CONTROL OF SEISMIC RESPONSE OF MULTI STORIED BUILDINGS USING WATER TANK AS PASSIVE TUNED MASS DAMPER

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Abstract: Current trends in construction industry demands taller and lighter structures, which are also more flexible and having quite low damping value. This increases failure possibilities and also problems from serviceability point of view. Now-a-days several techniques are available to minimize the vibration of the structure. Out of the several techniques available for vibration control, concept of using TMD is a new one. An earthquake directly affects a structure by increasing the energy within the structural system. A significant portion of this energy can be dissipated and/or reflected through the introduction of a passive, active, or semi-active control system. If certain performance criteria are established which require continuous reconfiguration of the structural system, either an active or semi-active control system will generally be required. In the case of semi-active control systems, the control forces are developed by the motion of the structure itself through appropriate adjustment of the stiffness and/or damping characteristics of semi-active control devices. Passive control systems do not require any kind of external energy. Tuned mass damper is a structure, connected to the main structure by means of springs and the parameters of TMD are tuned to that of main structure such that the dynamic response of main structure during Earthquake is reduced. Since every building necessarily needs water tank, usage of water tank as vibration control device is advantageous. Two buildings, one of which is 5 storied and the other is 10 storied are analyzed using time history analysis in SAP 2000. Behavior of structure subjected to El-Centro earthquake data, Bhuj earthquake data, Kobe earthquake data is studied. For each case, analysis is done for mass ratios varying from 5% to 25% for every 5% interval. Column height on which water tank is placed is also changed for 1m, 2m, 3m, 3.5m and its behavior is observed. From the study it was found that, for both 5 storied and 10 storied structures, placing water tank on 3m column height and mass ratio 20% gives optimum response reduction.

I. INTRODUCTION

A tuned mass damper (TMD) is a device consisting of a mass, a spring, and a damper that is attached to a structure in order to reduce the dynamic response of the structure. The frequency of the damper is tuned to a particular structural frequency so that when that frequency is excited, the damper wilI resonate out of phase with the structural motion. Energy is dissipated by the damper inertia force acting on the structure. The TMD concept was first applied by Frahm in 1909 (Frahm, 1909) to reduce the rolling motion of ships as well as ship hull vibrations. A theory for the TMD was presented later in the paper by Ormondroyd and Den Hartog (1928), followed by a detailed discussion of optimal tuning and damping parameters in Den Hartog's book on mechanical vibrations (1940). The initial theory was applicable for an undammed SDOF system subjected to a sinusoidal force excitation. Extension of the theory to damped SDOF systems has been investigated by numerous researchers.

An earthquake is a natural phenomenon like rain. Earthquakes have occurred for billions of years. Descriptions as old as recorded history show the significant effects they have had on people's lives. Long before there were scientific theories for the cause of earthquakes, people around the world created folklore to explain them. In simple terms, earthquakes are caused by the constant motion of Earth's surface. This motion creates buildup and releases energy stored in rocks at and near the Earth's surface. Earthquakes are the sudden, rapid shaking of the Earth as this energy is released. Earthquakes affect almost every part of the Earth and like rain they can be either mild or catastrophic. Over the course of geological time, earthquakes, floods, and other natural events have helped to shape the surface of our planet. An earthquake may last only a few seconds, but the processes that cause earthquakes have operated within the Earth for millions and millions of years. Until very recently, the cause of earthquakes was an unsolved mystery.

Earthquake shaking may cause loss of life and destruction of property. In a strong earthquake the ground shakes violently. Buildings may fall or sink into the soil. Rocks and soil may move downhill at a rapid rate. Such landslides can bury houses and people. The Earth's rock layer is broken into large pieces. These pieces are in slow but constant motion. They may slide by smoothly and almost imperceptibly. From time to time, the pieces may lock together, and energy that accumulates between the pieces may be suddenly released. This sudden release of energy, like the snapping of a rubber band that has been stretched too far, is what we call elastic rebound. Energy is released and travels through the Earth in the form of waves. People on the surface of the Earth experience an earthquake.

