Parametric study of rectangular water tank for various loading conditions and edge rotation effect using finite element method

[1]Mr. Akshay R. Desale, [2]Dr. V. R. Rathi, [3]Dr. P. K. Kolase

[1]Student, [2,3]Professor
Department of Civil Engineering
Pravara Rural Engineering College, Loni, India.

***Abstract*: The elevated rectangular water tank generally constructed with monolithic connections between short walls, long walls and base slab. Due to this monolithic connections joints are tends to rotate which modifies the moments in the tank wall. These moments are differ from the moments given by IS code for certain boundary conditions. Present work aims at the finite element analysis of elevated, closed rectangular (i.e. propped at top) partially filled water tanks of R.C.C. construction supported on four corner columns. For the purpose of studies, tanks of various heights i.e. 2.5m and 3m are considered with different aspect ratio of wall ranging from 0.67 to 2.8 and Lz /Lx ratio between 1.33 to 2.0. Thickness of the walls and base slab are assumed. Each wall is discredited into numbers of rectangular four nodded elements with six degrees of freedom per node. Type of load considered is hydrostatic load due to the tank in partially filled condition. After analysis it is found that I.S. Code moments get significantly modified mainly due to rotation of the junction of wall and base slab and also rotation of the vertical edges at junction of short wall and long wall.**

***Keywords*: Finite element analysis, edge rotation, partially filled condition.**

INTRODUCTION:

The elevated water tanks are generally constructed with monolithic connection between short wall, long wall and base slab. The design of wall depends on the ratio of its dimensions, depth of water, and actual boundary conditions. In most of the design tables it is observed that, generally moment coefficients are specified assuming fixity along base slab and the two vertical joints. Classical solution is not readily available for analysis of rectangular plate of tank for various possible boundary conditions. The analysis is also required for cases when top edge is free or propped under the case when top slab is provided, and also for partially filled condition of water tank.

I.S. code 3370 (Part IV) provides moment coefficients for plate subjected to hydrostatic loading with idealized boundary conditions that, fixity along two vertical edges as well as the base (i.e. the bottom edge) and free at the top edge. Further I.S. code 456 also represents coefficients for base slab supported on all 4 edges & corners restricted from lifting, when subjected to U.D.L. However due to monolithic connection between the base slab and walls, rotation of edges do occur which significantly changes the moment coefficients given in I.S Codes.

In case of square tanks, rotation of vertical edge is not feasible by virtue of equal loads on two equal adjacent wall panels. But in the case of rectangular tanks, the vertical edges of the wall will also undergo rotation. I.S. code does not take into account the effect of axial forces and the rotation of edges. Therefore B.M. Values obtained by using I.S. code values are required to be modified depending upon the relative stiffness.

To eliminate the approximations, more refined numerical method has been developed. One of the numerical methods is the **Finite Element Method.** It is powerful mathematical tool to solve engineering problems. This method is preferred for analysis because of the following reasons:

1) F.E.M. permits the full interaction between the walls, floor and roof of the tank and changes in aspect ratios or sizes and the thickness of members to easily to be considered in the general program.

2) The ease with which the boundary conditions can be applied.

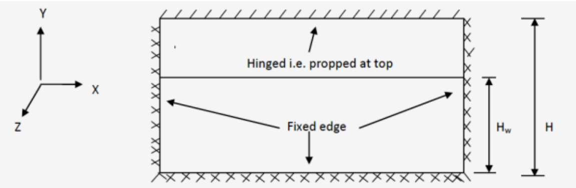
3) It is possible to determine the internal forces at number of points, so as to plot its variation along any given direction.

OBJECTIVE OF STUDY:

In earlier analysis of water tank, Joint rotation is not considered. In this dissertation, Analysis is being done by considering joint rotation and trying to achieve following objectives;

1. To study the change in horizontal and vertical moments developed in wall for different water height cases.
2. To study the effect produced on horizontal and vertical moments in the wall due to rotation of joints.
3. To study the comparison of moments for different dimensions of tank and for different water depth in tank.

