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Effect of Viscous Dampers application on the seismic response of a High Rise Building

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Abstract

Earthquakes cause severe damages to large-scale infrastructures. Conventionally, structures are designed to resist dynamic forces through a combination of strength, deformability and energy absorption. These structures may deform well beyond the elastic limit. In order to avoid such critical damages, structural engineers are working to figure out different types of structural systems that are robust and can withstand strong motions. Alternatively, some types of structural protective systems may be implemented to mitigate the damaging effects of these dynamic forces. These systems work by absorbing or reflecting a portion of the input energy that would otherwise be transmitted to the structure itself. The concept of structural control is to absorb vibration energy of the structure by introducing supplemental devices. Various types of structural control theories and devices have been recently developed and introduced to large-scale civil engineering structures. Viscous dampers, when used in high-rise buildings in seismic areas, should reduce the vibrations induced by both strong winds and earthquakes. In the present study, a residential building with 20 floors is analyzed with columns; columns with viscous dampers at different locations were for all the 2 cases. The building is analyzed in Zone 3 & Zone 5 with three soils in both static & Dynamic Analysis using software ETABS. Moments, Shear, Displacement was compared for all the cases. It is observed that the deflection was reduced by providing the viscous dampers.

Keywords: Viscous Dampers (VD); Visco Elastic Dampers (VED);

1. INTRODUCTION

Natural disasters are inevitable and it is not possible to get full control over them. The history of human civilization reveals that man has been combating with natural disasters from its origin but natural disasters like floods, cyclones, earthquakes, volcanic eruptions have various times not only disturbed the normal life pattern but also caused huge losses to life and property and interrupted the process of development. With the technological advancement man tried to combat with these natural disasters

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through various ways like developing early warning systems for disasters, adopting new prevention measures, proper relief and rescue measures. But unfortunately it is not true for all natural disasters. Earthquakes are one of such disaster that is related with ongoing tectonic process; it suddenly comes for seconds and causes great loss of life and property. So earthquake disaster prevention and reduction strategy is a global concern today. Hazard maps indicating seismic zones in seismic code are revised from time to time which leads to additional base shear demand on existing buildings. Retrofitting reduces the vulnerability of damage of an existing structure during future earthquakes. It aims to strengthen a structure to satisfy the requirements of the current codes for seismic design. In this thesis, a methodology has been proposed for retrofit of existing buildings for additional base shear demand and serviceability requirement using Viscoelastic dampers. Seismic zone map in Indian standard IS 1893 Part 1 2002 is being revised from time to time which leads to increase in elastic demands on existing buildings. Base shears for a typical low rise (three storey) and high rise (twenty storey) buildings for zone 2, zone 3, zone 4 and zone 5 for hard soil condition are estimated using seismic coefficient method and time history analysis with spectrum compatible acceleration [1].

Number of Viscoelastic dampers and damping ratio required for different cases are worked out and the comparisons are made. The common practice to strengthen existing buildings is to strengthen members and joints with concrete or steel jacketing and to increase the size of the structural members so as to meet the new design requirements. However, it is a time-consuming process and requires demolition of plastering of members, further it may cause pollution to the environment. Considering the above disadvantages, earthquake resistant design and retrofit of structures using energy absorption devices have received desirable attention in recent years (Soong and Dargush 1997). Primary objective of adding energy passive dissipaters is to enhance the damping of the structure and to bring down the demand on structural members without the help of external power supply and to minimize structural damage. Number of passive energy dissipaters are employed in structural design viz., friction dampers, metallic dampers, Viscoelastic dampers and dampers made out of smart materials. Amog the available devices, Viscoelastic dampers are chosen for the present study which is known to be effective in reducing vibrations of structures at all environmental temperatures under mild and moderate earthquake ground motions. In the present study, methodology has been proposed to enhance the capacity of building to meet additional base shear demand due to zone up gradation using Viscoelastic dampers. Methodology is demonstrated for a typical high rise (twenty storey) building to increase the seismic capacity of the buildings from zone 2 to zone 3, zone 3 to zone 4 and zone 4 to zone 5 by the addition of Viscoelastic dampers (designated as VE hereafter).