Earthquakes occur when rocks suddenly slide along a surface called a fault plane. The movement starts at the hypocenter (also called focus) and propagates outward at the speed of sound to form a rupture surface. The epicenter is the location on the Earth's surface directly above the hypocenter. Faults accommodate movement of rocks. The movement is typically episodic; the episodes of movement produce earthquakes.

Earthquakes produce both body waves, which travel through the Earth, and surface waves which only travel on its surface. Body waves travel faster than surface waves. There are two kinds of body waves: P waves and S waves. P waves are the fastest waves, and propagate as a compression and dilation of the Earth. S waves are slower, and propagate as shearing motion perpendicular to the direction of the wave. S waves cannot travel through fluids, like the outer core, because the fluids are not elastic to shear forces. Surface waves are the slowest waves and include Rayleigh and Love waves. Rayleigh waves resemble water waves, while Love waves cause the surface to move perpendicular to the motion of the wave.

All seismic waves increase in velocity toward the center of the Earth as far as the outer core, which is molten. The increase in velocity with depth causes body waves to curve as they enter the Earth, and eventually re-emerge on the surface. The bending of waves as they pass from one medium to another is called refraction. Large earthquakes are sometimes preceded by smaller foreshocks and are always succeeded by aftershocks. Aftershocks are due to the readjustment of the blocks of earth following a large shift, occur on or near the same fault, and decrease in frequency with time after the main shock. Earthquake waves are a complex mixture of frequencies. Large earthquakes tend to produce energy with a larger component of low-frequency (long-wavelength) waves, and the shaking produced by these waves lasts longer.

The main objective of this project is to find the response reduction of structures subjected to various earthquake data's using different mass ratios. Mass ratios varying from 5% to 25% with every 5% increment is considered. Analysis was done for each structure subjected to various mass ratio's with different heights of columns. Main aim of the study is to find the reduction of dynamic response of multistoried building using water tank as passive tuned mass damper. Observing the response reduction of multi storied building by varying the column height on which water tank is placed. By changing the mass ratio time history analysis is done. Tuned mass damper is one type of successful seismic response control devices. Analysis is done of three different types of earthquakes using water tank as passive TMD.

Objectives of study

•To study the seismic behavior of 5 storied and 10 storied buildings without water tank subjected to EL Centro Earthquake data, Bhuj Earthquake data and Kobe Earthquake data.

•To study the seismic behavior of 5 storied and 10 storied buildings with placement of water tank at centre of structure (acting as passive TMD) with water tank column height being 1m and with mass ratios ranging from 5% to 25% for every 5% interval, subjected to EL Centro Earthquake data, Bhuj Earthquake data and Kobe Earthquake data.

•To study the seismic behavior of 5 storied and 10 storied buildings with placement of water tank at centre of structure (acting as passive TMD) with water tank column height being 2m and with mass ratios ranging from 5% to 25% for every 5% interval, subjected to EL Centro Earthquake data, Bhuj Earthquake data and Kobe Earthquake data.

•To study the seismic behavior of 5 storied and 10 storied buildings with placement of water tank at centre of structure (acting as passive TMD) with water tank column height being 3m , 3.5m and with mass ratios ranging from 5% to 25% for every 5% interval, subjected to EL Centro Earthquake data, Bhuj Earthquake data and Kobe Earthquake data. In the present work, 2 symmetric structures one of which is 5 storied and the other 10 storied are considered. Each of the building is subjected to three types of earthquake data's namely EL Centro, Bhuj, Kobe earthquakes. Time history analysis is done for each structure with varying column heights of water tank namely 1m, 2m, 3m and 3.5mts. In each case mass ratio ranging from 5% to 25% is analyzed. Results show that using water tank as passive TMD is advantageous. The work can be extended for other types of earthquakes since this is the first thought of varying column heights of water tank.

II. LITERATURE SURVEY

FAHIM SADEK, BIJAN MOHRAZ, ANDREW W. TAYLOR AND RILEY M.CHUNG (1997) [1] , the optimum parameters of Tuned Mass Damper (TMD) that result in considerable reduction in the response of structures to seismic loading are presented. The criterion used to obtain parameters is to select, for a given mass ratio, the frequency (tuning) and damping ratios that would result in equal and large modal damping in the first two modes of vibration. The parameters are used to compute the response of several single and multi degree of freedom structures with TMDs to different earthquake excitations. The results indicate that the use of the proposed parameters reduces the displacement and acceleration responses significantly.

