A Study of Effect of Baffle Wall on Dynamic Response of Elevated Water Tank using Ansys 16

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Abstract

Finite element analysis is useful numerical technique to solve various structural problems. In this paper FEA model of rectangular elevated water tank with baffle wall is model using ANSYS 16.0 sloshing effect is a major problem encountered in the analysis of design of reinforced concrete rectangular elevated water tank. In this paper study of baffle wall is done with varying parameters such as thickness, spacing of baffle wall. In second stage opening effects are studied in baffle walls.

Keywords: Elevated water tank, Baffle wall, Finite element analysis, ANSYS

I. Introduction

The Reinforced concrete water tank design is based on IS3370:2009(Parts I-IV). The design depends on the location of tanks, i.e. overhead, on ground and underground water tanks. The tanks can be made in different shapes, usually circular and rectangular shapes are mostly used. The tanks can be made either RCC or of steel. The overhead water tanks are usually elevated from the roof top through column. In the other hand the underground tanks are rested on the foundation.

One of the vital considerations for design of tanks is that a structure has adequate resistance to cracking and has adequate strength. For achieving these following assumptions are made:

1) Concrete is capable of resisting limited tensile stresses the full section of concrete including cover and reinforcement is taken into account in this assumptions.
2) To guard against structural failure in strength calculation the tensile strength of concrete is ignored.
3) Reduced value of permissible stresses in steel are adopted in design.

Storage tanks are the containers used to store liquids. These may be resting on the ground, underground or elevated. All tanks are designed as crack-free structures for durability and to prevent leakage and concrete should be impervious to eliminate seepage.

Water storage tanks should remain functional in the post-earthquake period to ensure potable water supply to earthquake-affected regions and to the need for firefighting. The reinforced concrete circular water tanks are mainly subjected to direct tension in the form of hoop force. The tension is carried primarily by steel, and concrete is considered to provide protective cover to the steel reinforcement. In such structures, the values of allowable stresses in steel and concrete are restricted so that the strains in steel and concrete are not high, consequently crack widths are limited. This provision minimizes the danger of corrosion of steel. On the other hand, in the tanks with fixed bases, the walls are subjected to bending tension. The members under the direct tension are designed by elastic theory and those subjected to bending tension are designed.

The structure can be protected from the attack of severe earthquakes either through the concept of resistance or isolation. In designing a structure by resistance, it is assumed that the earthquake forces are transmitted directly to the structure, and that each member of the structure is required to resist the maximum possible forces that may be induced by earthquakes, based on various ductility criteria. In the category of earthquake isolation, Seismic Analysis And Design of Elevated Water Tank however, one is interested in reducing the peak response of the structure through implementation of certain isolation devices between the base and foundation of the structure, which prevents the transmission of earthquake.

A. Elevated or Tanks Overhead Water:

A wide variety of elevated water tanks can be seen in industries and complexes.
B. Supporting Tower for Tanks:

Overhead water tanks are generally supported on
1) Frame staging and
2) Shaft supported

Frame staging consisting of reinforced concrete columns braced together by ring beams at the top and bottom and also along number of places along the height by braces. The arrangement enables effective height of columns to be taken as the distance between centers of the adjacent bracings.

C. Performance of Elevated Water Tanks during Earthquake:

Many elevated water tanks damaged to their staging (support structure) in the Bhuj earthquake of January 26th 2001 and at least three of them collapsed. These water tanks are located in the area of a radius of approximately 125km from the epicenter. Tanks located in regions of the highest intensity of shaking collapsed while a few developed cracking near brace-column joint regions. Critical facilities like water tanks therefore require careful design.

Frame type stagings are generally regarded superior to shaft type staging for lateral resistance because of their large redundancy and greater capacity to absorb seismic energy through inelastic actions. Framed staging’s have many flexural members in the form of braces and columns to resist lateral loads and damage to a few will not result in the sudden collapse of the structure as inelastic deformations and damage is distributed to a large number of frame members. The sections near the beam ends can be designed and detailed to sustain inelastic deformation and dissipate seismic energy. However, if the frame members and the brace column joints are not designed and detailed for inelastic deformations, a collapse of the staging may occur under seismic overloads.

