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Study of Seismic Analysis of Non-Conventional Shapes of Elevated Water Tank

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***Abstract:** Any design of Water Tanks is subjected to Dead Load + Live Load and Wind Load or Seismic Load as per IS codes of Practices. But in past issues maximum water tank damages occur due to the earth quakes. So the seismic analysis of water tank is important as well as wind analysis. The reason for damage of the water tank is due to lack of knowledge about staging or bracing part of the tank which play important part during earth quake. Non-conventional shapes taken for design such as conical with shaft supported, etc. from them select the best water tank for construction with the reference of design parameters So the elevated water tank is analyzed for all seismic zones as per IS: 1893, analysis has been done using STAAD. Pro software and it is checked manually also. The rectangular shape of water tank is general shape and other designed water tanks are compare with rectangle one. In the design seismic forces are calculated considering zone IV.*

***Keywords:** Wind Load, Seismic Load, STAAD Pro, etc*

I. INTRODUCTION

The Water is a main source of our day to day life. Human being cannot live without water. So to store the water, water tanks can be constructed. Water can be used for domestic purpose as well as for industrial purpose. Water tanks can be classified on the basis of location where to be placed and shape which shape of tank can be constructed. Elevated water tanks are constructed in order to require head the provided so that water can flow under the gravity. The water tank project has great priority since it serves huge amount of water from small village to big city.

Water tank can be classified under three heads based on location listed as below:

1) Resting On Ground
2) Elevated Service Reservoir
3) Underground tanks

Fig. 1 Different types of an elevated water tanks according to shapes

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A. Modes of Failure
1) Shear Failure Modes in Beams
2) Bending- Shear Failure in Beams
3) Axial Failure in Columns
4) Cracks in Connection
5) Torsion Failure

B. Component Parts of ESR

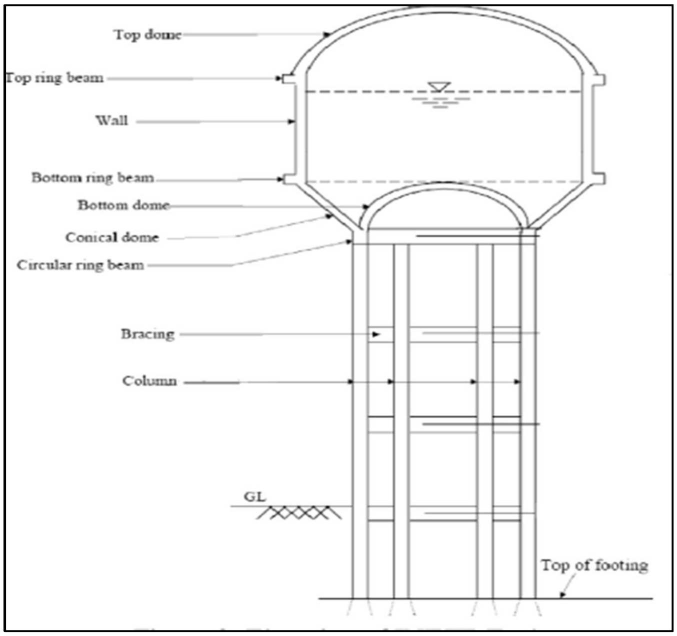


Fig. 2 Component parts of ESR

C. Forces Acting on ESR
While designing the water tanks it is most important part to consider the forces acting on the water tank. Referring IS 875 (part 1-3) load can be taken for designing. The loads can be considered as
1) *Dead Load:* It is the self-weight of different member. For calculation of dead load concrete density is taken to ne 25 KN/m^2
2) *Live Load:* Live load assumed to be produced by intended use or occupancy for roof slab and dome. Live load considered as two parts in E.S.R. one is weight of men and materials during the construction and maintenance of E.S.R. the other live load is considered as weight of water.
3) *Wind Load:* The flow of the water obstructed by the E.S.R. therefore this force is taken into account. Wind force given by designed wind pressure multiplied by projected area.
4) *Earthquake Load:* Earthquake also produces force on water tank and staging. This force is critical for design of E.S.R. Seismic forces are estimated by using IS 1893

