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Hydrodynamic Forces acting in Rectangular Tank with and without Baffle Walls

Ashwini Dalvi[1*], Prof. N. A. Maske[2], Dr. S. K. Kulkarni[3*]

[1]PG student, Dept. of Civil Engineering, Dr. D. Y. Patil SOET, Pune, India
[*]Corresponding Author E-mail: *dalvi_ashwini@ yahoo.co.in*

[2]Assistant Professor, Dept. of Civil Engineering, Dr. D. Y. Patil SOET, Pune, India

[3]HOD, Dept. of Civil Engineering, Dr. D. Y. Patil SOET, Pune, India

Abstract: The failure of liquid storage tanks due to earthquake induced sloshing action of the liquid was extensively observed during past major earthquakes. Sloshing refers to the movement of liquid inside another object which is typically undergoing motion. When sloshing occurs, there will be dynamic pressure due to fluid interaction with the walls of the tank causing large deformation in the tank as well as the supporting structure. The destructive effects of sloshing can however be suppressed in a passive manner by introducing additional substructure such a baffle into tanks. The main aim of constructing these substructures is to alter the period of sloshing action beneficially and to increase hydrodynamic damping ratio**.** To study the sloshing effect on tank i.e. hydrodynamic forces acting on tank and to understand the response of structure under sloshing load a rectangular tank resting on ground is analyzed. The seismic parameters, base shear, hydrodynamic pressure, sloshing height is worked out in accordance with IS 1893 part 2-Criteria for Earthquake resistant design of Structure, Part 2 Liquid Retaining Tanks. An extensive literature review is carried before carrying out the above analyses to understand the methodology of analyses and the codal provisions related to the same. The base shear, hydrodynamic forces, sloshing heights for Tank with and without baffle wall is studied

Keywords: Sloshing, Baffles, Hydrodynamic dynamic pressure, Eathquake

I. INTRODUCTION

Storage tanks are important components in water distribution systems, water treatment plants and waste water treatments plants, ships, petroleum plants etc. During earthquakes, due to the seismic excitations the tanks will get damaged which in turn damages life and property. In the case of ground supported tanks earthquake causes heavy sloshing in water resulting in hydrodynamic pressure in the walls of the tank. In the case of ship tanks the heavy sloshing will cause the tank fluid to interact with the water outside. As a result, pollution of ocean or sea water occurs, which in turn destroys the overall ecological system. The liquid sloshing may cause huge loss of human life, economic and environmental resources due to failure of the tanks. The expulsion of toxic components stored in tanks in the industries can be the reason of soil contamination and can create adverse effect in environment. Thus, sloshing will not only affect the structure but also the environment in which they are provided. Thus, there is a need to estimate the hydrodynamic pressures as well as the proper analysis of fluid tank interaction under seismic excitations. Thus, understanding the dynamic behaviour of liquid free-surface becomes necessary. Due to this many engineers and researchers are aiming to understand the complex behaviour of sloshing and finding ways to reduce its impact on structures and trying to develop structures to withstand its effect. The destructive effects of sloshing can however be suppressed in a passive manner by introducing additional substructure such a baffles into tanks. The main aim of constructing these substructures is to alter the period of sloshing action beneficially and to increase hydrodynamic damping ratio. Several studies on study of sloshing effects have been carried out by researchers.

Sung-Ho Yoon1 et.al (2015), focused on the effect of baffles on sloshing mitigation in a liquid storage tanks. A vibration producing system was manufactured to apply a predetermined vibration to the tank. The sloshing force applied to the tank wall was measured when the tank vibrating the natural sloshing frequency was stopped instantaneously. The introduction of baffles was effective at mitigating the sloshing force on the tank wall. The baffles have a significant influence on the mitigation of the sloshing force on the tank wall. Among the hollow baffle types with the same surface area, those with more holes of smaller diameters are more effective at reducing the sloshing force [1].

A. Kumar et.al (2016) stated that perforation is one of the methods for reducing ill effects of compartmentalization. Perforation reduces pressure drop across the baffle which in turn reduces required structural strength of the baffle. Screens with optimum perforation placed appropriately may ensure greater dynamic stability without reduction in damping. Screens are widely used as damping devices in TLD in structural engineering, as Propellant Management and Acquisition Devices (PMAD) in aerospace engineering.

