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ANALYTICAL STUDY OF EFFECT OF HORIZONTAL FORCES ON ELEVATED STORAGE TANK

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Abstract:-Elevated water tanks have heavy mass lumped at the top, just like an inverted Pendulum and hence, vulnerable to damage against earthquake motions. All structures must be designed for the lateral forces i.e. wind or earthquake whichever is critical. As large mass is concentrated at top and there is less exposed area for wind, earthquake forces are ought to govern the design in various zones and soil type. The present study aims to analyse and evaluate the wind and seismic forces for the elevated water tank staging using respective codes. For this purpose one capacity tanks are analysed with different diameter of tank (D) and diameter of staging (Do) ratios on four column staging configuration. Circular base slab analysis is carried out for all Do/D ratios and also analysed on saap2000 for various load combinations. From this entire analysis (circular slab analysis, wind analysis and earthquake analysis) one Do/D ratio is decided for optimum design and design the complete ESR is design for this Do/D ratios. Also studying the various types of tank, various staging configuration as per IS11682:1985 and method of analysis circular tanks are studied. From all this analysis it has been observed that the horizontal forces affect the ESR.

Key Words: Water tank, seismic forces, SAAP, circular slab.

1. INTRODUCTION

Past history says that, many water tanks have failed or there service life has reduced during the earthquake because of improper analysis, design and present engineering practices. This should not happen as water tanks is an important public utility structure, since it forms an essential part of the water distribution system, which is the life line facility that must remain functional following any natural calamity. Most municipalities in our country depend on water tanks to cater to the needs of the society.

These structures have heavy mass lumped at the top and hence, vulnerable to damage against earthquake motions. During the 30 September 1993, Killari earthquake and 26 January 2001, Bhuj earthquake large number of water tower structures were severely damaged. Figure1.1 shows some elevated water towers that had collapsed in the past earthquake. This has developed an active interest in the field so as to rationalize the ideas of the dynamic behavior of water tanks with particular reference to earthquake effects on them.

Many water tanks have failed due to damage to the staging of elevated water tanks in Bihar-Nepal earthquake of August 1988 also. Therefore all structures must be designed for the lateral forces i.e. wind or earthquake whichever is critical.

The supporting structures may be of two types i.e. Frame type and Shaft type. Frame type structures are more stable as they are more indeterminate and there seismic energy absorption capacity through inelastic action is better than shaft type structure. Frame type structures do not collapse suddenly as they have many flexural members to distribute lateral load. [1-6]

2. METHODOLOGY

2.1. Circular Slab Analysis

Circular slab in water tank is different slab from rectangular slab where bending takes places in two perpendicular directions along the two spans. When circular slab simply supported at the edge is loaded with uniformly distributed load, it bends in the form of disc, due to which stresses are developed both in radial as well as the in circumferential direction. The tensile radial and circumferential stresses developed towards the convex side of the disc, and hence reinforcement need be provide both in the radial as well as circumferential direction, but this arrangement would cause congestion and anchor aging problem at centre at the slab. Hence an alternative method of providing reinforcement is adopted, reinforcement is provided in the form of mesh of bar having equal area of cross section in the both direction, the area being equal to that required for the bigger of the radial moment and circumferential moment. This moment is calculated for Do/D range 0.6-1.0.[7,8]

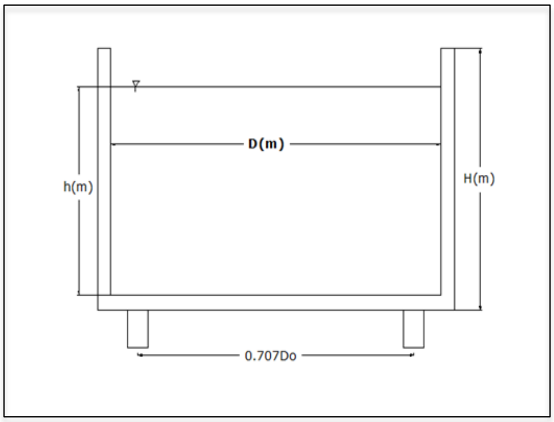

Fig-1: Detail of Circular slab

Problem

1. Capacity of tank 50m3,
2. Do/D =0.85
3. Dia of tank 4.6m,
4. Staging diameter 3.910m
5. LL on slab 1.5kN/m2, FF on slab 1 kN/m2,

