ANALYSIS AND DESIGN OF SUMP AND PUMP HOUSE

By

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ANALYSIS AND DESIGN OF SUMP AND PUMP HOUSE

Major Project

Submitted in partial fulfillment of the requirements

For the degree of

Master of Technology in Civil Engineering
(Computer Aided Structural Analysis & Design)

By

Pallav V Patel
(05MCL010)

Guide
Dr. P.V. Patel

DEPARTMENT OF CIVIL ENGINEERING
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CERTIFICATE

This is to certify that the Major Project entitled "Analysis and design of sump and pump house" submitted by Mr. Pallav V Patel (05MCL010), towards the partial fulfillment of the requirements for the degree of Master of Technology in Civil Engineering (Computer Aided Structural Analysis and Design) of Nirma University of Science and Technology, Ahmedabad is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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ABSTRACT

Earthquake is one of the causes for damage of liquid containing structures. When liquid storage structure faces the earthquake, liquid is accelerated. Due to this acceleration liquid undergoes sloshing motion. This effect develops additional pressure on the wall and base of liquid containing structure. These types of behavior of liquid containing structure may become hazardous. Overturning of whole tank structure or cracking of tank wall may occur due to earthquake. So it is necessary to consider seismic forces during design of liquid containing structure.

IS:1893-1984 specific criteria for seismic analysis of various type of structures, including water tanks. But it has not sufficient provisions for ground supported water tanks (sump). In view of present international practice, the provisions of IS:1893-1984 are revised and published recently in different parts by Bureau of Indian Standards. IS:1893 (Part II) is published as draft criteria for Earthquake Resistant Design of Liquid Containing Structures.

This major project includes seismic analysis for several types of water tanks resting on ground like circular and rectangular water tanks, which are covered, or uncovered. Detail discussion on seismic provisions like time period, liquid mass, base shear, moment at base of tank wall, overturning moment, hydrodynamic forces is carried out considering both impulsive and convective mode. Analysis results are presented in graphical form for various capacity tanks. Comparative study of results of seismic forces and static forces is carried out for circular tanks with different height to diameter ratios. Similarly analysis results due to seismic forces and static forces for rectangular tank with different length to height ratio and length to width ratio is included. It is observed that hydrodynamic forces due to earthquake are beyond the permissible limit in higher earthquake zones. Finite element modeling of circular and rectangular tank with hydrostatic and hydrodynamic pressure is carried out in SAP2000 software. Step by step procedure for modeling of water tank in SAP2000 is included. Analysis results obtained by SAP2000 and analysis results as per IS:3370 (part IV) are compared for both circular and rectangular tanks. Illustrative examples for analysis and design are included, considering provisions of IS:1893 (part II). Parametric study on design and estimation is carried out for

different dimensions of tank and economic configuration is worked out. For analysis, design and quantity estimation of different component of tank like wall, base slab, footing, cover (dome or flat slab), internal columns and its footing computer programs are developed in C++.

Pumps are used to lift water from sump to the elevated water tank. For installation of pumps and electrical accessories pump house is required. This major project also includes analysis, design of pump house using STAAD/pro software. Program is prepared using C++ which generates input file for STAAD model of pump house for further analysis and design using STAAD/pro software.

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Abbreviation Notation and Nomenclature

The symbols and notations given below apply

(A_h)	Design horizontal seismic coefficient
$(A_h)_c$	Design horizontal seismic coefficient for convective mode
$(A_h)_I$	Design horizontal seismic coefficient for impulsive mode
A_v	Design vertical seismic coefficient
B	Inside width of rectangular tank perpendicular to the direction of seismic force
C_c	Coefficient of time period for convective mode
C_i	Coefficient of time period for impulsive mode
d	Deflection of wall of rectangular tank, uniformly distributed pressure
d_{max}	Maximum sloshing wave height
D	Inner diameter of circular tank
D_c	Diameter of column
E	Modulus of elasticity of tank wall
F.B.	Height of free board
g	Acceleration due to gravity
h	Maximum depth of liquid
h_c	Height of convective mass above bottom of tank wall (without considering base pressure)
h_i	Height of impulsive mass above bottom of tank wall (without Considering base pressure)
h_s	Structural height of staging, measured from top of foundation to the bottom of container wall
h_t	Height of center of gravity of roof mass above bottom of tank wall
h_w	Height of center of gravity of wall mass above bottom of tank wall
h_c*	Height of convective mass above bottom of tank wall (considering base pressure)
h_i	Height of impulsive mass above bottom of tank wall (considering base pressure)
I	Importance factor
K_c	Spring stiffness of convective mode
h_{ch}	horizontal length of column head

L	Inside length of rectangular tank parallel to the direction of seismic force
l_{cf}	Length of column footing
m	Total mass of liquid in tank
m_h	Mass of base slab / plate
m_c	Convective mass of liquid
m_i	Impulsive mass of liquid
m_t	Mass of roof slab
m_w	Mass of tank wall
M	Total bending moment at the bottom of tank wall
M^*	Total overturning moment at base
M_c	Bending moment in convective mode at the bottom of tank wall
M_c^*	Overturning moment in convective mode at the base
M_i	Bending moment in impulsive mode at the bottom of tank wall
M_i^*	Overturning moment in impulsive mode at the base
P	Maximum hydrodynamic pressure on wall
p_{cb}	Convective hydrodynamic pressure on tank base
p_{cw}	Convective hydrodynamic pressure on tank wall
p_{ib}	Impulsive hydrodynamic pressure on tank base
p_{iw}	Impulsive hydrodynamic pressure on tank wall
p_v	Hydrodynamic pressure on tank wall due to vertical ground acceleration
p_{ww}	Pressure on wall due to its inertia
q	Uniformly distributed pressure on one wall of rectangular tank in the direction of ground motion
Q_{cb}	Coefficient of convective pressure on tank base
Q_{cw}	Coefficient of convective pressure
Q_i	Impulsive hydrodynamic force per unit length of wall
Q_c	Convective hydrodynamic force per unit length of wall
Q_{ib}	Coefficient of impulsive pressure on tank base
Q_{iw}	Coefficient of impulsive pressure on tank wall
R	Response reduction factor given in
(Sa/g)	Average response acceleration coefficient as per IS 1893 (Part 1): 2002

t	Thickness of tank wall
t_b	Thickness of base slab
t_f	Thickness of wall footing
t_p	Thickness of plain cement concrete
t_r	Top ring beam
t_s	Thickness of flat slab
t_{cf}	Thickness of column footing
T_c	Time period of convective mode (in seconds)
T_i	Time period of impulsive mode (in seconds)
V	Total base shear
V_c	Base shear in convective mode
V_i	Base shear in impulsive mode
V_{ch}	Vertical height of column head
x	Horizontal distance in the direction of seismic force, of a point on base slab from the reference axis at the center of tank
y	Vertical distance of a point on tank wall from the bottom of tank wall
Z	Seismic zone factor
Φ	Circumferential angle
ρ	Mass density of liquid
ρ_w	Mass density of tank wall
μ_i	Impulsive bending moment coefficient
μ_c	Convective bending moment coefficient

1. INTRODUCTION

1.1 GENERAL

Liquid storage tanks are lifeline structures and strategically very important, due to their vital use in industries and nuclear power plants. Large-capacity ground-supported tanks are used to store a variety of material, e.g. water for drinking and fire fighting, petroleum, chemicals, solid materials and liquefied natural gas.

Liquid storage tanks are very important components of industrial and agricultural facilities. They are critical elements in the municipal water supply and fire fighting systems. Conventionally reinforced concrete tanks have been used extensively for municipal and industrial facilities for several decades. The serviceability requirements of the liquid-containing concrete structures should be such that they must be able to withstand the applied loads without cracks that would permit leakage.

Each year hundreds of different kinds of water tanks and other liquid retaining structures are being built in different parts of the country. These tanks and reservoirs have faced many storms and earthquakes. During the past four decades there have been considerable developments in materials, design philosophies, construction techniques as well as attitudes of all the stakeholders. Therefore, the responsibility of the engineers is to produce stronger, durable, economical and aesthetically appealing liquid retaining structures.

Earthquake causes random motion of ground. This motion causes the structure to vibrate. The vibration intensity of ground expected at any location depends upon the magnitude of earthquake, the depth of focus, distance from the epicenter and the strata on which the structure stands. The predominant direction of vibration is horizontal. During seismic excitation, liquid inside the tank exerts hydrodynamic forces on tank walls and base. Traditionally, hydrodynamic forces in a tank-liquid system are evaluated using spring-mass system, which simulate the impulsive and convective mode of vibration of a tank-fluid system. Ground supported tanks are damaged in form of cracking of wall and overturning of whole structure. It is possible to prevent such types of damages by adopting appropriate design methods. IS:1893 (part II) is introduced as draft copy with more specific provisions compared to IS:1893-1984 for seismic analysis of liquid containing structures.

1.2 WATER DISTRIBUTION SYSTEM

Fresh water is basic need of mankind for drinking and various daily uses. It is also basic need for industry. Water storage and its distribution system is very important. First water is collected from the ground water sources. Water is stored in storage tank (sump) and it is pumped to the elevated storage reservoir. From elevated storage it is supplied to consumers. Components of water distribution system are shown in Fig.1.1.

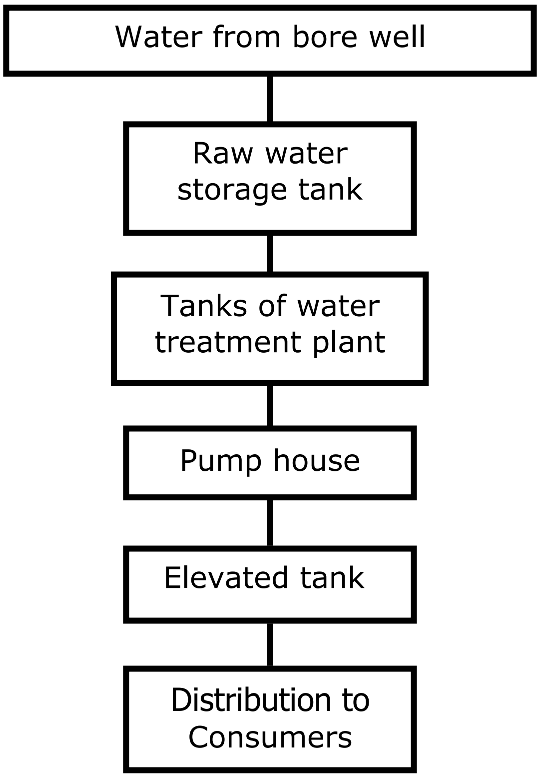


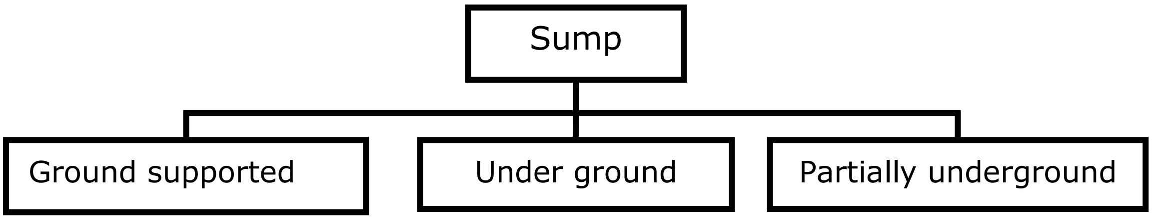
Fig 1.1 Water distribution systems

1.3 SUMP AND PUMP HOUSE

Sump is water storage structure of different shape like circular and rectangular resting on ground or under ground. It can be covered at top for drinking water storage while open in case of water treatment / effluent treatment plant. The function of pump house is to lift water from sump to elevated water tank from which, it can be supplied through gravity.

1.3.1 Classification of Sump Based on Position

Sumps are classified in three category based on its position with respect to ground as shown in Fig.1.2.



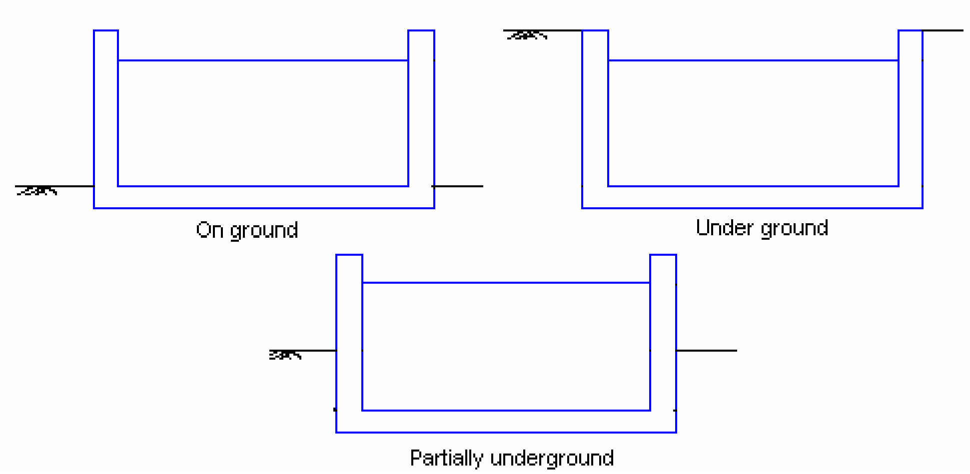


Fig.1.2 Classification of sump based on position

1.3.2 Classification of Sump Based on Material

Sumps are classified in three category based on material of construction as per Fig.1.3.

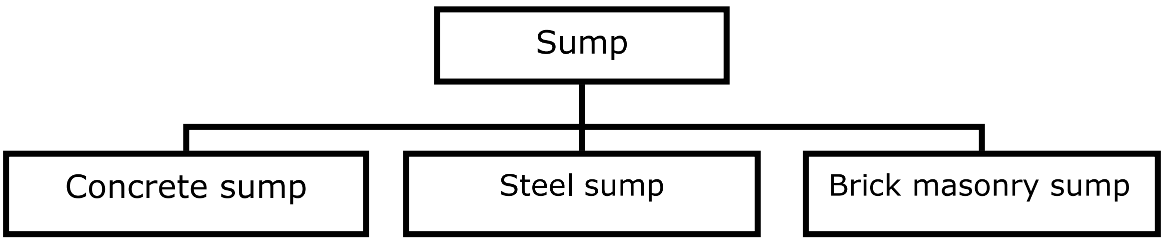
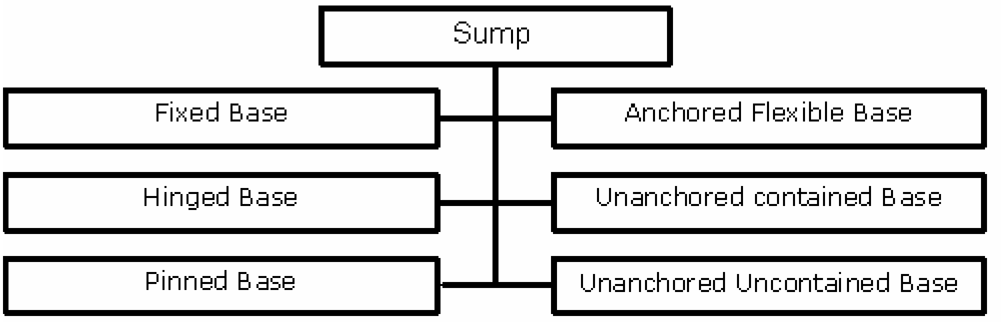


Fig.1.3. Classification of sump based on material

1.3.3 Classification of R.C.C Sump Based on Connection

As per connection between wall and base slab sumps are classified in six types as shown in Fig.1.4.



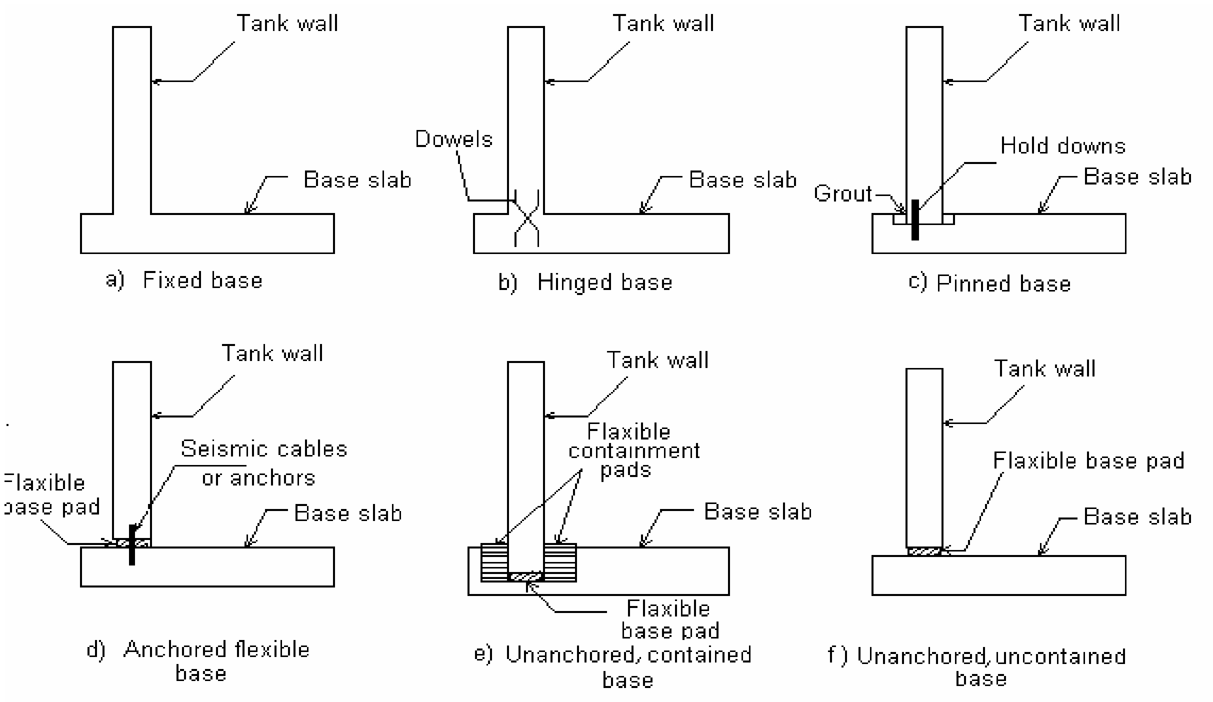


Fig.1.4 Classification of sump based on connection of wall and base slab

1.4 PUMP HOUSE

Pump house is concrete building, which is used for installation of pumps. Pump house can be classified in three categories, depending its position with respect to ground surface as shown in Fig.1.5. Sectional view for different types of pump house is shown in Fig.1.6.

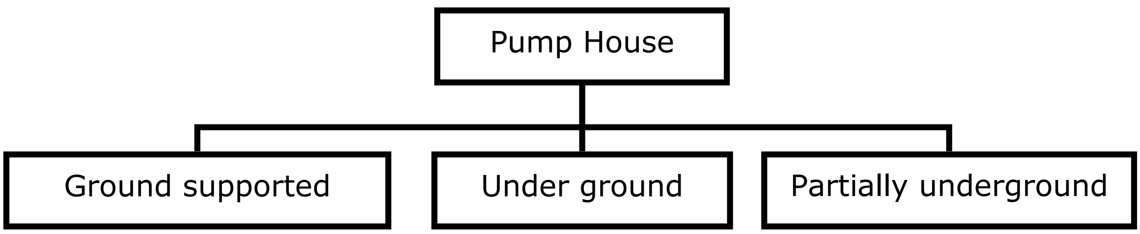


Fig.1.5 Different types of pump house

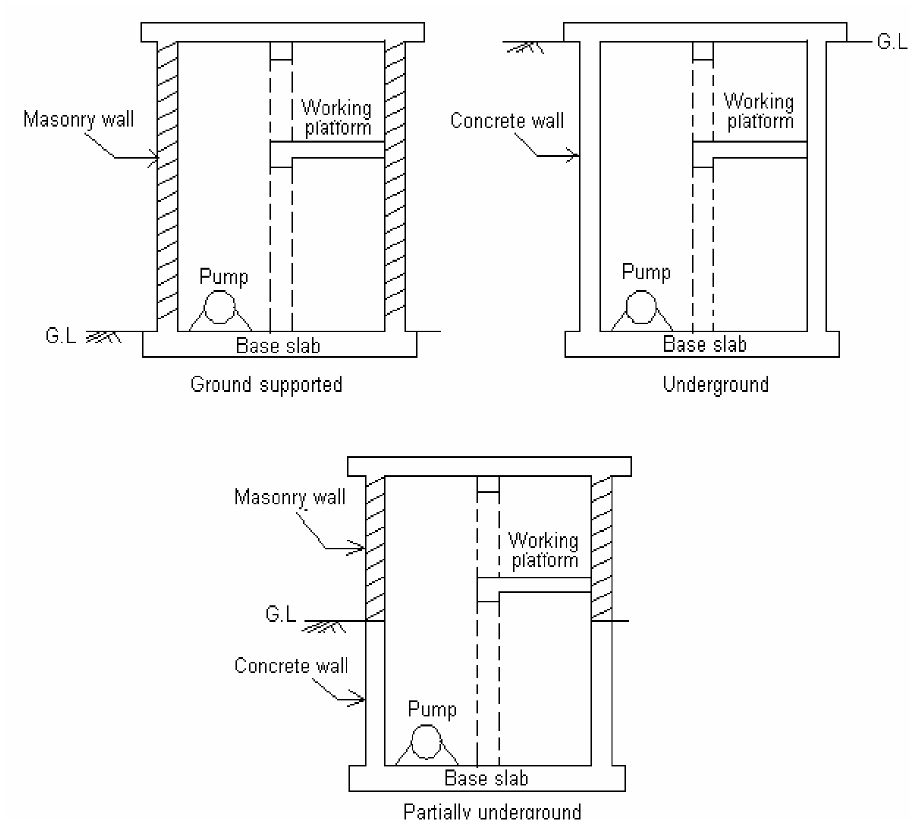


Fig.1.6 Sectional view of different types of pump house

Pump house consist of space for fixing pumps and for electrical accessories. It provides space for working platform. Position of pumps in pump house and connection of sump and pump house is shown in Fig.1.7.

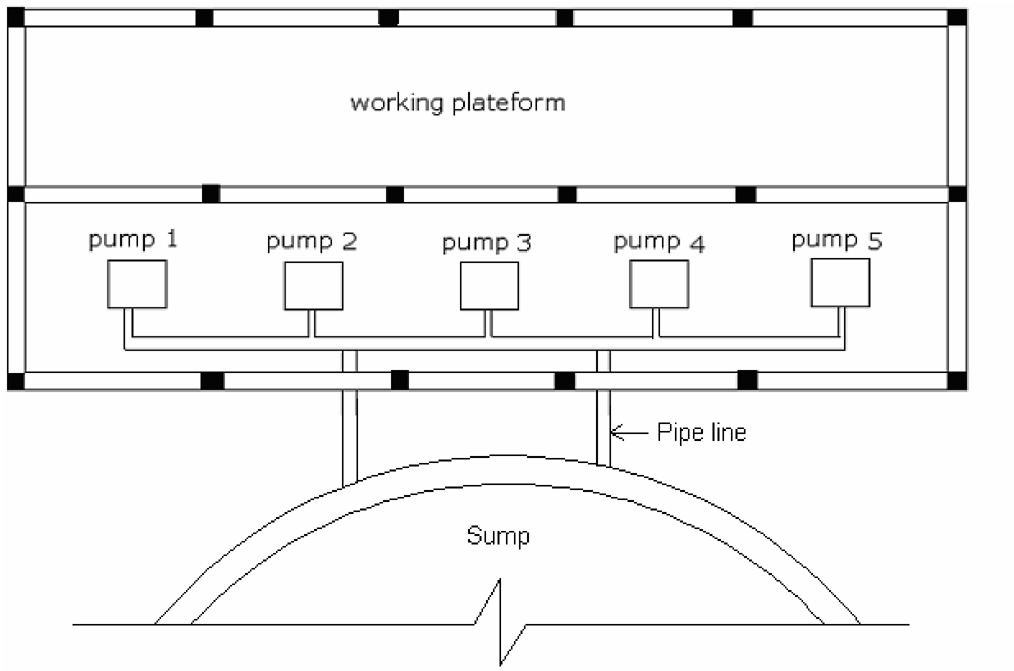


Fig 1.7 Assembly of sump and pump house

1.5 OBJECTIVE OF STUDY

The sump and pump house are major elements for water supply and water retaining structures. Their function should be ensured during the natural hazard like earthquake. Recently seismic provisions for liquid retaining structures have been revised and published as IS:1893 (part II) draft.

The main aim of present work is the critical study of the codal provisions of IS: 1893(part II) draft code. The work is carried out considering following objectives.

(i) To study effects of dimensions of circular water tank and earthquake zone on base shear, base moment, overturning moment, hydrodynamic pressure etc.

(ii) To study the effect of sizes of rectangular tank and location on various seismic parameters like base shear, base moment, overturning moment, hydrodynamic pressure etc.

(iii) To carry out design of R.C.C. circular and rectangular water tanks (sump) as per IS:1893 (part II) draft.

(iv) To carry out finite element modeling and analysis of tank wall subjected to nonlinear hydrodynamic pressure variation and its comparison with analysis results obtained using tables given in IS:3370 (part IV).

(v) To arrive at economical configuration of tanks, which require less materials.

(vi) To develop general purpose computer program for seismic analysis and design of circular and rectangular water tank (sump) resting on ground.

(vii) To develop computer program which generate geometry and loading of pump house for further analysis using STAAD/pro software.

1.6 SCOPE OF WORK

Based on the objective of the study stated above, scope of work is decided as follows;

(i) Visit of 'Gujarat Water Supply & Sewerage Board (GWSSB), Gandhinagar' for study of current design practices and structural detailing drawings of the sump and pump house.

(ii) Study of various provisions of IS: 1893 (part-II) draft code for circular as well as rectangular tanks.

(iii) Development of computer program using C++ for earthquake analysis of circular and rectangular ground supported tank which, can be used for on the ground, under ground and partially underground tank.

(iv) Comparative study of earthquake forces on tank wall and base for different capacity of circular and rectangular tank.

(v) Development of computer program for static analysis of circular and rectangular tank using design tables of IS: 3370 (part IV).

(vi) Finite element modeling and analysis of circular and rectangular tank considering hydrostatic and hydrodynamic pressure in SAP2000 software.

(vii) Comparative study of analysis results of finite element method and that by using design tables of IS: 3370 (IV).

(viii) Parametric study of finite element analysis of tanks for various capacities with different configuration.

(ix) Program development for designing and quantity estimation for various components of ground supported tank.

(x) Reinforcement detailing for circular and rectangular tank components.

(xi) Parametric study for design and estimation of various capacities of tank.

(xii) Development of Computer Program for generation of input file, which includes geometry and loading data for connectivity to STAAD-PRO software for analysis and design.

1.7 ORGANIZATION OF MAJOR PROJECT

The contents of major project are divided in various chapters as follows;

In chapter one, introduction about ground supported tank and pump house and their classification according different aspects are included. It also includes objective and scope of the major project.

In chapter two, review of literature for seismic analysis of water tank supported on ground is presented.

In chapter three, introduction of draft code and general provisions related to earthquake are discussed. Spring mass model of ground supported tank and its parameters are included. It also includes provisions regarding importance factor, response reduction factor etc.

Chapter four includes provisions of draft code for seismic analysis of circular tank. Procedure for calculation of time period, base shear, moment at base of wall, overturning moment, hydrodynamic pressure included. Development of computer program for seismic analysis of circular tank is discussed. It also includes input and output of program for seismic analysis of circular tank. Parametric study for various capacities and different height to diameter ratio is included.

In chapter five, provisions of draft code regarding seismic analysis of rectangular tank are included. Procedure for calculation of various parameters like, time period, base shear, moment at base of wall, overturning moment, hydrodynamic pressure etc are discussed. Development of computer program for seismic analysis of rectangular tank using C++ is discussed. It also includes input and output of program for seismic analysis of rectangular tank. Parametric study for various capacities with different length to width ratio and length to height ratio is included.

In chapter six, finite element modeling and analysis of circular tank using SAP2000 and design of various component of circular tank are included. Modeling procedure of circular tank with hydrostatic and hydrodynamic pressure is discussed. Comparative study of analysis results of SAP2000 and IS: 3370 (part IV) is presented. An illustrative design example of circular tank as per IS:1893 (part II) is presented.

In chapter seven, finite element modeling of rectangular tank using SAP2000 and design of various components are included. Modeling procedure of rectangular tank with hydrostatic and hydrodynamic pressure in SAP2000 is discussed. Comparative study of analysis results of SAP2000 and IS: 3370 (part IV) is incorporated. An illustrative design example of rectangular tank as per IS: 1893 (part II) is presented.

In chapter eight, analysis and design of pump house is included. It presents computer program for generation of input file including geometry and loading data which can be imported in STAAD/pro for further analysis and design.

In chapter nine, summary of work, conclusions and future scope of work is discussed.

2. LITERATURE SURVEY

2.1 GENERAL

Several research papers related to earthquake analysis for water tank are referred. Brief review of related research papers is presented in this chapter. The papers are mainly related to seismic behavior of water tank and discussion of codal provisions of various countries.

2.2 LITERATURE REVIEW

Kianoush et al [1] had provided directions to the designer for liquid containing concrete structures for computing seismic forces. This paper presented an overview of the basic concepts of the seismic analysis of liquid containing structures as per ACI 350. An outline of the basic theory that used for computation of seismic forces was included. The effect of the vertical and horizontal distribution of hydrodynamic forces on the wall of circular and rectangular wall was discussed. In this study, the effect of various parameters on the response of liquid containing structures and the behavior of liquid containing structures in terms of impulsive and convective modes were presented.

According to **Kianoush, Chen [2]** P-waves of earthquake are mainly associated with vertical component of ground motion and due to effect of such wave vertical acceleration of structure take place. In study, vertical component of ground acceleration on the overall seismic behavior of liquid storage tank was evaluated. The time history response of tank wall associated with hydrodynamic pressure distribution was presented. Two rectangular open tanks deep and shallow were used for the vertical acceleration study. Displacement v/s time, height v/s pressure, height v/s acceleration etc. graphs were developed for both deep and shallow tank in this study. This study indicated that vertical component of earthquake motion make significant effect on water retaining structure so it must be consider during seismic analysis of liquid storage tank.

Malhotra et al [3] had given theoretical background of a simplified seismic design procedure for cylindrical ground-supported tanks. The procedure was given of seismic calculation of impulsive and convective actions of the liquid. Flexible base condition was considered for steel tank, while for concrete tanks fixed to rigid base condition was considered. Seismic responses of bases shear, overturning moment, and sloshing wave height were calculated by using the site response spectra and performing a few sample calculations. An example was presented to illustrate the procedure. Explanation of single degree of freedom system spring mass model for cylindrical water tank was given.

Koller, Malhotra [4] found out seismic resistance of several existing unanchored cylindrical oil storage tanks according to Eurocode (EC) 8, part 4. Also pushover analysis was carried out and its results were compared to Eurocode provision. Base rotation v/s overturning moment graphs were presented. EC 8, type 1 response spectrum was used for study. Ground condition was considered as class B. Plastic rotation of base was reported for different capacity tank by pushover analysis and compared with Eurocode 8. Vast difference in plastic rotation is found in results of Eurocode 8.

Chount, Bang Yun [5] had obtained the effects of a bottom-mounted rectangular block on the sloshing characteristics of the fluid in rectangular tanks. For the sloshing analysis the velocity potential was decomposed into those for the wall-induced waves and the reflected, transmitted and scattered waves by the block. In this study different size of blocks were placed in different locations and frequency, mode shape and effect on hydrodynamic pressure were studied. The analysis results indicated that the size and location of the block significantly influence the sloshing frequencies and mode shapes. In general, sloshing frequencies reduced as the block became tall and wide. The hydrodynamic pressure exerted on the tank wall and the block changes significantly as the block became large and moved toward the wall.

Meier [6] had given some points for design of liquid retaining structure. Before 2000, different equations used for the seismic analysis were not proper. Some changes in equations came in picture by this paper. Response reduction factors and importance factor for various types of tanks were discussed. Minimum required freeboard was also discussed in this paper.

Dogangiin et al [7] included the formulation of three-dimensional Lagrangian fluid finite element which considered the effects of compressibility. Surface sloshing motion was programmed and incorporated into a general-purpose structural analysis program SAPIV. The static and dynamic behavior of rectangular liquid storage tanks were studied by finite element method using the Lagrangian approach, considering liquid-structure interaction. Both static and dynamic analysis models were generated and studied. Graphs for displacement and hydrodynamic pressure developed from results. The maximum wave height obtained from this study for the rigid tank was 10% less than that obtained by Housner's method for the same tank, and 9% less than that of flexible tank considered in this study.

Dima et al [8] had provided steps of seismic analysis of cylindrical water tank according to the Romanian Seismic Norm P100-92. Hydrodynamic pressure due to horizontal and vertical component of the earthquake motion was calculated and presented in graphical forms. Total bending moment distribution along height of wall was calculated. All work for seismic calculation presented in this paper was for the bolted steel cylindrical tank.

Chatterjee, Biswajit Basu [9] prepared model of tank-liquid system as a two-degree-of-freedom (2-DOF) system and analyzed. Both sloshing and impulsive actions of the tank liquid were considered. The wavelet domain dynamic equations had been formulated and solved to find out the coefficients of hydrodynamic pressure on the tank wall, base shear, and overturning moment at the tank base. Closed form expression for the instantaneous power spectral density function (PSDF) of the response quantities in terms of the functional of the input wavelet coefficients had been obtained

Biswala et al [10] indicated the influence of a baffle on the dynamic response of a partially liquid-filled cylindrical tank. A baffle was assumed to have the shape of a thin annular circular plate. The natural frequencies of an incompressible liquid were determined for varying positions and dimensions of a baffle attached normal to the tank wall. The flexibility of both the baffle and the tank were considered in studying the effects of liquid, baffle and liquid tank interactions on the sloshing mode frequencies. Finite element codes were developed and were used to analyze both the liquid domain and the structural domain.

J.R. Cho et al [11] presented numerical techniques for the seismic analysis as well as the free vibration analysis of liquid-storage tanks. In the numerical formulation of accurate added-mass matrix for the construction of uncoupled-separated structural dynamic system, the liquid free-surface fluctuation was taken into consideration. In study of resulting frequency dependent added-mass matrices and natural modes, a rapid convergent iterative numerical scheme for computing added-mass matrices, as well as a modified numerical procedure for the seismic analysis were carried out.

Cho et al [12] explained finite element formulation, free vibration characteristics of liquid-storage tanks with and without baffle. In order for the locking-free robustness as well as the numerical simplicity of the test FEM program, which was based upon degenerated shell elements and 3-D quadratic acoustic elements, the reduced integration (RI) technique and the modified shear correction factor (MSCF) were combined in the coupled symmetric two-field formulation. Natural frequencies and modes of cylindrical tanks were parametrically examined, with respect to the baffle number and location, the baffle inner-hole diameter, as well as the liquid fill height.

Study of **Nachtigall et al [13]** was based on two international well accepted design standards. One was Eurocode 8 Part 4 a code for Tanks and other was API Standard 650—Seismic Design of Storage Tanks. The structural response of seismically excited vertical circular cylindrical tanks was obtained. The common basic assumption, adopted from Haroun-Housner and Veletsos that a circular cylindrical tank containing liquid behave like a cantilever beam without deformation of its cross-section was obsolete. In the same paper study of damaged tanks was carried out and different deformed shapes of cylindrical tank given with different sketches.

Study of **Malhotra, Veletsos [14]** included the principal effects of base uplifting on the seismic response of laterally excited, unanchored, cylindrical liquid-storage tanks. Critical responses of representative tanks were evaluated for increasing intensities of earthquake ground motion. The ratio of liquid height to tank radius was the most important single parameter governing the uplifting response of tanks. Base uplifting increased the effective period of vibration of the system from that applicable to its fully anchored condition. Larger the height-to-radius ratio, the larger was the resulting increase in period. A similar increase in the time period was obtained with an increasing intensity of ground shaking.

Jaiswal et al [15] carried out an important study on various codes related to seismic analysis of ground supported water tanks**.** In this paper, provisions of ten seismic codes on tanks were reviewed and compared. Base shear coefficients were presented in graphical form for anchored based and unanchored based tank. Sloshing wave height and soil structural interaction according various codes were also included in study. This review had revealed that there are significant differences among these codes on design seismic forces for various types of tanks. Reasons for these differences were critically examined and the need for a unified approach for seismic design of tanks was highlighted.

2.3 SUMMARY

This chapter includes brief review of different research papers related with seismic behavior of liquid containing structure. These papers presented guidelines for seismic analysis of liquid containing tank. From these papers, it became possible to learn provisions of different country codes related to seismic analysis of tank. Parametric study carried out by various researchers gave direction to carry out further work in this major project.

3. PROVISIONS OF IS: 1893 (PART II) DRAFT CODE

3.1 GENERAL

Earthquake is a major cause of destruction. Seismic design of various structures should be given more attention and ensuring its safety during earthquake as well. IS:1893 (1984) is code of seismic analysis of various structure. IS:1893 (1984) is revised and divided in different parts by Bureau of Indian Standards. IS:1893 (part II) is code of seismic analysis of liquid containing structures. This chapter includes general provisions and explanation of IS:1893(part II) draft code for seismic analysis of ground supported liquid containing structures. Response reduction factor and importance factor for ground supported tank are also incorporated in this chapter.

3.2 SPRING MASS MODEL FOR SEISMIC ANALYSIS

Dynamic analysis of liquid containing tank is a complex problem involving fluid structure interaction. Based on numerous analytical, numerical, and experimental studies, simple spring mass models of tank liquid system have been developed to evaluate hydrodynamic forces.

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. Accelerated liquid mass affects the wall of water tank in forms of two different liquid mass: Impulsive mass and Convective mass.

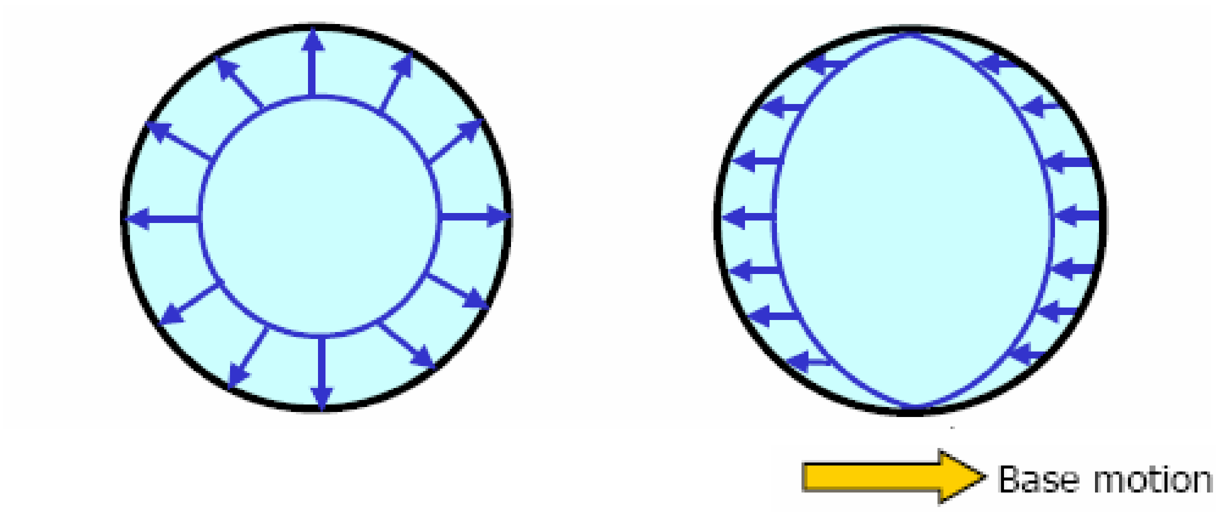
3.2.1 Impulsive Mass

The liquid in the lower region of tank behaves like a mass that is rigidly connected to tank wall. This mass of liquid is termed as impulsive liquid mass. This type of mass accelerates the pressure along increasing the depth. This pressure is known as impulsive hydrodynamic forces.

3.2.2 Convective Mass

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. This pressure is maximum at the top and reduces along depth.

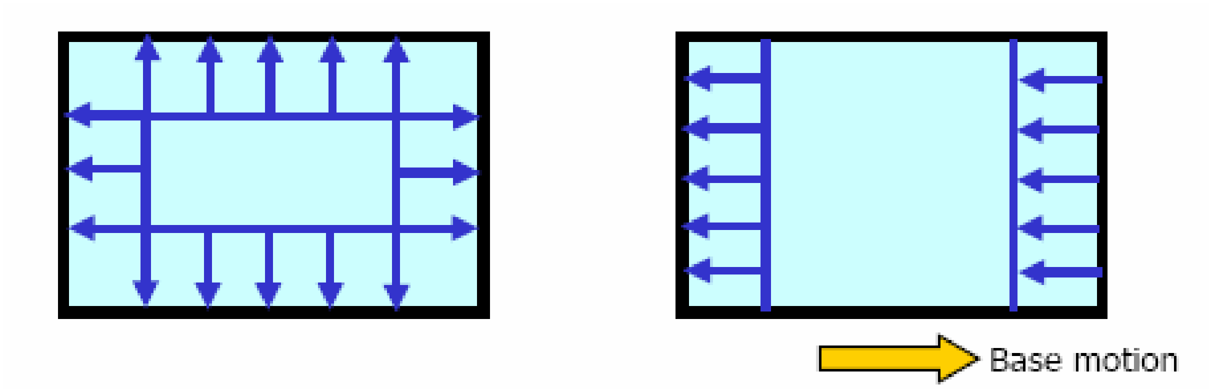
Hydrostatic and hydrodynamic forces acting on circular and rectangular water tank are shown in Fig.3.1 and Fig.3.2. Impulsive and convective pressure distributions are as per indicated in Fig.1.3.



Hydro static pressure | Hydrodynamic pressure

Net pressure is zero | Net pressure is not zero

Fig 3.1 Hydrostatic and hydrodynamic pressure distribution in circular tank



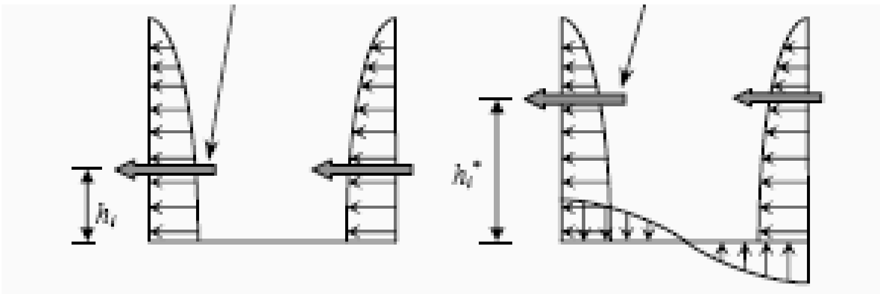
Hydro static pressure | Hydrodynamic pressure

Net pressure is zero | Net pressure is not zero

Fig.3.2 Hydrostatic and hydrodynamic pressure distribution in rectangular tank

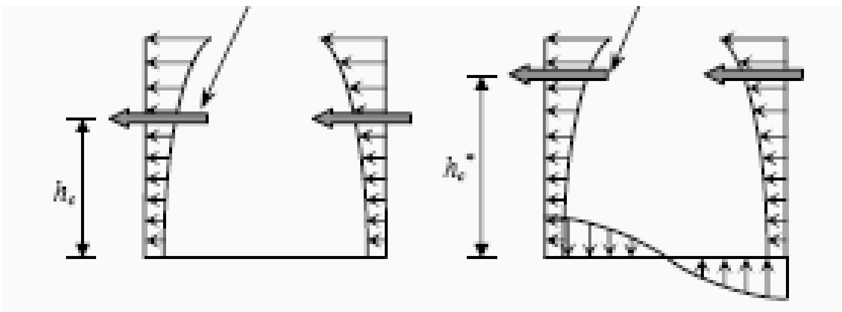
As shown in Fig.3.2, direction of hydrodynamic pressure is opposite to the direction of the earthquake. The hydrodynamic pressure distribution on tank wall and base in impulsive and convective mode is presented in Fig.3.3.

Resultant of impulsive pressure on wall — Resultant of impulsive pressure on wall and base



Impulsive pressure on wall — Impulsive pressure on wall and base

Resultant of convective pressure on wall — Resultant of convective pressure on wall and base



Convective pressure on wall — Convective pressure on wall and base

Fig.3.3 Hydrodynamic pressure distribution on tank wall and base

Where,

h_i = height at which the resultant of impulsive hydrodynamic pressure on wall is located from the bottom of tank wall.

h_i*= height at which the resultant of impulsive pressure on wall and base is located from the bottom of tank wall.

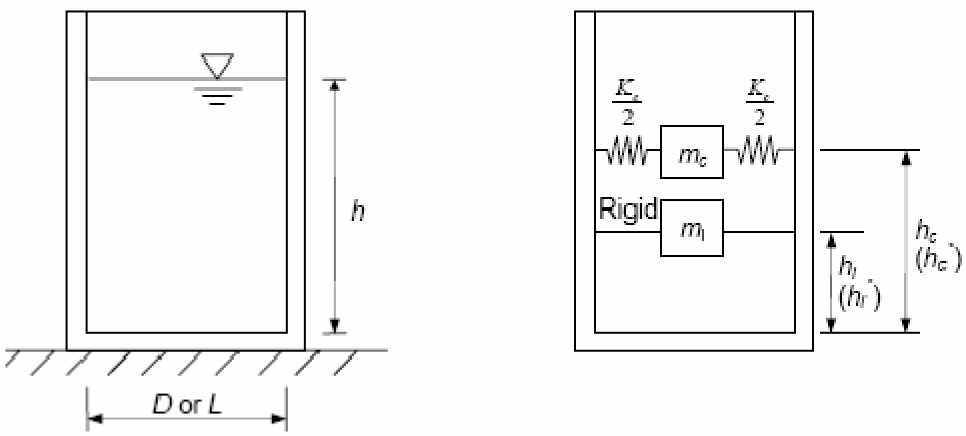
h_c = height at which the resultant of convective hydrodynamic pressure on wall is located from the bottom of tank wall.

h_c*= height at which the resultant of convective pressure on wall and base is located from the bottom of tank wall.

Tanks resting on ground can be idealized as spring mass model as shown in Fig.3.4, where m_i is rigidly attached impulsive mass to the tank wall at height h_i.

Similarly convective mass m_c is attached to the tank wall at height h_c by spring with stiffness K_c.

This spring mass model for ground-supported tank is as shown Fig.3.4.



Tank Spring mass model

Fig.3.4.Springs mass model for ground supported tank

3.3 EXPRESSION FOR SPRING MASS MODEL

Expression for various parameters of spring mass model is given in ACI-350.3(2001). Same expressions are considered in IS 1893 (part II) draft code.

3.3.1 Circular tank

Various expressions for parameters of spring mass model for circular water tank are given in Eq.3.1 to 3.9.

Impulsive mass (m_i) $$\frac{m_i}{m} = \frac{\tanh 0.866(D/h)}{0.866(D/h)} \quad \text{. . . (3.1)}$$

Height of resultant of impulsive mass (h_i) $$h_i / h = 0.375 \quad \text{. . . (3.2)}$$

for , h/D <= 0.75

$$\frac{h_i}{h} = 0.5 - \frac{0.09375}{h/D} \qquad \text{. . . (3.3)}$$

for h/D > 0.75

Height of resultant of impulsive mass (h_i*), (When pressure effect is considered on wall and base slab)

$$\frac{h_i*}{h} = \frac{0.866(D/h)}{2*\tanh 0.866(D/h)} - 0.125 \qquad \text{. . . (3.4)}$$

for, h/D <= 1.33

$$\frac{h_i*}{h} = 0.45 \qquad \text{. . . (3.5)}$$

for, h/D > 0.75

Convective mass (m_c)

$$\frac{m_c}{m} = 0.23 \frac{\tanh 3.68(h/D)}{h/D} \qquad \text{. . . (3.6)}$$

Height of resultant of convective mass (h_c)

$$\frac{h_c}{h} = 1 - \frac{\cosh(3.68h/d) - 1}{(3.68h/D)\sinh(3.68h/D)} \qquad \text{. . . (3.7)}$$

Height of resultant of convective mass (h_c*), (When pressure effect is considered on wall and base slab)

$$\frac{h_c*}{h} = 1 - \frac{\cosh(3.68h/d) - 2.01}{(3.68h/D)\sinh(3.68h/D)} \qquad \text{. . . (3.8)}$$

Stiffness of spring for convective mass,

$$k_c = 0.836 \frac{mg}{h} \tan^2(3.68h/D) \qquad \text{. . . (3.9)}$$

These parameters are presented in graphical form in Fig.3.5 and 3.6.

As per Fig.3.5, for any height to diameter ratio, value of impulsive and convective mass and convective spring stiffness can be obtained.

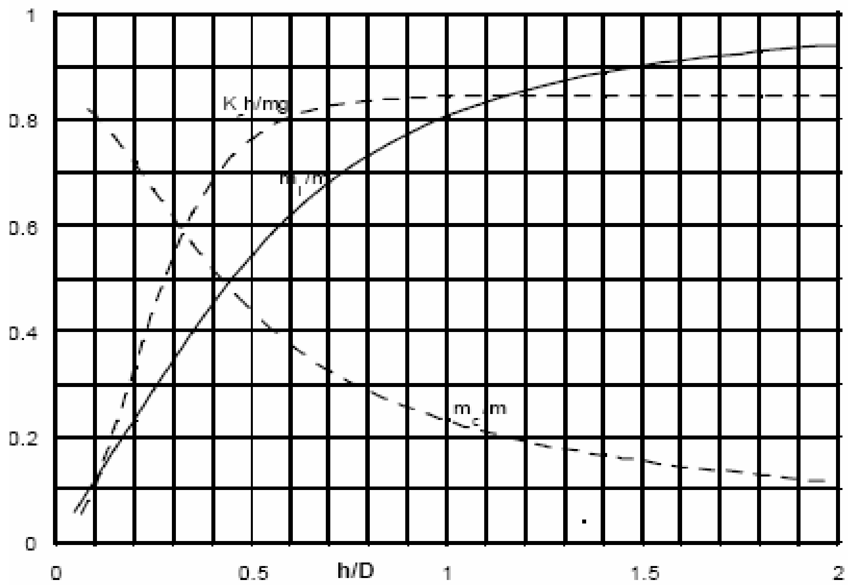


Fig. 3.5 Impulsive and convective mass and convective spring stiffness

For any height to diameter ratio height of resultant of impulsive and convective masses can be obtained from Fig 3.6.

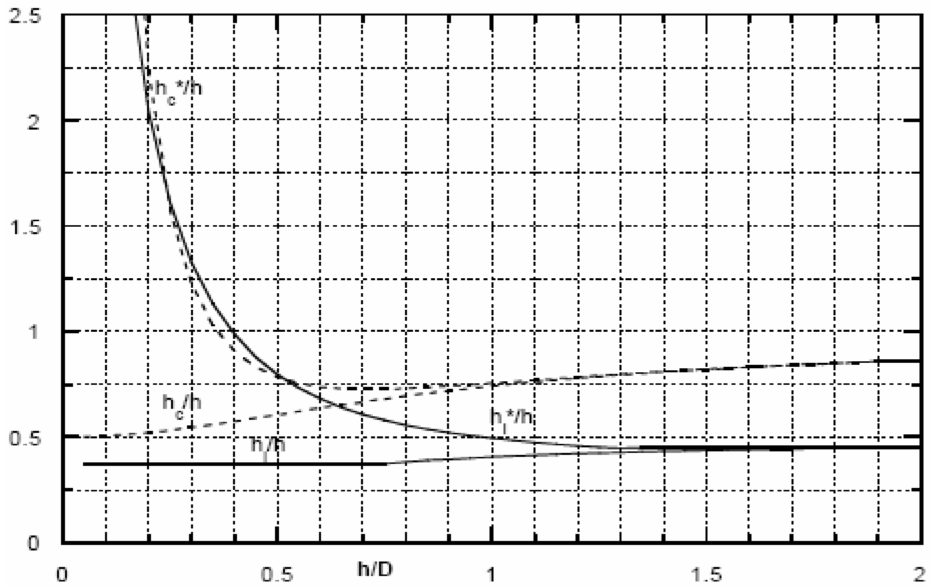


Fig 3.6 Heights of resultant of impulsive and convective masses

3.3.2 Rectangular tank

Various expressions of parameters of spring mass model for rectangular tank are given by Eq.3.10 to 3.18.

Impulsive mass (m_i) $$\frac{m_i}{m} = \frac{\tanh 0.866(L/h)}{0.866(L/h)} \quad ...(3.10)$$

Height of resultant

of impulsive mass (h_i) $$h_i / h = 0.375 \quad ...(3.11)$$

for, h/L <= 0.75

$$\frac{h_i}{h} = 0.5 - \frac{0.09375}{h/L} \quad ...(3.12)$$

for, h/L > 0.75

Height of resultant of impulsive mass (h_i*), (When pressure effect is considered on wall and base slab)

$$\frac{h_i*}{h} = \frac{0.866(L/h)}{2*\tanh 0.866(L/h)} - 0.125 \quad ...(3.13)$$

for h/L <= 1.33

$$\frac{h_i*}{h} = 0.45 \quad ...(3.14)$$

for h/L > 0.75

Convective mass (m_c) $$\frac{m_c}{m} = 0.264\frac{\tanh(3.16h/L)}{h/L} \quad ...(3.15)$$

Height of resultant of

convective mass (h_c) $$\frac{h_c}{h} = 1 - \frac{\cosh(3.16h/L) - 1}{(3.16h/L)\sinh(3.16h/L)} \quad ...(3.16)$$

Height of resultant of convective mass (h_c*), (When pressure effect is considered on wall and base slab)

$$\frac{h_c*}{h} = 1 - \frac{\cosh(3.16h/L) - 2.01}{(3.16h/L)\sinh(3.68h/L)} \quad ...(3.17)$$

Stiffness of spring for

convective mass, $$k_c = 0.833*\frac{mg}{h}\tan^2(3.16h/L) \quad ...(3.18)$$

As per indicated Fig 3.7, from any height to length ratio, value of impulsive and convective mass and convective spring stiffness can be obtained.