Finite element pressure formulation is used here to predict dynamic characteristics of bottom-mounted and surface-piercing baffles. The method is successfully extended to compute dynamic effects due to different type of perforated baffles and slat screens. Effective slosh damping, base shear force and overturning moment are computed for different type of solid and perforated baffle-mounted tanks. Effects of partially perforated baffle on dynamic response of the tank are computed for three different arrangement of perforation and optimum perforation configuration is found to achieve best dynamic advantages and reduced weight penalty without sacrificing benefits of rigidity or stiffness [5].

I.H cho et.al (2016) presented liquid sloshing inside tanks of a vessel may result in increased/decreased vessel motions or structural damages. The resonant sloshing motions can be suppressed by using baffles inside a tank. Especially, more energy dissipation is possible by using porous baffles. Here, the effect of dual vertical porous baffles on the sloshing reduction inside a rectangular tank is investigated both theoretically and experimentally. The porosity effect is included through inertial and quadratic-drag terms. The theoretical prediction is then compared with a series of experiments conducted by authors with harmonically oscillated rectangular tank at various frequencies and baffle parameters. The measured data reasonably correlate with the predicted values. It is found that the dual vertical porous baffles can significantly suppress sloshing motions when properly designed by selecting optimal porosity, submergence depth, and installation position

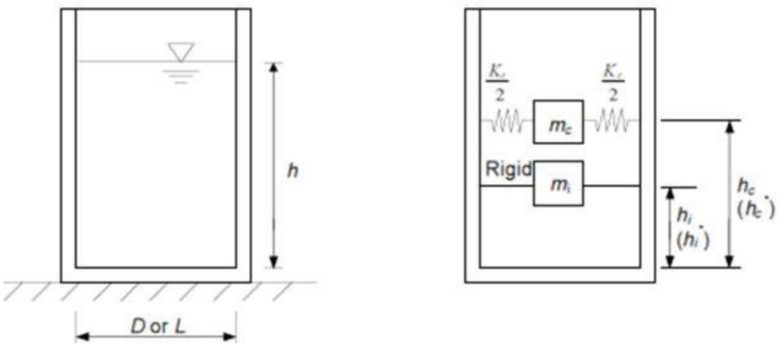
The presence of vertical baffle shifts the baffle-free sloshing natural periods, especially in the lowest mode. As baffle porosity (P) increases and its submergence depth (d /h) decreases, the fluid can move more freely across the baffles. Correspondingly, high amplification factor was observed at resonance frequencies and the natural sloshing frequencies got closer to those of the baffle-free tank. It is also seen that the pressure and sloshing force on tank wall are closely related to the change of wall amplification factor. Also, as the baffles get closer to the wall, the amplification factor and horizontal force on baffles become smaller although negative effects occur if they are too close to the wall [6].

II. SPRING MASS MODEL FOR SEISMIC ANALYSIS

When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank wall and the tank base in addition to the hydrostatic pressure. In order to include the effect of hydrodynamic pressure in the analysis, tank can be idealized by an equivalent spring mass model, which includes the effect of tank wall – liquid interaction. The parameters of this model depend on geometry of the tank and its flexibility.

When a tank containing liquid with a free surface is subjected to horizontal earthquake ground motion, tank wall and liquid are subjected to horizontal acceleration. The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass is termed as impulsive liquid mass which accelerates along with the wall and induces impulsive hydrodynamic pressure on tank wall and similarly on base. Liquid mass in the upper region of tank undergoes sloshing motion. This mass is termed as convective liquid mass and it exerts convective hydrodynamic pressure on tank wall and base. Thus, total liquid mass gets divided into two parts, i.e., impulsive mass and convective mass.

In spring mass model of tank-liquid system, these two liquid masses are to be suitably represented. A qualitative description of impulsive and convective hydrodynamic pressure distribution on tank wall and base is given in figure 2.