2. LITERATURE REVIEW

In this chapter, brief review of literature on the effect of infill and retrofitting of existing building with Viscoelastic dampers is presented. Seismic retrofitting is the modification of existing structures to make them more resistant to seismic activity, ground motion, or soil failure due to earthquakes. RC framed buildings are generally designed without considering the structural action of masonry infill walls that are present. These walls are widely used as partitions and considered as non-structural elements. But they affect both the structural and non-structural performance of the RC buildings during earthquakes.

2.1. Literature Review

Weng et al., proposed a simplified seismic design procedure for retrofitting earthquake damaged frames with viscous dampers. Various dampers or energy dissipation devices have been widely used in building structures for enhancing their performance during earthquakes, windstorm and other severe loading scenarios. With the scheme of designing the main frame and the supplemental viscous dampers respectively, the seismic analysis model of damped structure with viscous dampers and braces was studied. The expected damping forces for damped frame were first obtained based on storey shear forces; and then they were optimized to meet different storey drift requirements. A retrofit project of a RC frame school building damaged in the 2008, Wenchuan earthquake was introduced as a case study. This building was retrofitted by using viscous dampers designed through the simplified design procedure. It is concluded that this simplified design procedure can be effectively used to make seismic retrofit design of earthquake-damaged RC frames with viscous dampers. It is also stated that design procedure proposed can be used not only for the retrofit design of earthquake-damaged frame structures, but also for the damping design of new building or existing buildings [2].

Garcia and Soong , have explored a simple approach for the design of optimal damper configurations. This practical method is designated as simplified sequential search algorithm (SSSA). The SSSA is applied to several regular building models with different natural periods, numbers of storey, levels of added damping, and different ground motions. Only one type of passive energy dissipation device is considered linear viscous dampers. It is concluded that, in the case of regular buildings, the SSSA will generally lead to efficient damper configurations, particularly for low-to-medium-rise buildings and for a number of dampers equal to or greater than 1.5–2 times the number of storey. In this study, it is stated that the resulting damper configurations are found to be sensitive to ground motion characteristics, especially for low levels of supplemental damping. Four recorded seismic ground motions are used to perform the numerical simulations. It is reported that, for this study, two ground motions recorded on rock and two ground motions recorded on the soft soil are used out of which one has shorter epicentral distance and the other has longer epicentral distance. It is stated to be observed that damper configurations obtained for different ground motions are not equal to each other, but very similar. It is concluded that, while the SSSA does not provide a unique damper configuration, it nevertheless indicates a consistent pattern and hence in real-case applications, differences among damper configurations corresponding to different ground motions are minor enough to be resolved by engineering judgment [3].

Erfan and Mojtaba , have used mass isolation system (MIS), with Viscoelastic dampers for retrofitting of existing buildings. MIS consists of two separate frames, a flexible moment resisting frame, which bears main part of structure mass and a relatively rigid braced frame, which carries the remained little mass of the structure and these two frames are connected to each other with Viscoelastic dampers. Use of Viscoelastic dampers in MIS is here proposed instead of other dampers types, due to their smaller sizes, which make them more applicable specially for retrofitting of existing buildings, and their stiffness, which have very important role on regulating of the flexibility rate of the flexible frame and stability control of the system. Three steel structures with 4, 8, 12 stories are selected and nonlinear dynamic analysis under 7 time-histories acceleration records of the ground strong motions have been carried out for the structures, Drain-2DX software is used for modeling and nonlinear analysis of the structures. From economy point of view, numbers and vertical arrangement of Viscoelastic dampers between the two frames of the structures are optimized considering story drift limitations, structures responses and using various mechanical characteristics, stiffness and damping of the dampers. Input energy of earthquakes are obtained and compared with the dissipated energies in the systems. The results show that MIS effectively causes reduction of input energies of earthquakes and Viscoelastic dampers dissipate nearly 50% of the input energy and most of structural elements remain at the elastic ranges, which can be inferred that the performance levels of the structures have been significantly improved by using this system [4].