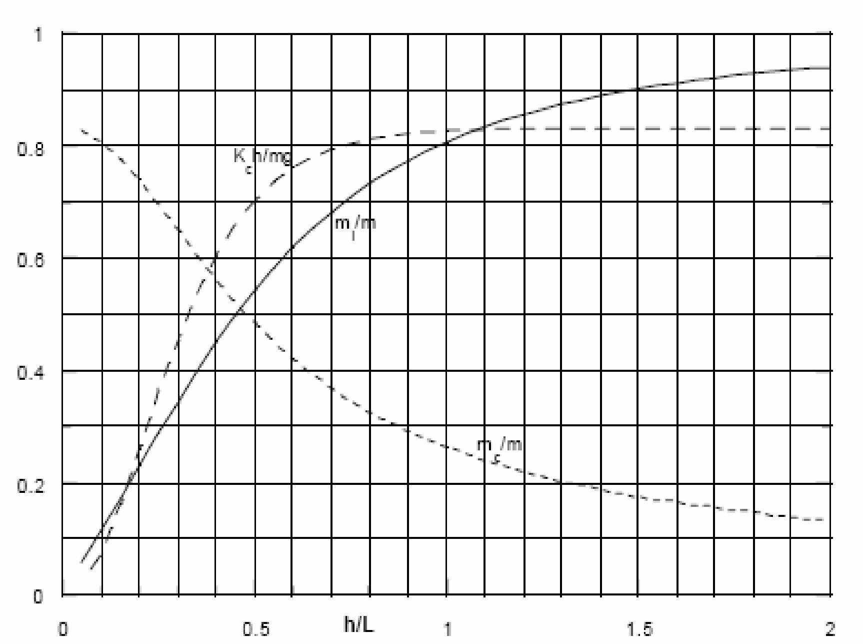


Fig.3.7 Impulsive and convective mass and convective spring stiffness

For any height to length ratio height of resultant pressure of impulsive and convective masses can be obtained from Fig 3.8.

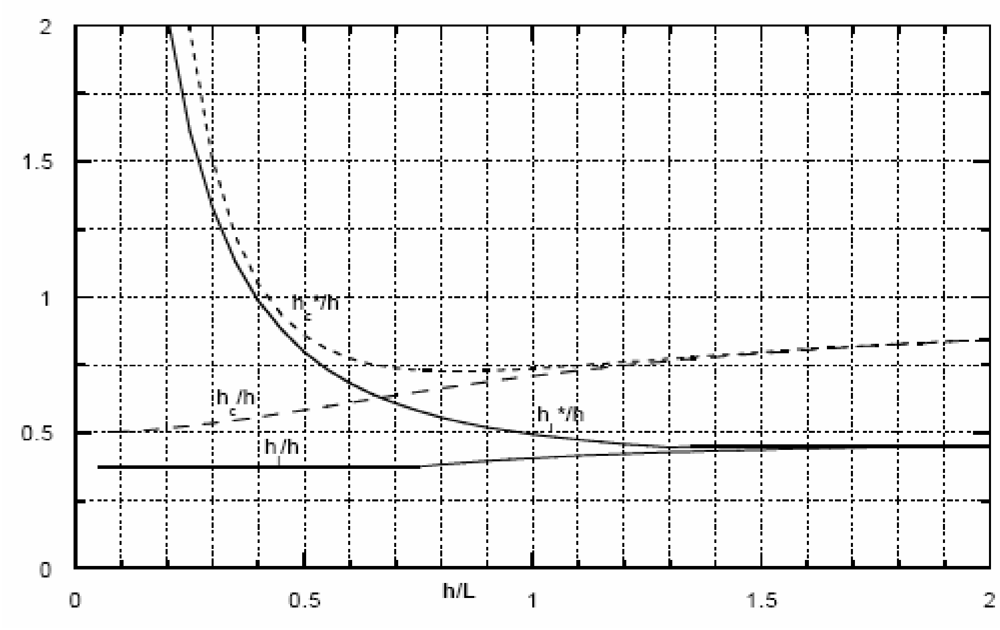


Fig 3.8 Heights of impulsive and convective masses

3.4 PARAMETERS OF SEISMIC ANALYSIS OF TANK

IS: 1893 (1984) is code for seismic analysis. Seismic analysis of liquid retaining structure is presently carried out as per clauses given in this code. But this code has very limited provision for seismic analysis of ground supported tank, which not sufficient. In draft code provisions for such type of tanks are included.

3.4.1 Design Horizontal Seismic Coefficient

Design horizontal seismic coefficient, A_h shall be obtained by the following expression.

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right) \qquad ...(3.19)$$

Where,

Z = Zone factor given in Table 2 of IS 1893 (Part I): 2002,

I = Importance factor

R = Response reduction factor

S_a/g = Average response acceleration coefficient as given in table 3 of IS 1893(Part I): 2002

3.4.1.1 Zone Factor (Z)

For different earthquake zone, zone factor is taken as per table given in IS 1893 (part I) :2002, clause 6.4.2

Table.3.1 Zone factor as per IS:1893 (part I)

Seismic zone	2	3	4	5
Seismic intensity	Low	moderate	sever	very sever
Zone factor (z)	0.10	0.16	0.24	0.36

3.4.1.2 Importance Factor (I)

Importance factor (I), is meant to ensure a better seismic performance of important and critical tanks. Its value depends on functional need, consequences of failure, and post earthquake utility of the tank.

Table.3.2 Value of importance factor (I) as per IS:1893 (part II).

Type of liquid storage tank	I
Tanks used for storing drinking water, non-volatile material, low inflammable petrochemicals etc. and intended for emergency services such as fire fighting services. Tanks of post earthquake importance.	1.5
All other tanks with no risk to life and with negligible consequences to environment, society and economy.	1.0

3.4.1.3 Response reduction factor (R)

Response reduction factor (*R*), represents ratio of maximum seismic force on a structure during specified ground motion if it were to remain elastic to the design seismic force. Thus, actual seismic forces are reduced by a factor *R* to obtain design forces. This reduction depends on over strength, redundancy, and ductility of structure.

An exhaustive review of response reduction factors used in various international codes is presented. In Table given below

Table.3.3 Value of response reduction factor (R) as per IS:1893 (part II).

Ground supported tank	*R*
Masonry tank a) Masonry wall reinforced with horizontal bands* b) Masonry wall reinforced with horizontal bands and vertical bars at corners and jambs of openings	 1.3 1.5
RC / prestressed tank a) Fixed or hinged/pinned base tank b) Anchored flexible base tank c) Unanchored contained or uncontained tank	 2.0 2.5 1.5
Steel tank a) Unanchored base b) Anchored base	 2.0 2.5
Underground RC and steel tank[+]	4.0

* These tanks are not allowed in seismic zone 4 and 5.

+ For partially buried tanks, values of *R* can be interpolated between ground supported and underground tanks based on depth of embedment.

3.4.1.4 Average Response Acceleration Coefficient (S_a/g)

Average response acceleration coefficient is obtained as per description given below.

For hard soil sites

S_a/g = 2.5 for $T < 0.4$

= $1.0/T$ for $T \geq 0.4$

For medium soil sites

S_a/g = 2.5 for $T < 0.55$

= $1.36/T$ for $T \geq 0.55$

For soft soil sites

S_a/g = 2.5 for $T < 0.67$

= $1.67/T$ for $T \geq 0.67$

3.4.1.5 Damping

Damping in the convective mode for all types of liquids and for all types of tanks shall be taken as 0.5% of the critical. Damping in the impulsive mode shall be taken as 2% of the critical for steel tanks and 5% of the critical for concrete or masonry tanks.

Damping factor is taken as per table 3 given in IS 1893(part I): 2002. Multiplying factors for 0% and 2% damping and value for 0.5% damping is not given. Value of multiplying factor for 0.5% damping shall be taken as 1.75.

3.5 SUMMARY

General information regarding seismic analysis of ground supported water tank is included in this chapter. Spring mass model of water tank is explained. Distribution of hydrostatic and hydrodynamic pressure is explained with sketches. Equations and their graphical form of parameters of spring mass model are also included. Importance factor and response reduction factor as per IS:3370 (part IV) are presented in tabulated form.

4. SEISMIC ANALYSIS OF CIRCULAR TANK

4.1 GENERAL

This chapter includes seismic analysis of ground supported circular tank based on IS:1893 (part II) draft code. In the seismic analysis time period, base shear, moment on wall, overturning moment etc. are calculated for circular tank. This chapter also includes parametric study for seismic analysis of various capacity circular tanks with different height to diameter ratio.

4.2 TIME PERIOD CALCULATION OF GROUND SUPPORTED CIRCULAR WATER TANK

There are two different equations for calculation of time period in impulsive and convective mode.

4.2.1 Time Period for Impulsive Mode

For a ground supported circular tank, wherein wall is rigidly connected with the base slab time period of impulsive mode of vibration T_i , in seconds, is given by

$$T_i = C_i \frac{h\sqrt{\rho}}{\sqrt{t/D}\sqrt{E}} \qquad \text{. . . (4.1)}$$

Where,

C_i = Coefficient of time period for impulsive mode. Value of C_i can be obtained from Eq. 4.2

h = Maximum depth of liquid,

D = Inner diameter of circular tank,

t = Thickness of tank wall,

E = Modulus of elasticity of tank wall, and

ρ = Mass density of liquid.

$$C_i = \left(\frac{1}{\sqrt{h/d}\,(0.46 - 0.3(h/D) + 0.067(h/D)^2} \right) \qquad \text{. . . (4.2)}$$

This equation for calculation of time period for impulsive mode is taken from Eurocode 8 (1998). This expression was developed for roofless steel tank fixed at base and filled with water. However, it may also be used for tank of other materials and fluids. Further, it may be mentioned that this expression is derived based on the assumption that tank mass is quite small compared to mass of fluid. This condition is usually satisfied by most of the tanks. In case of tanks with variable wall thickness (particularly, steel tanks with step variation of thickness), thickness of tank wall at 1/3rd height from the base should be used in the expression for impulsive time period.

4.2.2 Time Period in Convective Mode

Time period of convective mode, in seconds, is given by

$$T_c = 2\pi\sqrt{\frac{m_c}{K_c}} \qquad \text{. . . (4.3)}$$

The values of m_c and K_c can be obtained from Fig.3.5 or equation given for spring mass model for circular tank.

Other equation for calculation of time period for circular tank is,

$$T_c = C_c\sqrt{\frac{D}{g}} \qquad \text{. . . (4.4)}$$

Where,

C_c = Coefficient of time period for convective mode.

$$C_c = \frac{2\pi}{\sqrt{3.68\tanh(3.68h/D)}} \qquad \text{. . . (4.5)}$$

D = Inner diameter of tank.

Both Eq. 4.3 and Eq. 4.4 for calculation of time period are mathematically same. The expressions for convective mode time period of circular tank are taken from ACI 350.3 (2001).

Coefficients of time period C_i and C_c also obtained by shown in Fig.4.1.

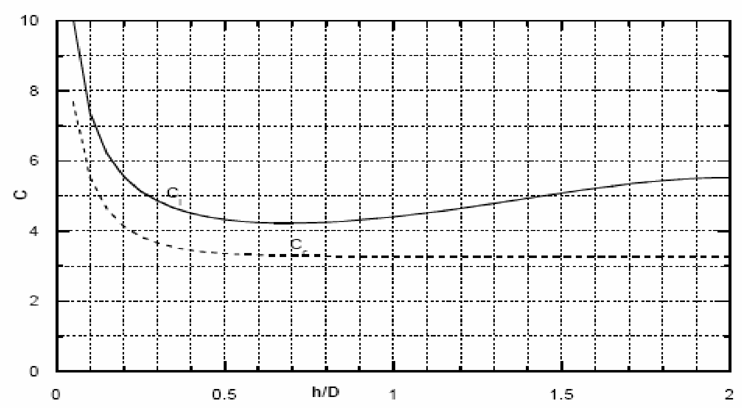


Fig. 4.1 Coefficient of impulsive (C_i) and convective (C_c) mode

4.3 BASE SHEAR CALCULATION

Value of base shear is different for both modes. Base shear in impulsive mode V_i and convective mode V_c are calculated by Eq.4.6 and 4.7.

$$V_i = (A_h)_i \, (m_i + m_w + m_t) \, g \qquad . . . (4.6)$$

$$V_c = (A_h)_c \, m_c \, g \qquad . . . (4.7)$$

Where,

$(A_h)_i$ = Design horizontal seismic coefficient for impulsive mode,

$(A_h)_c$ = Design horizontal seismic coefficient for convective mode,

m_i = Impulsive mass of water

m_w = Mass of tank wall

m_t = Mass of roof slab, and

g = Acceleration due to gravity.

Live load on roof is generally neglected for seismic load computations. However, in some ground-supported tanks, roof slab may be used as storage space. In such cases, suitable percentage of live load should be added in the mass of roof slab, m_t.

For ground-supported tanks, to obtain base shear at the bottom of base slab/plate, shear due to mass of base slab/plate shall be included. If the base shear at the bottom of tank wall is V then, base shear at the bottom of base slab, V', will be given by

$$V' = V + (A_h)_i \, m_b \qquad . . . (4.8)$$

Where, m_b is mass of base slab/plate.

Total base shear *V*, can be obtained by combining the base shear in impulsive and convective mode through square root of sum of squares (SRSS) rule and is given as follows

$$V = \sqrt{V_i^2 + V_c^2} \qquad . . . (4.9)$$

4.4 MOMENT CALCULATION AT BASE OF WALL

Bending moment in impulsive mode, at the bottom of wall is given by,

$$M_i = (A_h)_i \, (m_i \, h_i + m_w \, h_w + m_t \, h_t) g \qquad . . . (4.10)$$

and bending moment in convective mode is given by,

$$M_c = (A_h)_c \, m_c \, h_c \, g \qquad . . . (4.11)$$

Where,

h_w = Height of center of gravity of wall mass,

h_t = Height of center of gravity of roof mass.

4.4.1 Moment at Intermediate Height of Wall.

Sometimes it may be of interest to obtain bending moment at the intermediate height of tank wall. The bending moment at height, *y* from bottom will depend only on hydrodynamic pressure and wall mass above that height. Bending moment at any height *y* from the bottom of wall will be for impulsive and convective mode respectively given by,

$$M_i = (A_h)_i[m_i h_i \mu_i + m_w h_w (1 - y/h)^2/2 + m_t h_t (1 - y/h)]g \quad ...(4.12)$$

$$M_c = (A_h)_c m_c h_c \mu_c g \quad ...(4.13)$$

h_w = Height of center of gravity of wall mass, and

h_t = Height of center of gravity of roof mass.

y = Intermediate height on tank wall

Value of μ_i and μ_c can be obtained figure given below.

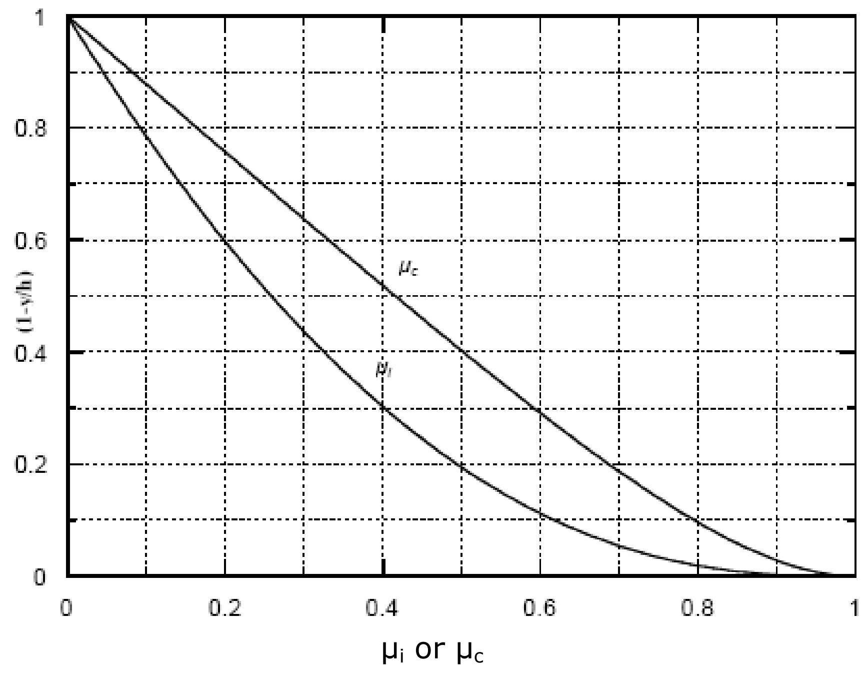


Fig.4.2 Variation of impulsive and convective bending moment coefficients

4.5 OVERTURNING MOMENT

Moment acting at base of water tank due to sloshing of stored liquid and self-weight of tank component during the earthquake is known as overturning moment. For obtaining overturning moment at the base of tank, hydrodynamic pressure on tank wall as well as tank base is considered. Hence, m_i and m_c are considered to be located at h_i *, and h_c*, which are described in Fig.3.3.

4.5.1 Overturning Moment in Impulsive Mode

Overturning moment in impulsive mode to be used for checking the tank stability at the bottom of base slab/plate is given by,

$$M_i{}^* = (A_h)_i\,[m_i\,(h_i^* + t_b) + m_w\,(h_w + t_b) + m_t(h_t + t_b) + (m_b t_b/2)]g \qquad . . . (4.14)$$

Where,

m_b = mass of base slab/plate, and

t_b = thickness of base slab/plate.

4.5.2 Overturning Moment in Convective Mode

Overturning moment in convective mode to be used for at the bottom of base slab/plate is given by,

$$M_c{}^* = (A_h)_c\, m_c\,(h_c{}^* + t_b)g \qquad . . . (4.15)$$

4.5.3 Total moment

Total moment shall be obtained by combining the moment in impulsive and convective modes through Square of Sum of Squares (SRSS) and is given below

Total moment at base of wall is

$$M = \sqrt{M_i^2 + M_c^2} \qquad . . . (4.16)$$

Total overturning moment at base of tank is

$$M^* = \sqrt{M_i^{*2} + M_c^{*2}} \qquad . . . (4.17)$$

4.6 HYDRODYNAMIC PRESSURE

When earthquake comes at that time structure subjected to lateral excitation. During lateral base excitation, tank wall is subjected to lateral hydrodynamic pressure and tank base is subjected to hydrodynamic pressure in vertical direction (as shown in Fig.3.3).

4.6.1 Impulsive Hydrodynamic Pressure for Circular Tank

Lateral hydrodynamic impulsive pressure on the wall, p_{iw} , is given by,

$$p_{iw} = Q_{iw}\,(y)(A_h)_i\,\rho g\,h\,cos\varphi \qquad . . . (4.18)$$

$$Q_{iw}(y) = 0.866\left[1-\left(\frac{y}{h}\right)^2\right]\tanh\left(0.866\frac{D}{h}\right) \qquad . . . (4.19)$$

Where,

ρ = Mass density of liquid,

φ = Circumferential angle, and

y = Vertical distance of a point on tank wall from the bottom of tank wall.

Q_{iw} can also obtained by Fig 4.4.

Impulsive hydrodynamic pressure in vertical direction, on base slab (y = 0) on a strip of length l', is given by,

$$p_{ib} = 0.866\left(A_h\right)_i \rho g h \frac{\sinh\left(0.866\frac{x}{h}\right)}{\cosh\left(0.866\frac{l'}{h}\right)} \qquad . . . (4.20)$$

Where,

l' = Length of strip.

x = Horizontal distance of a point on base of tank in the direction of seismic force, from the center of tank.

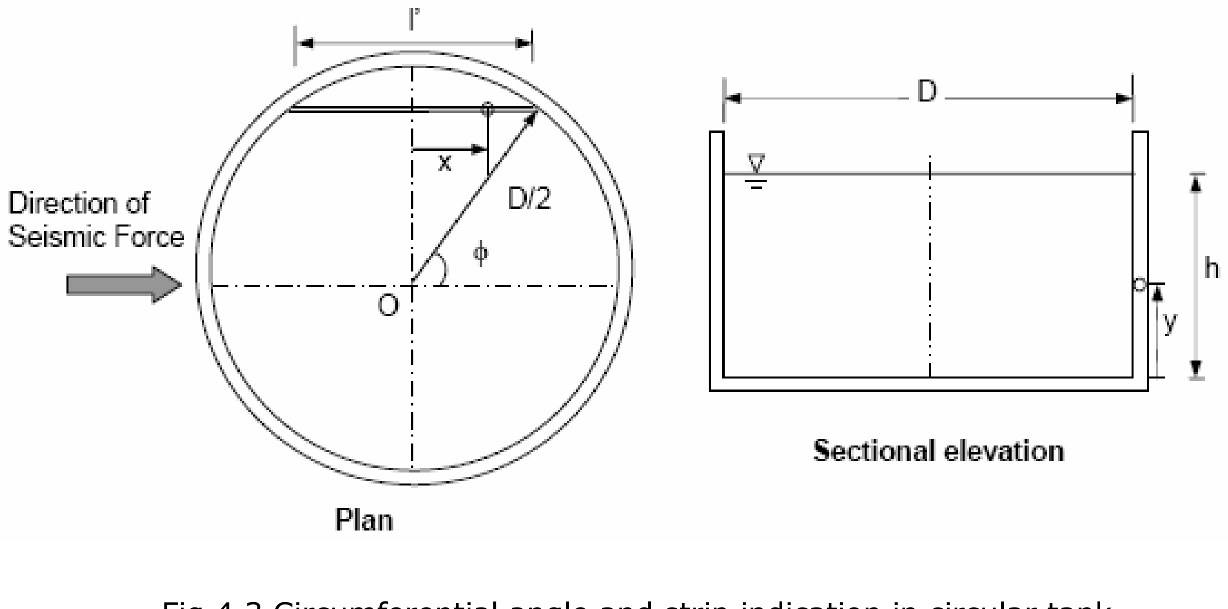


Fig.4.3 Circumferential angle and strip indication in circular tank

Impulsive pressure coefficient for Q_{iw} can be obtained from Fig.4.4

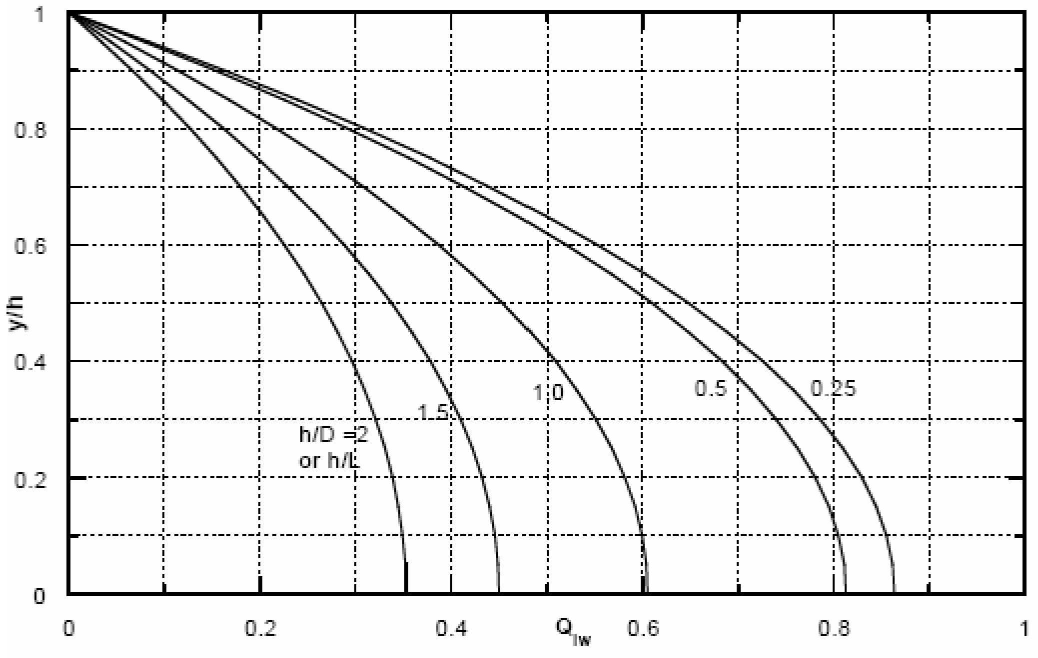


Fig.4.4 Impulsive pressure coefficient Q_{iw} for circular tank

4.6.2 Convective Hydrodynamic Pressure for Circular Tank

The convective pressure exerted by the oscillating liquid on the circular tank wall and base slab can be calculated as follows.

Lateral convective pressure on the wall P_{cw} is given by,

$$p_{cw} = Q_{cw}(y)(A_h)_c \rho g D\left[1-\frac{1}{3}\cos^2\phi\right]\cos\phi \qquad ...(4.21)$$

$$Q_{cw}(y) = 0.5625\frac{\cosh\left(3.674\frac{y}{D}\right)}{\cosh\left(3.674\frac{h}{D}\right)} \qquad ...(4.22)$$

Convective pressure in vertical direction, on the base slab (y = 0) is given by,

$$p_{cb} = Q_{cb}(x)(A_h)_c \rho g D \qquad ...(4.23)$$

Where ,

$$Q_{cb}(x) = 1.125\left[\frac{x}{D}-\frac{4}{3}\left(\frac{x}{D}\right)^3\right]\sec h\left(3.674\frac{h}{D}\right) \qquad ...(4.24)$$

$Q_{cw}(y)$ and $Q_{cb}(x)$ may also find from Fig.4.5 and Fig 4.6

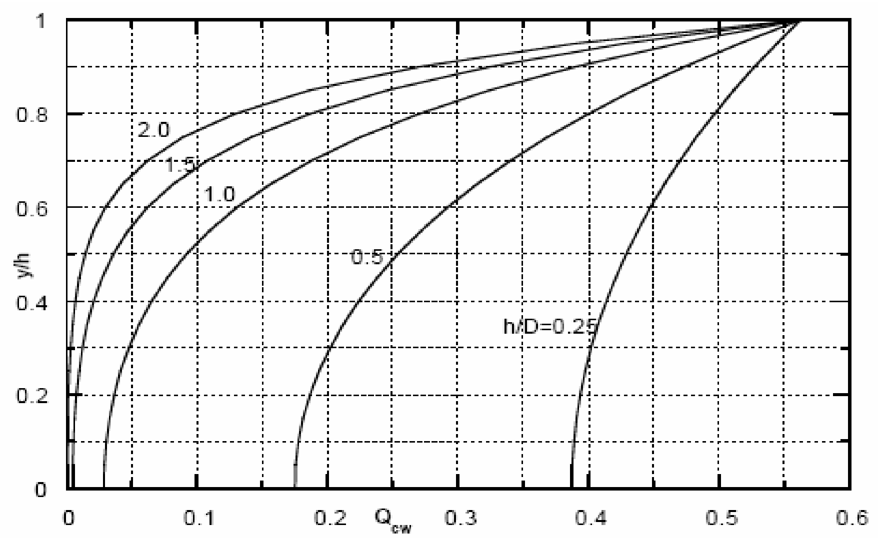


Fig 4.5 Convective pressure coefficient for circular tank on wall Q_{cw}

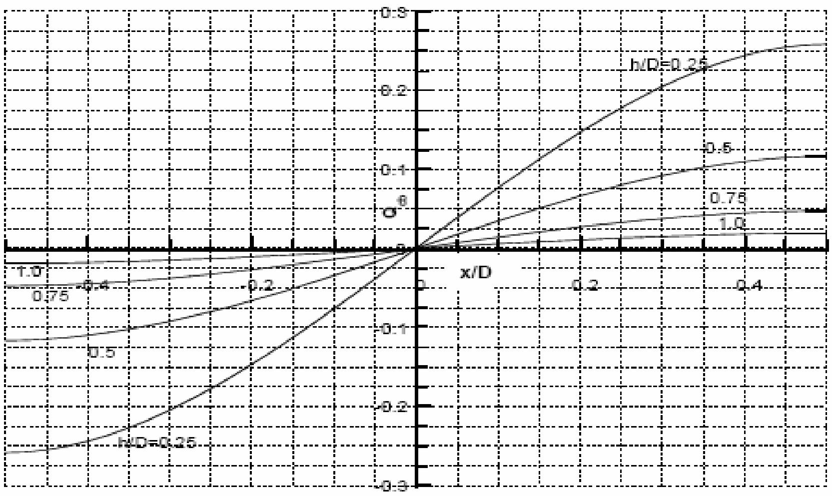


Fig.4.6 Convective pressure coefficient (Q_{cb}) for circular tank on base

Hydrodynamic pressure due to horizontal excitation has curvilinear variation along wall height. However, in the absence of more exact analysis, an equivalent linear pressure distribution may be assumed so as to give the same base shear and bending moment at the bottom of tank wall.

For circular tanks, maximum hydrodynamic force per unit circumferential length at $\varphi = 0$, for impulsive and convective mode, is given by Eq.4.25 and 4.26.

$$q_i = \frac{(A_h)_i m_i}{\pi D/2} g \qquad \text{. . . (4.25)}$$

$$q_C = \frac{(A_h)_c m_c}{\pi D/2} g \qquad \text{. . . (4.26)}$$

4.6.3 Equivalent Linear Pressure Distribution

Equivalent linear pressure distribution for impulsive and convective modes, shown in Figure 4.7

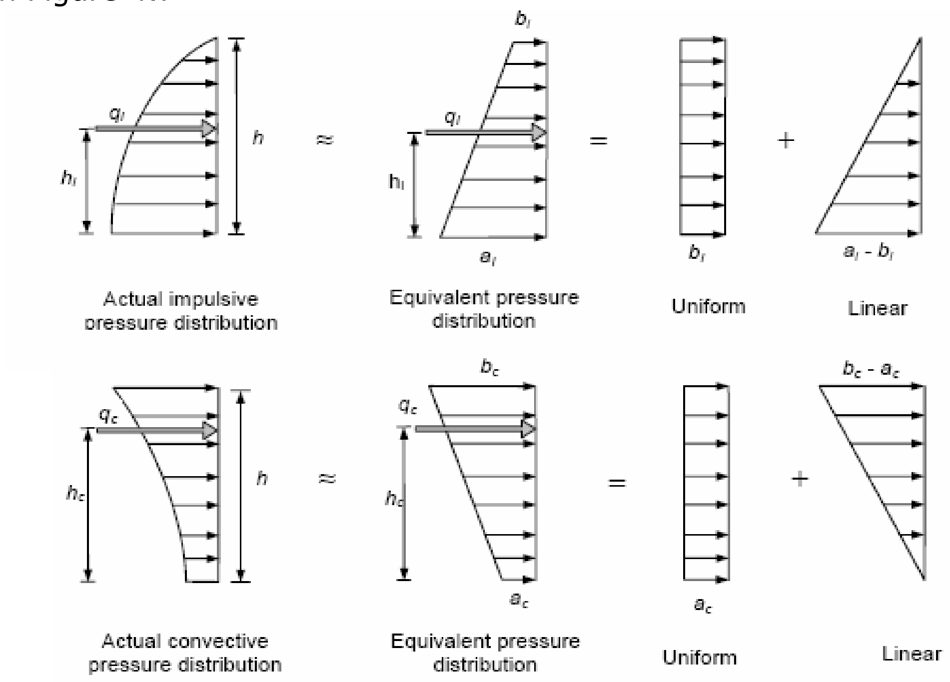


Fig. 4.7 Equivalent linear distribution along wall height

Value of pressure at bottom and at top of tank wall for impulsive pressure can be obtained by Eq.4.27 and Eq.4.28.

$$a_i = \frac{q_i}{h^2}(4h - 6h_i) \qquad \text{. . . (4.27)}$$

$$b_i = \frac{q_i}{h^2}(6h_i - 4h) \qquad \text{. . . (4.28)}$$

Value of pressure at bottom and at top of tank wall for impulsive and convective pressure can be obtained by Eq.4.29 and Eq.4.30.

$$a_c = \frac{q_c}{h^2}\left(4h - 6h_c\right) \qquad \text{. . . (4.29)}$$

$$b_c = \frac{q_c}{h^2}\left(6h - 2h_c\right) \qquad \text{. . . (4.30)}$$

4.6.4 Pressure Due To Wall Inertia

Pressure on tank wall due to its inertia is given by

$$p_{ww} = \left(A_h\right)_i t \rho_m g \qquad \text{. . . (4.31)}$$

Where,

ρ_m = Mass density of tank wall, and

t = Wall thickness.

Pressure due to wall inertia will act in the same direction as that of seismic force. For concrete tanks, wall inertia may be substantial. Pressure due to wall inertia, which is constant along the wall height for walls of uniform thickness, should be added to impulsive hydrodynamic pressure.

4.6.5 Effect of Vertical Ground Acceleration

Due to vertical ground acceleration, effective weight of liquid increases, this induces additional pressure on tank wall, whose distribution is similar to that of hydrostatic pressure.

Hydrodynamic pressure on tank wall due to vertical ground acceleration may be taken as,

$$P_v = (A_v)\rho\ g\ h\ (1 - y/d) \qquad \text{. . . (4.32)}$$

$$A_v = (2/3)(z/2)(I/R)(Sa/g) \qquad \text{. . . (4.33)}$$

Where,

y = vertical distance of point under consideration from bottom of tank wall, and

Sa/g = Average response acceleration coefficient

In absence of more refined analysis, time period of vertical mode of vibration for all types of tank may be taken as 0.3 sec.

4.6.6 Total Hydrodynamic Pressure

The maximum value of hydrodynamic pressure should be obtained by combining pressure due to horizontal and vertical excitation through square root of sum of square (SRSS) rule, which can be given as,

$$p = \sqrt{\left(p_{iw} + p_{ww}\right)^2 + p_{cw}^2 + p_v^2} \qquad . . . (4.34)$$

4.7 SLOSHING WAVE HEIGHT FOR CIRCULAR TANK

Maximum sloshing wave height is given by,

$$d_{\max} = \left(A_h\right)_c R \frac{D}{2} \qquad . . . (4.35)$$

Where, R is response reduction factor, D is diameter of tank.

Free board to be provided in a tank may be based on maximum value of sloshing wave height. If sufficient free board is not provided roof structure should be designed to resist the uplift pressure due to sloshing of liquid. Moreover, if there is obstruction to free movement of convective mass due to insufficient free board, the amount of liquid in convective mode will also get changed.

4.8 ANCHORAGE REQUIREMENT FOR CIRCULAR WATER TANK

Circular ground supported tanks shall be anchored to their foundation when,

$$\frac{h}{D} > \frac{1}{\left(A_h\right)_i}$$

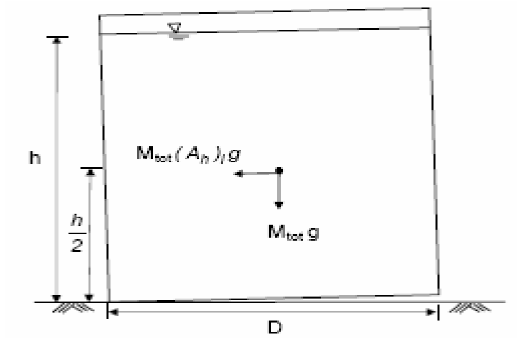


Fig. 4.8 Initiation of rocking of tank

Consider a tank, which is about to rock (Fig.4.8). M_{tot} denotes the total mass of the tank-liquid system, D denote the tank diameter, and $(A_h)_i$ is the peak response acceleration. Taking moments about the edge,

$$M_{tot}\left(A_h\right)_i g \frac{h}{2} = M_{tot}\, g \frac{D}{2}$$

$$\frac{h}{D} > \frac{1}{\left(A_h\right)_i}$$

Thus, when h/D exceeds the value $1/(A_h)_i$ indicated above, the tank should be anchored to its foundation. The derivation assumes that the entire liquid responds in the impulsive mode. This approximation is reasonable for tanks with high h/D ratios that are susceptible to overturning.

4.9 PROGRAM FOR CIRCULAR TANK

For seismic analysis of circular water tank computer program is developed in C++ language. By use of above described equations this program is developed. The flow chart of program is shown in Fig. 4.9. One example is presented here, which is solved using computer program. Detailed calculation on seismic analysis of circular tank is included in chapter 6.

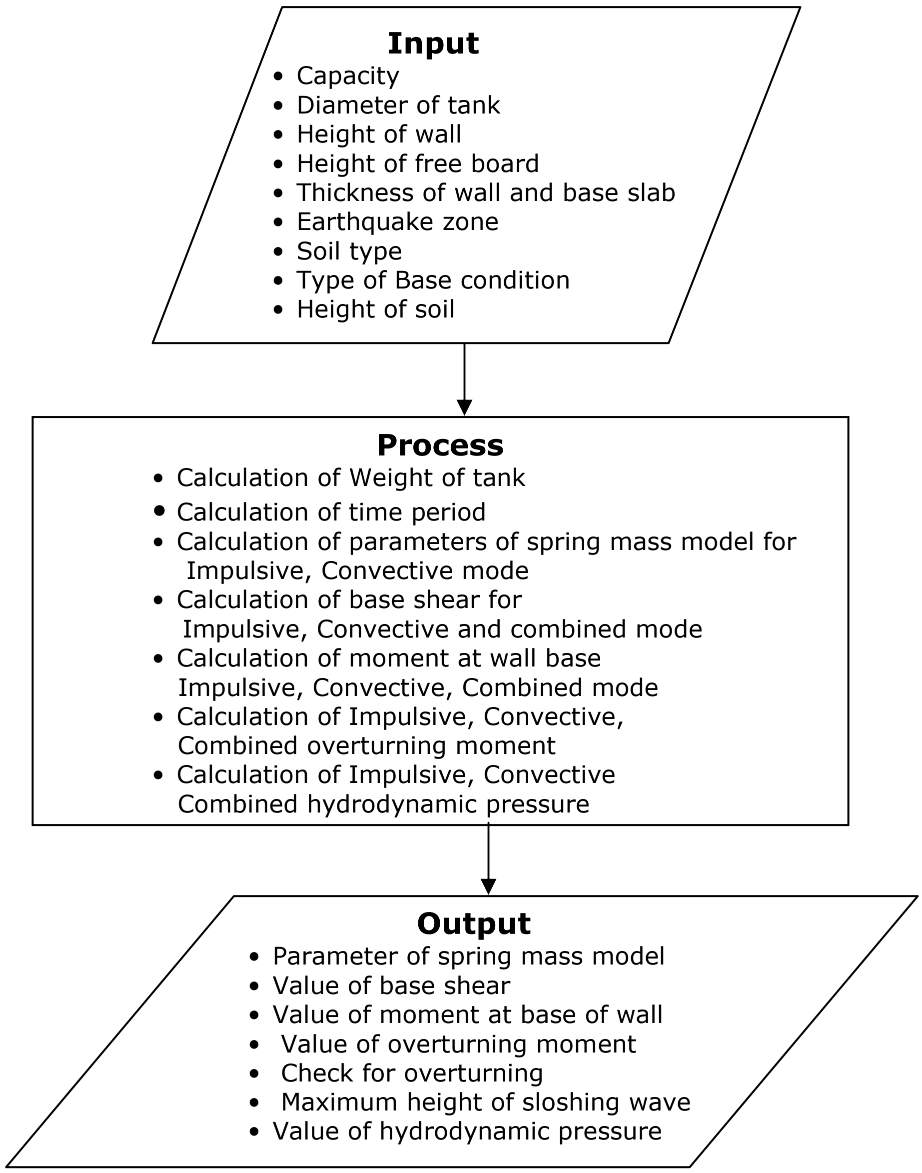


Fig 4.9 Flow chart of program

4.10 EXAMPLE

A ground supported cylindrical RC water tank without roof has capacity of 800 m^3. Inside diameter of tank is 13.65 m and height is 6 m (including a free board of 0.5 m). Tank wall has uniform thickness of 250 mm and base slab is 350 mm thick. Grade of concrete is M30. Tank is located on soft soil in seismic zone IV. Density of concrete is 25 kN/m^3. Analyze the tank for seismic loads.

Input data required for execution of program and its output is given below.

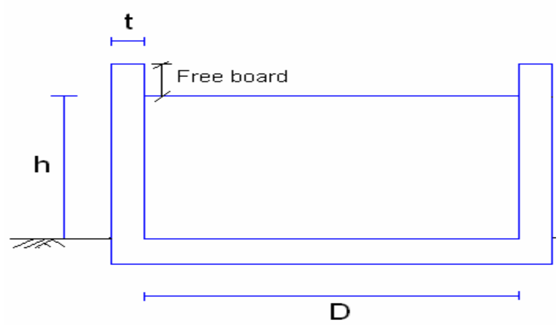


Fig 4.10 Ground supported circular tank

Input

This program for seismic analysis of ground supported circular water tank

1 : Tank without roof

2 : Tank with roof (flat slab)

3 : Tank with roof (dome)

1

Enter capacity of tank in liters	: 800000
Enter inside dia of tank in meter	: 13.65
Thickness of base slab in meter	: 0.35
Height of liquid in water tank above base slab	: 5.5
Enter height of free board in meter	: 0.5
Enter wall thickness in meter	: 0.250
Grade of concrete-M-	: 30
Enter zone	: 4

Select case for importance factor

1 :Tanks used for storing drinking water, non volatile material, low inflammable petrochemicals etc and intended for emergency services such as firefighting services ,tanks of post earthquake importance

2: All other tanks with no risk to life and with negligible consequences to environment, society and economy

1

Select case for response reduction factor

1 :Fixed or hinged/pinned base tank

2 :Anchored flexible base tank

3 :Unanchored contained or uncontained tank

1

Enter height of tank below ground level	: 0

Type of soil

1 : Hard soil

2 : Medium soil

3 : Soft soil

3

Output

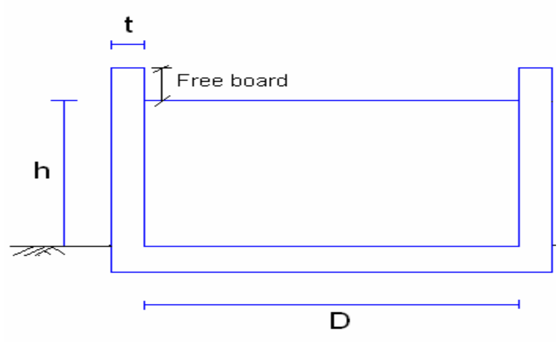
Weight of tank wall	: 1638.21 kN
Mass of tank wall	: 166994 kg
Mass of base slab	: 140319 kg
Mass of water	: 800000 kg
m_i/m	: 0.45
$m_i=$	: 362242 kg
m_c/m	: 0.52
$m_c=$	: 411897kg
h_i/h =	: 0.38
h_i =	: 2.06 meter
h_c/h =	: 0.58
h_c =	: 3.16 meter
h_i*/h =	: 0.98
h_i* =	: 5.39 meter
h_c*/h =	: 0.90
h_c* =	: 4.96 meter
Time period for impulsive	: 0.04 sec
Time period for convective	: 4.07 sec
Design seismic coefficient for impulsive mass	: 0.23

Design seismic coefficient for convective mass	: 0.06
Base shear for impulsive mode	: 1168.16 kN
Base shear for convective mode	: 261.15 kN
Total base shear at bottom of wall	: 1196.99 kN
Bending moment at bottom of wall in impulsive mode	: 2754.88 kN.m
Bending moment at bottom of wall in convective mode	: 826.08 kN.m
Total bending moment at bottom of wall	: 2876.07 kN.m
Overturning moment at the bottom of Base slab in impulsive mode	: 5875.1 kN.m
Overturning moment at the bottom of base slab in convective mode	: 1385.8 kN.m
Total overturning moment at bottom of base slab	: 6036.33 kN.m
Maximum sloshing wave height	: 0.88 meter
Sloshing wave height exceeding free board	
Anchorage is not required	
Impulsive hydrodynamic presser at base of wall	: 10.23 kN/m^2
Impulsive hydrodynamic pressure on base slab	: 8.32 kN/m^2
Convective hydro dynamic pressure at base of wall	: 1.41 kN/m^2
Convective pressure on wall y = h	: 3.26 kN/m^2
Convective pressure on top of base slab	: 1.58 kN/m^2
Base shear due to impulsive liquid mass per unit circumferential length	: 37.28 kN/m
Pressure at bottom and top is given by	: 11.86 kN/m^2
	: 1.69 kN/m^2
Base shear due to convective liquid mass per unit circumferential length	: 12.17 kN/m
Pressure at bottom and top is given by	: 1.22 kN/m^2
	: 3.21 kN/m^2
Pressure on wall due to inertia	: 1.41 kN/m^2
Pressure on wall base due to inertia	: 8.09 kN/m^2
Maximum hydro dynamic pressure at base of wall	: 14.25 kN/m^2

4.11 COMPARATIVE STUDY OF ANALYSIS RESULTS FOR VARIOUS CAPACITY WATER TANKS.

To study the effect of dimensions of circular tank on seismic analysis a parametric study is carried out.

In this parametric study results of seismic analysis for different capacity circular tank are presented. 8,00,000 liter to 12,00,000 liter capacity tanks are considered with different h/D ratio from 0.1 to 1.0. The dimension of tank with varying h/D ratio is shown in Table 4.1.



Earthquake Zone	= 4
Soil type	= Soft soil
Thickness of wall	=250 mm
Thickness of base slab	=400 mm
Free board	= 0.5 m

Fig.4.11 Ground supported tank with considered data for comparative study

Table.4.1 Considered capacity and its height and diameter of circular tank

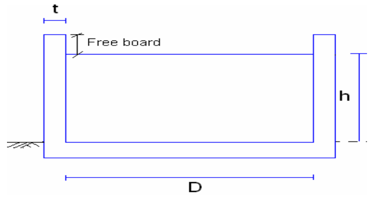
Capacity	8,00,000 lit		9,00,000 lit		10,00,000 lit		11,00,000 lit		12,00,000 lit	
h/D	h (m)	D(m)	h (m)	D(m)	h (m)	D(m)	h (m)	D(m)	h (m)	D(m)
0.1	2.16	21.68	2.25	22.54	2.33	23.35	2.41	24.1	2.48	24.81
0.2	3.44	17.2	3.57	17.89	3.7	18.53	3.82	19.13	3.94	19.69
0.3	4.51	15.03	4.69	15.63	4.85	16.19	5.01	16.71	5.16	17.2
0.4	5.46	13.65	5.68	14.2	5.88	14.71	6.07	15.18	6.25	15.63
0.5	6.33	12.67	6.59	13.18	6.82	13.65	7.04	14.09	7.25	14.51
0.6	7.15	11.93	7.44	12.4	7.71	12.85	7.96	13.26	8.19	13.65
0.7	7.93	11.33	8.25	11.78	8.54	12.2	8.82	12.6	9.08	12.97
0.8	8.67	10.84	9.02	11.27	9.34	11.67	9.64	12.05	9.92	12.4
0.9	9.38	10.42	9.75	10.84	10.1	11.22	10.43	11.59	10.73	11.93
1	10.06	10.06	10.46	10.46	10.84	10.84	11.19	11.19	11.52	11.52

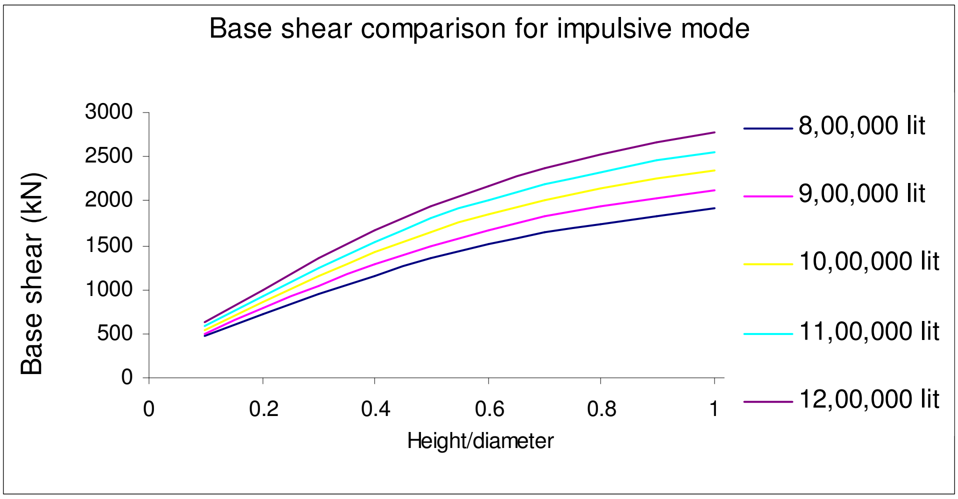
4.11.1 Base shear

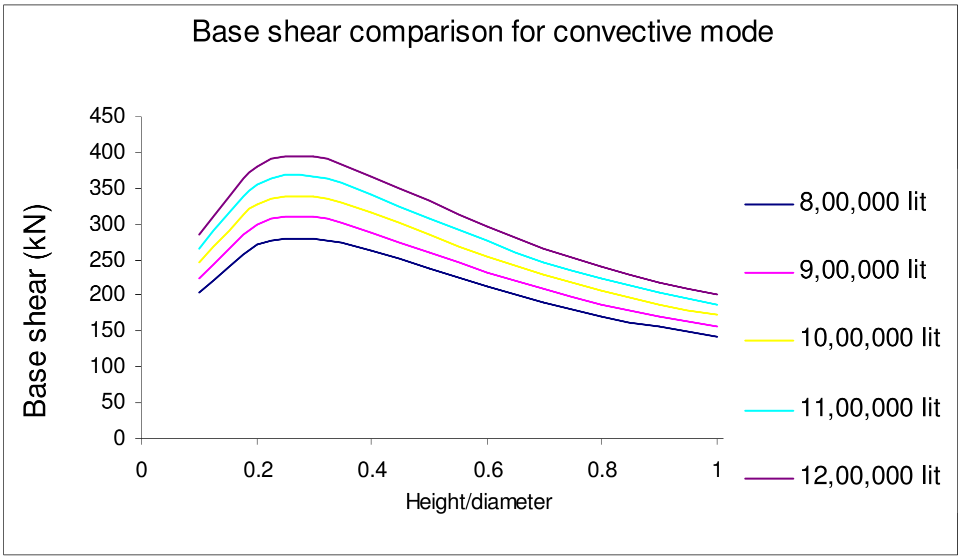
Base shear for various capacity tank is as shown in Table.4.2, and presented graphically as shown in Fig.4.11.

Table 4.2 Results of base shear in kN

h/D	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
Impulsive mode					
0.1	462.51	506.98	550.69	593.74	636.22
0.2	711.79	785.81	858.92	931.26	1002.91
0.3	946.29	1048.29	1149.28	1249.41	1348.77
0.4	1160.96	1288.65	1415.25	1540.92	1665.76
0.5	1348.44	1498.56	1647.53	1795.49	1942.58
0.6	1506.51	1675.50	1843.26	2009.96	2175.73
0.7	1637.34	1821.85	2005.09	2187.21	2368.36
0.8	1744.98	1942.19	2138.06	2332.78	2526.49
0.9	1833.74	2041.33	2247.55	2452.56	2656.52
1	1907.45	2123.60	2338.31	2551.79	2764.18
Convective mode					
0.1	203.76	224.77	245.40	265.68	285.66
0.2	271.40	299.39	326.86	353.88	380.49
0.3	280.19	309.09	337.45	365.35	392.82
0.4	262.10	289.13	315.67	341.76	367.46
0.5	236.32	260.70	284.62	308.15	331.32
0.6	211.18	232.96	254.34	275.36	296.07
0.7	189.26	208.78	227.94	246.78	265.34
0.8	170.87	188.49	205.79	222.80	239.56
0.9	155.57	171.61	187.36	202.85	218.10
1	142.79	157.51	171.97	186.18	200.19
Total base shear					
0.1	505.40	554.57	602.89	650.47	697.41
0.2	761.78	840.91	919.01	996.23	1072.67
0.3	986.90	1092.91	1197.80	1301.73	1404.81
0.4	1190.18	1320.69	1450.03	1578.36	1705.81
0.5	1368.99	1521.07	1671.93	1821.74	1970.63
0.6	1521.24	1691.61	1860.72	2028.73	2195.78
0.7	1648.24	1833.78	2018.00	2201.09	2383.18
0.8	1753.32	1951.31	2147.94	2343.40	2537.82
0.9	1840.33	2048.53	2255.34	2460.93	2665.46
1	1912.79	2129.43	2344.63	2558.57	2771.42







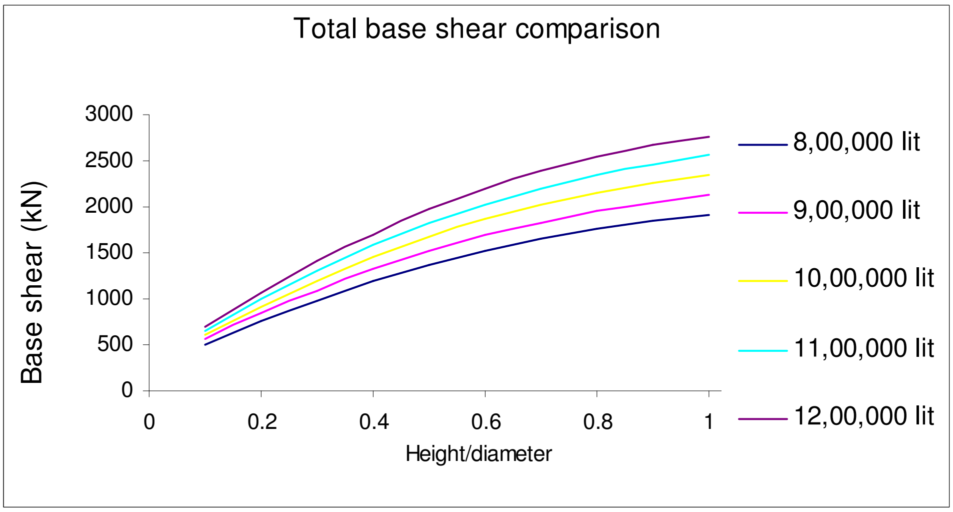


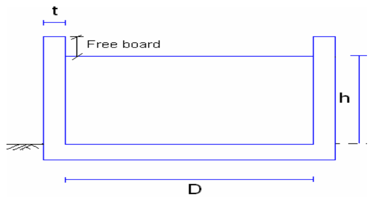
Fig.4.12 Base shear comparison

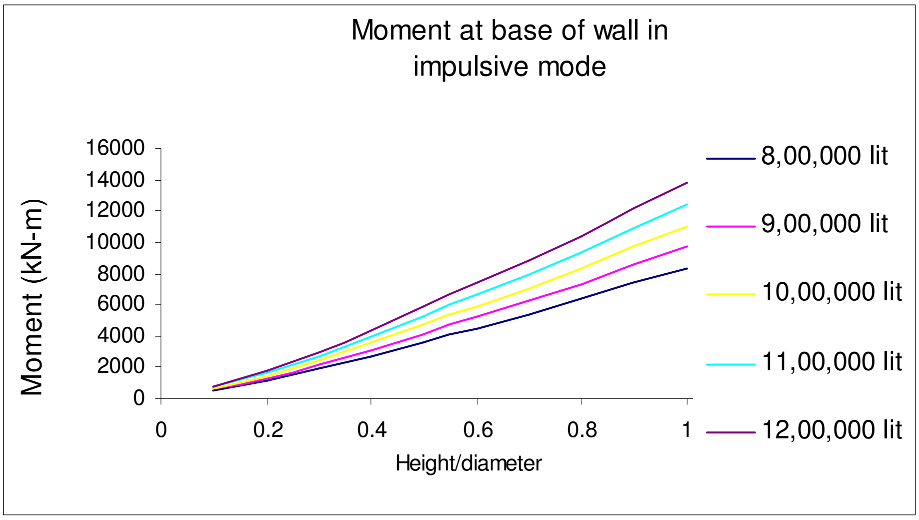
4.11.2 Moment at Base of Wall

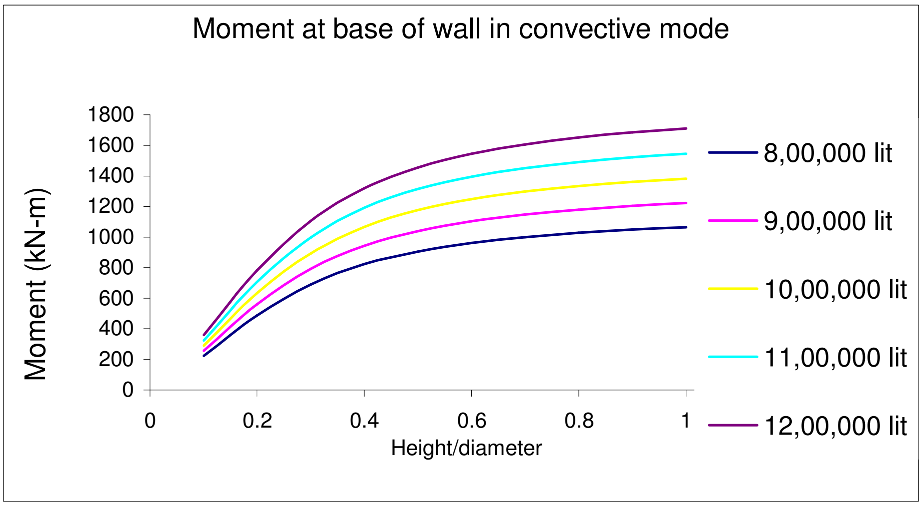
Moment at bottom of wall for various capacity tank is shown in Table 4.3 and its presented graphically as shown in Fig.4.12.