Tank Spring mass model

Figure 1 Spring mass model for rectangular tank

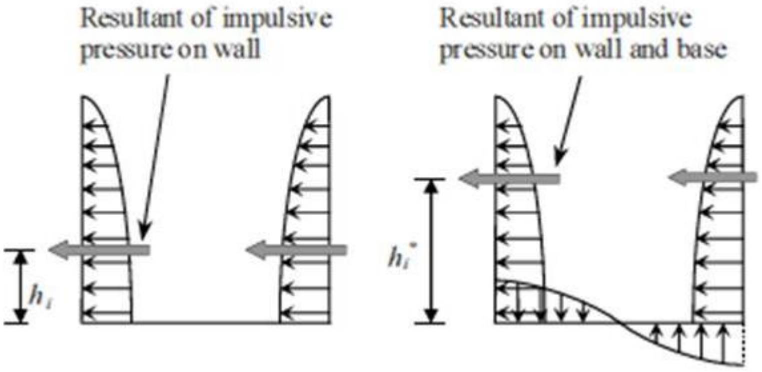
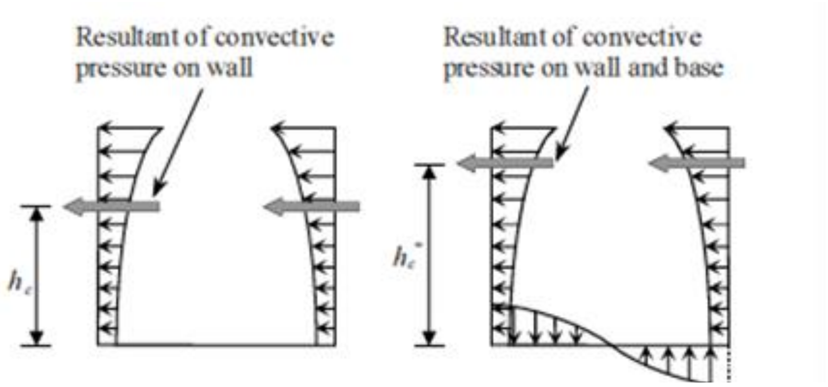


Figure 2 Qualitative description of hydrodynamic pressure on wall and base



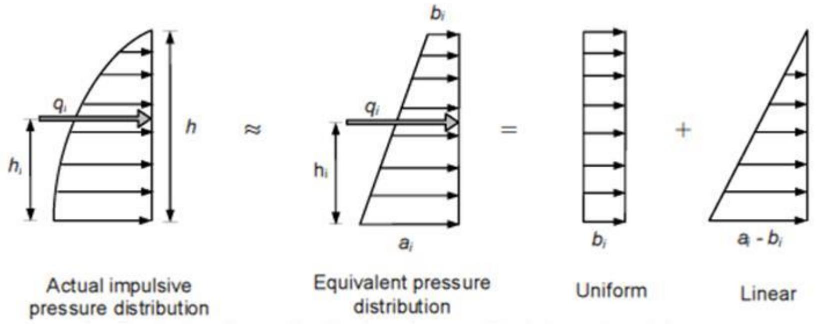


Figure 3. Equivalent linear distribution along wall height Impulsive pressure

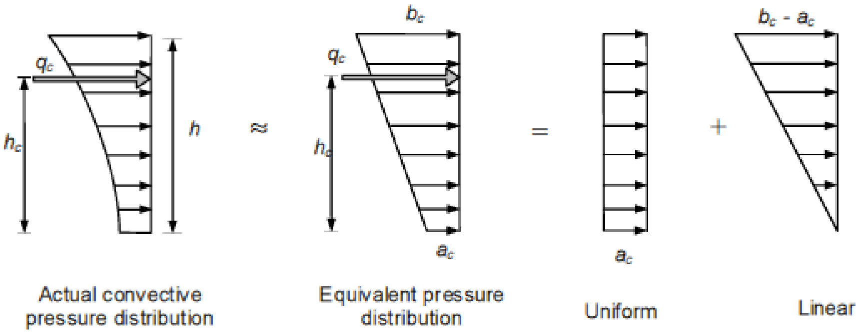


Figure 4 Equivalent linear distribution along wall height for convective pressure

Source: IS 1893 (Part2) 2014

III. METHODS AND MATERIALS

1. Objective: The purpose of this study is to study the hydrodynamic forces of rectangular tank resting on ground for tank with and without baffle wall

2. Problem statement considered for analysis: A Rectangular Tank resting on ground of 54,00,000-liter capacity has plan dimensions of 45m x 30m and height of 4.6 m (including free board of 0.6 m). Wall has a uniform thickness of 400 mm. The base slab is 500 mm thick. There is no roof slab on the tank. Tank is located on hard soil in Zone V. Grade of concrete is M30.Analyze the tank for seismic loads for following 3 cases

