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Comparative Study between Circular and Rectangular Elevated Service Reservoirs on varying Staging Heights along with Dynamic Analysis

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Abstract--- **Water tank is a structure used to store water for supplying to households as drinking purpose, for industries as a coolant and irrigational water for agricultural farming in some areas. Elevated water tanks are constructed in order to provide required head so that the water will flow under the influence of gravity. In this paper, an extensive computational study has been conducted to find out the performance of structural elements of elevated water tank under wind force. Since these struc¬tures have large mass concentrated at the top of slender supporting structure, these structures are especially vul¬nerable to horizontal forces due to wind. Finite element models of 8 elevated water tanks have been analyzed in software. After the completion of the analysis a comparative study is carried out with respect to moments, shear stresses of base slabs and axial load variation of the columns with different staging heights.**

Findings of the present study shall lead us to better understanding of the behavior of elevated water tank under wind load and safer design of such structure

I. INTRODUCTION

Many new ideas and innovation has been made for the storage of water and other liquid materials in different forms and fashions. Liquid storage tanks are used extensively by municipalities and industries for storing water, inflammable liquids and other chemicals. Thus, water tanks are very important for public utility and for industrial structure.

Based on the location the water tanks are classified into three ways:

- Underground water tanks
- Tank resting on grounds
- Elevated or overhead water tanks.

II. ELEVATED OR OVERHEAD WATER TANKS.

Elevated tanks have many advantages. Elevated tanks do not require the continuous operation of pumps. Short term pump shutdown does not affect water pressure in the distribution system since the pressure is maintained by gravity. And strategic location of the tank can equalize water pressures in the distribution system. However, precise water pressure can be difficult to manage in some elevated tanks.

The pressure of the water flowing out of an elevated tank depends on the depth of the water in the tank. A nearly empty tank probably will not provide enough pressure while a completely full tank may provide too much pressure. The optimal pressure is achieved at only one depth

The optimal depth of water for the purpose of producing pressure is even more specific for standpipes than for tanks elevated on legs. The length of the standpipe causes continual and highly unequal pressures on the distribution system. In addition, a significant quantity of the water in a standpipe is required to produce the necessary water pressure.

Also, the elevated water tanks are classified based on shape:

- Rectangular/ Square tanks
- Circular tanks
- Intez tanks
- Circular tank with spherical bottom
- Circular tank with domed bottom
- Circular tank with conical bottom

III. RELATED RESEARCH

Various literatures are presented in form of technical papers till date on wind analysis of elevated service reservoirs. Various issues and points are covered in the analysis. Some of the technical research papers are discussed below.

Manoj Nallanathel, Mr. B. Ramesh and L. Jagadeesh in the research paper ‘Design and analysis of water tanks using staad pro’ concluded that the shape of water tank plays vital role in the stress distribution. The shape of the tanks plays predominant role in the design of overhead water tanks. Usage of Staad pro in design gives accurate results for shear force and bending moment than convenient method.

Fig 1 The types of elevated water tanks classified based on shape

Hemishkumar Patel, Prof. Jayeshkumar Pitroda and Dr. K. B. Parikh in the research paper ‘Analysis of circular and rectangular overhead water tank’ designed and analysed circular elevated water tanks and rectangular water tanks. The total water load and dead load in rectangular tank is slightly higher than in circular tank. The axial force in column due to total water load in the circular tank is lower as compared to the rectangular tank for higher capacity. Software results compared to IS code calculation were slightly higher.

Nitesh J Singh and Mohammad Ishtiyaque in the research paper ‘Design analysis and comparison of water tank for different wind speed and seismic zones as per Indian codes’ studided the elevated structure for the wind forces 39 m/s, 44 m/s, 47 m/s and 50 m/s. The same elevated structure was studied for different seismic zones i.e. Zone-II, Zone-III, Zone-IV and Zone-V. It is found from the analysis that the total load, total moments and reinforcement in staging that is columns and braces varies for each case. The total load on columns and the total moments on column on each storey went on increasing in each cases. The moments at face of braces and the torsional moment acting on the braces increased as the wind speed increased. In each case, as the wind speed goes on changing or increasing the wind moment calculated manually and analyzed from Staad Pro software differ by 4-5 %.