Table 4.3 Results of moment at base of wall in kN-m

h/D	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
Impulsive mode					
0.1	510.77	576.33	642.61	709.57	777.20
0.2	1125.50	1282.95	1443.34	1606.50	1772.28
0.3	1875.68	2148.54	2427.51	2712.18	3002.25
0.4	2720.41	3125.00	3539.49	3963.23	4395.68
0.5	3613.05	4157.67	4716.30	5288.02	5872.06
0.6	4516.37	5202.93	5907.68	6629.45	7367.21
0.7	5407.40	6233.86	7082.65	7952.30	8841.55
0.8	6362.38	7339.67	8343.83	9373.08	10425.90
0.9	7380.98	8519.96	9690.76	10891.30	12119.70
1	8372.70	9668.82	11001.50	12368.40	13767.40
Convective mode					
0.1	223.34	256.24	289.75	323.83	358.43
0.2	487.02	558.76	631.84	706.15	781.60
0.3	689.01	790.50	893.89	999.03	1105.77
0.4	822.25	943.37	1066.76	1192.23	1319.61
0.5	907.13	1040.75	1176.87	1315.29	1455.82
0.6	962.71	1104.52	1248.99	1395.89	1545.03
0.7	1001.06	1148.52	1298.74	1451.48	1606.57
0.8	1028.84	1180.39	1334.78	1491.77	1651.16
0.9	1049.70	1204.32	1361.84	1522.01	1684.63
1	1065.66	1222.63	1382.54	1545.15	1710.24
Total moment at base of wall					
0.1	557.46	630.73	704.91	779.97	855.87
0.2	1226.35	1399.35	1575.58	1754.85	1936.98
0.3	1998.23	2289.35	2586.86	2890.33	3199.41
0.4	2841.96	3264.29	3696.75	4138.67	4589.49
0.5	3725.19	4285.95	4860.91	5449.14	6049.83
0.6	4617.84	5318.87	6038.27	6774.81	7527.47
0.7	5499.28	6338.78	7200.74	8083.68	8986.32
0.8	6445.03	7433.98	8449.92	9491.05	10555.90
0.9	7455.25	8604.66	9785.98	10997.10	12236.20
1	8440.24	9745.81	11088.10	12464.60	13873.30







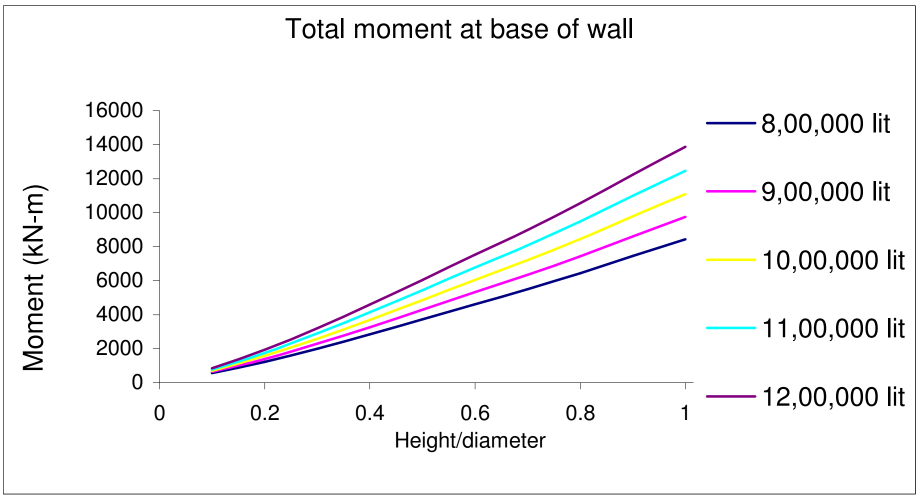


Fig. 4.13 Moment comparison at base of wall

4.11.3 Overturning Moment at Bottom of Base slab

Moment at bottom of wall for various capacity tank is shown in Table 4.4 and its presented graphically as shown in Fig.4.13.

Table.4.4 Results of overturning moment in kN-m

h/D	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
Impulsive mode					
0.1	2562.87	2948.03	3343.95	3749.99	4165.59
0.2	3858.17	4451.43	5061.97	5688.68	6330.62
0.3	4950.40	5714.77	6501.37	7308.76	8135.72
0.4	5909.11	6821.57	7760.33	8723.69	9710.18
0.5	6775.55	7820.65	8895.58	9998.39	11127.40
0.6	7577.60	8744.82	9945.04	11176.10	12436.20
0.7	8334.18	9616.21	10934.20	12285.80	13669.00
0.8	9057.82	10449.50	11879.90	13346.50	14847.10
0.9	9756.80	11254.20	12793.00	14370.60	15984.50
1	10436.60	12036.80	13680.90	15366.30	17090.20
Convective mode					
0.1	3526.29	4042.12	4567.30	5101.05	5642.71
0.2	2189.28	2506.97	2830.19	3158.49	3491.48
0.3	1662.28	1902.19	2146.16	2393.86	2645.01
0.4	1403.05	1605.09	1810.52	2019.05	2230.45
0.5	1269.62	1452.47	1638.37	1827.09	2018.40
0.6	1201.07	1374.26	1550.37	1729.16	1910.42
0.7	1166.86	1335.40	1506.80	1680.83	1857.30
0.8	1150.88	1317.38	1486.75	1658.73	1833.14
0.9	1144.40	1310.23	1478.92	1650.24	1823.99
1	1142.68	1308.47	1477.16	1648.49	1822.26
Total overturning moment					
0.1	4359.25	5002.96	5660.59	6331.12	7013.72
0.2	4436.03	5108.83	5799.44	6506.70	7229.61
0.3	5222.03	6023.03	6846.45	7690.81	8554.88
0.4	6073.39	7007.86	7968.73	8954.29	9963.05
0.5	6893.48	7954.39	9045.20	10164.00	11309.00
0.6	7672.20	8852.15	10065.20	11309.10	12582.10
0.7	8415.46	9708.49	11037.50	12400.20	13794.60
0.8	9130.64	10532.20	11972.50	13449.20	14959.90
0.9	9823.69	11330.20	12878.20	14465.00	16088.20
1	10499.00	12107.70	13760.50	15454.40	17187.10

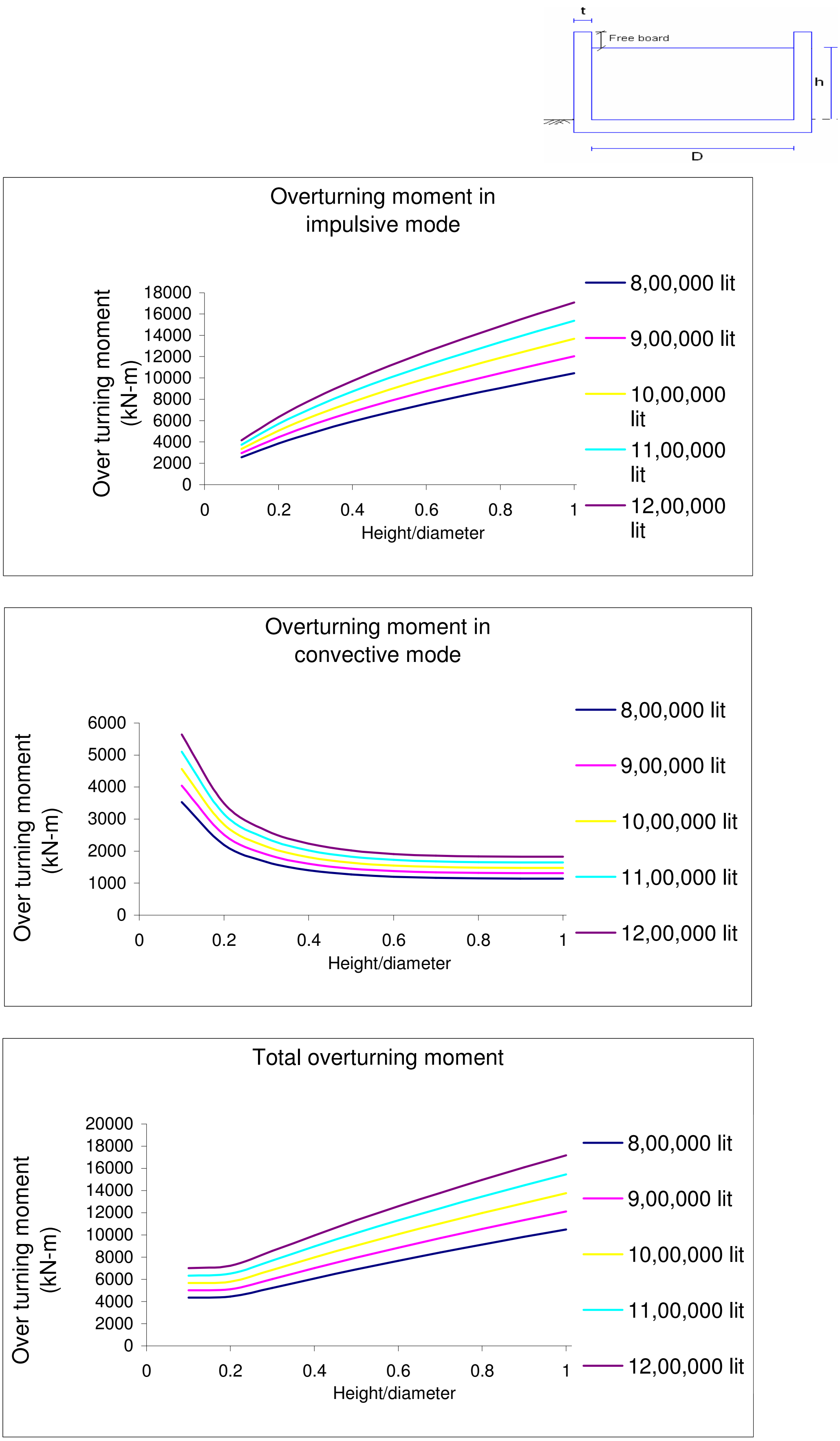


Fig. 4.14. Overturning moment comparison at base of wall

4.11.4 Hydrodynamic Pressure

Total hydrodynamic pressure for circular tank of capacity is given in Table.4.5. Results are presented graphically as shown in Fig.4.14.

Tab.4.5. Results of total hydrodynamic pressure in kN/m^2

h/D	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
0.1	6.84	7.05	7.25	7.43	7.60
0.2	9.75	10.08	10.39	10.68	10.95
0.3	12.13	12.57	12.97	13.35	13.70
0.4	14.17	14.69	15.17	15.62	16.04
0.5	15.86	16.45	17.00	17.51	17.99
0.6	17.25	17.90	18.50	19.06	19.59
0.7	18.40	19.09	19.74	20.34	20.91
0.8	19.37	20.10	20.79	21.42	22.02
0.9	20.22	20.99	21.70	22.37	22.99
1	20.98	21.78	22.52	23.22	23.87

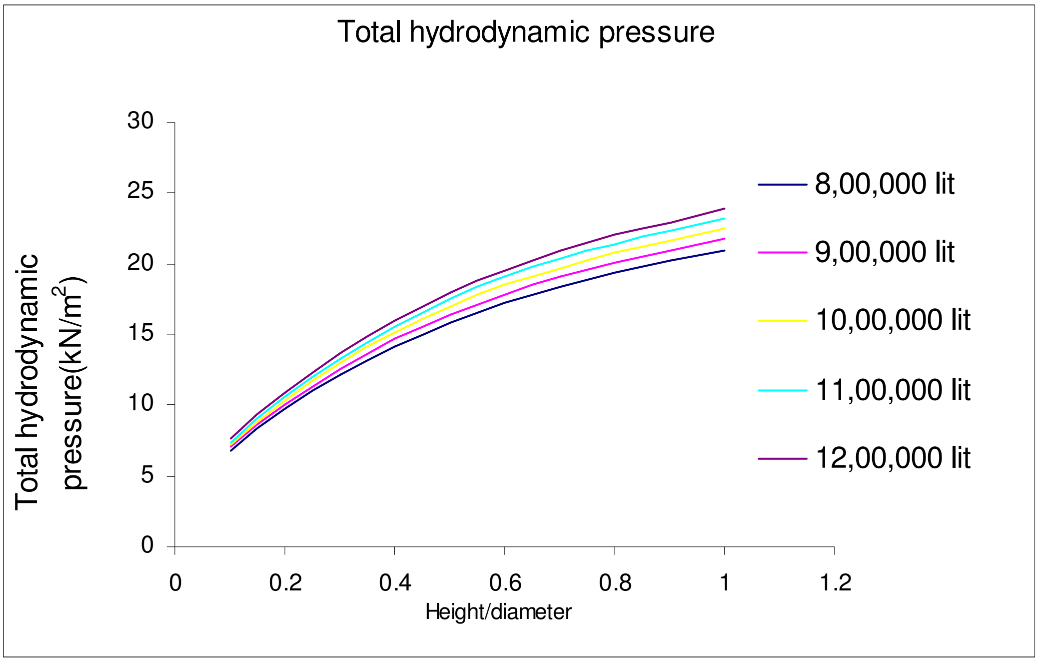


Fig.4.15 Hydrodynamic pressure comparison

4.12 COMPARISON OF HYDROSTATIC PRESSURE AND HYDRODYNAMIC PRESSURE

Comparison of hydrostatic and hydrodynamic pressure for circular tank in earthquake zone IV is shown in Table 4.6. Hydrodynamic pressure as % of hydrostatic pressure for various capacity and height to diameter ratio is shown in

Table.4.6. Its graphical presentation is as Shown in Fig.4.15. Horizontal line indicates hydrodynamic pressure 33% of hydrostatic pressure.

Table 4.6 Comparison of hydrostatic and hydrodynamic pressure
(For earthquake zone IV)

Capacity in liters	h/D	Height (m)	Diameter (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Hydrodynamic pressure as % of Hydrostatic pressure
8,00,000	0.1	2.16	21.68	21.68	6.83	31.54
	0.2	3.44	17.20	34.41	9.74	28.32
	0.3	4.51	15.03	45.09	12.13	26.90
	0.4	5.46	13.65	54.63	14.16	25.93
	0.5	6.33	12.67	63.39	15.86	25.01
	0.6	7.15	11.93	71.58	17.25	24.09
	0.7	7.93	11.33	79.33	18.40	23.19
	0.8	8.67	10.84	86.72	19.37	22.33
	0.9	9.38	10.42	93.80	20.21	21.55
	1.0	10.06	10.06	100.63	20.97	20.84
9,00,000	0.1	2.25	22.54	22.54	7.050	31.26
	0.2	3.57	17.89	35.79	10.08	28.16
	0.3	4.69	15.63	46.90	12.56	26.79
	0.4	5.68	14.20	56.82	14.68	25.84
	0.5	6.59	13.18	65.93	16.44	24.94
	0.6	7.44	12.40	74.45	17.89	24.03
	0.7	8.25	11.78	82.51	19.09	23.14
	0.8	9.02	11.27	90.19	20.10	22.29
	0.9	9.75	10.84	97.56	20.98	21.51
	1.0	10.4	10.46	104.66	21.77	20.80
10,00,000	0.1	2.33	23.35	23.35	7.24	31.02
	0.2	3.70	18.53	37.07	10.39	28.02
	0.3	4.85	16.19	48.58	12.97	26.69
	0.4	5.88	14.71	58.85	15.16	25.77
	0.5	6.82	13.65	68.29	16.99	24.88
	0.6	7.71	12.85	77.11	18.49	23.98
	0.7	8.54	12.20	85.46	19.73	23.09
	0.8	9.34	11.67	93.41	20.78	22.25
	0.9	10.10	11.22	101.05	21.69	21.47
	1.0	10.84	10.84	108.40	22.52	20.77

Table 4.6 Cont…

11,00,000	0.1	2.41	24.10	24.10	7.42	30.81
	0.2	3.82	19.13	38.27	10.67	27.90
	0.3	5.01	16.71	50.14	13.34	26.61
	0.4	6.07	15.18	60.75	15.61	25.70
	0.5	7.04	14.09	70.49	17.50	24.83
	0.6	7.96	13.26	79.60	19.05	23.94
	0.7	8.82	12.60	88.22	20.33	23.05
	0.8	9.64	12.05	96.43	21.42	22.21
	0.9	10.43	11.59	104.31	22.36	21.44
	1.0	11.19	11.19	111.90	23.21	20.74
12,00,000	0.1	2.48	24.81	24.81	7.60	30.62
	0.2	3.94	19.69	39.39	10.95	27.79
	0.3	5.16	17.20	51.62	13.70	26.53
	0.4	6.25	15.63	62.53	16.04	25.64
	0.5	7.25	14.51	72.56	17.98	24.78
	0.6	8.19	13.65	81.94	19.58	23.90
	0.7	9.08	12.97	90.81	20.90	23.02
	0.8	9.92	12.40	99.27	22.02	22.18
	0.9	10.73	11.93	107.38	22.99	21.41
	1.0	11.52	11.52	115.19	23.87	20.72

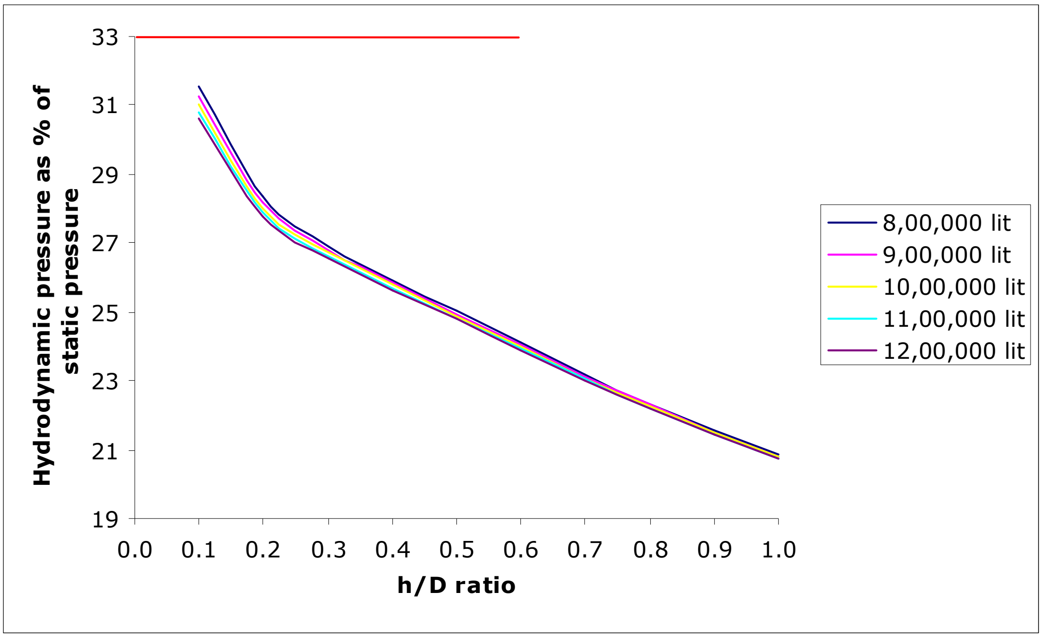


Fig.4.16 Hydrostatic and hydrodynamic pressure comparison

Comparison of hydrostatic and hydrodynamic pressure for earthquake zone V is as per Table.4.7. Its graphical presentation is as Shown in Fig.4.16.

Table 4.7 Comparison of static and dynamic pressure
(For earthquake zone V)

Capacity in liters	h/D	Height (m)	Diameter (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Hydrodynamic pressure as % of Hydrostatic pressure
8,00,000	0.1	2.16	21.68	21.68	10.25	47.30
	0.2	3.44	17.20	34.41	14.61	42.47
	0.3	4.51	15.03	45.09	18.19	40.34
	0.4	5.46	13.65	54.63	21.24	38.88
	0.5	6.33	12.67	63.39	23.78	37.51
	0.6	7.15	11.93	71.58	25.86	36.13
	0.7	7.93	11.33	79.33	27.59	34.77
	0.8	8.67	10.84	86.72	29.0	33.49
	0.9	9.38	10.42	93.80	30.31	32.31
	1.0	10.06	10.06	100.63	31.45	31.25
9,00,000	0.1	2.25	22.54	22.54	10.57	46.88
	0.2	3.57	17.89	35.79	15.11	42.23
	0.3	4.69	15.63	46.90	18.84	40.17
	0.4	5.68	14.20	56.82	22.02	38.75
	0.5	6.59	13.18	65.93	24.66	37.41
	0.6	7.44	12.40	74.45	26.83	36.04
	0.7	8.25	11.78	82.51	28.63	34.70
	0.8	9.02	11.27	90.19	30.14	33.42
	0.9	9.75	10.84	97.56	31.46	32.25
	1.0	10.46	10.46	104.66	32.65	31.20
10,00,000	0.1	2.335	23.35	23.35	10.86	46.52
	0.2	3.707	18.53	37.07	15.58	42.02
	0.3	4.85	16.19	48.58	19.44	40.03
	0.4	5.88	14.71	58.85	22.74	38.64
	0.5	6.82	13.65	68.29	25.48	37.32
	0.6	7.71	12.85	77.11	27.73	35.96
	0.7	8.54	12.20	85.46	29.59	34.63
	0.8	9.34	11.67	93.41	31.16	33.36
	0.9	10.10	11.22	101.05	32.53	32.20
	1.0	10.84	10.84	108.40	33.77	31.15

Table 4.7 Cont...

11,00,000	0.1	2.41	24.10	24.10	11.14	46.21
	0.2	3.82	19.13	38.270	16.01	41.84
	0.3	5.01	16.71	50.14	20.01	39.90
	0.4	6.07	15.18	60.75	23.41	38.54
	0.5	7.04	14.09	70.49	26.25	37.24
	0.6	7.96	13.26	79.60	28.57	35.90
	0.7	8.82	12.60	88.22	30.49	34.57
	0.8	9.64	12.05	96.43	32.12	33.31
	0.9	10.43	11.59	104.31	33.59	32.15
	1.0	11.19	11.19	111.90	34.81	31.11
12,00,000	0.1	2.48	24.81	24.81	11.39	45.93
	0.2	3.94	19.69	39.39	16.42	41.68
	0.3	5.16	17.20	51.62	20.54	39.79
	0.4	6.25	15.63	62.53	24.05	38.46
	0.5	7.25	14.51	72.56	26.97	37.17
	0.6	8.19	13.65	81.94	29.36	35.83
	0.7	9.08	12.97	90.81	31.34	34.51
	0.8	9.92	12.40	99.27	33.02	33.26
	0.9	10.73	11.93	107.38	34.48	32.11
	1.0	11.52	11.52	115.19	35.79	31.07

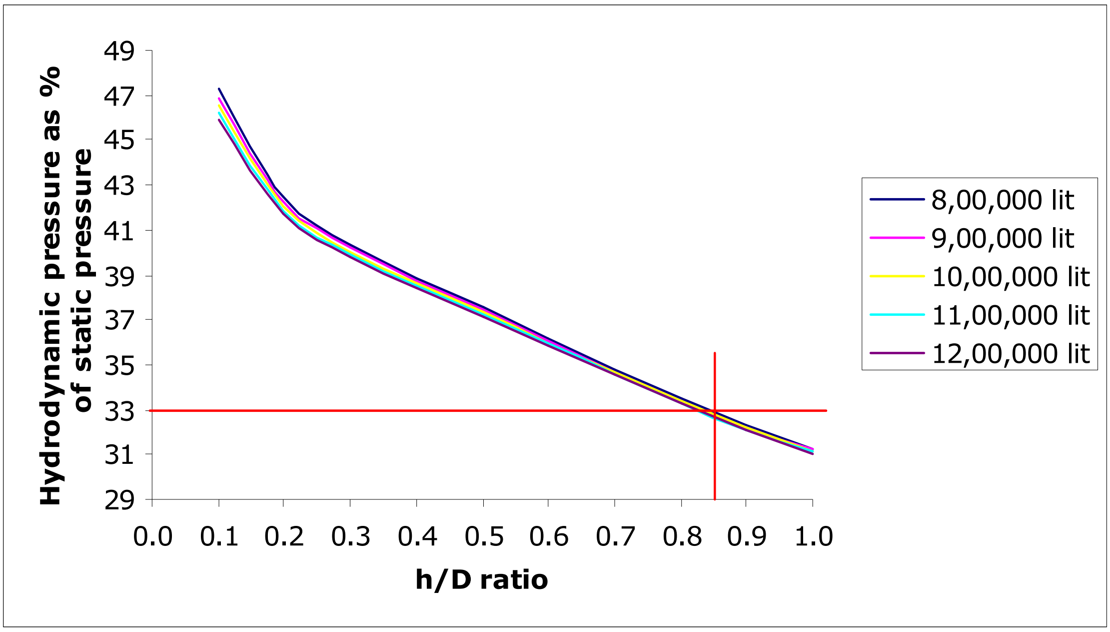


Fig.4.17 Hydrostatic and hydrodynamic pressure comparison

4.13 SUMMARY

This chapter includes detailed discussion of seismic analysis of circular tank. It includes evaluation of time period, base shear, moment at base of wall, overturning moment in two different modes impulsive and convective for circular water tank. A computer program in C++ is developed for seismic analysis of circular tank. Input and output of computer program for hydrodynamic analysis of circular tank is presented. Seismic analysis is carried out for 8,00,000 to 12,00,000 lit capacity tank and height to diameter ratio varying 0.1 to 1 in earthquake zone 4. Analysis results are presented in tabulated form as well as graphical form to understand variation in seismic response with different configuration. Comparison of hydrostatic and hydrodynamic pressure is carried out for earthquake zone 4 and earthquake zone 5. From the results it is observed that, hydrodynamic pressure is within permissible limit (i.e. less than 33% of static pressure) up to earthquake zone 4. So there is no need to consider hydrodynamic pressure in design of circular tank wall up to earthquake zone 4 for capacity considered here. But in earthquake zone 5, hydrodynamic pressure is more than permissible limit (i.e. more than 33% of static pressure) for height to diameter ratio less than 0.85. So, hydrodynamic pressure must be considered in design of circular tank wall for earthquake zone 5.

5. SEISMIC ANALYSIS OF RECTANGULAR TANK

5.1 GENERAL

This chapter gives general criteria for seismic analysis of ground supported rectangular tank based on IS: 1893 (part II) draft code. Various seismic provisions like time period, base shear, moment on wall, overturning moment etc is discussed for rectangular tank. A computer programming using C++ is developed for seismic analysis. Input and output of computer program developed for hydrodynamic analysis of rectangular tank is presented. It also included parametric study of rectangular tank for various capacities with different length to width ratio and length to height ratio.

5.2 TIME PERIOD CALCULATION FOR RECTANGULAR TANK

There are two different equations for calculation of time period in impulsive and convective mode.

5.2.1 Time period calculation for impulsive mode

For a ground supported rectangular tank, wherein wall is rigidly connected with the base slab, time period of impulsive mode of vibration, T_i in seconds, is given by, Eq.5.1.

$$T_i = 2\pi\sqrt{\frac{d}{g}} \qquad . . . (5.1)$$

Where,

d = deflection of the tank wall on the vertical center-line at a height of $\bar{h}$, when loaded by uniformly distributed pressure of intensity q,

$$q = \frac{\left(\frac{m_i}{2} + \overline{m}_w\right)g}{Bh} \qquad . . . (5.2)$$

$$\bar{h} = \frac{\frac{m_i}{2}h_i + \overline{m}_w \frac{h}{2}}{\frac{m_i}{2} + \overline{m}_w} \qquad . . . (5.3)$$

$\overline{m}_w$ = Mass of one tank wall perpendicular to the direction of seismic force,

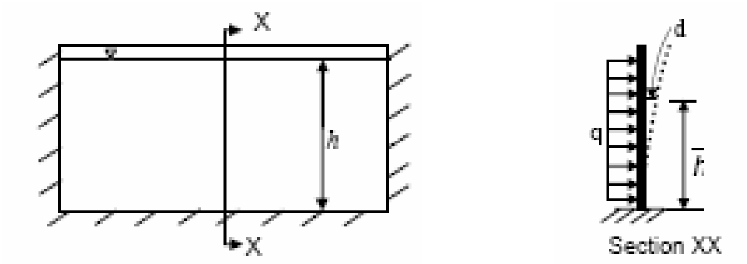
B = Inside width of tank.

$\bar{h}$ = height of combined center of gravity of half impulsive mass of liquid ($m_i/2$), and mass of one wall ($\bar{m}_w$).

For tanks without roof, deflection, d can be obtained by assuming wall to be free at top and fixed at bottom.

5.2.1.1 Deflection Calculation of Tank Wall for Tank without Cover

ACI 350.3 (2001) and NZS 3106 (1986) have suggested a simpler approach for obtaining deflection, d for tanks without roof. As per this approach, assuming that wall takes pressure q by cantilever action, one can find the deflection, d, by considering wall strip of unit width and height $\bar{h}$, which is subjected to concentrated load, $P = q\,h$



Rectangular tank wall subjected to uniformly distributed pressure

Description of strip of wall Cantile

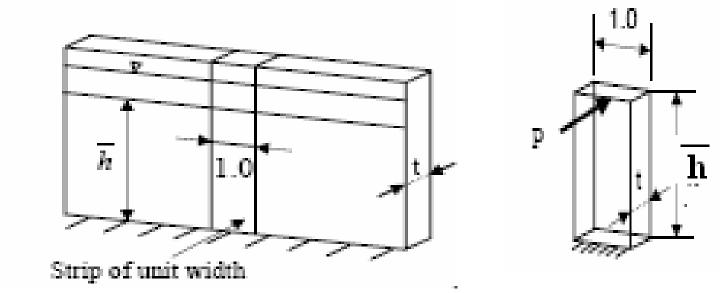


Fig.5.1. Description of deflection d of rectangular tank wall without cover

for a tank with wall of uniform thickness, one can obtain *d* as follows:

$$d = \frac{p\left(\bar{h}^3\right)}{3EI_w} \qquad . . . (5.4)$$

Where,

$$I_w = \frac{1.0 \times t^3}{12}$$

The above approach will give quite accurate results for tanks with long walls (say, length greater than twice the height).

5.2.1.2 Deflection Calculation of Tank Wall for Tank with Cover

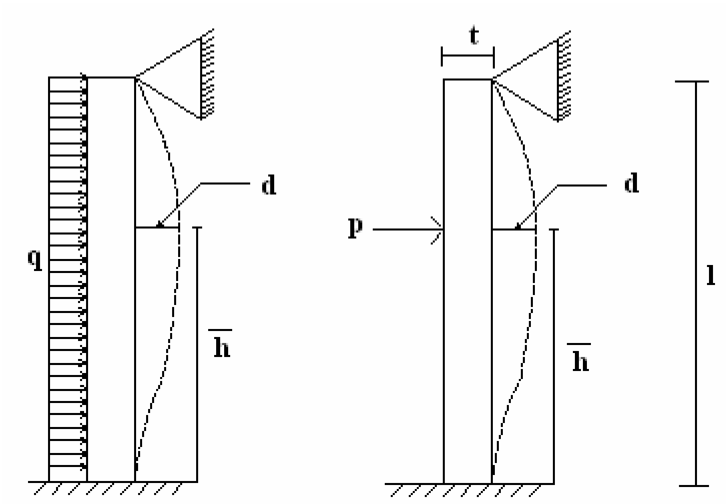


Fig.5.2 Description of deflection 'd' of rectangular tank wall with cover

For tanks with roof, deflection, *d* can be obtained by assuming wall hinge at top and fixed at bottom edges (Fig 5.2).

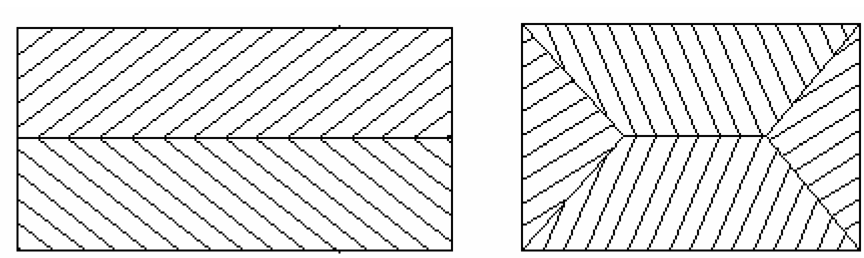
Height $\bar{h}$, which is subjected to concentrated load, $P = q\ h$ (Fig5.2). Thus, for a tank with wall of uniform thickness, and with cover one can obtain *d* as Eq.5.5.

$$d = \frac{\left(p\frac{\left(l-\bar{h}\right)}{l} \times \frac{\bar{h}^3}{6} \right) + \frac{4\bar{h}^3}{12}}{EI_w} \qquad . . . (5.5)$$

Where, $I_w = \dfrac{1.0 \times t^3}{12}$

Eq.5.5 is derived by use of Maculay's method.

If tank is with cover then in calculation of $\overline{m}_w$ weight of slab must be added as per one-way or two-way distribution.



One-way load distribution Two-way load distribution

Fig.5.3 Load distribution of cover on tank wall

Tank is with cover then $\overline{m}_w$ is summation of mass of one tank wall perpendicular to the direction of seismic force, and mass transfer to the wall due to slab. This mass transfer as per one way or two way on wall as shown in Fig.5.3, and then $\overline{m}_w$ use to calculate time period in impulsive mode.

5.2.2 Time Period Calculation for Convective Mode

Time period of convective mode of vibration, T_c in seconds, is given by Eq.5.6.

$$T_c = C_c\sqrt{\frac{L}{g}} \qquad . . . (5.6)$$

Where,

C_c = Coefficient of time period for convective mode.

L = Inside length of tank parallel to the direction of seismic force.

For ground supported rectangular tank value of C_c calculate by equation,

$$C_c = \frac{2\pi}{\sqrt{3.16\tanh\left(3.16\left(\frac{h}{L}\right)\right)}} \qquad . . . (5.7)$$

Value of C_c can also be obtained by figure given below.

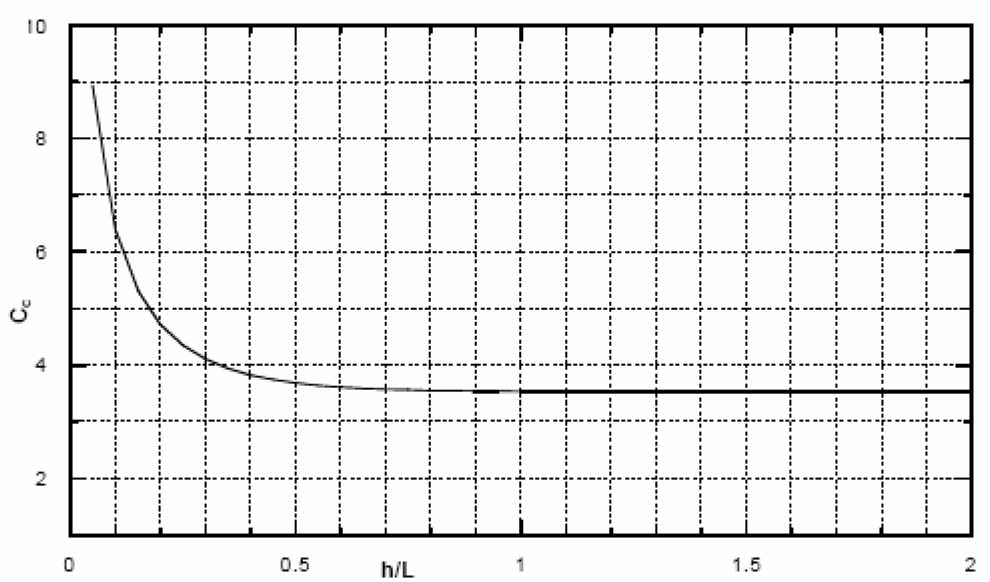


Fig.5.4 Coefficient of convective mode time period (c_c) for rectangular tank

5.3 CALCULATION OF BASE SHEAR, MOMENT AT BOTTOM OF WALL AND OVERTURNING MOMENT.

In calculation of base shear, moment at bottom of wall and overturning moment similar equation used which is described in detail in chapter 4, sections 4.3, 4.4, 4.5.

5.4 HYDRODYNAMIC PRESSURE CALCULATION

Due to earthquake, tank wall is subjected to lateral hydrodynamic pressure for two modes as given below.

5.4.1 Impulsive Hydrodynamic pressure

Lateral hydrodynamic impulsive pressure on wall p_{iw} , is given by Eq.5.8.

$$p_{iw} = Q_{iw}(y)(A_h)_i \rho g h \qquad \text{. . . (5.8)}$$

Where, Q_{iw} (y) is same as that for a circular tank as shown in Fig.5.4, with h / L being used in place of h / D.

Impulsive hydrodynamic pressure in vertical direction, on the base slab (y = 0), is given by

$$p_{ib} = Q_{ib}(x)(A_h)_i \rho g h \qquad \text{. . . (5.9)}$$

$$Q_{ib}(x) = \frac{\sinh\left(0.866\frac{x}{h}\right)}{\cosh\left(0.866\frac{L}{h}\right)} \qquad \text{. . . (5.10)}$$

The value of coefficient of impulsive hydrodynamic pressure on base Q_{ib} (x), can also be read from Fig.5.6.

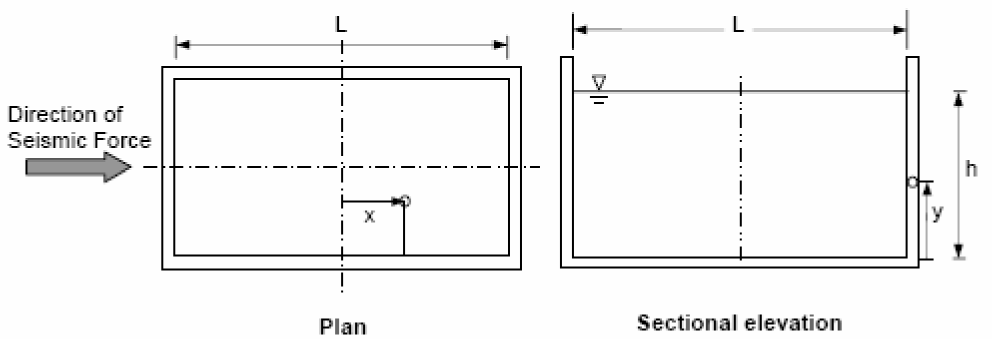


Fig.5.5 Geometry of rectangular water tank

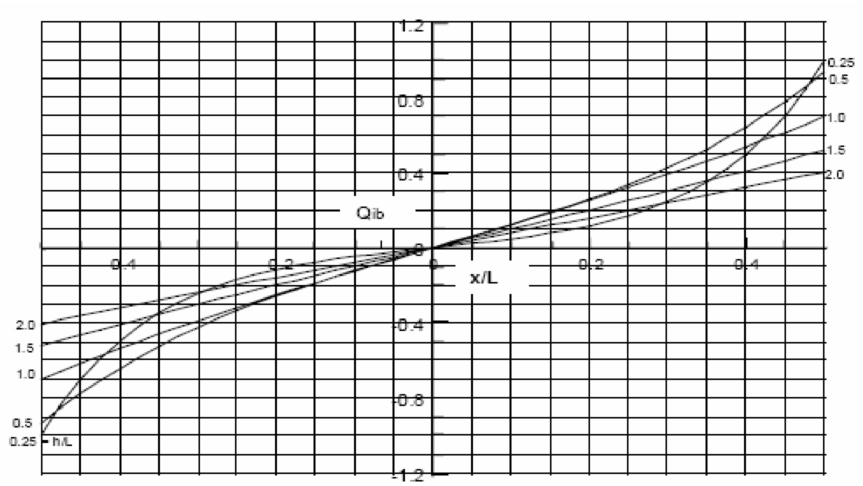


Fig.5.6 Impulsive pressure coefficient on base (Q_{ib})

5.4.2 Convective Hydrodynamic pressure

The hydrodynamic pressure on the wall p_{cw} , is given by Eq.5.11.

$$p_{cw} = Q_{cw}(y)(A_h)_c \rho g L \qquad \text{. . . (5.11)}$$

$$Q_{cw}(y) = 0.4165 \frac{\cosh\left(3.162\dfrac{y}{L}\right)}{\cosh\left(3.162\dfrac{h}{L}\right)} \qquad \text{. . . (5.12)}$$

The value of $Q_{cw}(y)$ can also be obtained from Fig.5.7.

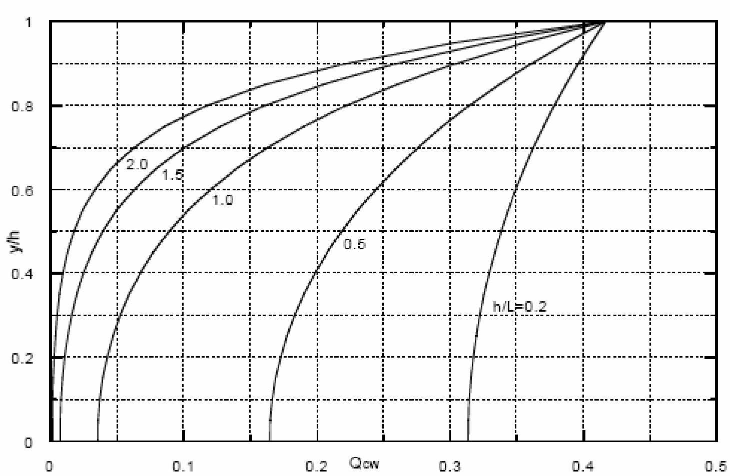


Fig 5.7.Convective hydrodynamic pressure coefficient for rectangular tank on wall (Q_{cw})

The pressure on the base slab (y=0) is given by,

$$P_{cb} = Q_{cb}(x)(A_h)_c \rho g l \qquad ...(5.13)$$

$$Q_{cb}(x) = 1.25\left[\frac{x}{L} - \frac{4}{3}\left(\frac{x}{L}\right)^3\right]\sec h\left(3.162\frac{h}{L}\right) \qquad ...(5.14)$$

The value of $Q_{cb}\,(x)$ can also be obtained from Fig.5.8.

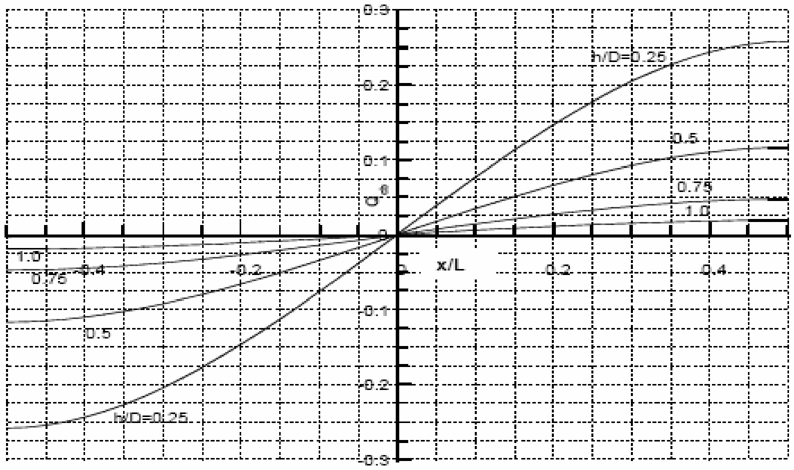


Fig.5.8 Convective hydrodynamic pressure coefficient for rectangular tank on base (Q_{cb})

Hydrodynamic pressure due to horizontal excitation has curvilinear variation along wall height. However, in the absence of more exact analysis, an equivalent linear pressure distribution may be assumed so as to give the same base shear and bending moment at the bottom of tank wall.

For rectangular tanks, maximum hydrodynamic force per unit length for impulsive and convective mode, is given by Eq.5.15 and 5.16.

$$q_i = \frac{(A_h)_i m_i}{2B} g \qquad ...(5.15)$$

$$q_c = \frac{(A_h)_c m_c}{2B} g \qquad ...(5.16)$$

5.4.3 Equivalent Linear Pressure Distribution

The equivalent linear pressure distribution for impulsive and convective modes, are same as described in chapter 4, section 4.3.3.

5.4.4 Pressure Due to wall Inertia and Pressure Due to Vertical Acceleration

It is determined in same as way as circular tank as discussed in chapter 4, section 4.4 and 4.5.

5.4.5 Total Hydrodynamic Pressure

The maximum value of hydrodynamic pressure should be obtained by combining pressure due to horizontal and vertical excitation through square root of sum of squares (SRSS) rule, which can be given as,

$$p = \sqrt{(p_{iw} + p_{ww})^2 + p_{cw}^2 + p_v^2} \qquad . . . (5.17)$$

5.5 PROGRAM FOR RECTANGULAR TANK

For seismic analysis of rectangular water tank a program is developed using C++ programming language. By using of above equations a program is developed. Flow chart of program is shown in Fig.9. One example of rectangular water tank is presented to illustrate input and output of program.

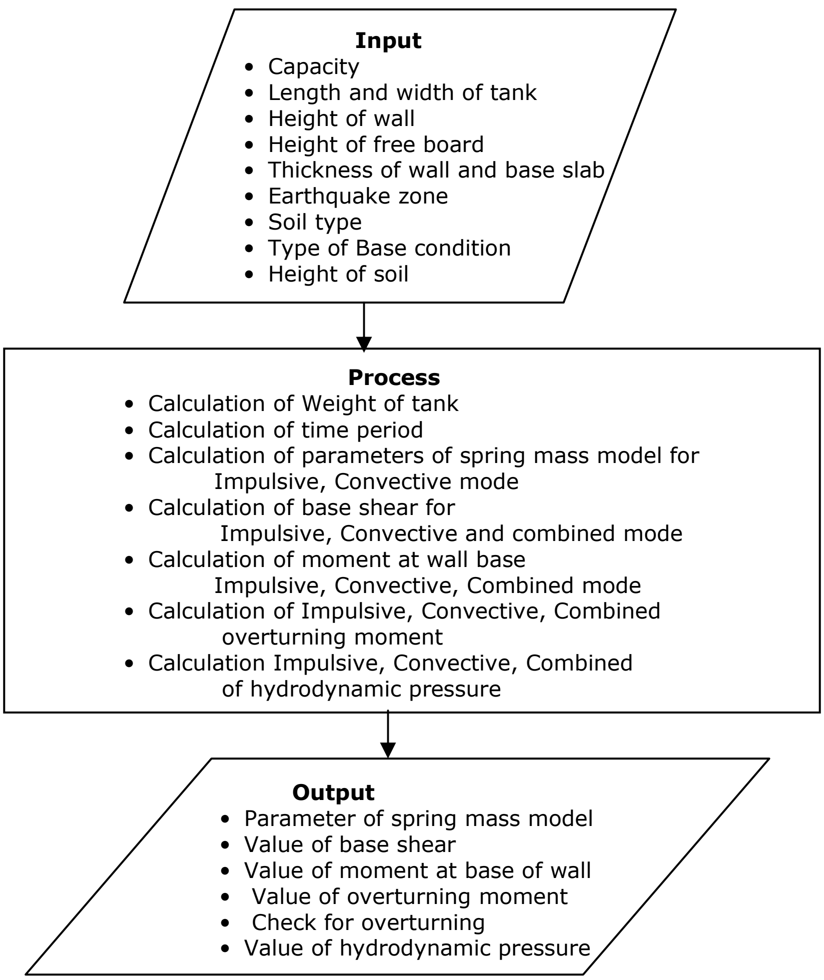


Fig.5.9.Flow chart for program of seismic analysis

5.5.1 EXAMPLE

A ground supported rectangular reinforced concrete water tank of 800 m^3 capacity has plan dimensions of 12.50 m x 10.25 m and height of 6.55 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.Analyze the tank for seismic loads.