Chang et al., proposed a seismic design procedure for structures with added Viscoelastic dampers (VED) with an example illustrating the proposed design procedure. A summary on the experimental and analytical study of VE dampers as energy dissipation devices in seismic structural applications is described in this paper. Comparisons on the seismic performance between the viscoelastically damped structure and a conventionally designed special moment resisting frame are carried out in this paper. Analytical studies show that the modal strain energy method can be used to reliably predict the equivalent structural damping of the structure and that the seismic response of the viscoelastically damped structure can be accurately simulated by conventional modal analysis techniques. Based on these studies, the modal strain energy method has been incorporated into the computer programs ETABS and DRAIN2D+ for seismic analysis and design of structures with added VE dampers. The proposed design procedure provides an alternative safe and economic solution for earthquake resistant structures under seismic design regulations. A sufficiently large design damping ratio, such as 15% is used in this study. It has been shown in this report that structures with added VE dampers and with such a large design damping ratio may remain elastic or experience only minor yielding under most current design earthquakes [5].

Min et al., proposed a design procedure for Viscoelastic dampers and experimental test results of a 5-storey single bay steel structure with added Viscoelastic dampers. In this paper, the mechanical properties of Viscoelastic dampers and the dynamic characteristics of the model structure were obtained from experiments using harmonic excitation, and the results were used in the design process. The additional damping ratios required to reduce the maximum response of the structure to a desired level were obtained first. Then the size of dampers to realize the required damping ratio was determined using the modal strain energy method by observing the change in modal damping ratio due to the change in damper stiffness. In this study, designed Viscoelastic dampers were installed in the first and the second stories of the model structure. On observing the results from experiments using harmonic and band limited random noise they had concluded that after the installation of dampers, the dynamic response of the full-scale model structure reduced as desired in the design process [6].

Tsai , in this paper, the features of energy-absorbing capacities of the Viscoelastic damper and its effect on the structure during earthquakes are investigated. To clarify the behavior of the structure with added Viscoelastic dampers, Tsai (1994) modeled a new analytical model for the Viscoelastic damper taking into consideration the earthquake like loading and the temperature effect, in good agreement with experimental results, and an advanced finite element formulation for the Viscoelastic damper was developed. The proposed method could be implemented easily in the finite element program. In this study the behavior of a 10-story building equipped with Viscoelastic dampers was examined while it was subjected to earthquake ground motions. Both analytical and experimental results show that the energy-absorbing capacity of the Viscoelastic damper decreases with increasing the ambient temperature. Tsai (1994) concluded that the proposed analytical model accurately describe the behavior of Viscoelastic dampers subjected to earthquake like loadings at different temperatures. The capacity of the energy-absorption of the Viscoelastic damper decreases with the increase of the ambient temperature. Not only displacements but also stresses of the structure are significantly reduced by the added Viscoelastic dampers during earthquakes [7].

Irfanullah and Vishwanath , in this paper, the influence of masonry in fills of a building in seismic analysis are studied. RC framed buildings are generally designed without considering the structural action of masonry infill walls present. These walls are widely used as partitions and considered as non-structural elements. But they affect both the structural and non-structural performance of the RC buildings during earthquakes. RC framed building with open first storey is known as soft storey, which performs poorly during earthquakes. To observe the effect of masonry infill panel, it is modelled as an equivalent diagonal strut. In this paper an investigation has been made to study the behaviour of RC frames with various arrangement of infill when subjected to earthquake loading. The results of bare frame, frame with infill, soft ground floor, soft basement and infill in swastika pattern in ground floor are compared and conclusions are made. The conclusion of the study is that, by providing infill below plinth and in swastika pattern in the ground floor improves earthquake resistant behaviour of the structure when compared to soft basement [8].

Wakchaure and Ped , in this study, the effect of masonry infill panel on the response of RC frames subjected to seismic action. In analysis infill walls are modeled as equivalent strut approach with various formulae derived by research scholars and scientist for width of strut and modeling. The infill behaves like compression strut between column and beam and compression forces are transferred from one node to another. In this study the effect of masonry walls on high rise building is studied. Linear dynamic analysis on high rise building with different arrangement is carried out. For the analysis G+9 R.C.C. framed building is modeled. Earthquake time history is applied to the models. The width of strut is calculated by using equivalent strut method. Various cases of analysis are taken. All analysis is carried out by software ETABS. Base shear, storey displacement, story drift are calculated and compared for all models and concluded that infill walls reduce displacements, time period and increases base shear. So it is essential to consider the effect of masonry infill for the seismic evaluation of moment resisting reinforced concrete frame. However, only limited work has been reported, on the use of VE damper for strength enhancement of existing building with and without infill which have undergone zone up gradation for Indian conditions. Hence an effort has been made in this study to develop a methodology for retrofitting of existing building with VE dampers and the methodology has been demonstrated for a low-rise building and a high rise building [9].