SCOPE OF ANALYSIS:



This work consist of analysis of water tank walls considering effect of edge rotation using finite element method, case with top edge is propped which is a practical case for no. of situations. Followings are the points to study:

- Analysis of partially filled elevated water tank, propped at top by considering bottom edge rotation and vertical edge rotation, for various ratios of (Hw/H) = 0.4, 0.6, 0.7, 0.8, 0.9. And (Lz/Lx) = 1.33 to 2.

- Find moments for different aspect ratio of (Lx/ H) = 0.67 to 2.8 for above mentioned case.
- Find detail variation of bending moment for horizontal section at certain depths along Y direction and also for vertical sections along X direction.
- Compare the results of wall (plate) before rotation of joint and after rotation of joint for partially filled water tank with different water heights.

PROBLRM FORMULATION:

ANSYS 11 is used for analysis of plates and water tank. Hydrostatic loading is considered for analysis. The elastic properties of the concrete are adopted as follows:
1) Young's modulus of concrete (E) = 2.0x106 t/m^2.
2) Poison's ratio = 0.2
3) Grade of concrete = M20.

Plate problem:
Plates of different aspect ratios i.e. (Lx/H) = 0.67, 0.8, 1, 1.2, 1.33, 1.4, 1.6, 1.67, 1.8, 2, 2.33, 2.4, 2.8 have been solve. Plate is discredited in to number of elements. This discretization is based on results of the plate problem which are done for validation. In plate problems, three edges are fixed and top edge is propped. All displacements and rotations are restrained in all direction at fixed edges. And top edge restrained against displacement in Z- direction. This edge is not restrained against rotation. Plate is solved for different (Hw/H) ratios i.e. 0.4, 0.6, 0.7, 0.8, 0.9. Also plot and list the results of bending moment in X – direction and in Y – direction for elements in the plate.

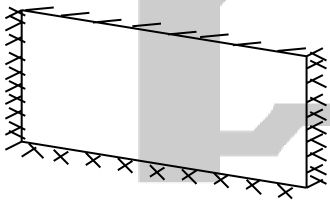
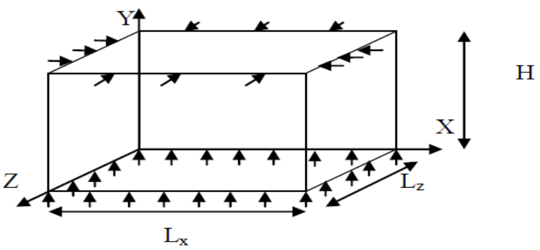


Plate with top edge is hinged and three edges fixed

Water tank problem:
Water tank for different (Lz/Lx) ratios in which above plates are used have been solve. Water tank structure is discredited into number of elements i.e. each plate of the water tank is also discredited into number of elements. In this tank, edges at the base are restrained against displacement in vertical direction i.e. Y-direction. Top two edges are restrained against displacement in Z-Direction and rest two edges are restrained against displacement in X-Direction. Water tank is solved for different (Hw/H) ratios i.e. 0.4, 0.6, 0.7, 0.8, 0.9. Also plot and list the results of bending moment in X – direction and in Y – direction for elements in the tank. In STADD-Pro, Due to continuity at edges of plates at joint, it acts as continuous member. Hence this joint rotates automatically. There is no need to provide external rotation at the joint. This water tanks are solved for different heights i.e. 2.5m, 3m for same (Lz/Lx) ratios.



Tank with all boundary conditions

In above fig. tank wall maintains continuity at the edges. To rotate joint freely, there is no restrain at joint.

Analysis of Plates:

After analysis of plates, Moments produced in the plates according to their size and water pressure applied. Following diagram shows graphical representation of moments for sample plate of size 5x2.5.

Analysis of Water Tank:

Water tanks of different dimensions are analyzed for different water pressure i.e. for different water height. Tank dimensions are such that, it made by using plates of size which are analyzed individually. Following diagrams shows the graphical representation of moments of sample tank of size 5x7x2.5. it maintains continuity at the edges. Due to this continuity, joints are freely rotates.

DISCUSSION OF RESULTS:

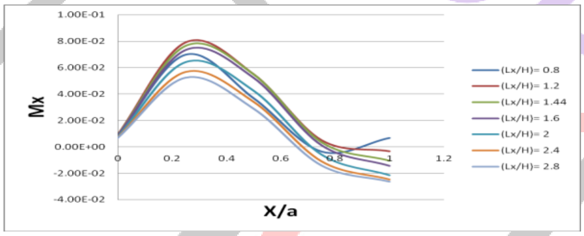
In the present work, Rectangular water tank with following conditions are analyzed.

