc}$	= 0.30 ×0.123×10^6 N = 37 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 $V_{u,beam} = V_{uc} + V_{us}$	= 37 + 0 =37 kN **< Shear Demand for Beams**
If hooks are 135° Total Shear Capacity of Beam $V_{u,beam} = V_{uc}$	= 37+109 = 146 kN **< Shear Demand for Beams**

3.7 Shear Capacity of Columns

Percentage of Longitudinal Reinforcement $\rho = \frac{100 A_{t\_st}}{A_c}$	$= \frac{100 \times 314 \times 16 \times 10^{-6}}{0.6 \times 0.552} = 1.5$
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 MPa
Area of concrete $A_{cc} = \frac{\pi}{4} d_{c,eff}^{\ 2}$	$= \frac{\pi}{4} \times 0.552^2$ = 0.239 m^2
Shear Carried by Concrete $V_{uc} = \tau_c A_{cc}$	= 0.74 ×0.239×10^6 N = 177 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 kN
If hooks are 90° Total Shear Capacity of Column $V_{u,column} = V_{uc} + V_{us}$	= 177+0 = 177 kN **< Shear Demand for Columns**
If hooks are 135° Total Shear Capacity of Column $V_{u,column} = V_{uc}$	= 177+146 = 323 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 kNm	$= 2981(26 + 6/2)$ = 47696 kNm
Restoring Moment $M_R = \left(W_{tank} + W_{staging} + W_{foundation} \right) \left(1 - \frac{2}{3} A_h \right) \frac{D_F}{2}$ 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 kNm	$= (3167 + 1965 + 1962)\left(1 - \frac{2}{3} \times 0.78\right)\frac{10}{2}$ = 16,933 kNm
Factor of Safety = M_R/M_{OT}	= 41918/135372 = *0.31*	= 16933/47696 = *0.36*
Check	**<< 1.5**	**<< 1.5**