Chintha Ravichandra and R. K. Ingle in the technical research paper ‘Analysis of cylindrical water tanks- wind or earthquake’ considerd ESR of staging height 12m with capacity varying from 20 m^3 to 100 m^3. Analysis has been done using SAP-2000. Seismic zones Zone-II, Zone-III, Zone-IV and Zone V are considered. Wind analysis is done for wind speeds of 39 m/s, 44 m/s, 47m/s and 50m/s. In order to find out the governing load case nine tanks of capacity 20 m^3 to 100 m^3 were considered in the paper having staging height 12m. To determine the governing load case equivalent point load for wind loading is calculated and then compared with seismic forces. This comparison is used to indicate predominant load case i.e. earthquake or wind. The wind forces are more significant as compared with the earthquake forces.

IV. METHODOLOGY AND DESIGN CALCULATION

The methodology includes the modeling of water tank of capacity 20 lakh litres. Fix the dimensions of the components of the water tanks. The circular and rectangular overhead water tanks are considered on staging heights 15 m, 18 m, 21 m and 24 m for analysis. It is analyzed for Nagpur zone having velocity of wind 44 m/s. The dynamic analysis (wind load) is performed through the Staad.Pro software. Lastly, the results of the analysis of the tanks have been compared by using the graphs.

V. GENERAL SPECIFICATIONS

For the ease of comparisons of the circular and rectangular water tanks the dimensions of the circular and rectangular tanks are considered the same for all the varying staging heights. The components on that the tanks rest are foundation, columns and bracing. The structural elements that make the staging for the water tank should have adequate strength to resist axial loads, moment and shear force due to lateral loads. These forces depend upon total weight of the structure that varies with the amount of water present in the tank container. The components of the tanks are the floor beams, floor slab, cylindrical or rectangular vertical walls, roof slab and gallery.

- Foundation

Bottom of foundation	2 m
Centre of plinth beam	0 m
Width of plinth beam	0.25 m
Depth of plinth beam	0.5 m

- Columns

Diameter of the column	0.55 m

- Bracing

Width of bracing beam	0.25 m
Depth of bracing beam	0.5 m

- Floor beam

Width of floor beam	0.3 m
Depth of floor beam	0.7 m

- Floor slab

Thickness of floor slab	0.2 m

- Walking gallery

Thickness of gallery	0.2 m

- Cylindrical wall or rectangular wall

Top width of wall	0.2 m
Bottom width of wall	0.2 m
Height of wall	4.2 m

- Roof Slab

Thickness of roof slab	0.2 m

VI. WEIGHT OF COMPONENTS

The weight of the components is calculated by multiplying the volume of the components and the density of the concrete. The essential requirement in design of water is imperviousness. To make the water tanks impervious, wider cracks should be avoided in the water tanks. So, the M30 grade of concrete is considered. Density (ρ) of M30 grade of concrete is 25kN/m³.

The structural weight includes the weight of the empty tank and one-third weight of the staging.. Water load is considered as dead load. And for dynamic analysis, freeboard is not included in the depth of water.

Table 1 Weight of various components in kN of elevated service reservoir having circular tank of capacity 20 lakh litres for the different staging heights

Various Components	Weight for staging heights (kN)			
	15 m	18 m	21m	24 m
Roof slab	2503	2503	2503	2503
Wall	1665	1665	1665	1665
Floor Slab	2503	2503	2503	2503
Floor Beam	1106	1106	1106	1106
Gallery	401	410	410	410
Water	19640	19640	19640	19640
Columns	2123	2568	3013	3459
Braces	2789	3347	3905	4463
Staging	4912	5915	6918	7922
Empty tank	8772	8772	8772	8772
Total weight	33324	34327	35330	36334

Table 2 Weight of various components in kN of elevated service reservoir having rectangular tank of capacity 20 lakh litres for the different staging

Various components	Weight for staging heights (kN)			
	15 m	18 m	21m	24 m
Roof slab	2500	2500	2500	2500
Wall	1890	1890	1890	1890
Floor Slab	2500	2500	2500	2500
Floor Beam	919	919	919	919
Gallery	460	460	460	460
Water	19620	19620	19620	19620
Columns	2547	3082	3616	4150
Braces	3828	4594	5359	6125
Staging	6375	7676	8975	10275
Empty tank	8982	8982	8982	8982
Total weight	34977	36278	37577	38877

VII. CENTRE OF GRAVITY

The centre of gravity affects the stability of objects. Centre of gravity vastly simplifies calculations involving gravitation and dynamics to be able to treat the mass of an object as if it is concentrated at one point. The centre of gravity of the empty tank is the summation of product of distance of the components of the empty tank from the top of the floor beam and the weight of the components divided by the total weight of the empty tank.