The water tank can be analyzed for two conditions,
a) Tank full condition
b) Tank empty condition

Seismic forces and wind forces are not considered simultaneously. Load combination can be designed for ESR for two conditions as,
- For tank full condition:
  Dead Load + Live Load
  Dead Load + Live Load + Earthquake Load
- For tank empty condition:
  Dead Load + Earthquake Load

D. Analysis of ESR

For the analysis of water tank there are two methods

1) Lumped mass model method
2) Two mass model method

E. Lumped Mass model Method

In the lumped mass model method, ESR shall be systems with single degree of freedom with their mass. Mass concentrated at the centre of gravity. The damping in the system is assumed. The analysis of ESR using two mass model method is done using IS 1893-2002 (part1).

F. Two Mass Model Method

Two mass models for elevated tank were proposed by Housner (1963). Generally we know that, ESR is not completely filled with water. Analysis of ESR with two mass model method is more appropriate than a one mass idealization. When a tank containing liquid with free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration.

II. PROBLEM FORMULATION

Capacity = 5, 00,000 lit.
SBC of soil 200 KN/m^2
Staging Ht. above GL = 12 m
Foundation depth = 1.5 m below ground level
Grade of concrete = M20
Grade of steel = Fe415

A. Analysis of Shaft Supported Conical Shape Water Tank with Flat Top

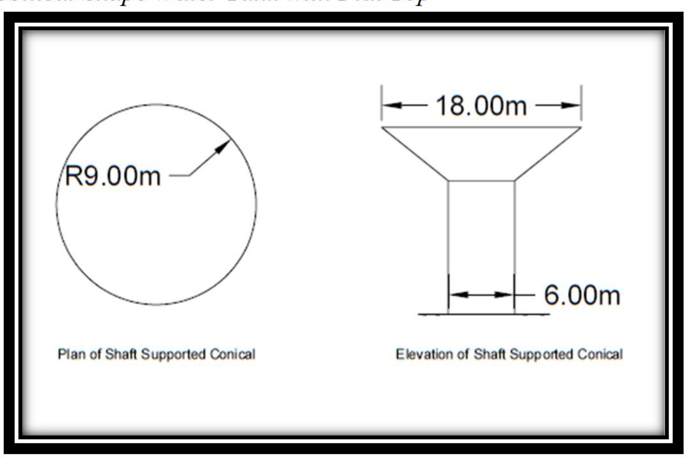


Fig. 3 Plan and Elevation on Shaft Supported Conical Shape of Water Tank

Seismic analysis
i) When container is full
Wt. of tank full less live load = 6354.459+ 5405 = 11759.459 KN
Wt. of shaft = 2321
W = wt. of container + $\frac{\text{wt.of shaft}}{3}$ = 12533.126 KN
Assume lateral load P= 100 KN
After analyzing space frame we have, $\delta = 0.00715\, m$
Stiffness of staging space frame K = $\frac{P \times 100}{\delta} = 13986.014$ KN/m

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{W/9.81}} = 3.308$$

$T = \frac{2\pi}{\omega} = 1.89$ sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g} = 0.641$

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g} = 0.0231$

Seismic force at C.G. of container = W A_h = 289.51 KN

Seismic coefficient = $\alpha_h = 0.09$

Moment due to seismic forces at GL

$M_q = \alpha_h(W_1h_1+W_2h_2) = 155039.508$ KN m

Total load = 11759.459 + 2321 = 14080459 KN

$\sigma_c = \frac{P}{A} + \frac{My}{I} = \frac{140804599 \times 10^3}{8.765\times10^6} + \frac{155039.508\times10^6\times3150}{94.859\times10^{12}} = 1.572\ N/mm^2 < 5\ N/mm^2$ (safe)

ii) When container is empty

W = [wt. of container when full – wt. of water] + $\frac{\text{wt.of staging}}{3}$ = 7128.125 KN