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6. Height of tank 3.3 m,
7. Water height 3m

2.2. Wind Effect on ESR

Wind analysis is carried out on the basis of geometrical parameter of ESR. The wind force calculated for circular column section and square column section. Other geometrical parameter is same for both the column section. IS 875:1987 p3 gives the complete guideline for wind analysis on elevated storage tank or structure. A wind force is calculated for Do/D ratio range 0.6-1.0. All ranges sizes of container are same but staging diameter is change according to their different Do/D ratios.[11,12]

Problem

1. RC circular elevated water tanks of 50m3 capacities,
2. With four column staging Configuration,
3. Tank diameter as 4.6m ,Water height as 3.0m,
4. Freeboard is 0.3m for wind loads for 12m staging height with panel height of 3m,
5. Tank is assumed to be designed for zone II located on medium soils,
6. Assume grade of concrete M25 and grade of steel Fe415.
7. Size of top beam 0.3x0.5m,sizes of braces 0.3x0.4m
8. Sizes of circular column 0.45m dia, square column 0.4x0.4m.
9. Do/D ratio 0.85

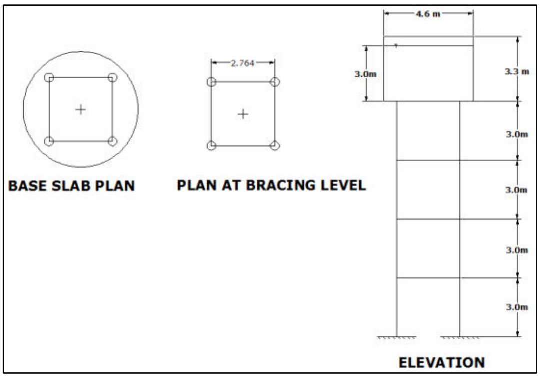

Fig-2 : Plan and Elevation of ESR

2.3. Earthquake Effect on ESR

Earthquake analysis is performed on the basis model of ESR and topographical condition of ground. In earthquake analysis single force is calculated on structure i.e. base shear. The base shears calculation methodology given in IS1983 p1:2002. Base shear is calculated in empty condition and full condition for different Do/D ratio range 0.6-1.0.[9]

Problem

1. RC circular elevated water tanks of 50m3 capacities,

3. RESULT & DISCUSSION

3.1. Circular Slab Analysis

The methodology apply for Do/D ratio range 0.6 to 1.0 & calculating radial moment and circumferential moment in

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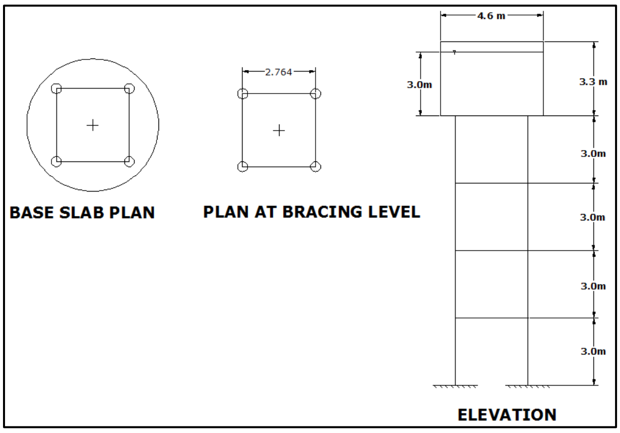

Fig-3: Plan and Elevation of ESR

2.4. Analysis on SAAP2000

In saap2000, the elevated storage tank staging is model according to their geometrical properties. The wind and earthquake load apply across x-direction and beam-column junctions on model. Dead & live load apply in gravity or -y direction and on top beam of staging.

Three mathematical models is developed for Do/ D ratio 0.6, 0.85 and 1.0. Apply the load on model and get the required analysis result for different load combinations. Dead load and live load calculation for top beam is given below.