3. Methodology for retrofitting of existing building

3.1. Concept of retrofitting

Retrofitting is technical interventions in structural system of a building that improve the resistance to earthquake by optimizing the strength, ductility and earthquake loads. Strength of the building is generated from the structural dimensions, materials, shape, and number of structural elements, etc. Ductility of the building is generated from good detailing, materials used, degree of seismic resistant, etc. Earthquake load is generated from the site seismicity, mass of the structures, importance of buildings, degree of seismic resistant, etc. Seismic retrofit of an existing building most often would be more challenging than designing a new one. The first step of seismic evaluation aims at detecting the deficiencies of the building. Seismic retrofitting of existing structures is one of the most effective methods of reducing the risk of human life and damage of the buildings. Retrofitting procedures could be selected and applied so that the performance objective of the retrofit depends upon the importance of the structure and the desired structural performance during a seismic event with a particular recurrence interval. Due to the variety of structural condition of building, it is hard to develop typical rules for retrofitting. Each building has different approaches depending on the structural deficiencies. Hence, engineers are needed to prepare and design the retrofitting approaches. In the design of retrofitting approach, the engineer must comply with the building codes. The results generated by the adopted retrofitting techniques must fulfill the minimum requirements on the buildings codes, such as deformation, detailing, strength, etc.

3.2. Causes of failure

Following were the main causes of failure and damages to the buildings.

- Old buildings constructed without considering engineering principles or modern construction practices
- New Buildings not being designed to Indian earthquake codes
- Lack of knowledge, understanding or training in the use of these codes by local engineers
- Buildings erected without owners seeking proper engineering advice
- Improper detailing of masonry and reinforced structures
- Poor materials, construction and workmanship used, particularly in commercial buildings
- Alterations and extensions being carried out without proper regard for effects on structure during an earthquake.
- Buildings having poor quality foundations or foundations built on poor soils.
- Little or no regularity authority administering or policing the codes.

3.3. Methods of retrofitting

- Addition of RC structural walls
- Steel jacketing
- Concrete jacketing
- FRP wrapping etc.

3.4. Recent Retrofitting Methods

There are many relatively new technologies developed for seismic Retrofitting which are based on "Response control". These techniques includes providing additional damping using dampers (Elastoplastic dampers, friction dampers, tuned mass and tuned liquid dampers, Viscoelastic dampers, lead extrusion dampers etc.) and techniques such as base isolation which are introduced to take care of seismic control. Among these the addition of Viscoelastic dampers are adopted because due to their smaller sizes, which make them more applicable specially for retrofitting of existing buildings, and their stiffness, which have very important role on regulating of the flexibility rate of the flexible frame and stability control of the system. The benefits of retrofitting include the reduction in the loss of lives and damage of the essential facilities, and functional continuity of the life line structures. For an existing structure of good condition, the cost of retrofitting tends to be smaller than the replacement cost. Thus, the retrofitting of structures is an essential component of long term disaster mitigation.

3.5. Viscoelastic Damper

The application of Viscoelastic materials to vibration control can be dated back to the 1950s when it was first used on aircraft as means of controlling vibration-induced fatigue in airframes. Since that time, it has been widely used in aircrafts and aerospace structures for vibration reduction. Its application to civil engineering structures appears to have begun in 1969 when 10,000 Viscoelastic dampers were installed in each of the twin towers of the World Trade Centre in New York to help resist wind loads. Seismic applications of Viscoelastic dampers have a more recent origin. Forces generated due to earthquake are more and larger damping is required for vibration control compared to damping required for control of wind-induced vibrations. Furthermore, during earthquake shaking, energy input into the structure is usually spread over a wider frequency range, requiring more effective use of the Viscoelastic materials. Extensive analytical and experimental studies in the seismic domain have led to the first seismic retrofit of an existing building using Viscoelastic dampers (designated as VED here after) in the U.S. in 1993.

