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Tension And Moment Coefficients For Hydrodynamic Pressure Design Of Intze Tank

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Abstract — *Intze tank can be termed as improved version of cylindrical tanks and are used for large storage capacity. As per IS 1893-2002 (Part 2), when a tank containing fluid vibrates, the fluid exerts hydrodynamic pressure in the form of impulsive and convective pressures having curvilinear variation, on the cylindrical wall of Intze tank. For simplicity in seismic analysis, the code suggests equivalent trapezoidal pressure distribution along the wall height. In the present study, efforts are made to determine tension and moment coefficients using finite element method for the equivalent hydrodynamic pressure distribution along the wall height, that are not available in the code. It is hoped that, these coefficients will prove useful for hydrodynamic pressure design. Further, the comparison of results of hydrodynamic pressure design is carried out by finite element method using STAAD Pro V8i.*

Keywords-*intze tank, hydrodynamic pressure, impulsive pressure, convective pressure, tension coefficients, moment coefficients, finite element method*

I. INTRODUCTION

Overhead water tanks or elevated service reservoirs are one of the most important components of any efficient water distribution system. The basic purpose of elevated water tanks is to secure constant water supply with sufficient flow to wide area by gravity. The height of the elevated tank depends on the area to be covered for the water supply. Wider the area to be served higher will be the required elevation of the tank.

Elevated tanks can be classified in a variety of ways:

- Classification based on shape of container.
- Classification based on supporting system.

Based on shape of the container elevated tanks can be classified as:

- Square Tank.
- Rectangle Tank.
- Circular Tank.
- Conical Tank.
- Intze Tank.

Based on supporting system elevated tanks can be classified as:

- Shaft supported Elevated Tank.
- Trestle supported Elevated Tank.

For large capacity of the tank generally intze type of tank is preferred compared to any other shape. Intze tank can be termed as improved version of cylindrical tanks. In case of cylindrical tank when dome with small rise is used only compressive stresses are produced which helps in making the water retaining structure water tight. But in case of cylindrical tank when load on the bottom dome is heavy and its diameter is large, the ring beam becomes very heavy and needs large amount of reinforcement. In such situations the more economical option could be to reduce its diameter by introducing one additional member in form of a conical dome. Such tank with additional member in form of conical shell is known as intze tank. In the present study, intze tank supported on shaft is considered.

The water tanks are subjected to following loads:

- Dead Load
- Wind Load
- Seismic Load
- Vibration forces

Seismic loads are also of horizontal nature and these are also estimated as equivalent static forces causing oscillation of the structure. The seismic forces largely depend upon mass of structure and thus it is necessary to study the behavior of water tanks under seismic forces. Using response spectrum method in which frequency of vibration and mode shapes

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have to be worked out. Compared to other tall structures, water tank is simpler to analyze due to less degree of freedom. When seismic loading is considered following two cases must be considered: (i) Tank empty and; (ii) Tank full.

II. HYDRODYNAMIC PRESSURE IN TANKS

When a tank containing fluid with a free surface is subjected to ground motion, it experiences dynamic fluid pressure of two types. Firstly when the walls of tank accelerate the adjacent fluid also accelerates and exerts on wall an impulsive pressure which is directly proportional to the acceleration of the wall. Secondly the effect of the impulsive pressure exerted by the wall on the fluid is to excite the fluid into oscillation and the oscillatory acceleration of the fluid produces convective pressures on the walls whose magnitude is proportional to the magnitude of the oscillation.

The hydrodynamic pressure on the wall and base of the tank is comprised of convective pressure and impulsive pressure. Under lateral accelerations the fluids in the upper regions of the tank do not move with the tank wall thus generate seismic waves or sloshing motion of fluids (Convective behavior). On the contrary, fluids nearer the base of tank move with the tank structure and therefore add to the inertial mass of tank structure (Impulsive behavior).

As per IS 1893 (Part 2), in circular tanks, hydrodynamic pressure due to horizontal excitation varies around the circumference of the tank. However, for convenience in stress analysis of the tank wall, the hydrodynamic pressure on the tank wall may be approximated by an outward pressure distribution of intensity equal to that of the maximum hydrodynamic pressure.