Assume lateral load P= 100 KN

After analyzing space frame we have, $\delta = 0.00715\,m$

Stiffness of staging space frame $K = \frac{P\times100}{\delta} = 13986.014$ KN/m

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{W/9.81}} = 6.703$$

$T = \frac{2\pi}{\omega} = 0.94$ sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g} = 1.067$

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g} = 0.0384$

Seismic force at C.G. of container = W A_h = 273.720 KN

Seismic coefficient = $\alpha_h = 0.09$

Moment due to seismic forces at GL

$M_q = \alpha_h(W_1h_1+W_2h_2) = 90179.508$ KN m

B. Analysis of Cylindrical with top and Bottom Dome

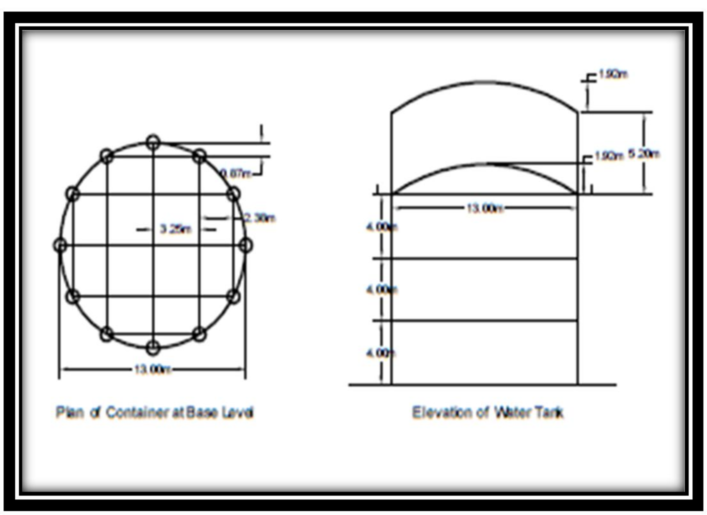


Fig.4 Plan and Elevation of Cylindrical with top and Bottom Dome Tank

Seismic analysis

1) When Container is Full

Wt. of tank full less live load = [udl/m on bottom ring beam ×(dia, of container + width of bottom ring beam)]-[LL + FF)× 2π × inside radius×rise of dome]

= [191.7× 100 ×(13 + 0.3)]-[1 + 0.75)× 2π × 6.5×1.92]

= 8771.045 KN

Wt. of staging = (self wt. of column×no. of columns) + self wt. of brace beam

= 1763.436 KN

W = wt. of container + $\frac{\text{wt.of staging}}{3}$ = 8458.857KN

Assume lateral load P= 100 KN

After analyzing space frame we have, $\delta = 0.00715\, m$

Stiffness of staging space frame K = $\frac{P\times100}{\delta}$ = 13986.014 KN/m

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{W/9.81}} = 4.03$$

T = $\frac{2\pi}{\omega}$ = 1.56 sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g}$ = 0.641

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$ = 0.0231

Seismic force at C.G. of container = W A_h = 195.19KN

Seismic force at base beam level = seismic force at C.G. of container ×

$$\left[\frac{\text{Ht. of staging above GL} + \frac{\text{ht. of water}}{2}}{\text{Ht. of staging above GL}}\right]$$

= 265.13 KN

2) When Container is Empty

W = [wt. of container when full – wt. of water] + $\frac{\text{wt.of staging}}{3}$ = 3053.893 KN

Assume lateral load P= 100 KN

After analyzing space frame we have, $\delta = 0.00715\, m$

Stiffness of staging space frame K = $\frac{\text{P}\times100}{\delta}$ = 13986.014 KN/m

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{W/9.81}} = 6.703$$

T = $\frac{2\pi}{\omega}$ = 0.94 sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g}$ = 1.067