VIII. WIND LOAD

Design wind speed (Vz) at any height can be calculated as follows:

$$V_z = V_b\, k_1\, k_2\, k_3$$

Where,

V_z = Design wind speed at any height 'z'
V_b = Basic wind speed for any site
k_1 = Probability factor (Risk coefficient)
k_2 = Terrain, height and size factor
k_3 = Topography factor

IX. DESIGN WIND PRESSURE (PZ)

The design wind pressure at any height above mean ground level is obtained by the following relationship between wind pressure and wind velocity:

$$P_z = 0.6\, V_z^2$$

Where,

P_z = Design wind pressure at height z
V_z = Design wind velocity at height z

X. WIND FORCE

The value of force coefficients apply to a building or structure as a whole, and when multiplied by the effective frontal area A_e of the building or structure and by design wind pressure *pd* is the total wind load on that particular building or structure.

$$F = C_f A_e p_d$$

Where,

F = force acting in a direction specified,
C_f = force coefficient for the building,
A_e = the effective frontal area,
p_d = design wind pressure.

The components of the elevated service reservoirs for that the wind forces calculated are:

(a) Wind forces on the centre of gravity of the tank
(b) Wind force on individual structural elements. The structural elements are floor beams, bracing beams and circular columns.

Table 3.1 Calculation of centre of gravity from top of the floor beam for circular tank

Components	Distance	Weight	Distance × Weight
Roof Slab	4.3	2503	10762.9
Cylindrical wall	2.1	1665	3496.5
Floor Slab	0.1	2503	250.3
Floor Beam	0.35	1106	387.1
Gallery	0.05	401	20.05

Center of gravity

$$= \frac{10762.9 + 3496.5 + 250.3 + 387.1 + 20.05}{8772}$$

Center of gravity $= 1.70$ m

Therefore, the center of gravity of the circular tanks from the top of the floor beam is 1.70 m.

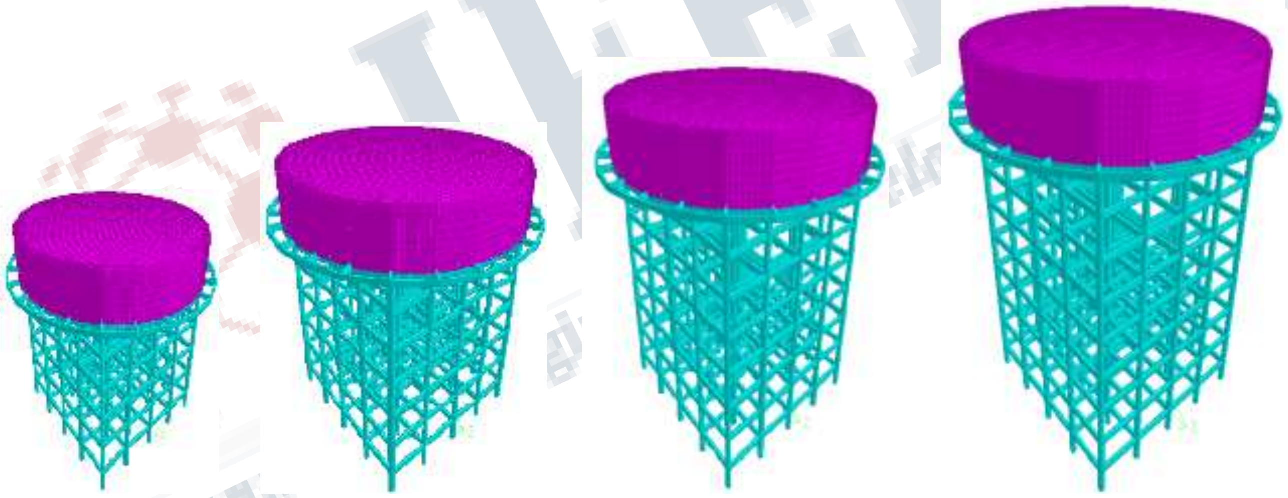

Fig 2 Circular tanks of capacity 20 lakh litres on staging heights 15 m, 18 m, 21 m and 24 m respectively

Table 3 Wind forces on elevated service reservoirs in kN/m for circular tank on staging height 15 m, 18 m, 21 m and 24 metres for wind speed 44 m/s

Various components	Wind forces for staging heights (kN/m)			
	15 m	18 m	21m	24 m
Wind force on C.G.	94.00	95.00	96.00	98.00
Floor beam	1.11	1.13	1.14	1.16
Bracing beams	0.83	0.84	0.85	0.87
Circular columns	0.42	0.43	0.44	0.45

