Vibration Control of High Rise Structures by using Tuned Mass Dampers

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***Abstract*— Need for taller structure in construction is increasing all over the world. These structures are flexible and constructed as light as possible (as seismic load acts on a structure is a function of self-weight), which have low value of damping, makes them vulnerable to unwanted vibration. This vibration creates problem to serviceability requirement of the structure and also reduce structural integrity with possibilities of failure. Current trends use several techniques to reduce wind and earthquake induced structural vibration. Shear wall is an already existing technique and commonly used. Passive tuned mass damper (TMD) is widely used to control structural vibration under wind load but its effectiveness to reduce earthquake induced vibration is an emerging technique. This is to study the comparison of using shear walls and Tuned Mass Dampers in reducing vibration of a high rise structure due to earthquake loading by using a finite element software SAP2000. For this a symmetrical Moment Resistance Frame (MRF) 30 storeyed three-dimensional model is to be modeled in SAP2000 and then Earth quake loading is applied. Then shear walls and Tuned Mass Dampers are assigned in the structure alternatively. Various arrangements of Tuned Mass Dampers in this 30 storey building are studied and the best arrangement among these is applied in a 50 storey building to study the effectiveness in controlling vibration. And also the charecteristics of this 50 storey building is studied by applying Time History Analysis of El-Centro earthquake.**

I. INTRODUCTION

Vibration means mechanical oscillation about an equilibrium point. The oscillation may be periodic or non-periodic. Vibration control is essential for machinery, space shuttle, aeroplane, ship floating in water. With the modernisation of engineering the vibration mitigation technique has find a way to civil engineering and infrastructure field.

Now-a-days innumerable high rise building has been constructed all over the world and the number is increasing day by day. This is not only due to concerned over high density of population in the cities, commercial zones and space saving but also to establish country land marks and to prove that their countries are up to the standards. The structural system designed to carry vertical load may not have the capacity to resist lateral load or even if it has, the design of lateral load will increase the structural cost substantially with increase in number of storey. As the seismic load acting on a structure is a function of the self-weight of the structure these structures are made comparatively light and flexible which have relatively low natural damping. Results make the structures more vibration prone under wind, earthquake loading. In many cases this type of large displacements may not be a threat to integrity of the structure but steady state of vibration can cause considerable discomfort and even illness to the building occupant.

In every field in the world conservation of energy is followed. If the energy imposed on the structure by wind and earthquake load is fully dissipated in some way the structure will vibrate less. Every structure naturally releases some energy through various mechanisms such as internal stressing, rubbing, and plastic deformation. In large modern structures, the total damping is almost 5% of the critical. So new generation high rise building is equipped with artificial damping device for vibration control through energy dissipation. The various vibration control methods include passive, active, semi-active, hybrid. Various factors that affect the selection of a particular type of vibration control device are efficiency, compactness and weight, capital cost, operating cost, maintenance requirements and safety A Tuned mass damper (TMD) is a passive damping system which utilizes a secondary mass attached to a main structure normally through spring and dashpot to reduce the dynamic response of the structure. It is widely used for vibration control in mechanical engineering systems. Now a days TMD theory has been adopted to reduce vibrations of tall buildings and other civil engineering structures. The secondary mass system is designed to have the natural frequency, which is depended on its mass and stiffness, tuned to that of the primary structure. When that particular frequency of the structure gets excited the TMD will resonate out of phase with the structural motion and reduces its response. Then, the excess energy that is built up in the structure can be transferred to a secondary mass and is dissipated by the dashpot due to relative motion between them at a later time. Mass of the secondary system varies from 1-10% of the structural mass. As a particular earthquake contains a large number of frequency content now a days multiple tuned mass dampers (MTMD) has been used to control earthquake induced motion of high rise structure where the

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more than one TMD is tuned to different unfavourable structural frequency.

The SAP name has been synonymous with state of the art analytical methods since its introduction over 30 years. SAP2000 is a stand-alone finite-element-based structural program for the analysis and design of civil structures. It offers an intuitive, yet powerful user interface with many tools to aid in the quick and accurate construction of models, along with the sophisticated analytical techniques needed to do the most complex projects. SAP2000 is object based, meaning that the models are created using members that represent the physical reality. SAP2000 has proven to be the most integrated, productive and practical general purpose structural program on the market today. Complex models can be generated and meshed with powerful built in templates. 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. Results for analysis and design are reported for the overall object, and not for each sub-element that makes up the object, providing information that is both easier to interpret and more consistent with the physical structure. SAP2000 is an easiest and most productive solution for our structural analysis and design needs.

