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Analysis of Underground Circular and Rectangular Water Tanks by using Stiffener

Archana Dattatray Thorat
archanathorat0@gmail.com
KJEI's Educational Institute of Trinity College of Engineering and Research, Pune, Maharashtra

Dr. Vaibhav Vilas Shelar
vaibhavvshelar.tcoer@kjei.edu.in
KJEI's Educational Institute of Trinity College of Engineering and Research, Pune, Maharashtra

Mr. Vijay Shivaji Shingade
v46090792@gmail.com
KJEI's Educational Institute of Trinity College of Engineering and Research , Pune, Maharashtra

ABSTRACT

This paper presents an analysis of a circular water tank using the finite element method (FEM). The tank's wall is examined for parameters such as moment and hoop tension at various levels, considering the effects of hydrostatic and soil pressures, along with the use of stiffeners. Additionally, the wall of a rectangular water tank is analyzed for vertical and horizontal moments at different levels, subjected to similar pressures. The analysis is performed using the FEM software STAAD-Pro V8i. For both tank types, the wall is modeled with its bottom fixed and top free. The wall is divided into several 4-node rectangular (quadrilateral) plate elements, and vertical beam elements are added up to the full height of the tank. The tank is then subjected to a triangularly varying hydrostatic load and soil load. Various types of stiffeners are incorporated into the tank design, and the results are compared with conventional design methods based on moment values.

Keywords: *STAAD-Pro, FEM, Water Tank, Stiffener*

1. INTRODUCTION

Water is essential for all life on Earth and serves various purposes, including drinking, irrigation, industrial manufacturing, and fire suppression. Therefore, efficient water storage is crucial. A water tank is a container designed to store large quantities of water. These tanks are constructed at ground level to meet daily water needs, for water treatment, product manufacturing, emergency storage, and rainwater collection, among other uses. As a vital infrastructure, water tanks play an important role in human society. Over time, the advancement of human civilization has led to the development of various types of water storage tanks to meet different needs and challenges.

Water is essential for all living beings and is a fundamental element for maintaining health. Safe drinking water is critical for human survival and well-being. The demand for clean and safe water continues to rise, as it is impossible to live without it. Therefore, it is crucial to store water in a safe and efficient manner. The force analysis of these reservoirs or tanks is generally consistent, regardless of the chemical nature of the stored product. All tanks are designed to be crack-free structures to prevent any leakage.

Slabs and walls designed to retain water or raw petroleum can be constructed from reinforced concrete, provided the reinforcement is adequately covered. Since water and petroleum can react with concrete, no special treatment is necessary. The need for water tanks has existed since the dawn of civilization, serving as storage for water used in various applications. Water tanks are generally categorized as circular, rectangular, or conical, depending on their size and intended location. They can be made from either steel or concrete. Tanks placed on the ground are typically circular or rectangular in shape and are used for storing large quantities of water. Key considerations in water tank design include the overall structure, material selection, and the choice of linings. When designing water tanks, it is important to follow established guidelines and carefully consider the loads that will be applied.

2. TYPES OF TANKS

Water tank can be classified into following two types as follows.

i. According to Shape
ii. Circular Tank
iii. Rectangular tank
iv. Spherical Tank
v. Intze Tank

vi. Circular Water Tank with Conical Bottom
vii. According to Placement
viii. Tank Resting on Ground
ix. Underground Tank
x. Elevated tank

3. STIFFENER

Stiffeners are secondary plates or sections added to structures to prevent out-of-plane deformations. Most primary bridge beams include stiffeners, typically in the form of transverse web stiffeners, which are vertical members attached to the web. In deep beams, longitudinal web stiffeners may also be used. Flange stiffeners, on the other hand, are commonly found on large-span box girder bridges, but are rare in other types of structures.

A. Longitudinal Stiffener
B. Transverse Stiffener

Longitudinal web stiffeners are aligned along the span direction of the beam, while transverse stiffeners are positioned perpendicular to the span direction.