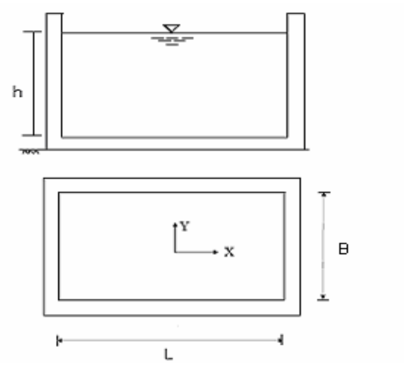


Fig.5.10. Elevation and plan of rectangular tank

INPUT

This program for seismic calculation for rectangular water tank

1: Tank without roof slab

2: Tank with roof slab (flat slab)

1

Enter capacity of water tank in liters :800000

Enter inner length of water tank in meter : 12.50

Enter inner width of water tank in meter : 10.25

Enter thickness of tank wall in meter: 0.4

Height of water from bottom of base slab in meter : 6.25

Enter free board in meter : 0.3

Enter thickness of base slab in meter : 0.5

Enter grade of concrete : 30

Enter zone : 5

Select case for importance factor

1 : tanks used for storing drinking water, non volatile material,
low inflammable petrochemicals etc and
intended for emergency services such as fire fighting services
tanks of post earthquake importance

2 : All other tanks with no risk to life

and with negligible consequences
to environment, society and economy
1
Select case for response reduction factor
1: Fixed or hinged/pinned base tank
2: Anchored flexible base tank
3: Unanchored contained or uncontained tank
1
Enter height of tank below ground level
0
Type of soil
1: Hard soil
2: Medium soil
3: Soft soil
1

OUTPUT

Weight of tank wall	: 2849.55 kN
Mass of tank wall	: 290474 kg
Mass of base slab	:187264 kg
Weight of water	: 7227.21 kN
Mass of water	: 800000 kg

Analysis in X direction

Impulsive mass	: 405702 kg
Convective mass	: 411566 kg
Height of resultant of impulsive water pressure (effect on base slab is not considered)	: 2.16 meter
Height of resultant of convective water pressure (effect on base slab is not considered)	: 3.29 meter
Height of resultant of impulsive water pressure (effect on base slab is considered)	: 4.95 meter
Height of resultant of convective water pressure (effect on base slab is considered)	: 5.27 meter
Time period of impulsive mode	: 0.18 sec

Time period for convective mode	: 4.2 sec
Design seismic coefficient for impulsive mass	:0.34
Design seismic coefficient for convective mass	:0.06
Base shear for impulsive mode	:2304.95 kN
Base shear for convective mode	:226.46 kN
Total base shear at bottom of wall	:2316.05 kN
Moment at bottom of wall in impulsive mode	:5805.55 kN-m
Moment at bottom of wall in convective mode	:745.76 kN-m
Total bending moment at bottom of wall	:5805.68 kN-m
Overturning moment at bottom of base slab in impulsive mode	:10866.3 kN-m
Overturning moment at bottom of base slab in convective mode	:1306.37 kN-m
Total overturning moment at the bottom of base slab	:10944.5 kN-m
Impulsive hydrodynamic pressure on wall	:15.74 kN/m^2
Impulsive hydrodynamic pressure on the base slab	:6.15 kN/m^2
Convective hydrodynamic pressure on base of wall	:1.27 kN/m^2
Convective hydrodynamic pressure at y=h is	:2.86 kN/m^2
Convective hydro dynamic pressure at on top of base slab (y=0)	:1.27 kN/m^2
Pressure due to wall inertia	:3.38 kN/m^2
Hydrodynamic pressure on tank wall due to vertical ground acceleration	:12.69 kN/m^2
Maximum hydrodynamic pressure	:22.98 kN/m^2
Base shear per unit periphery length due to impulsive liquid mass	:65.52 kN/m
Value of equivalent linear pressure at bottom	:19.94 kN/m^2
Value of equivalent linear pressure at top	:2.85 kN/m^2
Base shear per unit periphery length due to convective liquid mass	:11.05 kN/m
Value of equivalent linear pressure at bottom	:1.08 kN/m^2
Value of equivalent linear pressure at top	:2.76 kN/m^2
Maximum sloshing wave height	:0.70 meter

Sloshing wave height is more then free board so, increase free board

No anchorage requirement

Analysis in Y direction

Impulsive mass	:473006 kg
Convective mass	:355367 kg
Height of resultant of impulsive water pressure	
(effect on base slab is not considered)	:2.16 meter
Height of resultant of convective water pressure	
(effect on base slab is not considered)	:3.45 meter
Height of resultant of impulsive water pressure	
(effect on base slab is considered)	:4.14 meter
Height of resultant of convective water pressure	
(effect on base slab is considered)	:4.59 meter
Deflection of the tank wall on vertical center line	:0.01 meter
Time period of impulsive mode	
0.17 sec	
Time period for convective mode	:3.72 sec
Design seismic coefficient for impulsive mass	:0.34
Design seismic coefficient for convective mass	:0.06
Base shear for impulsive mode	:2527.79 kN
Base shear for convective mode	:221.58 kN
Total base shear at bottom of wall	:2537.48 kN
Moment at bottom of wall in impulsive mode	:6286.03 kN-m
Moment at bottom of wall in convective mode	:764.09 kN-m
Total bending moment at bottom of wall	:6286.16 kN-m
Overturning moment at bottom of base slab in impulsive mode	:10817.50kN-m
Overturning moment at bottom of base slab in convective mode	:1128.86 kN-m
Total overturning moment at the bottom of base slab	:10876.3 kN-m
Impulsive hydrodynamic pressure on wall	:15.05 kN/m^2
Impulsive hydrodynamic pressure on the base slab	:6.62 kN/m^2
Convective hydrodynamic pressure on base of wall	:0.88 kN/m^2
Convective hydrodynamic pressure at y=h is	:2.66 kN/m^2
Convective hydro dynamic pressure at	
on top of base slab (y=0)	:0.88 kN/m^2
Pressure due to wall inertia	:3.38 kN/m^2

Hydrodynamic pressure on tank wall due to	
vertical ground acceleration	:12.69 kN/m^2
Maximum hydrodynamic pressure	:22.39 kN/m^2
Base shear per unit periphery length	
due to impulsive liquid mass	:62.64 kN/m
Value of equivalent linear pressure at bottom	:19.07 kN/m^2
Value of equivalent linear pressure at top	:2.72 kN/m^2
Base shear per unit periphery length	
due to convective liquid mass	:8.86 kN/m
Value of equivalent linear pressure at bottom	:0.62 kN/m^2
Value of equivalent linear pressure at top	:2.46 kN/m^2
Maximum sloshing wave height	:0.65 meter

Sloshing wave height is more then free board so increase free board

No anchorage requirement

5.6 PARAMETRIC STUDY FOR SEISMIC ANALYSIS OF RECTANGULAR TANK

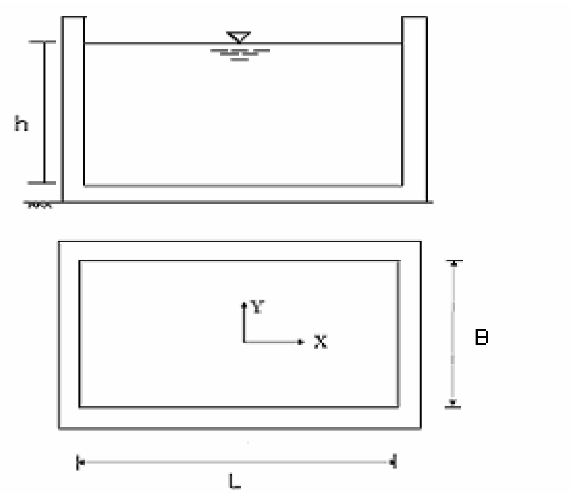
To study the effect of configuration of seismic response of the ground supported rectangular tank parametric study carried out for following two cases.

(I) With different length to height ratio.

(II) With different length to width ratio.

5.6.1 Effect of Length to Height Ratio

Rectangular water tank 8,00,000 liter to 12,00,000 liters with different length to height ratio from 1 to 5 are considered for seismic analysis. Earthquake forces are considered both directions i.e. parallel to length and parallel to width and critical forces are presented here. Dimensions of tanks are considered for water tank are given in Table.5.1. The results of seismic analysis in terms of base shear, base moment, overturning moment and hydrodynamic pressure are obtained from computer program developed. The results are presented in following section.



h = Height of water in rectangular tank
L = Length of tank
B = Width of rectangular tank
Earthquake zone = 5
Soil type = soft soil
Thickness of wall = 400 mm
Thickness of base slab = 500 mm

Fig.5.11. Plan, elevation and essential data for analysis.

Table.5.1 Considered dimensions for different capacity rectangular tank

Capacity	8,00,000 lit			9,00,000 lit			10,00,000 lit		
L/h	L (m)	h(m)	B(m)	L (m)	h(m)	B(m)	L (m)	h(m)	B(m)
1	10.50	10.50	7.26	11.00	11.00	7.44	11.50	11.50	7.56
2	12.50	6.25	10.24	13.00	6.50	10.65	13.50	6.75	10.97
3	14.50	4.83	11.42	15.00	5.00	12.00	15.50	5.17	12.49
4	16.50	4.13	11.75	17.00	4.25	12.46	17.50	4.38	13.06
5	18.50	3.70	11.69	19.00	3.80	12.47	19.50	3.90	13.15

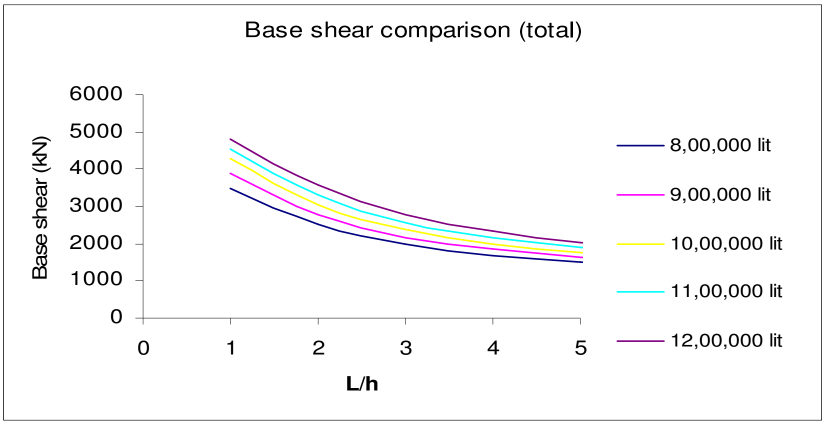
Capacity	11,00,000 lit			12,00,000 lit		
L/h	L (m)	h(m)	B(m)	L (m)	h(m)	B(m)
1	12.00	12.00	7.64	12.50	12.50	7.68
2	14.00	7.00	11.22	14.50	7.25	11.42
3	16.00	5.33	12.89	16.50	5.50	13.22
4	18.00	4.50	13.58	18.50	4.63	14.02
5	20.00	4.00	13.75	20.50	4.10	14.28

5.6.1.1 Base Shear

Base shear for different capacity rectangular tank is calculated considering combined effect of impulsive and convective mass. The critical value of base shear is given in Table 5.2 and presented graphically in Fig.5.12.

Table 5.2 Total Base shear in kN

L/h	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
1	3498.78	3881.41	4263.94	4535.78	4807.62
2	2503.35	2767.08	3029.53	3291.04	3551.86
3	1974.02	2173.38	2371.35	2568.14	2763.98
4	1674.92	1837.05	1997.90	2157.63	2316.40
5	1490.44	1628.59	1765.62	1901.65	2036.80



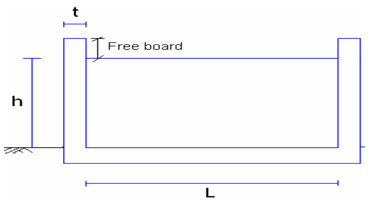


Fig.5.12 Base shear comparison for various capacities

5.6.1.2 Moment at Base of Wall

Moment at base of wall for different capacity rectangular tank is calculated considering combined effect of impulsive and convective mass. The critical value of moment at base of wall is given in Table 5.3 and presented graphically in Fig.5.13.

Table 5.3 Total moment at base of wall in kN-m

L/h	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
1	12007.00	13814.80	15722.60	17306.50	18890.40
2	6124.88	6913.27	7732.40	8583.09	9466.05
3	4280.79	4762.64	5257.13	5764.85	6286.34
4	3480.40	3831.07	4187.84	4551.15	4921.40
5	3065.82	3346.84	3631.09	3918.91	4210.62

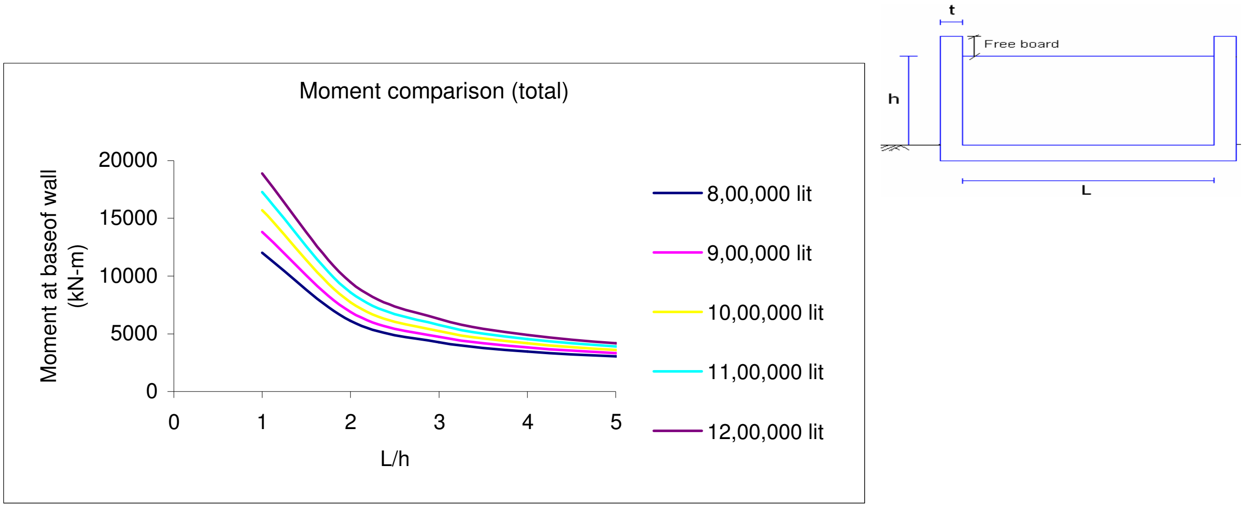


Fig.5.13 Moment at base of wall

5.6.1.3 Overturning Moment at Bottom of Base Slab

Overturning moment for different capacity rectangular tank is calculated considering combined effect of impulsive and convective mass. The critical value of overturning moment is given in Table 5.4 and presented graphically in Fig.5.14.

Table 5.4 Total overturning moment in kN-m

L/h	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
1	16626.10	19124.10	21753.50	23935.00	26116.50
2	11502.90	13106.60	14777.90	16517.70	18327.00
3	9785.92	11087.40	12434.80	13828.90	15270.30
4	9042.82	10206.20	11405.10	12639.80	13910.70
5	8748.87	9848.56	10977.70	12136.60	13325.50

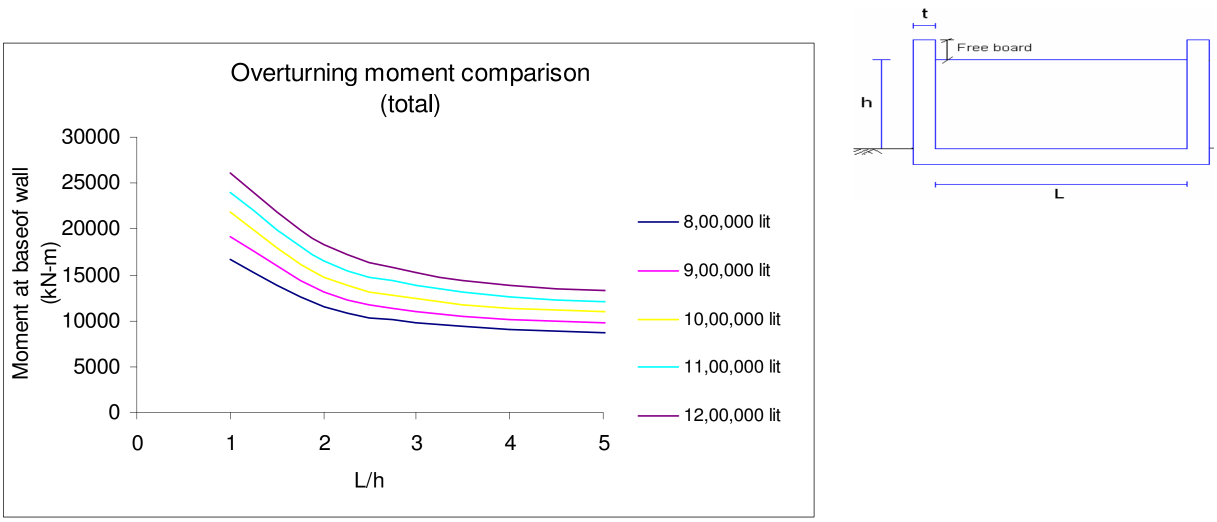


Figure 5.14 Overturning moment at bottom of tank

5.6.1.4 Total Hydrodynamic Pressure

Total hydrodynamic pressure for different capacity rectangular tank is calculated considering combined effect of impulsive and convective mass. The critical value of hydrodynamic pressure is given in Table 5.5 and presented graphically in Fig.5.15.

Tab.5.5 Hydrodynamic pressure for various capacities

L/H	8,00,000 lit	9,00,000 lit	10,00,000 lit	11,00,000 lit	12,00,000 lit
1	33.68	35.16	36.65	37.22	37.80
2	24.54	25.41	26.28	27.15	28.01
3	20.36	20.96	21.55	22.15	22.75
4	18.05	18.50	18.95	19.40	19.85
5	16.63	16.99	17.36	17.72	18.08

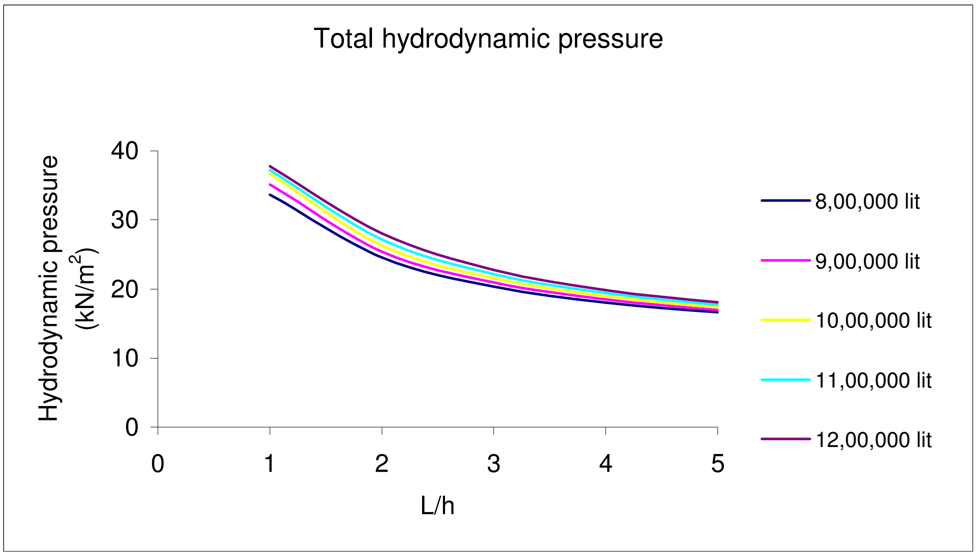


Figure 5.15 Total hydrodynamic pressure

5.6.1.5 Comparison of Hydrostatic and Hydrodynamic Pressure

Comparison of hydrostatic and hydrodynamic pressure for various capacity tanks is carried out. This comparison is done for earthquake zone 4 and earthquake zone 5. Comparison is presented in tabulated form in Table.5.6 and Table 5.7. Comparison also presented graphically in Fig. 5.16 and Fig.5.17. Horizontal line indicate permissible limit of hydrodynamic pressure.

Table 5.6 Comparison of hydrostatic and hydrodynamic pressure (Zone =IV)

Capacity in liters	L/h	Length (m)	Height (m)	Width (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Hydrodynamic Pressure as % of Hydrostatic pressure
8,00,000	1	10.50	10.50	7.26	105.00	22.45	21.38
	2	12.50	6.25	10.24	62.50	16.36	26.18
	3	14.50	4.83	11.42	48.33	13.57	28.08
	4	16.50	4.13	11.75	41.25	12.03	29.17
	5	18.50	3.70	11.69	37.00	11.09	29.97
9,00,000	1	11.00	11.00	7.44	110.00	23.44	21.31
	2	13.00	6.50	10.65	65.00	16.94	26.06
	3	15.00	5.00	12.00	50.00	13.97	27.94
	4	17.00	4.25	12.46	42.50	12.33	29.02
	5	19.00	3.80	12.47	38.00	11.33	29.81
10,00,000	1	11.50	11.50	7.56	115.00	24.43	21.25
	2	13.50	6.75	10.97	67.50	17.52	25.95
	3	15.50	5.17	12.49	51.67	14.37	27.81
	4	17.50	4.38	13.06	43.75	12.64	28.88
	5	19.50	3.90	13.15	39.00	11.57	29.67
11,00,000	1	12.00	12.00	7.64	120.00	24.82	20.68
	2	14.00	7.00	11.22	70.00	18.10	25.85
	3	16.00	5.33	12.89	53.33	14.77	27.69
	4	18.00	4.50	13.58	45.00	12.94	28.75
	5	20.00	4.00	13.75	40.00	11.81	29.53
12,00,000	1	12.50	12.50	7.68	125.00	25.14	20.11
	2	14.50	7.25	11.42	72.50	18.68	25.76
	3	16.50	5.50	13.22	55.00	15.17	27.57
	4	18.50	4.63	14.02	46.25	13.24	28.62
	5	20.50	4.10	14.28	41.00	12.05	29.39

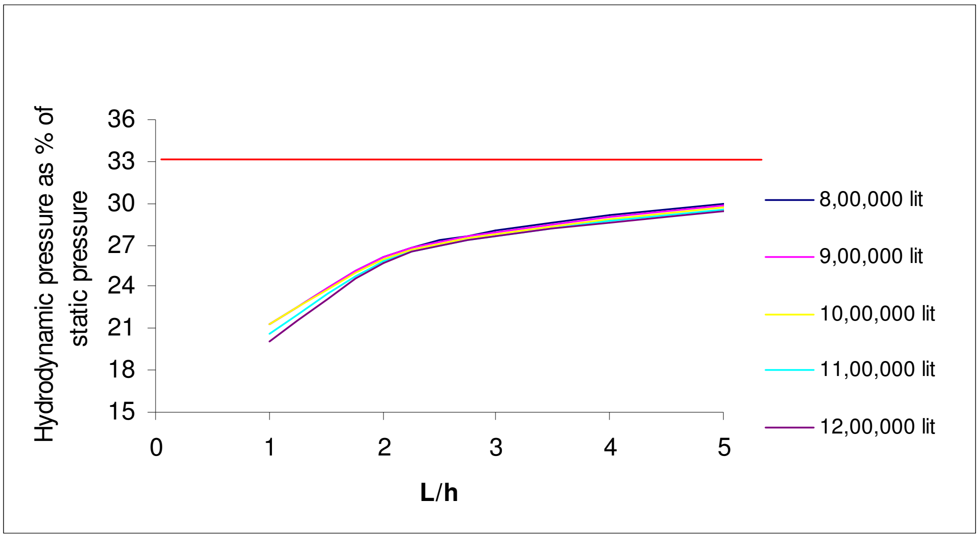


Fig.5.16 Comparison of hydrostatic and hydrodynamic pressure

Table 5.7. Comparison of hydrostatic and hydrodynamic pressure (Zone = V)

Capacity in liters	L/h	Length (m)	Height (m)	Width (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Hydrodynamic Pressure as % of Hydrostatic pressure
8,00,000	1	10.50	10.50	7.26	105.00	33.68	32.07
	2	12.50	6.25	10.24	62.50	24.54	39.27
	3	14.50	4.83	11.42	48.33	20.36	42.12
	4	16.50	4.13	11.75	41.25	18.05	43.76
	5	18.50	3.70	11.69	37.00	16.63	44.95
9,00,000	1	11.00	11.00	7.44	110.00	35.16	31.97
	2	13.00	6.50	10.65	65.00	25.41	39.09
	3	15.00	5.00	12.00	50.00	20.96	41.91
	4	17.00	4.25	12.46	42.50	18.50	43.53
	5	19.00	3.80	12.47	38.00	16.99	44.72
10,00,000	1	11.50	11.50	7.56	115.00	36.65	31.87
	2	13.50	6.75	10.97	67.50	26.28	38.93
	3	15.50	5.17	12.49	51.67	21.55	41.72
	4	17.50	4.38	13.06	43.75	18.95	43.32
	5	19.50	3.90	13.15	39.00	17.36	44.50
11,00,000	1	12.00	12.00	7.64	120.00	37.22	31.02
	2	14.00	7.00	11.22	70.00	27.15	38.78
	3	16.00	5.33	12.89	53.33	22.15	41.53
	4	18.00	4.50	13.58	45.00	19.40	43.12
	5	20.00	4.00	13.75	40.00	17.72	44.29
12,00,000	1	12.50	12.50	7.68	125.00	37.80	30.24
	2	14.50	7.25	11.42	72.50	28.01	38.64
	3	16.50	5.50	13.22	55.00	22.75	41.36
	4	18.50	4.63	14.02	46.25	19.85	42.93
	5	20.50	4.10	14.28	41.00	18.08	44.09

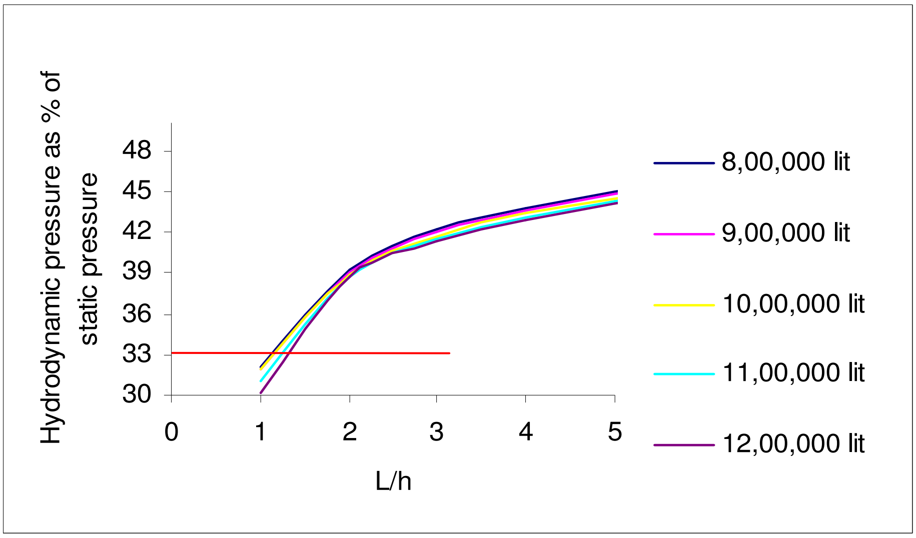
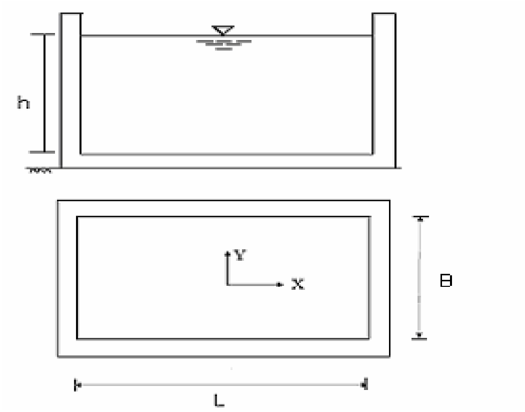


Fig.5.17 Comparison of hydrostatic and hydrodynamic pressure

5.6.2 Effect of Length to Width Ratio

Rectangular tanks of 8,00,000 liters to 12,00,000 liters with length to width ratio 1.0 to 1.5 are considered for seismic analysis. Earthquake forces are considered for the both directions i.e. parallel to length and parallel to width and critical values of forces are presented. Dimensions of water tank considered are given in Table 5.8.



h = Height of water in rectangular tank
= 5 m
L = Length of tank
B = Width of rectangular tank
Earthquake zone = 5
Soil type = hard soil
Thickness of wall = 400 mm
Thickness of base slab = 500 mm

Fig.5.18. Plan, elevation and essential data for analysis

Table 5.8 Dimension for different capacity rectangular tank

Capacity (liters)	8,00,000		9,00,000		10,00,000		11,00,000		12,00,000	
L/B	L(m)	B(m)	L(m)	B(m)	L(m)	B(m)	L(m)	B(m)	L(m)	B(m)
1.0	12.65	12.65	13.42	13.42	14.14	14.14	14.83	14.83	15.49	15.49
1.1	13.27	12.06	14.07	12.79	14.83	13.48	15.56	14.14	16.25	14.77
1.2	13.86	11.55	14.70	12.25	15.49	12.91	16.25	13.54	16.97	14.14
1.3	14.42	11.09	15.30	11.77	16.12	12.40	16.91	13.01	17.66	13.59
1.4	14.97	10.69	15.87	11.34	16.73	11.95	17.55	12.54	18.33	13.09
1.5	15.49	10.33	16.43	10.95	17.32	11.55	18.17	12.11	18.97	12.65

5.6.2.1 Comparison of Hydrostatic and Hydrodynamic Pressure

The seismic analysis is carried out using computer program developed. Results of hydrodynamic pressure and hydrostatic pressure are compared in Table.5.9. Hydrodynamic pressure presented as % of hydrostatic pressure for both, along length and along width earthquake direction respectively in Fig.5.19 and Fig.5.20.

Table 5.9 Hydrodynamic pressure as percentage of hydrostatic pressure

Capacity liters	L/B	Static Pressure kN/m^2	Hydrodynamic Pressure kN/m^2		Hydrodynamic Pressure as % of Hydrostatic pressure	
			Earthquake in X	Earthquake in Y	Earthquake in X	Earthquake in Y
8,00,000	1.0	50	20.62	20.62	41.24	41.24
	1.1	50	20.69	20.55	41.37	41.10
	1.2	50	20.74	20.47	41.47	40.95
	1.3	50	20.78	20.40	41.56	40.79
	1.4	50	20.81	20.32	41.62	40.64
	1.5	50	20.84	20.24	41.68	40.48
9,00,000	1.0	50	20.70	20.70	41.40	41.40
	1.1	50	20.75	20.64	41.51	41.28
	1.2	50	20.80	20.57	41.59	41.15
	1.3	50	20.83	20.51	41.66	41.01
	1.4	50	20.86	20.44	41.72	40.88
	1.5	50	20.88	20.37	41.76	40.74
10,00,000	1.0	50	20.76	20.76	41.52	41.52
	1.1	50	20.80	20.71	41.61	41.41
	1.2	50	20.84	20.65	41.68	41.30
	1.3	50	20.87	20.59	41.74	41.19
	1.4	50	20.89	20.53	41.79	41.07
	1.5	50	20.91	20.47	41.83	40.95
11,00,000	1.0	50	20.80	20.80	41.61	41.61
	1.1	50	20.84	20.76	41.69	41.52
	1.2	50	20.87	20.71	41.75	41.42
	1.3	50	20.90	20.66	41.80	41.32
	1.4	50	20.92	20.61	41.84	41.22
	1.5	50	20.94	20.56	41.87	41.11
12,00,000	1.0	50	20.84	20.84	41.68	41.68
	1.1	50	20.87	20.80	41.75	41.60
	1.2	50	20.90	20.76	41.80	41.52
	1.3	50	20.92	20.71	41.85	41.43
	1.4	50	20.94	20.67	41.88	41.34
	1.5	50	20.96	20.62	41.91	41.24

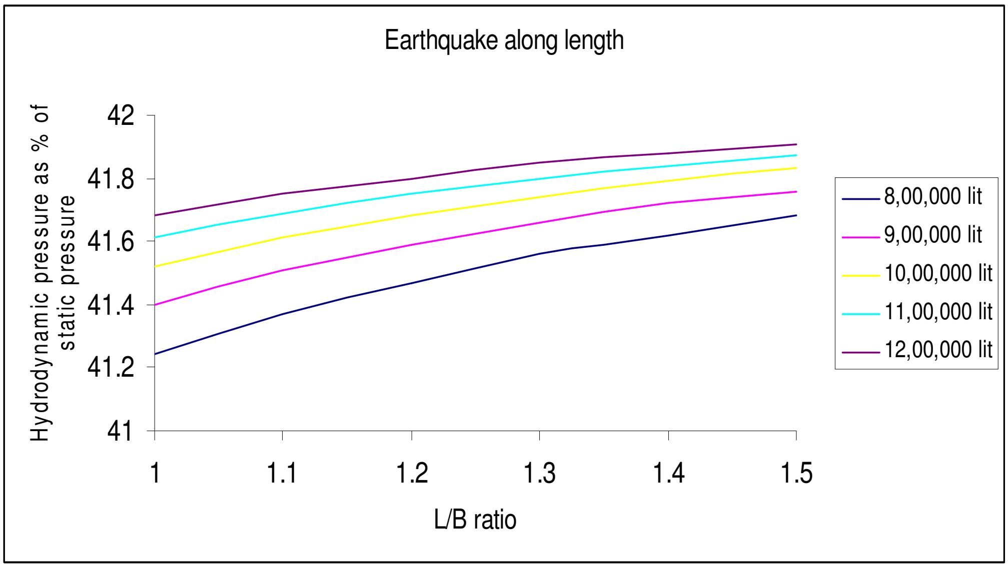


Fig.5.19 Hydrodynamic pressure as % of hydrostatic pressure (Earthquake along length)

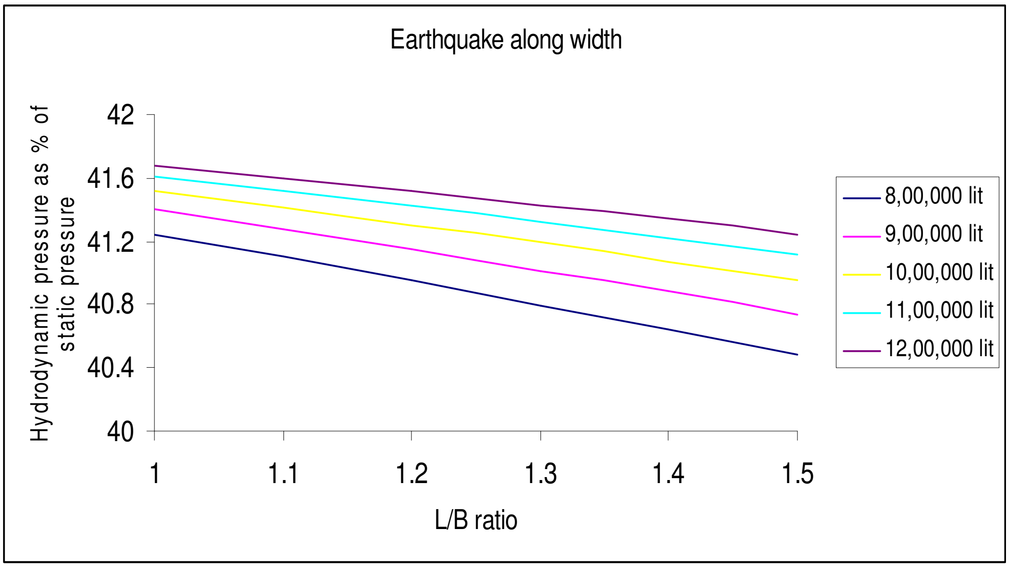


Fig.5.20 Hydrodynamic pressure as % of hydrostatic pressure (Earthquake along width)

5.7 SUMMARY

This chapter includes seismic analysis of ground supported rectangular tank as per IS:1893 (part II) draft. Codal provisions are discussed and computer program is developed for seismic analysis. Further to understand effect of configuration two parametric studies are carried out. In one study rectangular tank of different capacity with length to height ratio 1 to 5 are considered in earthquake zone IV and V. In other parametric study length to width ratio 1 to

1.5 are considered in earthquake zone V. Results are presented in terms of base shear, moment at base of wall, overturning moment, hydrodynamic pressure etc. Results show that, hydrodynamic pressure is within permissible limit (i.e. less than 33% of hydrostatic pressure) up to earthquake zone 4. There is no need to consider hydrodynamic pressure in design of rectangular tank wall up to earthquake zone 4. But in earthquake zone 5, hydrodynamic pressure is more than permissible limit (i.e. more than 33% of hydrostatic pressure) for length to height ratio more than 1.2. So, hydrodynamic pressure must be considered in design of circular tank wall for earthquake zone 5.

6. DESIGN OF CIRCULAR TANK

6.1 GENERAL

This chapter discusses modeling, analysis and design of circular tank considering hydrodynamic forces. It also includes the step by step procedure for modeling circular tank resting on ground subjected to hydrodynamic pressure as well as hydrostatic pressure using SAP2000 software. A computer program using C++ language is developed for calculating hydrodynamic pressure on circular tank resting on ground having various capacity and height to diameter ratio. As the hydrodynamic is not linear in nature, tension and moment coefficient of IS:3370 (part IV) can not be used directly. So for calculating tension and bending moment in wall finite element based software SAP2000 is used.

6.2 INTRODUCTION OF SAP2000

SAP2000 is a full-featured program that can be used for the variety of problems. It is developed by Computers and Structures, Inc. Berkeley, California, USA. SAP2000 is the most sophisticated and user-friendly computer program. It features a powerful graphical user interface. Creation and modification of the model, execution of the analysis, checking and optimization of the design, and production of the output are all accomplished using this single interface. A single structural model can be used for a variety of different types of analysis and design.

6.3 MODELING OF CIRCULAR TANK IN SAP2000

In SAP2000 following steps should be followed for the modeling of circular tank resting on ground.

Step 1: Selection of units

SAP2000, software gives flexibility to choose units as shown in Fig.6.1, when it is started.

Step 2: Selection of geometry of the model

There are various options for the ready made geometry for different type of structure. Geometry of circular tank resting on ground can be easily developed by selecting shells, which is marked with rectangle in Fig.6.1.

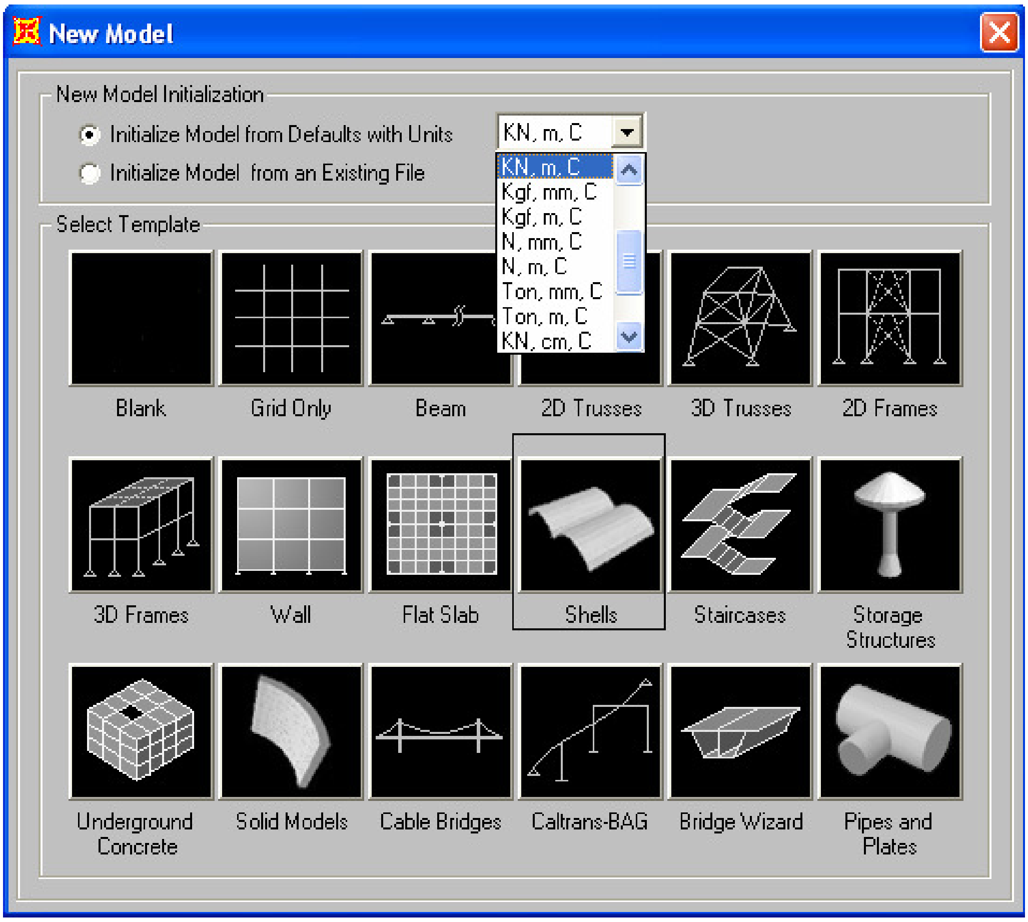


Fig. 6.1 Geometries for various structures

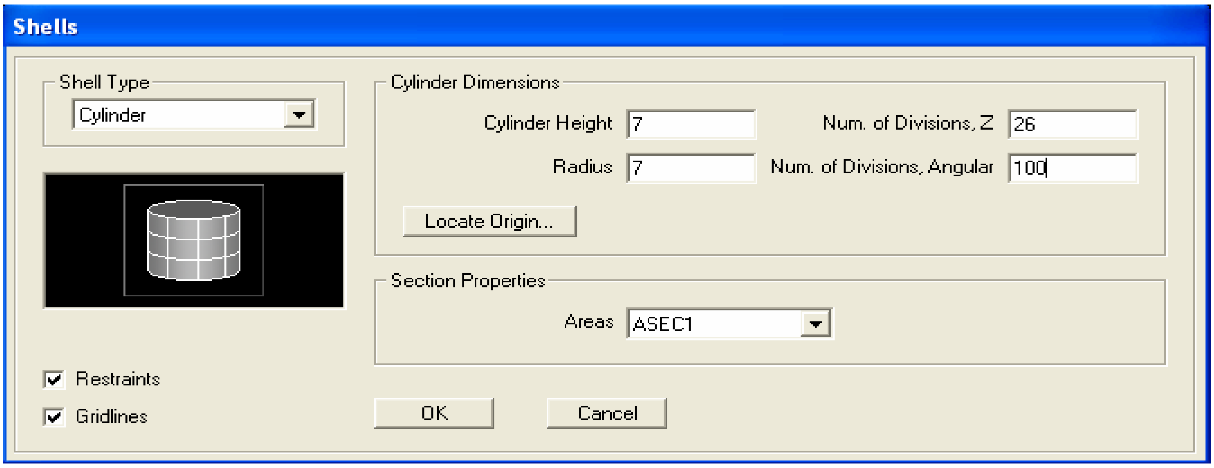


Fig. 6.2 Dimension for circular tank

Step 3: From select menu select area section and from define menu assign type of material, thickness of area section and type of load.

Step 4: Select all point at zero height level and assign support condition by joint restrain option from the assign menu.

Step 5: Assign surface pressure to the various elements of tank, which is obtained by addition of hydrostatic and hydrodynamic pressure. This total pressure is not linearly varying pressure. There are two methods to assign such type of pressure to the tank wall.

(i) Assign element pressure to the each element.

In this method pressure is assign to the each shell element on the face-5. This procedure is very lengthy and time consuming so it is advisable to use file export function. In this method assign constant surface pressure to all elements and then export to MS Excel. From exported file it is very easy to edit element pressure for each element. After editing due modifications, values of surface pressure is imported to SAP2000 through MS Excel file.

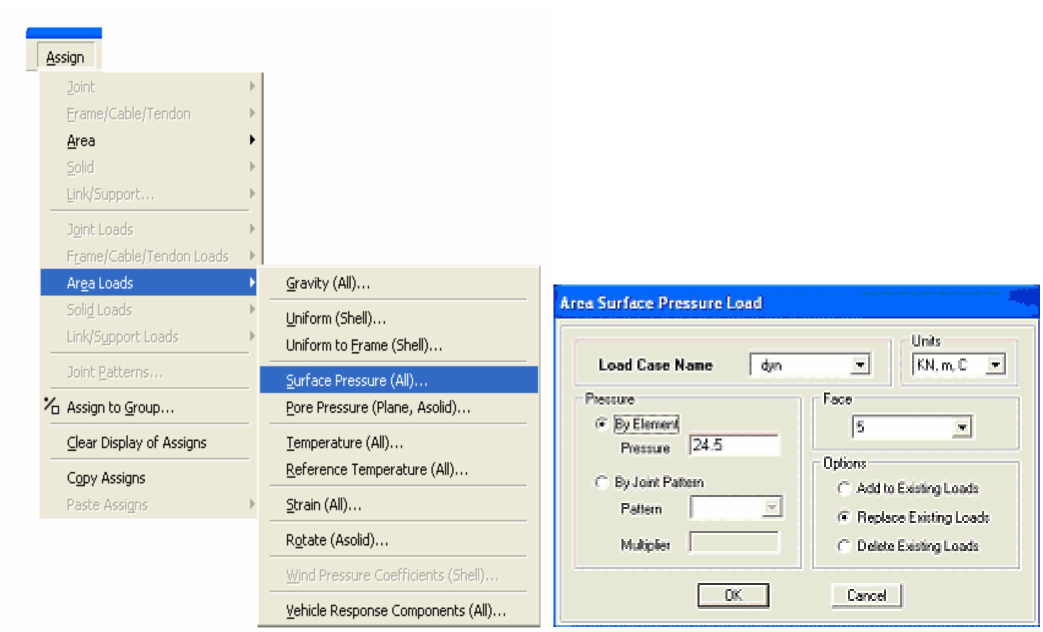


Fig. 6.3 Assign of element pressure

(ii) Assign element pressure by converting equivalent linear pressure distribution. In IS: 1893 (part II), there are equations to convert nonlinear hydrodynamic pressure in to linear pressure distribution. After converting in to equivalent pressure distribution it can be defined through the joint pattern as shown in Fig.6.4. Then select all elements and assign it. After assignment the element pressure, can be viewed in contour form as shown in Fig 6.5.

Step 6: Analyze the model of tank by commands as shown in Fig.6.5, and export all results in MS Excel so force can be easily found at various locations. Force F11 gives value of hoop tension and moment M22 gives the vertical moment.

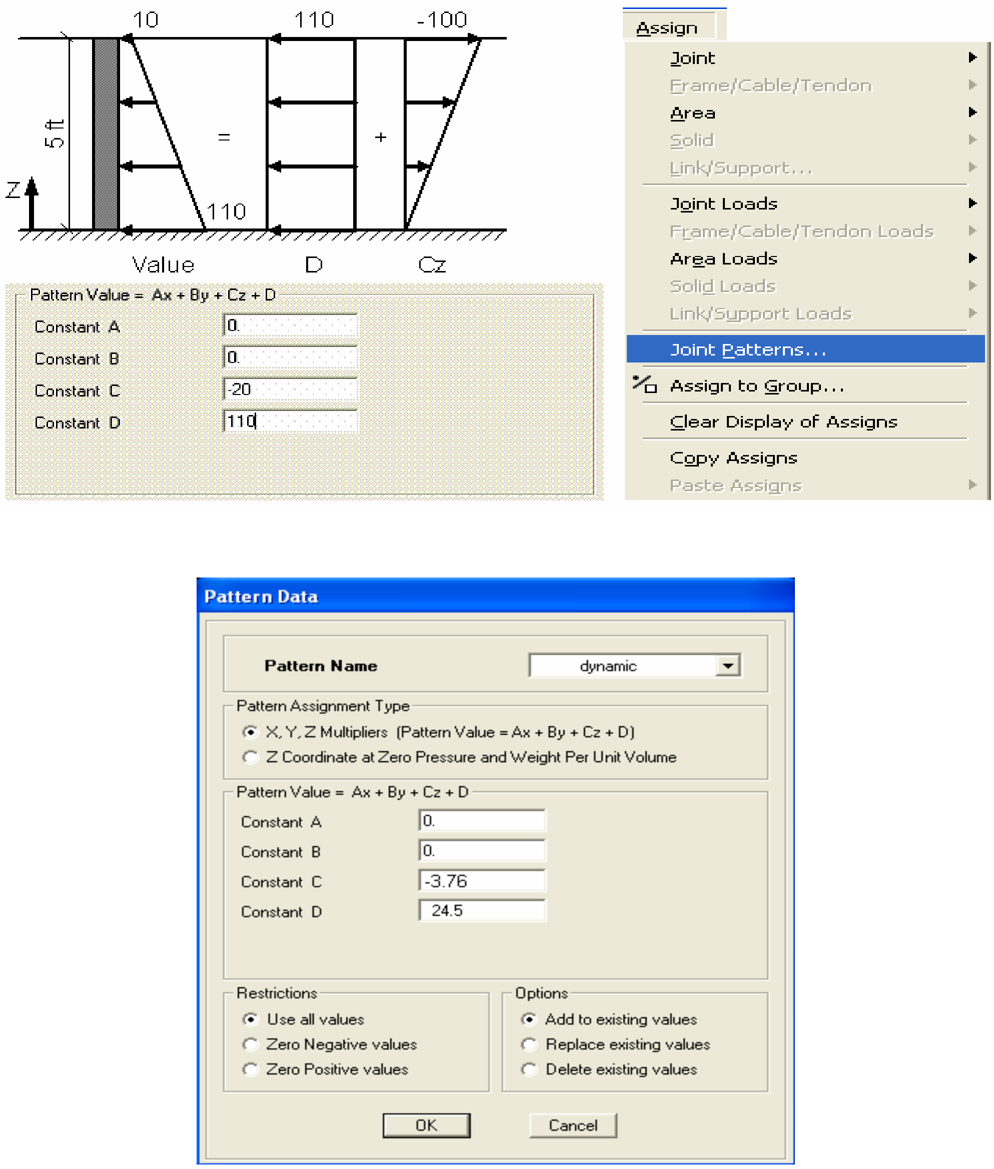


Fig. 6.4 Assignment of element pressure by joint pattern

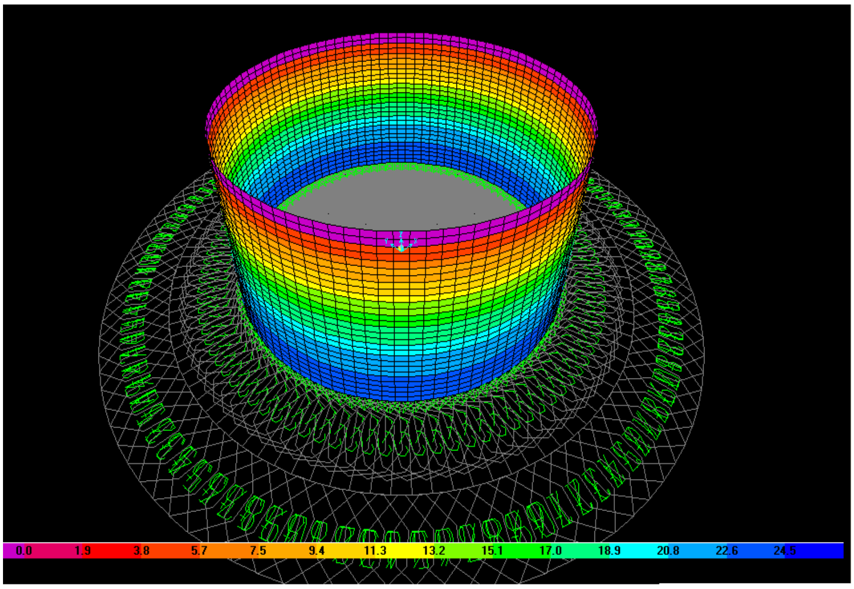


Fig. 6.5 Contours of element pressure

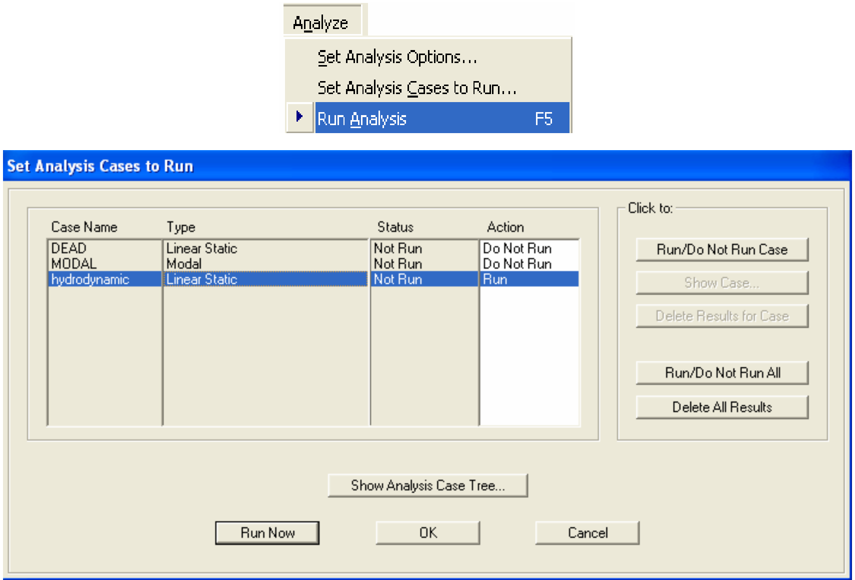
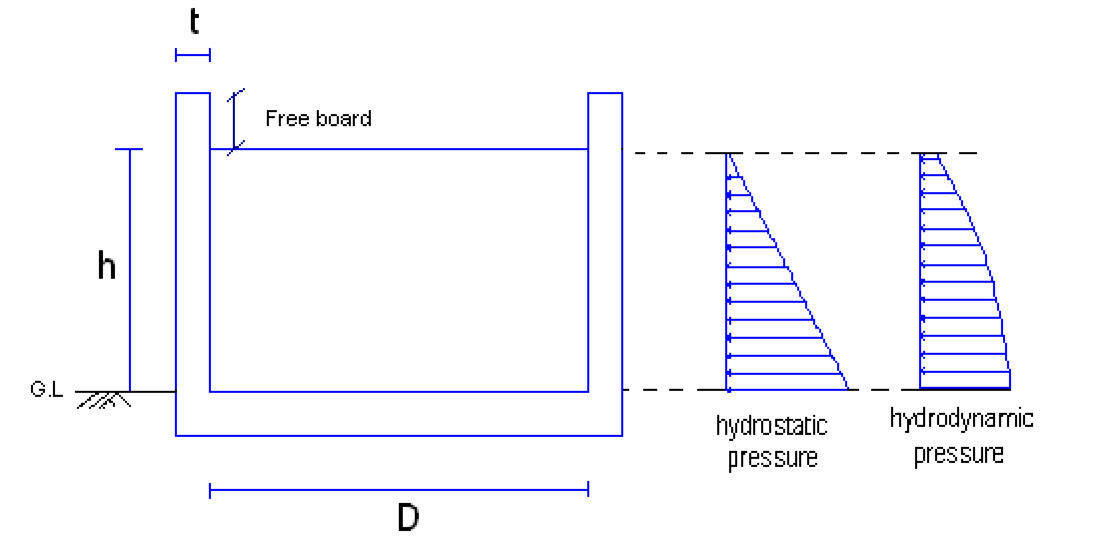


Fig. 6.6 Analyses command in SAP2000

6.4 COMPARISON OF ANALYSIS RESULTS OF SAP2000 AND AS PER IS: 3370 (PART: IV)

Modeling of circular tank wall is carried out in SAP2000 as per data given in Fig.6.7. Tank wall is considered as free at top and hinged at bottom to get maximum tension. And tank wall is considered as free at top and fixed at bottom to get maximum bending moment.



Diameter of tank	= 14 m
Earthquake zone	= 5
Soil type	= soft soil
Thickness of wall (t)	= 0.250 m
Thickness of base slab	= 0.4 m
Height of water (h)	= 6.5 m
Height of free board	= 0.5 m

Fig. 6.7 Details of circular water tank

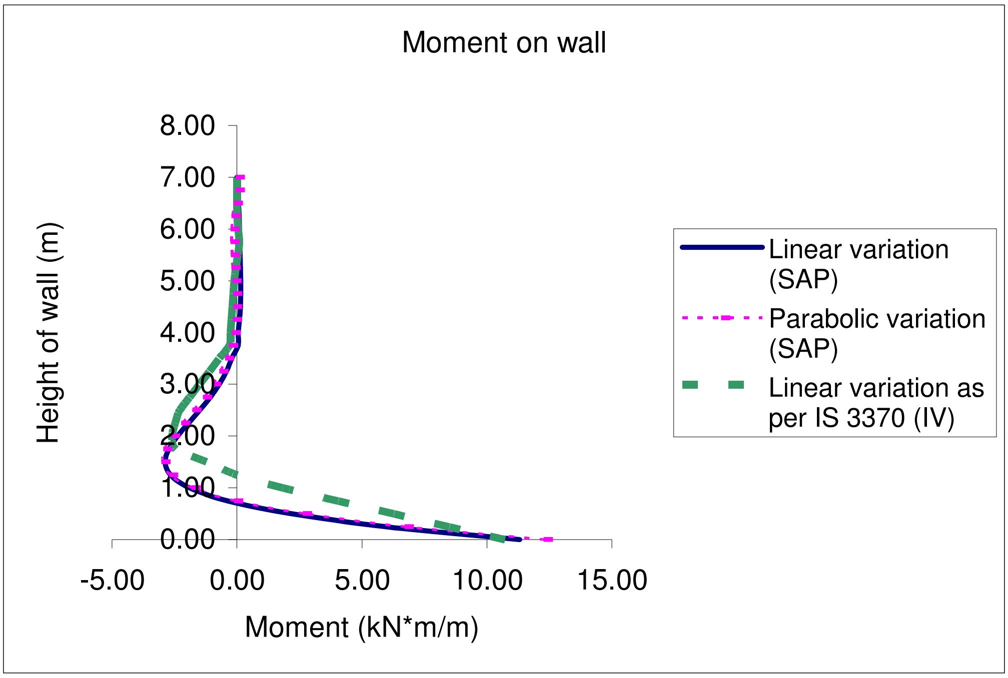
6.4.1 Comparison of Analysis Results for Base Fixed Top Free Condition

Modeling and analysis of tank wall in SAP2000 is carried out considering base fixed and top free condition. The tank is also analyzed considering linear variation of hydrostatic and hydrodynamic pressure as per design table given in IS: 3370 (part IV). A computer program is developed in C++ for calculating moment and tension in wall using coefficient of IS: 3370 (part IV). Finite element analysis is further carried out considering parabolic variation and equivalent linear variation of hydrostatic and hydrodynamic pressure. Analysis results in terms of moment and tension as obtained through finite element analysis and IS: 3370 (part IV) is presented in Table 6.1.