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$ = 0.0384

Seismic force at C.G. of container = W A_h = 117.3 KN

C. Analysis for Rectangular Overhead water Tank

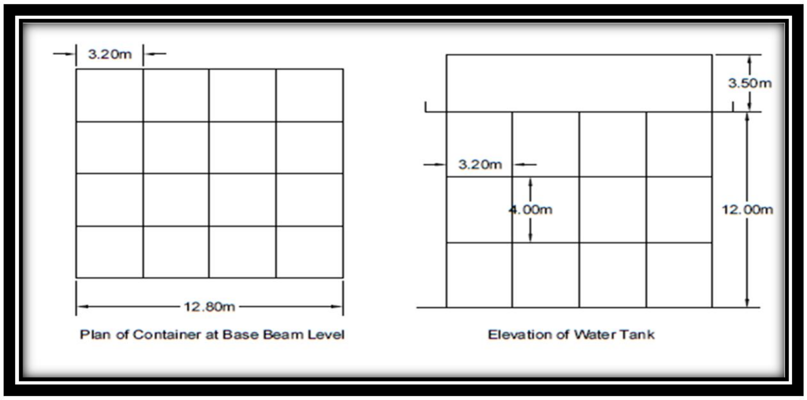


Fig. 5 Plan and Elevation of Rectangular Tank

Seismic analysis

i) When container is full

W = wt. of container + $\frac{\text{wt.of staging}}{3}$ = 8874.03 KN

Assume lateral load P= 100 KN

After analyzing space frame we have, $\delta = 0.00715\, m$

Stiffness of staging space frame K = $\frac{P\times 100}{\delta}$ = 15128593 KN/m

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{W/9.81}} = 4.03$$

T = $\frac{2\pi}{\omega}$ = 1.54 sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g}$ = 0.641

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$ = 0.02343

Seismic force at C.G. of container = W A_h = 208 KN

Seismic force at base beam level = seismic force at C.G. of container ×

$$\left[\frac{\text{Ht. of staging above GL} + \frac{\text{ht. of water}}{2}}{\text{Ht. of staging above GL}}\right]$$

= 235.7 KN

ii) When container is empty

W = [wt. of container when full – wt. of water] + $\frac{\text{wt.of staging}}{3}$ = 3339.5 KN

Assume lateral load P= 100 KN

After analyzing space frame we have, $\delta = 0.00715\, m$

Stiffness of staging space frame K = $\frac{P\times 100}{\delta}$ = 15128593 KN/m

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{W/9.81}} = 6.67$$

T = $\frac{2\pi}{\omega}$ = 0.943 sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g}$ = 1.067

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$ = 0.0384

Seismic force at C.G. of container = W A_h = 128 KN

D. Analysis of Partially Dome and Partially Flat

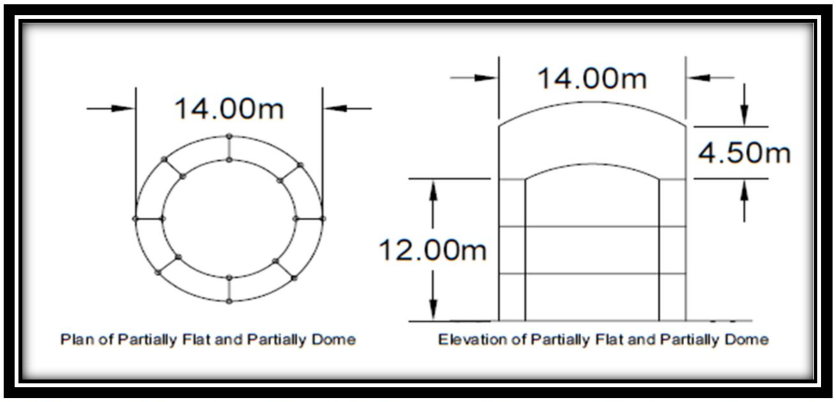


Fig.6 Plan and Elevation of Partially Dome and Partially Flat Shape Water Tank

Seismic analysis

1) When Container is Full

W = wt. of container + $\frac{\text{wt.of staging}}{3}$ = 8956.57 KN

Assume lateral load P= 100 KN

After analyzing space frame we have, $\delta = 0.00715\, m$

Stiffness of staging space frame K = $\frac{P\times100}{\delta} = 15128593$ KN/m

$$\omega = \sqrt{\frac{K}{m}} = \sqrt{\frac{K}{W/9.81}} = 3.89$$

T = $\frac{2\pi}{\omega}$ = 1.53 sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g}$ = 0.641

