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Use of Overhead Water Tank to Reduce Peak Response of the Structure

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Abstract- This paper presents analytical investigation carried out to study the use of over head water tank as passive TMD using SAP. Three multi-storey concrete structures, three, five and fifteen storey were taken for the study. The water tank was placed at the roof. The mass and frequency of the tank including its water, walls, roof, beams and columns were tuned to the optimized values. The behaviour of the tank subjected to three earthquake data, namely, Elcentro, Bhuj, Washington was studied under three conditions, namely building only with empty tank, two third full tank and full tank with damping. The results shows if the tank is tuned properly it can reduce the peak response of structures subjected to seismic forces.

Keywords: Vibration control; seismic excitation; passive TMD;water tank; optimization

I. INTRODUCTION

Recent devastating earthquakes around the world have underscored the tremendous importance of understanding the way in which civil engineering structures respond during such dynamic events. Today, one of the main challenges in structural engineering is to develop innovative design concepts to protect civil structures, including their material contents and human occupants from hazards like wind and earthquakes. The traditional approach to seismic hazard mitigation is to design structures with sufficient strength capacity and the ability to deform in a ductile manner. Alternately, newer concepts of structural control, including both passive and active control systems have been growing in acceptance and may preclude the necessity of allowing for inelastic deformations in the structural system. A passive control system does not require an external power for operation and utilizes the motion of the structure to develop the control forces. Systems in this category are very liable since they are unaffected by power outages which are common during earthquakes. Since they do not inject energy into the system, they are unable to stabilize the structure. Another advantage of such devices is their low maintenance requirements. Examples of passive systems are base isolation,-elastic dampers, liquid column dampers, liquid mass dampers, metallic yield dampers and friction dampers. An active control system requires external power for operation and has the ability to adapt to different loading conditions and to control different vibration modes of the structures. Active Tuned Mass Dampers (ATMD), active tendon systems and actuators/ controllers are examples of active systems. Active and passive control systems may be combined to form hybrid systems; operating both systems together enhances the robustness of the passive system and reduces the energy requirements of the active system. There are two main approaches for the implementation of hybrid systems: the Hybrid Mass Damper (HMD) and the hybrid seismic isolation system. A compromise between passive and active control systems has been developed in the form of semi-active control systems, which are based on semi-active devices. A semi active control device has properties that can be adjusted in real time but cannot inject energy into the controlled system. Frequently, such devices are referred to as controllable passive dampers. Because they offer the adaptability of active control devices without requiring large power sources, semi-active control systems have attracted a great deal of attention in recent years. Many of these systems can operate on battery power alone, proving advantageous during seismic events when the main power source to the structure may fail. Also, because semi-active devices cannot inject energy into the structural system, they do not have the potential to destabilize the system. Of all these control devices passive control systems in the form of TMD's, base isolation and frictional dampers have been implemented in many building across the world. In India passive control system in the form of base isolation technique was first demonstrated after the 1993 Killari (Maharashtra) earthquake. Two single storey buildings (one school building and another shopping complex building) in newly relocated Killari town were built with rubber *base isolators* resting on hard ground. Both were brick masonry buildings with concrete roof. After the 2001 Bhuj (Gujarat) earthquake, the four-storey Bhuj Hospital building was built with base isolation Technique. Friction dampers have been provided in a 18-storey RC frame structure in Gurgaon (IITK-BMPTCEQTip24). Buildings with such improved seismic performance usually cost more than normal buildings do. However, this cost is justified through improved earthquake performance. The Bhuj earthquake left many low to medium rise buildings damaged, but only one important building i.e., hospital building has installed a control device in the form of base isolation after the earthquake. The common man in a developing country like India may not be in a position to afford for implementing control device of any sort which may prove uneconomical. Hence in this paper an attempt has been made to study the feasibility of utilizing the water tank in the structure to resist seismic forces. The first implementation of water tank to resist natures force like wind was the 304m high Sydney center point tower.