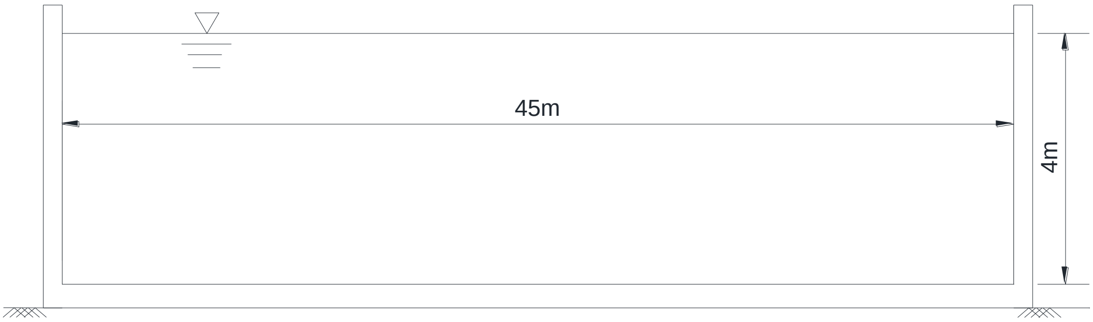
a) Case I-Tank without Baffle

b) Case II- Tank with single baffle wall at equidistance in tank

c) Case III Tank with multiple baffle wall

Case I- Tank Without Baffle

PLAN



SECTIONAL ELEVATION

Figure. 5. Rectangular tank sizes (not to scale)

A) Summary of Hydrostatic Pressure & hydrodynamic Pressure Acting In X Direction

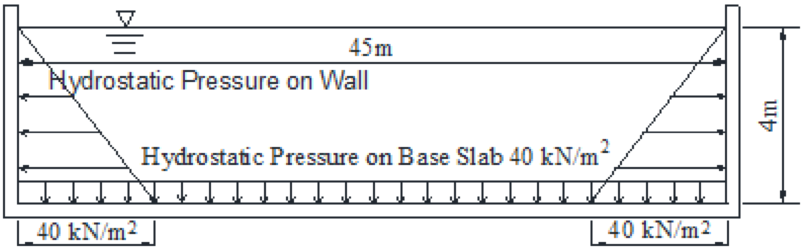


Figure22 Hydrostatic Pressure

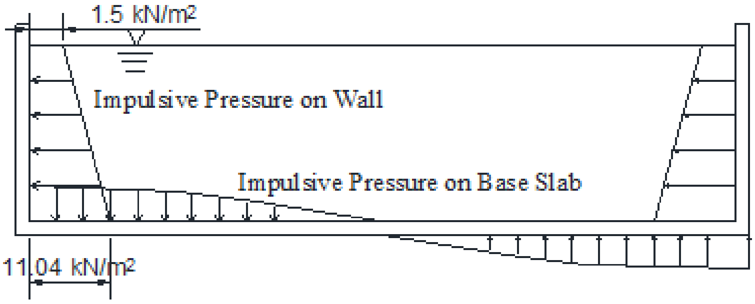


Figure 23 Hydrodynamic Impulsive Pressure X Direction

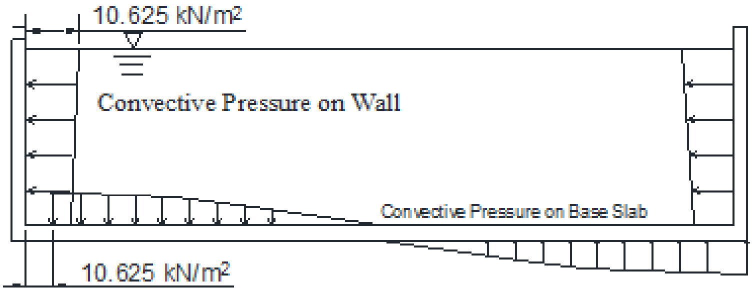
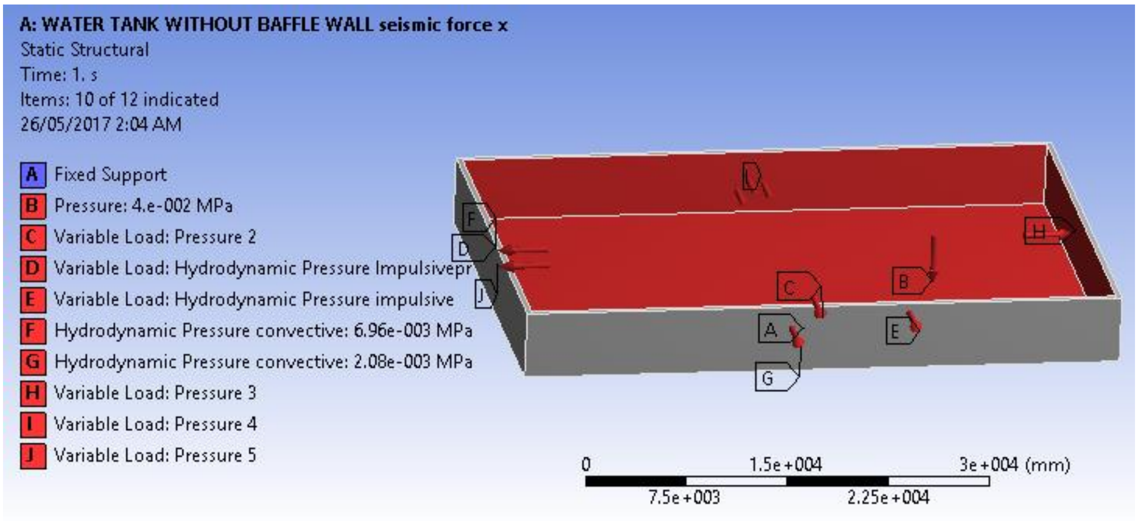