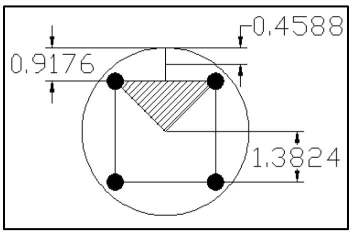

Fig-4: Dead load and live load calculation for top beam

circular slab at different location.The following graph shows the variation in radial & circumferential moment according to their different Do/D ratio at different location in slab.

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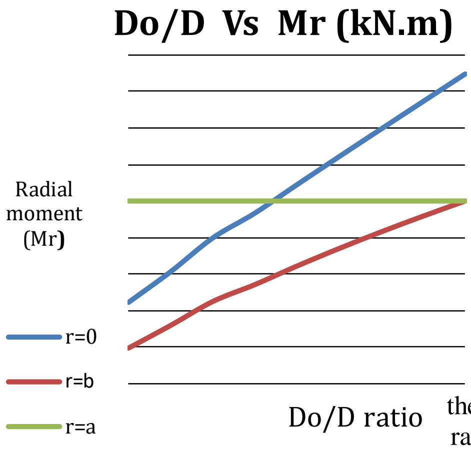


Fig-5: Graph shows the variation in radial moment for different Do/D ratios

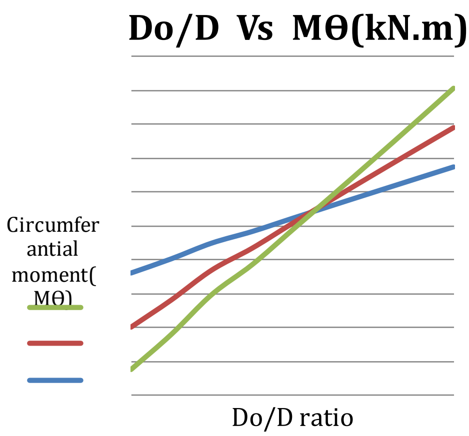


Fig-6: Graph shows the variation in cicumferential moment for different Do/D ratios

Discussion on Circular Slab Analysis

1) Radial moment (Mr) will be zero at outer edge of slab(r=a).

2) Radial moment (Mr) at staging (r=b) is –ve moment in every Do/D ratios that means tension will occurs at water face.

3) Do/D ratio range 0.6 to 0.75 the radial moment is –ve (hogging) throughout the slab.

4) Do/D ratio range 0.6 to 0.85 the circumferential moment (MΘ) is -ve (i.e. hogging) throughout the slab.

5) Do/D ratio range 0.85 to 1.00 the circumferential moment (MΘ) is +ve (i.e. sagging) throughout the slab.

6) Sagging moments means tension at bottom in slab, chances of leakages in slab is not possible.

3.2. WIND EFFECT ON ESR

The same procedure applied for calculation of wind forces on circular column section and square column section for different Do/D ratio. The following graps shows the variation of wind forces on different Do/D ratio for column section and square column section.

Fig- 7: graph shows the variation in wind force for circular column

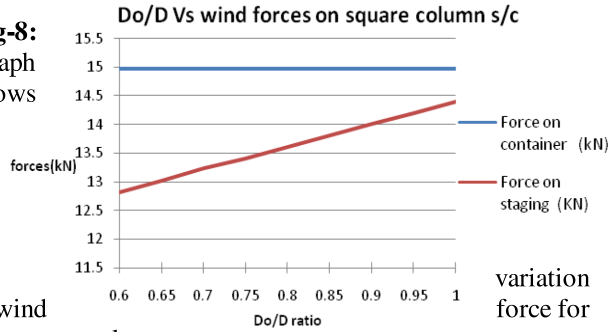


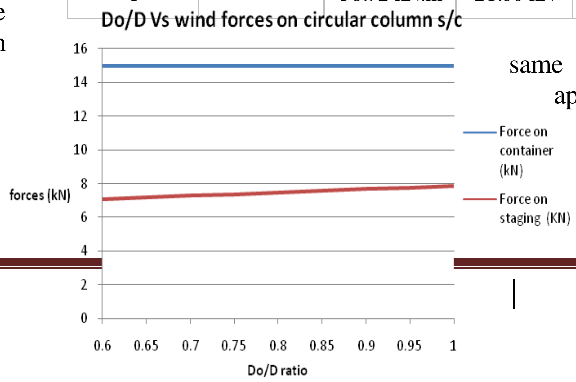
Fig-8: Graph shows the variation in wind force for square column

Discussion on Wind Analysis

1) Wind force on container is same for circular column and square column staging.
2) square column and circular column shows that in case of square column the wind force on staging increases multiplication factor for shape column is double in case of square column
3) The base moment and force in column is high in square column staging as compare to circular column staging.
4) Wind speed (Pz) is same for both the column staging.