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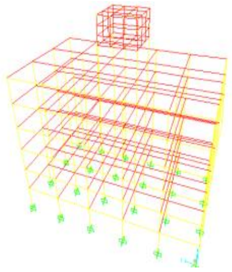
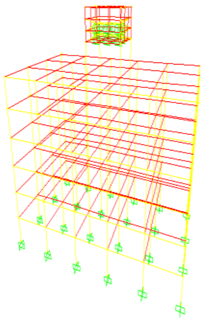
This building is considered as one of the safest buildings in the world. The tower has a 162,000 liter water tank at the top that acts as a stabilizer on windy days. In the Hafei 339m high TV tower, the 60 tonnes of water tank in the top serves to act as tuned mass dampers to resist the wind induced motion. Many researchers have carried out experimental and analytical work to study the use of Tuned Liquid Damper (TLD) to resist wind and earthquake forces. Kareem and Sun [1] have presented a perturbation based procedure to represent the modal properties of a system comprising of a fluid- containing appendages attached to a multi-degree-of-freedom system in terms of the individual dynamic properties of the primary and secondary system. The procedure is validated using a 10-storey building in which the water tank is located either at the top of the building or the fifth floor. The dimension of the water tank was assumed such that the second tank mode was tuned with the fundamental building mode. The mass ratio was taken as the mass of the sloshing fluid to building mass plus the water mass associated with the rigid body mode. The water level in the tank was varied and the results suggest that the water level, if not too shallow, has no significant effect on the combined frequency of the system. Sun and Fujino [2] presented an analytical model for a TLD using a rectangular tank filled with shallow liquid (1/2>h/L> 1/20- 1/25). It was assumed that the free surface is continuous; hence the model was valid as long as no breaking of waves occurs in the TLD. To account for breaking of waves two coefficients was introduced into the equation of motion. The response of a SDOF structure fitted with a TLD was experimentally studied and it was found that the TLD is very satisfactory for suppressing structural vibrations. Liquid motions in shallow TLDs with rectangular, circular and annular tanks, subject to harmonic excitation were measured experimentally by Sun et. Al [3]. Using a SDOF TMD analogy, equivalent mass, stiffness and damping of the TLD are calibrated from the experimental results. A virtual mass and a virtual damping for a TLD attached to an undamped linear SDOF structure were calculated and then amplitude-dependent equivalent mass, frequency and damping were obtained using the TMD analogy. The behaviour of TLD under large amplitude excitation was presented by Dorothy Reed [4]. The authors found that to achieve the most robust system, the design frequency for the damper, if computed by the linearized water-wave theory, should be set at a value lower than that of the structure response frequency and even if the damper frequency has been mistuned slightly, the TLD always performed favourably. The literature shows that the mass of water alone was taken for mass ratio (mass of TMD to mass of structure) calculation and weight of tank was not included and the tank used for all study did not include staging for the tank. Hence in the present work the mass ratio and frequency ratio includes water, walls and roof of tank, beams and columns supporting the tank. A procedure to fix the dimensions of the tank and the optimum water level in the tank to reduce the peak response has been presented.

II. MODEL

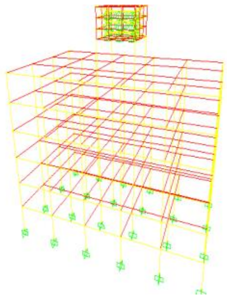
Three building models were taken for the study. The details of which are given in Table 1. The material properties used for the analysis are Young's Modulus of Concrete –22360 N/mm2, Poisson's ratio –0.15 and Density of concrete –25 KN/m3. The model of the structures is shown in Figure presented.



G+5 Building Without Water in Tank



G+5 Building with Tank Full of Water



G+5 Building with Tank 2/3 Full of Water

2.1 Optimization

The effectiveness of the TMD depends on the proper tuning of the characteristics of TMD to that of the structure. In the present work the mass ratio μ (Mass of TMD to Mass of the Structure) and frequency ratio α (Frequency of TMD to the frequency of the structure) are optimized and the objective function is to reduce the peak structural response subjected to seismic excitation. For optimization the structure was modelled as lumped single degree of freedom spring-mass system with mass equal to that of the unit modal mass and stiffness adjusted to the natural frequency of the structure. The TMD was attached to the idealized system as spring mass system.