II. MODELS CREATED

Model 1 : 30 storey building with shear wall
Model 2 : 30 storey building with 4 TMDs located at four exterior corner joints of all the floors.
Model 3 : 30 storey building with 4 TMDs located at interior corner joints of all the floors.
Model 4 : 30 storey building with 8 TMDs located at exterior and interior corner joints of all the floors.
Model 5 : 30 storey building with 8 TMDs located at joints in a plus shape of all the floors.
Model 6 : 30 storey building with 12 TMDs are located at all exterior joints of all the floors.
Model 7 : 30 storey building with 12 TMDs are located at joints in a plus shape of all the floors.
Model 8 : 30 storey building with 16 TMDs are located at all joints of all the floors.

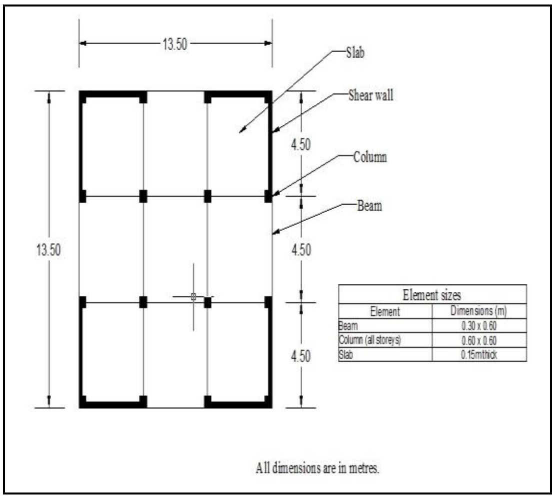

Fig. 1. Plan of model with shear wall

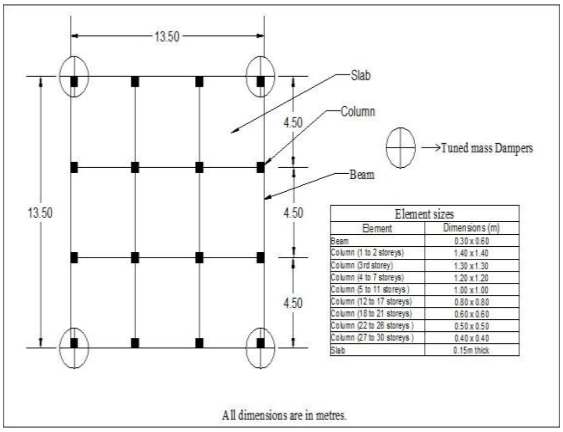

Fig. 2. plan of model with four TMDs at exterior corner joints

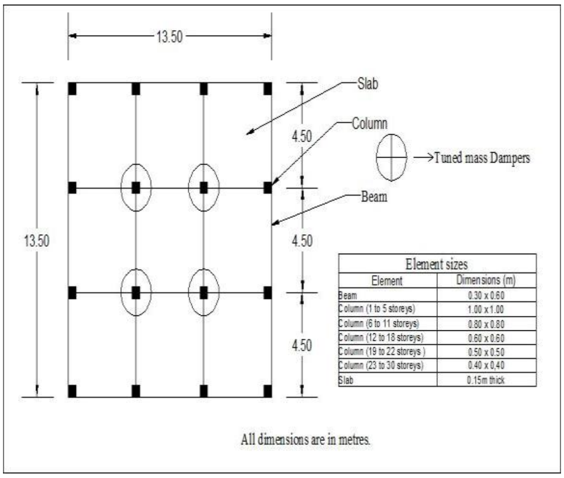

Fig. 3. plan of model with four TMDs at interior corner joints

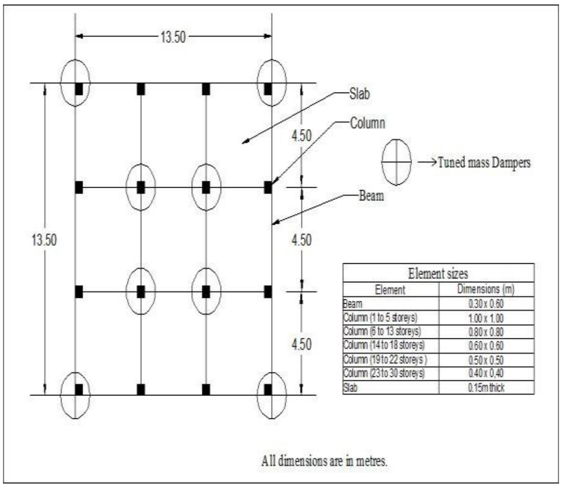

Fig. 4. plan of model with eight TMDs at exterior and interior corner joints

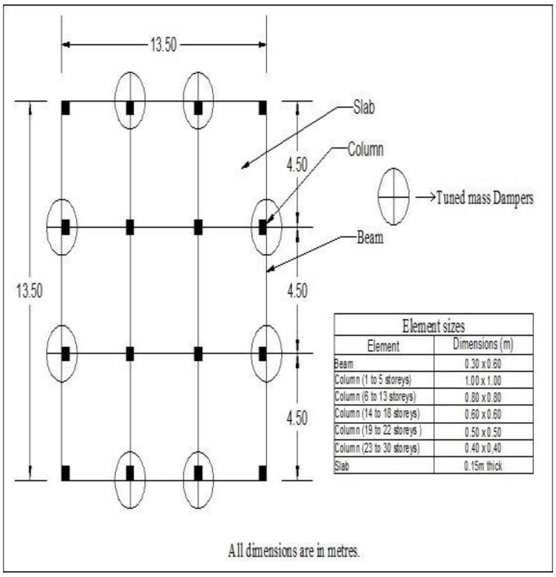

Fig. 5. plan of model with eight TMDs at joints in a plus shape

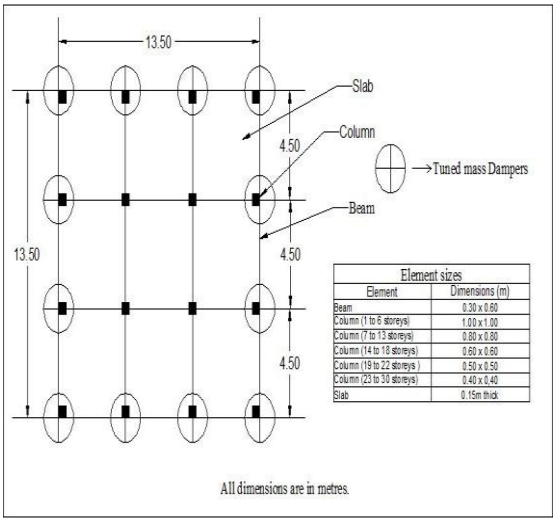

Fig. 6. plan of model with twelve TMDs at all exterior joints.