Table 6.1 Tension and moment results due to hydrodynamic pressure

Wall height (m)	Moment (kN-m/m)			Tension force (kN/m)		
	linear variation		parabolic variation	linear variation		parabolic variation
	FEM	IS 3370 (part IV)	FEM	FEM	IS 3370 (part IV)	FEM
0.00	11.31	10.73	12.33	-8.26	0.00	-8.28
0.25	5.99	8.51	6.76	-0.33	7.92	0.40
0.50	2.17	6.28	2.69	18.00	15.84	20.75
0.75	-0.38	4.06	-0.07	40.35	23.75	45.99
1.00	-1.90	1.84	-1.77	62.40	31.67	71.46
1.25	-2.66	0.02	-2.67	81.56	43.91	94.27
1.50	-2.87	-1.21	-2.97	96.50	62.65	112.85
1.75	-2.73	-2.44	-2.90	106.80	81.38	126.64
2.00	-2.38	-2.59	-2.59	112.66	92.45	135.71
2.25	-1.94	-2.47	-2.18	114.62	101.59	140.53
2.50	-1.49	-2.29	-1.73	113.37	108.84	141.76
2.75	-1.07	-1.89	-1.31	109.64	108.45	140.11
3.00	-0.71	-1.49	-0.95	104.12	108.07	136.28
3.25	-0.43	-1.09	-0.65	97.40	104.53	130.86
3.50	-0.21	-0.70	-0.43	89.94	98.88	124.33
3.75	0.04	-0.30	-0.27	82.12	93.23	117.08
4.00	0.04	-0.26	-0.17	74.19	85.69	109.36
4.25	0.11	-0.22	-0.12	66.32	78.15	101.34
4.50	0.14	-0.18	-0.10	58.61	70.53	93.11
4.75	0.15	-0.15	-0.11	51.13	62.81	84.71
5.00	0.15	-0.11	-0.13	43.88	55.09	76.13
5.25	0.14	-0.04	-0.16	36.87	47.74	67.33
5.50	0.13	0.04	-0.19	30.09	40.48	58.26
5.75	0.12	0.09	-0.21	23.52	33.29	48.87
6.00	0.10	0.05	-0.21	17.14	26.36	39.14
6.25	0.08	0.02	-0.17	10.93	19.44	29.07
6.50	0.06	0.00	-0.08	4.86	-0.08	18.72
6.75	0.02	0.00	0.00	-1.11	0.00	8.24
7.00	0.00	0.00	0.00	-7.59	0.00	-3.02

Moment and tension at various locations along the height due to hydrodynamic pressure for base fixed and top free condition are shown in Fig.6.8.



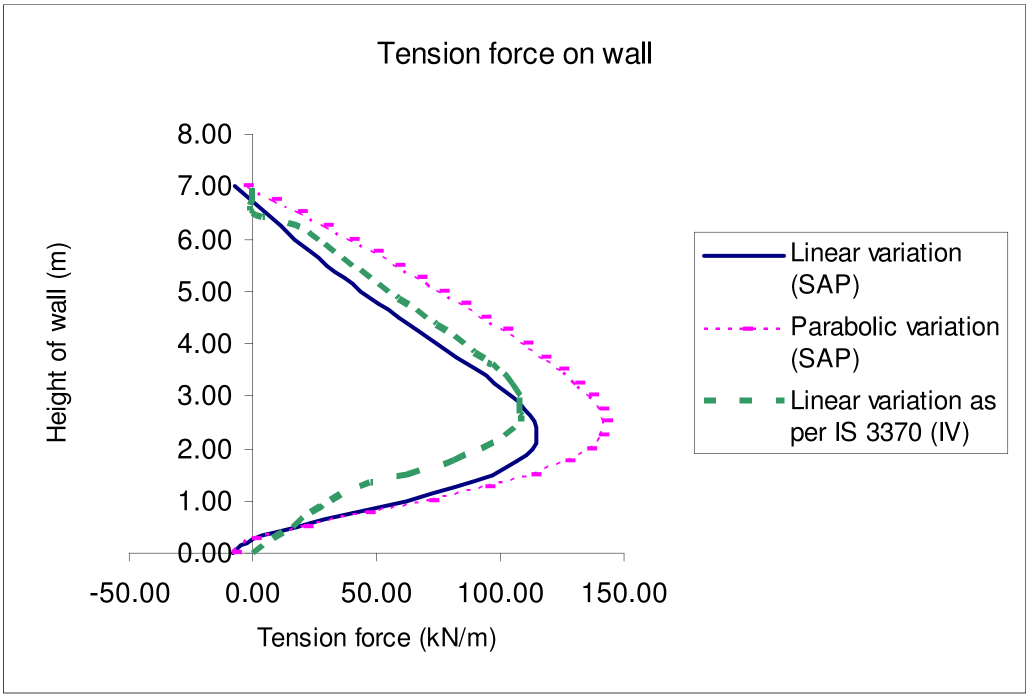


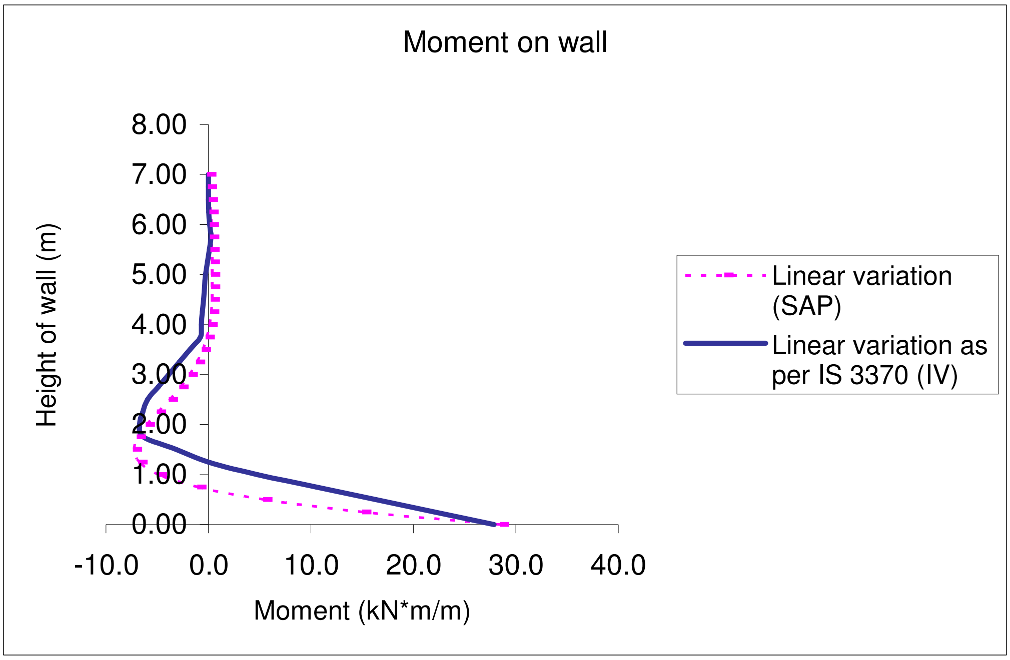
Fig. 6.8 Moments and tension forces due to hydrodynamic pressure

Hydrostatic pressure is linearly varying along the height of tank wall. Modeling and analysis of tank subjected to linearly varying pressure is carried out using SAP2000. Similar analysis is also carried out using IS: 3370 (part IV) design tables. Results for both the methods of analysis are as presented in Table 6.2.

Table 6.2 Tension and moment results due to hydrostatic pressure

Wall height (m)	Moment (kN-m/m)		Tension force (kN/m)	
	FEM	IS 3370 part IV	FEM	IS 3370 part IV
0.00	28.56	27.88	-8.51	0.00
0.25	15.14	22.11	11.07	20.58
0.50	5.48	16.33	56.95	41.16
0.75	-0.96	10.56	112.96	61.73
1.00	-4.82	4.78	168.22	82.31
1.25	-6.72	0.04	216.16	114.13
1.50	-7.25	-3.15	253.42	162.82
1.75	-6.89	-6.34	278.99	211.51
2.00	-6.01	-6.72	293.32	240.27
2.25	-4.91	-6.41	297.79	264.05
2.50	-3.76	-5.95	294.14	282.87
2.75	-2.71	-4.91	284.25	281.88
3.00	-1.80	-3.87	269.82	280.88
3.25	-1.08	-2.84	252.35	271.68
3.50	-0.53	-1.81	233.03	256.99
3.75	-0.14	-0.79	212.79	242.31
4.00	0.11	-0.69	192.27	222.71
4.25	0.27	-0.58	171.90	203.10
4.50	0.35	-0.48	151.96	183.32
4.75	0.37	-0.38	132.57	163.25
5.00	0.37	-0.28	113.79	143.18
5.25	0.35	-0.10	95.61	124.08
5.50	0.33	0.10	78.02	105.22
5.75	0.30	0.24	60.96	86.53
6.00	0.26	0.14	44.39	68.52
6.25	0.22	0.04	28.25	50.52
6.50	0.16	0.00	12.47	-0.22
6.75	0.06	0.00	-3.06	0.00
7.00	0.00	0.00	-19.43	0.00

Comparison of moment and tension at various locations along the height due to hydrostatic pressure is for base fixed top free condition is as shown Fig.6.9.



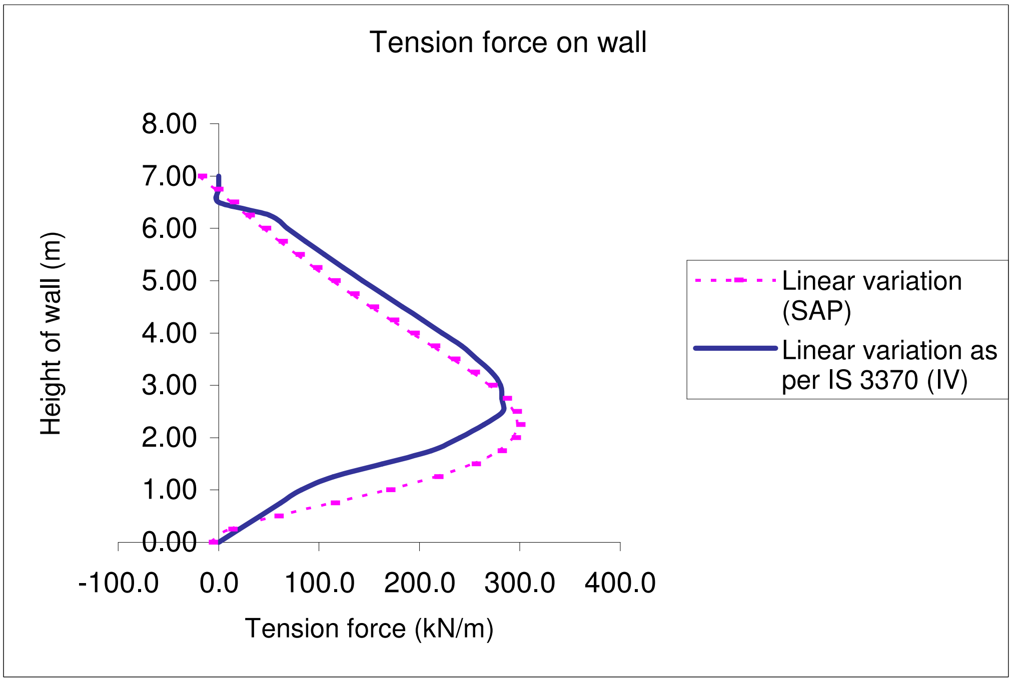


Fig. 6.9 Moment and tension forces due to hydrostatic pressure

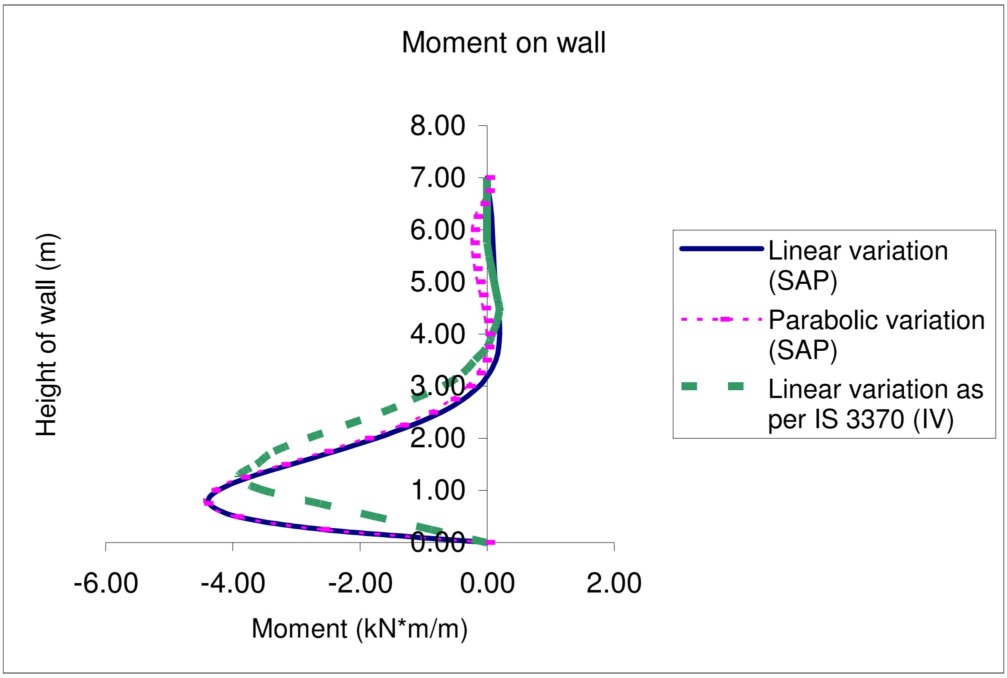
6.4.2 Comparison of Analysis Results for Base Hinged and Top Free Condition

Modeling and analysis of tank wall in SAP2000 is carried out considering base hinged and top free condition. The tank is also analyzed considering linear variation of hydrostatic and hydrodynamic pressure as per design table given in IS: 3370 (part IV). A computer program is developed in C++ for calculating moment and tension in wall using coefficient of IS: 3370 (part IV). Finite element analysis is further carried out considering parabolic variation and equivalent linear variation of hydrostatic and hydrodynamic pressure. Analysis results in terms of moment and tension as obtained through finite element analysis and IS:3370 (part IV) is presented in Table 6.3.

Table 6.3 Tension and moment results due to hydrodynamic pressure

Wall height	Moment (kN-m/m)			Tension force (kN/m)		
	linear variation		parabolic variation	linear variation		parabolic variation
(m)	FEM	IS 3370 (part IV)	FEM	FEM	IS 3370 (part IV)	FEM
0.00	0.00	0.00	0.00	-8.88	0.00	-8.95
0.50	-3.93	-1.75	-3.95	62.56	35.71	69.34
0.75	-4.37	-2.62	-4.43	90.14	53.57	100.28
1.00	-4.23	-3.50	-4.31	110.68	71.43	124.10
1.25	-3.75	-3.91	-3.85	124.33	88.56	140.89
1.50	-3.09	-3.63	-3.22	131.83	104.60	151.37
2.00	-1.75	-2.82	-1.90	132.64	125.39	157.49
2.50	-0.72	-1.65	-0.90	121.64	127.73	150.78
3.00	-0.13	-0.69	-0.31	105.54	116.29	137.83
3.25	0.04	-0.38	-0.14	96.93	109.12	130.35
3.50	0.14	-0.19	-0.05	88.37	100.99	122.62
3.75	0.18	0.00	-0.01	80.01	92.85	114.78
4.00	0.20	0.08	-0.01	71.95	84.66	106.91
4.25	0.19	0.16	-0.03	64.20	76.47	99.03
4.50	0.17	0.19	-0.06	56.77	68.53	91.10
4.75	0.15	0.15	-0.11	49.62	60.94	83.08
5.00	0.13	0.11	-0.15	42.72	53.36	74.87
5.25	0.11	0.07	-0.19	36.04	46.30	66.42
5.50	0.10	0.03	-0.23	29.54	39.38	57.66
5.75	0.09	0.00	-0.24	23.21	32.51	48.53
6.00	0.08	0.00	-0.23	17.03	25.91	39.01
6.25	0.07	0.00	-0.19	10.98	19.31	29.12
6.50	0.05	0.00	-0.08	5.05	0.00	18.93
7.00	0.00	0.00	0.00	-7.14	0.00	-2.53

Moment and tension at various locations along height due to only hydrodynamic pressure for base hinged and top free condition is as shown Fig.6.10.



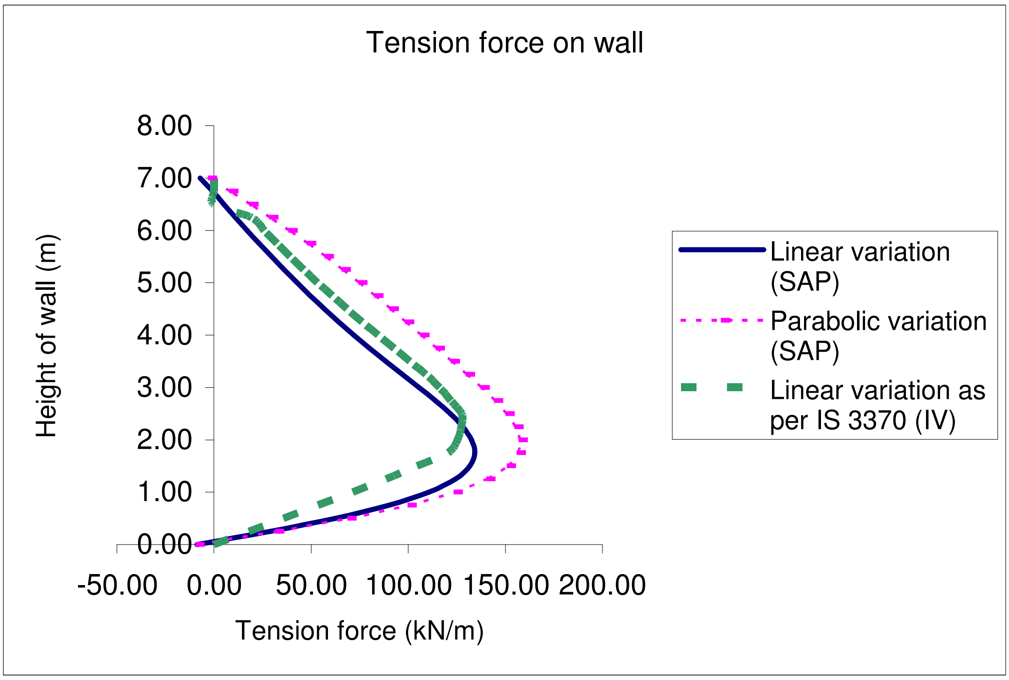


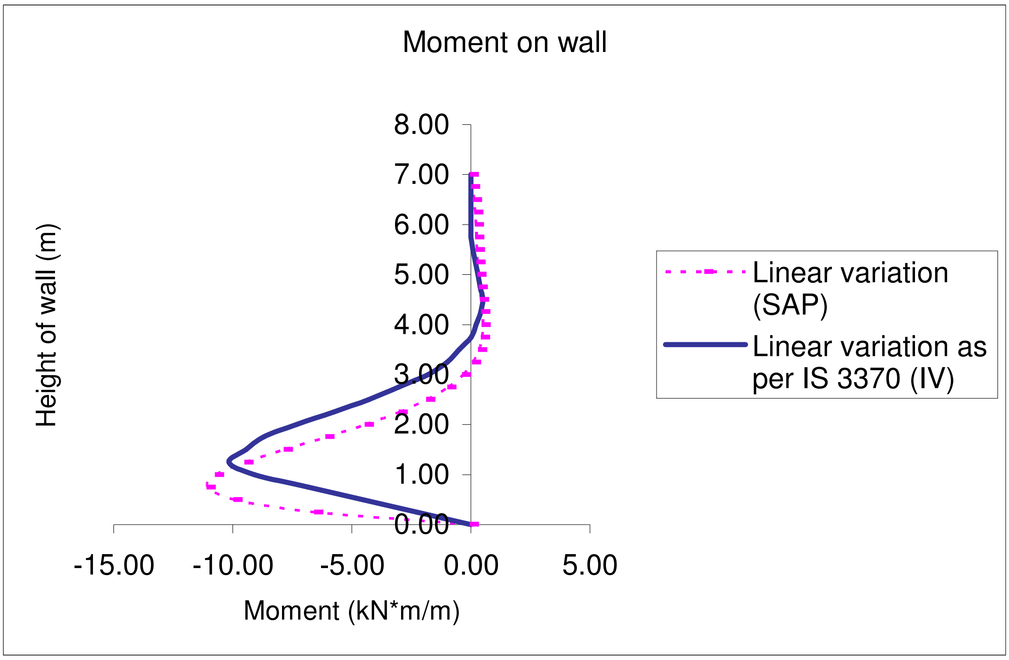
Fig. 6.10 Moments and tension forces due to hydrodynamic pressure

Hydrostatic pressure is acting linearly on the tank wall. Modeling in SAP2000 is done for linearly varying pressure considering base hinged and top free condition. Similar analysis is done by use of IS: 3370 (part IV). Analysis results for both method of analysis are as shown in Table 6.4.

Table 6.4 Tension and moment results due to hydrostatic pressure

Wall height (m)	Moment (kN-m/m)		Tension force (kN/m)	
	FEM	IS: 3370 (part IV)	FEM	IS: 3370 (part IV)
0.00	0.00	0.00	-10.06	0.00
0.25	-6.54	-2.27	84.63	46.41
0.50	-9.92	-4.54	169.53	92.82
0.75	-11.05	-6.82	238.77	139.23
1.00	-10.70	-9.09	290.19	185.64
1.25	-9.47	-10.16	324.20	230.16
1.50	-7.81	-9.43	342.68	271.85
1.75	-6.06	-8.71	348.27	313.55
2.00	-4.41	-7.32	343.79	325.90
2.25	-2.98	-5.77	331.94	330.92
2.50	-1.83	-4.28	315.05	331.97
2.75	-0.95	-3.04	295.06	317.11
3.00	-0.32	-1.80	273.42	302.24
3.25	0.10	-1.00	251.18	283.61
3.50	0.35	-0.49	229.05	262.47
3.75	0.47	0.01	207.45	241.32
4.00	0.50	0.21	186.60	220.04
4.25	0.48	0.42	166.56	198.76
4.50	0.44	0.50	147.30	178.10
4.75	0.38	0.39	128.77	158.40
5.00	0.33	0.29	110.87	138.69
5.25	0.29	0.19	93.52	120.35
5.50	0.25	0.08	76.63	102.34
5.75	0.23	0.00	60.18	84.50
6.00	0.21	0.00	44.10	67.34
6.25	0.19	0.00	28.37	50.18
6.50	0.14	0.00	12.95	0.00
6.75	0.06	0.00	-2.26	0.00
7.00	0.00	0.00	-18.29	0.00

Moment and tension at various locations along height due to only hydrostatic pressure is for base hinged and top free condition is as shown Fig.6.11.



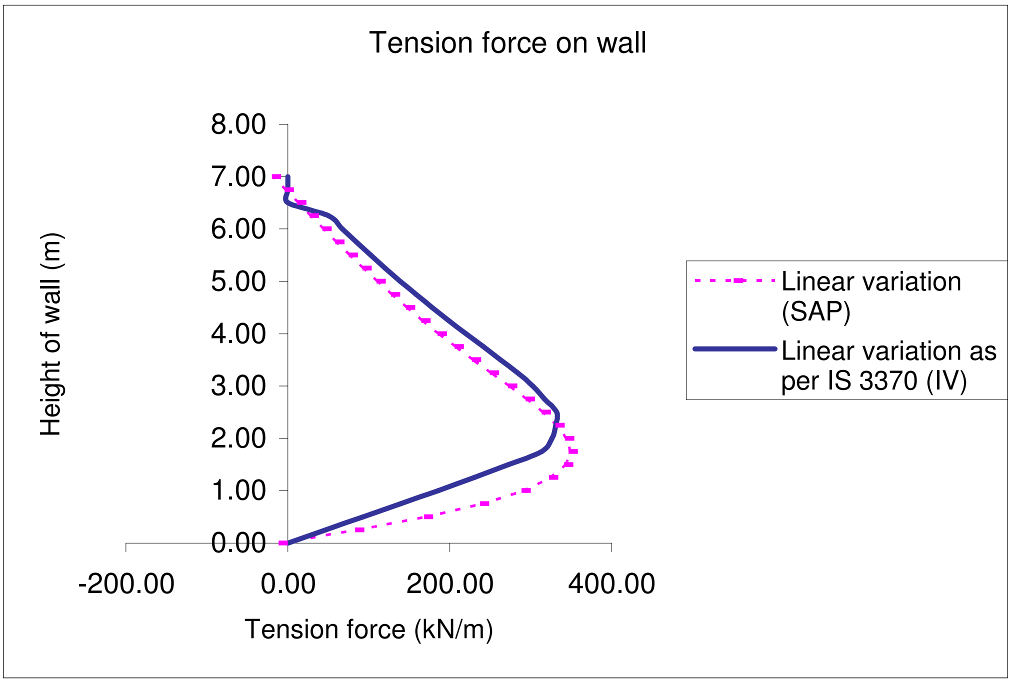


Fig 6.11 Moment and tension forces due to hydrostatic pressure

Form the comparison of results as presented in section 6.4.1 and 6.4.2, it is observed that tank wall with fixed base and free top gives higher bending moment, while tank wall with hinged base and free top gives higher tension. This trend is similar for both the finite element analysis and IS: 3370 (part IV).

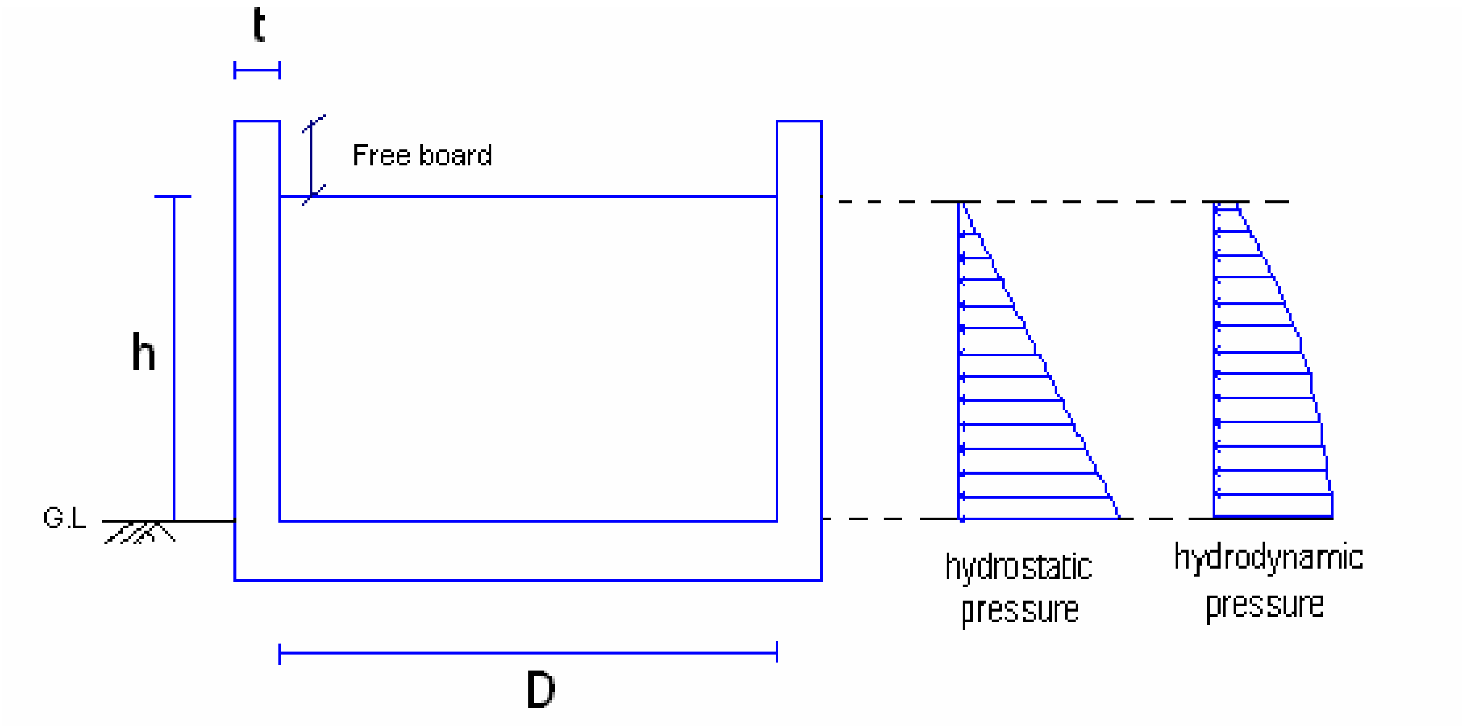
Finite element analysis considering parabolic variation of hydrodynamic pressure gives higher moment and tension compared to equivalent linear variation.

In case of hydrostatic pressure also finite element analysis gives marginally higher value of moment and tension in comparison to that obtained using IS 3370 (part IV) design table.

6.5 COMPARISON OF MAXIMUM MOMENT AND MAXIMUM TENSION FORCE

After detailed investigation of variation in moment and tension along the height of circular tank wall considering hydrostatic and hydrodynamic pressure using finite element method and IS: 3370 (part IV) design table for particular capacity, different capacity water tanks are considered in this section.

IS: 3370 (part IV) gives design tables of coefficients for determination of bending moment and tension at various locations of the circular tank wall. Coefficients of IS: 3370 (part IV) are applicable for linear variation only. Hydrostatic pressure is linear in nature but, hydrodynamic pressure is not linear. Hydrodynamic pressure is parabolic in nature as shown in Fig. 6.12. For calculation of bending moment and tension due to hydrostatic pressure IS:3370 (part IV) design tables can be used directly. For calculation of bending moment and tension due to hydrodynamic pressure finite element analysis is employed. Parametric study is carried out for various capacity circular tanks with height to diameter ratio varying from 0.1 to 0.5. Maximum moment and tension due to hydrostatic pressure are found as per IS: 3370 (part IV). Maximum moment and tension due to hydrostatic plus hydrodynamic pressure are found using SAP2000. Results are compared and % increase in moment and tension forces is presented Table.6.5 to Table 6.10. The results are shown in graphical form in as per Fig. 6.13 to Fig 6.17.



Earthquake zone = 5

Soil type = soft soil

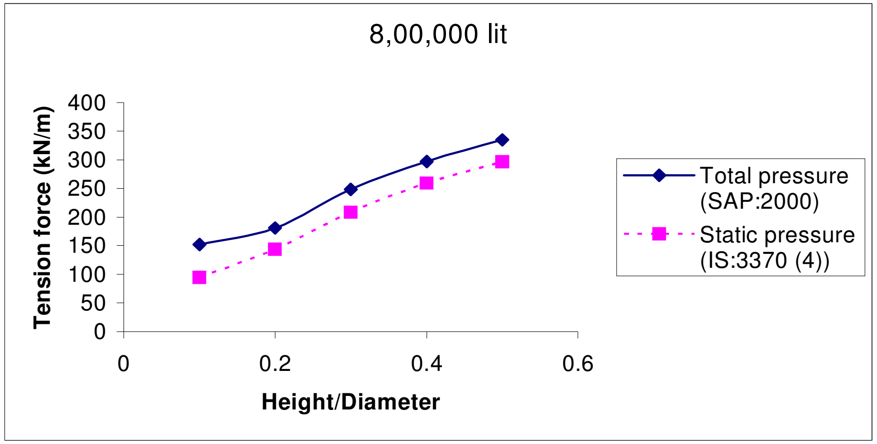
Thickness of wall (t) = 0.250 m

Thickness of base slab = 0.4 m

Fig. 6.12 Pressure distribution on tank wall

Table 6.5 Maximum tension and maximum moment results for 8, 00,000 liter capacity tank

Capacity	h/D	Height (m)	Diameter (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Total pressure (kN/m^2)	Tension force (kN/m)			Moment (kN*m/m)		
							Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase	Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase
8,00,000 lit	0.10	2.16	21.68	21.19	10.23	31.42	94.61	151.91	60.56	7.57	10.38	37.08
	0.20	3.44	17.20	33.75	14.62	48.36	143.43	181.01	26.21	14.32	16.86	17.75
	0.30	4.51	15.03	44.24	18.20	62.44	208.17	248.27	19.27	18.68	21.46	14.92
	0.40	5.46	13.65	53.56	21.24	74.80	259.24	296.94	14.54	21.90	24.49	11.80
	0.50	6.33	12.67	62.10	23.76	85.86	296.45	334.98	13.00	24.74	29.31	18.43



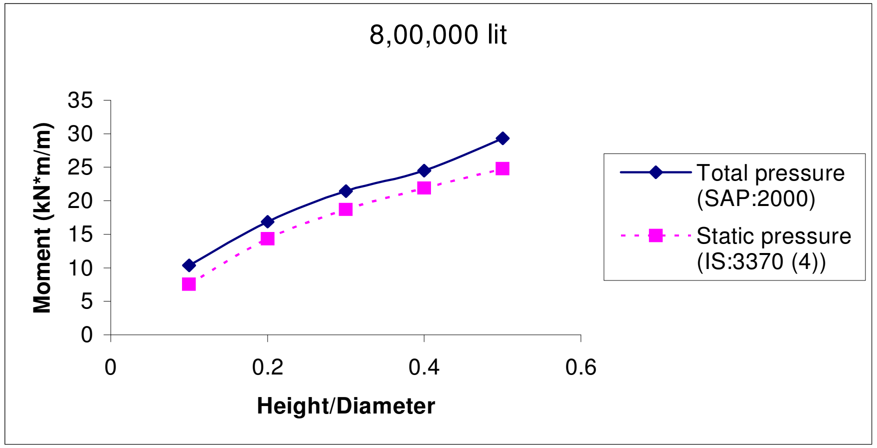
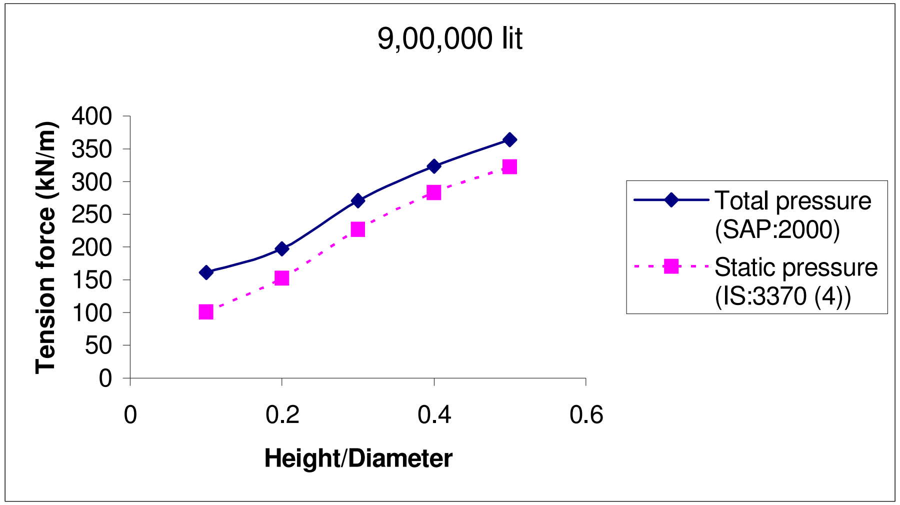


Fig. 6.13 Maximum moments and tension force for 8, 00,000 liter capacity

Table 6.6 Maximum tension and maximum moment results for 9, 00,000 liter capacity tank

Capacity	h/D	Height (m)	Diameter (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Total pressure (kN/m^2)	Tension force (kN/m)			Moment (kN*m/m)		
							Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase	Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase
9,00,000 lit	0.10	2.25	22.54	22.07	10.56	32.63	100.76	161.17	59.96	8.35	11.27	34.89
	0.20	3.57	17.89	35.02	15.09	50.11	152.37	197.26	29.46	15.01	18.31	21.96
	0.30	4.69	15.63	46.01	18.85	64.86	226.83	270.57	19.29	20.24	23.27	15.00
	0.40	5.68	14.20	55.72	22.02	77.74	282.85	322.99	14.19	23.90	26.55	11.08
	0.50	6.59	13.18	64.65	24.66	89.31	322.29	364.12	12.98	26.88	29.06	8.10



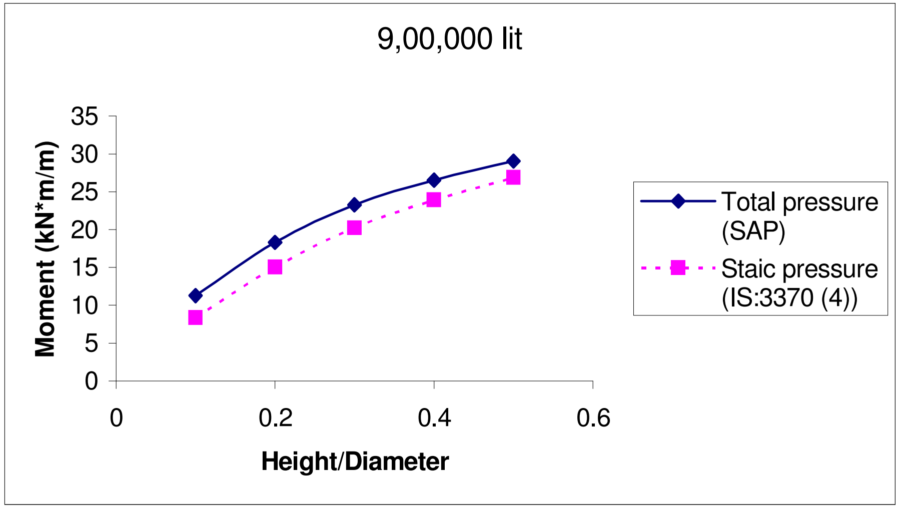
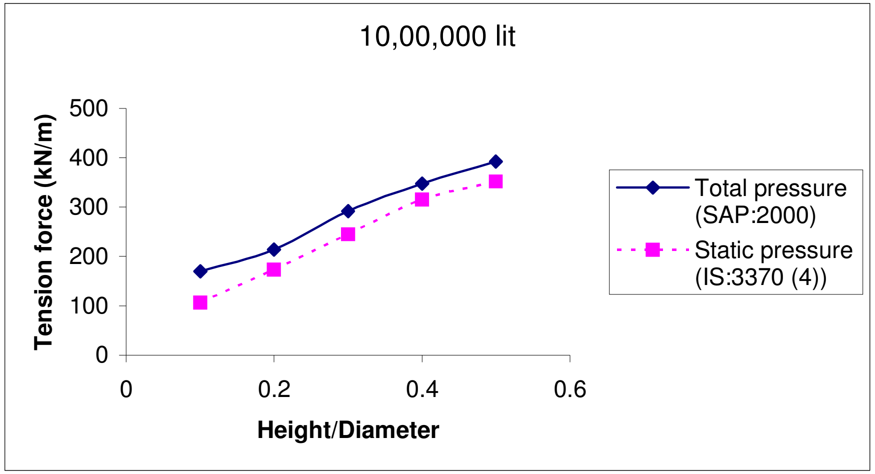


Figure 6.14 Maximum moments and tension force for 9, 00,000 liter capacity

Table 6.7 Maximum tension and maximum moment results for 10, 00,000 liter capacity tank

Capacity	h/D	Height (m)	Diameter (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Total pressure (kN/m^2)	Tension force (kN/m)			Moment (kN*m/m)		
							Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase	Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase
10,00,000 lit	0.10	2.33	23.35	22.86	10.85	33.71	106.50	169.88	59.51	9.08	12.11	33.40
	0.20	3.70	18.53	36.30	15.56	51.86	173.03	213.97	23.66	16.78	19.79	17.94
	0.30	4.85	16.19	47.58	19.43	67.01	244.97	291.61	19.04	21.67	24.99	15.32
	0.40	5.88	14.71	57.68	22.73	80.42	315.28	347.71	10.29	25.76	28.51	10.68
	0.50	6.92	13.65	67.89	24.48	92.37	351.64	392.25	11.55	29.23	31.17	6.65



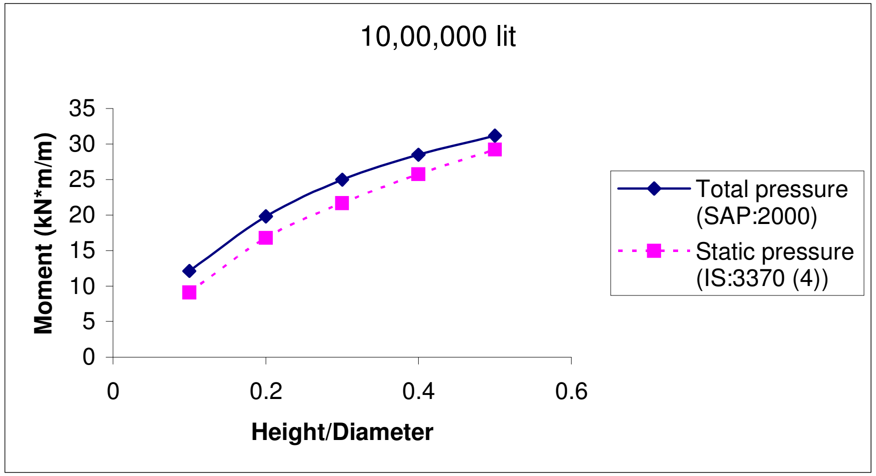
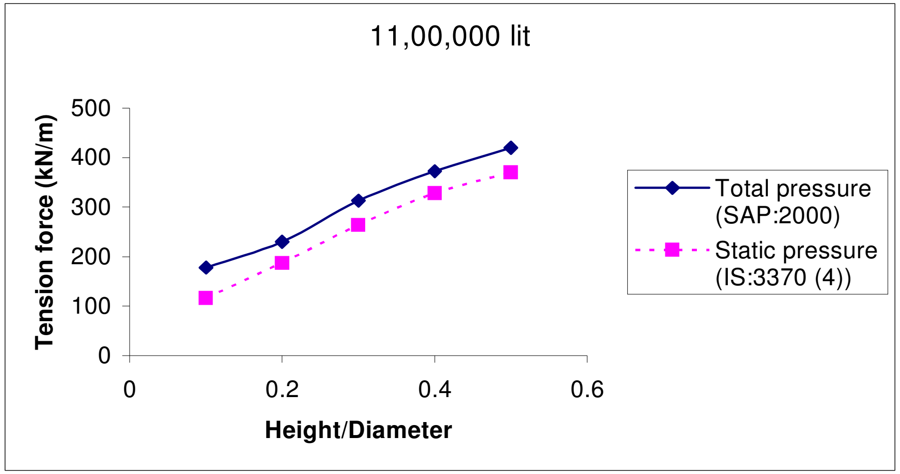


Fig. 6.15 Maximum moments and tension force for 10, 00,000 liter capacity

Table 6.8 Maximum tension and maximum moment results for 11, 00,000 liter capacity tank

Capacity	h/D	Height (m)	Diameter (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Total pressure (kN/m^2)	Tension force (kN/m)			Moment (kN*m/m)		
							Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase	Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase
11,00,000 lit	0.10	2.41	24.10	23.64	11.14	34.78	116.16	177.98	53.23	9.18	12.97	41.20
	0.20	3.82	19.13	37.47	15.99	53.47	187.13	230.01	22.91	18.03	21.20	17.62
	0.30	5.01	16.71	49.15	20.00	69.15	264.13	312.82	18.44	23.05	26.70	15.85
	0.40	6.07	15.18	59.55	23.41	82.95	327.76	372.39	13.62	27.53	30.41	10.43
	0.50	7.04	14.09	69.06	26.23	95.29	370.31	419.84	13.37	30.67	33.24	8.37



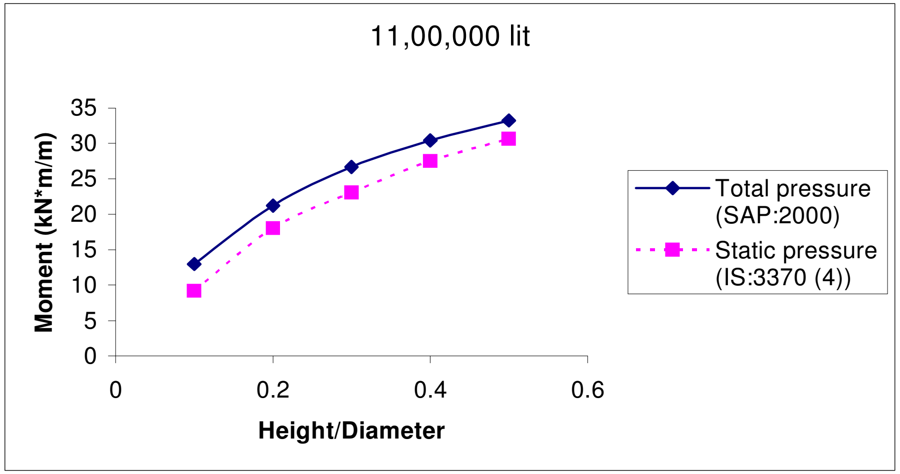
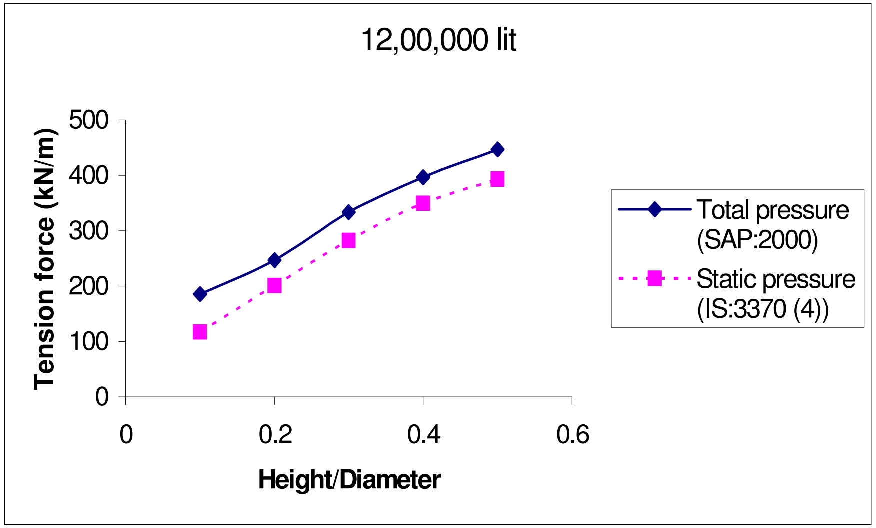


Fig. 6.16 Maximum moments and tension force for 11, 00,000 liter capacity

Table 6.9 Maximum tension and maximum moment results for 12, 00,000 liter capacity tank

Capacity	h/D	Height (m)	Diameter (m)	Hydrostatic pressure (kN/m^2)	Hydrodynamic pressure (kN/m^2)	Total pressure (kN/m^2)	Tension force (kN/m)			Moment (kN*m/m)		
							Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase	Static pressure IS:3370 (4)	Total pressure (SAP)	% Increase
12,00,000 lit	0.10	2.48	24.81	24.33	11.40	35.72	117.11	185.66	58.54	10.51	13.77	30.94
	0.20	3.94	19.69	38.65	16.43	55.08	201.00	246.57	22.67	19.38	22.64	16.80
	0.30	5.16	17.20	50.62	20.54	71.16	282.17	333.43	18.17	24.67	28.37	14.97
	0.40	6.25	15.63	61.31	24.05	85.36	349.76	396.66	13.41	29.23	32.28	10.45
	0.50	7.25	14.51	71.12	26.96	98.08	393.05	447.01	13.73	32.64	35.28	8.10



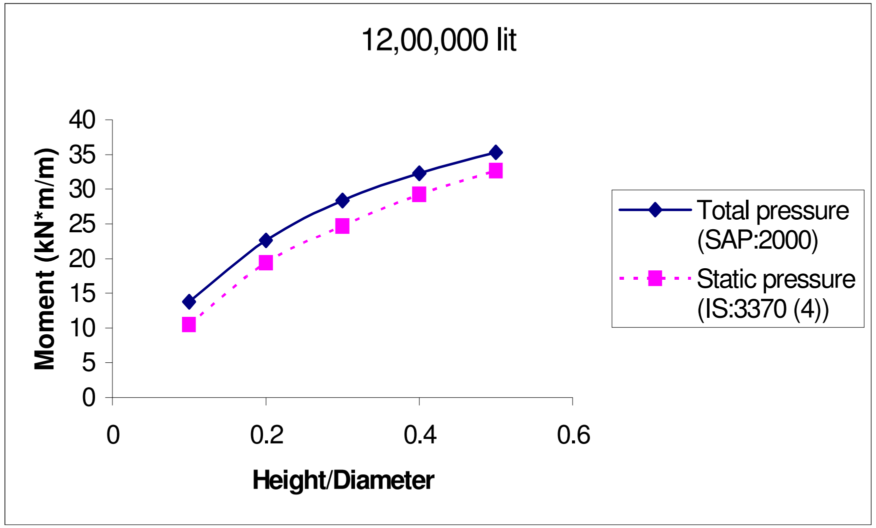


Fig. 6.17 Maximum moments and tension force for 12, 00,000 liter capacity

6.6 DESIGN EXAMPLE OF CIRCULAR TANK

The procedure for design of circular tank considering hydrostatic pressure and hydrodynamic pressure as per IS:1893 (part II) draft code is illustrated by an example of in this section.