Figure 6. Hydrostatic and Hydrodynamic pressure acting in X Direction



A: WATER TANK WITHOUT BAFFLE WALL seismic force x
Static Structural
Time: 1. s
Items: 10 of 12 indicated
26/05/2017 2:04 AM

A Fixed Support
B Pressure: 4.e-002 MPa
C Variable Load: Pressure 2
D Variable Load: Hydrodynamic Pressure Impulsivepr
E Variable Load: Hydrodynamic Pressure impulsive
F Hydrodynamic Pressure convective: 6.96e-003 MPa
G Hydrodynamic Pressure convective: 2.08e-003 MPa
H Variable Load: Pressure 3
I Variable Load: Pressure 4
J Variable Load: Pressure 5

Figure 7. Hydrostatic and Hydrodynamic pressure acting in X Direction

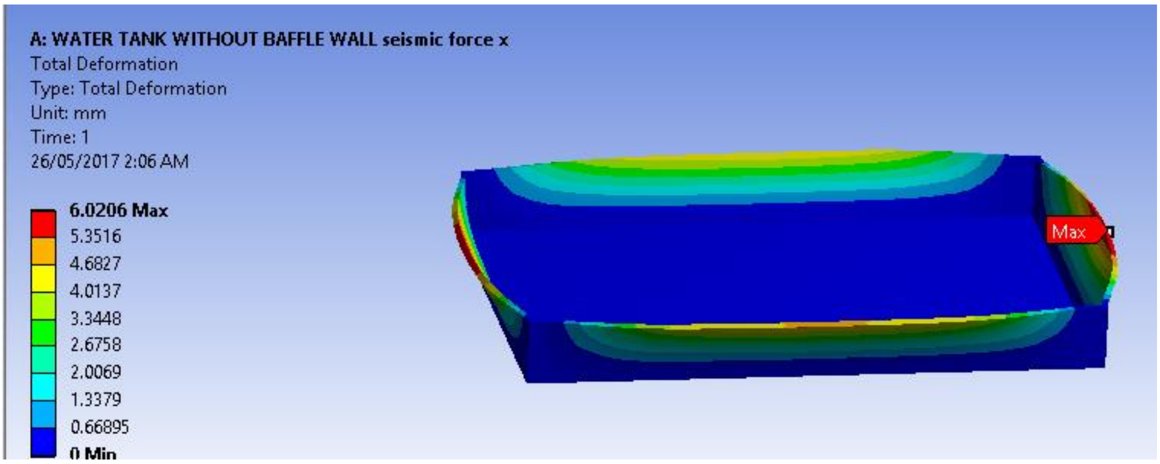


Figure 8. Total deformation of Tank without baffle wall