The method can also be used in vibration control of tall buildings using the so called 'mega sub–structure configuration', where substructures serve as vibration absorbers for the main structure. It is shown that by selecting the optimum TMD parameters as proposed in this paper, significant reduction in the response of tall buildings can be achieved. It was found that the equal damping ratios in the first two modes are greater than the average of damping ratios of lightly damped structure and heavily damped TMD. Consequently, the fundamental modes of vibrations are heavily damped.

The results indicate that using the proposed TMD parameters reduces the displacement and acceleration responses significantly (Up to 50percent). The results show that in order for TMDs to be effective, large mass ratios must be used, especially for structures with high damping ratios. The top floor with appropriate stiffness and damping can act as a vibration absorber for the lower floors.

The safety and functionality of top floors, however, may present problems since the top floor may experience large displacements.

PETER NAWROTZKI (2006) [2] , Passive seismic control strategies are based on the reduction of energy, which affects a structure in case of earthquake events. Some well knew approaches make use of frictional, plastic or other energy dissipating behavior of special devices. This paper presents some special ideas for the increase damping in order to improve the seismic performance of buildings. For this purpose additional-mass systems are proposed and their performance is investigated theoretically as well as on the shaking table.

Usually these systems are considered as not suitable for seismic applications, but this paper is no more valid as a general rule, if certain design approaches are kept. Tuned-Mass Control Systems (TMCS) can be used to control the displacements, accelerations and internal stress variables of a structure in case of earthquakes. The safety against collapse and defined states of serviceability of the structures can be achieved.

This system can also be used for the seismic retrofit of existing buildings as the inside of the structure is usually not objective to modification. Hence, the usual operation inside the building may go on during the upgrade activities. Properly designed tuned-mass control systems can be characterized as follows:

They reduce seismically induced responses in terms of displacements, accelerations, internal stresses and strains as well as subsoil demands.

They increase the structural safety. The collapse of a building becomes less probable and hence, human life is protected.

They improve the serviceability of structures. Damage and corresponding repair cost in case of seismic events are reduced significantly.

In comparison to conventional strengthening methods, the building can usually be under operation during the installation of the TMCS (if no additional measures are required).

Regarding the overall procedure and required material for the installation of a tunedmass system this strategy can be classified as 'cost effective‘

P. CHAIVIRIYAWONG, W. PRACHASEREE (2007) [3], a passive mass damper is one kind of passive energy absorbing substructures to suppress translational and torsional vibrations of civil engineering structures.

The objective of this paper is to review the applications of passive mass dampers to the civil engineering structures. The passive mass dampers reviewed here consist of tuned mass dampers (TMDs), tuned liquid dampers (TLDs) and tuned liquid column dampers (TLCDs). TMD consisting of a mass connected to the structures through a spring and a dashpot is the simplest damper. TLD is a type of TMD in which the mass is replaced by a liquid container firmly fixed on the structures. TLCD is another variation of TLD. It comprises of two vertical columns of liquid connected by a horizontal cross-over duct in the form of a U-tube container.

A detailed literature review of these three passive mass dampers is provided concentrating on their applications to full-scale structures. In addition, some discussion of the effectiveness of the aforementioned dampers for mitigating wind and earthquake induced vibrations is also presented. The review clearly indicates that the passive mass dampers can be served as a rational device to mitigate the translational and torsional vibrations from wind and earthquake excitations.

A discussion of the passive mass dampers used to mitigate the structure motion is presented. Passive mass dampers are found to be attractive due to their unique advantages such as lower cost, easy handling, and low maintenance requirements. Furthermore, their natural frequency and damping characteristics can be easily modified. It has been shown that these passive mass dampers are extremely versatile in their applications for temporary use, and are easy to adapt for retrofit schemes for existing structures. A number of passive mass damper systems for vibration control of civil engineering structures are also given.