3.6. Applications Of Viscoelastic Dampers

VEDs have been installed in four buildings in the United States for the minimization of wind-induced vibrations, with the earliest installation being the World Trade Center Towers in New York. In Japan, VEDS have been used to reduce the wind-induced response of several buildings: Seavans South Tower in Tokyo (1991), the Old Wooden Temple, Konohanaku Symbol Tower (1999), ENIX Headquarter Building, the Sogo Gymnasium in Chiba (1993), the Goushoku Hyogo Port Distribution Center (1998) with Viscoelastic joint dampers which reduce the seismic response by one half, and the Torishima Riverside Hill Symbol Tower, whose 1999 installation features 8 VEDs per story for the 1st to 19th floors and reduces to 4 VEDs per story for the 20th to 38th stories. In addition, the Chientan Railroad Station in Taipei, Taiwan has also been equipped with 8 Viscoelastic units to control the wind-induced vibrations of its unique suspended dragon boat roof. Although the use of VEDs to control excitations due to wind has been commonplace for over 20 years, their use in seismic applications has just begun to flourish. Their installation in the form of rubber-asphalt attached to the walls in one direction of every floor of a 24 story building was found to improve the structural responses under earthquake conditions by 30%. There have been numerous other seismic applications, particularly in the area of retrofitting, in the United States, including the Santa Clara Civic Center Office Building.

3.7. Advantages and Disadvantages

In general, friction, Viscoelastic, viscous fluid and hysteretic dampers reduce the seismic response of structures and minimize structural and non-structural damage. They are easy to install and do not impact the foundation design. They are attractive for the upgrading of existing buildings. The problems are the following: first, dampers are effective only for flexible structures that may be subjected to large deformations. Also, they encumber the design procedure and make it more expensive. For instance, several alternatives have to be considered to find their optimum number and location.

3.8. Methodology

In the present study, a methodology is proposed for the selection of dampers to enhance the base shear capacity of building in order to meet the additional demand due to zone up-gradation. The base shear demands for different zones are estimated using seismic coefficient method as per IS 1893-2002 (Part 1). In addition, since linear time history analysis is the most accurate procedure to estimate the dynamic response of the building, response spectrum analyses are carried out using ETABS 2013 (Computers and Structures Inc., 2011) to determine base shears, acceleration and displacement responses of the structures using spectrum compatible time histories. The response of the structure is obtained for given input earthquake ground motion acceleration. To study the effectiveness of the dampers, peak base shears, maximum displacements and accelerations are determined from the response of the damped buildings subjected to earthquake ground motion acceleration and the comparison has been made with those of the un-damped buildings. The damping devices used in this study is Viscoelastic dampers. The dampers are placed in chevron bracing of the framed building. In the present study this methodology is followed to retrofit a typical low rise building and high rise building with the Viscoelastic dampers to increase the seismic capacity of the buildings.

4. Results and discussions

Moment is compared in both the models i.e., without dampers & with dampers it is observed that 50% Shear is reduced when the dampers are provided in each elevation as shown in Figs.1 to 5.

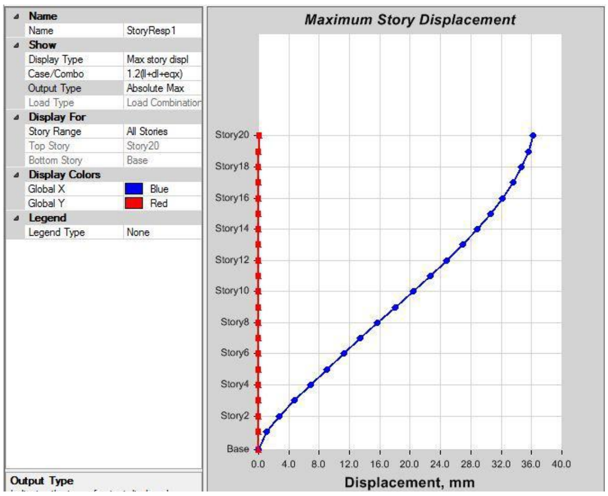

Fig.1. Showing displacement of high rise building.