- Tank propped at top
- When tank is filled for different water heights.
- For different aspect ratios of wall

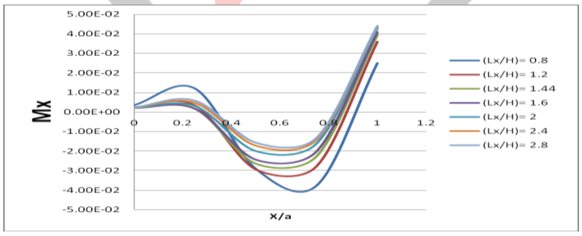
Bending moments at different location in the plate are listed in the previous chapter. In this part, moments are compared for following cases;

- Moments in the plate before rotation of joint for different aspect ratios
- Moments after rotation and before rotation with respect to different (L_z/L_x) ratios of tank.

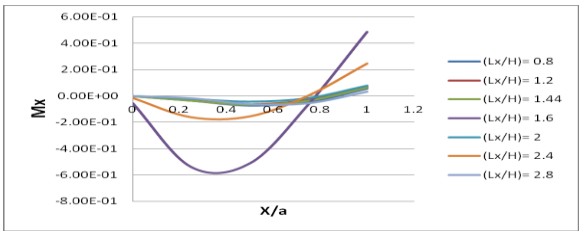
Horizontal and vertical moments both in short wall and long wall are considered for comparison.



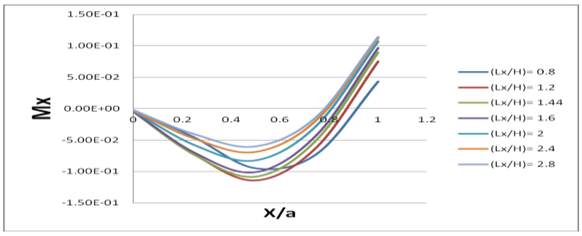
Comparison of horizontal moments at mid span for (H_w/H) = 0.4, H = 2.5



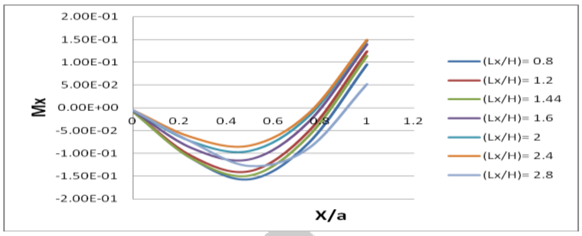
Comparison of horizontal moments at mid span for (H_w/H) = 0.6, H = 2.5



