HYDRODYNAMIC PRESSURE DISTRIBUTION OF OVERHEAD WATER TANKS USING SHAKING TABLE

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Abstract

Understanding the behaviour and nature of hydrodynamic pressures is essential for safe design of overhead water tanks. Sloshing of liquid and wave induced at the free surface can significantly affect failure modes. The experimental study utilizes scale models to analyse the hydrodynamic pressure distribution of elevated rectangular overhead water tank models, utilizing shaking table tests to understand their behaviour, despite the challenges of testing full-scale models. Pressure sensors and acceleration sensors are used to measure the response. The study reveals that the maximum impulsive and convective pressure occurs when the tank aspect ratio is 2.0, with hydrodynamic pressure at the top increasing with an increasing aspect ratio. The variation of impulsive and convective pressure along depth is not linear, unlike static pressure variation.

Keywords: *Impulsive mode, convective mode, shaking table test, hydrodynamic Pressure.*

1.0 Introduction

The water storage tank is a structure constructed in sufficient height to cover the large area for supply of water. Generally, water tanks are analysed and designed by considering the earthquake forces imposed over the water tank body [1]. At the time of earthquake, the container experiences huge hydrodynamic pressure. Thus the understanding of behavior and nature of these pressures becomes more important for the safe design [2]. Most of these failure modes are largely affected by sloshing of liquid and wave induced at the free surface [10]. To safeguard against these, a good idea of sloshing height and sloshing load is required, so that sufficient freeboard or strength to prevent these damages may be provided economically [11]. According to seismic code IS: 1893 (Part 1): 2014[7], more than 60% of India is prone to earthquakes. The main reason for life loss is collapse of structure. Hence, it is important to analysis the structure properly for earthquake effects [15].

When a tank containing liquid vibrates, the liquid exerts impulsive and convective hydrodynamic pressure on the tank wall and the tank base, in addition to the hydrostatic pressure [5]. The dynamic analysis of a liquid filled tank may be carried out using the concept of generalized single degree of freedom (SDOF) systems representing the impulsive and convective modes of vibration of the tank -liquid system [12]. The finite element method [3] is well established for the complex engineering analysis of problems involving structures, fluids and interaction between fluid and solid [13]. The primary aim of this experimental research is to study the behaviour of elevated rectangular water tank during shaking that cause significant hydrodynamic pressure [8] [9] in the tank.

2.0 Model Idealization of overhead tank

Overhead water tanks storing liquid with a free surface when subjected to ground motion, the walls of the tank and the water get accelerated. The liquid in the lower region acts as a rigid mass that is attached to the tank wall [4]. This mass is called the impulsive mass (m_i) which is assumed to gain acceleration along with the tank and exerts impulsive pressure on the wall and the base of the tank. The mass in the upper region of the tank undergoes sloshing motion. This mass is called the convective liquid mass (m_c) and it exerts convective hydrodynamic pressure on the walls and base of the tank. Thus, the total liquid mass is divided into two discrete masses i.e. the impulsive mass and the convective mass. The two masses are suitably represented in a spring-mass model for the tank liquid system. The Fig.1 represents description of hydrodynamic pressure distribution on the tank walls and the base and also the two mass idealisation of water tank

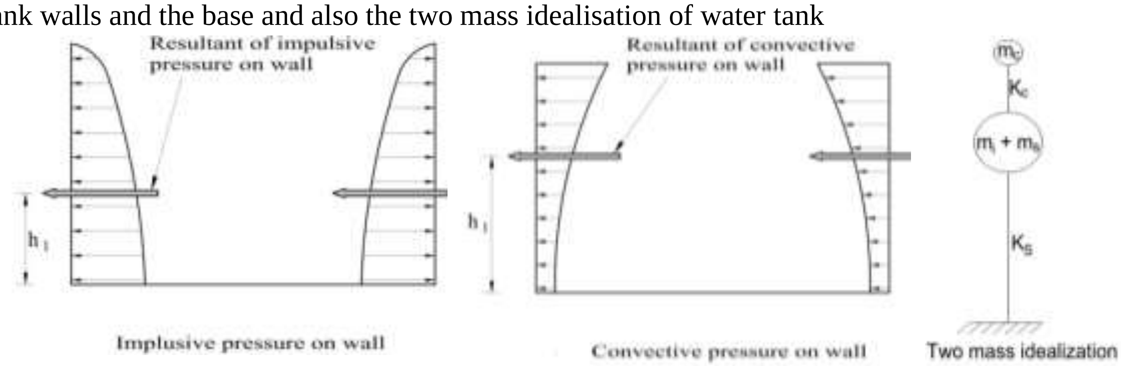


Fig. 1: Description of hydrodynamic pressure distribution on tank wall and two mass idealisation [6]

3.0 Experimental Setup

Experimental study is the important way of finding the correct response of the structures. Full scale models yield good results compared to their scale models. However, due to its tough nature, testing of full-scale models may not be affordable in all instances. Sometimes, model tests play an important role in understanding the behaviour of structures. In the present study, an attempt is made to study the pressure distribution of elevated rectangular overhead water tank models using shaking table tests.

