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# Seismic Analysis of Completely Buried Rectangular Concrete Reservoir

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Abstract - Behavior of liquids within the container or tank is one of the important aspects that need to be seriously and carefully captured in order to account for the serviceability of the container. Any inadequacy in the proper estimation of seismic forces that the tank wall would be subjected to during ground motions may cause serious damage to the container and there may be interruption in the supply chain causing inconvenience to public. Therefore in this study a rectangular tank is analyzed for seismic forces in two of the principal direction and the variation of these forces for different level of water within the tank is investigated in this study. In this study a general processor is built to calculate seismic forces and results are tabulated according to Housners mechanical model.

*Key Words: Hydrodynamic Pressure1, Time period, Finite element.*

## 1. INTRODUCTION

Concrete liquid containing structures as a part of environmental engineering structures are considered as essential facilities during earthquakes. While the leakage of tanks containing hazardous materials is essential to be controlled in water tanks, the contents are important for firefighting operations as well as for meeting the public demands. To date, intensive research has been conducted on the dynamic response of liquid storage tanks. However, most of them are related to steel tanks. Little attention has been drawn to reinforced concrete tanks. Reinforced concrete tanks are widely used in environmental engineering applications in the form of rectangular or circular configuration. It is necessary to have a good understanding of the seismic behavior of these structures to meet safety objectives while containing construction and maintenance costs.

Loading conditions of liquid storage tanks subjected to subject to seismic ground motion earthquakes are very complex. Beside the inertial force due to the weight of the tank walls, the hydrodynamic pressures are also applied on the tank walls. As the nonlinear hydrodynamic pressure loads are strongly dependent on the input of ground motion, in this study, rectangular reinforced concrete tanks are subjected to seismic ground motions of different intensities. The results of this study will provide useful information on the response of concrete.

### 1.1 MACHENICAL MODEL APPROACH

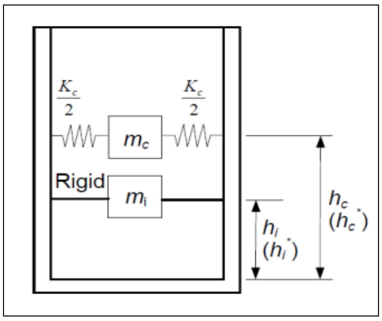

Fig- 1 (Housners spring mass model)

Housner was one among the pioneers in formulating a Spring Mass model for a tank containing fluids, with a horizontal earthquake ground motion. The wall of the tank and the fluid present inside the tank are subjected to the horizontal acceleration. The Hydrodynamic pressure can be divided in to Impulsive hydrodynamic pressure and convective hydrodynamic pressure. The impulsive liquid mass of liquid which is present in the lower region of tank which behaves like a mass which is rigidly connected to walls of the tank. These fluid mass which is rigidly connected to the wall of tank, which accelerates along with the walls of the tank and induces impulsive hydrodynamic pressure on tank and on the base of the tank. Fluid present in the upper region of the tank undergoes sloshing motion. These mass is convective liquid mass, it exerts a convective hydrodynamic pressure on tank wall and the base of the tank.

If the vertical column is present inside the tank filled with fluid which may cause obstruction to the convective mode of the liquid or the sloshing motion. The presence of column will lead to the obstruction to the impulsive and convective mode. It is expected that impulsive pressure will increases and convective pressure will decreases. Housner's model does not address this phenomenon.

The draft code for liquid retaining structures of Indian Standard code [6]also recommends the following expressions to calculate the fundamental time period of impulsive and convective mode of vibration of fluid tank system

1.Time period for convective Mode

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

$C_c$ depend on the depth of the fluid.

2.Time period of impulsive Mode

$$T_i = 2\pi\sqrt{d/g}$$

$d$ – *Deflection of the tank wall on the Vertical center-line at a height h when loaded by a uniformly distributed pressure* $q, \frac{KN}{m^2}$.

3.Max Hydrodynamic pressure

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

$p_{iw}$ –*Impulsive hydrodynamic pressure, at the base of the wall Y=0*

$p_{cw}$ –Convective hydrodynamic pressure, at the base of the wall Y=0

$p_{ww}$ –Pressure due to wall inertia.