Transverse web stiffeners are usually provided at bearing positions and these are known as bearing stiffeners. For future maintenance it is good practice to provide bearing stiffeners at jacking points (for when girders have to be raised to free bearings for replacement). Other transverse stiffeners are called intermediate transverse web stiffeners.

4. OBJECTIVE OF THE STUDY

a. To make the study about the analysis and design of water tanks.
b. To study the behavior of different type of stiffeners in different position under different load conditions.
c. To compare the design of rectangular & circular water tank with the design of water tank using different type of stiffeners.
d. To know economical design of water tank.

5. Problem Statement

The basic purpose of this work is to "analyze the wall of circular & rectangular tank for moment and tension values at various levels along the height of wall subjected to hydrostatic pressure by using eccentric stiffeners."

For the analysis of wall finite element method is used. The analysis is to be carried out on the wall of circular & rectangular water tank with vertical stiffeners. For the analysis of wall vertical stiffeners are used along the periphery of tank and height of stiffener is kept up to the top of the wall height.

6. METHODOLOGY

The basic dissertation of this work is to "analyze the wall of circular & rectangular tank for moment and tension values at various levels along the height of wall subjected to hydrostatic pressure by using eccentric stiffeners."

Finite element modelling of wall is done as this method is effective than other methods. Though modelling of eccentric stiffeners is rather difficult and time consuming.

6.1 Method of Analysis

A) Circular Tank

From experience we know that, for shallow tanks of large diameter, the hoop stress or in plane tension in the tank wall is very small and the wall acts like vertical cantilever fixed at the base of wall. In case of deep tank of small diameter, the moment due to cantilever action is very small and hoop tension is predominant. Thus, following factors, influence the design of circular wall of tank.

a. The magnitude of maximum cantilever bending moment at the base of wall.
b. The magnitude of maximum hoop tension and the position of maximum tension.
c. The design of the tank is carried out by one of the following methods.
   i. Carpenters Method
   ii. Approximate Method
   iii. IS Code Method

In the IS code method bureau of Indian standards specifies the design table in IS: 3370 (Part IV) (Code of practice for concrete structures for the storage of liquid). The values of moment and tension coefficients taken from these tables are used to calculate the moment and tension in the wall cross section. These coefficients depend on the ration H2/Dt.

Were,

H = Depth of water in the tank

D = Diameter of tank

t = Thickness of the tank wall

I.S code specifies the values of these coefficients upto H2/Dt = 16

The moment and tension in the wall is calculated as

M = Cm x w x H3

T = Ct x w x H x R

Where,

M = Maximum moment in the wall

T = Maximum hoop tension in the wall

Cm = Maximum moment coefficient from IS: 3370 (Part IV)

Ct = Maximum hoop tension coefficient from IS: 3370 (Part IV)
w = Density of water
H = Height of wall
R = Radius of the circular tank

B) Rectangular Tank

When designing a rectangular tank, it is crucial to focus on these areas for stress analysis to ensure structural integrity and safety. Using methods like finite element analysis (FEA) can provide a detailed understanding of stress distributions if the tank has complex geometry or loading conditions. Thus following factors, influence the design of cylindrical wall of tank.

The maximum bending stresses occur near the base of the tank at the corners where the walls meet the base.

The vertical walls experience maximum shear stresses at their base due to the weight of the liquid. The shear stress is greatest at the bottom and decreases as you move upward.

For bending stress, the midpoints of the wall heights also experience significant stress due to the distribution of hydrostatic pressure.

The design of the tank is carried out by one of the following methods.

a. Impirical Method
b. Approximate Method
c. IS Code Method

In the IS code method bureau of Indian standards specifies the design table in IS: 3370 (Part IV) (Code of practice for concrete structures for the storage of liquid). The values of moment and tension coefficients taken from these tables are used to calculate the moment and tension in the wall cross section. These coefficients depend on the ration b/a. Where,

a = height of the wall
b = width of the wall
w = density of the liquid
I.S code specifies the values of these coefficients upto a / b = 3.
Horizontal moment = My x w x a3
Vertical moment = Mx x w x a3
For a / b > 3
Moment = (w x a3) / 6

6.2 Details of Structure

A) Wall

Wall of circular water tank is considered as Shell. The element considered is four nodded (quadrilateral) flat shell element. Flat shell element is considered because as we divide shell into number small element its curved surface becomes flat. The following geometry related modelling roles must be considered while using the plate/shell element.