2.2 Response of Structure with Various Water Levels of Tank

The behaviour of the tank to seismic forces was studied under three conditions namely, building with empty tank with, two third full tank and full tank with damping. Time history analysis was carried using the following data:

III. BUILDING GEOMETRY

Each storey height = 3 m
Plan dimensions = 5 x 5 m for each bay
Member Cross Sections:
Beam = 230 x 400 mm
Column = 230 x 450
Slab Thickness = 100 mm

3.1 Details of Model and Earthquake Data

Building	WATER TANK SIZE
G+5	5 X 5X 3 (75000 Liters)
G+10	5 X 5X 4 (100000 Liters)
G+15	5 X 5X 5 (125000 Liters)

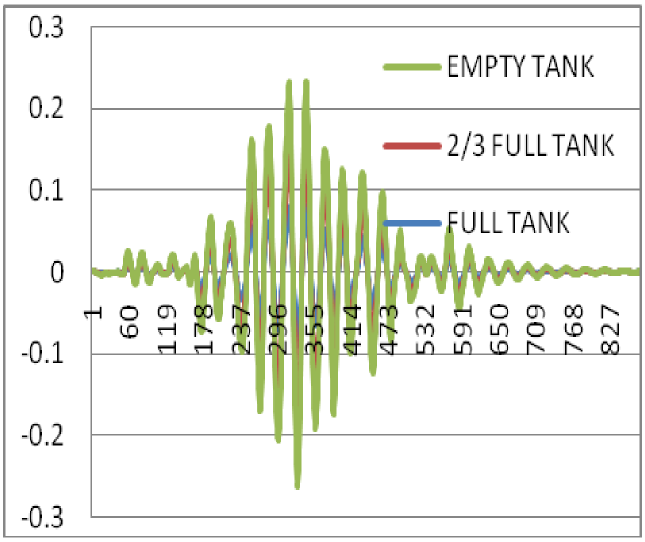
3.2 Earthquake Data

Record	Time	Time Interval	No. of Output Time Steps
Bhuj	25 Sec	0.04	875
Elcentro	7.78 Sec	0.005	2000
Washington	60 Sec	0.04	1750

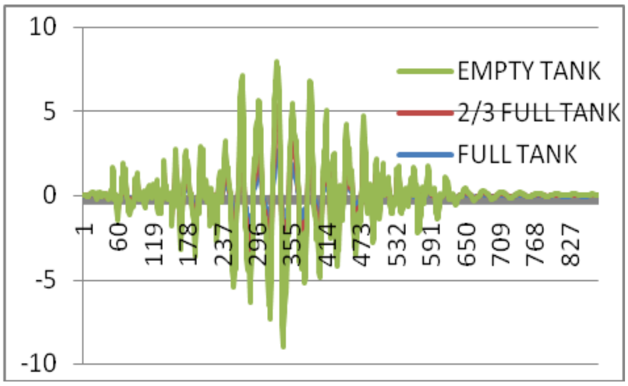
IV. COMPARATIVE STUDY

The present study leads to the conclusion that it is reasonable to implement tuned liquid damper for mitigation of structural response under dynamic action. Analysis of a SDOF structure subjected to both harmonic and recorded ground motions shows that a properly designed TLD can substantially reduce structural response. The effect of tuned condition on structural response with and without TLD, are evaluated and presented in graphical forms. This paper shows only comparative study of G+5 building with empty tank,2/3 full water tank and full water tank

