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Analysis of Shear Stress Bending Moment Deflection and Design of Base Beam for an Elevated Circular Water Tank With Varying Outer Wall Cross-sections and Its Comparison Using Manual and STAAD Pro

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ABSTRACT

Aim: The aim of this study is to analyze and design a base beam for an elevated circular water tank with varying outer wall thickness 200mm, 300mm and 400mm and its comparison using manual and STAAD Pro. **Materials and methods:** The total number of sample sizes considered to obtain the accurate result is 18. Nine numbers of samples have been chosen per group and performed the analysis and design using Manual method and STAAD Pro method. **Results:** On performing an independent sample t-test on two groups has revealed that there is a statistically significant difference in bending moment ($p<0.05$) and there is no statistically significant difference in shear stress and deflection ($p>0.05$). **Conclusion:** It is concluded that STAAD Pro results obtained more accurate values when compared to manual design.

Keywords: Elevated Circular Water Tank, Base Beam, Novel Design, Manual, STAAD Pro.

INTRODUCTION

Water is stored in overhead water tanks, which are often utilised for human consumption. The estimated daily water consumption for a population of 278 people is roughly 1,00,000 litres, and the tank built to meet that demand has a capacity of 100 m3. Water is also crucial in the chemical, irrigation, agricultural and industrial sectors. [1] [2]. The appropriate optimization method was carried out to deal with the minimum cost of structural design of an elevated circular water tank [1]. The base moment is maximum when the tank is in full condition due to the weight of water [3]. The seismic behaviour of an elevated rectangular water tank was studied for different seismic zones of India and for different soil conditions [4].

In most of the research articles, analysis & design comparison of software methods with the conventional method was made. Many research articles were published on elevated water tanks in the past 5 years. Nearly, research articles were published in Google Scholar and 5 research articles were published in science direct. In recent times STAAD Pro software was explored mostly as the software saves time in doing the design with a percentage of accuracy. Many research articles were based on design and the applications of different types of elevated water tanks. The inbuilt feature of solving seismic coefficient methods in STAAD pro V8i software [5]. It is concluded that a concrete baffle wall was used to reduce the sling effect of the water tank [6]. From the literature study, it is found that nodal displacement increases as staging height increases [7]. To judge the seismic response of elevated rectangular water tanks with different staging patterns and different water level conditions [8]. As the number of stories increases with the height of the structure, the value of the peak story shear decreases [9]. In the research article, it has been identified as the failure modes of shear forces in beams and the axial forces are dominant in the reservoir [10]. The study is to investigate the appropriate optimization method to deal with the minimum cost of structural design of an elevated circular water tank [11]. Beforehand our team has a rich experience in working on various research projects across multiple disciplines[12]–[21]

Water demand is one of the key issues in supplying the water. To overcome this issue, the present water tank designs have to be modified. Elevated circular water tanks are the most effective storing facility used for domestic or even industrial purposes. This study gives an overall designing procedure of an elevated circular water tank using the Working stress method from IS-3370:2009.

MATERIALS AND METHODS

Study setting

Using STAAD Lab and a manual working stress method, analyse and design the elevated circular water tank structure at Saveetha school of Engineering, SIMATS, chennai. There are two different groups that have been considered for this project. The Manual design group for various parameters are compared to those of the STAAD Pro group. From the sample size calculation, the number of simulation models per group is calculated to be nine. The total sample size needed for this study is 18, with a G power of 50 and alpha (0.05). Clincalc.com is used to calculate the sample size based on the previous literature review.