Element aspect ratio should not be excessive. The ratio should be almost to the order of 1:1.

Individual element should not be distorted.

Angles between two element side should not be larger than 900 and never larger than 1800.

B) Vertical Wall

The height of vertical stiffeners is considered as 100% of the height of wall of water tank from bottom of tank. The stiffener is connected to the common nodes to tank of wall. The stiffeners are placed at the equal angle. Beam element is taken to assign the stiffener, various numbers of stiffeners are used for modelling such as 36 number of stiffeners with 5m c/c spacing.

Section of stiffeners

For Circular section stiffeners

Table No 1: Sectional properties of rectangular stiffeners for Circular Tank

Height of Tank	Width of Stiffener (b)	Depth of Stiffener (d)
4 m	0.4 m	0.4 m
5 m	0.5 m	0.5 m
6 m	0.6 m	0.6 m
7 m	0.7 m	0.7 m

For Rectangular section stiffeners

Table No 2: Sectional properties of rectangular stiffeners for Rectangular Tank.

Height of Tank	Width of Stiffener (b)	Depth of Stiffener (d)
4 m	0.45 m	0.45 m
5 m	0.55 m	0.555 m
6 m	0.65 m	0.65 m
7 m	0.75 m	0.75 m

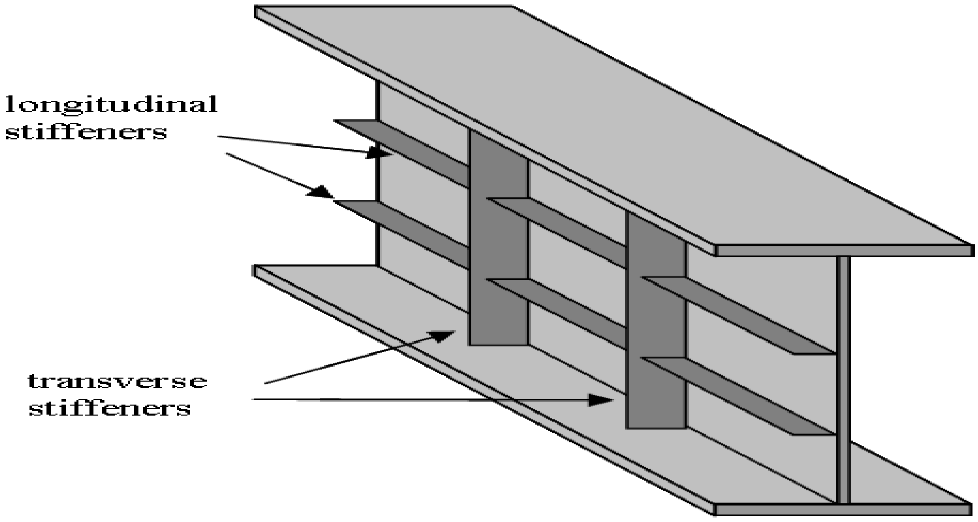


Fig No 1: Stiffener Section

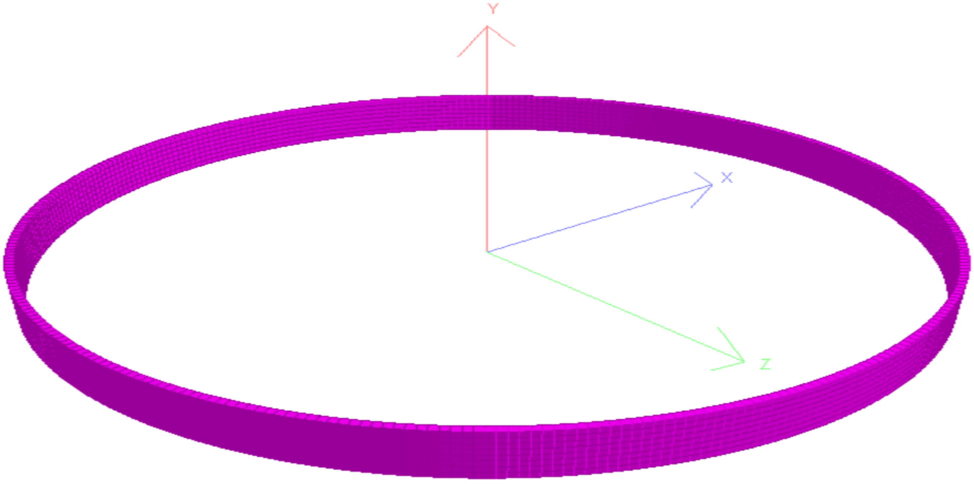


Fig No 2: Circular Tank without Vertical Stiffeners

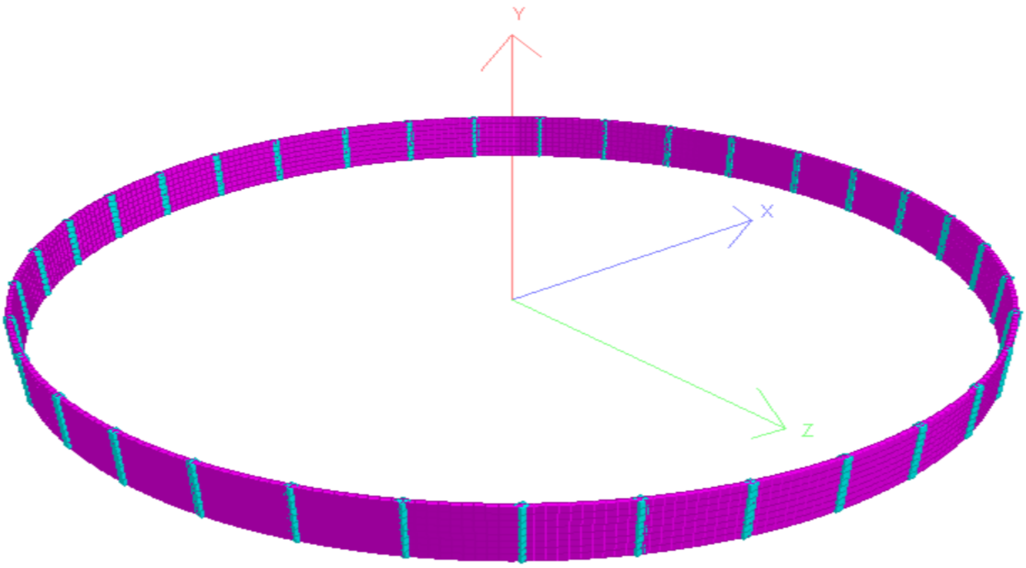


Fig No 3: Circular Tank with Vertical Stiffeners

7. RESULT AND DISCUSSION

7.1 Circular Water Tank

The results for moments and hoop tension for vertically stiffened tank and for tank without stiffener of 56.50 m diameter.

Table No 3: Moments for Circular Water Tank for Tank with Stiffener & Without Stiffener for Water Pressure

Height of Tank	4 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	2.16	0.49	125.60
0.2h	3.76	2.53	39.13
0.3h	2.82	6.01	-72.29
0.4h	2.82	6.01	-72.29
0.5h	3.02	8.13	-91.63
0.6h	16.12	3.67	125.77
0.7h	16.12	3.67	125.77
0.8h	25.90	13.95	59.99
0.9h	73.49	39.24	60.77
1.0h	73.49	39.24	60.77

Height of Tank	5 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	0.70	0.97	-32.89
0.2h	4.42	3.48	23.78
0.3h	9.88	7.47	27.78
0.4h	14.73	7.47	65.39
0.5h	16.57	17.54	-5.69
0.6h	12.97	19.17	-38.62
0.7h	15.42	15.65	-1.49
0.8h	20.64	4.12	133.40
0.9h	55.76	19.95	94.62
1.0h	106.42	57.56	59.59