3.3. Earthquake Effect on ESR

DEAD LOAD + LIVE LOAD+ WIND LOAD				
Do/D	MEMBER	MAX BM	MAX SF	MAX AXIAL FORCE
0.6	TOP BEAM	37.93 kN.m	75.50 kN	
0.85		86.98 kN.m	123.80 kN	
1		116.40 kN.m	139.63kN	
0.6	COLUMN	27.54 kN.m	11.69 KN	268.27 kN
0.85		52.88 kN.m	26.80 KN	357.69 kN
1		85.81 kN.m	37.44 kN	392.78 kN
0.6	BRACES	36.90 kN.m	29.67 KN	
0.85		38.93 kN.m	23.75 kN	
1		38.72 kN.m	21.60 kN	



The same procedure apply for

calculating base shear and base moment for different Do/D ratio range 0.6-1.0 in tank full and tank empty condition. Base shear results given below for Do/D=0.85

	For Tank Empty	For Tank Full
Seismic weight(W)	581.583kN	1080.06kN
Time period (T)	0.361 sec	0.492 sec
Design horizontal seismic coefficient(Ah)	0.06	0.06
Base shear(V_B)	**34.895 kN**	**64.803 kN**
Base moment	**483.295kN.m**	**897.529kN.m**

Discussion on Earthquake Analysis

1) Base shear is depends upon the seismic weight and time period of structure, this changes due to different Do/D ratios.
2) Base shear in tank full condition is 85-90% increasing as compare to tank empty conditions, in tank full condition seismic weight of water also added.
3) Design horizontal seismic coefficient (Ah) is same for tank empty and tank full conditions because zone factor, importance factor, response reduction factor & average response acceleration coefficient is same for both the cases.

3.4. ANALYSIS ON SAAP2000

Mathematical model:

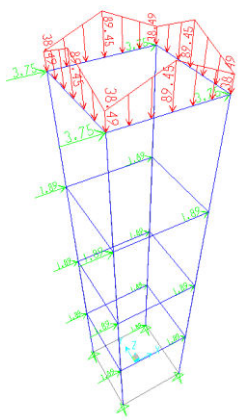


Fig-9: Mathematical model of DL+LL+WL combination

Table- 2: analysis result of DL+LL+WL combination

Mathematical model:

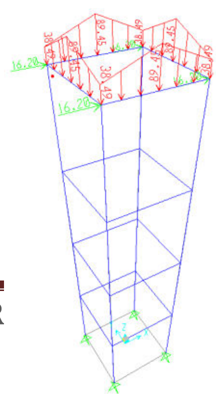


Fig- 10: Mathematical model of DL+LL+EL combination

Table-3 : Analysis result of DL+LL+EL combination

DEAD LOAD +LIVE LOAD+ EARTHQUAKE LOAD				
Do/D	MEMBER	max BM	max SF	max AXIAL FORCE
0.6	TOP BEAM	48.52 kN.m	91.83 kN	
0.85		86.98 kN.m	135.26 kN	
1		116.40 kN.m	150.23 KN	
0.6	COLUMN	49.34 kN.m	24.51 kN	354.41 kN
0.85		84.59 kN.m	39.26 kN	416.79 kN
1		110.23 kN.m	49.86 KN	445.98 kN
0.6	BRACES	71.88 kN.m	55.04 kN	
0.85		71.73 kN.m	40.53 kN	
1		73.03 kN.m	36.52 kN	
DEAD LOAD +LIVE LOAD+ EARTHQUAKE LOAD				
Do/D	MEMBER	max BM	max SF	max AXIAL FORCE
0.6	TOP BEAM	48.52 kN.m	91.83 kN	
0.85		86.98 kN.m	135.26 kN	
1		116.40 kN.m	150.23 KN	
0.6	COLUMN	49.34 kN.m	24.51 kN	354.41 kN
0.85		84.59 kN.m	39.26 kN	416.79 kN
1		110.23 kN.m	49.86 KN	445.98 kN
0.6	BRACES	71.88 kN.m	55.04 kN	
0.85		71.73 kN.m	40.53 kN	
1		73.03 kN.m	36.52 kN	

Discussion on Saap2000 Analysis.