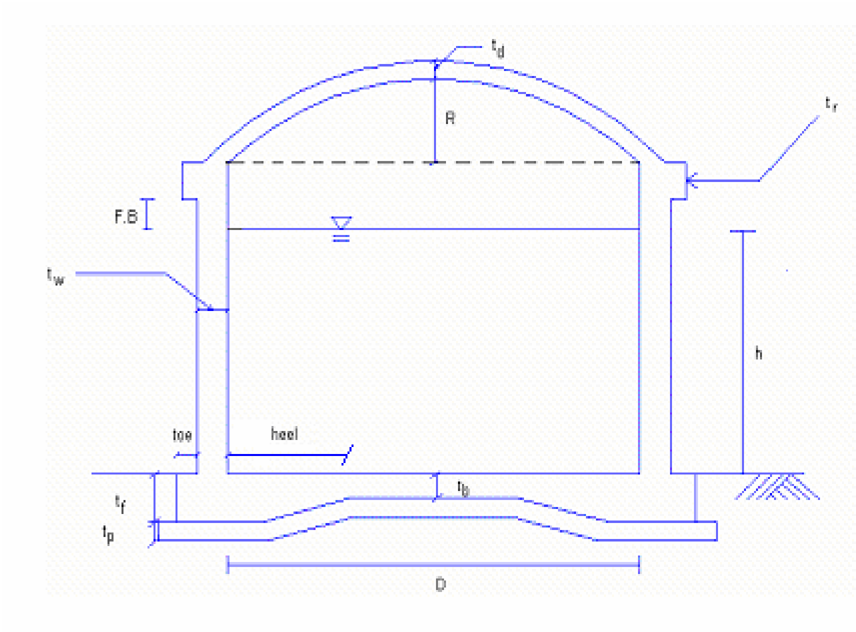


Fig. 6.18 Circular tank

Capacity of tank	= 10,00,000 lit
Diameter of tank (D)	= 14 m
Height of water in tank (h)	= 6.5 m
Height of free board (F.B)	= 0.5 m
Total height of tank wall (H)	=7 m
Height of soil (h_s)	= 0 m
Thickness of wall (t_w)	= 250 mm
Thickness of dome (t_d)	= 120 mm
Rise of dome	= 2.5 m
Top ring beam(t_r)	= 300X300 Top ring beam
Thickness of footing(t_f)	= 540 mm
Thickness of base slab (t_b)	= 250 mm
toe	= 0.3 m
heel	= 1.95 m
Thickness of p.c.c (t_p)	= 100 mm thick pcc

Weight Calculation

Weight of tank wall = 1959.38 kN

Mass of tank wall (m_w) = 199732 kg

Mass of base slab = 168396 kg

Volume of water = 10,00,000 lit

Parameters of Spring Mass Model

$$\frac{m_i}{m} = \frac{\tanh 0.866(D/h)}{0.866(D/h)}$$

$m_i/m = 0.511$

Impulsive mass (m_i) = 511014 kg

$h_i / h = 0.375$ for h/D <= 0.75

$= 0.5 - \frac{0.09375}{h/D}$ for h/D > 0.75

h_i = 2.44 meter

$$\frac{h_i *}{h} = \frac{0.866(D/h)}{2 * \tanh 0.866(D/h)} - 0.125$$ for h/D <= 1.33

=0.45 for h/D > 0.75

h_i* = 5.55 meter

$$\frac{m_c}{m} = 0.23 \frac{\tanh 3.68(h/D)}{h/D}$$

m_c = 463914 kg

$$\frac{h_c}{h} = 1 - \frac{\cosh(3.68h/d) - 1}{(3.68h/D)\sinh(3.68h/D)}$$

h_c = 3.86 meter

$$\frac{h_c *}{h} = 1 - \frac{\cosh(3.68h/d) - 2.01}{(3.68h/D)\sinh(3.68h/D)}$$

h_c* = 5.30 meter

Time Period Calculation

Time period in impulsive mode

$$T_i = Ci \frac{h\sqrt{\rho}}{\sqrt{t/D}\sqrt{E}} \qquad = 0.04 \text{ sec}$$

Where,

$$Ci = \left(\frac{1}{\sqrt{h/D}(0.46 - 0.3(h/D) + 0.067\,(h/D)^2} \right)$$

E = young's modulus

$= 5{,}000\sqrt{f_{ck}}$

Time period for convective mode,

$$T_c = Cc\sqrt{\frac{D}{g}} \qquad = 4.04 \text{ sec}$$

$$Cc = \frac{2\pi}{\sqrt{3.68\tanh(3.68h/D)}}$$

Design Horizontal Seismic Coefficient

Design horizontal seismic coefficient for impulsive mode,

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right)_i$$

= 0.34

Design horizontal seismic coefficient for convective mode,

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right)_c$$

= 0.1

Base Shear

Base shear at the bottom of wall in impulsive mode,

$V_i = (Ah)_i\,(m_i + m_w + m_t)\,g$ = 2388.76 kN

Base shear at the bottom of wall in convective mode,

$V_i = (Ah)_c(m_c)\,g$ = 443.89 kN

Total base shear at bottom of wall

$$V = \sqrt{Vi^2 + Vc^2}$$

= 2429.65 kN

Moment at Bottom of Wall

Bending moment at bottom of wall in impulsive mode,

$M_i = (A_h)_i (m_i h_i + m_w h_w + m_t h_t)g$ = 6696.08 kN.m

Bending moment at bottom of wall in convective mode,

$M_c = (A_h)_c m_c h_c g$ = 1714.52 kN-m

Total bending moment at bottom of wall,

$$M = \sqrt{M_i^2 + M_c^2}$$

= 6912.1 kN-m

Overturning Moment at Bottom of Base Slab

Overturning moment at bottom of base slab impulsive mode,

$M_i^* = (A_h)_i[m_i(h_i^*+t_b)+ m_w(h_w+t_b)+ m_t(h_t+t_b)+(m_b t_b/2)]g$ = 12774.3 kN.m

Overturning moment at bottom of base slab convective mode,

$M_c^* = (A_h)_c m_c(h_c^*+t_b)g$ = 2530.9 kN.m

Total bending moment at bottom of wall,

$$M^* = \sqrt{M_i^{*2} + M_c^{*2}}$$

=13022.6 kN.m

$P/A + M^*/Z$ =139.82 kN/m^2 < S.B.C (150 kN/m^2)

Safe in overturning

$P/A - M^*/Z$ =43.094 kN/m^2 > 0

Safe in uplifting

Hydrodynamic Pressure

Lateral hydrodynamic impulsive pressure on the wall P_{iw} is given by,

$p_{iw} = Q_{iw}(y)(A_h)_i \rho g\, h \cos\varphi$

Where,

$$Q_{iw}(y) = 0.866\left[1-\left(\frac{y}{h}\right)^2\right]\tanh\left(0.866\,\frac{D}{h}\right)$$

p_{iw} = 17.76 kN/m^2

Impulsive hydrodynamic pressure in vertical direction, on base slab (y = 0)

$$p_{ib} = 0.866\,(A_h)_i\,\rho g h\,\frac{\sinh\left(0.866\,\frac{x}{h}\right)}{\cosh\left(0.866\,\frac{l'}{h}\right)}$$

=13.64 kN/m^2

Lateral hydrodynamic convective pressure on the wall P_{cw} is given by,

$$p_{cw} = Q_{cw}(y)(A_h)_c\,\rho g D\left[1-\frac{1}{3}\cos^2\phi\right]\cos\phi$$

where,

$$Q_{cw}(y) = 0.5625\,\frac{\cosh\left(3.674\,\frac{y}{D}\right)}{\cosh\left(3.674\,\frac{h}{D}\right)}$$

p_{cw} = 1.78 kN/m^2 (y = 0)

p_{cw} = 5.05 kn/m^2 (y = h)

Convective hydrodynamic pressure in vertical direction, on base slab (y = 0)

$$p_{cb} = Q_{cb}(x)(A_h)_c\,\rho g D$$

Where,

$$Q_{cb}(x) = 1.125\left[\frac{x}{D}-\frac{4}{3}\left(\frac{x}{D}\right)^3\right]\sec h\left(3.674\,\frac{h}{D}\right)$$

p_{cb} = 1.99 kN/m^2

Equivalent linear pressure distribution,

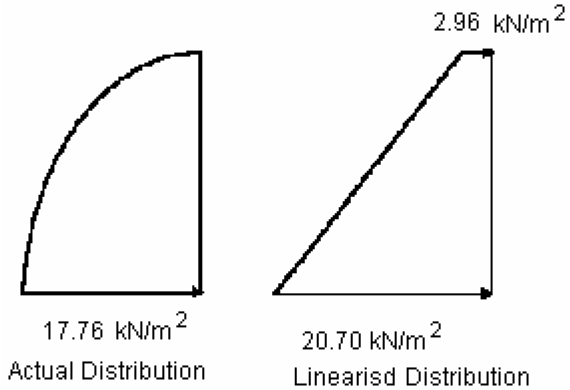
Base shear due to impulsive liquid mass per unit circumferential length,

$$q_i = \frac{(A_h)_i m_i}{\pi D/2}g \quad = 76.90 \text{ kN/m}$$

Pressure at bottom and top is given by

$$a_i = \frac{q_i}{h^2}(4h-6h_i) \quad = 20.70 \text{ kN/m}^2$$

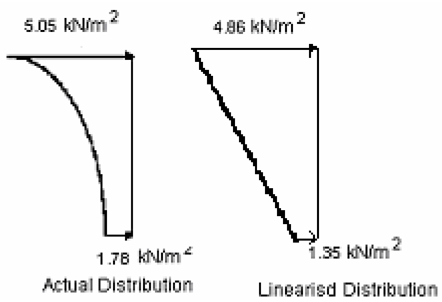
$$b_i = \frac{q_i}{h^2}(6h_i-4h) \quad = 2.96 \text{ kN/m}^2$$



$q_C = \frac{(A_h)_c m_c}{\pi D/2} g$ = 20.18 kN/m

$a_c = \frac{q_c}{h^2}(4h - 6h_c)$ = 1.35 kN/m^2

$a_c = \frac{q_c}{h^2}(6h - 2h_c)$ = 4.86 kN/m^2



Pressure Due To Wall Inertia

$p_{ww} = (A_h)_i t \rho_m g$ = 2.11 kN/m^2

Pressure Due To Vertical Excitation

$P_v = (A_v)\rho\ g\ h\ (1\text{-}y/d)$

Where,

$A_v = (2/3)\ (z/2)\ (I/R)\ (S_a/g)$

P_v = 14.34 kN/m^2

Maximum Hydrodynamic Pressure

$$p = \sqrt{(p_{iw} + p_{ww})^2 + p_{cw}^2 + p_v^2}$$

p = 24.58 kN/m^2

Design of Tank Wall

σ_{cbc} = 10.0 N/mm^2

m = 9.33

σ_{st} = 150.0 N/mm^2

k_c = 0.38

j = 0.87

R = 1.67

Table 6.10 Maximum tension force (bottom hinged and top free)

Height of wall (m)	Tension force kN/m			Hoop steel (mm^2)	Min steel (mm^2)
	Hydrodynamic	Hydrostatic	Total*0.75		
0.00	-8.95	-10.06	-14.26	95.05	570
0.50	69.34	169.53	179.15	1194.35	570
1.00	124.10	290.19	310.72	2071.45	570
1.50	151.37	342.68	370.54	2470.25	570
2.00	157.49	343.79	375.96	2506.40	570
2.50	150.78	315.05	349.37	2329.15	570
3.00	137.83	273.42	308.44	2056.25	570
3.50	122.62	229.05	263.75	1758.35	570
4.00	106.91	186.60	220.13	1467.55	570
4.50	91.10	147.30	178.80	1192.00	570
5.00	74.87	110.87	139.31	928.70	570
5.50	57.66	76.63	100.72	671.45	570
6.00	39.01	44.10	62.33	415.55	570
6.50	18.93	12.95	23.91	159.40	570
7.00	-2.53	-18.29	-15.62	104.10	570

h1 = 3 m, provide 16 mm dia bar rings @150 mm c/c

h2 = 2m, provide 20 mm dia bar rings @120 mm c/c

h3 = 2m, provide 20 mm dia bar rings @120 mm c/c

Steel quantity (rings) = 10175.17 kg

Table 6.11 Maximum moment (bottom fixed and top free)

Height of wall (m)	Moment kN-m/m			Vertical Steel (mm^2)	Min steel (mm^2)
	Hydrodynamic	Hydrostatic	Total*0.75		
0.00	12.33	28.56	30.67	1065.58	570
0.50	2.69	5.48	6.13	212.87	570
1.00	-1.77	-4.82	-4.94	171.74	570
1.50	-2.97	-7.25	-7.67	266.44	570
2.00	-2.59	-6.01	-6.45	224.23	570
2.50	-1.73	-3.76	-4.12	143.20	570
3.00	-0.95	-1.80	-2.06	71.69	570
3.50	-0.43	-0.53	-0.72	25.01	570
4.00	-0.17	0.11	-0.04	1.50	570
4.50	-0.10	0.35	0.18	6.38	570
5.00	-0.13	0.37	0.18	6.21	570
5.50	-0.19	0.33	0.10	3.41	570
6.00	-0.21	0.26	0.04	1.27	570
6.50	-0.08	0.16	0.06	2.02	570
7.00	0.00	0.00	0.00	0.02	570

h1 = 3 m

16 mm dia vertical bar @185 mm c/c

h2 = 2m

12 mm dia vertical bar @125 mm c/c

h3 = 2m

12 mm dia vertical bar @125 mm c/c

Ld = Development length

Steel quantity (vertical) = 2880.24 kg

Concrete quantity of wall = 84.88 m^3

6.7 Computer Program for Roof and Base Slab Design

An interactive computer program is developed using C++ for analysis and design of top dome and base slab.

6.7.1 Program for Design of Top Dome and Top Ring Beam

Enter the grade of concrete (M-?)	:30
Enter the grade of steel (Fe-?)	:415
Enter the thickness of dome in mm	:120
Thickness selected is	:120 mm
Enter the dia of tank in meter	:14
Rise of dome required	:2.52
Enter the rise of top dome	:2.5
Enter the ht. of container	:7
The rise of top dome is	:2.5 m.
The ht. of container is	:7m.
Enter the LL load on dome in kN/m^2	:1.2
Angle of dome with vertical is	:39.32 degree
Radius of dome is	:11.05 meter
Meridional stress is	:0.22 N/mm^2
Hoop stress is	:0.083 N/mm^2
Meridional stresses are within safe limit	
Circumferential Stresses are within safe limit	
Minimum Ast. is sufficient	
Ast. Required	:360 mm^2
For user dia - 1	

Default dia.(8 mm) - 2

2

8 mm dia. bars are used

Spacing required is 139.62 mm c/c

For user spacing - 1

Obtained spacing is to be provided - 2

1

Enter the spacing in mm :135

Provide 8mm dia. bars @ 135 mm c/c spacing both ways

Steel quantity is :1694.05 kg

Concrete quantity is :37.36m^3

Hoop tension on top ring beam is :145.09 kN

For user dia. of bars for top ring beam - 1

Default (12mm dia) - 2

2

----

12 mm dia. bars are selected for top ring beam

Provide 10 bars of 12 mm dia.

Width and depth require for top ring beam are 300 mm 300 mm

Provide distribution steel of 8 mm @ 200 mm c/c

Quantity of steel for ring beam is :474.63 kg

Quantity of concrete for ring beam is :3.93 m^3

6.7.2 Program for Design of Base Slab

Enter weight of circular (tank wall + roof) in kN :2612.56

Enter internal diameter of tank in meter :14

Enter thickness of tank wall in meter :0.25

Enter max moment at wall base in kN-m/m

(Maximum of soil pressure or water pressure) :30.67

Enter soil density in kN/m^3 :18

Enter height of soil in meter :0

Enter maximum water height in tank in meter :6.5

Enter soil bearing capacity in kN/m^2 :150

Footing length : 2.5 meter

Length of toe :0.3 meter

Length of heel :1.95 meter

Design moment

Select concrete grade

1: M 30

2: M 35

3: M 40

4: M 45

5: M 50

2

Select steel

1: plain round mild steel bars

2: high strength deform bars

2

Effective depth required for footing in mm :294.67

Enter effective depth provided in mm :300

Enter concrete cover in mm :50

Total depth of footing of base slab :350

Area of steel required for footing :400 mm^2

Enter bar diameter in mm :10

Provide 10 mm dia bar mesh (as form of rings and radial bars)
in two layer 195 mm c/c

Quantity of concrete for wall footing is 32.12 m^3

Quantity of steel for wall footing is 1289.96 kg

Enter total depth of base slab (middle portion of base slab) in mm

250

Area of steel required for middle portion of slab :285.71 mm^2

Enter bar diameter in mm :8

Provide 8 mm dia bar mesh in two layer 175 mm c/c

Quantity of concrete for base slab 18.95 m^3

Quantity of steel for wall footing is 686.56 kg

Total quantity of steel = 18920.67 kg

Total quantity of concrete is = 177.24 m^3

Structural cost of tank per lit =1.01 Rs

Total cost as per s.o.r of G.W.S.S.B = 1.37 Rs

The standard reinforcement detailing of ground supported circular tank is shown in Fig.6.19.

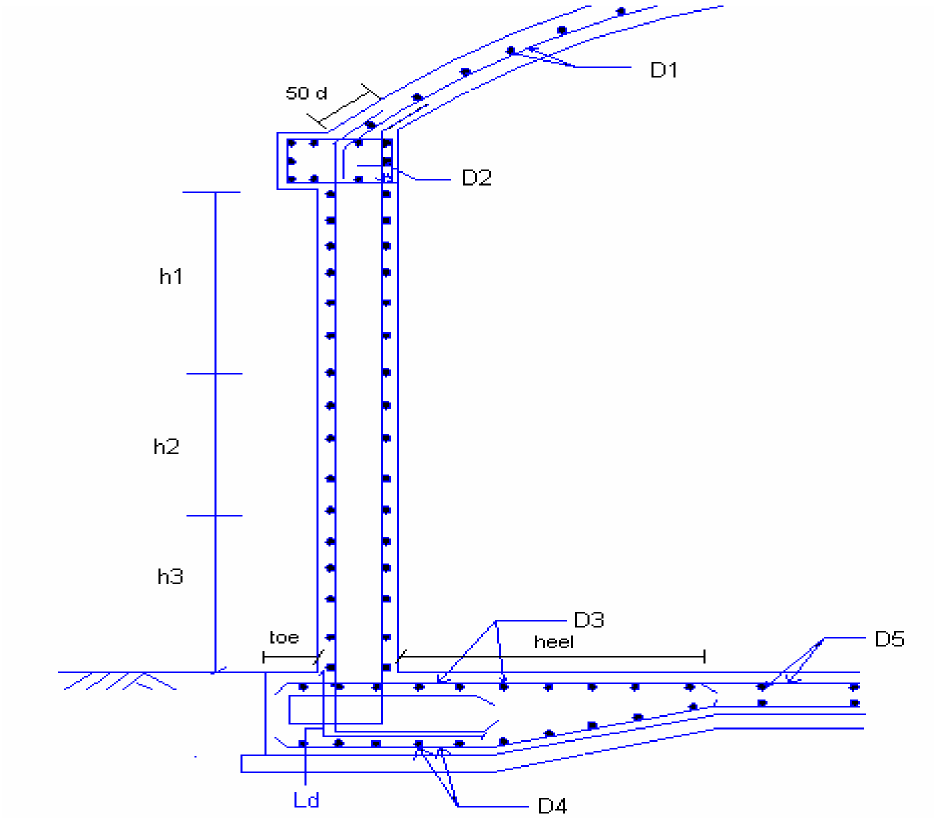


Fig. 6.19 Detailing in circular tank

D1 = 8 mm dia bars @ 135 mm c/c

D2 = 10 bars of 12 mm dia

D3 = 10 mm dia bar @ 195 mm c/c mesh as form of radial and rings

D4 = 10 mm dia bar @ 195 mm c/c mesh as form of radial and rings

D5 = 8 mm dia bar @ 175 mm c/c mesh in two layers

toe = 0.3 m

heel = 1.95 m

6.8 PARAMETRIC STUDY FOR ECONOMICAL CONFIGURATION

Design of water tank with capacity varying from 8,00,000 liters to 12,00,000 liters with height to diameter ratio 0.1 to 0.5 is carried out. From quantity of concrete and steel the cost of water tank is calculated considering rate of materials as per S.O.R of G.W.S.S.B. Reinforcement detail of various elements of covered circular tank and structural cost per liter is presented in Table 6.12. The variation in cost per liter with height to diameter ratio for different capacity tank is shown in Fig. 6.20.

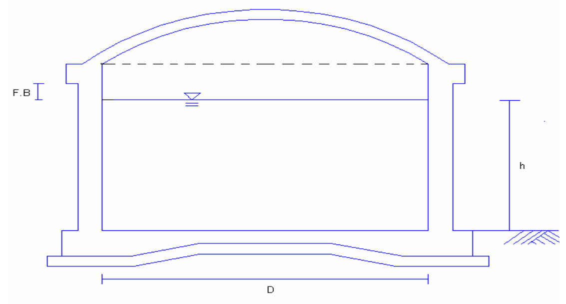


Table 6.12 Parametric study of design for circular water tank

Capacity	h/D	h (m)	D (m)	Dome				Ring beam				Tank Wall												Wall footing						Base slab			Rate	
				Thickness (mm)	Rise (m)	Detailing Both way		Section (mXm)	Reinforce detail		Thickness (mm)	Reinforcement (rings)						Reinforcement (vertical)						Length (m)	Toe (m)	Heel (m)	Thickness (mm)	Reinforcement (Rings & Radial)		Thickness (mm)	Detailing Both way		Rs/lit	S.O.R of GWSSB
												h1		h2		h3		h1		h2		h3												
						Dia mm	c/c mm		Nos	Dia (mm)		Dia mm	c/c mm	Dia mm	c/c mm	Dia mm	c/c mm	Dia mm	c/c mm	Dia mm	c/c mm	Dia mm	c/c mm					Dia mm	c/c mm		Dia (mm)	C/C mm		
	0.1	2.16	21.68	100	4	8	160	0.43X0.43	12	16	250	12	125	12	110	12	125	12	150	12	150	12	140	1	0.3	0.45	350	10	195	250	8	175	1.14	
	0.2	3.44	17.2	100	3	8	160	0.35X0.35	8	16	250	16	160	16	160	16	180	12	150	12	150	12	120	1	0.3	0.45	350	10	195	250	8	175	0.98	
8,00,000	0.3	4.51	15.03	100	2.7	8	165	0.3X0.3	10	12	250	16	150	16	120	16	150	12	150	12	125	12	95	1.3	0.3	0.75	350	10	195	250	8	175	0.77	1.40
	0.4	5.46	13.65	80	2.5	8	200	0.25X0.25	8	12	250	15	150	16	100	16	120	12	160	12	135	12	110	1.5	0.3	0.95	350	10	195	250	8	175	0.678	
	0.5	6.33	12.67	80	2.3	8	200	0.24X0.24	6	12	270	16	120	20	140	16	120	12	140	12	120	12	110	2	0.3	1.43	350	10	195	250	8	175	0.68	
	0.1	2.25	22.54	100	4	8	160	0.46X0.46	12	16	250	12	120	12	100	12	125	12	150	12	140	12	130	1	0.3	0.45	350	10	195	250	8	175	1.1	
	0.2	3.57	17.89	100	3.2	8	160	0.36X0.36	8	16	250	16	160	16	150	16	160	12	120	12	100	12	100	1.1	0.3	0.55	350	10	195	250	8	175	0.83	
9,00,000	0.3	4.69	15.63	100	2.8	8	160	0.315X0.315	12	12	250	16	125	16	100	16	125	12	100	12	100	12	100	1.4	0.3	0.85	350	10	195	250	8	175	0.757	1.39
	0.4	5.68	14.2	100	2.55	8	160	0.28X0.28	10	12	250	16	120	20	145	16	125	16	200	16	200	16	190	1.7	0.3	1.15	350	10	195	250	8	175	0.705	
	0.5	6.59	13.18	80	2.4	8	200	0.24X0.24	8	12	280	20	150	20	125	20	150	16	180	16	180	16	160	2	0.3	1.42	350	10	195	250	8	175	0.706	
	0.1	2.33	23.35	110	4	8	160	0.485X0.485	14	16	250	12	110	12	100	12	120	12	270	12	255	12	240	1	0.3	0.45	350	10	195	250	8	175	1.022	
	0.2	3.7	18.53	100	3.3	8	160	0.37X0.37	10	16	250	16	155	16	155	16	170	12	170	12	155	12	145	1.2	0.3	0.65	350	10	195	250	8	175	0.74	
10,00,000	0.3	4.85	16.19	100	2.9	8	160	0.325X0.325	12	12	250	16	120	16	100	16	120	12	130	12	130	12	115	1.5	0.3	0.95	350	10	195	250	8	175	0.67	1.37
	0.4	5.88	14.71	100	2.65	8	160	0.3X0.3	10	12	280	20	140	20	130	20	145	12	130	12	125	12	115	1.9	0.3	1.32	350	10	195	250	8	175	0.66	
	0.5	6.92	13.65	100	2.5	8	200	0.25X0.25	8	12	290	20	135	20	120	20	135	12	130	12	120	12	105	2.2	0.3	1.61	350	10	195	250	8	175	0.63	
	0.1	2.41	24.1	110	4.3	8	150	0.5X0.5	16	16	250	16	165	16	165	16	175	12	250	12	250	12	225	1	0.3	0.45	350	10	195	250	8	175	1.027	
	0.2	3.82	19.13	100	3.5	8	160	0.375X0.375	10	16	250	16	140	16	130	16	145	12	150	12	145	12	135	1.3	0.3	0.75	350	10	195	250	8	175	0.753	
11,00,000	0.3	5.01	16.71	100	3	8	160	0.34X0.34	12	12	250	20	165	20	150	20	165	12	140	12	125	12	110	1.7	0.3	1.15	350	10	195	250	8	175	0.68	1.35
	0.4	6.07	15.18	100	2.7	8	160	0.305X0.305	10	12	280	20	135	20	125	20	140	12	130	12	120	12	110	2	0.3	1.42	350	10	195	250	8	175	0.662	
	0.5	7.04	14.09	100	2.5	8	160	0.285X0.285	10	12	290	20	130	20	110	20	130	12	130	12	115	12	100	2.5	0.3	1.91	350	10	195	250	8	175	0.66	
	0.1	2.48	24.81	110	4.5	8	160	0.51X0.51	10	20	250	16	175	16	160	16	170	12	235	12	225	12	200	1	0.3	0.45	350	10	195	250	8	175	1	
	0.2	3.94	19.69	100	3.5	8	160	0.4X0.4	10	16	250	16	135	16	120	16	135	12	155	12	145	12	130	1.4	0.3	0.85	350	10	195	250	8	175	0.73	
12,00,000	0.3	5.16	17.2	100	3	8	160	0.35X0.35	14	12	250	20	155	20	140	20	160	12	145	12	130	12	100	1.8	0.3	1.25	350	10	195	250	8	175	0.66	1.33
	0.4	6.25	15.63	100	2.8	8	160	0.31X0.31	12	12	280	20	130	20	115	20	130	16	225	16	215	16	190	2.2	0.3	1.62	350	10	195	250	8	175	0.64	
	0.5	7.25	14.51	100	2.6	8	160	0.29X0.29	10	12	290	20	110	20	105	20	115	16	170	16	120	16	145	2.7	0.3	2.11	350	10	195	250	8	175	0.68	

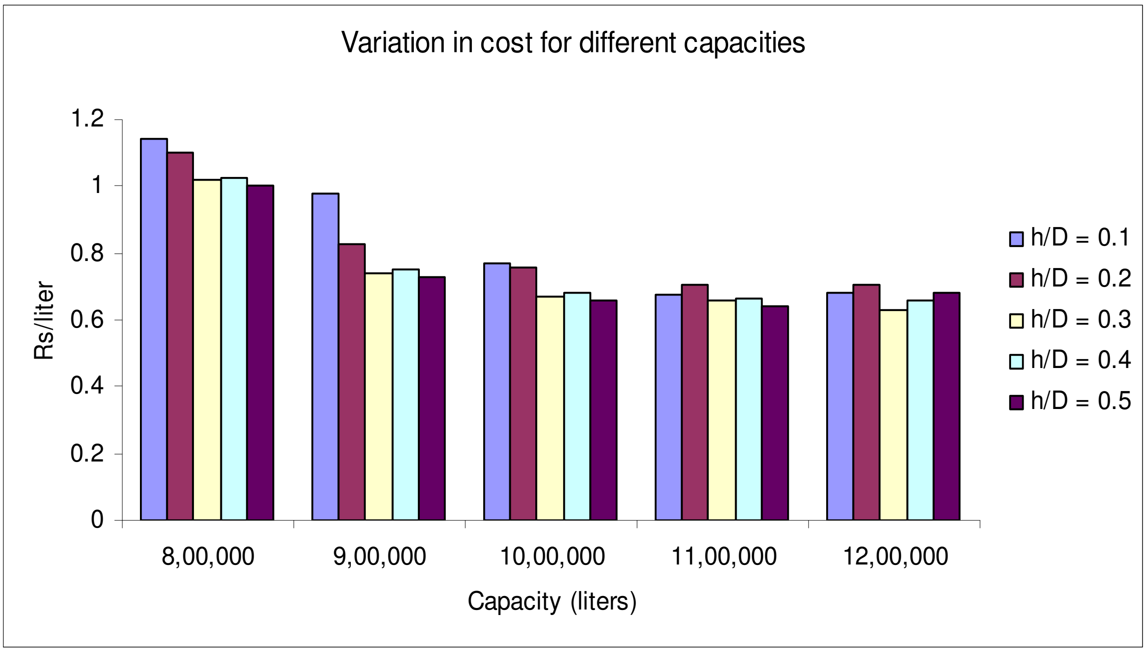


Fig.6.20 Cost comparison of different configuration for circular tank

6.9 SUMMARY

In this chapter finite element modeling and analysis of ground supported circular tank is discussed. As distribution of hydrodynamic pressure is not linear in nature, design tables of IS:3370 (part IV) can not be used directly. Finite element model is prepared in SAP2000 software for calculation of maximum moment and maximum tension in wall of circular tank. Comparison of analysis results due to hydrostatic pressure and total pressure (hydrostatic +hydrodynamic) are carried out for various capacity tank with different height to diameter ratio. It is found that, tension force due to total pressure is 13% to 60% more than hydrostatic pressure for different height to diameter ratio. Moment due to total pressure is 6 to 42 percent more than hydrostatic pressure for different height to diameter ratio. An illustrative example including analysis, design and detailing of circular tank is presented. Parametric study of design and estimation is also carried out and found that height to diameter ratio 0.4 to 0.5 is more economical than other height diameter ratio. Computer program for design of different component of tank is also presented.

7. DESIGN OF RECTANGULAR TANK

7.1 GENERAL

This chapter includes modeling, analysis and design of rectangular tank considering hydrodynamic forces. It also includes the step by step procedure to prepare finite element model of rectangular tank resting on ground and subjected to hydrodynamic pressure as well as hydrostatic pressure in SAP2000 software. Using C++ language computer program is developed for calculating hydrodynamic pressure on rectangular tank resting on ground having different lengths to width ratio. For design of various component of water tank different C++ program is prepared.

7.2 MODELING OF RECTANGULAR TANK IN SAP2000

In SAP2000 following steps are followed for the modeling of rectangular tank resting on ground.

Step 1: Selection of units

SAP2000, software gives flexibility to choose units as shown in Fig.7.1, when it is started.

Step 2: Selection of geometry of the model

Ready made geometry for rectangular tank is not available in SAP2000. It can be prepared selecting 'grid only' option as per indicate in Fig.7.1.

Step 3: After selecting grid only option module of grid system will display as per Fig 7.2. In this module, select Cartesian option. Number of grid line in X, Y and Z direction should be two. Grid spacing will change according dimension of tank.

Step 4: Fill area element object as wall panel of tank. In such a way that, face 5 of element should be inside of tank.

Step 5: Select all area elements and modify its property from define menu area section option. By this option thickness of element and element type can be changed.

Step 6: Select all area elements and divide them from divide area option as per indicated Fig.7.3 (A). Finer mesh gives good results than the coarser mesh.

Step 7: Select all point at zero height level and assign support condition by joint restrain option from assign menu as per indicate in Fig.7.3 (B).

Step 8: Assign hydrostatic and hydrodynamic pressure to the tank wall as per indicated as per step: 5 of section 6.3 of chapter 6.

Step 9: Analyze model as per procedure indicated step: 6 of chapter 6. In analysis results, moment M22 indicate vertical moment and M11 indicate horizontal moment.

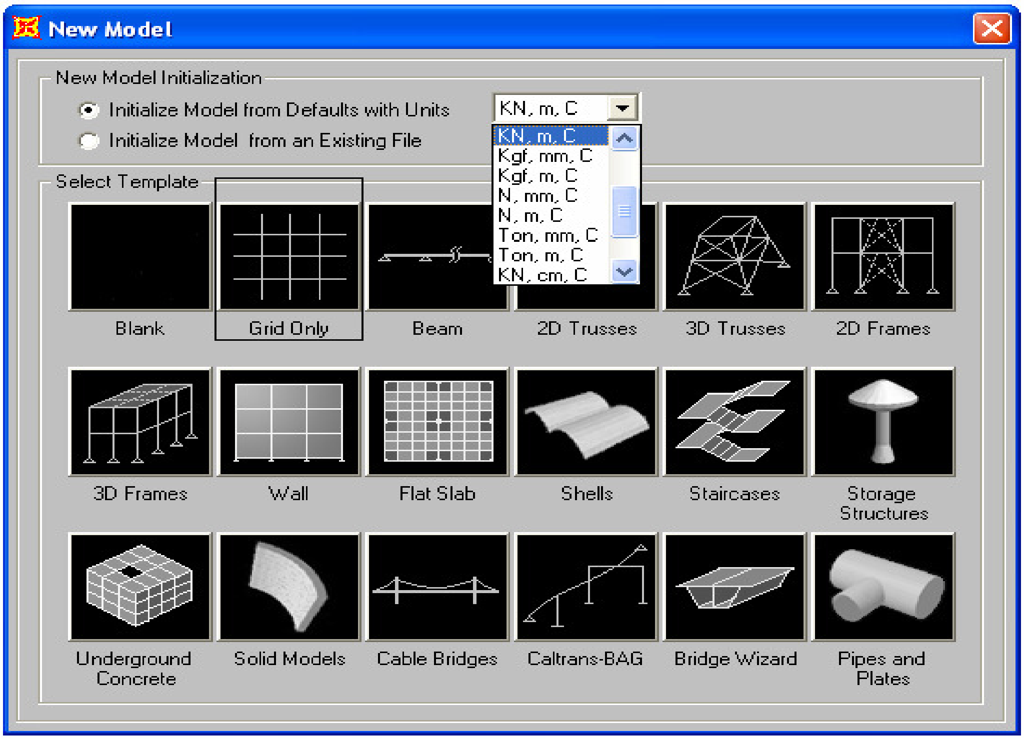


Fig. 7.1 Geometries for various structures

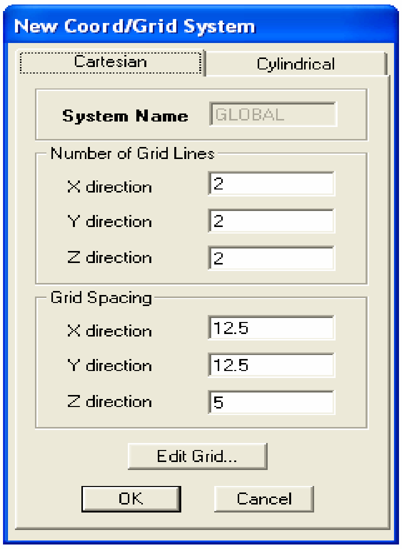
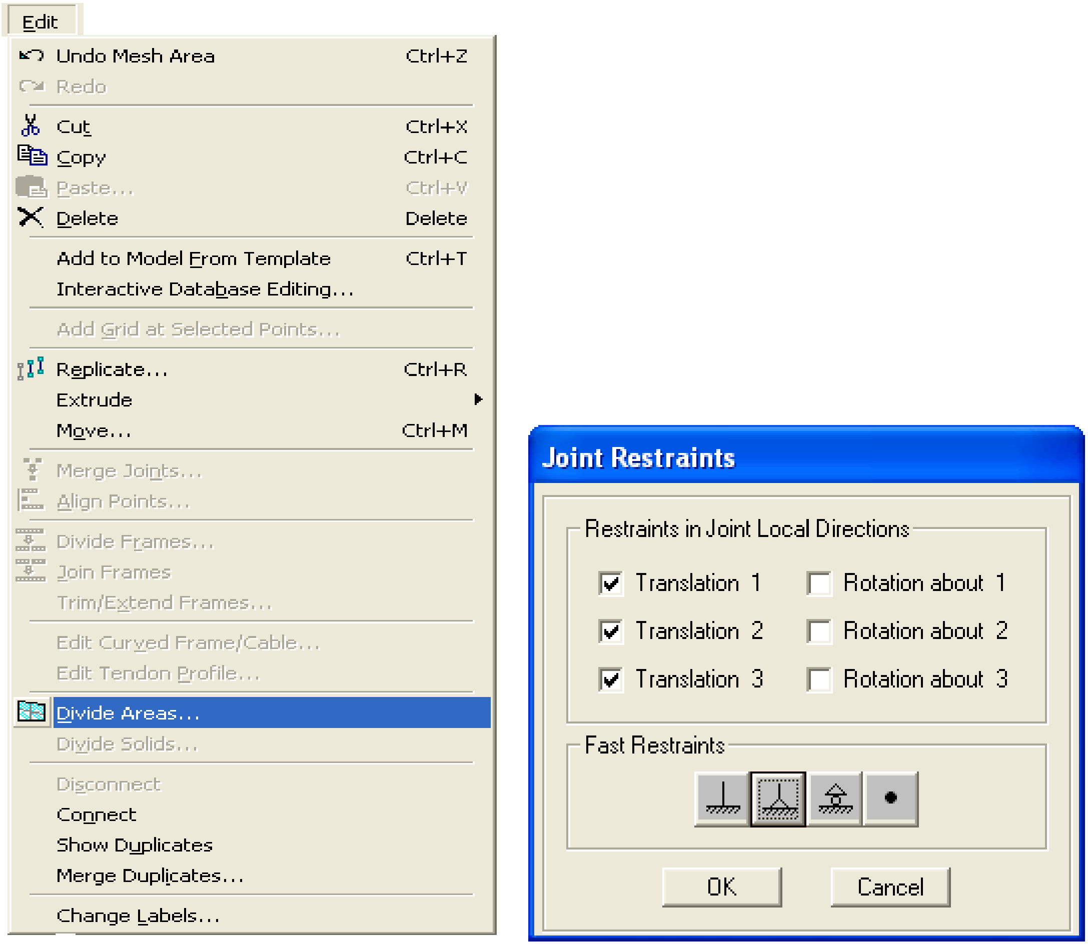


Fig. 7.2 Dimension for circular tank



(A) (B)

Fig.7.3 Modules for meshing and joint restrains

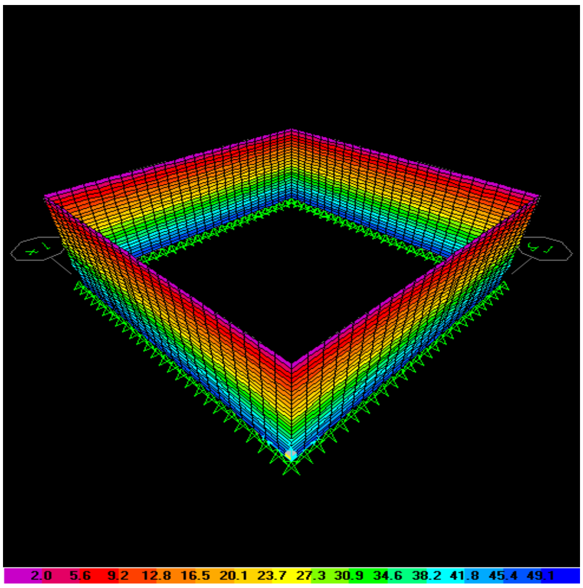
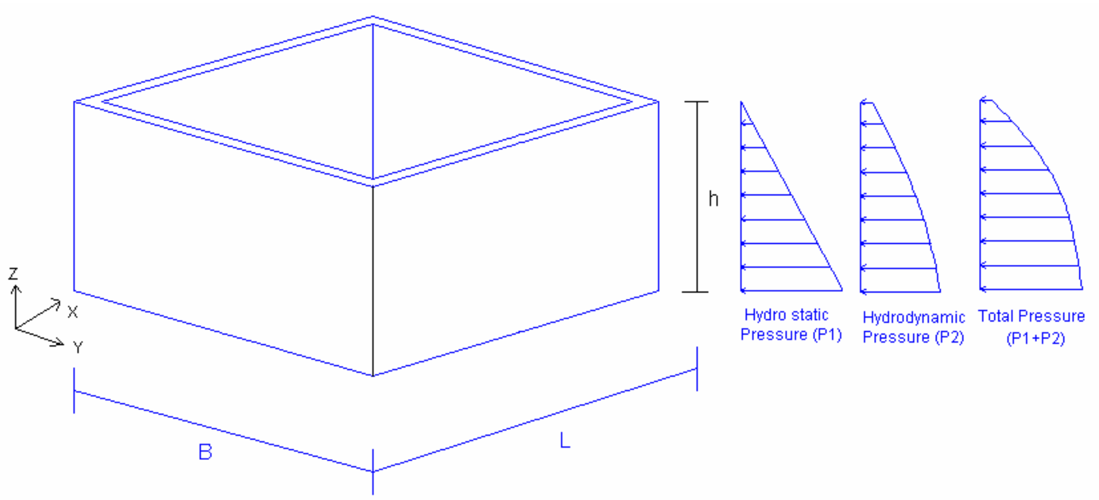


Fig.7.4. Module of rectangular tank wall in SAP2000.

7.3 COMPARISON OF ANALYSIS RESULTS OF SAP2000 AND AS PER IS: 3370 (PART IV)

Modeling of rectangular tank wall as shown in Fig.7.5 is done in SAP2000. For this parametric study rectangular tank considered as free at top and hinged at bottom. In rectangular tank horizontal moment and vertical moment both are important for detailing of reinforcement. Finite element modeling of 8,00,000 liter capacity tank is done and analyzed in SAP2000. Analysis is also carried out using design tables of IS:3370 (part IV) and compared with results of SAP2000. Moment at centre of wall and at corner is as per indicated in Table 7.1 and Table 7.2. Positive sign indicates tension out side.

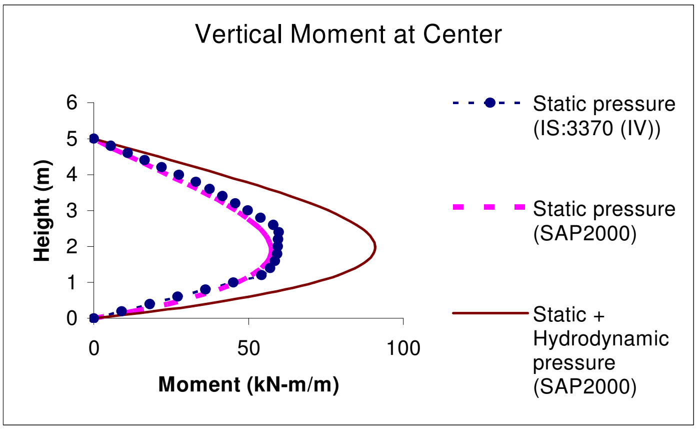


Capacity = 8,00,000 lit
Earthquake Zone = 5
Soil type = Soft Soil
Height of wall (h) = 5 m
Length of wall (L) = 12.65 m
Width of wall (B) = 12.65 m
Thickness of wall (t) = 0.3 m
Base hinge top free condition
Maximum hydro static pressure (P1) = 50 kN/m^2
Maximum hydrodynamic pressure (P2) = 20.02 kN/m^2

Fig. 7.5 Details of rectangular tank

Table 7.1 Moment comparison at center of wall

Height (m)	Vertical moment at center of wall (kN-m/m)			Horizontal moment at center of wall (kN-m/m)		
	Static pressure		Static + Hydrodynamic pressure	Static pressure		Static + Hydrodynamic pressure
	IS : 3370(IV)	FEM	FEM	IS : 3370(IV)	FEM	FEM
0	0.00	0.00	0.00	0.00	0.01	0.01
0.4	18.05	23.74	35.95	11.77	12.94	21.33
0.8	36.10	40.41	61.85	23.54	24.36	40.47
1.2	54.15	50.97	78.87	35.32	34.32	57.52
1.6	58.54	56.30	88.17	43.63	42.94	72.57
2	59.46	57.28	90.88	51.46	50.30	85.73
2.4	59.79	54.74	88.08	59.28	56.53	97.18
2.8	53.91	49.45	80.79	65.05	61.79	107.09
3.2	45.67	42.12	69.97	70.12	66.23	115.70
3.6	37.43	33.40	56.54	75.20	70.05	123.26
4	27.47	23.89	41.30	79.54	73.45	130.08
4.4	16.48	14.12	25.01	83.44	76.66	136.48
4.8	5.49	4.57	8.32	87.35	79.93	142.81
5	0.00	0.00	0.00	88.34	81.66	146.06



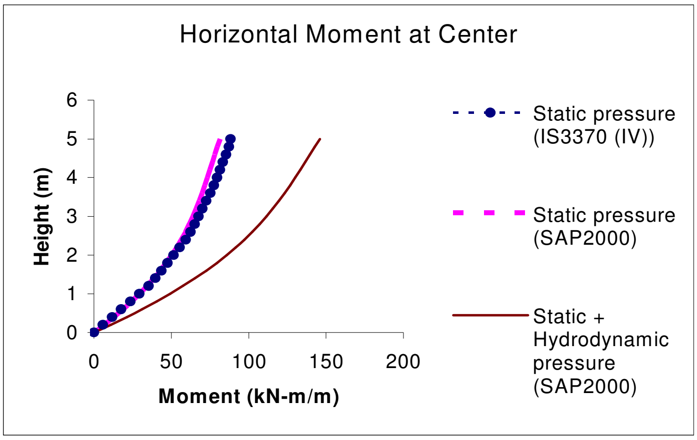
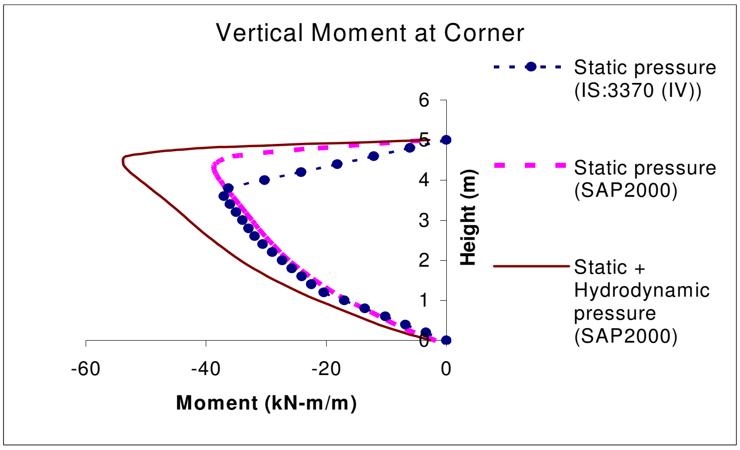


Fig. 7.6 Moment comparison at center of wall in rectangular tank

Table 7.2 Moment comparison at corner of tank

Height (m)	Vertical moment at corner of wall (kN-m/m)			Horizontal moment at corner of wall (kN-m/m)		
	Static pressure		Static + Hydrodynamic pressure	Static pressure		Static + Hydrodynamic pressure
	IS : 3370(IV)	FEM	FEM	IS : 3370(IV)	FEM	FEM
0	0.00	-1.74	-2.69	0.00	0.63	0.59
0.4	-6.80	-8.44	-11.23	-33.67	-37.61	-47.94
0.8	-13.60	-13.80	-18.07	-67.34	-69.36	-88.83
1.2	-20.40	-18.70	-24.38	-101.02	-95.44	-122.83
1.6	-24.09	-22.82	-29.78	-120.09	-116.44	-150.62
2	-27.34	-26.19	-34.27	-137.09	-133.13	-173.13
2.4	-30.59	-28.95	-38.03	-154.08	-146.43	-191.46
2.8	-32.94	-31.29	-41.31	-165.97	-157.35	-206.85
3.2	-34.98	-33.42	-44.39	-176.16	-166.96	-220.68
3.6	-37.03	-35.55	-47.57	-186.35	-176.40	-234.38
4	-30.24	-37.67	-50.97	-194.80	-186.52	-249.11
4.4	-18.14	-38.53	-53.78	-202.19	-196.23	-263.41
4.8	-6.05	-21.36	-40.38	-209.58	-193.50	-260.59
5	0.00	-3.01	-2.87	-202.27	-184.50	-251.10



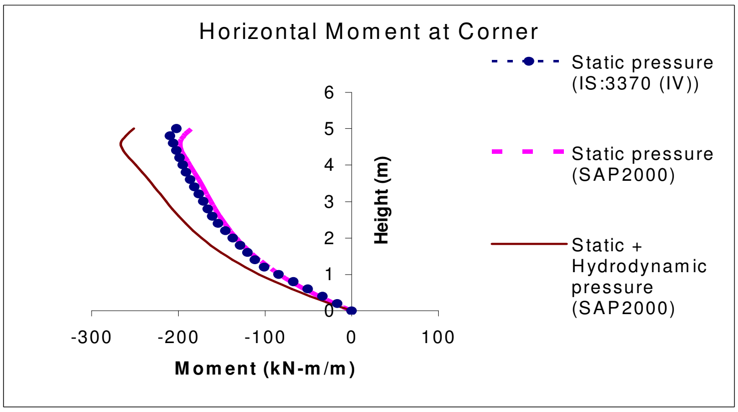
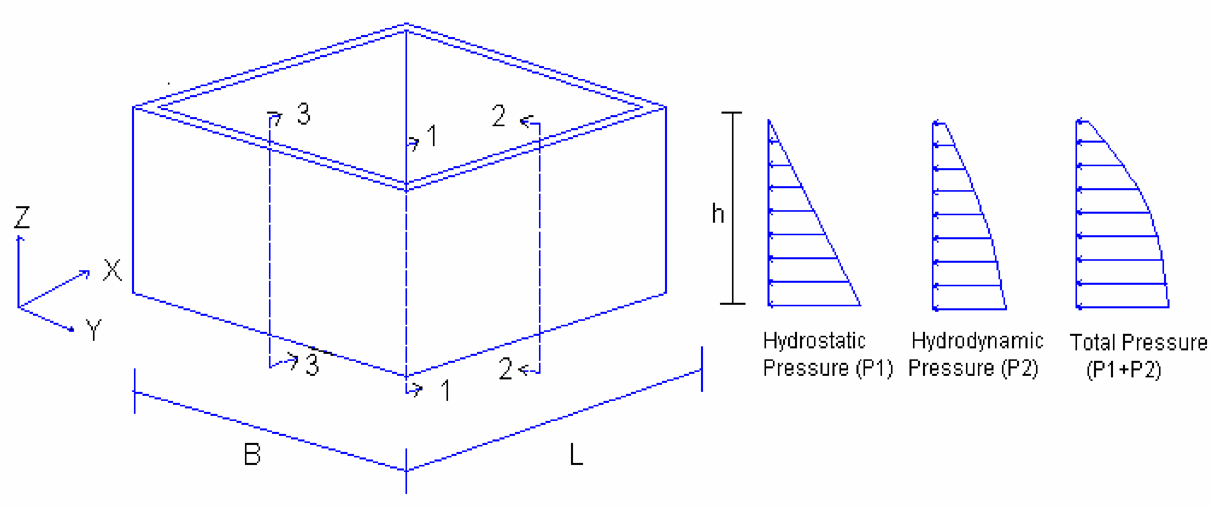


Fig. 7.7 Moment comparison at corner of wall in rectangular tank

7.4 PARAMETRIC STUDY OF RECTANGULAR WATER TANK

The parametric study is carried out for 8,00,000 liter capacity rectangular tank. In this parametric study, different Finite element models of rectangular water tank are prepared with different length to width ratio in SAP2000. Earthquake in both directions, along length and along width is considered in this study. Horizontal and vertical moments are find out at different location indicated in Fig. 7.8.



Capacity = 8,00,000 lit
Earthquake Zone = 5
Soil type =Soft Soil
Height of wall (h) = 5 m

Fig. 7.8 Rectangular tank with pressure distribution

Table 7.3 Dimensions of rectangular tank

Capacity (Lit)	L/B	Length (L) m	Width (B) m
8,00,000	1	12.65	12.65
	1.1	13.27	12.06
	1.2	13.86	11.55
	1.3	14.42	11.09
	1.4	14.97	10.69
	1.5	15.49	10.33

7.4.1 Analysis Results Considering Free at Top and Hinged at Base

Analysis results considering earthquake along length for various configurations are as per Table 7.4 to 7.6, and its graphs are presented in Fig. 7.9.

Table 7.4 Horizontal moment (kN-m/m) at section (1-1)

h	L/B					
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	47.9	47.6	47.3	47.0	46.2	46.7
0.8	88.8	88.1	87.6	87.1	86.1	86.5
1.6	150.6	149.3	148.3	147.4	147.0	146.5
2	173.1	171.4	170.2	169.1	168.6	168.1
2.4	191.4	189.4	187.9	186.7	186.2	185.5
2.8	206.8	204.4	202.7	201.3	200.7	200.1
3.2	220.6	217.8	215.84	214.3	213.7	213.1
4	249.1	245.2	242.6	240.7	240.2	239.7
4.4	263.4	258.9	256.0	253.9	253.5	253.0
4.8	260.5	256.1	253.4	251.5	251.5	251.3

Table 7.5 Horizontal moment (kN-m/m) at section (2-2)

h	L/B					
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	-12.0	-12.7	-13.2	-13.6	-13.9	-14.2
0.8	-22.6	-23.9	-24.9	-25.7	-26.4	-27.0
1.2	-31.7	-33.6	-35.2	-36.4	-37.4	-38.4
1.6	-39.4	-42.0	-44.1	-45.8	-47.1	-48.4
2	-45.9	-49.2	-51.8	-53.9	-55.6	-57.2
2.4	-51.3	-55.2	-58.4	-61.0	-63.1	-64.9
2.8	-55.7	-60.3	-64.0	-67.0	-69.5	-71.7
3.2	-59.3	-64.6	-68.8	-72.3	-75.2	-77.7
3.6	-62.3	-68.2	-73.0	-77.0	-80.3	-83.0
4	-64.9	-71.5	-76.8	-81.2	-84.9	-87.9
4.4	-67.4	-74.5	-80.3	-85.1	-89.2	-92.5
4.8	-70.0	-77.7	-83.9	-89.1	-93.6	-97.1

Table 7.6 Horizontal moment (kN-m/m) at section (3-3)

h	L/B					
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	-21.3	-20.6	-20.0	-19.3	-18.5	-18.0
0.8	-40.4	-39.1	-37.8	-36.5	-34.9	-33.8
1.2	-57.5	-55.5	-53.5	-51.5	-49.2	-47.5
1.6	-72.5	-69.9	-67.2	-64.5	-61.4	-59.1
2	-85.7	-82.3	-79.0	-75.5	-71.7	-68.8
2.4	-97.1	-93.1	-89.0	-84.8	-80.38	-76.6
2.8	-107.0	-102.2	-97.4	-92.5	-87.4	-83.0
3.2	-115.7	-110.1	-104.6	-99.0	-93.3	-88.0
3.6	-123.2	-116.9	-110.7	-104.4	-98.1	-92.1
4.4	-136.4	-128.8	-121.3	-113.6	-106.4	-98.9
4.8	-142.8	-134.5	-126.4	-118.2	-110.6	-102.4

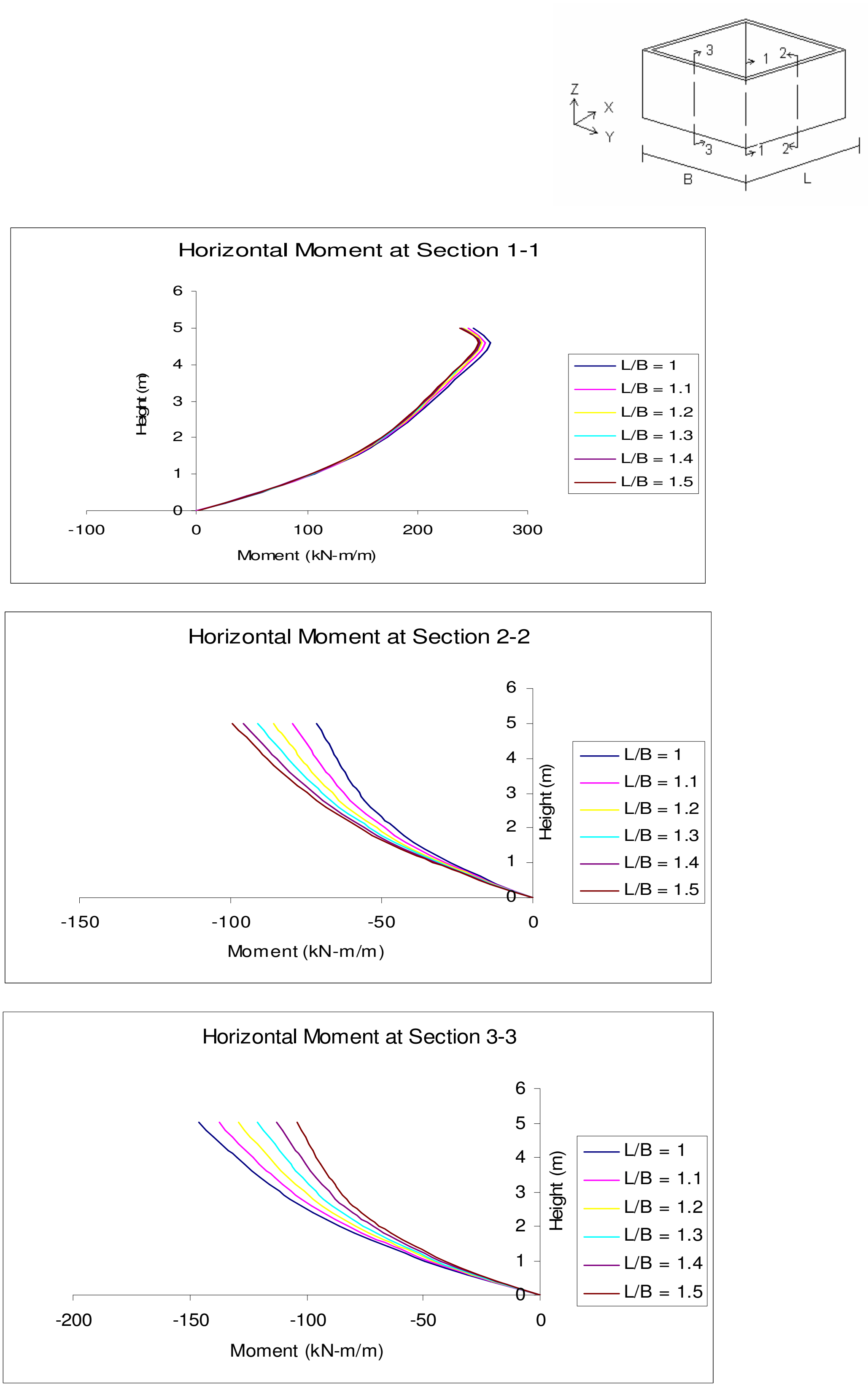


Fig. 7.9 Horizontal moment at various locations due to earthquake along length

Vertical moments due to earthquake along length for various configurations are as per Table 7.7 to 7.9 and graphically presented in Fig. 7.10.