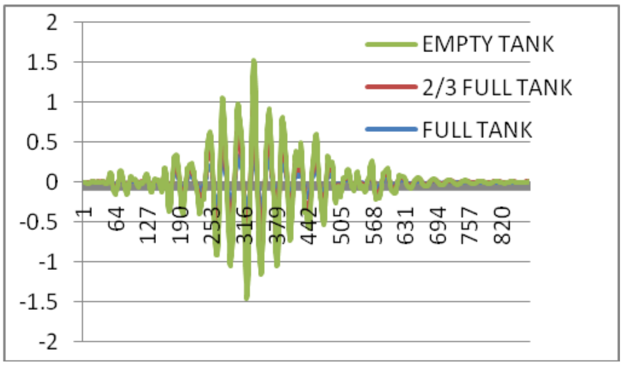
1) Response of the G+5 Building with Empty Tank, 2/3 Full Tank and Full Tank for Bhuj Earthquake



Graph-1 Bhuj Displacement

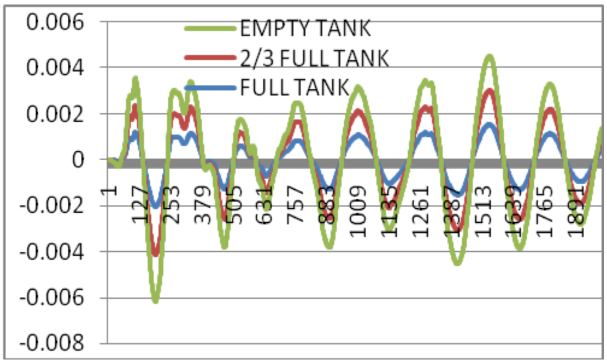


Graph-2 Bhuj Acceleration

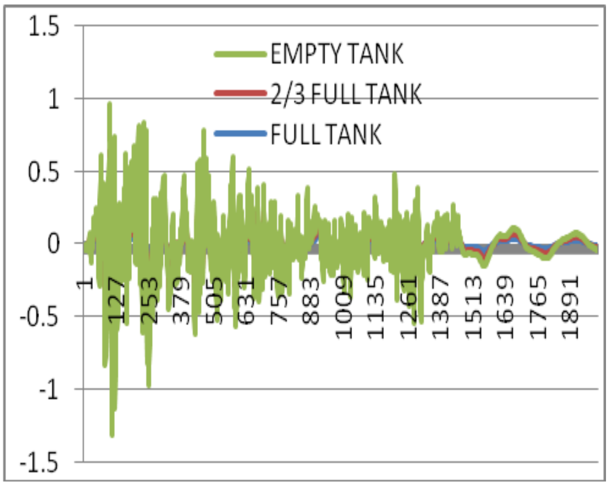


Graph-3 Bhuj Velocity

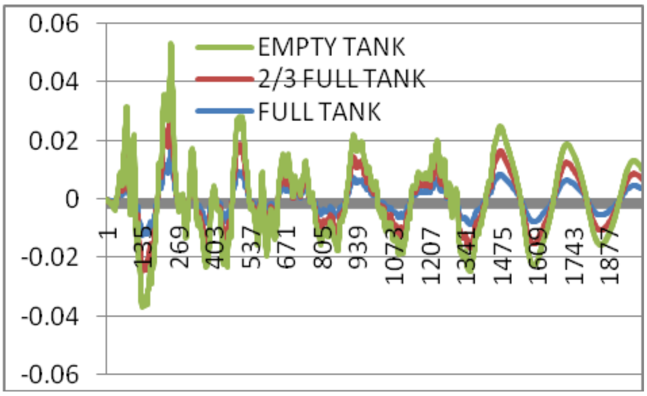
2) Response of the G+5 Building with Empty Tank, 2/3 Full Tank and Full Tank for El Centro Earthquake