Design procedure for STAAD Pro

Open STAAD PRO V8i software and create a new Space structure and select Meter and Kilo Newton as Length Units and Force Units. Select the Beam page under Geometry, the beam window is displayed. Close the Beam window. In the Nodes window, create the nodes with the related data as provided. Now, we will create the members in the upward direction so that the plates could be created with the same position. If the plates are created in different positions, you cannot assign a single load case to the plates. Create the members with the related data. Now, we will create a portion of the tank using the Circular Repeat tool. 3D Circular Tool in STAAD Pro. Select all the members and then choose the Circular Repeat tool from the menu, the 3D Circular dialog box is displayed. Enter the values. Choose the OK button, the model will be repeated in Y-axis. Select the geometry under that add plate, choose the triangle. Draw the triangle to the node points. Select add 4 nodded plates, click no plate cursor and select the plates. Choose the circular repeat and enter the values, click on the ok button. Click on view +z and choose the beam cursor, select the beam and right click the mouse under that choose the new view and then create a new window for the view, click on ok button. New window is displayed. Choose the node cursor, then select the node points and click on translational repeat and give the values then select the link steps, click on ok button. Choose the isometric view then click on add beams and draw the beams to the node points. Select general under that choose property, click on define add rectangle and enter the values, select the material type as concrete and click on add button and close. Choose the thickness, give the values for the thickness of the tank wall, click on add and close it. Select assign to view then click on yes. Select the support in that create and choose the type of support and assign a view to the selected points. Click on loads and definitions on the right side it will be displayed then add dead load, live load, wind load and auto load combinations. In dead load add self-weight. In live load, select plate loads that choose the pressure on full plate and enter the values, click on add button. In plate loads, select hydrostatic and enter the values. In auto load combinations, select the load combination as Indian code and click on add and assign to view. Select the beam and assign to the selected plates, click on yes. Select the trapezoidal and enter the values then we have to assign to the selected beam. Select analyze in that click on run analysis, the STAAD Analysis and Design window is displayed showing the progress of the solution. Once the analysis is completed, go to the Post Processing Mode radio button and choose the Done button, the results Setup dialog box is displayed. Choose the apply and click on ok button, the post-processing mode is displayed along with various results. Now, keeping the structure in front view and using the beam cursor, select the base of the circular water tank and click on the new view, only the base slab will be displayed on screen as shown in Fig. 1. After post processing, various parametric values like shear stress, bending moment and deflection can be determined for the base slab. The results of STAAD Pro data will be compared to data collected manually, as shown in Table 1.

Statistical Analysis

Independent sample t-test is done using the SPSS software and its mean,standard deviation and standard mean error is evaluated and Graph is plotted for each parameter as group vs shear stress, group vs bending moment and group vs deflection. The group of the tank wall is plotted along the y-axis whereas shear stress, bending moment and deflection is plotted along the x-axis. Table 2, Table 3 and Table 4 show the values for shear stress, bending moment, and deflection in base beam determined using manual and STAAD Pro methods for various tank wall thicknesses.

RESULTS

Figure. 2, Figure. 3 and Figure. 4 demonstrate the statistical analysis of this study, which shows that as the wall thickness increases, shear stress and deflection decreases but there is an increase in bending moment. Based on group statistical data in table 5, the performance of two different groups STAAD Pro and Manual can be identified based on mean values,standard deviation and standard error mean values.The mean values predicted for shear stress,bending moment and deflection of base beam analyzed in STAAD Pro seems to be higher than the values obtained by Manual.The standard deviation of STAAD Pro and Manual possess nearly equal values for shear stress and deflection, whereas there is a huge difference in value for the bending moment.The standard error mean values for shear stress, bending moment and deflection of STAAD Pro and Manual have the same characteristics like standard deviation.Thus, STAAD Pro gives higher accuracy than manual. Table 6 the Independent Sample t-test,compares the means between two unrelated groups on the same continuous, dependent variable. Here, thickness of wall is a dependent variable and shear stress, bending moment and deflection are independent variables. mean differences and standard error differences of equal variances assumed and equal variances not assumed values are equal for shear stress, bending moment & deflection. In 95% confidence intervals the difference of lower and upper values of equal variances assumed and equal variances not assumed are equal in shear stress and deflection, but there is a difference in bending moment.