Case II- Rectangular tank with single baffle wall at equidistance in tank

A) Summary of Hydrostatic Pressure & hydrodynamic Pressure Acting In X Direction

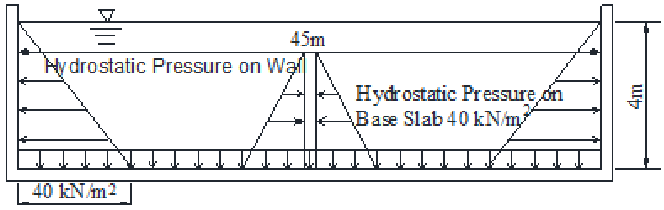


Figure 44 Hydrostatic forces in X direction

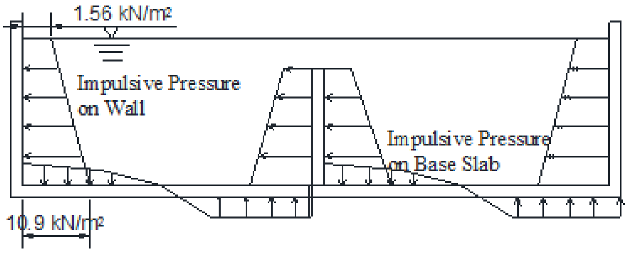


Figure 45 Hydrodynamic Impulsive Pressure acting in X direction

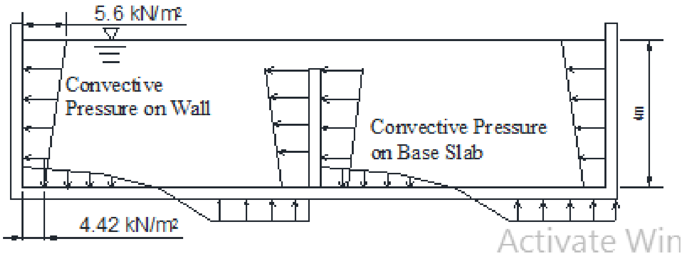


Figure 46 Hydrodynamic Convective Pressure acting in X direction

Figure 9. Hydrostatic and Hydrodynamic pressure acting in X Direction

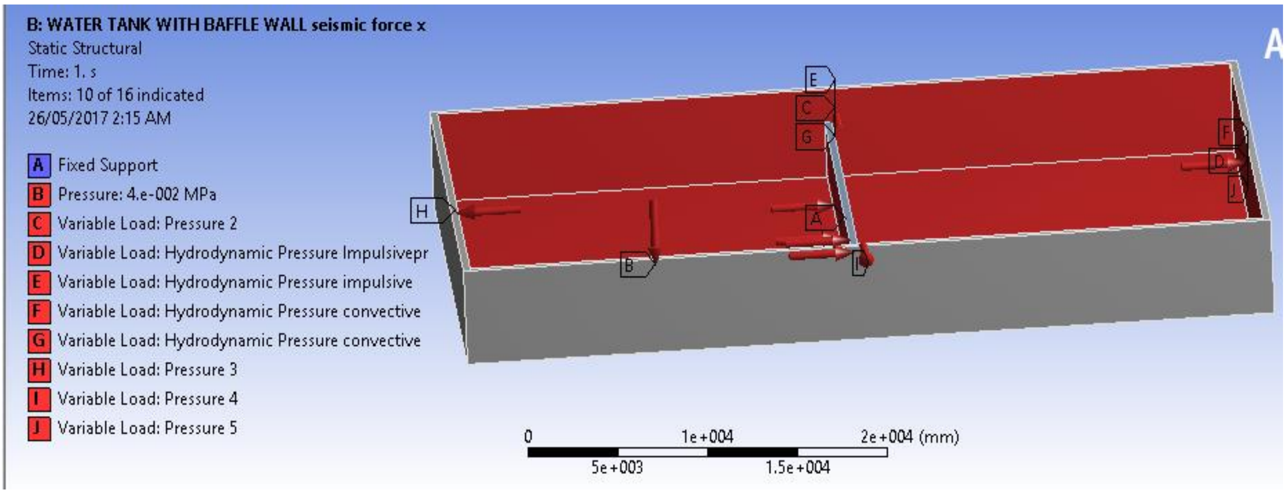


Figure10. Hydrostatic and Hydrodynamic pressure acting in X Direction

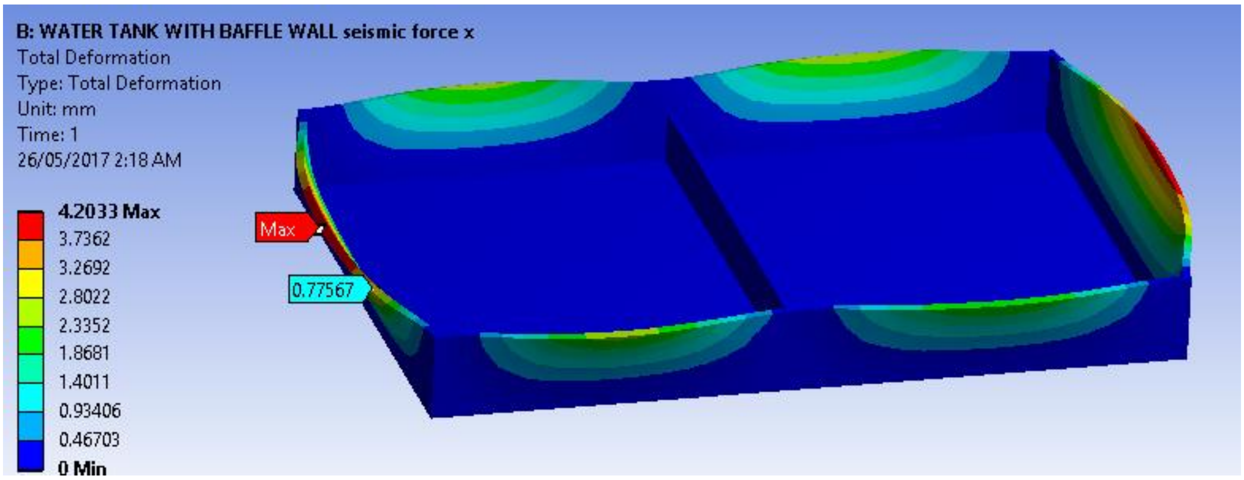