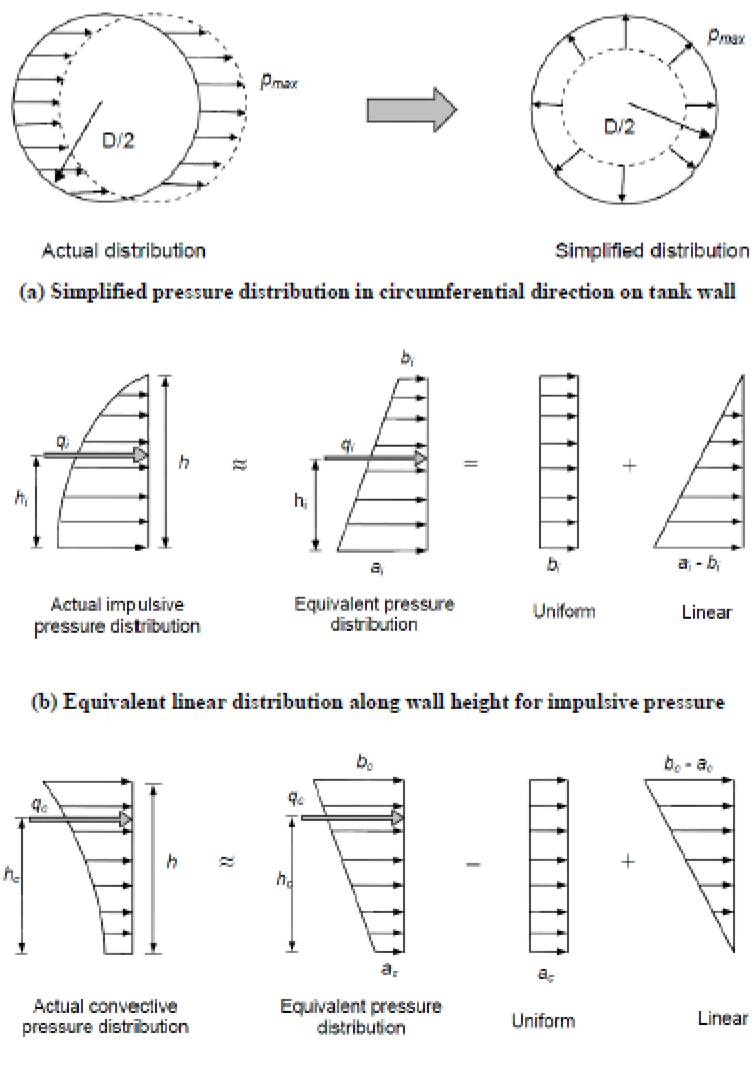

Figure 1. Hydrodynamic pressure distribution for wall analysis

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where,

$$q_i = \frac{(A_h)_i m_i}{\pi D/2} g$$

$$a_i = \frac{q_i}{h^2}(4h - 6h_i) \text{ and } b_i = \frac{q_i}{h^2}(6h_i - 2h)$$

$$q_c = \frac{(A_h)_c m_c}{\pi D/2} g$$

$$a_c = \frac{q_c}{h^2}(4h - 6h_c) \text{ and } b_c = \frac{q_c}{h^2}(6h_c - 2h)$$

q_i and q_c = maximum hydrodynamic force per unit circumferential length for impulsive and convective modes respectively
a_i, b_i, a_c and b_c = equivalent pressure distribution for impulsive and convective modes respectively
h_i = height at which the resultant of impulsive hydrodynamic pressure on wall is located from the bottom of tank wall
m_i = impulsive mass of liquid
h_c = height at which resultant of convective pressure on wall is located from the bottom of tank wall
m_c = convective mass of liquid
$(Ah)_i$ = Design horizontal seismic coefficient in impulsive mode
$(Ah)_c$ = Design horizontal seismic coefficient in convective mode
h = height of cylindrical wall of Intze tank

Hydrodynamic pressure due to horizontal excitation has curvilinear variation along wall height. However, as shown in figure 1, in the absence of more exact analysis, an equivalent linear pressure distribution may be assumed so as to give the same base shear and bending moment at the bottom of tank wall.