Comparison of horizontal moments at mid span for (H_w/H) = 0.7, H = 2.5

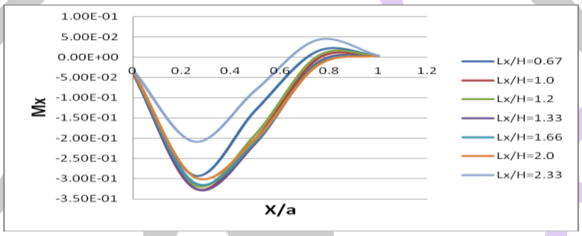


Comparison of horizontal moments at mid span for (Hw/H) = 0.8, H = 2.5

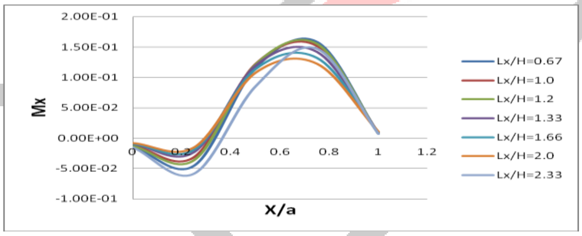


Comparison of horizontal moments at mid span for (Hw/H) = 0.9, H = 2.5

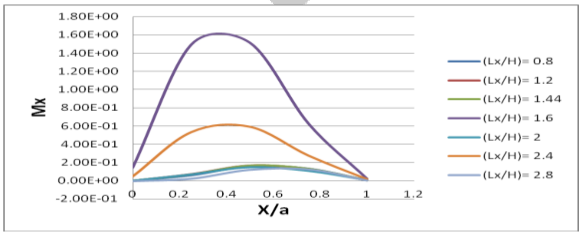
When partial pressure is acting on the plate such that (H_w/H = 0.4), maximum hogging moment (0.08 T.M.) is produced at position (X/a) = 0.3 for (Lx/H) = 1.2. There is sagging behavior at the bottom of the plate. Pressure is being increased such that (H_w/H = 0.6), at position (X/a) = 0.2 there is small hogging moment as compared to previous case. But at position (X/a) = 0.6, maximum sagging moment is created. When pressure is increases such that (H_w/H = 0.6 to 0.9), there is sagging moment up to position (X/a) = 0.8 and hogging moment at bottom. Same kind of behavior is observed for plate of height 3m.



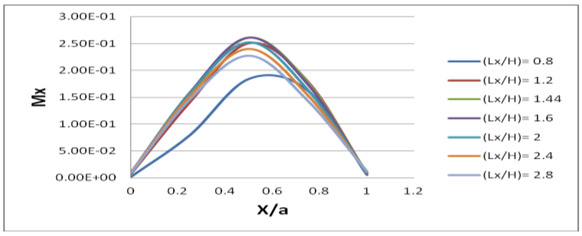
Comparison of horizontal moments at mid span for (Hw/H) = 0.4, H = 2.5



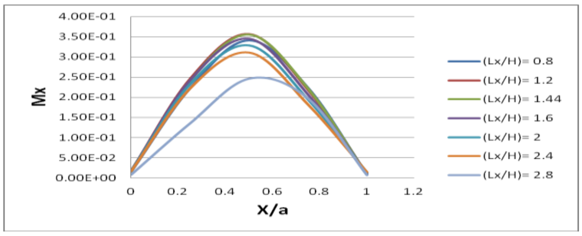
Comparison of horizontal moments at mid span for (Hw/H) = 0.6, H = 2.5