$p_v$ –Hydrodynamic Pressure on the tank due to vertical ground excitation.

## 1.2 Problem Data

In the following table 1 the dimension, materials and the densities of materials have been given. For a rectangular tank, seismic analysis is to be performed for loading in X and Y directions.

Analysis along X-direction.

This implies that earthquake force is applied in X-direction.

| | | |
|---|---|---|
| L (X) | 18 | m |
| B (Y) | 37 | m |
| Wall Thickness | 0.4 | m |
| Base Slab thickness | 0.5 | m |
| Free Board | 0.3 | m |
| Height of water, *h* | 5 | m |
| Density of Concrete | 25 | KN/m³ |
| Density of water | 9.81 | KN/m³ |
| $f_{ck}$ | 30 | N/mm² |
| $\rho$ | 1000 | KN/m³ |

Table I

| | |
|---|---|
| Seismic zone | V |
| Seismic intensity | Very severe |
| Z | 0.36 |
| Site | Hard soil |
| Damping | 5% |
| Response reduction factor , Underground RC | 4 |

Table 2

## 2. Result and Discussion

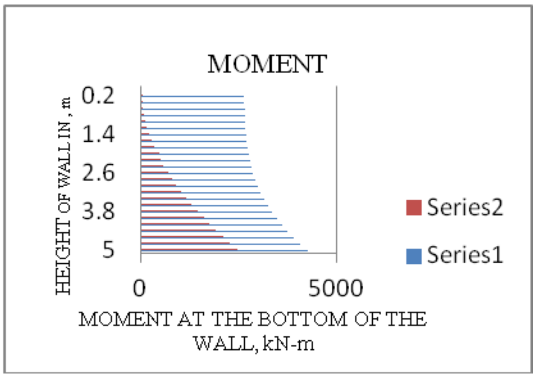

Fig- 3 (variation of base shear verses varying height of water)

The above graph-3 conveys the message that moment at the bottom of the wall varies with decreasing depth of water.

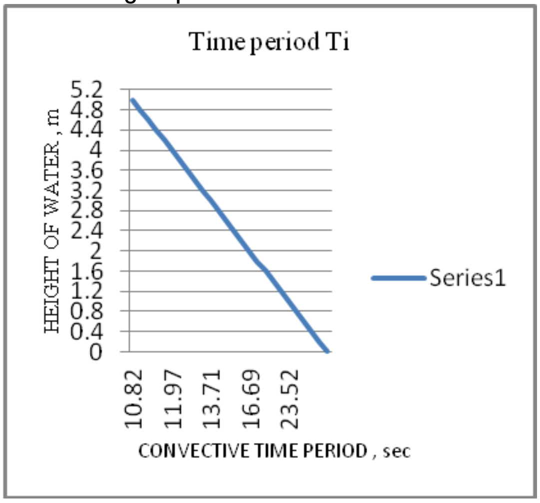

Fig- 4 (variation of base shear verses varying height of water)

The above graph-4 conveys the message that time period linearly varies with decreasing depth of water. And it is the same with convective mode of time period as shown in graph-5.

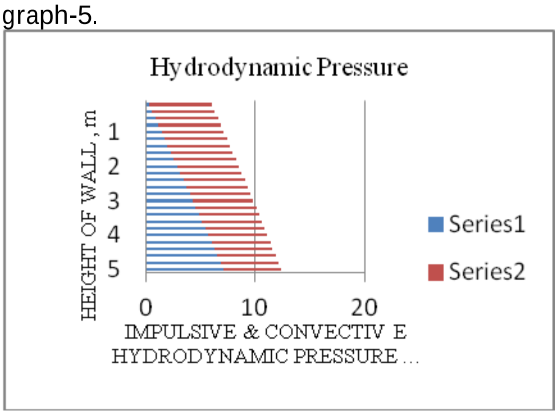

Fig- 6 (variation of base shear verses varying height of water)

The above graph-6 conveys the message that impulsive hydrodynamic pressure (series 1) linearly decrease with decreasing depth of water at the base of the wall y=0.
Convective hydrodynamic pressure (series 2) linearly increase with decreasing depth of water at the base of the wall y=0.