Sloshing, the motion of the free liquid surface inside its container is one of the major concerns in design liquid storage tanks, moving tankers fuel tank space vehicles and also in ships in major cities and also in rural areas elevated water tank forms in integral part of water supply scheme and these tanks must remain functional to meet the demand in any extreme situation like earthquake, fire, etc.

During the earthquakes, a number of large elevated water tanks were severely damaged whereas others survived without damage. An analysis of the dynamic behavior of such tanks must take into account the motion of the water relative to the tank as well as the motion of the relative to the ground.

The main concerns for failure of water tanks are,
1) Consideration is not given to sloshing effects of liquid and flexibility of container wall while evaluating the seismic forces on tanks.
2) It is recognized that tanks are less ductile and have low energy absorbing capacity and redundancy compared to the conventional building systems which is not considered properly.
3) Unsuitable design or wrong selection of supporting system and underestimated demand or overestimated strength of the tank.

This study is focus mainly on sloshing effect that is happening in the water tank during earthquake and how to overcome it.

Water is one of the most important part or need in our daily activities. Continuous water supply is very difficult task to do. The storage tanks help to store water in large amount. The water storage tank plays the vital role in water supply system. Now days we can optimize water storage tank by using baffle wall and stiffeners and considering latest technologies that we use in construction.
D. Baffle Wall:

Lightweight, high strength fiber glass baffle panels are ideal for underwater flow control application. Fiberglass Baffle Panels are fiber glass baffle panels are cost effective because they have a much longer life cycle than wood, concrete, steel and other traditional materials that are easy to install and can be easily removed for cleaning and access.

Baffle panels are available in 12” and 24” widths for easy fabrication and installation of new systems or the rehabilitation of existing systems. Baffles can be mounted to existing columns, attached to I-beams or attached to concrete walls with clip angles.

Fig. 2: Baffle wall

1) Materials of Construction

Baffle panels are available in 12’ and 24’ widths to offer flexibility in design and fabrication. Standard baffle panels are manufactured using a polyester resin. Optional resin systems offered include a fire retardant polyester resin system, a vinylester resin system for enhanced corrosion resistance and a resin system that meets NSF 61 requirements. Panels include a UV inhibitor and a surfacing veil for additional corrosion resistance and UV protection

E. Objective

1) To study analysis rectangular storage tank with empty and full condition.
2) To study seismic behavior of rectangular water tank with and without baffle wall.
3) To study seismic behavior of rectangular water tank with baffle wall using ANSYS.
4) To study sloshing effect on baffle walls and according to study change the various thickness, spacing. Opening of baffle wall in the elevated water tank

II. SYSTEM DEVELOPMENT

A. General:

This chapter deals with the line of action of project study i.e. the methodology need to carry out for the achievement of desired goals of it. This methodology basically has number of steps or set of procedures discussed in this section. A flow chart for the project methodology is shown in fig.

The need for study is that, Indian code needs inclusion of convective mode of vibration in the seismic analysis of tanks and more importance should be given to sloshing, rather than considering it’s as a parameter to fix the free float of the tank. When the tank containing liquid 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 wall. This mass is termed as impulsive liquid mass (Mi), 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 (Mc) and 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 fig.
Fig. 3:

Where,

- $h_i$ is the height at which the resultant of impulsive hydrodynamic pressure on wall is located from the bottom of tank wall.
- $h_i^*$ is the height at which the resultant of impulsive pressure on wall and base is located from the bottom of tank wall.
- $h_c$ is the height at which resultant of convective pressure on wall is located from the bottom of tank wall.
- $h_c^*$ is the height at which resultant of convective pressure on wall and base is located.

**B. Assumption:**

When design of rectangular water storage tank or any other water retaining structures following basic assumptions take place.

In water retaining structures a dense impermeable concrete is required therefore, proportion of fine and course aggregates to cement should be such as to give high quality concrete. Concrete mix weaker than M200 is not used. The minimum quantity of cement in the concrete mix shall be not less than 300 kg/m$^3$.