DISCUSSION

In this study we observed that STAAD Pro results are higher when compared to Manual calculation. No significance difference between the two groups based on the p values and independent sample t-test. There is a statistically significant difference in bending moment ($p<0.05$) and there is no statistically significant difference in shear stress and deflection ($p>0.05$).

It is found for storing large volumes of water, intze tank is suitable to have a floor slab which is a combination of conical dome and bottom spherical dome. Similar findings are [22] There is not much difference in the design of water tanks done by manual and software analysis. It can be clearly seen that the quantities of PCC and steel reinforcement needed for the construction of rectangular shape tanks is comparatively more than those required for circular one but ease of construction is more difficult in circular water tanks compared to that of rectangular water tanks. [23], limit state method was found to be most economical for design of water tank as the quality of steel and concrete needed is less as compared to working stress method. [24], in case of the overhead water tanks, the wind effect is to be considered. Wind acts horizontally to the walls of the water tank which causes the base shear to the tanks. So, the wind load is also considered in the design of the overhead tanks in order to reduce the base shear on the water tanks. For smaller capacities rectangular shape tanks are economical and for large capacities circular shape tanks are economical. Factors affecting the shear, bending moment and deflection are thickness,loading conditions, elastic modulus and shape of the water tank.

Limitations of elevated circular water tanks with larger capacity and flat bottoms need larger reinforcement at the ring beam. In future, dynamic analysis for the same can be performed and the behavior of the liquid storage structure can be evaluated under dynamic loads by both Manual and STAAD Pro.

CONCLUSION

As the thickness of the wall of the circular elevated water tank increases,shear stress & deflection of the base beam decreases whereas bending moment increases. Analysis & design of the base beam is done using both conventional and software methods for the same loading conditions. The design methods used in STAAD-Pro analysis are Working Stress Method conforming to Indian Standard Code of Practice. For the study,we have considered the thickness of the circular wall as 200 mm,300 mm and 400 mm which satisfies the thickness of wall criteria for circular water tanks and compared the results determined for three thickness values by Manual & STAAD Pro. Hence, minimum value of thickness of wall should be considered for the economical design of base beam of circular elevated water tank.The results obtained from STAAD Pro is more when compared to the results obtained by manual calculation.The value of shear stress, bending moment and deflection predicted by manual is less than that of STAAD Pro method. STAAD Pro shows accurate results in the measurement of shear stress, bending Moment and deflection of base beam of circular elevated water tank.

DECLARATIONS

Conflict of Interests

No conflict of interest in this manuscript.

Author Contribution

Author BUB was involved in data collection, data analysis, graphical output and manuscript writing. Author MT was involved in conceptualization, guidance and critical review of manuscript.