Comparison of horizontal moments at mid span for (Hw/H) = 0.7, H = 2.5



Comparison of horizontal moments at mid span for (Hw/H) = 0.8, H = 2.5

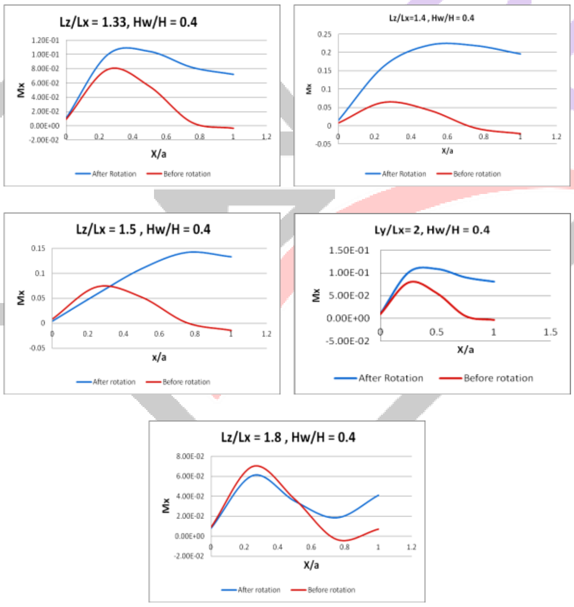


Comparison of horizontal moments at mid span for (Hw/H) = 0.9, H = 2.5

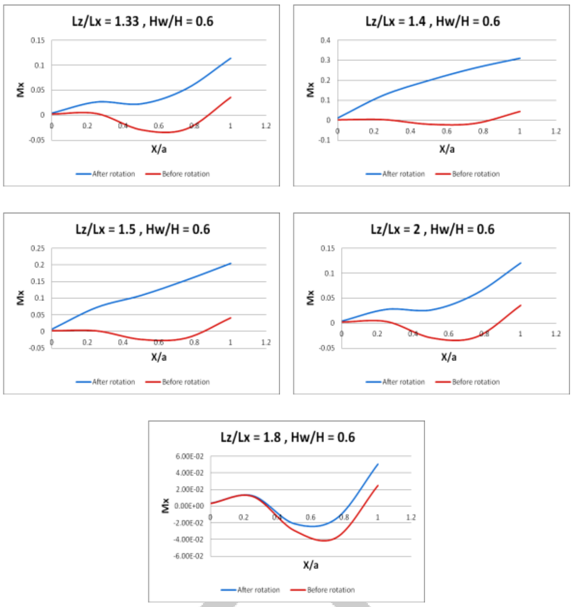
When partial pressure is acting on the plate such that (H_w/H = 0.4), maximum sagging moment (0.08 T.M.) is created at position (X/a) = 0.3 for (Lx/H) = 1.2. There is hogging behavior at the bottom of the plate. Pressure is being increased such that (H_w/H = 0.6), at position (X/a) = 0.2 there is small sagging moment as compared to previous case. But at position (X/a) = 0.6, maximum hogging moment is created. When pressure is increases such that (H_w/H = 0.6 to 0.9), there is hogging moment up to position (X/a) = 0.8 and sagging moment at bottom. Same kind of behavior is also shown for plate of height 3m

Note: if pressure is applied on face 2 of shell element, hogging moments are positive and Sagging moments are negative

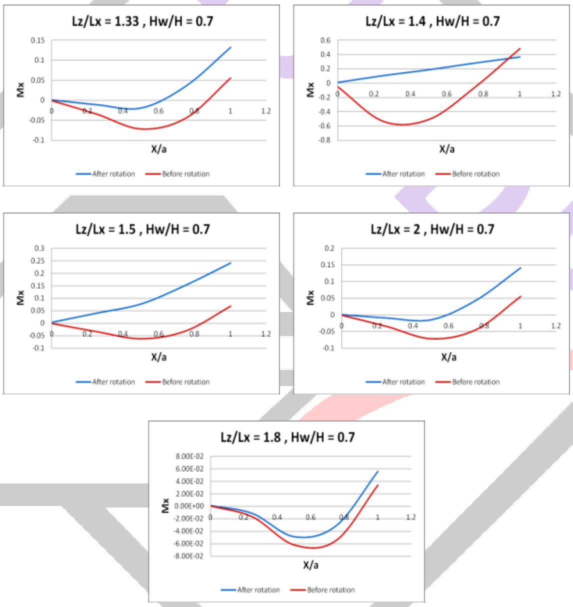
Following figures shows Comparison between horizontal moments before rotation and after rotation. Comparisons are shown for moments at midspan for different L_z/L_x ratios with different Hw/H for short wall:



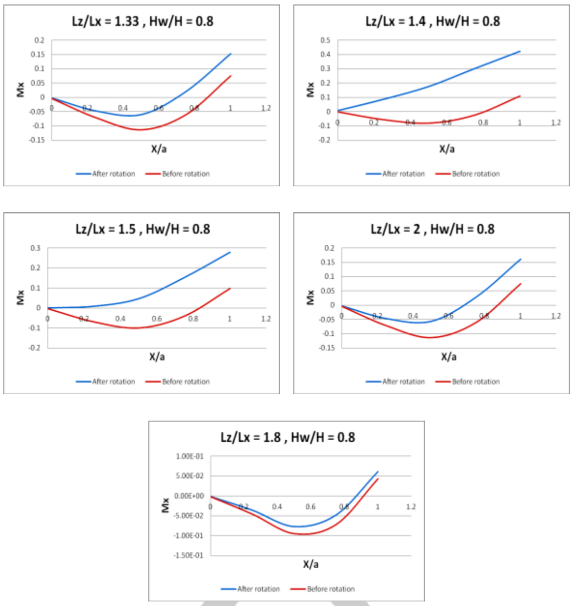
Comparison between horizontal moments before rotation and after rotation for short wall with different (L_z/L_x) ratios for (H_w/H) = 0.4