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$ = 0.02343

Seismic force at C.G. of container = W A_h = 208 KN

Seismic force at base beam level = seismic force at C.G. of container ×

$$\left[\frac{\text{Ht. of staging above GL} + \frac{\text{ht. of water}}{2}}{\text{Ht. of staging above GL}}\right]$$

= 204.216 KN

2) When Container is Empty

W = [wt. of container when full – wt. of water] + $\frac{\text{wt.of staging}}{3}$ = 3339.5 KN

Assume lateral load P= 100 KN

After analyzing space frame we have, $\delta = 0.00715\, m$

Stiffness of staging space frame K = $\frac{\text{P}\times100}{\delta} = 15128593$ KN/m

$$\omega = \sqrt{\frac{\text{K}}{\text{m}}} = \sqrt{\frac{\text{K}}{\text{W}/9.81}} = 6.67$$

T = $\frac{2\pi}{\omega}$ = 0.94 sec

Now calculation of A_h as per IS 1893:2002

Z=0.24 I=1.5 R=5 $\frac{S_a}{g}$ = 1.067

$A_h = \frac{Z}{2}\frac{I}{R}\frac{S_a}{g}$ = 0.0384

Seismic force at C.G. of container = W A_h = 128 KN

III. RESULTS AND DISCUSSION

Table-1
Seismic Analysis Details for Shaft Supported Conical Water Tank

Sr. No.	Particulars	Theoretical Result		Software Result	
		Tank empty	Tank full	Tank empty	tank full
1.	Wt. of tank	3053.89 KN	8458.857 KN	2990 KN	8421 KN
2.	Time period	0.94 sec	1.56 sec	0.91 sec	0.15 sec
3.	Hz. Seismic coefficient	0.0384	0.0231	0.0384	0.0231
4.	Base shear	117.3 KN	265.13 KN	114.86 KN	194.525 KN
5.	Base moment	4587.575 KN m	10799.92 KN m	4543 KN m	10690 KN m

Table-2
Seismic Analysis Details for Circular with Dome At Top And Bottom

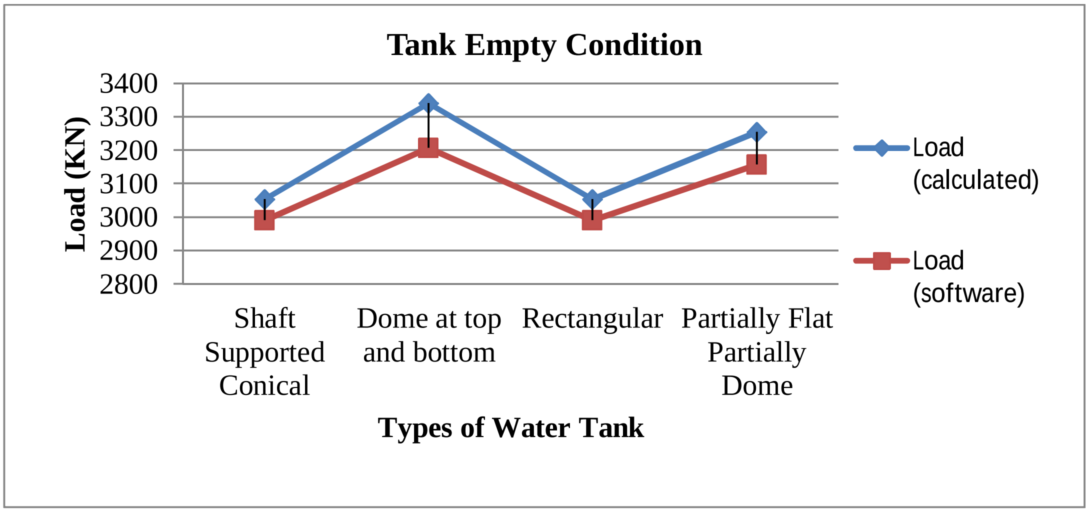
Sr. No.	Particulars	Theoretical Result		Software Result	
		Tank empty	Tank full	Tank empty	tank full
1.	Wt. of tank	3053.89 KN	8458.857 KN	2990 KN	8421 KN
2.	Time period	0.94 sec	1.56 sec	0.91 sec	0.15 sec
3.	Hz. Seismic coefficient	0.0384	0.0231	0.0384	0.0231
4.	Base shear	117.3 KN	265.13 KN	114.86 KN	194.525 KN
5.	Base moment	4587.575 KN m	10799.92 KN m	4543 KN m	10690 KN m