Table 4 Calculation of centre of gravity from top of the floor beam for rectangular tank

Components	Distance	Weight	Distance × Weight
Roof Slab	4.3	2500	10750
Wall	2.1	1890	3969
Floor Slab	0.1	2500	250
Floor Beam	0.35	919	321.65
Gallery	0.05	460	23

Center of gravity

$$= \frac{10750 + 3969 + 250 + 321.65 + 23}{8982} = 1.70$$

Center of gravity $= 1.70$ m

Therefore, the center of gravity of the circular tanks from the top of the floor beam is 1.70 m.

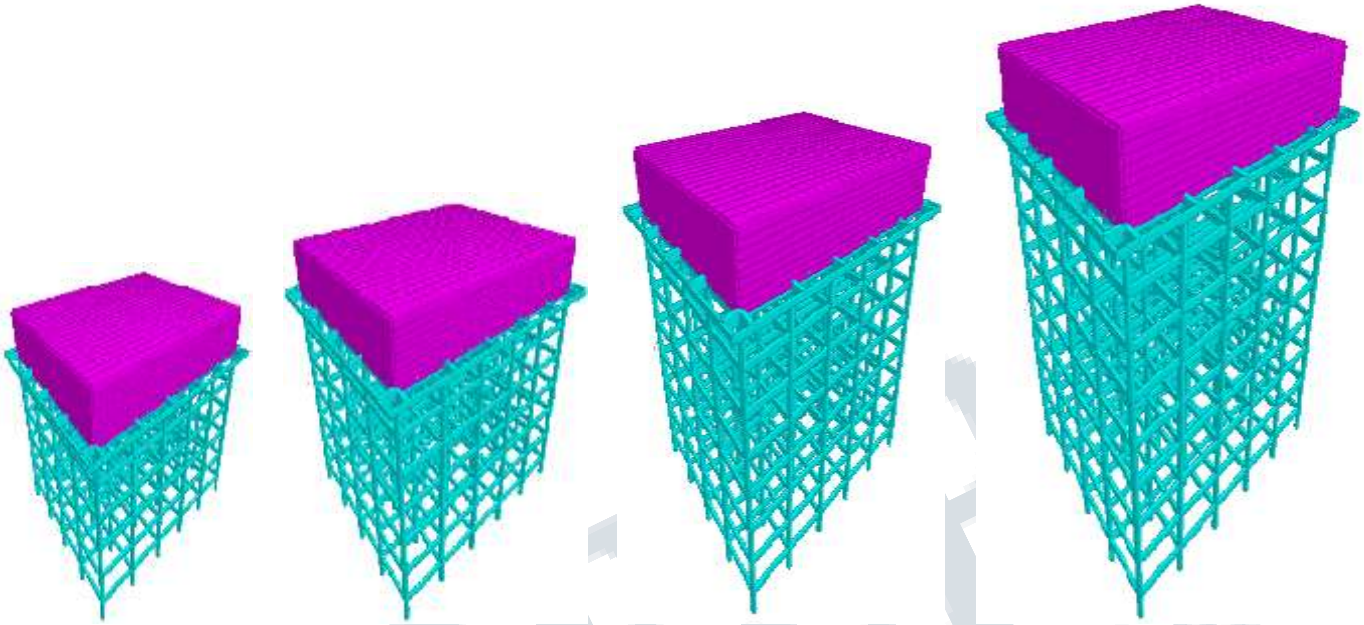

Fig 3 Rectangular tanks of on staging heights 15 m, 18 m, 21 m and 24 m respectively

Table 5 Wind forces on elevated service reservoirs in kN/m for rectangular tank on staging height 15 m, 18m, 21 m and 24 metres for wind speed 44 m/s

Various components	Wind forces for staging heights (kN/m)			
	15 m	18 m	21m	24 m
Wind force on C.G.	132.00	134.00	136.00	138.00
Floor beam	1.12	1.13	1.15	1.17
Bracing beams	0.85	0.86	0.87	0.88
Circular columns	0.42	0.43	0.44	0.45

XI. LOAD TYPES

The circular and rectangular tanks are subjected to basically dead load, live load, water load and wind loads. Dead load includes the self weight of the structure while live load consists of superimposed load. The water pressure of on the base slab is considered as water load. In addition to this the elevated service reservoirs are subjected to wind forces. The loads applied to the modeled elevated service reservoirs in STAAD Pro are:

- Dead load
- Live load
- Water load
- Wind load X+
- Wind load X-
- Wind load Z-
- Wind load Z-

XII. LOAD COMBINATIONS

As per IS 1893 (Part 1): 2002 Clause no. 6.3.1.2, the following load cases have to be considered for analysis:

- DL+LL
- 1.5 DL+1.5 LL
- 1.5 DL+1.5 W_X
- 1.5 DL-1.5 W_X
- 1.5 DL+1.5 W_Z
- 1.5 DL-1.5 W_Z
- 1.2 DL+1.2 W_X+0.3 LL
- 1.2 DL-1.2 W_X+0.3 LL
- 1.2 DL+1.2 W_Z+0.3 LL
- 1.2 DL-1.2 W_Z+0.3 LL
- 0.9 DL+1.5 W_X
- 0.9 DL-1.5 W_X
- 0.9 DL+1.5 W_Z
- 0.9 DL-1.5 W_Z

XIII. RESULTS

The models of tank capacity 20 lakh litres are designed and analyzed in the software for the staging heights 15 metres, 18 metres, 21 metres and 24 metres. The comparison is made between the moments along x-direction and z-direction for the circular and rectangular tanks. The maximum axial load acting on the column is compared for circular and rectangular elevated service reservoirs on different staging heights.

Table 6 Maximum moments along x-direction and z-direction for the circular tanks on different staging heights.

Staging heights	Circular tanks	
	Mx	Mz
15 m	160	187
18 m	179	209
21 m	213	237
24 m	245	285

Table 7 Maximum moments along x-direction and z-direction for the rectangular tanks on different staging heights.

Staging heights	Rectangular tanks	
	Mx	Mz
15 m	160	187
18 m	179	209
21 m	213	237
24 m	245	285

Table 8 Comparison of values of maximum axial load on the column for the circular and rectangular tank for different staging height

Staging heights	Circular tanks	Rectangular tanks
15 m	3048	2187
18 m	3152	2271
21 m	3403	2453
24 m	3526	2674

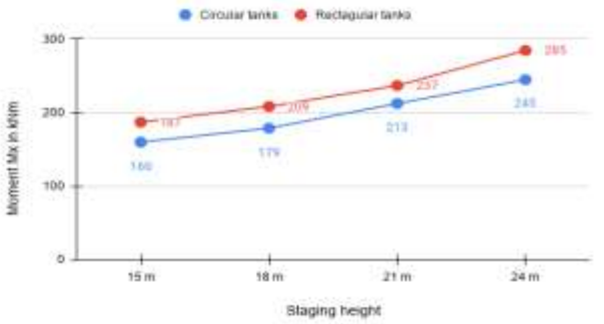

Fig 4 Comparison of moments along x-direction for the circular and rectangular elevated services reservoirs for different staging heights

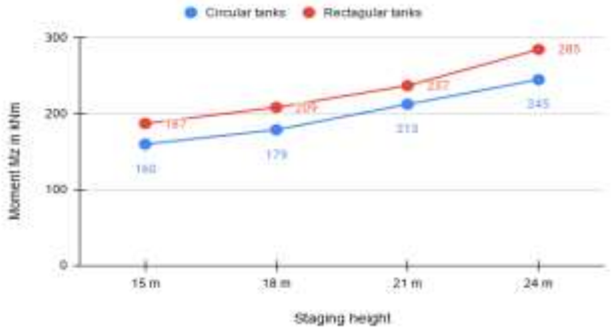

Fig 5 Comparison of moments along z-direction for the circular and rectangular elevated services reservoirs for different staging heights

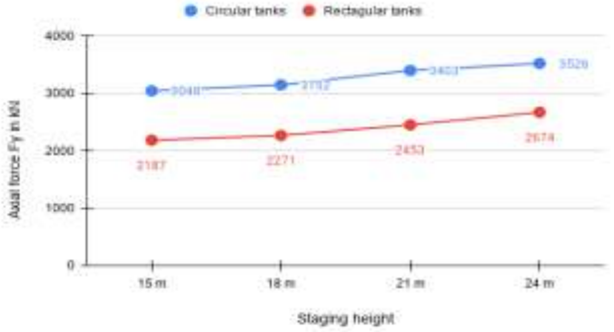

Fig 6 Comparison of axial force on the column for the circular and rectangular elevated services reservoirs for different staging heights

XIV. CONCLUSIONS

The comparison between the circular and rectangular elevated services reservoirs is done using the graphs. The conclusions dawn are:

The maximum moments for circular and rectangular elevated services reservoirs are the same along x-direction and z-direction.