Figure13. Total Deformation of Tank

Case III- Rectangular tank with two baffle wall placed at equidistance

A) Summary of Hydrostatic Pressure & Hydrodynamic Pressure Acting in X Direction

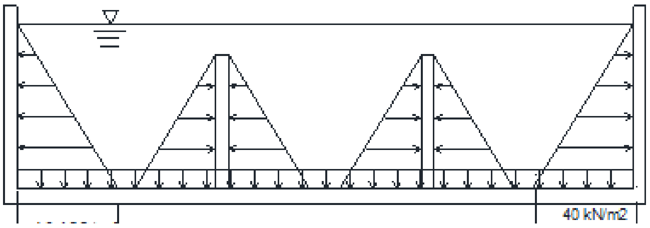


Figure 65 Hydrostatic Pressure

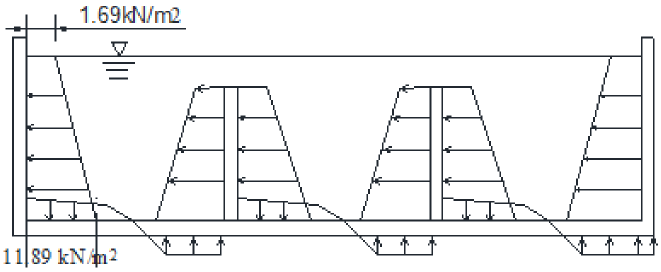


Figure 66 Hydrodynamic Impulsive pressure X direction

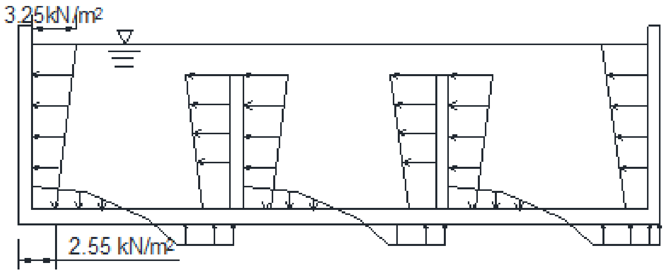
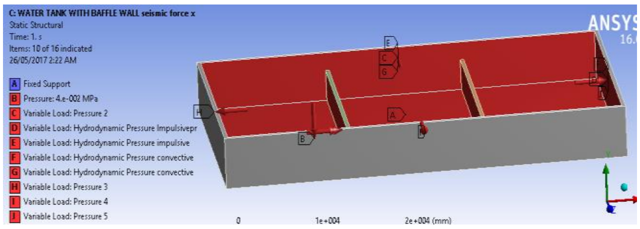


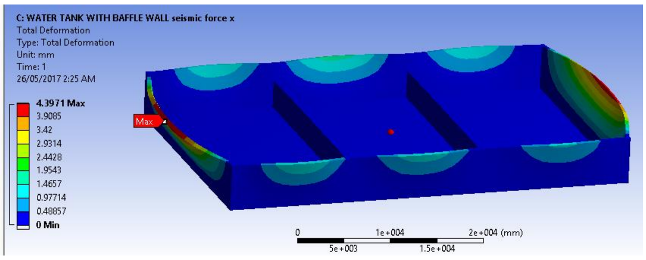
Figure 11. Hydrostatic and Hydrodynamic pressure acting in X Direction



C: WATER TANK WITH BAFFLE WALL seismic force x
Static Structural
Time: 1. s
Items: 10 of 16 indicated
26/05/2017 2:22 AM