Table-3
Seismic Analysis Details for Rectangular Tank

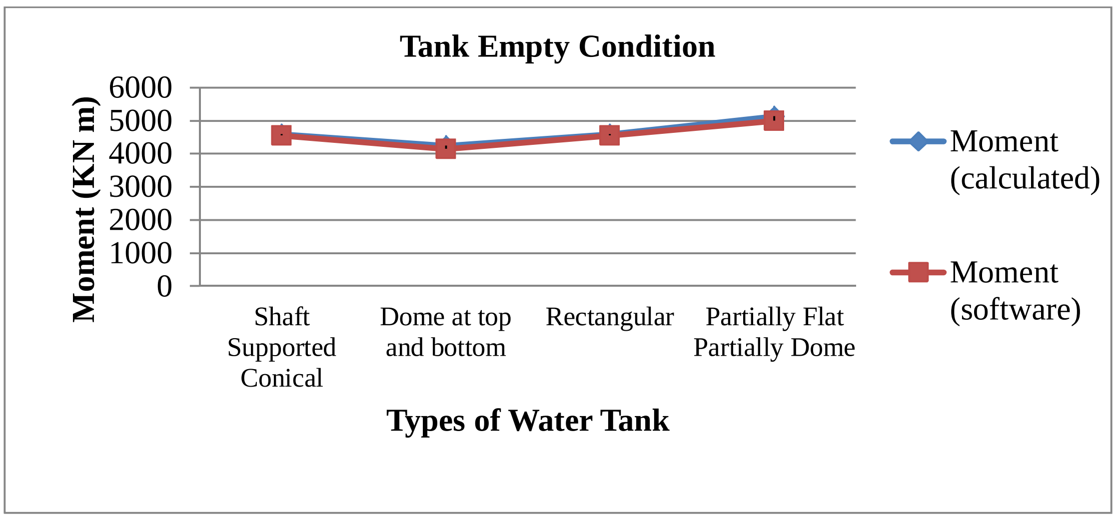
Sr. No.	Particulars	Theoretical Result		Software Result	
		Tank empty	Tank full	Tank empty	tank full
1.	Wt. of tank	3339.5 KN	8874.03 KN	3206 KN	8520 KN
2.	Time period	0.94 sec	1.54	0.92 sec	0.151 sec
3.	Hz. Seismic coefficient	0.0382	0.0234	0.0382	0.0234
4.	Base shear	128 KN	235.7 KN	126 KN	234 KN
5.	Base moment	4239.9 KN m	10799.92 KN m	4150 KN m	10670 KN m

Table-4
Seismic Analyses Details for Partially Flat And Partially Dome

Sr. No.	Particulars	Theoretical Result		Software Result	
		Tank empty	Tank full	Tank empty	tank full
1.	Wt. of tank	3253.893 KN	8956.857 KN	3156 KN	8421 KN
2.	Time period	0.92 sec	1.53 sec	0.90 sec	1.50 sec
3.	Hz. Seismic coefficient	0.0375	0.0228	0.0375	0.0228
4.	Base shear	122.02 KN	204.216 KN	121.5 KN	203.238 KN
5.	Base moment	5123.68 KN m	11056.63 KN m	4986 KN m	10980 KN m