Height of Tank	6 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	0.88	1.09	-21.68
0.2h	5.69	4.68	19.55
0.3h	13.34	10.24	26.37
0.4h	21.51	16.89	24.08
0.5h	29.91	30.57	-2.18
0.6h	25.29	33.42	-27.71
0.7h	11.46	30.93	-91.85
0.8h	14.14	20.51	-36.76
0.9h	54.09	8.02	148.36
1.0h	187.25	93.20	67.07

Height of Tank	7 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	7.19	1.02	150.34
0.2h	17.61	5.04	111.02
0.3h	30.21	11.76	87.90
0.4h	53.18	29.55	57.13
0.5h	59.00	39.08	40.62
0.6h	57.86	51.43	11.77
0.7h	47.24	50.45	-6.59
0.8h	13.10	41.60	-104.20
0.9h	68.32	18.29	115.55
1.0h	242.59	139.84	53.74

Table No 4: Moments for Circular Water Tank for Tank with Stiffener & Without Stiffener for Outside Soil Pressure

Height of Tank	4 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	1.17	0.26	128.11
0.2h	2.46	1.10	76.25
0.3h	2.90	2.93	-1.10
0.4h	2.90	4.56	-44.55
0.5h	1.23	4.82	-118.76
0.6h	3.81	2.42	44.74
0.7h	3.81	2.42	44.74
0.8h	13.48	4.97	92.24
0.9h	29.04	16.77	53.57
1.0h	29.04	16.77	53.57

Height of Tank	5 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	0.33	0.48	-36.72
0.2h	2.15	1.69	24.39
0.3h	5.12	3.38	40.82
0.4h	8.07	3.58	77.21
0.5h	9.75	6.56	39.15
0.6h	8.85	10.35	-15.66
0.7h	4.05	8.97	-75.64
0.8h	6.03	8.80	-37.44
0.9h	22.74	8.53	90.89
1.0h	47.46	27.44	53.47

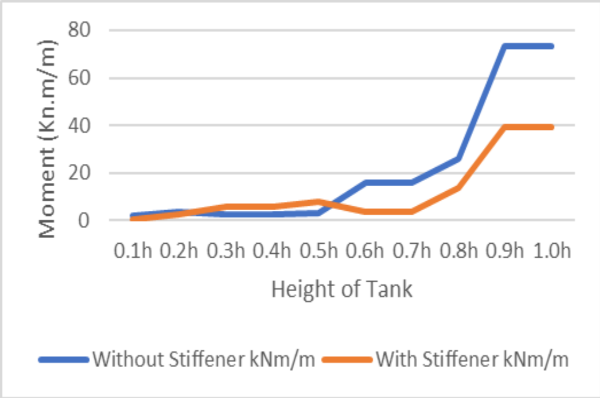
Height of Tank	6 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	0.43	0.53	-21.99
0.2h	2.82	2.27	21.72
0.3h	6.92	5.12	29.92
0.4h	11.57	8.57	29.80
0.5h	17.53	16.18	7.96
0.6h	16.23	18.03	-10.49
0.7h	10.32	17.12	-49.55
0.8h	1.58	12.08	-153.67
0.9h	20.87	2.53	156.74
1.0h	87.15	46.63	60.58

Height of Tank	7 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
0.1h	0.52	0.49	6.50
0.2h	3.54	2.44	36.99
0.3h	15.79	5.89	91.31
0.4h	22.79	15.43	38.52
0.5h	32.58	20.67	44.76
0.6h	32.84	27.85	16.43
0.7h	28.21	27.71	1.78
0.8h	1.41	2.39	-177.30
0.9h	68.32	7.79	159.08
1.0h	119.12	72.10	49.18