The design of the concrete mix shall be such that the resultant concrete is sufficiently impervious. Efficient compaction preferably by vibration is essential. The permeability of the thoroughly compacted concrete is dependent on water cement ratio. Increase in water cement ratio increases permeability, while concrete with low water cement ratio is difficult to compact.

Other causes of leakage in concrete are defects such as segregation and honey combing. All joints should be made water-tight as these are potential sources of leakage. Design of liquid retaining structures is different from ordinary R.C.C, structures as it requires that concrete should not crack and hence tensile stresses in concrete should be within permissible limits. A reinforced concrete member of liquid retaining structures is designed on the usual principles ignoring tensile resistance of concrete in bending. Additionally it should be ensured that tensile stress on the liquid retaining face of the equivalent concrete section does not exceed the permissible tensile strength of concrete as given in table.

Cracking may be caused due to restraint to shrinkage, expansion and contraction of concrete due to temperature or shrinkage and swelling due to moisture effects. Such restraint may be caused by –

- The interaction between reinforcement and concrete during shrinkage due to drying.
- The boundary conditions.
- The differential conditions prevailing through the large thickness of massive concrete.

Use of small size bars placed properly, leads to closer cracks but of smaller width. The risk of cracking due to temperature and shrinkage effects may be minimized by limiting the changes in moisture content and temperature to which the structure as a whole is subjected.

The risk of cracking can also be minimized by reducing the restraint on the free expansion of the structure with long walls or slab founded at or below ground level, restraint can be minimized by the provision of a sliding layer. This can be provided by founding the structure on a flat layer of concrete with interposition of some material to break the bond and facilitate movement. In case length of structure is large it should be subdivided into suitable lengths separated by movement joints, specially where sections are changed the movement joints should be provided.

Where structures have to store hot liquids, stresses caused by difference in temperature between inside and outside of the reservoir should be taken into account. The coefficient of expansion due to temperature change may be taken as 11 x 10^-6°C and coefficient of shrinkage may be taken as 450 x 10^-6 for initial shrinkage and 200 x 10^-6 for drying shrinkage.

**C. Design Criteria:**

1) Spring Mass Model for Seismic Analysis:

Hydrodynamic forces exerted by liquid on tank wall shall be considered in the analysis in addition to hydrostatic forces. These hydrodynamic forces are evaluated with the help of spring mass model of tanks.
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.

2) Rectangular Elevated Water Tank

For rectangular tanks these parameter \(m_i, m_c, h_i, h_c\) and \(K_c\) shall be obtained from Fig. 5. \(h_i\) and \(h_c\) account for hydrodynamic pressure on the tank wall only, \(h_i\) and \(h_c\) account for hydrodynamic pressure on tank wall and the tank base. Hence, the value of \(h_i\) and \(h_c\) shall be used to calculate moment due to hydrodynamic pressure at the bottom of the tank wall. The value of \(h^*\)i and \(h^*\)c shall be used to calculate overturning moment at the base of tank.

For elevated tanks, the two degree of freedom system of Fig. 6 can be treated as two uncoupled single degree of freedom systems, one representing the impulsive plus structural mass behaving as an inverted pendulum with lateral stiffness equal to that of the staging, \(K_s\) and the other representing the convective mass with a spring.

ANSYS 16 is useful to finite element simulation for RCC structure, we use Solid 186 for concrete, link8 for Rebar (Reinforcement), Conta 174 and Targe 173 to define contact between them.

3) SOLID186 Element Description:

SOLID186 is a higher order 3-D 20-node solid element that exhibits quadratic displacement behaviour. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element supports plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials.
CONTA 174 and TARGE170:
The 3-D contact surface elements (CONTA173 and CONTA174) are associated with the 3-D target segment elements (TARGE170) via a shared real constant set. ANSYS looks for contact only between surfaces with the same real constant set. For either rigid-flexible or flexible-flexible contact, one of the deformable surfaces must be represented by a contact surface. If more than one target surface will make contact with the same boundary of solid elements, you must define several contact elements that share the same geometry but relate to separate targets (targets which have different real constant numbers), or you must combine two target surfaces into one (targets that share the same real constant numbers).