The maximum moments for the circular tanks are less as compared to the rectangular tanks.

The value of moments goes on increasing as the staging height for the tanks goes on increasing for the same tank capacity.

The dominating load combination for the moments along the x-direction is 1.5 DL-1.5 W_Z and along the z-direction is 1.5 DL+1.5 W_X.

The circular tanks attract lesser wind forces as compared to rectangular tanks because the effective area for the circular tank is less than that of the rectangular tank.

The axial load on the foundation level is more for the circular tank as compared to the rectangular tank. This is observed as the number of column on that the circular tank rest are less than the number of columns on that the rectangular tank rest.

The value of axial load goes on increasing as the staging height for the tanks goes on increasing for the same tank capacity.

REFERENCES

[1] M. Bhandari and Karan Deep Singh, "Economic design of water tank of different shapes with reference to IS: 3370 2009.", International journal of modern engineering research (IJMER), Vol. 4, 12th December 2014.

[2] M N S Radhuri and B Sri Harsha, "Design of circular water tank by using staad pro software.", ISSN 2277-4408, International journal of computer science information and engineering technologies.

[3] Hasan Jasim Mohammed, "Economical design of water concrete tanks.", ISSN 1450-216X, European journal of scientific research, Vol.49 No.4 (2011), pp. 510-520.

[4] Mr. Manoj Nallanathel, Mr. B. Ramesh and L. Jagadeesh, "Design and analysis of water tanks using staad pro.", ISSN: 1314-3395, International journal of pure and applied mathematics, Volume No. 119, 2018, 3021-3029.

[5] Hemishkumar Patel, Prof. Jayeshkumar Pitroda and Dr. K. B. Parikh, "Analysis of circular and rectangular overhead water tank.", 978-81-929339-0-0, National conference on: "Trends and challenges of civil engineering in today's transforming world", 29th March, 2014.

[6] Nitesh J Singh and Mohammad Ishtiyaque, "Design analysis and comparison of water tank for different wind speed and seismic zones as per Indian codes.", International journal of research in engineering and technology, Volume: 04, 9th September 2015.

[7] Chintha Ravichandra and R. K. Ingle, "Analysis of cylindrical water tanks- wind or earthquake.", ISBN: 978-93-85465-11-6, IRF International conference, 10th May 2015, Chennai, India.

[8] Hasan Manish, N. Gandhi and Prof. A. Rajan, "Necessity of dynamic analysis of elevated water storage structure using different bracing in staging.", E-ISSN: 2321-9637, International journal of research in advent technology, Vol.2, No.2, February 2014.

[9] Sudip Jha ,Cherukupally Rajesh and P.Srilakshmi, "Behavior of an elevated water tank for different staging patterns and different staging heights.", ISSN No: 2348-4845 International journal and magazine of engineering, technology, management and research, Volume No: 2 (2015), Issue No: 8 (August) 2015.

[10] Shilja Sureshkumar and Asha Joseph, "Review on structural performance of water tanks under dynamic loading.", e-ISSN: 2395 -0056, International research journal of engineering and technology (IRJET), Volume: 04, Issue: 04th April 2017.

[11] B.V. Ramana Murthy, M Chiranjeevi. "Design of Rectangular Water Tank by Using Staad Pro Software.", International Journal of Computer Science information and Engg., Technologies, issue 6-volume 1, series 3, issn 2277-4408.

[12] M N S R Madhuri, B Sri Harsha. "Design of Circular Water Tank by Using STAAD PRO Software.", International Journal of Computer Science information and Engg., Technologies, Issue 6, Volume 1, Series 3, Issn 2277-4408.

[13] S.Ramamruthan and R.Naryan, "Design of Reinforced Concrete Structure" Dhanpat Rai Publishing Company (P) Ltd., New Delhi

[14] IS: 3370 (Part I-II) -2009, General Requirements, Code of Practice for Concrete Structures for the Storage of liquids.

[15] IS: 3370 (Part IV) -1967, Design Tables, code of practice for concrete structures for the storage of liquids.

[16] IS: 875 (2002) "Code of practice for design load" Bureau of Indian Standard, New Delhi.

[17] IS: 456 (2000) "Plain and reinforced concrete- Code for practice" Bureau of Indian Standard, New Delhi.

[18] STAAD Pro. 2007, Structural Analysis and Desi147gn programming-2007 for analysis of lateral stiffness.