El Centro Displacement

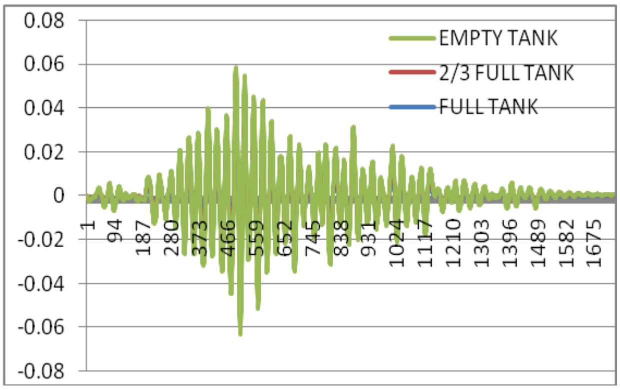


El Centro Acceleration

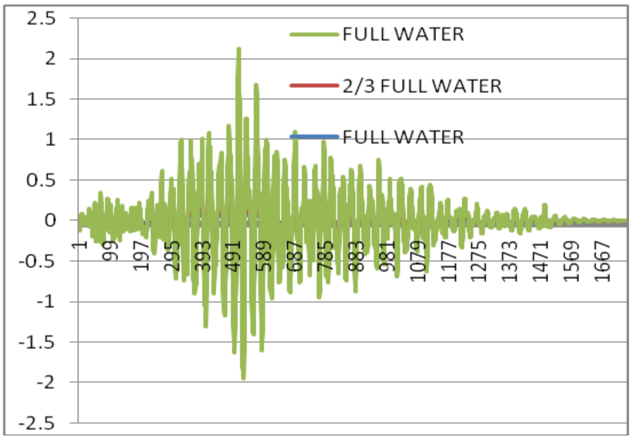


El Centro Velocity

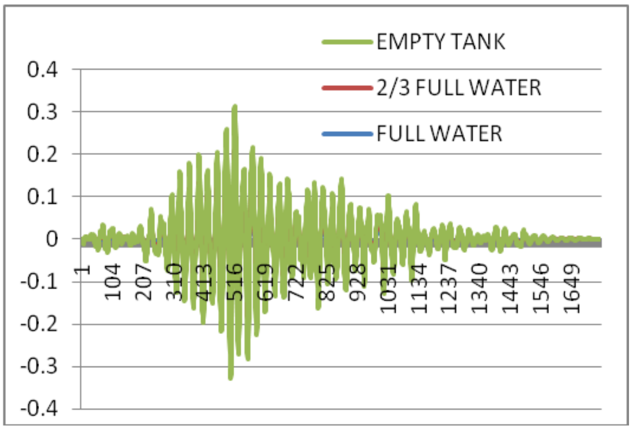
3) Response of the G+5 Building with Empty Tank, 2/3 Full Tank and Full Tank for Washington Earthquake



Washington Displacement



Washington Acceleration



Washington Velocity (1)

V. CONCLUSION

1) Different mass ratios ranging from 0.5 to 6 % of the structure has been considered to evaluate the effectiveness of TLD. The reduction in the displacement is significant as the mass ratio increases up to 4 %.The increase in mass ratio from 3% to 4% increase the efficiency in the displacement reduction only by 4%, while the considerable mass of the water that needs to be employed. It is suggested that 3% mass ratio can be recommended as the optimum value. For mass ratios larger than 4% beating phenomenon was observed in the TLD behaviour and efficiency is reduced.

2) The damping ratio of the structure is evaluated experimentally with and without TLD corresponds to the resonance condition. It is observed that the presence of TLD enhances the structural damping.

3) From this study, it can be concluded that properly designed TLD with efficient design parameters such as tuning ratio, depth ratio and mass ratio is considered to be a very effective device to reduce the structural response.

Hence it is concluded that the procedure used for implementation of TMD can be satisfactorily used. The response of tank with full water level should be half of structure only so that it can be effective to implement water tank as a passive TMD. Water level can be maintained to reduce the peak response of structures subjected to seismic forces.

FURTHER SCOPE OF STUDY

1. The structural model considered in this study is linear one which provides a further scope to study the problem using a nonlinear model for the structure.
2. The study can be further extended by introducing obstacles like baffles, screens and floating particles in the tank to obtain changed control performance.
3. Application of TLD to control different type of motions other than horizontal motions.
4. The study can be further extended to observe the effect of different tank geometries which include shape of the tank and the nature of the tank bottom.
5. Response of liquid domain can be studied by Mess Free Methods.

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