D. Problem statement

A rectangular RC water tank of 1,000 m³ capacity has plan dimensions of 20 x 10 m and height of 5.3 m (including a free board of 0.3 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.

A comparison is made between two water tanks:
1) RECTANGULAR WATER TANK WITHOUT BAFFLE WALL
2) RECTANGULAR WATER TANK WITH BAFFLE WALL.

A. Finite Element meshing in ANSYS:
Figure shows finite element meshing in ANSYS WORKBENCH, without baffle wall no. of nodes are 24093 and elements are 5029. Triangular surface meshing is used over rectangular for convergence criteria.

Fig. 8:

Figure shows finite element meshing in ANSYS WORKBENCH, with baffle wall no. of nodes are 25193 and elements are 5161. Triangular surface meshing is used over rectangular for convergence criteria.

III. Loading consideration and boundary conditions

At X-direction,

Impulsive Hydrodynamic Pressure

Impulsive hydrodynamic pressure on wall is

\[ P_w = Q_{iw}(y) \cdot (A_h) \cdot \rho \cdot g \cdot h \]
\[ Q_{iw}(y) = 0.866[1-(y / h)^2] \times \tanh (0.866 \cdot L / h) \]

At base of wall, \( y = 0 \):
\[ Q_{iw}(y = 0) = 0.866 \cdot [1-(0/5)^2] \times \tanh(0.866 \times 20/5) \]
\[ = 0.86. \]

Impulsive pressure at the base of wall,
\[ P_{iw}(y = 0) = 0.86 \times 0.34 \times 1,000 \times 9.81 \times 5 \]
\[ = 14.3 \text{ kN/m}^2. \]

Impulsive hydrodynamic pressure on the base slab (\( y = 0 \))
\[ P_b = Q_{ib}(x) \cdot (A_h) \cdot \rho \cdot g \cdot h \]
\[ Q_{ib}(x) = \sinh (0.866 \cdot x / L) / \cosh (0.866 \cdot L / h) \]
\[ = \sinh (0.866 \times 20/10) / \cosh (0.866 \times 20/5) \]
\[ = 0.171. \]

Impulsive pressure on top of base slab (\( y = 0 \))
\[ P_b = 0.171 \times 0.34 \times 1,000 \times 9.81 \times 5 \]
\[ = 2.9 \text{ kN/m}^2. \]

Convective Hydrodynamic Pressure

Convective hydrodynamic pressure on wall is

\[ P_{cw} = Q_{cw}(y) \cdot (A_h) \cdot \rho \cdot g \cdot L \]
\[ Q_{cw}(y) = 0.4165 \cdot [\cosh(3.162(y/L))/[\cosh(3.162(h/L))] \]

At base of wall, \( y = 0 \):
\[ Q_{cw}(y = 0) = 0.4165[\cosh(3.162(0/20))]/[\cosh(3.162(5/20))] \]
\[ = 0.31. \]
$P_{cw}(y = 0) = 0.31 \times 0.038 \times 1,000 \times 9.81 \times 20$

$= 2.31 \text{kN/m}^2$

At $y = h$,

$Q_{cw}(y = h) = 0.4165$

Convective pressure at $y = h$,

$P_{cw}(y = h) = 0.4165 \times 0.038 \times 1,000 \times 9.81 \times 20$

$= 3.11 \text{kN/m}^2$

Convective hydrodynamic pressure on the base slab ($y = 0$)

$P_{cb} = Q_{cb}(x) (Ah) \rho g D$

$Q_{cb}(x) = 1.25[x/L - 4/3 (x/L)^3] \text{sech} (3.162 h/L)$

$= 1.25[L/2L - 4/3 (L/2L)^3] \text{sech} (3.162 x5 /20)$

$= 0.313$

Convective pressure on top of base slab ($y = 0$)