A Fixed Support
B Pressure: 4.e-002 MPa
C Variable Load: Pressure 2
D Variable Load: Hydrodynamic Pressure Impulsivepr
E Variable Load: Hydrodynamic Pressure impulsive
F Variable Load: Hydrodynamic Pressure convective
G Variable Load: Hydrodynamic Pressure convective
H Variable Load: Pressure 3
I Variable Load: Pressure 4
J Variable Load: Pressure 5

Figure12. Hydrostatic and Hydrodynamic pressure acting in X Direction



C: WATER TANK WITH BAFFLE WALL seismic force x
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
26/05/2017 2:25 AM

4.3971 Max
3.9085
3.42
2.9314
2.4428
1.9543
1.4657
0.97714
0.48857
0 Min

Figure13. Hydrostatic and Hydrodynamic pressure acting in X Direction

IV. RESULTS -COMPARISON OF SEISMIC FORCE FOR TANK WITHOUT BAFFLE AND TANK WITH BAFFLE WALL

Seismic Force in X Direction

Sr. no	***Tank without baffle wall***	***Tank with single baffle wall***	***Tank with double baffle wall***
Impulsive mass of liquid	5,40,000kg (10% participates in Impulsive mode)	5,35,200kg (20% participates in Impulsive mode)	548700kg (31% participates in Impulsive mode)
Convective mass of liquid	44,82,000kg (83% of liquid participates in convective mode)	20,87,280kg (78% of liquid mass participates in convective mode)	1203600kg (68% of liquid mass participates in convective mode)
Time for convective mode	15.63 sec	7.538sec	5.15sec
Base shear at bottom of wall	3952kN	3014kN	2841kN
Equivalent Impulsive pressure –X Direction	Top=1.57kN/m2 Bottom=11.04kN/m2	Top = 1.56kN/m^2 Bottom=10.9kN/m^2	Top = 1.69kN/m^2 Bottom=11.89kN/m^2
Equivalent linear convective pressure- X Direction	Top=10.625kN/m^2 Bottom=10.625kN/m^2	Top=5.6 kN/m^2 Bottom=4.42kN/m^2	Top=3.25kN/m^2 Bottom=2.55kN/m^2
Sloshing Height	2.61m	1.3m	0.87m

SEISMIC FORCE IN Y DIRECTION

Sr. no	***Tank without Baffle***	***Tank With Single Baffle Wall***	***Tank With Double Baffle Wall***
Impulsive mass of liquid	702000kg (13% participates in Impulsive mode)	347880kg (13% participates in convective mode)	230100kg (13% participates in convective mode)
Convective mass of liquid	4185000kg (78% of liquid participates in convective mode)	2073900kg (78% of liquid mass participates in impulsive mode)	1371750kg (78% of liquid mass participates in impulsive mode)
Time for convective mode	11.77 sec	9.61 sec	9.61sec
Base shear at bottom of wall	4404kN	2854kN	1866
Equivalent Impulsive pressure –Y Direction	Top=1.34kN/m^2 Bottom=9.4kN/m^2	Top = 1.32kN/m^2 Bottom=9.29kN/m^2	Top = 1.34kN/m^2 Bottom=9.43kN/m^2
Equivalent linear convective pressure- Y Direction	Top=7.25kN/m^2 Bottom=6.429kN/m^2	Top=7.2kN/m^2 Bottom=6.4kN/m^2	Top=7.25kN/m^2 Bottom=6.43kN/m^2
Sloshing Height	1.8m	1.8m	1.8m

V. CONCLUSIONS

In present study, tanks with and without baffle having same geometric size, seismic parameter, water height, from above calculation and analysis the following conclusion is made

- Time calculated for tanks without baffle wall is more than the time period for tanks with single baffle wall and double baffle wall. Time reduces with introduction of number of baffle walls.
- When the seismic forces act in X direction, the sloshing height calculated for tank without baffle wall is more than the sloshing height calculated for tank with baffle walls.
- When the Seismic forces acts perpendicular to baffle wall direction i.e X direction, the sloshing height reduces by introduction of additional number of baffle walls when compared to Tanks without baffle and with single baffle and so on.
- Base shear acting at bottom of wall in case of tank without baffle is more as compared to Base shear in case of tank with baffle walls.
- When the seismic force is acting in X direction, the convective pressure acting at top for Tank with Baffle is almost half of the convective pressure acting at top of Tank without baffle walls. Introduction of additional baffle walls reduces convective pressure
- The total deformation, shear stresses and normal Stress are reduced in case of tank with baffle walls

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Statement: The authors declare that they have followed ethical responsibilities

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