III. DETERMINATION OF TENSION AND MOMENT COEFFICIENTS

Table 1. Coefficients for tension in circular ring wall , hinged base, free top and subjected to inverted triangular load

H^2/Dt	Coefficients at point									
	0.0H	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H
0.4	0.9490	0.8490	0.7490	0.6491	0.5491	0.4492	0.3494	0.2495	0.1497	0.0499
0.8	0.9498	0.8492	0.7489	0.6487	0.5487	0.4488	0.3490	0.2492	0.1495	0.0498
1.2	0.9502	0.8495	0.7487	0.6483	0.5482	0.4482	0.3485	0.2488	0.1493	0.0497
1.6	0.9521	0.8499	0.7485	0.6478	0.5475	0.4476	0.3480	0.2485	0.1490	0.0497
2.0	0.9533	0.8501	0.7482	0.6472	0.5469	0.4471	0.3475	0.2481	0.1488	0.0496
3.0	0.9563	0.8504	0.7472	0.6458	0.5456	0.4461	0.3469	0.2478	0.1487	0.0496
4.0	0.9590	0.8502	0.7459	0.6445	0.5448	0.4458	0.3469	0.2480	0.1489	0.0496
5.0	0.9614	0.8496	0.7445	0.6433	0.5442	0.4457	0.3473	0.2484	0.1492	0.0497
6.0	0.9637	0.8488	0.7430	0.6423	0.5438	0.4459	0.3477	0.2489	0.1495	0.0499
8.0	0.9679	0.8467	0.7401	0.6408	0.5438	0.4467	0.3487	0.2497	0.1500	0.0500
10.0	0.9716	0.8441	0.7375	0.6399	0.5443	0.4476	0.3494	0.2501	0.1502	0.0501
12.0	0.9750	0.8413	0.7354	0.6398	0.5452	0.4486	0.3500	0.2503	0.1502	0.0500
14.0	0.9777	0.8382	0.7336	0.6399	0.5460	0.4492	0.3502	0.2502	0.1501	0.0500
16.0	0.9799	0.8349	0.7320	0.6402	0.5468	0.4496	0.3502	0.2501	0.1499	0.0499

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Table 2. Coefficients for moment in circular ring wall, hinged base, free top and subjected to inverted triangular load using STAAD Pro V8i

H²/Dt	Coefficients at point									
	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H	1.0H
0.4	0.0008	0.0007	0.0006	0.0005	0.0004	0.0003	0.0003	0.0002	0.0001	0.0000
0.8	0.0008	0.0007	0.0006	0.0005	0.0004	0.0003	0.0002	0.0001	0.0001	0.0000
1.2	0.0008	0.0007	0.0006	0.0004	0.0003	0.0003	0.0002	0.0001	0.0000	0.0000
1.6	0.0008	0.0006	0.0005	0.0004	0.0003	0.0002	0.0001	0.0000	0.0000	0.0000
2.0	0.0008	0.0006	0.0005	0.0004	0.0002	0.0001	0.0001	0.0000	0.0000	0.0000
3.0	0.0008	0.0006	0.0004	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
4.0	0.0007	0.0006	0.0004	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
5.0	0.0007	0.0005	0.0003	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
6.0	0.0007	0.0005	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8.0	0.0007	0.0005	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10.0	0.0007	0.0004	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12.0	0.0007	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14.0	0.0007	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
16.0	0.0007	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 3. Coefficients for moment in circular ring wall, hinged base, free top and subjected to rectangular load using STAAD Pro V8i