Table 7.7 Vertical moment (kN-m/m) at section (1-1)

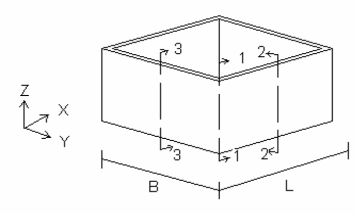
h	L/B					
(m)	1.0	1.1	1.2	1.3	1.4	1.5
0.4	10.4	10.2	10.0	9.9	9.8	9.7
0.8	17.5	17.2	17.1	16.9	16.9	16.7
1.2	23.9	23.7	23.5	23.3	23.3	23.1
1.6	29.4	29.1	28.9	28.7	28.7	28.5
2.0	34.0	33.6	33.4	33.2	33.1	33.0
2.4	37.8	37.4	37.1	36.9	36.8	36.7
2.8	41.0	40.6	40.2	40.0	39.9	39.8
3.6	47.0	46.4	46.0	45.7	45.7	45.6
4.0	49.8	49.2	48.8	48.5	48.6	48.6
4.4	49.9	49.7	49.7	49.8	50.2	50.5
4.8	18.1	21.3	24.2	26.9	29.4	31.8

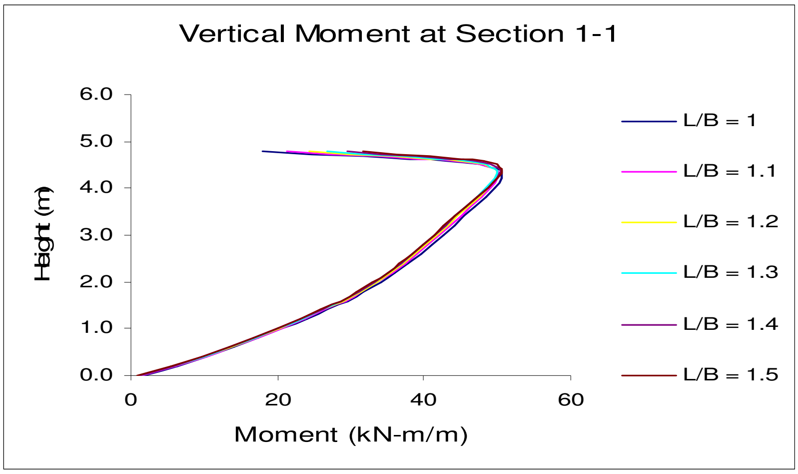
Table 7.8 Vertical moment (kN-m/m) at section (2-2)

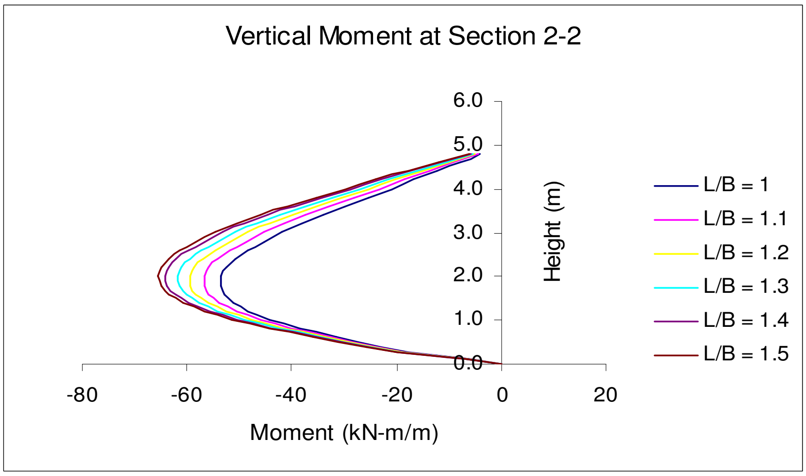
h			L/B			
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	-22.8	-23.6	-24.3	-24.9	-25.5	-25.8
0.8	-38.6	-40.2	-41.5	-42.6	-43.8	-44.4
1.2	-48.3	-50.6	-52.5	-54.1	-55.8	-56.7
1.6	-53.0	-55.8	-58.2	-60.2	-62.3	-63.5
2.0	-53.5	-56.7	-59.5	-61.8	-64.1	-65.5
2.4	-50.6	-54.1	-57.1	-59.5	-62.0	-63.5
2.8	-45.3	-48.8	-51.8	-54.3	-56.8	-58.3
4.0	-21.1	-23.4	-25.4	-27.1	-28.7	-29.8
4.4	-12.2	-13.8	-15.1	-16.2	-17.3	-18.0
4.8	-3.9	-4.4	-4.9	-5.3	-5.7	-6.0

Table 7.9 Vertical moment (kN-m/m) at section (3-3)

h	L/B					
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	-36.0	-35.0	-34.1	-33.2	-32.7	-31.5
0.8	-61.9	-60.0	-58.2	-56.5	-55.6	-53.2
1.2	-78.9	-76.2	-73.7	-71.2	-69.8	-66.4
1.6	-88.2	-84.9	-81.7	-78.5	-76.8	-72.7
2	-90.9	-87.1	-83.5	-79.9	-77.9	-73.1
2.4	-88.1	-84.0	-80.1	-76.3	-74.1	-69.1
2.8	-80.8	-76.7	-72.8	-68.9	-66.7	-61.7
3.6	-56.5	-53.1	-49.8	-46.6	-44.7	-40.6
4	-41.3	-38.6	-36.0	-33.4	-31.8	-28.6
4.4	-25.0	-23.2	-21.5	-19.8	-18.8	-16.7
4.8	-8.3	-7.7	-7.1	-6.5	-6.1	-5.3







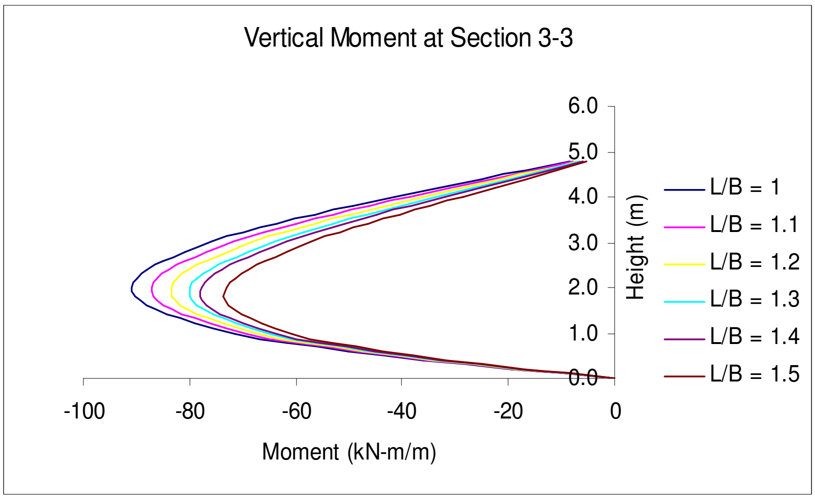


Fig. 7.10 Vertical moment at various locations due to earthquake along length

Horizontal moment due to earthquake along width for various configurations are as per Table 7.10 to 7.12 and its graphically presented as shown in Fig. 7.11.

Table 7.10 Horizontal moment (kN-m/m) at section (1-1)

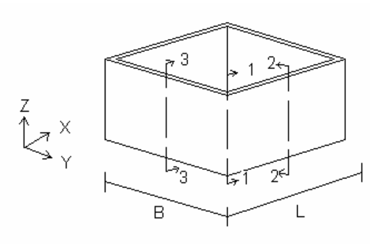
h (m)	L/B					
	1.0	1.1	1.2	1.3	1.4	1.5
0.4	48.1	48.4	48.7	49.0	49.5	49.7
0.8	89.0	89.7	90.4	91.0	92.1	92.5
1.2	123.0	124.0	125.2	126.2	128.0	128.5
1.6	150.7	152.2	153.8	155.3	157.8	158.6
2.4	191.5	194.0	196.5	199.1	203.2	204.6
2.8	206.9	209.9	213.0	216.1	221.3	223.0
3.2	220.7	224.3	228.1	231.9	238.2	240.2
3.6	234.4	238.6	243.2	247.8	255.4	257.9
4.4	263.5	269.3	275.7	282.1	293.0	296.5
4.8	262.2	268.7	275.9	283.2	295.4	299.3
5.0	249.2	255.1	261.8	268.8	280.9	284.6

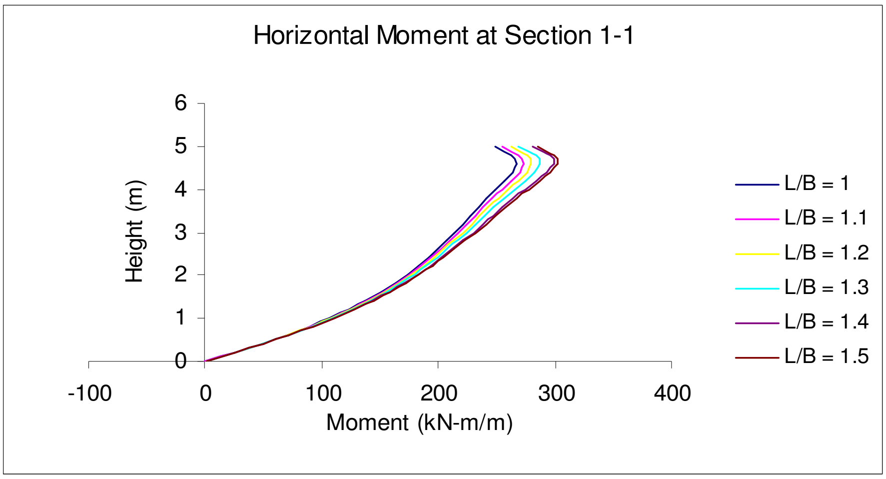
Table 7.11 Horizontal moment (kN-m/m) at section (2-2)

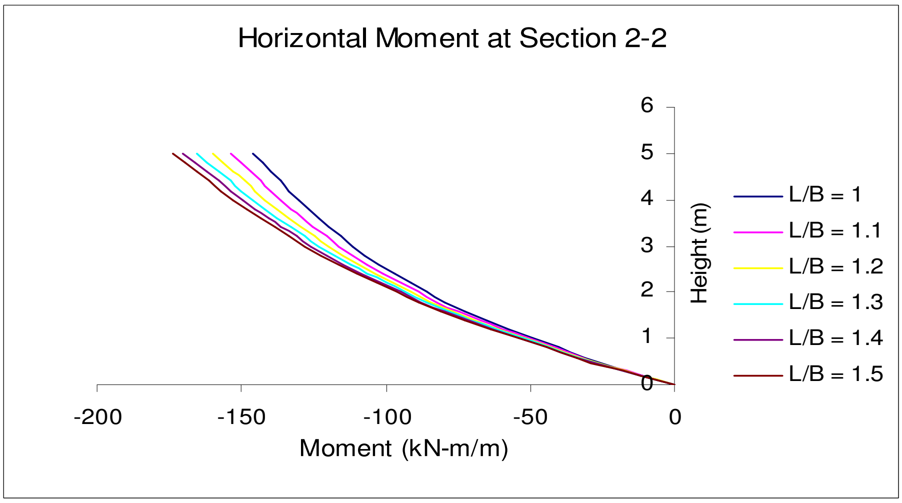
h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	-21.3	-21.9	-22.4	-22.7	-23.1	-23.3
0.8	-40.5	-41.6	-42.6	-43.3	-44.0	-44.5
1.2	-57.5	-59.3	-60.7	-61.9	-62.8	-63.6
1.6	-72.6	-74.9	-76.9	-78.4	-79.8	-80.9
2.4	-97.2	-100.8	-103.8	-106.3	-108.4	-110.1
2.8	-107.1	-111.4	-115.0	-117.9	-120.4	-122.4
3.6	-123.3	-128.9	-133.6	-137.4	-140.8	-143.4
4.4	-136.5	-143.4	-149.1	-153.8	-158.0	-161.3
4.8	-142.8	-150.3	-156.5	-161.6	-166.2	-169.7
5	-146.1	-153.8	-160.2	-165.5	-170.2	-173.9

Table 7.12 Horizontal moment (kN-m/m) at section (3-3)

h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	-12.0	-11.3	-10.5	-9.8	-8.8	-8.2
0.8	-22.6	-21.1	-19.6	-18.0	-16.2	-14.9
1.2	-31.7	-29.4	-27.2	-24.8	-22.1	-20.1
1.6	-39.4	-36.4	-33.4	-30.3	-26.7	-24.0
2.4	-51.3	-46.8	-42.3	-37.6	-32.3	-28.2
2.8	-55.7	-50.5	-45.2	-39.7	-33.8	-28.8
3.2	-59.3	-53.3	-47.3	-41.1	-34.5	-28.8
3.6	-62.3	-55.6	-48.9	-42.0	-34.8	-28.2
4.4	-67.4	-59.4	-51.4	-43.2	-35.1	-26.9
4.8	-70.0	-61.5	-52.9	-44.1	-35.6	-26.8
5	-71.5	-62.6	-53.8	-44.8	-36.2	-27.0







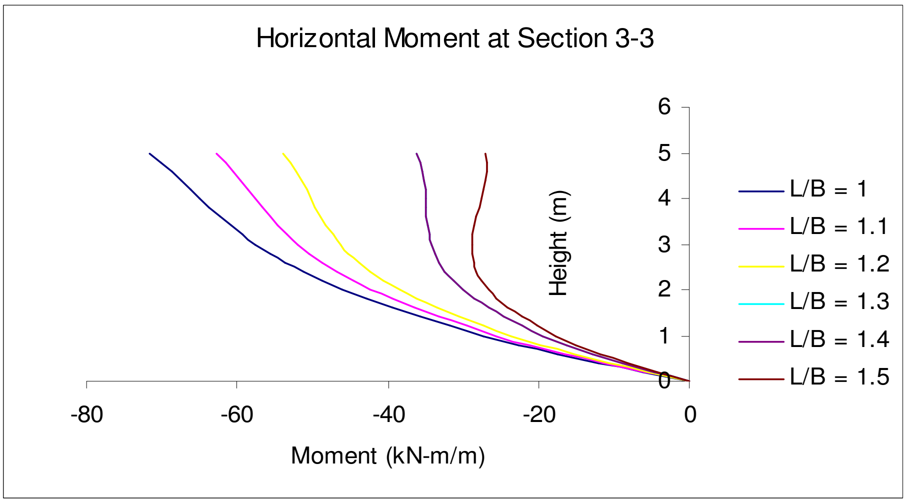


Fig. 7.11 Horizontal moment at various locations due to earthquake along width

Vertical moments due to earthquake along width for various configurations are as per Table 7.13 to 7.15 and its graphical representation is as per Fig. 7.12.

Table 7.13 Vertical moment (kN-m/m) at section (1-1)

h (m)	L/B					
	1.0	1.1	1.2	1.3	1.4	1.5
0.4	11.2	11.1	11.0	10.9	10.9	10.8
0.8	18.1	18.1	18.1	18.1	18.2	18.3
1.2	24.4	24.5	24.7	24.8	25.0	25.2
1.6	29.8	30.0	30.3	30.6	30.9	31.2
2.4	38.0	38.5	39.0	39.5	40.1	40.7
2.8	41.3	41.9	42.6	43.2	44.0	44.7
3.2	44.4	45.1	46.0	46.8	47.7	48.5
3.6	47.6	48.5	49.5	50.5	51.6	52.7
4.0	51.0	52.1	53.4	54.6	56.0	57.4
4.4	53.8	55.6	57.4	59.2	61.2	63.1
4.8	40.4	44.6	48.5	52.2	55.5	58.8

Table 7.14 Vertical moment (kN-m/m) at section (2-2)

h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	-36.0	-36.8	-37.5	-38.2	-38.7	-39.1
0.8	-61.8	-63.5	-65.0	-66.2	-67.3	-68.1
1.2	-78.9	-81.3	-83.4	-85.1	-86.7	-87.9
1.6	-88.2	-91.2	-93.8	-96.0	-98.0	-99.5
2.0	-90.9	-94.4	-97.3	-99.8	-102.2	-103.9
2.4	-88.1	-91.8	-95.0	-97.7	-100.2	-102.0
2.8	-80.8	-84.6	-87.8	-90.5	-93.0	-94.9
3.2	-70.0	-73.6	-76.6	-79.2	-81.6	-83.4
4.0	-41.3	-43.8	-46.0	-47.8	-49.5	-50.7
4.4	-25.0	-26.7	-28.1	-29.3	-30.4	-31.2
4.6	-16.7	-17.8	-18.8	-19.6	-20.4	-21.0

Table 7.15 Vertical moment (kN-m/m) at section (3-3)

h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	-22.8	-21.9	-21.1	-20.2	-19.9	-18.6
0.8	-38.6	-36.9	-35.2	-33.6	-32.8	-30.5
1.2	-48.3	-45.9	-43.5	-41.2	-40.1	-36.7
1.6	-53.0	-49.9	-47.0	-44.0	-42.7	-38.5
2	-53.5	-50.0	-46.6	-43.2	-41.7	-36.9
2.4	-50.6	-46.9	-43.2	-39.6	-37.9	-32.8
2.8	-45.3	-41.5	-37.8	-34.1	-32.4	-27.2
3.2	-38.1	-34.5	-31.0	-27.5	-25.8	-20.9
3.6	-29.9	-26.7	-23.5	-20.5	-18.9	-14.6
4	-21.0	-18.5	-16.0	-13.6	-12.3	-8.9
4.8	-3.9	-3.3	-2.7	-2.1	-1.8	-1.0

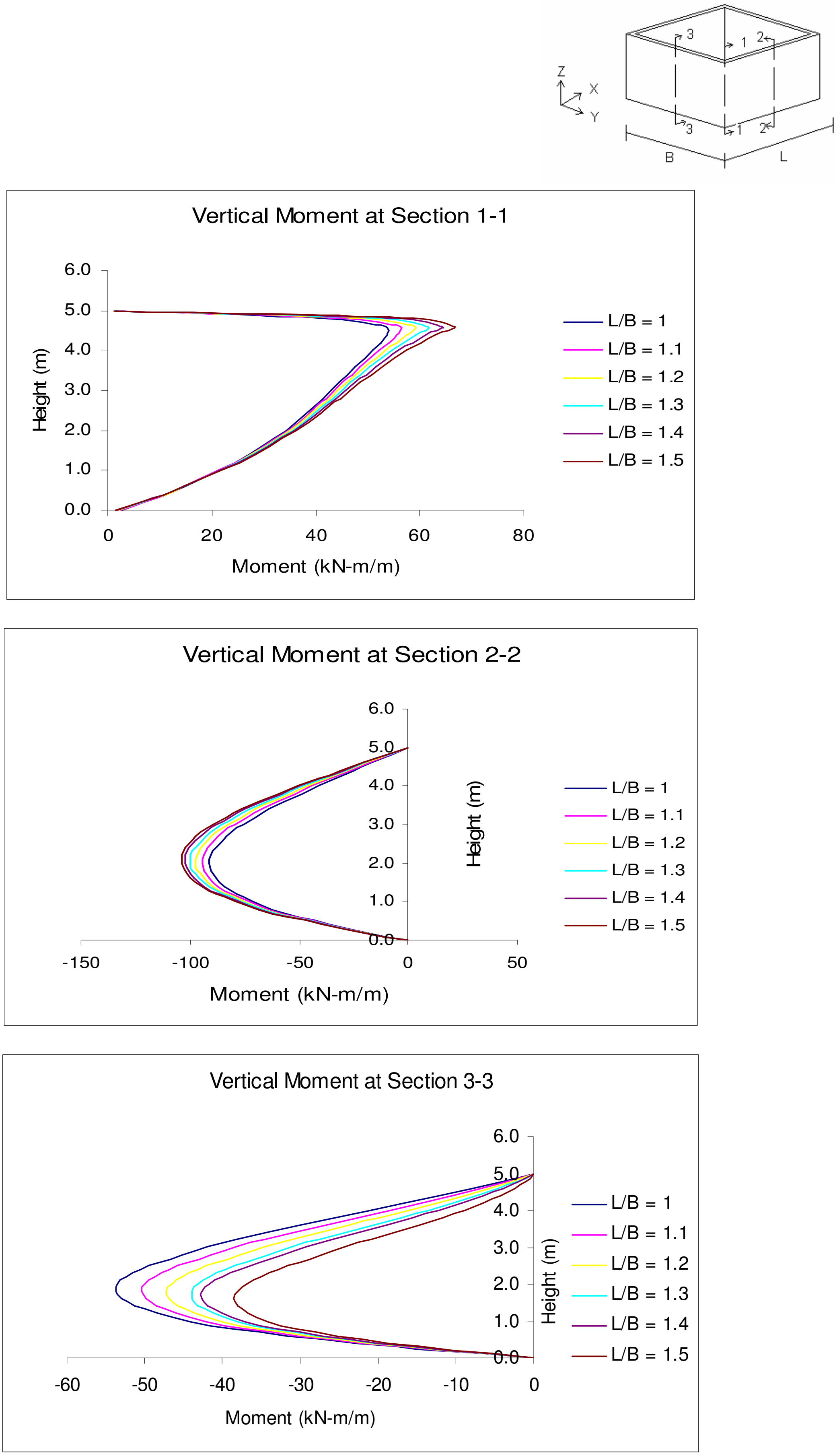


Fig. 7.12 Vertical moment at various locations due to earthquake along width

7.4.2 Analysis Results for Hinged at Top and Hinged at Base

Analysis results considering earthquake along length for various configurations are as per Table 7.16 to 7.18 and graphically presented in Fig. 7.13.

Table 7.16 Horizontal moment (kN-m/m) at section (1-1)

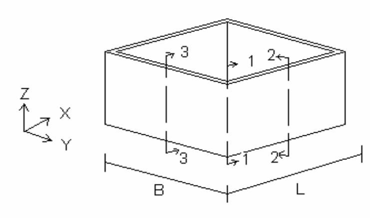
h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	34.5	34.5	34.4	34.3	34.2	34.1
0.8	61.6	61.6	61.5	61.4	61.2	61.0
1.2	81.3	81.3	81.2	81.0	80.8	80.6
1.6	93.8	93.8	93.7	93.5	93.2	92.9
2	99.6	99.6	99.4	99.2	99.0	98.6
2.4	99.3	99.3	99.2	99.0	98.7	98.4
2.8	93.7	93.7	93.6	93.4	93.1	92.8
3.2	83.4	83.4	83.4	83.2	82.9	82.6
3.6	69.3	69.3	69.3	69.1	68.9	68.7
4	52.1	52.2	52.1	52.0	51.9	51.7
4.8	11.3	11.3	11.3	11.2	11.2	11.1

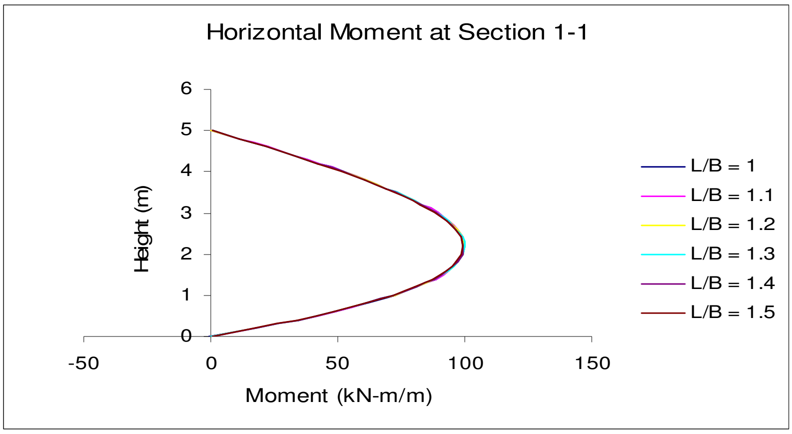
Table 7.17 Horizontal moment (kN-m/m) at section (2-2)

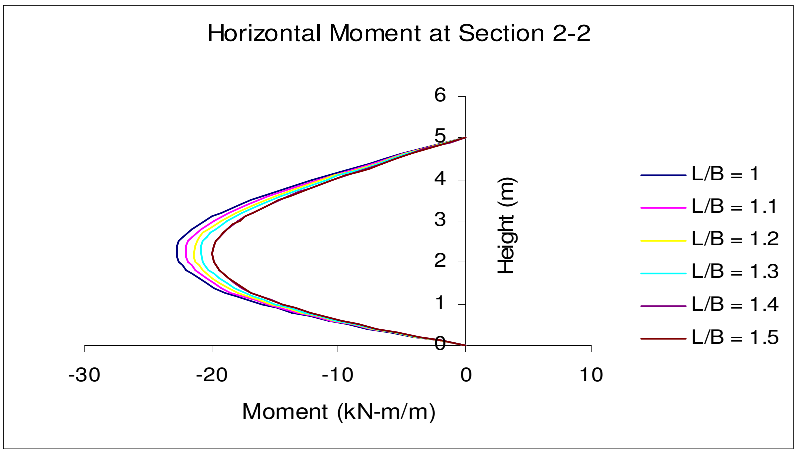
h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	-7.6	-7.4	-7.3	-7.1	-6.9	-6.9
0.8	-13.6	-13.3	-12.9	-12.7	-12.2	-12.2
1.2	-18.1	-17.6	-17.1	-16.7	-16.1	-16.1
1.6	-21.0	-20.4	-19.9	-19.4	-18.6	-18.6
2	-22.5	-21.8	-21.2	-20.7	-19.8	-19.8
2.4	-22.6	-21.9	-21.3	-20.7	-19.8	-19.8
2.8	-21.5	-20.8	-20.2	-19.6	-18.7	-18.7
3.2	-19.2	-18.6	-18.0	-17.5	-16.7	-16.7
3.6	-16.0	-15.5	-15.0	-14.6	-13.9	-13.9
4	-12.0	-11.6	-11.3	-10.9	-10.4	-10.4
4.8	-2.5	-2.5	-2.4	-2.3	-2.2	-2.2

Table 7.18 Horizontal moment (kN-m/m) at section (3-3)

h (m)	L/B				
	1.0	1.1	1.2	1.3	1.4
0.4	-11.2	-11.5	-11.7	-12.0	-11.9
0.8	-20.1	-20.7	-21.2	-21.6	-21.5
1.2	-26.8	-27.6	-28.3	-29.0	-28.7
1.6	-31.3	-32.3	-33.2	-33.9	-33.7
2	-33.7	-34.8	-35.7	-36.6	-36.3
2.4	-34.1	-35.2	-36.2	-37.1	-36.8
2.8	-32.5	-33.6	-34.6	-35.4	-35.1
3.2	-29.3	-30.2	-31.1	-31.9	-31.7
3.6	-24.5	-25.3	-26.1	-26.8	-26.5
4	-18.5	-19.1	-19.7	-20.2	-20.1
4.8	-4.0	-4.1	-4.2	-4.3	-4.3







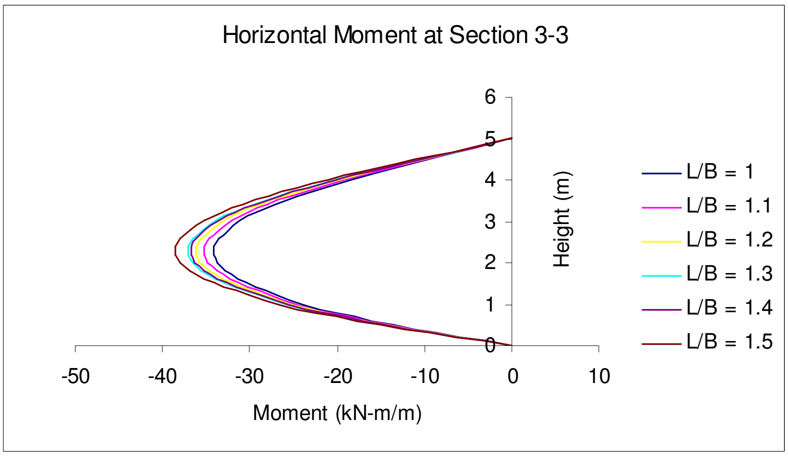


Fig. 7.13 Horizontal moment at various locations due to earthquake along length

Vertical moments due to earthquake along length for various configurations are as per Table 7.19 to 7.21 and graphically presented in Fig. 7.14.

Table 7.19 Vertical moment (kN-m/m) at section (1-1)

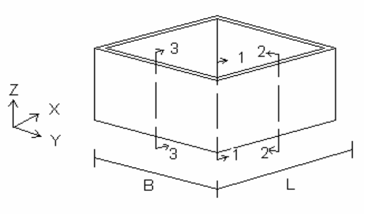
h (m)	L/B 1	1.1	1.2	1.3	1.4	1.5
0.4	7.5	7.4	7.3	7.2	7.1	7.0
1.2	15.4	15.3	15.3	15.2	15.2	15.1
1.4	16.7	16.7	16.7	16.6	16.5	16.5
1.8	18.5	18.5	18.5	18.4	18.4	18.3
2.2	19.1	19.1	19.1	19.0	19.0	18.9
2.4	18.9	18.9	18.9	18.9	18.8	18.8
2.8	17.9	17.9	17.9	17.9	17.8	17.8
3.2	15.9	16.0	16.0	16.0	15.9	15.9
3.6	13.2	13.3	13.3	13.3	13.3	13.2
4	9.9	10.0	10.0	10.0	10.0	10.0
4.4	6.2	6.3	6.3	6.4	6.4	6.4
4.8	1.8	1.9	2.0	2.0	2.1	2.1

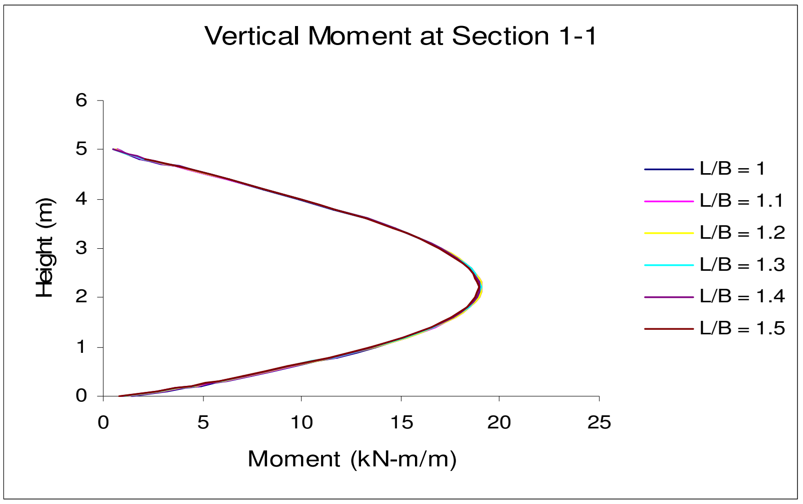
Table 7.20 Vertical moment (kN-m/m) at section (2-2)

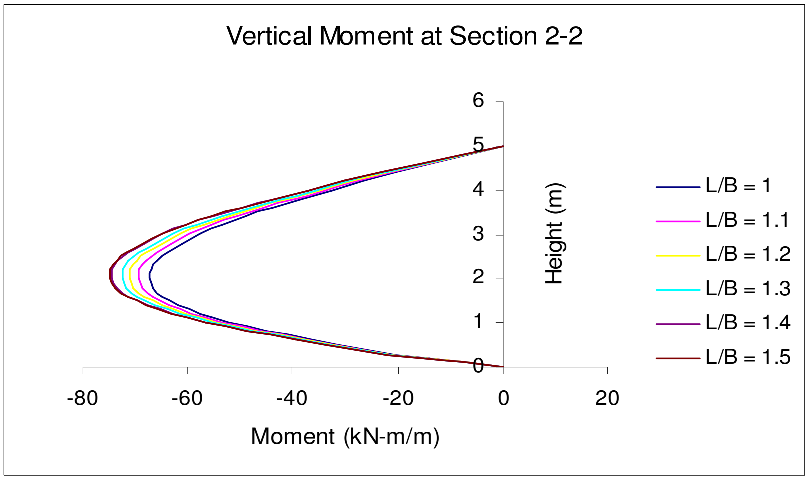
h (m)	L/B 1	1.1	1.2	1.3	1.4	1.5
0.4	-26.1	-26.6	-27.1	-27.5	-28.0	-28.0
1.2	-57.7	-59.2	-60.5	-61.5	-62.9	-63.1
1.6	-64.9	-66.8	-68.3	-69.5	-71.3	-71.5
2	-67.4	-69.5	-71.2	-72.6	-74.5	-74.8
2.4	-65.9	-68.1	-69.9	-71.3	-73.4	-73.6
2.8	-61.1	-63.2	-65.0	-66.4	-68.4	-68.7
3.2	-53.6	-55.5	-57.1	-58.5	-60.3	-60.6
3.6	-43.9	-45.6	-46.9	-48.1	-49.6	-49.8
4	-32.6	-33.9	-34.9	-35.8	-37.0	-37.1
4.4	-20.1	-20.9	-21.5	-22.1	-22.8	-22.9
4.8	-6.8	-7.1	-7.3	-7.5	-7.7	-7.8

Table 7.21 Vertical moment (kN-m/m) at section (3-3)

h (m)	L/B 1	1.1	1.2	1.3	1.4	1.5
0.4	-40.0	-39.2	-38.5	-37.7	-37.7	-36.3
1.2	-90.3	-88.3	-86.2	-84.2	-84.1	-80.2
1.6	-102.6	-100.2	-97.7	-95.1	-95.1	-90.3
2	-107.8	-105.0	-102.2	-99.3	-99.3	-93.9
2.4	-106.6	-103.7	-100.8	-97.8	-97.7	-92.1
2.8	-100.0	-97.1	-94.3	-91.3	-91.3	-85.8
3.2	-88.7	-86.1	-83.5	-80.8	-80.7	-75.7
3.6	-73.6	-71.4	-69.2	-66.9	-66.8	-62.6
4	-55.3	-53.6	-51.9	-50.2	-50.2	-47.0
4.2	-45.2	-43.8	-42.4	-41.0	-41.0	-38.4
4.4	-34.5	-33.5	-32.4	-31.3	-31.3	-29.3
4.8	-11.9	-11.5	-11.1	-10.8	-10.8	-10.1







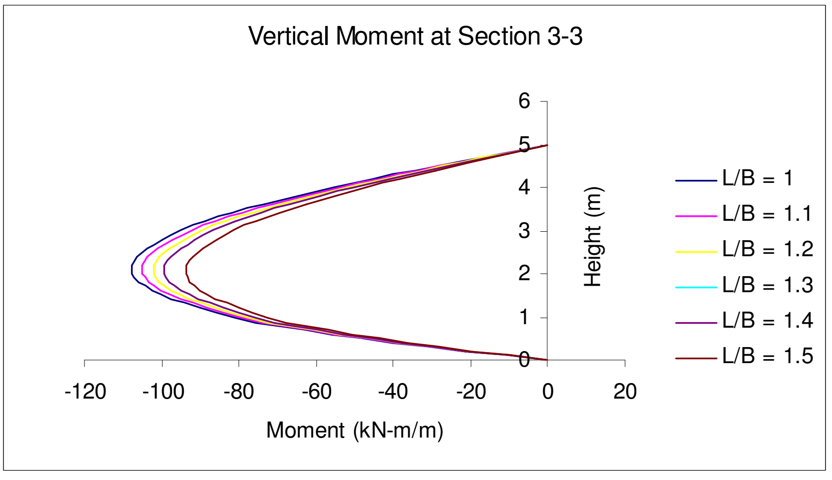


Fig. 7.14 Vertical moment at various locations due to earthquake along length

Horizontal moments due to earthquake along width for various configurations are as per Table 7.22 to 7.24 and graphically presented as per Fig. 7.15.

Table 7.22 Horizontal moment (kN-m/m) at section (1-1)

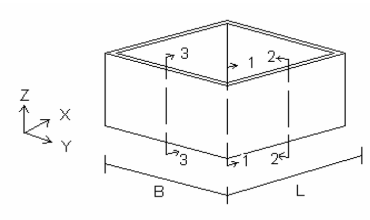
h	L/B					
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	34.6	34.5	34.4	34.2	34.1	33.9
0.8	61.7	61.6	61.4	61.2	61.0	60.7
1.2	81.4	81.2	81.0	80.8	80.5	80.1
1.6	93.8	93.7	93.4	93.1	92.8	92.4
2	99.6	99.4	99.2	98.9	98.5	98.1
2.4	99.3	99.1	98.9	98.6	98.2	97.8
2.8	93.7	93.5	93.3	93.0	92.6	92.2
3.2	83.4	83.3	83.1	82.8	82.5	82.1
3.6	69.3	69.2	69.0	68.8	68.5	68.2
4	52.1	52.0	51.9	51.7	51.5	51.2
4.4	32.6	32.5	32.4	32.3	32.2	32.1
4.8	11.2	11.2	11.2	11.1	11.1	11.0

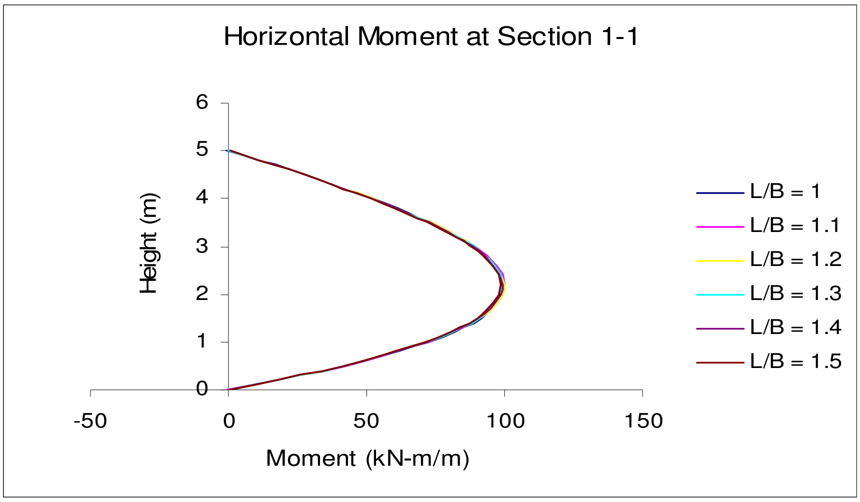
Table 7.23 Horizontal moment (kN-m/m) at section (2-2)

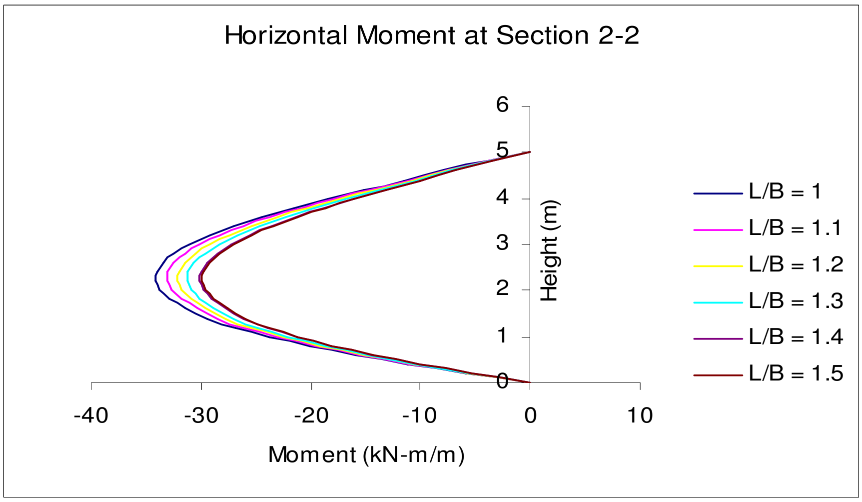
h	L/B					
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	-11.2	-10.9	-10.7	-10.4	-10.1	-10.1
0.8	-20.1	-19.6	-19.1	-18.7	-18.1	-18.0
1.2	-26.8	-26.1	-25.4	-24.8	-24.0	-23.8
1.6	-31.3	-30.4	-29.6	-28.9	-27.8	-27.7
2.4	-34.1	-33.0	-32.0	-31.2	-29.9	-29.8
2.8	-32.5	-31.4	-30.5	-29.7	-28.5	-28.3
3.2	-29.3	-28.3	-27.4	-26.7	-25.5	-25.4
3.6	-24.5	-23.7	-22.9	-22.3	-21.3	-21.2
4	-18.5	-17.9	-17.3	-16.8	-16.1	-16.0
4.4	-11.6	-11.2	-10.8	-10.5	-10.1	-10.0
4.8	-4.0	-3.8	-3.7	-3.6	-3.4	-3.4

Table 7.24 Horizontal moment (kN-m/m) at section (3-3)

h	L/B					
(m)	1	1.1	1.2	1.3	1.4	1.5
0.4	-7.6	-7.8	-7.9	-8.1	-8.0	-8.3
0.8	-13.6	-14.0	-14.3	-14.6	-14.3	-15.0
1.2	-18.1	-18.6	-19.0	-19.4	-19.1	-20.0
1.6	-21.0	-21.6	-22.2	-22.6	-22.3	-23.4
2	-22.5	-23.2	-23.8	-24.3	-23.9	-25.2
2.4	-22.6	-23.3	-24.0	-24.5	-24.1	-25.4
2.8	-21.5	-22.2	-22.8	-23.3	-22.9	-24.2
3.2	-19.2	-19.9	-20.4	-20.9	-20.5	-21.7
3.6	-16.0	-16.6	-17.0	-17.4	-17.1	-18.1
4	-12.0	-12.4	-12.8	-13.1	-12.9	-13.6
4.4	-7.5	-7.7	-7.9	-8.1	-8.0	-8.4
4.8	-2.5	-2.6	-2.7	-2.8	-2.7	-2.9







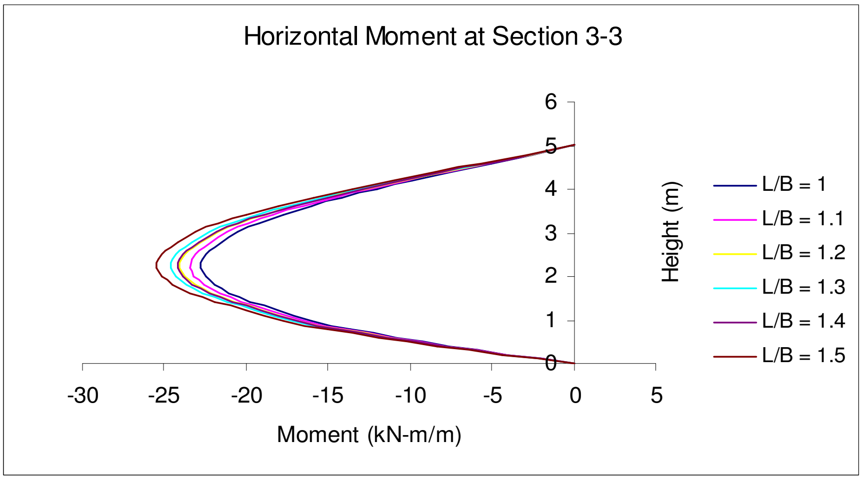


Fig. 7.15 Horizontal moment at various locations due to earthquake along width

Vertical moments due to earthquake along width for various are as per Table 7.25 to 7.27 and graphically presented as per Fig. 7.16.

Table 7.25 Vertical moment (kN-m/m) at section (1-1)

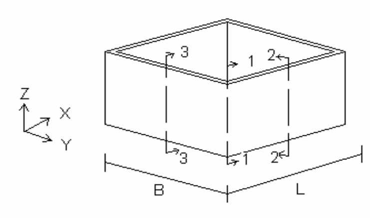
h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	7.9	7.7	7.5	7.4	7.3	7.2
0.8	12.0	11.8	11.7	11.6	11.5	11.4
1.2	15.4	15.3	15.2	15.1	15.0	14.9
1.6	17.7	17.6	17.5	17.5	17.4	17.3
2	18.7	18.7	18.6	18.6	18.5	18.4
2.4	18.6	18.6	18.6	18.5	18.5	18.4
2.8	17.5	17.5	17.5	17.5	17.4	17.4
3.2	15.5	15.5	15.5	15.5	15.5	15.4
3.6	12.7	12.8	12.8	12.8	12.8	12.8
4	9.4	9.4	9.5	9.5	9.5	9.5
4.8	1.3	1.4	1.6	1.6	1.7	1.8

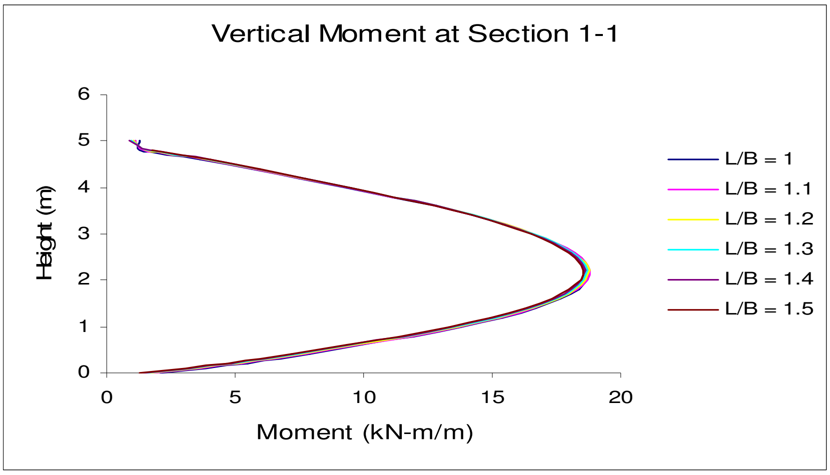
Table 7.26 Vertical moment (kN-m/m) at section (2-2)

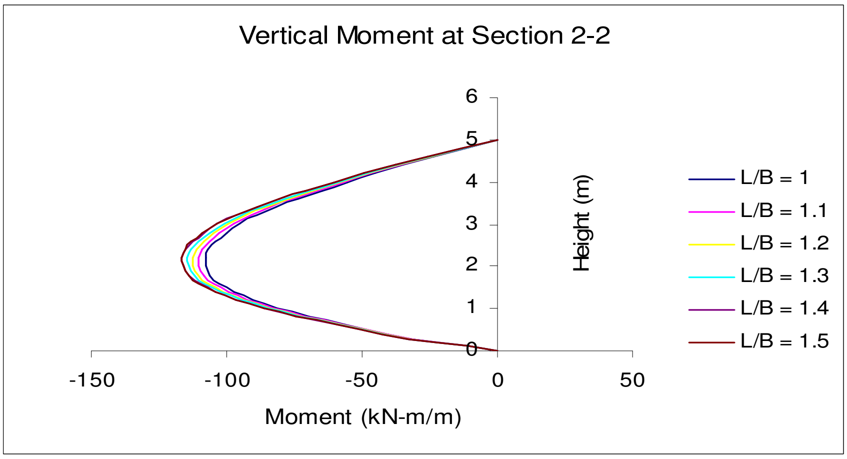
h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	-40.0	-40.6	-41.1	-41.5	-42.1	-42.1
0.8	-69.7	-71.0	-72.0	-72.8	-73.9	-74.0
1.2	-90.3	-92.1	-93.5	-94.7	-96.3	-96.4
1.6	-102.6	-104.9	-106.7	-108.1	-110.0	-110.2
2	-107.8	-110.3	-112.3	-113.9	-116.1	-116.3
2.4	-106.6	-109.2	-111.3	-113.0	-115.4	-115.6
2.8	-100.0	-102.6	-104.6	-106.3	-108.6	-108.8
3.2	-88.7	-91.1	-93.0	-94.5	-96.6	-96.8
3.6	-73.6	-75.6	-77.2	-78.5	-80.3	-80.5
4	-55.3	-56.8	-58.1	-59.0	-60.4	-60.5
4.4	-34.5	-35.5	-36.2	-36.8	-37.7	-37.8
4.8	-11.9	-12.2	-12.4	-12.6	-12.9	-12.9

Table 7.27 Vertical moment (kN-m/m) at section (3-3)

h (m)	L/B					
	1	1.1	1.2	1.3	1.4	1.5
0.4	-26.1	-25.5	-24.9	-24.3	-24.4	-23.2
0.8	-45.1	-43.9	-42.8	-41.6	-41.7	-39.4
1.2	-57.7	-56.1	-54.5	-52.8	-52.9	-49.8
1.6	-64.9	-62.9	-60.9	-58.9	-59.0	-55.1
2	-67.4	-65.1	-62.9	-60.7	-60.8	-56.4
2.4	-65.9	-63.5	-61.2	-58.9	-59.0	-54.5
2.8	-61.1	-58.8	-56.5	-54.2	-54.4	-49.9
3.6	-53.6	-51.4	-49.4	-47.3	-47.4	-43.3
4.4	-43.9	-42.1	-40.3	-38.6	-38.7	-35.2
4.8	-20.1	-19.2	-18.4	-17.5	-17.6	-16.0







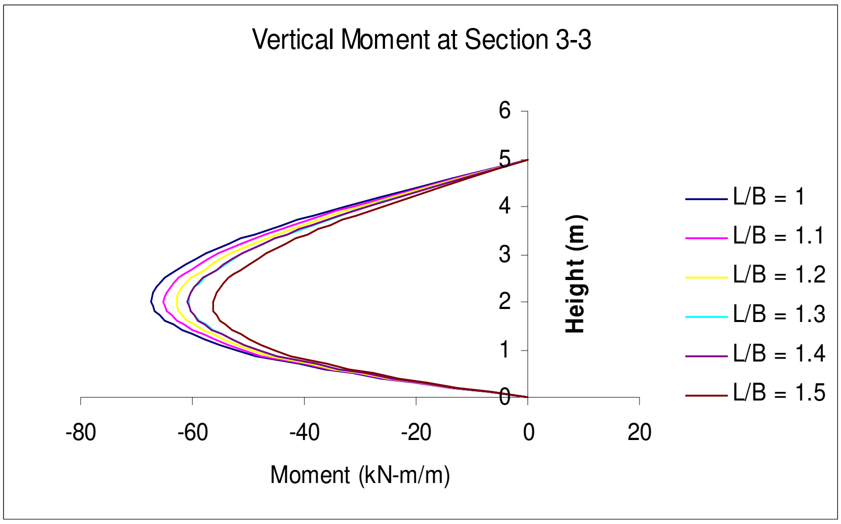
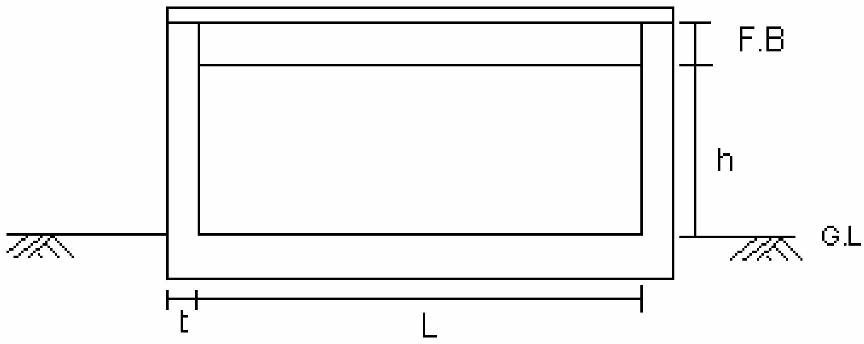
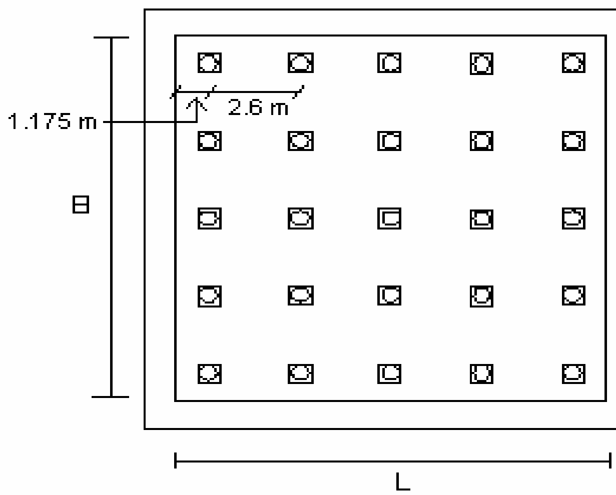


Fig. 7.16 Vertical moment at various locations due to earthquake along width

7.5 DESIGN EXAMPLE OF RECTANGULAR TANK

The procedure for design of rectangular tank considering hydrostatic pressure and hydrodynamic pressure as per IS: 1893 (part II) draft code is illustrated by an example of in this section.