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TABLES AND FIGURES

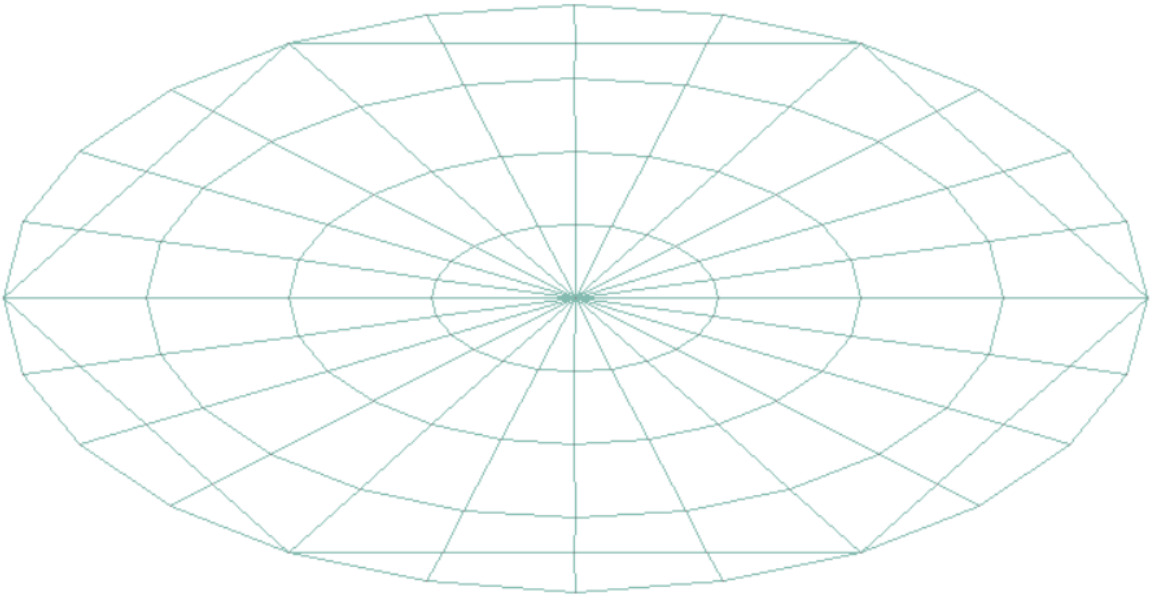

Fig. 1 Geometrical model of base slab of circular elevated water tank

Fig. 2 Bar plot showing the mean Shear Stress(N/mm^2) plotted for the two groups considered, manual and STAAD Pro**.** The mean shear stress by STAAD pro has better accuracy than manual. X-axis: Group and Y-axis: Shear Stress(N/mm^2).

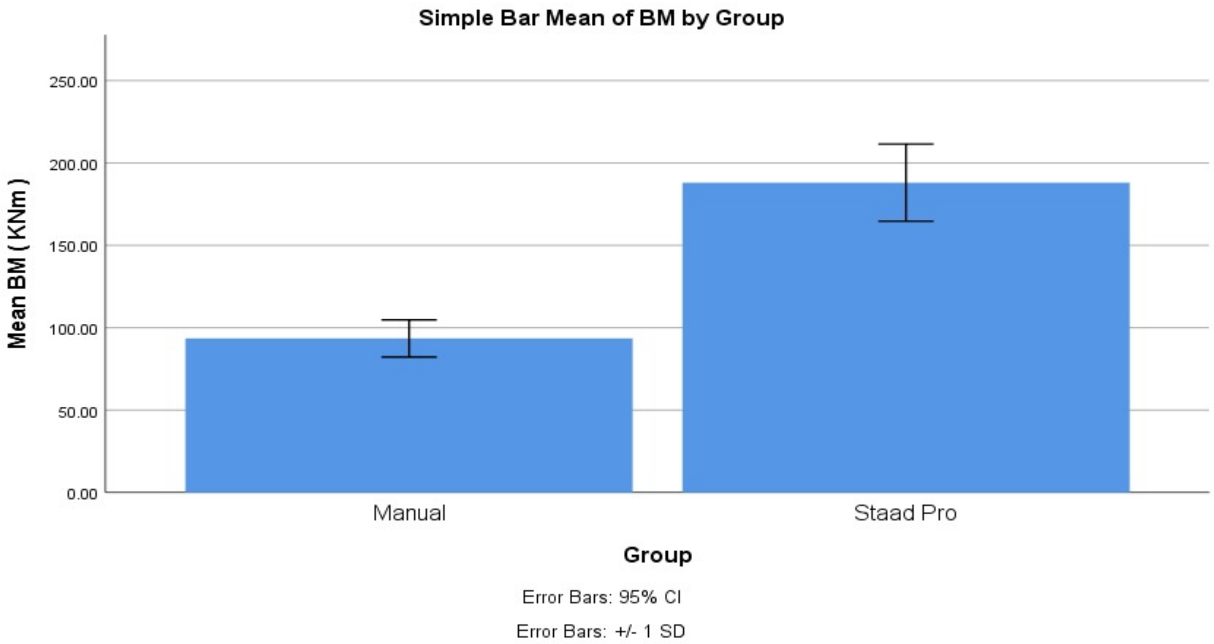

Fig. 3 Bar plot showing the mean BM(KNm) plotted for the two groups considered, manual and STAAD Pro**.** The mean shear stress by STAAD pro having better accuracy than manual. X-axis: Group and Y-axis: BM(KNm).