H²/Dt	Coefficients at point									
	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H	1.0H
0.4	-0.0002	0.0033	0.0092	0.0162	0.0230	0.0284	0.0312	0.0299	0.0231	0.0090
0.8	-0.0002	0.0029	0.0082	0.0146	0.0210	0.0262	0.0290	0.0280	0.0218	0.0086
1.2	-0.0003	0.0023	0.0069	0.0125	0.0182	0.0231	0.0259	0.0254	0.0201	0.0080
1.6	-0.0004	0.0017	0.0055	0.0103	0.0153	0.0197	0.0226	0.0226	0.0182	0.0073
2.0	-0.0005	0.0012	0.0042	0.0082	0.0125	0.0165	0.0194	0.0199	0.0163	0.0067
3.0	-0.0007	0.0002	0.0019	0.0043	0.0072	0.0104	0.0132	0.0145	0.0126	0.0053
4.0	-0.0007	-0.0003	0.0006	0.0020	0.0041	0.0066	0.0092	0.0109	0.0101	0.0044
5.0	-0.0008	-0.0005	0.0000	0.0008	0.0023	0.0043	0.0066	0.0085	0.0084	0.0038
6.0	-0.0008	-0.0006	-0.0003	0.0002	0.0013	0.0029	0.0049	0.0068	0.0071	0.0033
8.0	-0.0008	-0.0006	-0.0004	-0.0002	0.0003	0.0013	0.0028	0.0046	0.0054	0.0027
10.0	-0.0008	-0.0005	-0.0003	-0.0002	0.0000	0.0006	0.0017	0.0033	0.0043	0.0022
12.0	-0.0007	-0.0005	-0.0003	-0.0001	0.0000	0.0003	0.0011	0.0024	0.0035	0.0019
14.0	-0.0007	-0.0004	-0.0002	-0.0001	0.0000	0.0000	0.0007	0.0018	0.0029	0.0016
16.0	-0.0007	-0.0004	0.0000	0.0000	0.0000	0.0003	0.0004	0.0014	0.0025	0.0015

3.1. Convective pressure distribution

As shown in Table 1, tension coefficients for circular ring wall having top free and bottom hinged condition, subjected to inverted triangular load, are found using principle of superposition, by subtracting the tension coefficients for triangular loading given in Table 12, from tension coefficients for rectangular loading given in Table 14 of IS 3370:1967 (Part IV). Moment coefficients in circular ring wall for top free and bottom hinged condition, subjected to inverted triangular load as seen for convective pressure distribution, and for rectangular load, have been found at different heights for various

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H^2/Dt ratios using STAAD Pro V8i as shown in Table 2 and Table 3, and analysis and design for hydrodynamic pressure are carried out using Excel worksheets.

3.2. Impulsive pressure distribution

In circular ring wall for top free and bottom hinged condition, subjected to triangular and rectangular load, tension coefficients have been taken from Table no. 12 and 14 of IS 3370:1967 (Part IV), and moment coefficients for trapezoidal load are taken from table 13, and analysis and design for hydrodynamic pressure are carried out using Excel worksheets and results are compared using STAAD Pro V8i by FEM, as shown below.

IV. COMPARISON OF RESULTS OF HYDRODYNAMIC PRESSURE ANALYSIS BY FINITE ELEMENT METHOD USING STAAD PRO V8I

4.1. Problem Data considered for MS Excel worksheet

- Capacity of tank = 1000 m^3
- Inside diameter of tank = 15 m.
- C/c diameter of Staging shaft = 10 m
- Inside diameter of Stair shaft = 2 m
- Thickness of stair shaft = 0.1 m
- Rise of top dome = 2.0 m
- Height of cylindrical wall = 5.0 m
- Thickness of cylindrical wall = 250 mm
- Thickness of conical wall = 500 mm
- Height of staging shaft above G.L. = 18.0 m
- Rise of bottom spherical dome = 1.8 m
- Thickness of top dome = 0.1 m
- Thickness of bottom spherical dome = 0.25 m
- Free board = 0.3 m
- Grade of concrete = 30 MPa
- Grade of steel = 415 MPa
- Unit wt. of water = 10 kN/m^3
- Unit wt. of concrete = 25 kN/m^3

For comparison of results of tension and moment by finite element method using STAAD Pro V8i, only modeling and analysis of cylindrical wall of intze tank which is subjected to hydrodynamic pressure, needs to be considered.

Data considered for modeling and analysis of cylindrical wall of intze tank by finite element method using STAAD Pro V8i:
Diameter of tank = 15m
Height of cylindrical wall = 5m
Thickness of cylindrical wall = 250mm
Meshing size = 0.5 x 0.5m, 0.25 x 0.25m and 0.1 x 0.1m
ai = 9.35 kPa, bi = 1.34 kPa, ac = 0.88 kPa and bc = 2.09 kPa

4.2. Calculations

For Impulsive hydrodynamic pressure on tank wall:
From Excel worksheet calculation, Tension at 0.7H, T_{max} =49.35 kN/m
From STAAD Pro V8i by FEM (meshing size = 0.5m x 0.5m), Tension at 0.7H = SX x thickness
= 0.198648 x 250 = 49.66 kN/m

Where, SX = Membrane stresses (Force/unit length/thickness)

From Excel worksheet calculation, Moment at 0.8H, M_{max} = 1.66 kN/m
From STAAD Pro V8i by FEM (meshing size = 0.1m x 0.1m), Moment at 0.8H = MY = 1.64 kNm
Where MY = Moments per unit width (Force x Length/length). For MY, the unit width is a unit distance parallel to the local X axis.