Capacity of tank	= 800 m^3
Length of tank wall (L)	= 12.75 m
Width of tank wall (B)	= 12.75 m
Height of water in tank (h)	= 5 m
Height of free board (F.B)	= 0.3 m
Total height of tank wall (H)	= 5.3 m
Thickness of wall (t)	= 400 mm
Thickness of cover	= 125 mm
Earthquake zone	= 5
Soil type	= soft soil

Fig.7.17 Elevation and plan of rectangular tank

Weight Calculation

Weight of tank wall	= 2787.80kN
Mass of tank wall (m_w)	= 284179 kg
Mass of base slab	= 233948 kg
Volume of water	= 8,00,000 lit

Parameters of Spring Mass Model

$$\frac{m_i}{m} = \frac{\tanh 0.866(L/h)}{0.866(L/h)} = 0.41$$

Impulsive mass (m_i) =353625 kg

$h_i / h = 0.375$ for h/L <= 0.75

$$= 0.5 - \frac{0.09375}{h/D}$$

for h/L > 0.75

$h_i = 1.88$ meter

$$\frac{h_i*}{h} = \frac{0.866(L/h)}{2*\tanh 0.866(L/h)} - 0.125$$ for h/L <= 1.33

=0.45 for h/L > 0.75

h_i* = 5.03 meter

$$\frac{m_c}{m} = 0.264\frac{\tanh(3.16h/L)}{h/L}$$

m_c = 455208 kg

$$\frac{h_c}{h} = 1 - \frac{\cosh(3.16h/L) - 1}{(3.16h/L)\sinh(3.16h/L)}$$

h_c = 2.77 meter

$$\frac{h_c*}{h} = 1 - \frac{\cosh(3.16h/L) - 2.01}{(3.16h/L)\sinh(3.68h/L)}$$

h_c* = 5.33 meter

Time Period Calculation

Time period in impulsive mode

$$T_i = 2\pi\sqrt{\frac{d}{g}} \quad = 0.12 \text{ sec}$$

$$q = \frac{\left(\frac{m_i}{2} + \overline{m}_w\right)g}{Bh} \quad = 35.45 \text{ kN/m}^2$$

$$\overline{h} = \frac{\frac{m_i}{2}h_i + \overline{m}_w\frac{h}{2}}{\frac{m_i}{2} + \overline{m}_w} \quad = 2.02 \text{ m}$$

$$d = \frac{p\left(\overline{h}^3\right)}{3EI_w}$$

$$I_w = \frac{1.0 \times t^3}{12} \quad = 0.0053 \text{ m}^4$$

$d =$ 0.003 m

E = young's modulus

= 5,000 $\sqrt{f_{ck}}$

= 27386.13 N/mm^2

Time period for convective mode,

$$T_c = C_c\sqrt{\frac{L}{g}}$$

$T_c =$ 4.38 sec

where,

$$C_c = \frac{2\pi}{\sqrt{3.16\tanh\left(3.16\left(\frac{h}{L}\right)\right)}} \quad = 3.8$$

Design Horizontal Seismic Coefficient

Design horizontal seismic coefficient for impulsive mode,

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right)_i$$

= 0.34

Design horizontal seismic coefficient for convective mode,

$$A_h = \left(\frac{Z}{2}\right)\left(\frac{I}{R}\right)\left(\frac{S_a}{g}\right)_c$$

=0.09

Base Shear

Base shear at the bottom of wall in impulsive mode,

$V_i = (Ah)_i\,(m_i + m_w + m_t)\,g$

= 2111.69 kN

Base shear at the bottom of wall in convective mode,

$V_i = (Ah)_c(m_c)\,g$

= 402.18 kN

Total base shear at bottom of wall

$$V = \sqrt{Vi^2 + Vc^2}$$

= 2149.65 kN

Moment at Bottom of Wall

Bending moment at bottom of wall in impulsive mode,

$M_i = (A_h)_i\,(m_i h_i + m_w h_w + m_t h_t)g$

= 4688.84 kN.m

Bending moment at bottom of wall in convective mode,

$M_c = (A_h)_c m_c h_c g$

= 2354.32 kN.m

Total bending moment at bottom of wall,

$$M = \sqrt{M_i^2 + M_c^2}$$

= 4688.84 kN.m

Overturning Moment at Bottom of Base Slab

Overturning moment at bottom of base slab impulsive mode,

$M_i^* = (A_h)_i\,[m_i(h_i^*+t_b) + m_w(h_w+t_b) + m_t(h_t+t_b) + (m_b t_b/2)]g$

= 9632.82 kN.m

Overturning moment at bottom of base slab convective mode,

$M_c^* = (A_h)_c m_c(h_c^*+t_b)g$

= 2354.32 kN.m

Total bending moment at bottom of wall,

$$M^* = \sqrt{M_i^{*2} + M_c^{*2}}$$

= 9116.36 kN.m

$P/A + M^*/Z$ = 60.32 kN/m^2 < S.B.C (150 kN/m^2)

Safe in overturning

$P/A - M^*/Z$ = 1.98 kN/m^2 > 0

Safe in uplifting

Hydrodynamic Pressure

Lateral hydrodynamic impulsive pressure on the wall P_{iw} is given by,

$$p_{iw} = Q_{iw}(y)(A_h)_i \rho g h$$

Where,

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

p_{iw} = 13.99 kN/m^2

Impulsive hydrodynamic pressure in vertical direction, on base slab (y = 0)

$$p_{ib} = Q_{ib}(x)(A_h)_i \rho g h$$

Where,

$$Q_{ib}(x) = \frac{\sinh\left(0.866\frac{x}{h}\right)}{\cosh\left(0.866\frac{L}{h}\right)}$$

= 4.82 kN/m^2

Lateral hydrodynamic convective pressure on the wall P_{cw} is given by,

$$p_{cw} = Q_{cw}(y)(A_h)_c \rho g L$$

Where,

$$Q_{cw}(y) = 0.4165\frac{\cosh\left(3.162\frac{y}{L}\right)}{\cosh\left(3.162\frac{h}{L}\right)}$$

p_{cw} = 2.51 kN/m^2 (y = 0)

p_{cw} = 4.69 kN/m^2 (y = h)

Convective hydrodynamic pressure in vertical direction, on base slab (y = 0)

$$P_{cb} = Q_{cb}(x)(A_h)_c \rho g l$$

Where,

$$Q_{cb}(x) = 1.25\left[\frac{x}{L} - \frac{4}{3}\left(\frac{x}{L}\right)^3\right]\sec h\left(3.162\frac{h}{L}\right)$$

p_{cb} = 2.50 kN/m^2

Equivalent linear pressure distribution,

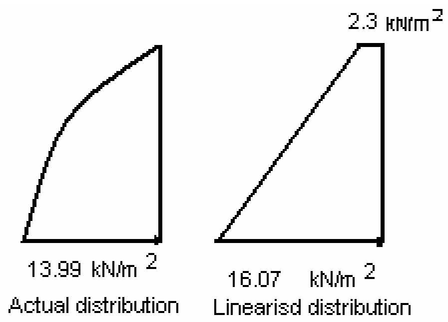
Base shear due to impulsive liquid mass per unit periphery length,

$$q_i = \frac{(A_h)_i m_i}{2B} g \quad = 45.91 \text{ kN/m}$$

Pressure at bottom and top is given by

$$a_i = \frac{q_i}{h^2}(4h - 6h_i) = 16.07 \text{ kN/m}^2$$

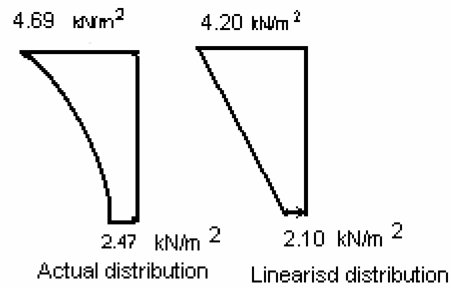
$$b_i = \frac{q_i}{h^2}(6h_i - 4h) = 2.3 \text{ kN/m}^2$$



$$q_c = \frac{(A_h)_c m_c}{2B} g \quad = 15.77 \text{ kN/m}$$

$$a_c = \frac{q_c}{h^2}(4h - 6h_c) = 2.10 \text{ kN/m}^2$$

$$b_c = \frac{q_c}{h^2}(6h - 2h_c) = 4.20 \text{ kN/m}^2$$



Pressure Due To Wall Inertia

$$p_{ww} = (A_h)_i t \rho_m g$$

$= 3.375$ kN/m^2

Pressure Due To Vertical Excitation

$P_v = (A_v)\rho\, g\, h\, (1\text{-}y/d)$

Where,

$A_v = (2/3)\,(z/2)\,(I/R)\,(S_a/g)$

$= 0.22$

P_v = 11.04 kN/m^2

Maximum Hydrodynamic Pressure

$$p = \sqrt{(p_{iw} + p_{ww})^2 + p_{cw}^2 + p_v^2}$$

p = 20.73 kN/m^2

NOTE: Hydrodynamic analysis of water tank should be done for both cases, when earthquake direction is along length or along width. In example 7.4 tanks is square so analysis results due to earthquake are same in both directions.

Design of Tank wall

Analysis results of rectangular tank wall due to total pressure (hydrostatic + hydrodynamic) are as per table 7.28.

Table 7.28 Analysis results of rectangular tank wall

Height (m)	Moment at corner of tank kN-m/m		Moment at center of wall kN-m/m	
	Horizontal moment	Vertical moment	Horizontal moment	Vertical moment
0.4	36.09	8.43	-15.99	-26.96
0.8	66.75	13.55	-30.36	-46.39
1.2	92.23	18.29	-43.14	-59.15
1.6	113.05	22.34	-54.42	-66.13
2	129.92	25.71	-64.30	-68.16
2.4	143.65	28.53	-72.88	-66.06
2.8	155.18	30.99	-80.32	-60.59
3.2	165.55	33.30	-86.78	-52.48
3.6	175.82	35.68	-92.45	-42.40
4	186.87	38.23	-97.56	-30.98
4.4	197.66	40.34	-102.36	-18.76
4.8	196.68	30.29	-107.11	-6.24
5	186.91	2.16	-109.54	-0.09

σ_{cbc} = 10.00 N/mm^2
m = 9.33
σ_{st} = 150.00 N/mm^2
k_c = 0.38
j = 0.87
R = 1.67

Horizontal reinforcement
h1 = 20 mm dia bar 130 mm c/c at center of wall
= 25 mm dia bar 115 mm c/c at corner of wall
h2 = 20 mm dia bar 140 mm c/c at center of wall
= 25 mm dia bar 115 mm c/c at corner of tank

Vertical reinforcement
Provide 20 mm dia bar 215 mm c/c

Quantity of steel for tank wall = 17191.5 kg
Quantity of concrete for tank wall = 103 m^3

7.5.1 Program for Design of Flat slab

To cover water tank beam and slab or flat slab can be used. In this study a computer program using C++ is prepared for analysis and design of flat slab for covering rectangular water tank. Input and output of program is as follows:

Select case
1: Circular flat slab
2: Rectangular flat slab
2
Enter length of slab in meter :12.75
Enter width of slab in meter :12.75
Enter live load kN/m^2 :1.2
Enter c/c distance between columns in meter in X direction :2.6
Enter c/c distance between columns in meter in Y direction :2.6
Enter concrete grade :30
Select steel
1: mild steel

2: HYSD
2
Select case
1: columns without column head and drop
2: columns with column head and drop
2
Select case
1: circular column head or drop
2: rectangular column head or drop
2

Enter column head width	:0.5
Enter column head depth	:0.3
Thickness of slab including concrete cover of 0.015 meter is	:0.125 meter

----

In X direction

Column strip width :1.3 meter
-Ve B.M = 3.02 kN*m
+Ve B.M = 1.30 kN*m
Middle strip width :1.3 meter
-Ve B.M = 1.00 kN*m
+Ve B.M = 0.87 kN*m

In Y direction

Column strip width :1.3 meter
-Ve B.M = 3.62 kN*m
+Ve B.M = 1.56 kN*m
Middle strip width :1.3 meter
-Ve B.M = 1.20 kN*m
+Ve B.M = 1.04kN*m

In X direction

Column strip width :1.3 meter

-Ve steel req = 158.01 mm^2

Enter diameter of bar in mm

10

Provide 10 mm bar 250 mm center to center

+Ve steel req = 68.06 mm^2

Enter diameter of bar in mm

10

Provide 10 mm bar 250 mm center to center

Middle strip width :1.3 meter

-Ve steel req = 52.67 mm^2

Enter diameter of bar in mm

8

Provide 8 mm bar 250 mm center to center

+Ve steel req = 45.37 mm^2

Enter diameter of bar in mm

8

Provide 8 mm bar 250 mm center to center

In Y direction

Column strip width :1.3 meter

-Ve steel req = 189.54 mm^2

Enter diameter of bar in mm

10

Provide 10 mm bar 250 mm center to center

+Ve steel req = 81.65 mm^2

Enter diameter of bar in mm

10

Provide 10 mm bar 250 mm center to center

Middle strip width	:1.3 meter

-Ve steel req = 63.18 mm^2

Enter diameter of bar in mm

8

Provide 8 mm bar 250 mm center to center

+Ve steel req = 54.43 mm^2

Enter diameter of bar in mm

8

Provide 8 mm bar 250 mm center to center

Enter no of rectangles induced by overlapping of column strips	:25
Enter no of rectangles induced by overlapping of column strips and middle strip	:50
Enter no of rectangles induced by overlapping of middle strips	:36
Total quantity of concrete is	:20.18 m^3
Total quantity of steel is	:1008.43 kg

7.5.2 Program for Design of Columns

Enter length of column in meter	:5.3
Enter factored axial load on column in kN	:30

Select column

1: circular column

2: rectangle column

1

Enter column dia in meter	:0.3
Enter no of columns	:25
Enter cover in mm	:40
Enter concrete grade	:30
Area of steel required	:1413.54 mm^2
Enter diameter of longitudinal bar in mm	:12

Provide 13 nos of 12 mm diameter bar

Enter diameter for lateral ties in mm :8

Provide 8 mm dia lateral ties 185 mm c/c

Total concrete quantity for columns is 8.84 m^3

Total steel quantity for columns is 4066.68 kg

Enter soil bearing capacity in kn/m^2	:150
Dimension required for square footing	:0.67 meter
Provide dimension for square footing in meter	:0.7

Select steel for footing

1: mild steel

2: HYSD

2

Enter diameter of bar	:12
Enter concrete cover for footing in mm	:25

Provide footing depth 95 mm with 25 mm concrete cover

Provide 10 no of bar 12 mm dia both ways

Total concrete quantity for footing is 1.11 m^3

Total steel quantity for footing is 428.49 kg

7.5.3 Program for Design of Base Slab

Enter weight of rectangular tank wall in kN	:2414.7
Enter inner length of tank in meter	:12.75
Enter inner width of tank in meter	:12.75
Enter thickness of tank wall in meter	:0.4

Enter max moment at wall base in kN-m/m

(Maximum of soil pressure or water pressure)

0

Enter soil density in kN/m^3	:18
Enter height of soil in meter	:0
Enter maximum water height in tank in meter	:5
Enter soil bearing capacity in kN/m^2	:150

Footing length 1.5 meter

Length of toe 0.2 meter

Length of heel 0.9 meter

Select concrete grade

1: M 30

2: M 35

3: M 40

4: M 45

5: M 50

1

Select steel

1: Plain round mild steel bars

2: High strength deform bars

2

Effective depth required for footing in mm	:127.41
Enter effective depth provided in mm	:300

Enter concrete cover in mm	:50
Total depth of footing of base slab	:350
Area of steel required for footing	:400 mm^2
Enter bar diameter in mm	:10

Provide 10 mm dia bar mesh in two layer 195 mm c/c

Quantity of concrete for wall footing is 74.31 m^3

Quantity of steel for wall footing is 691.12 kg

Enter total depth of base slab (middle portion of base slab) in mm	:250
Area of steel required for middle portion of slab	:255.71 mm^2
Enter bar diameter in mm	:10

Provide 10 mm dia bar mesh in two layer 265 mm c/c

Quantity of concrete for base slab 55.52 m^3

Quantity of steel for wall footing is 1035.28 kg

Total quantity of steel for rectangular tank = 20354.83 kg

Total quantity of concrete for rectangular tank = 254.12m^3

Structural rate of tank = 1.55 Rs/lit

Rate as per G.W.S.S.B = 1.403 Rs/lit

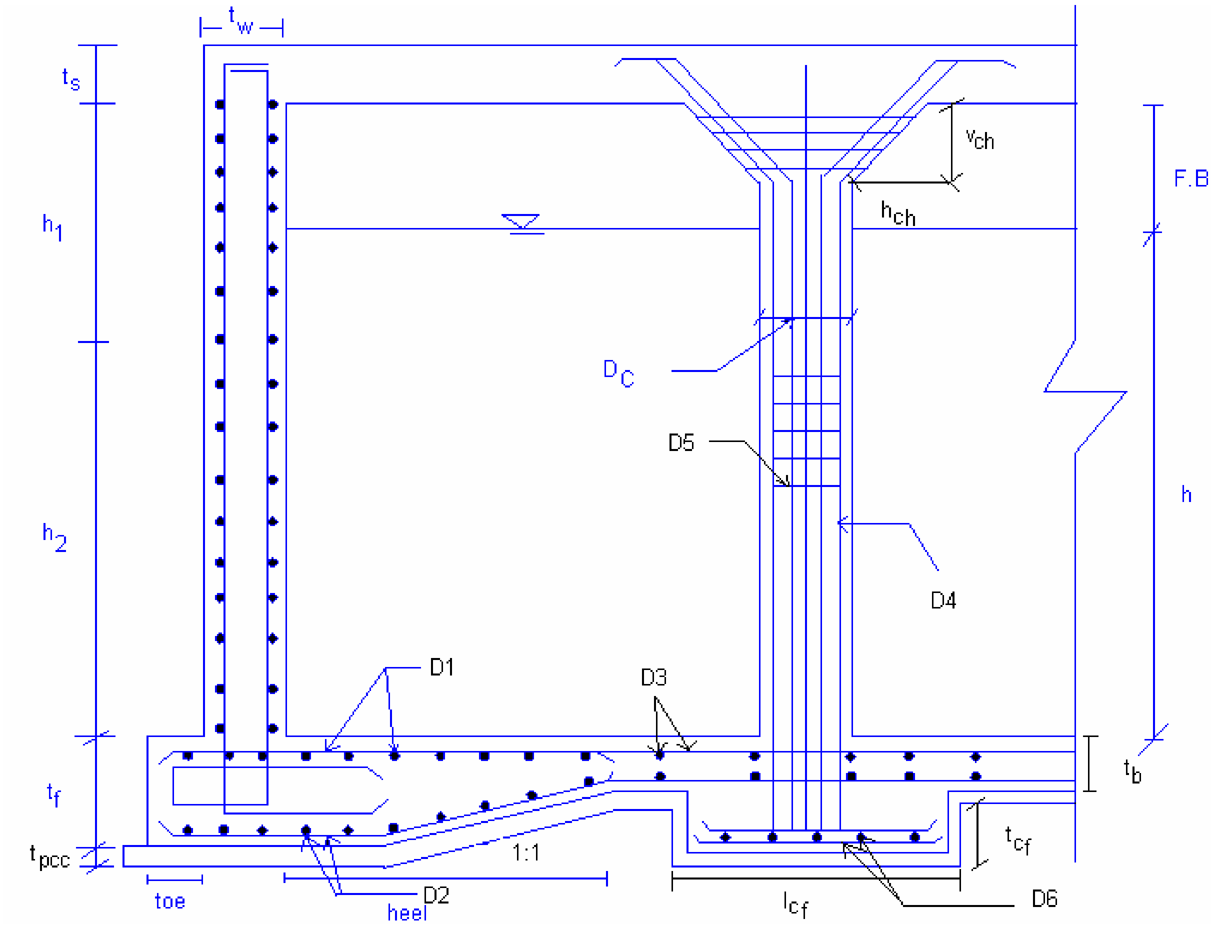


Fig.7.18 Reinforcement detailing in rectangular tank

Thickness of wall (t_w) = 400 mm

Thickness of flat slab (t_s) = 125mm

Thickness of footing (t_f) = 350 mm

Thickness of base slab (t_b) = 250 mm

toe = 0.2 m

heel = 0.9 m

Thickness of p.c.c (t_{pcc}) = 100 mm

Horizontal reinforcement in wall

h1 = 20 mm dia bar 95 mm c/c at center of wall

= 25 mm dia bar 80 mm c/c at corner of wall

h2 = 20 mm dia bar 130 mm c/c at center of wall

= 25 mm dia bar 105 mm c/c at corner of tank

Vertical reinforcement in wall

20 mm dia 155 mm c/c.

D_c = 300 mm

D1 = 10 mm dia bar 195 mm c/c

D2 = 10 mm dia bar 195 mm c/c

D3 = 10 mm dia bar 265 mm c/c

D4 = 13 no of 12 mm dia bar

D5 = 8 mm dia 165 mm c/c

l_{cf} = 0.7 m

D6 = 10 no of 12 mm dia both way

t_{cf} = 95 mm

h_{ch} = 0.5 m

v_{ch} = 0.3 m

7.6 PARAMETRIC STUDY FOR ECONOMICAL CONFIGURATION

Design of water tank with capacity 8,00,000 liters with length to height ratio 1 to 5 is carried out. From quantity of concrete and steel the cost of water tank is calculated considering rate of materials as per S.O.R of G.W.S.S.B. Reinforcement detail of various elements of open rectangular tank and structural cost per liter is presented in Table 7.29. The variation in cost per liter with length to height ratio for different capacity tank is shown in Fig.7.18.

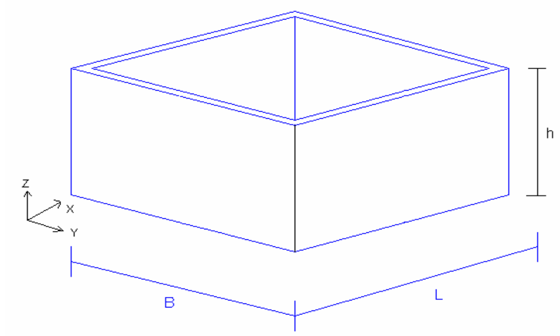


Table 7.29 Parametric study on design of rectangular tank

				Wall in X-direction					Wall in Y-direction														
Capacity lit	L/B	length (L) (m)	Width (B) (m)	Thickness (m)	Detailing				Thickness (m)	Detailing				Detailing in corner of tank		Wall footing			Base slab			Total rate	
					Horizontal		Vertical			Horizontal		Vertical				Thickness (m)	Detailing		Thickness mm	Detailing		Rs/lit	G.W.S.S.B
					Dia (mm)	c/c (mm)	Dia (mm)	c/c (mm)		Dia (mm)	c/c (mm)	Dia (mm)	c/c (mm)	Dia (mm)	c/c (mm)		Dia (mm)	c/c (mm)		Dia (mm)	c/c (mm)		
8,00,000	1	12.65	12.65	0.4	20	130	20	215	0.4	20	130	20	215	25	115	0.3	10	215	250	10	285	1.380	1.403
	1.1	13.27	12.06	0.4	20	125	20	205	0.4	20	140	20	225	25	115	0.3	10	215	250	10	185	1.393	
	1.2	13.86	11.55	0.4	20	120	20	200	0.4	20	150	20	135	25	110	0.4	10	175	250	10	285	1.400	
	1.3	14.42	11.09	0.4	20	115	20	195	0.4	20	160	20	245	25	100	0.4	10	175	250	10	285	1.420	
	1.4	14.97	10.69	0.4	20	115	20	190	0.4	20	175	20	250	25	100	0.4	10	175	250	10	285	1.430	
	1.5	15.49	10.33	0.4	20	110	20	190	0.4	20	185	20	265	25	100	0.4	10	175	250	10	285	1.460	

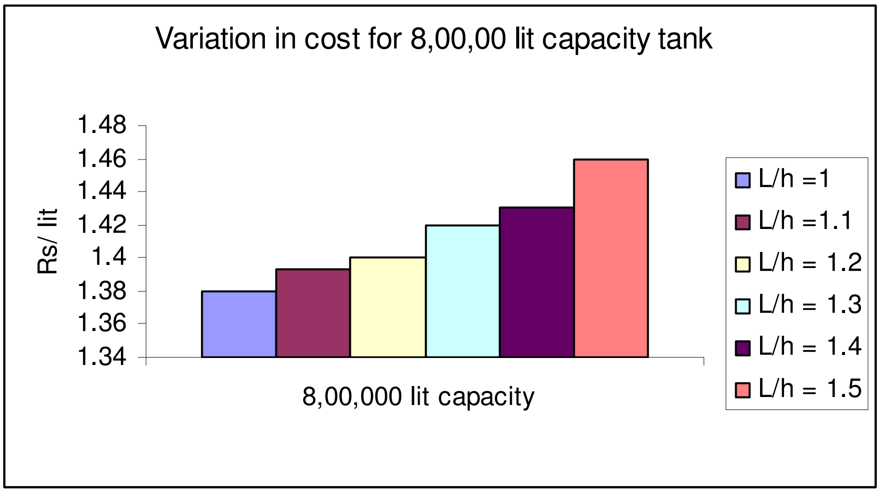


Fig.7.19. Cost comparison of different configuration for rectangular tank

7.7 SUMMARY

In this chapter finite element modeling and analysis of ground supported rectangular tank is discussed. Finite element model is prepared in SAP2000 software for calculation of maximum horizontal and vertical moments in rectangular tank wall. Comparison of results of SAP2000 and results as per design tables given in IS:3370(IV) is done and presented in tabulated and graphical form. Comparison of analysis results due to hydrostatic pressure and total pressure (hydrostatic +hydrodynamic) is carried out for 8,00,000 liter capacity tank with different length to width ratio. An illustrative example including analysis, design and detailing of rectangular tank is presented. Input and output of computer program for design of different component of tank is also presented. Parametric study of design and structural cost estimation is also carried out.

8. ANALYSIS AND DESIGN OF PUMP HOUSE

8.1 GENERAL

Pumps are used to lift water to elevated reservoir from sump. Pump house is structure, which is used to install the pumps, electrical equipments and it gives the space for working. It is simple beam, column and slab type building structure. For analysis and design of pump house computer program is developed in C++ language with connectivity of STAAD/pro software. This chapter includes input and output data of program for geometry and load generation in STAA/pro. Program is developed in such a way that, by entering required input data whole structural model is generated in STAAD/pro automatically.

8.2 COMPUTER PROGRAM OF PUMP HOUSE

For analysis and design of pump house, computer program is developed to generate structural model in STAAD/pro software. Function of computer program can be easily understood by flow chart shown in Fig.8.1.

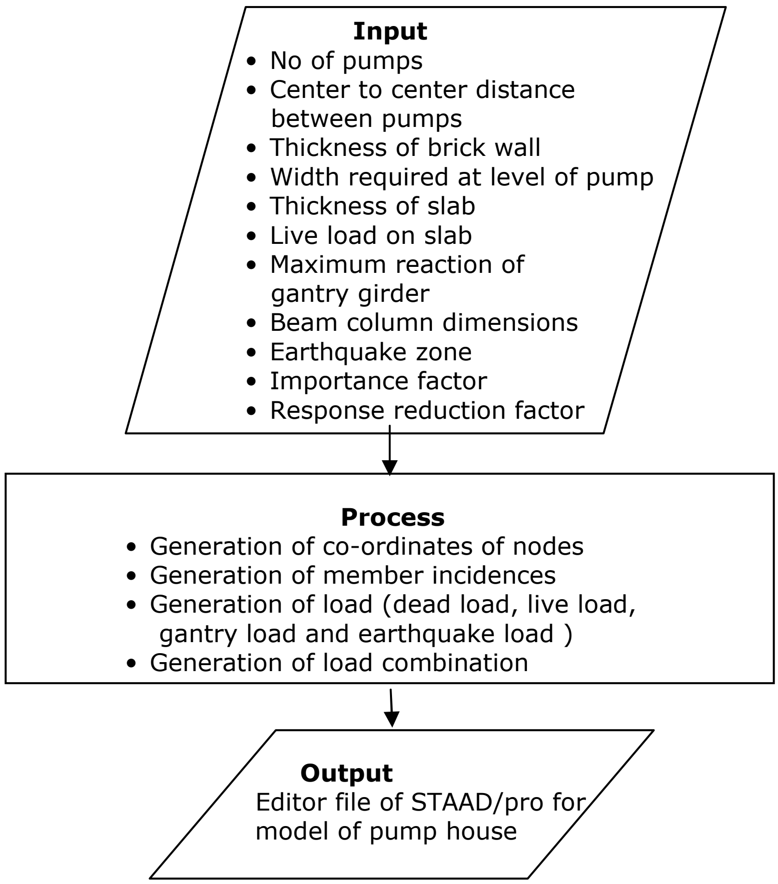
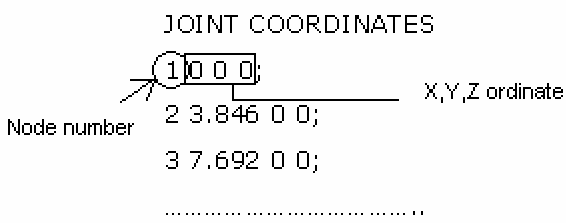


Fig.8.1. Flowchart of program for pump house

8.2.1 Structural Geometry Generation

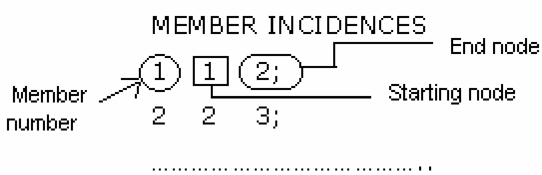
For creation any structural geometry in STAAD/pro software, nodes have to be generated with proper co-ordinates. Members are connected in these nodes. Then material definition, property definition and assignment of loading are done. In STAAD/pro software, there is a facility of STAAD-Editor. During generation of structural model in STAAD/pro its related data is generated and stored in .std file which can be viewed by STAAD. By modifying in this generated file, it is possible to change data in structural model. This feature of STAAD/pro software makes it more user-friendly than other software of Analysis. By use of any computer language, it is possible to generate data file for structural model. For generation of geometry of pump house, computer program using C++ programming language is developed. By use of file input/output function, STAAD file (.std) can be generated as program output.

Generation of nodes: Node definition in STAAD-Editor is given below,



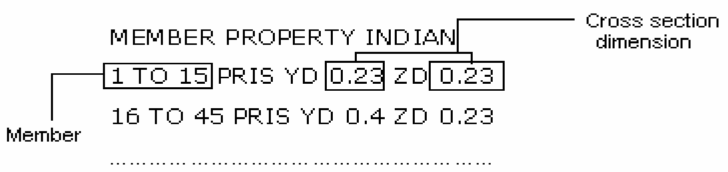
First number indicates the number of node. Other three number indicate X,Y,Z ordinate of node. Programming for generation of node numbers and their ordinates is carried out. By giving dimensions of pump house as input, node numbers and its co-ordinates are generated.

Member generation: Member connectivity in STAAD/pro is as shown below



First number indicates the member number. Second number indicate starting node and third number indicates end node. Member numbers with its starting and ending node is generated using program output.

Property Definition: cross sectional properties of members are defined as follows.



Cross sectional dimension are given as input data.

Member load definition:

```
MEMBER LOAD
1 TO 5 11 TO 20 26 TO 30 46 51 52 57 58 63 TO 65 UNI GY -14.72
```

Load due to brick wall is assigned as uniformly varying load. Various member numbers and respective value of load is generated by computer program.

Floor load definition:

```
FLOOR LOAD
YRANGE 6.4 6.4 FLOAD -3
YRANGE 3.2 3.2 FLOAD -3 XRANGE 0 19.23  ZRANGE 0 4.115
```

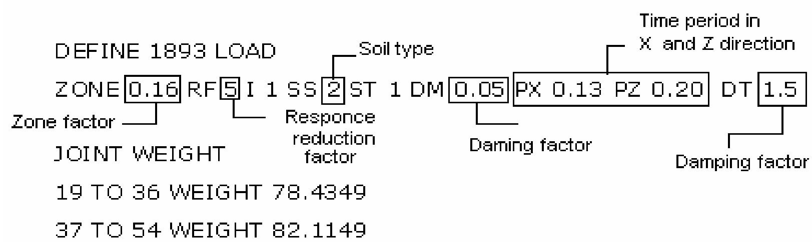
Dead load and live load re assigned as floor load. In definition of floor load value of load is given as input. Program generates its X and Z ordinate range.

Point load definition:

```
MEMBER LOAD
64 65 CON GY -20
```

Reactions of gantry girder, act as concentrated load on beam which supports it.

Earthquake load definition:



For earthquake data zone, type of structural frame (S.m.r.f or O.m.r.f), type of soil, damping as percentage etc is given as input in program. From input data of zone factor, response reduction factor, damping factor, time period in X and Z direction and damping factor etc calculated by program. Program calculates joint weight from the dimensions of structural components.

8.2.2 Load combinations for Analysis

For analysis of pump house load combination is used as per given in IS:1893 (part I).

1) 1.5(DL+LL)
2) 1.2(DL+LL +/- EL)
3) 1.5(DL +/- EL)
4) 0.9 DL +/- 1.5 EL

8.3 INPUT AND OUTPUT OF PROGRAM

Input of program for generation of STAAD model for analysis is as follows:

Enter no of pump required for pumping	:6
Center to center distance between two pump in meter	:3
Margin in X direction (R.H.S)	:2
Margin in X direction (L.H.S)	:2
Thickness of brick wall in meter	:0.23
Width required at pump level in meter	:4
Length required in meter	:19.23meter
Width of pump house	:8.23meter
Provide column in 3 series	
no of column in one series	:6
Depth of foundation	:1.5
Select type of support	
1 : Fixed	
2 : Pinned	
1	
Enter depth of plinth beam in meter (in x dir beams)	:0.23
Enter width of plinth beam in meter (in x dir beams)	:0.23
Enter depth of beam in meter (in x dir beams)	:0.4
Enter width of beam in meter (in x dir beams)	:0.23
Enter depth of plinth beam in meter (in z dir beams)	:0.23
Enter width of plinth beam in meter (in z dir beams)	:0.23

Enter depth of beam in meter (in z dir beams) :0.4

Enter width of beam in meter (in z dir beams) :0.23

Enter depth of column section :0.4

Enter width of column section :0.23

Enter thickness of slab in meter :0.115

Enter earthquake zone 2 or 3 or 4 or 5 :3

Importance factor 1 or 1.5 :1

Response reduction factor

O.m.r.f = 3

S.m.r.f = 5

5

Enter soil type 1 : Hard soil

2 : Medium soil

3 : Soft soil

2

1: One way load distribution

2: Two way load distribution

2

Enter live load on slab in kN/m^2

3

1: One way load distribution

2: Two way load distribution

2

Enter maximum reaction due gantry girder in kN :20

Output of program for generation of STADD model for analysis is as follows.

STAAD SPACE

START JOB INFORMATION

ENGINEER DATE 21-Sep-06

END JOB INFORMATION

INPUT WIDTH 79

UNIT METER KN

JOINT COORDINATES

1 0 0 0;

2 3.846 0 0;

```
3 7.692 0 0;
……………………………..
72 19.23 -1.5 8.23;
MEMBER INCIDENCES
1 1 2;
2 2 3;
………………………………..
SUPPORTS
55 TO 72 FIXED
DEFINE MATERIAL START
ISOTROPIC CONCRETE
E 2.17185e+007
POISSON 0.17
DENSITY 23.5616
ALPHA 1e-005
DAMP 0.05
END DEFINE MATERIAL
CONSTANTS
MATERIAL CONCRETE ALL
MEMBER PROPERTY INDIAN
1 TO 15 PRIS YD 0.23 ZD 0.23
16 TO 45 PRIS YD 0.4 ZD 0.23
………………………………………………
46 TO 57 PRIS YD 0.23 ZD 0.23
58 TO 77 PRIS YD 0.4 ZD 0.23
78 TO 131 PRIS YD 0.4 ZD 0.23
DEFINE 1893 LOAD
ZONE 0.16 RF 5 I 1 SS 2 ST 1 DM 0.05 PX 0.131351 PZ 0.200781 DT 1.5
JOINT WEIGHT
19 TO 36 WEIGHT 78.4349
37 TO 54 WEIGHT 82.1149
LOAD 1 EQ X
1893 LOAD X 1
LOAD 2 EQ Z
1893 LOAD Z 1
```

```
LOAD 3 DEAD LOAD
FLOOR LOAD
YRANGE 6.4 6.4 FLOAD -2.875
YRANGE 3.2 3.2 FLOAD -2.875 XRANGE 0 19.23  ZRANGE 0 4.115
SELFWEIGHT Y -1
MEMBER LOAD
1 TO 5 11 TO 20 26 TO 30 46 51 52 57 58 63 TO 65 UNI GY -14.72
LOAD 4 LIVE LOAD
FLOOR LOAD
YRANGE 6.4 6.4 FLOAD -3
YRANGE 3.2 3.2 FLOAD -3 XRANGE 0 19.23  ZRANGE 0 4.115
LOAD 5 GL
MEMBER LOAD
72 To 77 CON GY -20
LOAD COMB 6 1.5(DL+LL+GL)
3 1.5 4 1.5 5 1.5
LOAD COMB 7 1.2(DL+LL+GL+ELX)
3 1.2 4 1.2 1 1.2 5 1.2
LOAD COMB 8 1.2(DL+LL+GL-ELX)
3 1.2 4 1.2 1 -1.2 5 1.2
LOAD COMB 9 1.2(DL+LL+GL+ELZ)
3 1.2 4 1.2 2 1.2 5 1.2
LOAD COMB 10 1.2(DL+LL+GL-ELZ)
3 1.2 4 1.2 2 -1.2 5 1.2
LOAD COMB 11 1.5(DL+ELZ)
3 1.5 1 1.5
LOAD COMB 12 1.5(DL-ELZ)
3 1.5 1 -1.5
LOAD COMB 13 1.5(DL+ELZ)
3 1.5 2 1.5
LOAD COMB 14 1.5(DL-ELZ)
3 1.5 2 -1.5
LOAD COMB 15 0.9 DL+ 1.5 ELX
3 0.9 1 1.5
LOAD COMB 16 0.9 DL- 1.5 ELX
```

3 0.9 1 -1.5
LOAD COMB 17 0.9 DL+ 1.5 ELZ
3 0.9 2 1.5
LOAD COMB 18 0.9 DL- 1.5 ELZ
3 0.9 2 -1.5
PERFORM ANALYSIS
PRINT ALL
START CONCRETE DESIGN
CODE INDIAN
TRACK 2 ALL
DESIGN BEAM 1 TO 77
DESIGN COLUMN 78 TO 131
CONCRETE TAKE
END CONCRETE DESIGN
FINISH

8.4 MODEL OF PUMP HOUSE IN STAAD/pro

From the output of program model of pump house is generated in STAAD. The model which is generated by program is presented in Fig.8.2 and Fig.8.3.

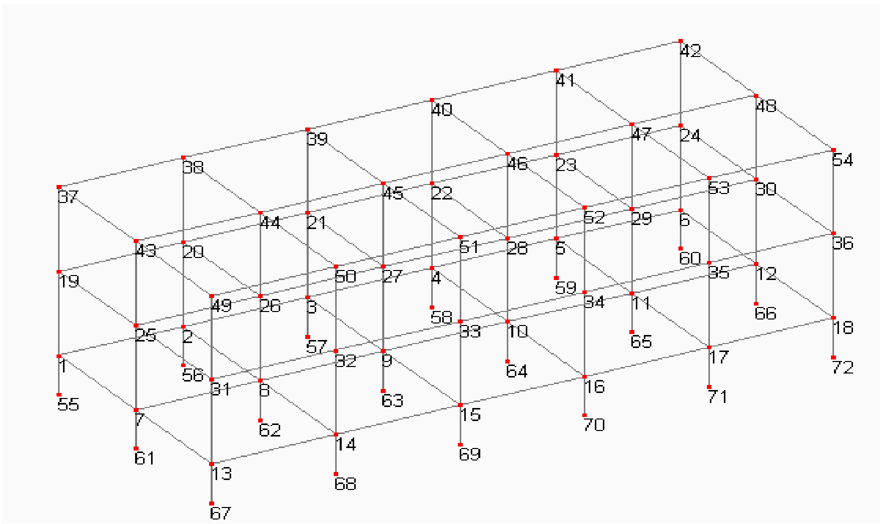


Fig.8.2 Model of pump house with node number

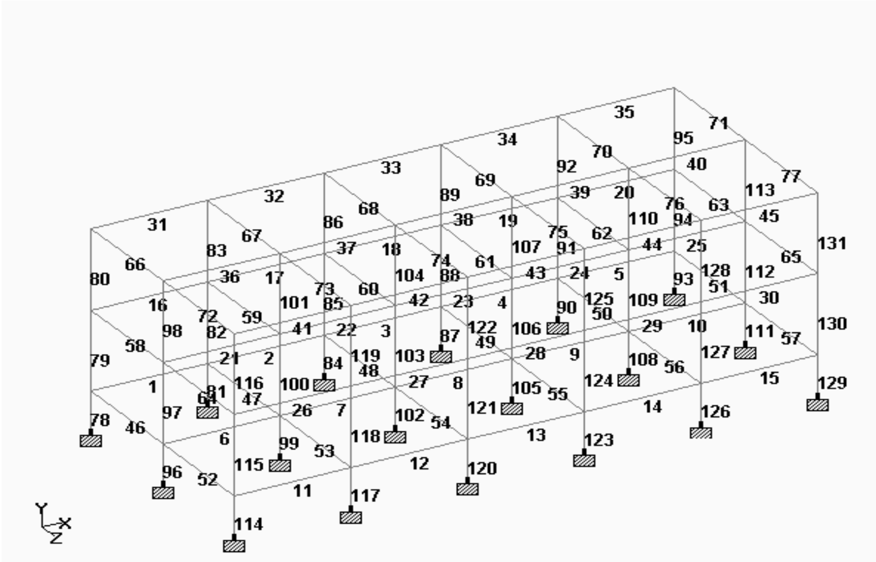


Fig.8.3 Model of pump house with member number

8.4.1 Generation of Load

Dead load and live load are allocated as floor load. There is an option given to user for selecting load distribution one way or two way distribution. In Fig.8.4 two way load distribution is shown. Gantry girder is used to lift the pumps for maintenance purpose. Reactions of gantry girder are transferred on beam as shown in Fig.8.5.

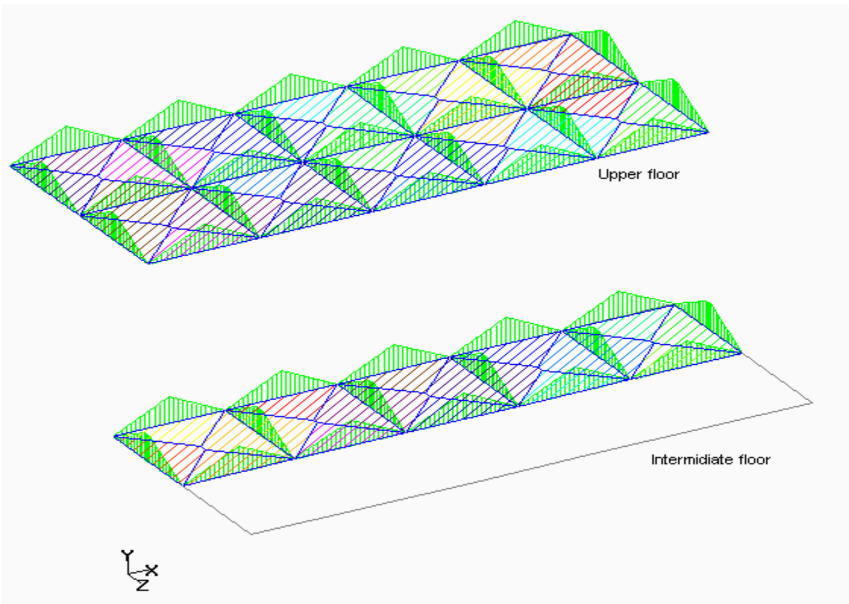


Fig.8.4 Floor load distribution

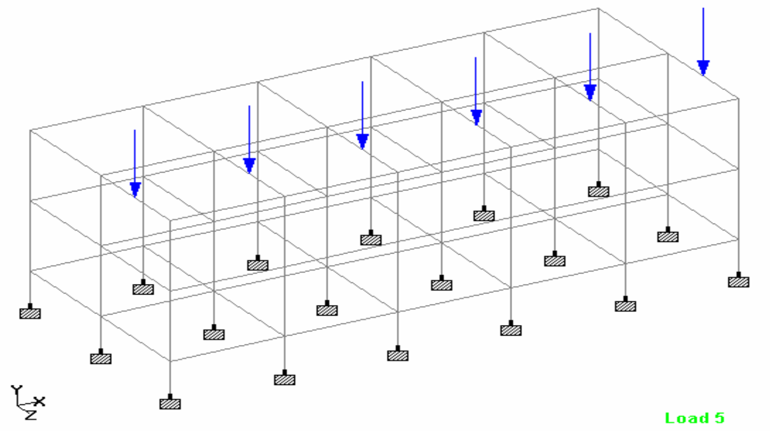


Fig.8.5 Reaction of gantry girder

8.4.2 3D Model of Pump House

Model of pump house generated by output of program is shown in Fig.8.6.

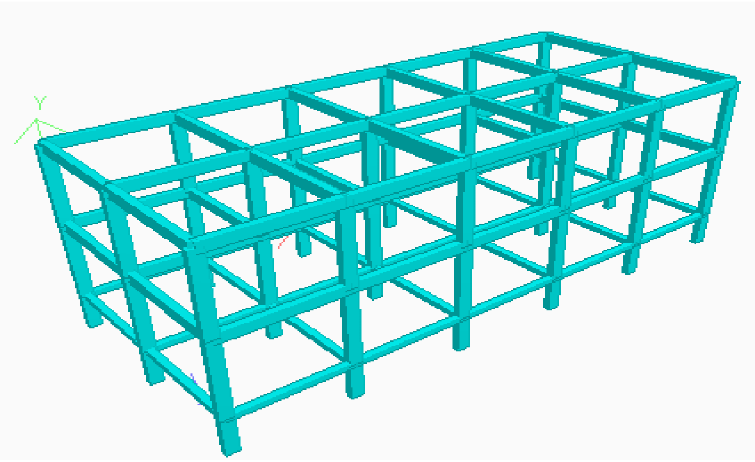


Fig.8.6 3-D View of Pump House

8.5 ANALYSIS AND DESIGN

The structural model generated through program (.std) file is ran in STAAD/pro environment. Subsequently analysis and design results are obtained. The results can be viewed in post processing mode or through output file. Design of beams and columns are carried out as per IS:456 and quantity of materials is given by STAAD/pro.

8.6 SUMMARY

This chapter includes modeling of pump house in STAAD/pro software. Flow chart of computer program is presented. Input and output data of program for generation of STAAD model is included. Geometry of model and load distribution are discussed in this chapter.

9. SUMMARY AND CONCLUSION

9.1 SUMMARY

IS: 1893 (1984) specifies criteria for seismic design of various structures. The provisions for the seismic analysis of ground supported tanks in IS: 1893 (1984) are not enough. It includes provisions regarding impulsive hydrodynamic pressure. Other provisions for base shear, moment at base of wall, overturning moment and convective hydrodynamic pressure for ground-supported tank are not included. In IS: 1893 (part II) draft there are number of provisions regarding seismic analysis. This major project is based on critical study of IS: 1893 (part II) draft. Study of draft code is carried out and its provisions are explained in details with illustrations. Computer programs for seismic analysis of ground supported circular and rectangular tanks are prepared in C++ language. Input and output of programs of seismic analysis are presented. These programs are used for parametric study for seismic analysis of various configurations. In parametric study circular tank of capacity 8,00,000 liters to 12,00,000 liters with height to diameter ratio varying from 0.1 to 1 are considered. Two parametric studies for analysis of rectangular tanks are carried out. In one study, rectangular tank of different capacity with length to height ratio 1 to 5 are considered in earthquake zone IV and V. In other parametric study length to width ratio 1 to 1.5 are considered in earthquake zone V.

Computer programs in C++ language are also developed for analysis of circular and rectangular water tank as per design tables given in IS: 3370 (part IV). Design tables given in IS: 3370 (part IV) are for linear pressure variation only, while hydrodynamic pressure variation is nonlinear along height of wall. So, design tables of IS: 3370 (part IV) cannot be applied directly. To get analysis results due to nonlinear pressure variation, finite element analysis in SAP2000 software is carried out. Modeling and analysis of wall of circular and rectangular water tanks are carried out with hydrodynamic and hydrostatic pressure. Finite element analysis results and analysis as per IS: 3370 (part IV) are compared for 10,00,000 liters capacity circular tank along the height of wall. Similarly, finite element analysis results and analysis results as per IS: 3370 (part IV) are compared for 8,00,000 liter capacity rectangular tank along the height. Different finite element models of circular tank with height to diameter ratio 0.1 to 0.5 are prepared for capacity 8,00,000 liters to 12,00,000 liters, and analysis results of maximum bending moment and tension as obtained from SAP2000 and IS:3370 (part IV) are compared. Different finite element models of rectangular tank with length to width ratio varying 1 to 1.5 are prepared for capacity 8,00,000 liter, and analysis results of horizontal and vertical bending moments are obtained from SAP2000 and are compared with those obtained as per IS:3370 (IV).

Computer programs are also developed for design of different components of circular and rectangular water tanks like, dome and top ring beam, base slab, flat slab, column and its footing. Illustrative examples for design of circular and rectangular tank are presented with reinforcement detailing and structural cost estimation considering effect of hydrodynamic pressure.

Parametric study is also carried out for design and estimation. Design and structural cost estimation for circular and rectangular tank with different configuration are carried out. From parametric study economical configuration is obtained for both the circular and rectangular tank.

Analysis and design of pump house is carried out in STAAD/pro software. For geometry generation, and load calculations a separate computer program is prepared in C++ language. This program is linked with STAAD/pro for further analysis and design.

9.2 CONCLUSIONS

From the present study following conclusions are obtained;

- For the circular tanks total base shear, moment at base of wall, overturning moment, total hydrodynamic pressure are increasing as height to diameter ratio increases.

- Hydrodynamic pressure for circular tank in earthquake zone up to IV is within permissible limit (i.e. less than 33% of hydrostatic pressure) for the capacities considered.

- Hydrodynamic pressure for various capacity circular tanks in earthquake zone V with height to diameter ratio less than 0.85 is critical (i.e. more than 33% of hydrostatic pressure).

- Value of maximum moment and tension due to hydrostatic pressure, are marginally more in case of finite element analysis using SAP2000 in comparison with that obtained using IS: 3370 (part IV).

- Tensile force due to total (hydrostatic + hydrodynamic) pressure is 13% to 60% more than hydrostatic pressure for circular tank with different height to diameter ratio.

- Moment due to total pressure (hydrostatic + hydrodynamic) is 6% to 42% more than hydrostatic pressure for circular tank with different height to diameter ratio.

- Height to diameter ratio 0.4 to 0.5 is economical in the circular tank.

- For rectangular tanks total base shear, moment at base of wall, overturning moment, total hydrodynamic pressure are decreasing as length to height ratio increases.

- Hydrodynamic pressure is within permissible limit (i.e. less than 33% of hydrostatic pressure), up to earthquake zone IV for various capacities of rectangular tanks considered.

- In earthquake zone V, hydrodynamic pressure is critical (i.e. more than 33% of hydrostatic pressure) for rectangular tanks with length to height ratio more than 1.2.

- Values of maximum horizontal and vertical moment due to hydrostatic pressure, are marginally more in case of finite element analysis using SAP2000 compared to that obtained using IS:3370 (part IV).

- Square tank is more economical than other type of configuration in rectangular tank.

- Shallow rectangular tanks are subjected to lower hydrodynamic pressure.

9.3 FUTURE SCOPE OF WORK

The present work can be extended to consider following aspects.

- Parametric study for under ground and partially underground water tank can be carried out.
- Analysis and design of steel water tank using IS: 1893 (part II) draft can be done.
- Using computer programs developed in this study general purpose software for analysis and design of various types of sumps with Graphical User Interface (GUI) can be developed.
- Computer program can be linked with AutoCAD for structural drawings including bar bending schedule.
- General purpose computer software for analysis and design of pump house can be developed.

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[20] IS 3370 (part IV) : "Code of Practice for Concrete Structures for Storage of Liquid", Bureau of Indian Standards, New Delhi.

APPENDIX A

List of Useful Website

- http://www.Google.com
- http://www.nicee.org
- http://www.nisee.org
- http://www.nptel.iitm.ac.in
- http://www.nicee.org/IITK-GSDMA_Codes.php

APPENDIX B

List of Papers Published

Pallav, V., Patel, P.V., ” Seismic behavior of Ground Supported Circular Liquid Retaining Structure as per IS 1893 (part II) Draft Code”, *Emerging Technology and Development in Civil Engineering*, March 2007.

List of Papers Communicated

Pallav, V., Patel, P.V., ” Seismic Behavior of Ground Supported Rectangular Liquid Containing Structure as per IS:1893 (part II) Draft Code”, *Geotechnical and Structural Aspects of Earthquake Engineering,* Jamia Milia Islamia, Delhi, July 2007.

Pallav, V., Patel, P.V., ” Seismic Behavior of Ground Supported tank as per IS:1893 (part II) Draft Code”, *8th Pacific Conference on Earthquake Engineering*, Singapore, December 2007.

Pallav, V., Patel, P.V., ” Seismic Analysis and design of Ground Supported Circular Tank as per IS 1893 (part II) Draft Code”, *Recent Development in Structural Engineering*, Manipal Institute of Technology, Manipal, August 2007.

Pallav, V., Patel, P.V., ” Seismic Analysis and design of Ground Supported Rectangular Tank as per IS 1893 (part II) Draft Code”, *Structural Engineers World Congress*, Banglore, November 2007.

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Pallav, V., Patel, P.V., ″ Seismic Analysis and design of Ground Supported Rectangular Tank as per IS 1893 (part II) Draft Code”, *Structural Engineers World Congress*, Banglore, November 2007.