$P_{cb} = 0.313 \times 0.038 \times 1,000 \times 9.81 \times 20$

$= 2.33 \text{kN/m}^2$

At $Y$-direction

Impulsive hydrodynamic pressure on wall is

$P_{iw} = Q_{iw}(y) (Ah) \rho g h$

$Q_{iw}(y) = 0.866[1-(y/h)^2] \text{tanh} (0.866 L/h)$

At base of wall, $y = 0$;

$Q_{iw}(y = 0) = 0.866[1-(0/5)^2] \text{tanh}(0.866 x10 /5)$

$= 0.81$

Impulsive pressure at the base of wall,

$P_{iw} = 0.81 \times 0.34 \times 1,000 \times 9.81 \times 5$

$= 13.5 \text{kN/m}^2$

Impulsive hydrodynamic pressure on the base slab ($y = 0$)

$P_{ib} = Q_{ib}(x) (Ah) \rho g h$

$Q_{ib}(x) = \text{sinh} (0.866 x/L) / \text{cosh} (0.866 L/h)$

$= \text{sinh} (0.866 x 10 /10) / \text{cosh} (0.866 x 10/5)$

$= 0.336$

Impulsive pressure on top of base slab ($y = 0$)

$P_{ib} = 0.336 \times 0.34 \times 1,000 \times 9.81 \times 5$

Convective Hydrodynamic Pressure

Convective hydrodynamic pressure on wall is

$P_{cw} = Q_{cw}(y) (Ah) \rho g L$

$Q_{cw}(y) = 0.4165[\text{cosh}(3.162(y/L))/\text{cosh}(3.162(h/L)]$

$Q_{cw}(y) = 0.4165[\text{cosh}(3.162(0/10))/\text{cosh}(3.162(5/10)]$

$= 0.16$

Convective pressure at the base of wall,

$P_{cw} = 0.16 \times 0.006 \times 1,000 \times 9.81 \times 10$

$= 1 \text{kN/m}^2$

At $y = h$;

$Q_{cw}(y = h) = 0.4165$

Convective pressure at $y = h$,

$P_{cw}(y = h) = 0.4165 \times 0.06 \times 1,000 \times 9.81 \times 10$

$= 2.57 \text{KN/m}^2$

Convective hydrodynamic pressure on the base slab ($y = 0$)

$P_{cb} = Q_{cb}(x) (Ah) \rho g D$

$Q_{cb}(x) = 1.25[x/L - 4/3 (x/L)^3] \text{sech} (3.162 h/L)$

$= 1.25[L/2L - 4/3 (L/2L)^3] \text{sech} (3.162 x5 /20)$

$= 0.165$

Convective pressure on top of base slab ($y = 0$)

$P_{cb} = 0.165 \times 0.06 \times 1,000 \times 9.81 \times 10$

$= 1.02 \text{kN/m}^2$. 
IV. RESULTS AND CONCLUSION

Following results are natural frequency differences between rectangular water tank with baffle wall and without baffle wall.

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Fig. 11: Total Deformation of Without Baffle Wall Tank

Fig. 12: Shear Stress of Without Baffle Wall Tank

Fig. 13: Total Deformation of With Baffle Wall Tank
V. CONCLUSIONS

Present study is based on Finite Element Simulation of elevated RCC watertank in ANSYS workbench
In first stage pressure and loads are calculated in accordance with IS 1893:2002 part-2.
Later comparison is made between watertank with baffle wall and without baffle wall and following conclusion can be made
1) Natural frequency and time period is increased in baffle wall tank
2) Deformation and shear stress along long wall is considerably reduced by using baffle walls

VI. FUTURE SCOPE

It is clear that baffle walls increases performance of water tank against water pressure. Still Effect of spacing of walls and thickness against static and dynamic condition need to be studied

REFERENCES

[9] Dynamic analysis of water tanks with interaction between fluid and structure L. Kalani Sarokolayi1, B. Navayineya M. Hosainalibegi J. Vaseghi Amiri P.h.D student of structural Engineering, Faculty of Civil Eng., Babol University of Technology, Iran.