G. HEMALATHA AND K.P. JAYA (2008) [4], this paper presents analytical investigation carried out to study the feasibility of implementing water tank as passive TMD using ANSYS. Two multi-storey concrete structures, three and five 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 behavior of the tank subjected to four earthquake data, namely, El-centro, Hachinohe, Kobe and Northridge was studied under five conditions, namely tank empty, 1/4th water, 1/2th water, 3/4th water and full tank. The results show if the tank is tuned properly it can reduce the peak response of structures subjected to seismic forces. Time history analysis has been carried out for the full model without water tank and water tank with five conditions of water level for models M3 and M5.

III. METHODOLOGY

Water tanks are integral part of all buildings and they impart large dead load on the structure. This additional mass can be utilized as TMD to absorb the extra energy imparted on the structure during earthquakes. In the present work, 2 types of buildings namely 5storied and 10 storied were considered. Water tank was placed at centre so that the center of mass of structure and that of the tank coincided. The tank had a plan dimension of 15 x 15 m for both the models. The behaviour of the structure with and without tank to seismic forces was studied. Time history analysis was carried out for structures without water tank and with water tank subjected to 3 types of earthquake data’s (EL CENTRO, BHUJ, KOBE) with diff mass ratios and diff water tank column heights.

4.2 Material Properties

a) Grade of concrete - M25

b) Grade of steel - Fe 415

c) 5 storied symmetric building is analysed using the following data:

i) Building Geometry:

Foundation Depth = 1.5m

Each storey height = 3 m

Plan dimensions = 3 x 3 m for each bay

No.of Bays = 5 on both sides

ii) Member Cross Sections:

Beam size = 230 x 300 mm

Column size = 300 x 300 mm

Slab Thickness = 125 mm

10 storied symmetric building is analysed using the following data:

i) Building Geometry:

Foundation Depth = 1.5m

Each storey height = 3 m

Plan dimensions = 3 x 3 m for each bay

No.of Bays = 5 on both sides

ii) Member Cross Sections:

Beam size = 230 x 300 mm

Column size = 600 x 600 mm

Slab Thickness = 125 mm

4.3 Loads acting on structure:

a. For 5 Storied building

Live Load = 2 KN/Sqm
Floor Finishes = 1.5 KN/Sqm
Wall Loads (Exterior) = 12 KN/m
Wall Loads (Interior) = 6 KN/m

b. For 10 storied building

Live Load = 2 KN/Sqm
Floor Finishes = 1.5 KN/Sqm
Wall Loads (Exterior) = 12 KN/m
Wall Loads (Interior) = 6 KN/m

4.4 Time history loading:

The time history loading is applied from earthquake data functions.

The El Centro 1940 North South Component data file loading is used in global-X direction with 8 points per line at a time interval 0.02 seconds.

Bhuj Earthquake occurred at January 26, 2001 data file loading is used in global-X direction with 8 points per line at a time interval 0.005 seconds.

Kobe Earthquake occurred at January 16, 1995 data file loading is used in global-X direction with 5 points per line at a time interval 0.02 seconds.

4.5 About SAP (Structural Analysis Program):

SAP refers to Structural analysis program. The SAP name has been synonymous with state-of-the-art analytical methods since its introduction over 30 years ago. SAP2000 follows in the same tradition featuring a very sophisticated, intuitive and versatile user interface powered by an unmatched analysis engine and design tools for engineers working on transportation, industrial, public works, sports, and other facilities. From its 3D object based graphical modeling environment to the wide variety of analysis and design options completely integrated across one powerful user interface, SAP2000 has proven to be the most integrated, productive and practical general purpose structural program on the market today.

This intuitive interface allows creating structural models rapidly and intuitively without long learning curve delays. Integrated design code features can automatically generate wind, wave, bridge, and seismic loads with comprehensive automatic steel and concrete design code checks per US, Canadian and international design standards.

Advanced analytical techniques allow for step-by-step large deformation analysis, Eigen and Ritz analyses based on stiffness of nonlinear cases, catenaries cable analysis, material nonlinear analysis with fiber hinges, multi-layered nonlinear shell element, buckling analysis, progressive collapse analysis, energy methods for drift control, velocity-dependent dampers, base isolators, support plasticity and nonlinear segmental construction analysis.