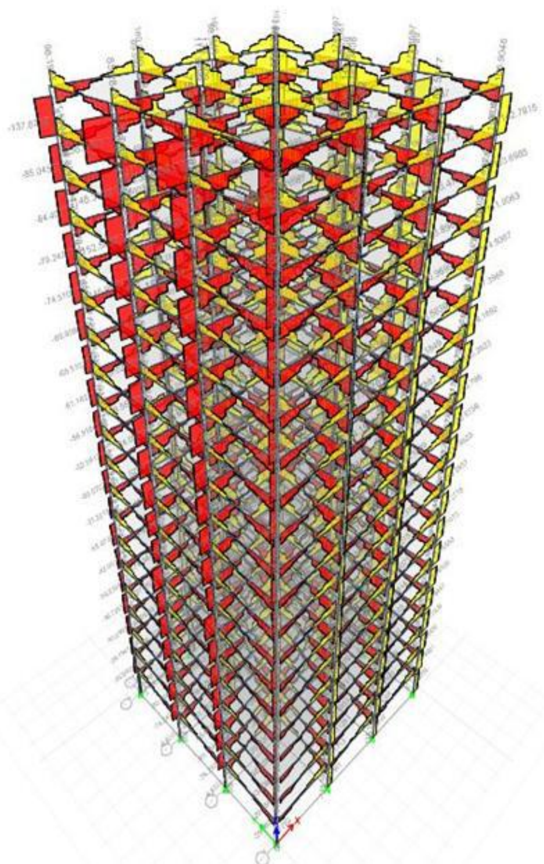

Fig.2. Showing shear diagram of high rise building in 3D view.

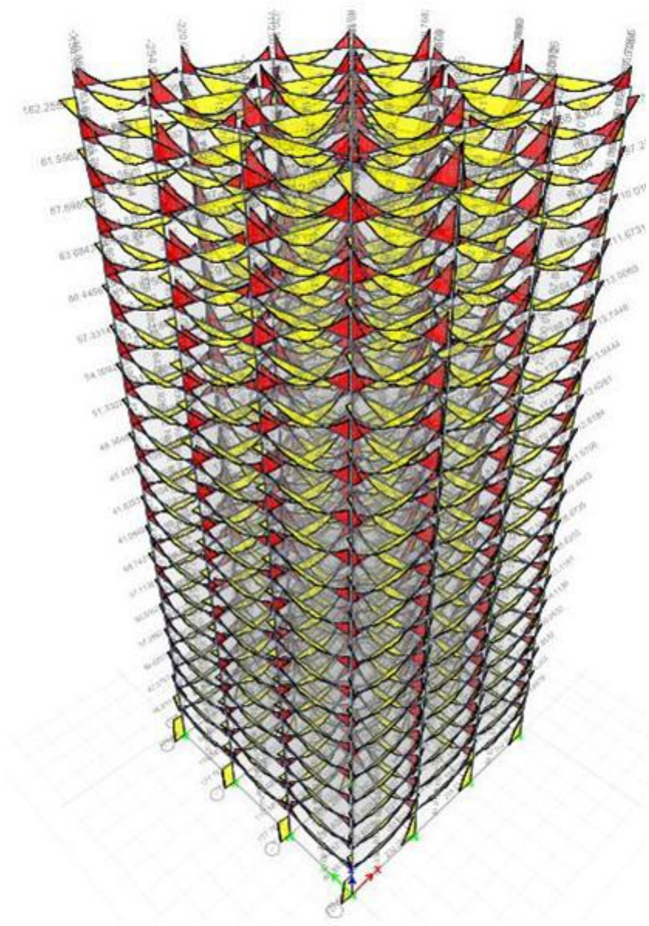

Fig.3. Showing moment diagram of high rise building in 3d view.