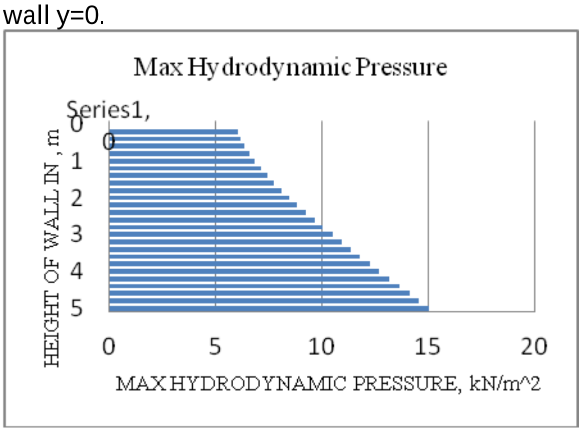

Fig- 6 (variation of base shear verses varying height of water)

The above graph-6 conveys the message that time max hydrodynamic pressure linearly varies with decreasing depth of water.

## 3. Problem Data

Analysis along Y-direction.

This implies that earthquake force is applied in Y-direction.

| | | |
|---|---|---|
| L (X) | 37 | m |
| B (Y) | 18 | m |
| Wall Thickness | 0.4 | m |
| Base Slab thickness | 0.5 | m |
| Free Board | 0.3 | m |
| Height of water, *h* | 5 | m |
| Density of Concrete | 25 | KN/m³ |
| Density of water | 9.81 | KN/m³ |
| fck | 30 | N/mm² |
| ρ | 1000 | KN/m³ |

Table 3

### 3.1 Problem Data

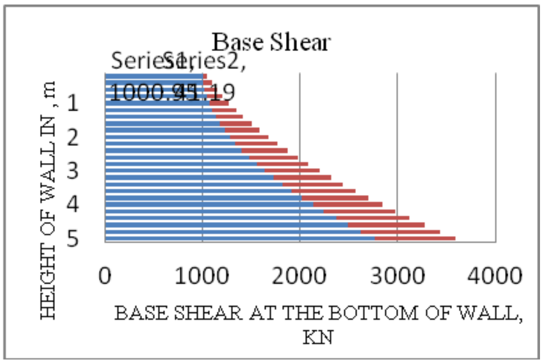

Fig- 8 (variation of base shear verses varying height of water)

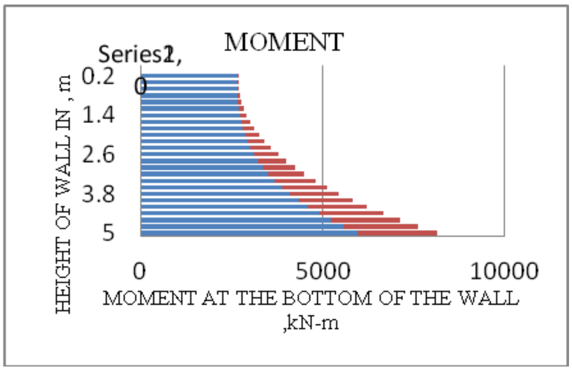

Fig- 9 (variation of moment verses varying height of water)

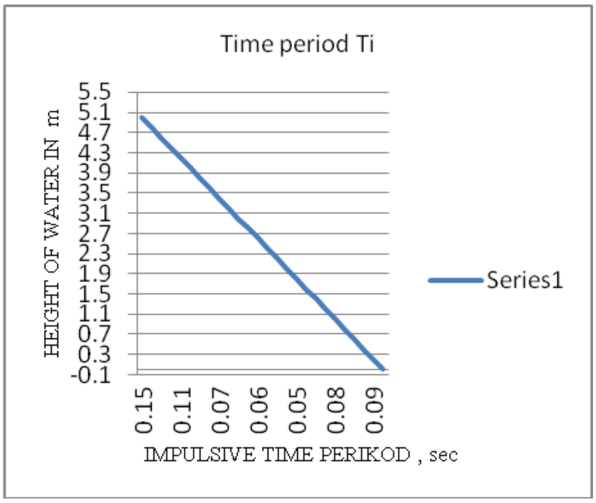

Fig- 10 (variation of impulsive time period verses varying height of water)