3.1 Shaking Table Apparatus

The shaking table apparatus mounted with a DC powered motor is shown in Fig. 2 with a flywheel and cam arrangement. It can produce only sinusoidal vibration at the base in the horizontal direction. The maximum payload of the shake table is 30kg. The operating frequency is limited to

25 Hz with a least count of 0.05 Hz and the amplitude range lies between 0 to 10mm with a least count of 1mm. The size of the table is 400 X 400 mm. sufficient to place small scale models.

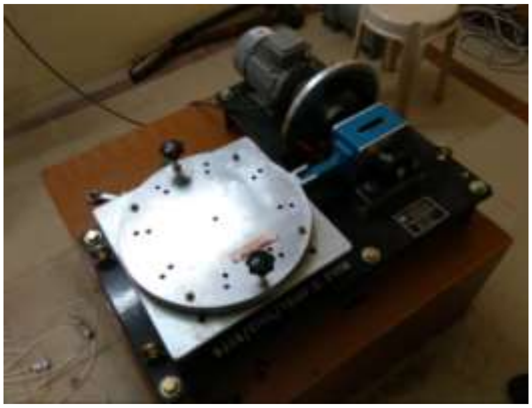


Fig. 2: Horizontal shaking table apparatus

3.2 Pressure sensor and Acceleration sensors

The acceleration sensors are used in the experiment for collecting the acceleration time history. These devices use piezoelectric effect in measuring the changes in acceleration and convert them into electrical charge. Fig. 3 shows acceleration sensor and the capacity of the acceleration sensor is 6.25 g. The device is calibrated in such a way that the voltage signals are converted into an equivalent acceleration.

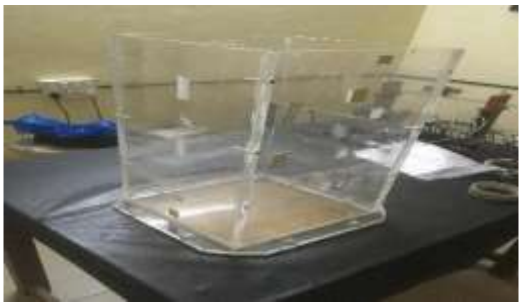
Fig. 4 shows the pressure sensor used in the experiment for collecting both static pressure and hydrodynamic pressure due to water in the tanks. The device is calibrated for static pressure to ensure proper measurement of pressure during the experiment. The capacity of the sensor is 35 kpa and the sensitivity ranges to 0.019 mV/V/mbar.

Fig. 3: Acceleration Sensor

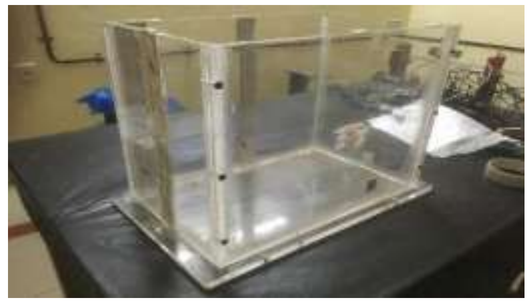
Fig. 4: Pressure Sensor

3.3 Experimental model description

The dimensions of the model is fixed based on the natural frequency of the model to be within the operating frequency range of shaking table and the total mass of the structure should lie within the maximum payload (30 kg). For achieving light weight of the model, the containers are made of acrylic plates of thickness 12 mm. Four models of the tank with different aspect ratio are considered for the study and are shown in Fig. 5 and the dimensions of the tank are shown in Table 1.