Nonlinear analyses can be static and/or time history, with options for FNA nonlinear time history dynamic analysis and direct integration. From a simple small 2D static frame analysis to a large complex 3D nonlinear dynamic analysis, SAP 2000 is the easiest, most productive solution for structural analysis and design needs.

4.6 Modeling:

a. Modeling of 5 storied building in SAP is done as follows:

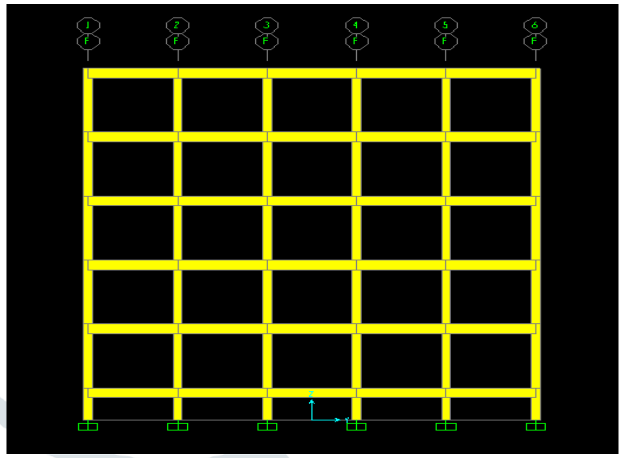


Fig 4.1: 5 Storied Building without Water Tank – Elevation

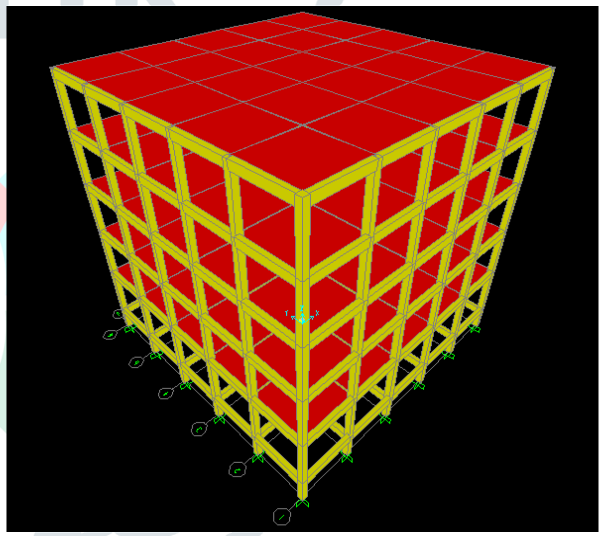