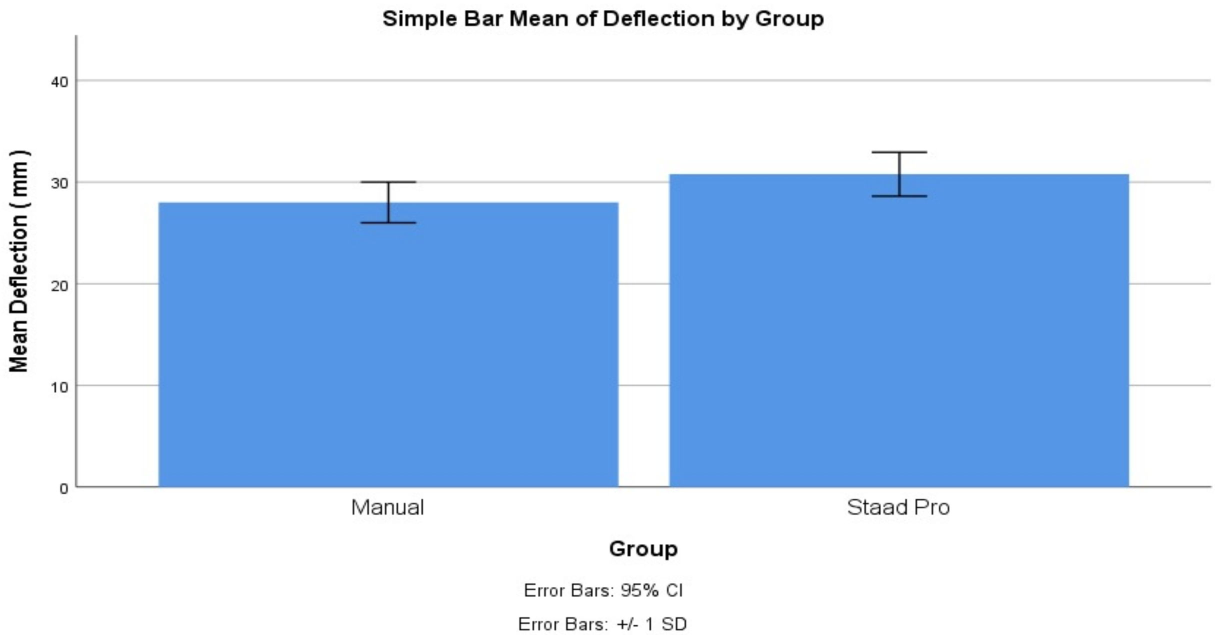

Fig. 4 Bar plot showing the mean deflection(mm) plotted for the two groups considered, manual and STAAD Pro**.** The mean shear stress by STAAD pro has better accuracy than manual X-axis: Group and Y-axis: deflection(mm).

Table 1. Testing setup for manual design

Design of circular slab	
Volume of Elevated Circular Water Tank	**100 m^3**
Assumed diameter of circular water tank	**10 m**
Depth of water	**1.27m**
Weight of water	**12.74**
Self weight of slab	**7.2**
Total load	**19.94 KN/m^2**
Maximum radial and ciecumferecial moments	
Positive moment at the centre of the span	**93.4634 KN.m**
Negative moment at supports	**62.3089 KN.m**
Circumferential moment	**31.1544 KN.m**
Effective depth of the slab	**304.3513 mm**
Adopt effective depth d	**310 mm**
Adopted overall depth	**330 mm**
Reinforcement in circular slab	
Area of steel (center of span)	**1782.9376 mm^2**
Provided bar size	**16 mm**
Area of one bar	**200.96 mm^2**