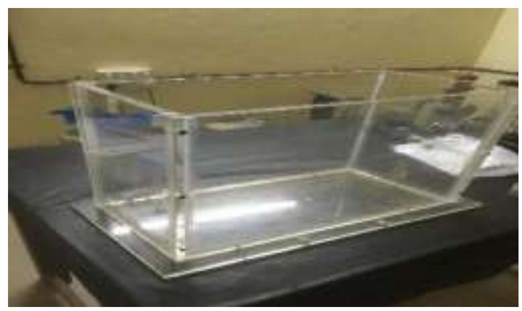


a. Model-1 (AR-1.0)



b. Model-2 (AR-1.5)

c. Model-3 (AR-2.0)



d. Model-4 (AR-2.5)

Fig. 5: Acrylic models used in the experimental study

Table 1: Dimensions of the water tank

Model No	Aspect Ratio	Length (mm)	Width (mm)	Height (mm)	Mass (Kg)
1	1	200	200	500	12.53
2	1.5	350	200	300	10.54
3	2.0	400	200	350	13.56
4	2.5	450	200	350	15.28

All the tanks are supported on a staging of height 400 mm and there are no braces. The staging consists of four aluminium columns of cross section 25 mm x 3 mm. An aluminum base plate corresponding to the size of the tank is used to provide platform so as to rest water tank.

4.0 Natural Frequency of Models using shaking table

The natural frequency plays an important role in understanding the dynamic behaviour of structures[14].Initially fabricated models are placed on horizontal shaking table with water and then the acceleration sensors and pressure sensors are calibrated and placed. Acceleration sensors are then connected to channels in data acquisition system DEWE-43. The amplitude in the horizontal shaking table is made fixed and frequencies are controlled or altered using frequency controller from lowest to highest value. It is observed during shaking that when the frequency of base motion is gradually increased, two types of behaviour is observed and are known as convective mode and impulsive mode. The data or values obtained from sensors are stored in the data acquisition system. The stored values are then processed for further analysis. Using the acceleration time history, the predominant frequencies are obtained by fast Fourier transform (FFT).

5.0 Convective and Impulsive Hydrodynamic Pressure

As per Housner (1963), the water tank has to be modelled as two mass idealizations. This indicates that there exist two masses. Hence, in the present study, an attempt is made to obtain two natural frequency during shaking i.e., impulsive and convective. The convective component is caused by sloshing waves; the impulsive component is determined by the interaction between the liquid and the tank wall.

To study the behaviour of convective and impulsive pressure in the water tank during shaking, the behaviour was studied under different frequencies. The frequency which produces maximum response amplitude is known as the resonant frequency or natural frequency. At this frequency, even small periodic driving forces can produce large amplitude oscillations. Thus, natural frequency plays a vital role in any dynamic analysis. At resonance, the top part of the liquid sloshes periodically due to the convective frequency, which is the primary frequency as shown in Fig.6. At another frequency, the liquid exhibits impulsive and unpredictable behaviour which is known as the impulsive frequency as shown in Fig.7. In contrast to the convective component, it does not display a distinct pattern of behavior.

Fig. 6: Resonance at convective frequency

Fig. 7: Resonance at impulsive frequency

6.0 Variation of Convective and Hydrodynamic pressure

After placing the pressure sensors at the required locations, the tank was allowed to vibrate at impulsive and convective mode frequencies. The amplitude was kept at 6 mm and 150 mm height of water are considered.

At resonance in impulsive mode, the maximum pressure is recorded in the pressure sensor located at the bottom of the tank and the corresponding pressure readings of the pressure sensors located at different intervals during the same time is tabulated and the pressure variation of the hydrodynamic pressure along the wall height is plotted. Similarly, when at resonance in convective mode, the maximum pressure is recorded at the top of the water level. The corresponding pressure readings of the pressure sensors located at different intervals during the same time is tabulated and the pressure variation of the hydrodynamic pressure along the wall height is plotted for convective mode. In order to study the variation of convective and impulsive hydrodynamic pressure along the depth of water, the results for 150mm water, hydrodynamic pressure was recorded at four locations.