Fig 4.2: 5 Storied Building Without Water Tank – 3d View

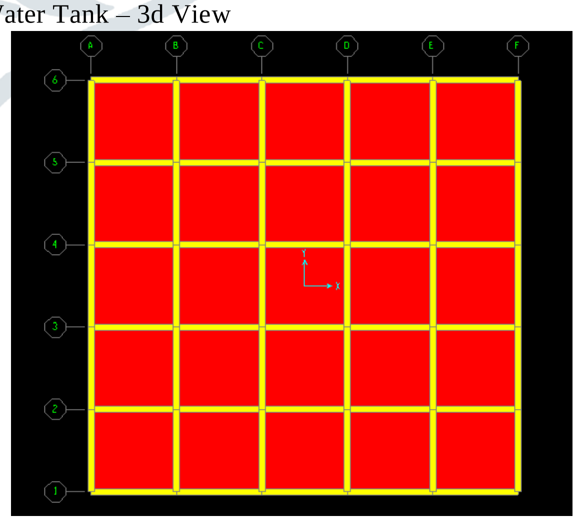


Fig 4.3: 5 Storied Building Without Water Tank – Plan View

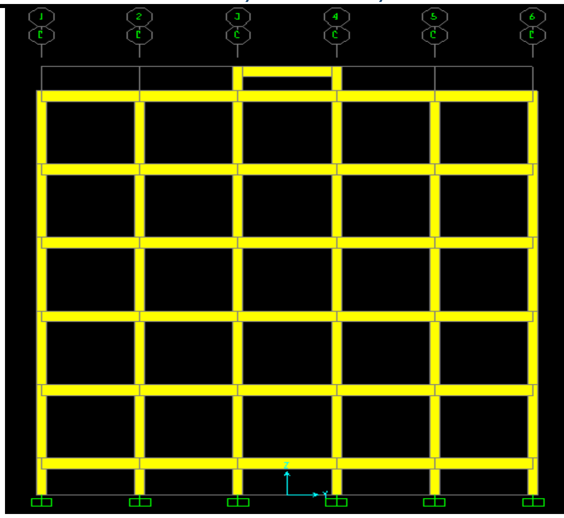


Fig 4.4: 5 Storied Building With Water Tank – Elevation

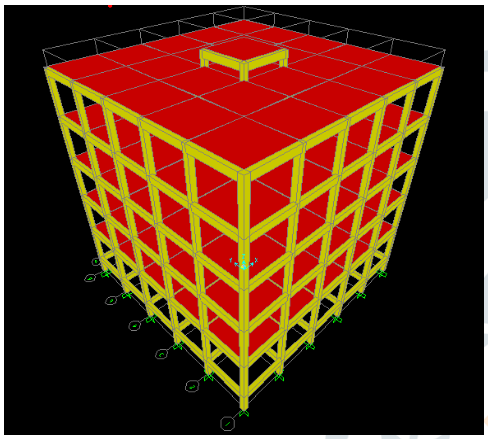


Fig 4.5: 5 Storied Building With Water Tank – 3d View

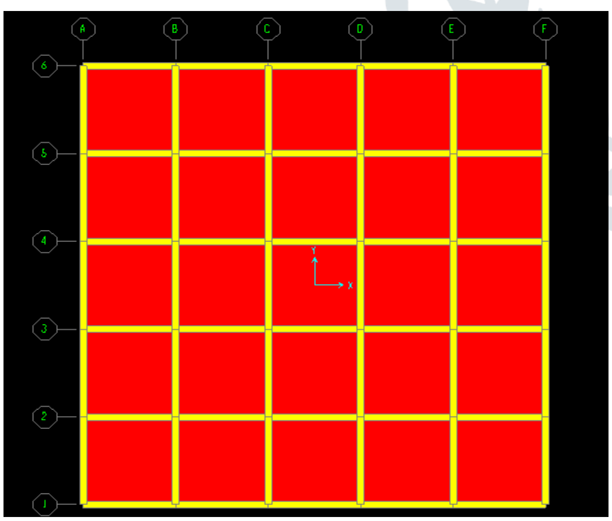


Fig 4.6: 5 Storied Building With Water Tank – Plan View

Modeling of 10 Storied building in SAP is done as follows:

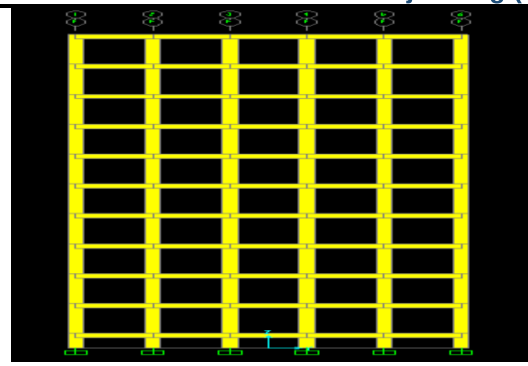


Fig 4.7: 10 Storied Building Without Water Tank – Elevation

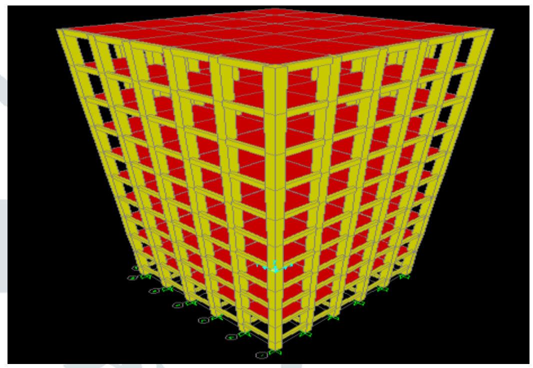


Fig 4.8: 10 Storied Building Without Water Tank – 3d View

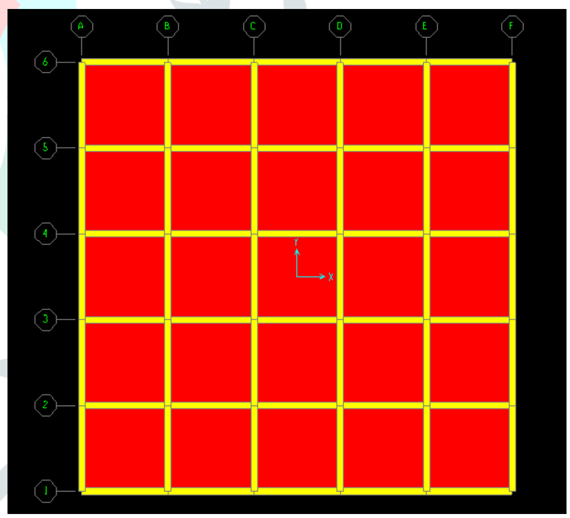


Fig 4.9: 10 Storied Building Without Water Tank – Plan View

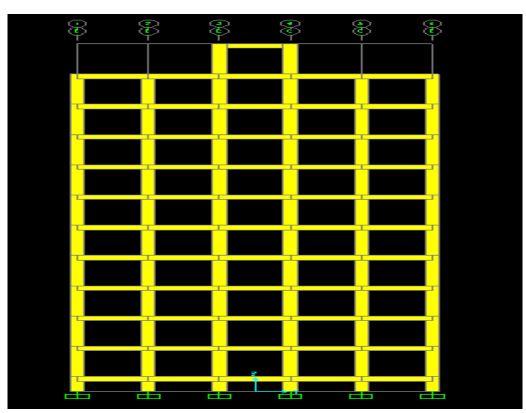


Fig 4.10: 10 Storied Building With

Water Tank – Elevation

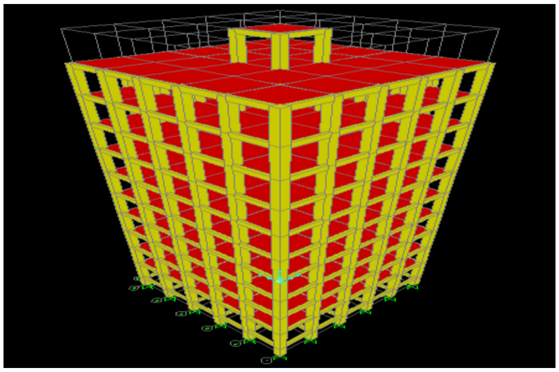


Fig 4.11: 10 Storied Building With Water Tank – 3d View

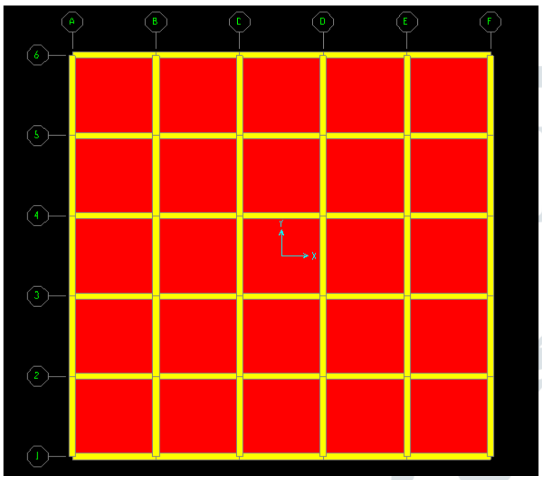
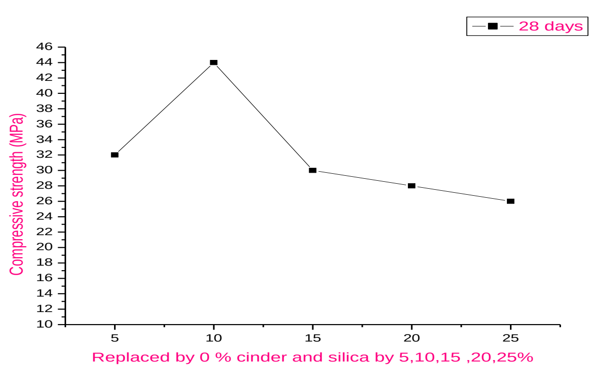