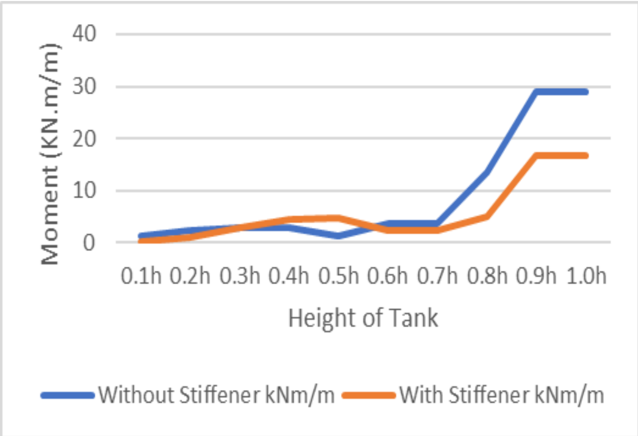
Table No 5: Hoop Tension for Circular Water Tank for Tank with Stiffener & Without Stiffener for Water Pressure

Height of Tank	4 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	N/mm2	N/mm2	%
0.1h	0.593	1.801	-100.92
0.2h	0.486	1.621	-107.74
0.3h	0.377	1.42	-116.08
0.4h	0.377	1.187	-103.58
0.5h	0.265	0.906	-109.48
0.6h	0.155	0.584	-116.10
0.7h	0.155	0.584	-116.10
0.8h	0.057	0.259	-127.85
0.9h	0.009	0.026	-97.14
1.0h	0.009	0.026	-97.14

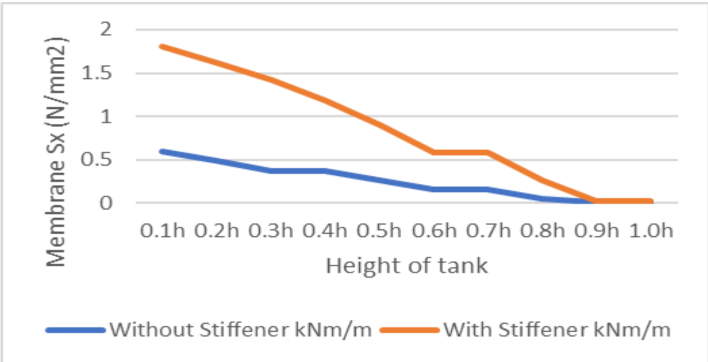
Height of Tank	5 m		
	Without Stiffener	With Stiffener	Difference in Percentage
M	N/mm2	N/mm2	%
0.1h	1.134	2.3	-67.91
0.2h	1.029	2.282	-75.69
0.3h	0.921	2.232	-83.16
0.4h	0.806	2.139	-90.53
0.5h	0.677	1.969	-97.66
0.6h	0.535	1.696	-104.08
0.7h	0.381	1.316	-110.19
0.8h	0.225	0.852	-116.43
0.9h	0.086	0.378	-125.86
1.0h	0.009	0.042	-129.41
Height of Tank	6 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	N/mm2	N/mm2	%
0.1h	0.986	2.092	-71.86
0.2h	0.914	2.22	-83.34
0.3h	0.84	2.387	-95.88
0.4h	0.762	2.387	198.75
0.5h	0.678	2.295	-108.78
0.6h	0.482	2.092	-125.10
0.7h	0.371	1.771	-130.72
0.8h	0.255	0.848	-107.52
0.9h	0.142	0.366	-88.19
1.0h	0.045	0.035	25.00
Height of Tank	7 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	N/mm2	N/mm2	%
0.1h	1.192	1.811	-41.23
0.2h	1.108	2.044	-59.39
0.3h	1.06	2.258	-72.21
0.4h	1.003	2.575	-87.87
0.5h	0.846	2.638	-102.87
0.6h	0.741	2.607	-111.47
0.7h	0.617	2.204	-112.51
0.8h	0.332	1.826	-138.46
0.9h	0.187	0.836	-126.88
1.0h	0.061	0.352	-140.92



Graph No 1: Moments for Circular Water Tank for Water Pressure



Graph No 2: Moments for Circular Water Tank for Soil Pressure



Graph No 3: Hoop Tension for Circular Water Tank for Soil Pressure

7.2 Rectangular Water Tank

The results for vertical and horizontal moments of for vertically Stiffened tank and for tank without stiffener of size 50 x 50 m.