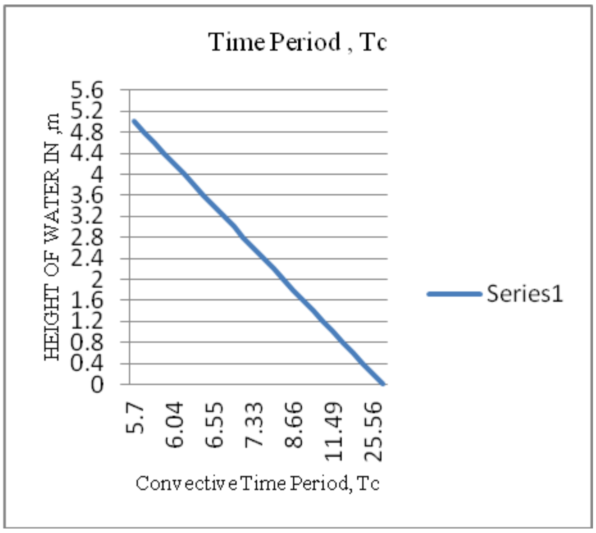

Fig- 11 (variation of convective time period verses varying height of water)

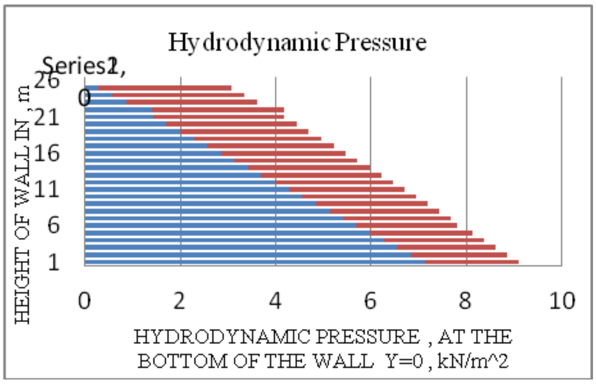

Fig- 12 (variation of Hydrodynamic pressure at the bottom of the wall period verses varying height of water)

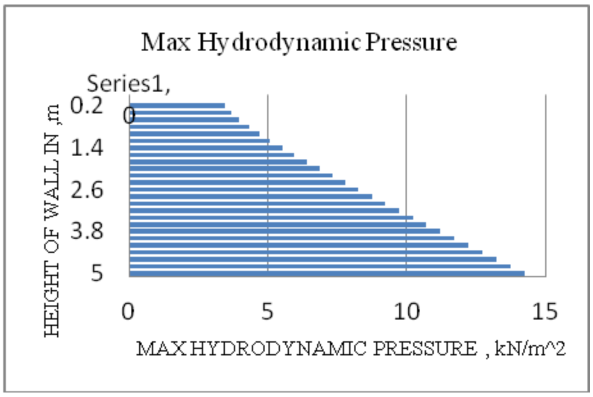

Fig- 13 (variation of Max Hydrodynamic pressure at the bottom of the wall period verses varying height of water)

## 4. FINITE ELEMENT MODEL IN SAP2000

In sap2000 plain stress elements are used to build the finite element model of the liquid storage tanks. The 2-D FEM model that is built is as shown in fig-2. Sap2000 is capable of applying acceleration time history to the FEM model. Parameters like nodal displacements, velocity and acceleration can be recorded at any point within the specified time step of time history data. Though sap2000 has no inbuilt fluid elements to capture the behavior of water within the tank, solid elements can be made use by using bulk modulus of elasticity of water and appropriate Poisson's ratio to capture fluid effect [9]. To evaluate hydrodynamic pressure that the retaining wall would be subjected to is not direct in sap2000. This is because plane stress elements are four nodded plane elements each node having six degrees of freedom namely three for translational degrees and other three for rotational degrees of freedom and they can only report spatial deformations and internal stress that they would be subjected during ground motion. Since it is possible to record the displacement, velocity and acceleration time history of nodes of water elements. If we are able derive a relationship between pressure and any of the above three parameters there is a hope of deriving hydrodynamic pressure.

Sap2000 has in-built acceleration Time History records of few historical ground motions. Other than this PEER ground motion database has the ability to filter site specific ground motions.