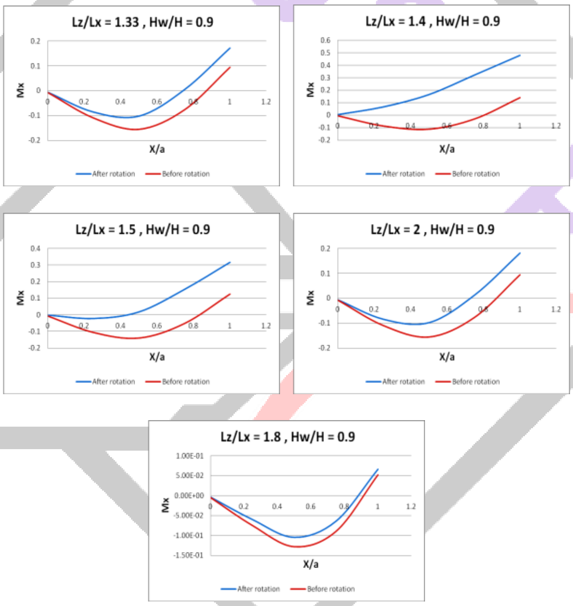
Comparison between horizontal moments before rotation and after rotation for short wall with different (L_z/L_x) ratios for (H_w/H) = 0.



Comparison between horizontal moments before rotation and after rotation for short wall with different (L_z/L_x) ratios for (H_w/H) = 0.7



Comparison between horizontal moments before rotation and after rotation for short wall with different (L_z/L_x) ratios for (H_w/H) = 0.8



Comparison between horizontal moments before rotation and after rotation for short wall with different (L_z/L_x) ratios for (H_w/H) = 0.9

Graphs shows for comparision of moments between before rotation and after rotation for short wall. Above fig shows that, there is difference between the momnets before rotation and after rotation. There is maximum rotation is taking place at bottom of the vertical joint of the tank. When water tank is filled upto the height such that (H_w/H) = 0.4, there is increment in hogging moments after rotation. When there is sagging behavior in bottom of tank plate before rotation it turns into hogging at the same location after rotation of joint. so many things which governs the rotation. As water height is increases in such that (H_w/H) = 0.6 to 0.9, rotation is decreased as compared to previous case but still there is difference between moments before rotation and after rotation. It is observed that when ratio (L_z/L_x) = 1.4, there is maximum difference between moments after rotation and before rotation. That means when tank dimentions are such that it makes ratio (L_z/L_x) = 1.4 then more rotation is takes place. Same kind of behaviour is observed in case long wall also.

CONCLUSIONS:

➢ When tank is filled up to height (H_w/H) = 0.4, more inward rotation takes place in upper part of short wall. Due to this inward rotation more hogging moment generates at mid span. This effect reduces hogging moments in long wall at mid span.

- When tank filled up to height (H_w/H) = 0.9, rotation reduces which makes small difference in sagging moments at mid span. It concludes that, when water height is less then inner face of the wall undergoes in tension and when water height is more, outer face of the wall undergoes in tension.
- When water tank is partially filled such that (H_w/H) = 0.4, there is more inward rotation of base joint which induces more hogging moments. It concludes that, there more tension is generated on inside face of the wall.
- When water height is more, rotation is decreased. It concludes that, to reduce effect of rotation, more water height should prefer.
- When (L_z/L_x) = 1.8, least rotation is takes place. It concludes that; provide dimensions of the tank such that, it should make least rotation.
- Moments given by IS 3370 are exactly opposite in nature as compared to moments found in analysis for partially filled condition.
- At some location of wall, IS code gives sagging moments in fully filled condition but at the same location, due partially filled condition there is hogging moments. This may not be safe for design.

REFERENCES:

[1] W. D Moody "Moment and Reaction for Rectangular Plates" Division of design, Denver, Colorado.
[2] Buchi J.F. "The Design of Walls of Open Rectangular Tanks" Concrete and construction engineering, July 1951
[3] Charles E. Reynolds, James C. Steedman, Anthony J. Threlfall "Reynolds's Reinforced Concrete Designer's Handbook"
[4] Davies J. D. "Bending Moment in Long Rectangular Tanks on Elastic Foundation" Concrete and construction engineering, Oct. 1961s
[5] S.K Chavan "Finite Element Analysis of Elevated Rectangular Water Tank Considering the Effect of Rotations at the Edges". M.E. Dissertation, 1995
[6] Indian Standards- 3370 Part-IV (1967) "Code of Practice for Concrete Structures for The Storage Of Liquids"