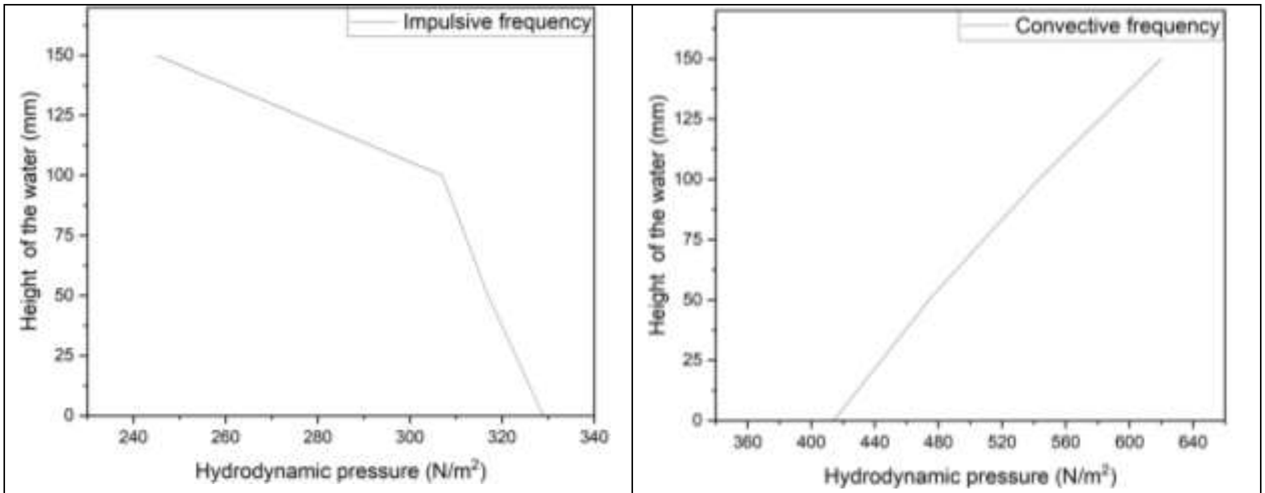


Fig.8: Hydrodynamic pressure distribution - Model-1

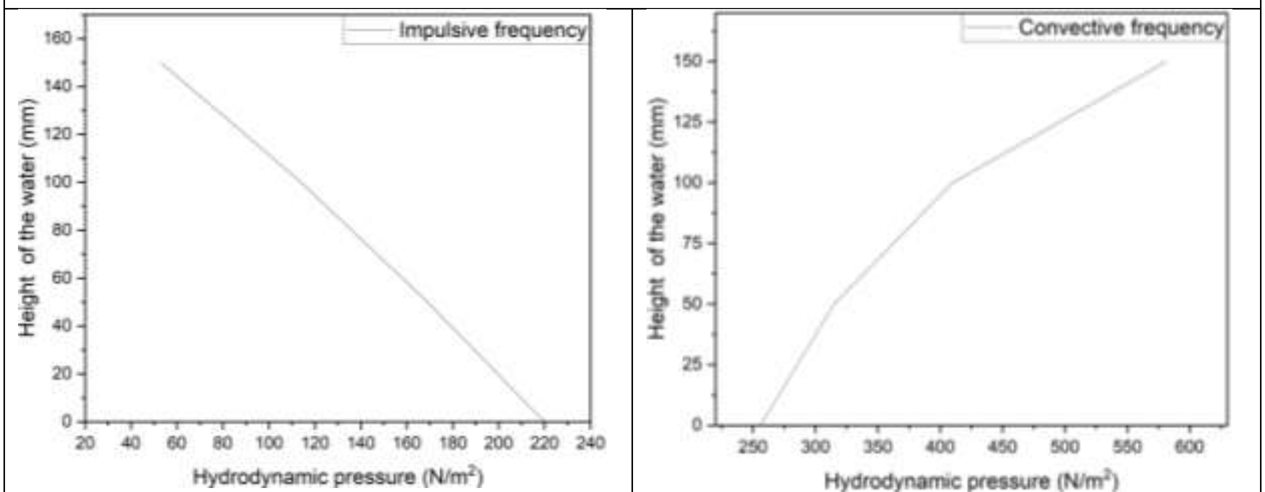


Fig.9: Hydrodynamic pressure distribution - Model-2

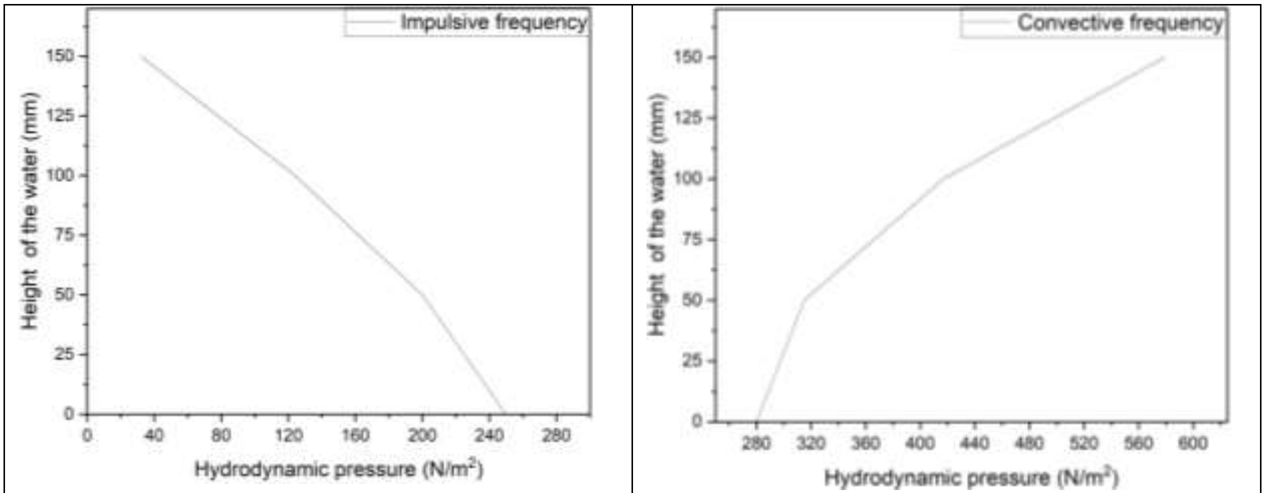


Fig. 10: Hydrodynamic pressure distribution - Model-3

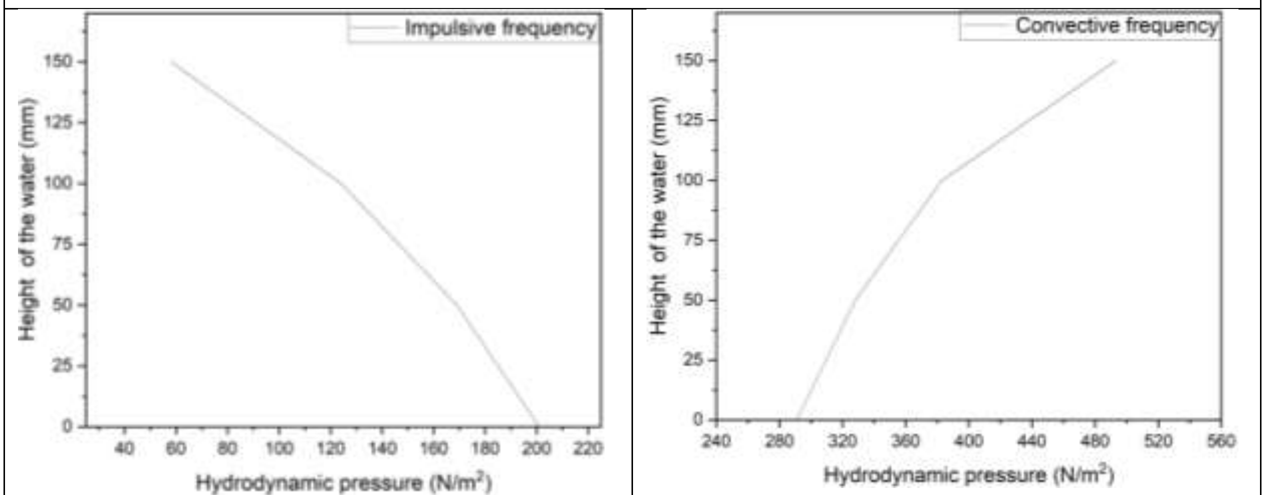


Fig. 11: Hydrodynamic pressure distribution - Model-4

7.0 Results and discussion

The hydrodynamic pressure distribution in convective mode and impulsive mode was recorded using pressure sensors. The variation of each pressure along the depth of water is plotted and following conclusions are drawn.

- In impulsive mode, the hydrodynamic pressure is minimum at the top and maximum at the bottom. Also, as the aspect ratio increase, the maximum impulsive pressure at the bottom decreases.

- In convective mode, hydrodynamic pressure is maximum at the top and gradually decreases to a minimum at the bottom. The convective pressure at the top slightly decreases with an increasing aspect ratio.
- The present study revealed that the maximum impulsive and convective pressure occurs when the tank aspect ratio is 2.0.
- In addition, depending on the tanks aspect ratio, the maximum hydrodynamic pressure at resonance is approximately 2 to 4 times greater than the maximum static pressure.
- It is interesting to note that the hydrodynamic pressure at the top is not zero, unlike static pressure. Further, the variation of impulsive and convective pressure along depth is not linear, as compared to linear static pressure variation.

8.0 References

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