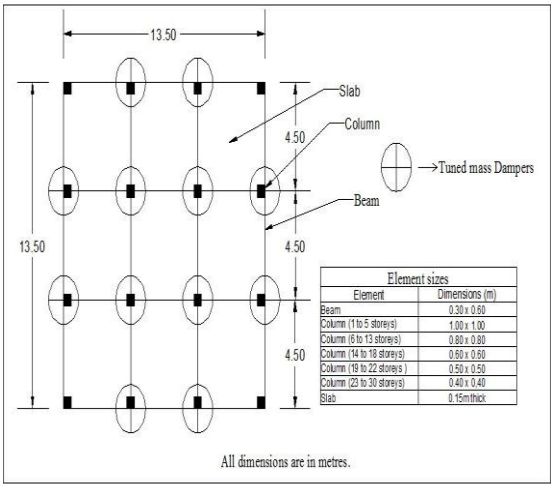

Fig. 7. plan of model with twelve TMDs at joints in a plus shape

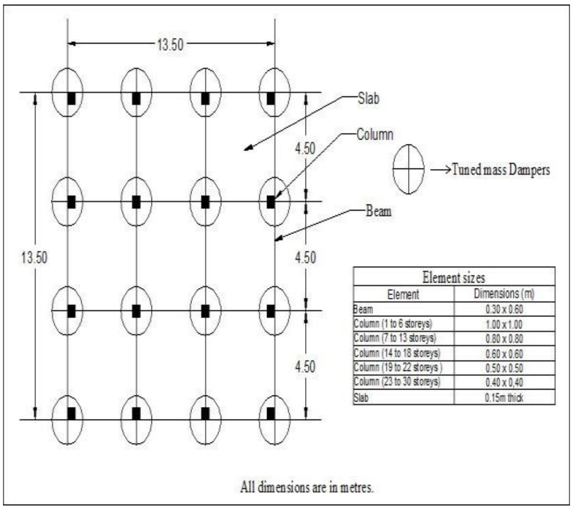

Fig. 8. plan of model with TMDs at all joints

These building models are analysed in SAP2000 by using Response Spectrum Analysis and various characteristics such as base shear, storey displacement, joint accelerations and frequency are studied. The size of shear wall has been obtained by doing trial and error method. The optimum parameters of Tuned Mass Dampers obtained by proper designing used in the analysis are as follows.

A. For four TMDs per each floor :

- Assume mass ratio = 5%
- Mass of damper , m_2 = 3900 kN.
- Total number of dampers = 120.
- Therefore mass of one damper = 32.5 kN
- Frequency of the building , ω =14.849 rad/sec
- Frequency of damper, ω_d = 13.81 rad/sec.
- Stiffness of damper, K_d = 619830 N/m
- Damping ratio ξ_d = 0.13
- The value of damping, C_d = 12000 Ns^2/m.

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B. For eight TMDs per each floor :

- Assume mass ratio = 5%
- Mass of damper , m_2 = 3900 kN.
- Total number of dampers = 240.
- Mass of one damper = 16.25 kN
- Frequency of the building , ω =14.849 rad/sec
- Damping frequency , ω_d = 13.81 rad/sec.
- Stiffness of damper, K_d = 310000N/m
- Optimum damping ratio, ξ_d = 0.13
- The value of damping, C_d = 6000 Ns^2/m.

C. For 12 TMDs per each floor :

- Assume mass ratio = 5%
- Mass of damper , m_2 = 3900 kN.
- Total number of dampers = 360.
- Mass of one damper = 10.83 kN
- Frequency of the building , ω = 14.849 rad/sec
- Damping frequency , ω_d = 13.81 rad/sec.
- Stiffness of damper, K_d = 206550 N/m
- Optimum damping ratio, ξ_d = 0.13
- Value of damping, C_d = 3900 Ns^2/m.

D. For TMDs at all joints :

- Assume mass ratio = 5%
- Mass of damper , m_2 = 3900 kN.
- Total number of dampers = 480.
- Mass of one damper = 8.125 kN
- Frequency of the building , ω =14.849 rad/sec
- Damping frequency , ω_d = 13.81 rad/sec.
- Stiffness of damper, K_d = 155000 N/m
- Optimum damping ratio, ξ_d = 0.13
- The value of damping, C_d = 3000 Ns^2/m.

III. RESULTS AND DISCUSSIONS

From the analysis it has been observed that for a 30 storeyed building the base shear, storey displacement, joint acceleration and frequency are very less in buildings with Tuned Mass Dampers than with shear wall. The difference in these values of buildings with shear wall and with Tuned Mass Dampers are very high. And the variations among the different arrangements of TMDs are very small. So one of the arrangements are made in a fifty storeyed building. The arrangement selected is TMDs located at all joints because the mass of single TMD is very less and it can be easily placed in the stricture because of less volume.

A. Application of TMDs in a 50 storeyed structure

Mainly composite construction or construction by using steel sections are done in the case of high rise structures because of large concrete sections. But the cost of steel sections and composite construction are high in comparison with concrete construction. So it will be very useful if there is a technique to use concrete in high rise structures with lateral load resistance because of its less cost and fire resistance capacity. So Tuned Mass Dampers are applied in fifty storey building and its charecteristics are studied by using Response Spectrum Analysis and Time History Analysis of El-Centro earthquake.

The results obtained in response spectrum analysis are positive and the application of Tuned Mass Dampers in 50 storey building makes it safe and earthquake resistant. The base shear , storey displacement , joint acceleration and frequency of the 50 storey structure after Time History Analysis are same as that obtained after Response spectrum analysis. It is seen that the natural frequency of the El-Centro earthquake is above 10Hz. And after analysis we obtained that the maximum frequency of 50 storey building is 1.53Hz . There is a large difference between the frequency of El Centro earthquake and frequency of the 50 storey building. So the building is safe .