Spacing of bars	**112.71 mm**
Provide 16 mm bar with spaing 112.71 mm	
Area of steel(supports)	**1505.5918 mm^2**
Provided bar size	**16 mm**
Area of one bar	**200.96 mm^2**
Spacing of bars	**133.48 mm**
Provide 16 mm bar with spacing 133.48 mm	
Area of steel (circumferential)	**752.7959 mm^2**
Provided bar size	**16 mm**
Area of one bar	**200.96 mm^2**
Spacing of bars	**266.95 mm**
Provide 16 mm bar with spacing 266.95 mm	
Shear stress	**0.06 KN/m^2**
Shear stress from IS 456	**0.22 KN/m^2**
Since shear value is negligible.	
Diameter of the base slab, D	**10000 mm**
Deflection of base slab	**28.5714 mm**

Table 2. Shear stress in base slab obtained by Manual and STAAD Pro method for different tank wall thickness.

Sample No.	Thickness (mm)	Load Cases	Manual Shear(N/mm^2)	STAAD Shear(N/mm^2)
1	200	Total load	0.542	0.642
2	300	Total load	0.39	0.468
3	400	Total load	0.35	0.464

Table 3. Bending moment in base slab obtained by Manual and STAAD Pro method for different tank wall thickness.

Sample No.	Thickness (mm)	Load Cases	Manual	staad
			Moment (KNm)	Moment (KNm)
1	200	Total load	82.213	213.869
2	300	Total load	93.46	182.018
3	400	Total load	104.73	168.204

Table 4. Deflection in base slab obtained by Manual and STAAD Pro method for different tank wall thickness.

Sample No.	Thickness (mm)	Load Cases	Manual	Staad
			Deflection(mm)	Deflection(mm)
1	200	Total load	30	33.2
2	300	Total load	28	30.069
3	400	Total load	26	29.263

Table 5.Analysis of group statistics in terms of mean, standard deviation and standard error mean for the two groups done for six samples. Mean shear stress, BM and deflection is observed to be higher in STAAD pro when compared to manual.

Group statistics					
	Groups	**N**	**Mean**	**Std. Deviation**	**Std.Error mean**
Shear stress	Manual	3	0.4267	0.10017	0.05783
	STAAD Pro	3	0.5240	0.10048	0.05801
BM	Manual	3	93.4677	11.2585	6.50010
	STAAD Pro	3	188.0277	23.4197	13.52137
Deflection	Manual	3	28	2	1.155
	STAAD Pro	3	30.78	2.158	1.246

Table 6. Independent sample-t-test results carried out for two groups for shear stress, BM and deflection in order to determine statistical significance. It is observed that on performing two-tailed t-test, there is a statistically significant difference in bending moment ($p<0.05$) and there is no statistically significant difference in shear stress and deflection ($p>0.05$).

		Leven's Test For Equality of Variances		**T-Test For Equality Of Means**						
				t	**df**	**Sig (2-tailed)**	**Mean difference**	**Std.Error Difference**	**95% Confidence Interval Of The Difference**	
		F	**Sig**						**Lower**	**Upper**
Shear stress	**Equal variances assumed**	0.004	0.955	-1.188	4	0.300	-0.09733	0.08191	-0.3247	0.13009
	Equal variances not assumed			-1.188	4.000	0.300	-0.09733	0.08191	-0.3247	0.13010
BM	**Equal variances assumed**	1.948	0.235	-6.303	4	0.003	-94.56	15.00262	-136.21396	-54.9060

	Equal variances not assumed			-6.303	2.878	0.009	-94.56	15.00262	-136.21396	-45.6445
Deflection	**Equal variances assumed**	0.115	0.752	-1.635	4	0.177	-2.777	1.699	-7.493	1.939
	Equal variances not assumed			-1.635	3.977	0.178	-2.777	1.699	-7.493	1.939