In this study the idea is to first find the fundamental frequencies of liquid response. Then later the FEM model is subject to acceleration time histories ground motion records. Linear modal time history is made use to capture the response of several modes of vibration of the system.

## 5. BOUNDFRY CONDITIONS

The contact between the retaining wall and water elements in only through gap elements. These gap elements are link elements having six degrees of freedom and are only designated to convey compressive forces between the two nodes to which it is connected. Therefore these elements serve as contact or boundary elements between water and wall elements. By this fluid-structure can be established irrespective of rigid or flexible behavior of the retaining wall.

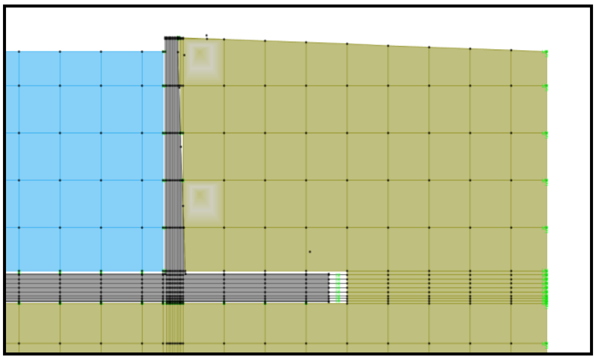

Fig- 14 (variation of Max Hydrodynamic pressure at the bottom of the wall period verses varying height of water)

Bottom of soil elements is assigned with fixed support so that the program can apply acceleration records at those nodes. The left and right boundary of soil is restrained against translation in global-X direction to model the constraints due to infinite boundary. Radiation boundaries can be incorporated using viscous dampers at the soil boundary nodes. The free surface of soil is not restrained in any degrees of freedom so it is free to deform in global-Y direction.

At the free surface of water there is a sloshing phenomenon that would manifest in real systems, since the contact between water and wall is only through gap elements in the current model, water domain behaves as if the energy can only flow into the wall or directed towards the wall through the link elements resulting in conservative stresses on wall elements. In reality wave energy is dissipated or restored in the form of slosh wave height following the conservation of energy this phenomenon can be accounted for by incorporating linear springs to surface nodes of water free surface.

## 6. RESULT OF FINITE ELEMENT ANALYSIS

The following plots depict the response of individual nodes that are present at extreme position of impulsive and convective domain of liquid domain.

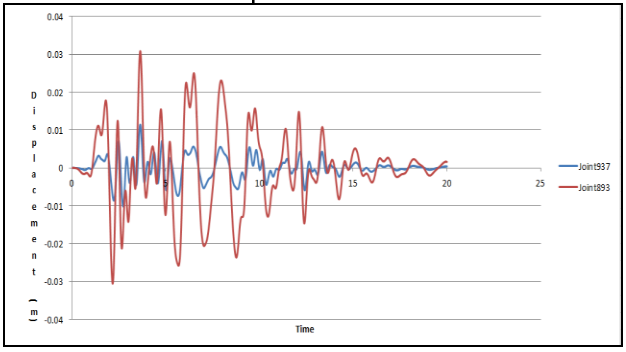

Fig- 15 (Displacement of node 937 and 893 w.r.t time)

The fig-15 gives an insight that the nodes at free surface are experiencing large deformations compared to the nodes that present in the impulsive region

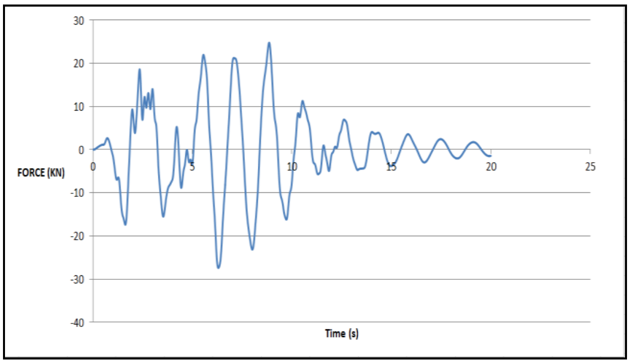

Fig- 16 (Link force that is conveyed between water and wall)

The above plot depicts a picture of varying forces w.r.t time that the inertia of water is transferred to the wall.

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