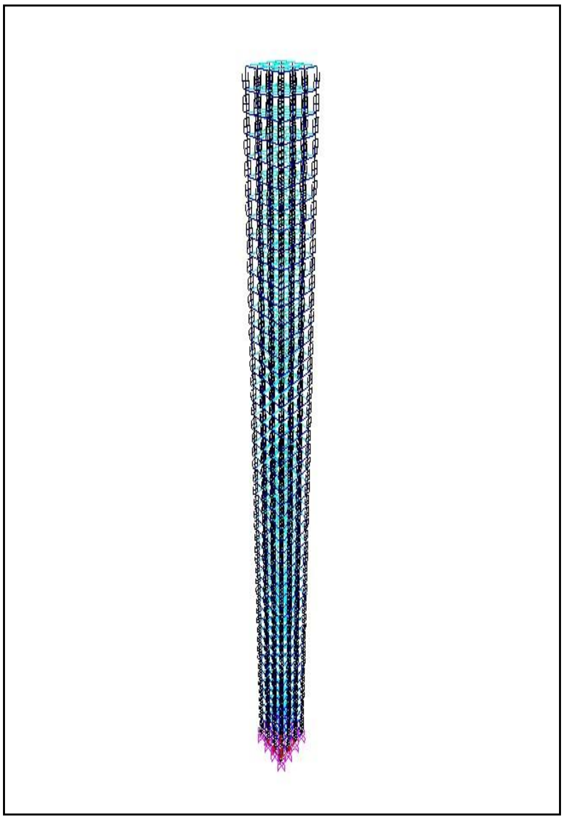

Fig. 9. Model of 50 storeyed building

V. CONCLUSIONS

In this, the analytical study on the effect of Tuned Mass Damper in high rise structures has been done. The parameters like base shear, storey displacement, joint acceleration and frequency have been compared with building with shear wall and also between various arrangements of Tuned Mass Dampers. The applicability of Tuned Mass Damper in 50 storey building also is studied for both Response Spectrum Analysis and Time History Analysis.From the study following conclusions were drawn out.

- The base shear of 30 storey buildings with Tuned Mass Dampers in all the directions are very less when compared to building with shear wall.. The base shear obtained for building with shear wall are 23670 kN, 10512 kN and 161399 kN in X, Y and Z directions respectively and the minimum base shear obtained for

TMD arrangement are 3404 kN , 750 kN and 132183 kN for X, Y and Z directions respectively. The other values of various TMD arrangements are having only slight variation with the above mentioned values.

- The storey displacement of 30 storey buildings with TMDs are also very less when compared with building with shear wall. The maximum storey displacement obtained for building with shear wall is 0.088m and the maximum displacement of buildings with TMDs are 0.046m. It is almost just the half of that with shear wall. The minimum displacement obtained is 0.037m.
- The joint acceleration obtained for 30 storey buildings with TMDs are also having a large difference between that of building with shear wall. The joint acceleration obtained for building with shear wall is 24.391 m/s^2 and 4.1799m/s^2 for buildings with TMDs. Least value obtained for joint acceleration is 2.49m/s^2.
- The frequency obtained for 30 storey building with shear wall is 38.949 rad/sec and the frequency of buildings with TMDs are less than 16 rad/sec for all the arrangements. So frequency is also having a large difference between the buildings with TMDs and building with shear wall.
- The application of TMDs in 50 storey building also proved to be safe. The Base shear , Storey displacements, joint accelerations and frequency of the structure are very less. These storey displacements , joint accelerations and frequency of the 50 storey structure are less than that of 30 storey building with TMDs for the designed optimum parameters of TMDs,
- And in Time History Analysis it could be seen that there is no chance of resonance to occur when an earthquake as same as El Centro earthquake arrives. There is a large difference between frequency of the structure and the natural frequency of El Centro earthquake.
- The model used for the analysis is not having proper base width. With in these limitation the structure could me made safe with TMDs against lateral loads.
- The cost of TMDs are almost similar to that of shear wall in 30 storeyed structure. But less base shear, storey displacement, joint acceleration, and frequency makes TMDs more applicable than shear wall. For 50 storey building the TMDs could be cost effective.

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