For Convective hydrodynamic pressure on wall:
From Excel worksheet calculation, Tension at 0.0H, T_{max} =15.57 kN/m
From STAAD Pro V8i by FEM (meshing size = 0.1m x 0.1m), Tension at 0.0H = SX x thickness
= 0.987409 x 250 = 15.49 kN/m

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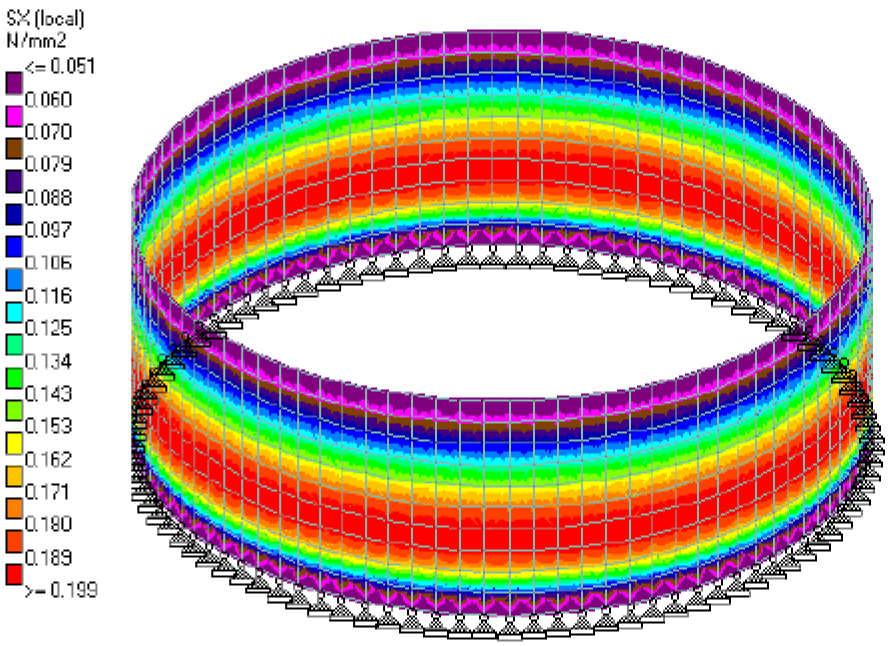

Figure 2. Tension due to Impulsive pressure distribution on cylindrical wall by FEM (0.50 x 0.50m)

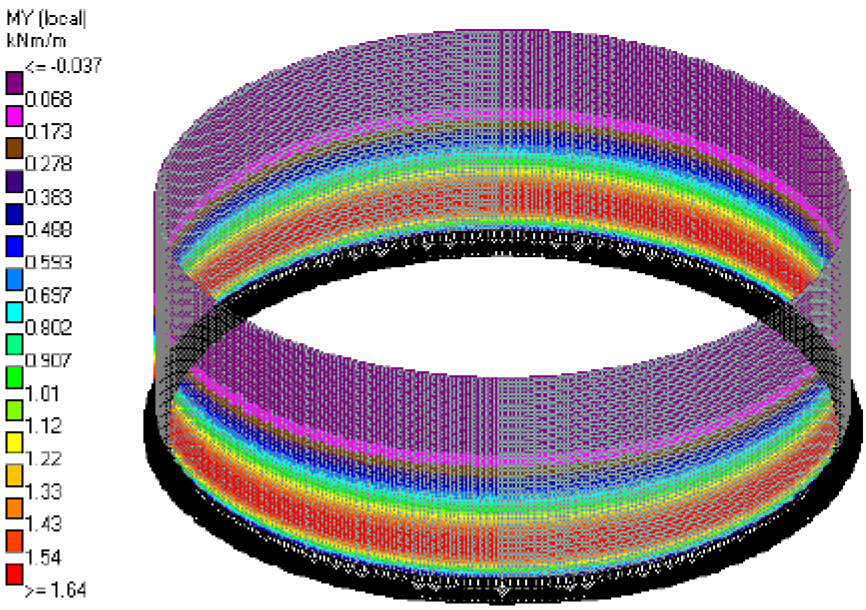

Figure 3. Moments due to Impulsive pressure distribution on cylindrical wall by FEM (0.10 x 0.10m)