1) In Top beam maximum bending moment and maximum shear force is occurred at Do/D ratio equals to 1.0 due to change in diameter of staging and their loading conditions.

2) In column the maximum moment, shear force and axial force is occurred at DO/D ratio equals to 1.0 but DL+LL+EQ load combination is critical.

3) In braces the maximum bending moment occurred at Do/D =1.0 and maximum shear force occurred at Do/D =0.6, but DL+LL+EQ load combination is critical.

4) Overall analysis DL+LL+EQ load combination is critical and design for DL+LL+EQ load case results.

3.4. Comparison of Analysis Result

Analysis result obtained from all effects and their variation is studied. The three effects on ESR shows the variation in analysis result for each Do/D ratio, from these results, the Do/D ratio 0.6, 0.85 and 1.0 was decided for analysis on SAAP2000 with DL+LL+WL and DL+LL+EL load combinations. Table no 8.1 and 8.2 shows the analysis result & its discussion is given below.

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1) Diameter of staging and container is directly affecting the bending moment in base slab at different locations.
2) The maximum economy is achieved in ESR on the basis of the design moment in base slab which should balance the moment at support and moments along the spans of staging.
3) Minimum radial and circumferential moment in circular base slab is obtained from Do/D ratio 0.8.
4) From circular slab analysis effect it is concluded that the radial moment and circumferential moment should be possible as +ve (sagging) moment in circular slab for reducing leakages in tank.
5) **Table-4:** % change in max BM for base slab

% change in max BM for base slab

Do/D ratio range	% decreasing in max BM w.r. to Do/D=1	% increasing in max BM w.r. to Do/D=1
0.95	21.65%	
0.9	43.35%	
0.85	62.57%	
0.8		48.78%
0.75		34.18%
0.7		20.89%
0.65		2.07%
0.6		1.16%

From above graph it is concluded that, in Circular base slab maximum % decreases in
From above graph it is concluded that, in Circular base slab maximum % decreases in BM w.r. toDo/D=1 is obtained Do/D ratio is 0.85 & maximum

Table-6: SAAP2000 analysis result

Do/D	Member	DEAD LOAD+LIVE LOAD+WIND LOAD			DEAD LOAD+LIVE LOAD+EARTHQUAKE LOAD		
		Max BM	Max SF	Max AXIAL FORCE	Max BM	Max SF	Max AXIAL FORCE
0.6	TOP BEAM	37.93 kNm	73.50 kN		48.52 kN.m	91.83 kN	
0.85		86.98 kNm	123.80 kN		86.98 kN.m	135.26 kN	
1		116.40 kN.m	139.65kN		116.40 kN.m	150.23 KN	
0.6	COLUMN	27.34 kNm	11.69 KN	268.27 kN	49.34 kN.m	24.51 kN	354.41 kN
0.85		52.88 kNm	26.80 KN	357.69 kN	84.59 kN.m	39.26 kN	416.79 kN
1		85.81 kNm	37.44 kN	392.78 kN	110.23 kN.m	49.86 KN	445.98 kN
0.6	BRACES	36.90 kNm	29.67 KN		71.88 kN.m	55.04 kN	
0.85		38.93 kNm	23.75 kN		71.73 kN.m	40.53 kN	
1		38.72 kNm	21.60 kN		73.03 kN.m	36.52 kN	

4. CONCLUSION

In the present work, the study is carried out on various aspect of elevated storage reserviour and the effort is given to study the effect of horizontal forces on ESR. Following conclusion can be drawn from study.

1) The effect of horizontal forces on ESR depends on geometrical parameter of container (H/D ratio) and staging (Do/D ratio).
2) From horizontal force effect on ESR, it is concluded that the Circular columns staging configuration is most stable & economical as compared to square.
3) From all three effects namely the optimum design moment for different Do/D ratio are obtained in the

% increases in BM w.r.to Do/D=1obtained ratio is 0.8.