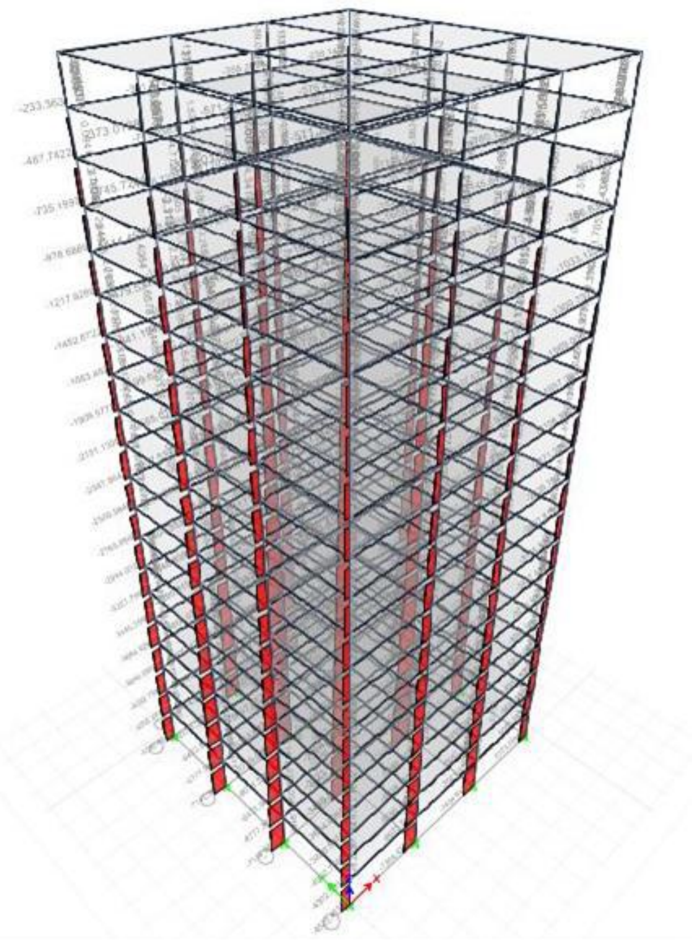

Fig.4. Showing axial force diagram of high rise building in 3d view.

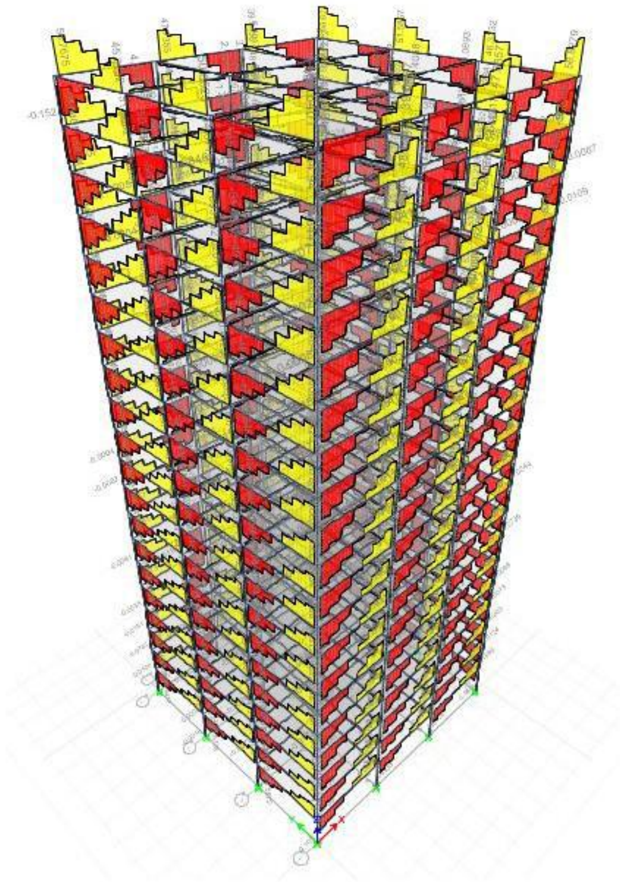

Fig.5. Showing torsion diagram of high rise building in 3d view

5. Conclusions

- Displacement is compared for two models i.e., without dampers & with dampers at top storey of a high rise building in zone-3 & zone -5 in each soil it is observed that 50% displacement is reduced when the dampers are provided at each elevation.
- Shear is compared for two models i.e., without dampers & with dampers at top storey of a high rise building in zone-3 & zone -5 in each soil it is observed that 40% shear is reduced when the dampers are provided at each elevation.
- Moment is compared for two models i.e., without dampers & with dampers at top storey of a high rise building in zone-3 & zone -5 in each soil it is observed that 45% moment is reduced when the dampers are provided at each elevation.

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