Graph 7 Comparison of load and Moment When Tank is Empty Condition



Graph 8 Comparison of load and Moment When Tank is Empty Condition

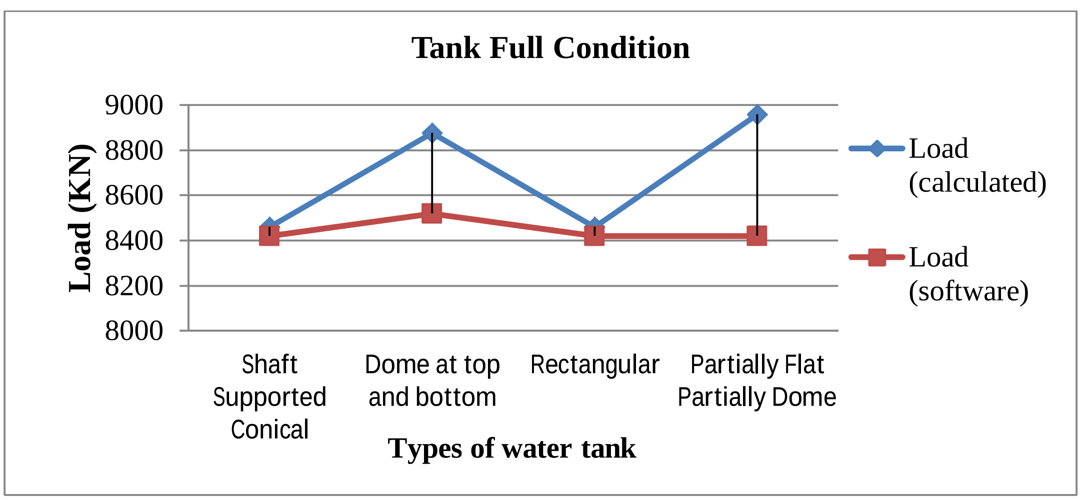


Fig.9 Comparison of load When Tank is Full Condition

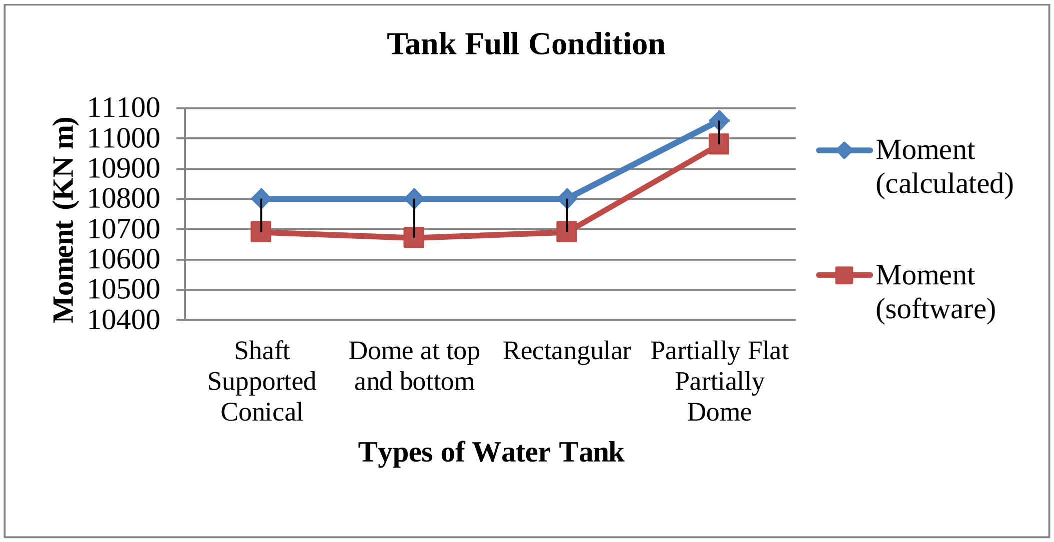


Fig.10 Comparison of load When Tank is Full Condition

IV. CONCLUSION

A. Software results are 3-4% lesser than manual results due to from calculation there are more values in decimal system so we take round figure.
B. The base moment is maximum when tank is in full condition due to wt. of water.
C. Base shear, time period are comparatively more for tank full condition than tank empty condition.
D. Considering earthquake effect partially flat and partially dome at bottom type of tank is best to bear earthquake loads
E. From chart we analyzed that seismic force if increases when tank is in full condition.