Fig 4.12: 10 Storied Building with Water Tank – Plan View

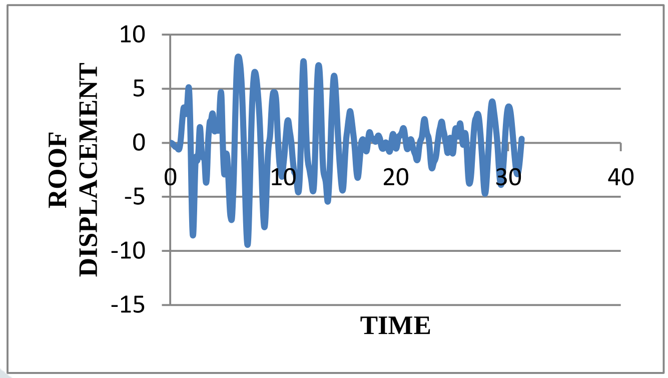
IV. RESULTS&DISCUSSIONS

Time history analysis is done for 5 Storied and 10 Storied buildings with and without water tanks, with water tank columns of varying heights i.e., 1m, 2m,3m and 3.5m and different mass ratios varying from 5% to 25%.Analysis is done for EL Centro Earthquake data, Bhuj Earthquake data and Kobe Earthquake data. 5 storied and 10 storied structures are analysed placing water tank at centre varying the column heights for 1m, 2m,3m and 3.5m. Each of the case is analysed by changing the mass ratio's varying from 5% to 25% for every 5% increment. Displacements, base shears and storey drifts have been studied and the results are presented as follows:



Graph 1 Roof displacement vs time for a 5 storied building without water tank

Analysis is carried out for 5 storied building with water tank column height varying from 1m to 3.5m and for different mass ratios varying from 5% to 25%. Maximum response reduction is found @ 3m column height and for 20% mass ratio.



Graph 2: Roof displacement vs time for a 5 storied building with water tank column height of 3m and mass ratio 20%

V.CONCLUSION

•Idea of using water tank as passive tuned mass damper, can be successfully used for control of seismic response of multi storied building.

•Maximum reduction in roof displacement is observed when 5 storied building is subjected to EL Centro Earthquake data with mass ratio being 20% and water tank is placed on columns of 3m height. Max response reduction for this condition is 39%.

•Maximum reduction in base shear is observed when 5 storied building is subjected to Bhuj Earthquake data with mass ratio being 15% and water tank is placed on columns of 3m height. Max response reduction for this condition is 52%.

•Maximum reduction in Storey drift is observed when 5 storied building is subjected to EL Centro Earthquake data with mass ratio being 20% and water tank is placed on columns of 3m height. Max response reduction for this condition is 48%.

•For buildings with water tank at centre, maximum shear force occurred for tank columns. This shear force value is high when compared to that of building columns at different levels. Hence water tank designing should be done separately and given much importance due to this high lateral forces at tank columns. Using water tank as passive TMD is advantageous in control of seismic response of multistoried building. Idea of using water tank as seismic response control device is advantageous since water tank is an integral part of any type of building. Tuning the parameters of water tank, it can be used as passive TMD to reduce the seismic response. Time history analysis is done using SAP 2000 for 5 storied and 10 storied buildings subjected to different Earthquake data's. Majority of the cases prove that results are appreciable when water tank is placed on columns of 3m height and mass ratio of 20%.

Scope for further work

•Studying the seismic behavior of structures by placing water tanks at various positions.

•Studying the seismic behavior of unsymmetrical building, placing water tank at a position such that seismic response is reduced.

•Studying the seismic behavior of structures with and without water tank subjected to different types of Earthquake data.

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