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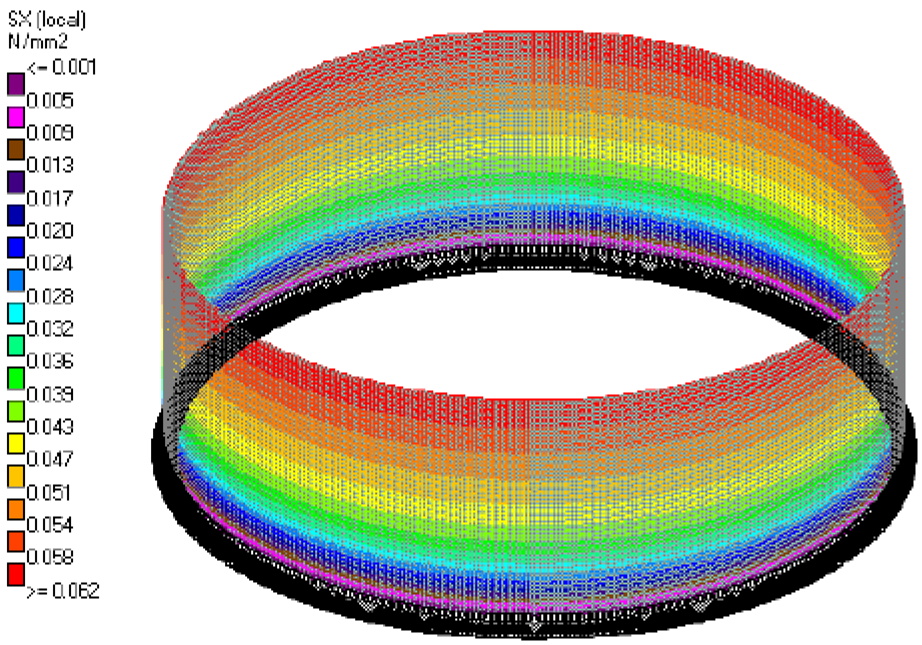

Figure 4. Tension due to Convective pressure distribution on cylindrical wall by FEM (0.10 x 0.10m)

V. RESULT SUMMARY

Table 3. Impulsive pressure distribution

Meshing	Ht. (m)	Tension (kN/m)	STAAD	Error %	Ht. (m)	Moment (kN-m)	STAAD	Error %
0.5x0.5	0.7H	49.38	49.66	0.567	0.8H	1.66	1.53	7.83
0.25x0.25	0.7H		50.12	1.498	0.8H		1.61	3.01
0.1x0.1	0.7H		50.39	2.045	0.8H		1.64	1.2

Table 4. Convective pressure distribution

Meshing	Ht. (m)	Tension (kN/m)	STAAD	Error %
0.5x0.5	0.0H	15.57	15.45	0.77
0.25x0.25	0.0H		15.46	0.706
0.1x0.1	0.0H		15.49	0.51

The results of moment for convective pressure distribution need not be compared as the coefficients for moment are determined from STAAD Pro V8i.

VI. CONCLUSION

- Due to their unavailability in IS 3370:1967 (Part IV), the coefficients for hydrodynamic pressure design of circular ring wall with top free and bottom hinged, for an intze tank are determined by finite element method using STAAD Pro V8i, as mentioned below:
  - For convective pressure distribution, coefficients for moment due to inverted triangular load
  - For convective pressure distribution, coefficients for moment due to rectangular load
  - The tension coefficients due to inverted triangular load for convective hydrodynamic pressure design of circular ring wall with top free and bottom hinged, for an intze tank are determined using principle of superposition.

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- The results of impulsive and convective hydrodynamic pressure analysis from Excel worksheets are compared using STAAD Pro V8i by finite element method. It can be seen from table 3 and table 4, that the error for both the modes is negligible.
- For hydrodynamic pressure analysis in STAAD Pro V8i, only the circular ring wall needs to be modeled and analyzed. The entire tank along with staging need not be modeled.

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