6) From wind effect it can be observed that the magnitude of wind forces depends upon shape factor and effective area of member. Also it depends upon the position of braces, column and top beam.
7) analysis of four column staging with square column and circular column shows that in case of square column the wind force on staging increases as multiplication factor is double in case of square column.
8) From earthquake effect it is observed that base shear depends upon the seismic weight and time period of structure, this change according to their different Do/D ratios.
9) For calculating base shear for ESR, time period is same for all Do/D ratios. Hence, the type of base slab does not affect the dynamic properties of elevated water tank staging.
10) From all three effects the optimum design moment for different Do/D ratio are obtained in range 0.8 to 0.9.
11) In analysis Maximum magnitude BM, SF & axial force is obtained for Do/D ratio equals to 1.0, because the diameter of staging is increasing & this is affecting the dead load on ESR.
12) Overall SAAP analysis DL+LL+EQ load combination is critical in each member and design of ESR for Do/D ratio 0.85 with DL+LL+EQ load case analysis is presented.

Table -5: Result of wind effect, circular slab analysis effect & earthquake effect on ESR

Do/D	Wind Effect For Circular Column		Circular Slab Analysis Effect final Mr(kN-m)			final M? (kN-m)			Earthquake Effect Tank Full Condition	
	Base Moment (kN.m)	Force (kN)	r=0	r=b	r=a	r=0	r=b	r=a	Base Shear (kN)	Base Moment(kN.m)
0.600	331.405	120.074	-27.756	-40.285	0.000	-27.756	-31.932	-24.988	64.183	888.928
0.650	333.201	111.439	-19.376	-34.080	0.000	-19.376	-24.278	-20.282	64.307	890.649
0.707	335.232	103.149	-10.135	-27.531	0.000	-10.135	-15.933	-14.458	64.448	892.610
0.750	336.795	97.622	-3.331	-22.907	0.000	-3.331	-9.856	-9.741	64.555	894.089
0.800	338.592	92.009	4.447	-17.827	0.000	4.447	-2.978	-3.905	64.679	895.809
0.850	340.388	87.056	12.117	-13.027	0.000	12.117	3.736	2.307	64.804	897.529
0.900	342.185	82.653	19.715	-8.474	0.000	19.715	10.319	8.895	64.928	899.249
0.950	343.982	78.714	27.269	-4.140	0.000	27.269	16.799	15.860	65.052	900.970
1.000	345.779	75.169	34.802	0.000	0.000	34.802	23.201	23.201	65.176	902.690

range 0.8 to 0.9.

4) Analysis of staging is mostly governed by the horizontal forces due to wind and earthquakes, all the models studied are critical under earthquake loads.
5) The radial moment in base slab is always –ve at staging i.e. hogging moment at support & tension will occurred at water face. For this effect radial reinforcement is provided in design. Radial moment is zero at outer edge of base slab for every Do/D ratios of tank.

6) From wind analysis, the wind speed (P_z) is same for square and circular column staging. Only change in shape factor, effective frontal area & also depend upon the position of braces, column and top beam, the wind forces on staging and container are different for circular and square column.
7) In earthquake analysis, Base shear in tank for full condition is increasing by 85-90% as compared to tank for empty conditions; this change is due to addition of seismic weight of water in tank. This base shear is governing the base moment and forces in column.
8) In earthquake analysis, Equivalent stiffness (Ke), Time Period (T), Design horizontal seismic coefficient (Ah) calculations depend upon the seismic weight of ESR. Zone factor (z), importance factor (I) & response reduction factor(R) is same for tank empty and full condition of tanks and given in IS codes.

9) In analysis it is observed that top beam, column and braces is critical under DL+LL+EQ load condition, because earthquake forces are acting on only at top nodes of staging and this is highly affecting member forces in top beam, column and braces.
10) In container analysis the maximum moment occurred at base of tank wall and maximum hoop tension occurred at 0.6 height of tank, this depends upon the weight of water, radius of container and height of container.
11) In container design, area of main steel provide is equal to minimum area of steel given by IS codes because of hoop tension and bending moment developed is tank small in magnitudes, this depends the geometrical parameter of tanks.
12) Container design by WSM and LSM, both methods area of steel obtained is minimum as compared to minimum area of steel given in IS codes.

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