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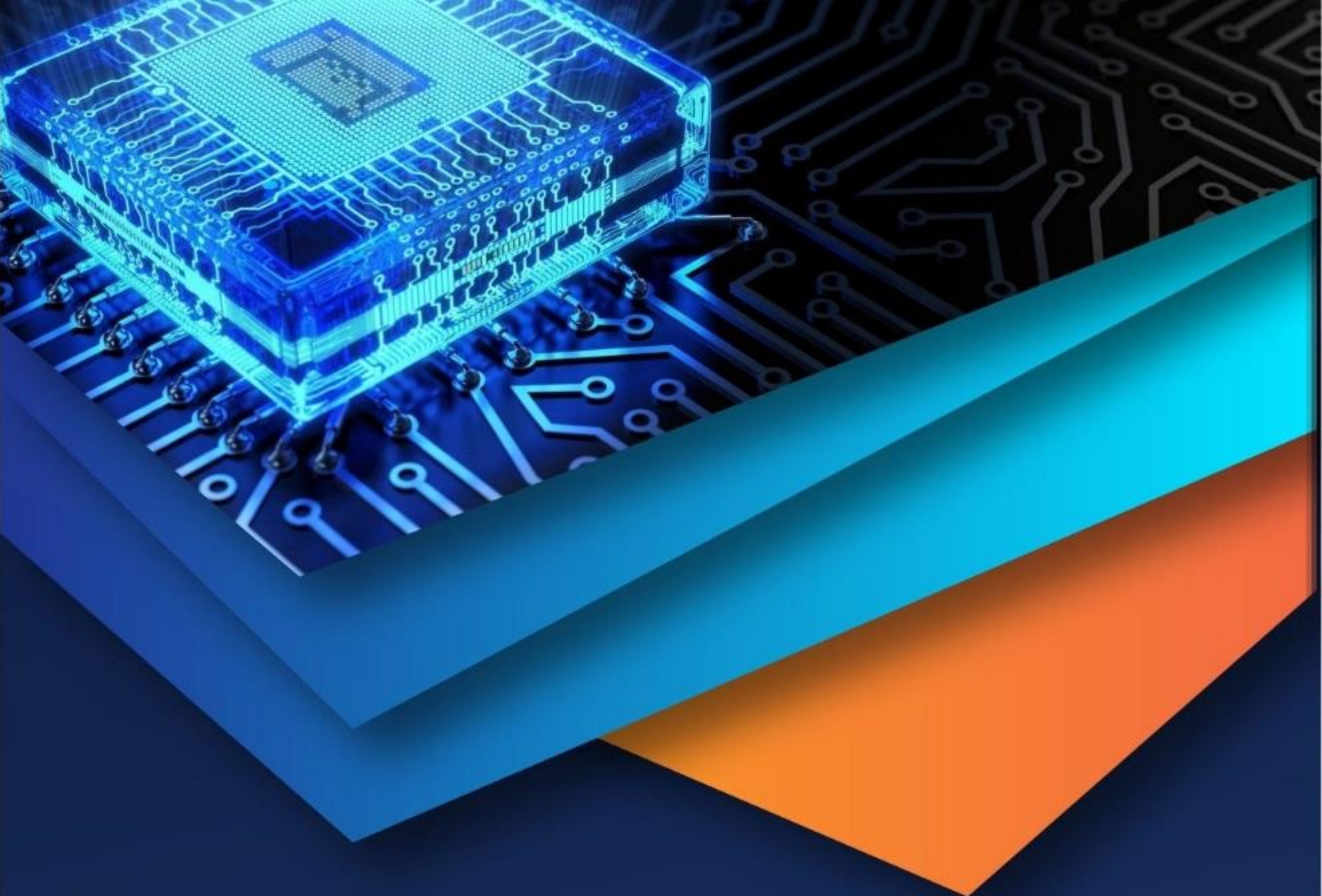

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