Table No 6: Moments for Rectangular Water Tank for Tank with Stiffener & Without Stiffener for Water Pressure

Height of Tank	4 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	127.165	65.308	64.28
Horizontally	21.618	11.843	58.43

Height of Tank	5 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	269.837	239.385	11.96
Horizontally	45.87	60.269	-27.13

Height of Tank	6 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	476.017	322.263	38.52
Horizontally	80.911	107.129	-27.89

Height of Tank	7 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	764.328	573.091	28.60
Horizontally	129.896	215.043	-49.37

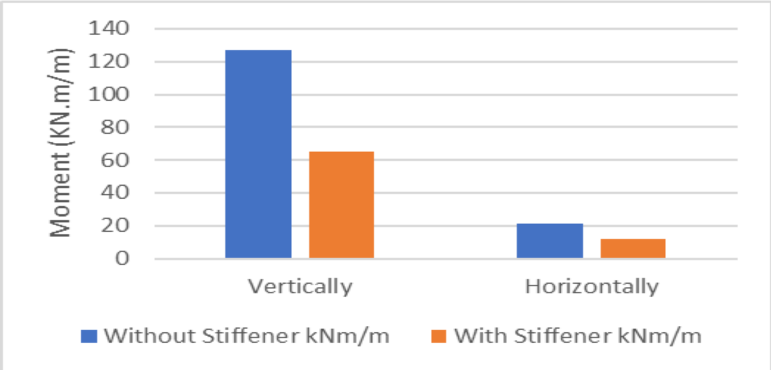
Table No 7: Moments for Rectangular Water Tank for Tank with Stiffener & Without Stiffener for Outside Soil Pressure

Height of Tank	4 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	48.626	25.979	60.71
Horizontally	8.266	4.678	55.44

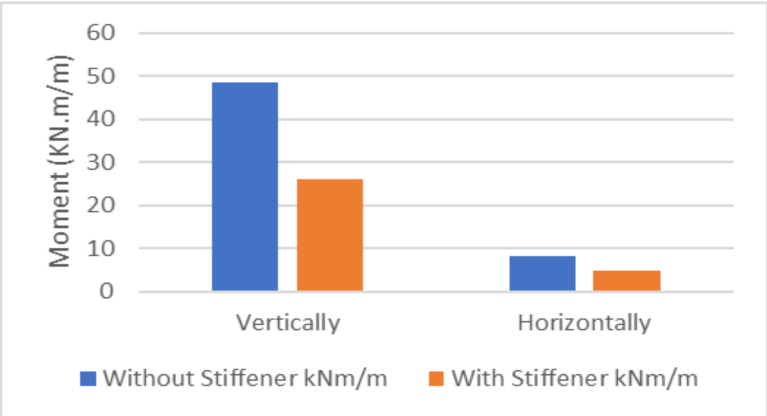
Height of Tank	5 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	115.053	102.33	11.71
Horizontally	19.558	24.725	-23.34

Height of Tank	6 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	215.511	146.97	37.82
Horizontally	36.632	46.628	-24.01

Height of Tank	7 m		
	Without Stiffener	With Stiffener	Difference in Percentage
m	KN.m/m	KN.m/m	%
Vertically	360.831	271.439	28.28
Horizontally	61.323	97.565	-45.62



Graph No 4: Moments for Rectangular Water Tank for Water Pressure



Graph No 5: Moments for Rectangular Water Tank for Soil Pressure

8. CONCLUSION

In this dissertation circular water tank & rectangular water tank is analyzed for various heights, stiffened with vertical stiffeners upto 100% height of tank from bottom. This model is compared with circular tank having no stiffeners. From the analysis following conclusions are drawn.

The stresses in the structure with stiffeners are less as compare to the stresses in the structure without stiffener.

Use of stiffener is more efficient for Rectangular Water Tank as compare to Circular Water tank.

Hoop Tension in Circular tank with stiffener is more as compare to the Circular Water Tank without stiffener.

9. ACKNOWLEDGEMENT

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