International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 12 | Dec 2018 www.irjet.net p-ISSN: 2395-0072

Base Isolation and Damping Systems for Earthquake Resistance

Omkar R. Shelar[1]

[1]B.E. Civil (MIT, Pune), Structural Design Engineer, Altron Consultants, Pune, India

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Abstract - *Nowadays large number of buildings are being frequently prone to the earthquakes and this has highlighted the fact of unawareness in construction of high rise building and it has triggered the concern towards the need for having earthquake resistant buildings. This paper reviews the types of damping systems such as viscous dampers, tuned mass dampers, base isolation dampers, Active damping and semi passive damping. The results obtained of structures with base isolation and structures with dampers are compared with fixed base structures. Graphs are plotted of the results. Recent developments of damping systems around the world are studied. Cost analysis of the life cycle of structures with damping systems is found out.*

Key Words: Damping systems, Base Isolation, Passive Dampers, Earthquake,

1. INTRODUCTION

The population of the urban areas is increasing because of industrialization, commercialization, migration of people from rural areas to urban areas and better standard of living. There is an increasing need and interest of construction of high-rise buildings in urban areas to accommodate the increasing population. The demand for high rise building will increase in the future. High-rise buildings and super high rise buildings need to resist external loadings such as wind and earthquake loads. Improvement of flexibility of such high rise buildings for extreme wind and earthquake loads is a major concern. (Hashimoto et al, 2015)

Earthquakes are one of the greatest calamities which have caused damage to cities and villages all over the globe. The damage caused by the earthquakes is associated with the man-made structures. Earthquakes give little or no warning before occurring and thus earthquake engineering is important. As the population of the earth increases, the problems caused to human settlements due to earthquakes also increases. Some of the major problems of the building because of earthquake forces are high overturning moment in high rise buildings and torsion from ground motion due to eccentricity (Julius Marko, 2006). The earthquakes in the recent past have provided enough evidence of performance of different type of structures under different earthquake conditions and at different foundation conditions as a food for thought to the engineers and scientists. This has given birth to different type of techniques to save the structures from the earthquakes (Subramani et al., 2014). In order to achieve satisfactory earthquake response of a structure, methods such as isolation, energy absorption at plastic hinges and use of mechanical devices to provide structural control are efficiently used.

Isolation is a method that reduces the seismic response of a building by extending its vibration period, which is achieved by inserting a special device between the building and its foundation or into a middle story. It is an effective technology that brings about great improvement in the seismic behavior of a superstructure. The main targets of early isolation methods were low-story buildings and high stiffness buildings, and the outstanding and successful effects of these early methods already have been demonstrated. However, the latest architectural trends are high-story, lightweight, slender buildings, and so, isolation technology is now being developed to address these gradually increasing building trends. (Young Soo Chun and Mun Woo Hur, 2015)

Base isolation reduces earthquake intensity and losses, which directly reduces the shaking intensity and damage that permanent equipment and building contents experience during earthquake ground shaking. It is useful to controlling energy, which is passing from foundation or ground to the upper stories. The main use of isolation system is to decrease the displacements, base reactions and member forces in structure (Verma et al., 2017). The base-isolation techniques prove to be very effective for the seismic protection of new framed buildings as well as for the seismic retrofitting of existing ones. Design guidelines have been developed in many countries with a high seismic hazard (e.g., United States, Japan, New Zealand) and, lately, suitable code provisions have been drafted also in Europe. However, under near-fault ground motions, even base-isolated structures designed according to recent seismic codes can undergo unforeseen structural damages.

Mechanical energy absorbers absorb the energy from the earthquake reducing the effects on the critical components of the structure. These absorbers do not support the structure but are replaced after the seismic activity leaving the building undamaged. There are two types of structural control which are active and passive control Active control requires a power supply to activate the dampers and hence can be undependable during seismic activity where the power supply can be possibly disrupted. Passive energy dissipation systems are incorporated within the structure to absorb a portion of the seismic energy.

2. TYPES OF DAMPING SYSTEMS

There are many methods proposed to accomplish the task of reducing occupant discomfort due to lateral accelerations and reduce structure damage due to excessive vibration and displacement. Damping systems are primarily separated into three types: active, semi-active and passive systems.
Several common passive damping systems include but are not limited to viscous, tuned mass, and base isolation damping. Passive damping systems have set parameters based on an expected loading envelope for a given area and an expected structure self-weight and are not designed to react effectively outside of that range, which results in a conservative design. Passive damping types are described in the following sections (Steven Pritchett, 2014).

2.1 Viscous Dampers

Viscous damping can be subdivided into two categories, fluid and solid material damping. The amount of energy dissipated by viscous fluid damping is dependent on the rate of deformation, while the energy dissipated by solid material damping is dependent on the total displacement of the system as well as the rate of deformation.

2.2 Tuned Mass Dampers

A Tuned Mass Damper is a device which consists of a mass attached to a structural system and is used to reduce the dynamic response of a structure to a predetermined loading (Steven Pritchett, 2014). The properties of the Tuned Mass Damper, including the exact mass and the precise location of the mass are calibrated with the dynamic properties of the structure such that when any of the predetermined frequencies of excitation are reached, the mass will vibrate out of phase with the structure, reducing overall displacement and energy in the structure (Connor, 2003).

2.3 Base Isolation

Many modern structural base isolation systems utilize steel-reinforced elastomeric rubber bearing pads, but while bearing pads alone are adequate for seismic loading, they allow excessive deflection from wind loads imposed directly on the structure and other low-level loads. A common solution is to pair rubber bearing pads with springs or steel rods designed to behave elastically up to a certain point and offer increased lateral stiffness, but yeild when loading exceeds a certain threshold so as not to counteract the benefits of the rubber pads.

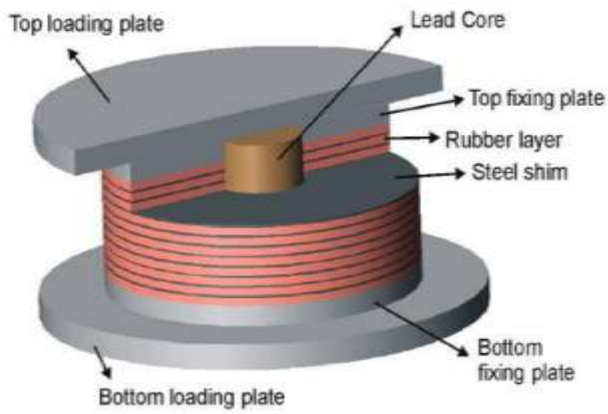

Fig -1: Elastomeric Bearing pad with Lead Core (*Courtesy*: Base Isolation-The Seismic Zone, 2013)

2.4 Active Damping

Active Damping systems use external sources of energy to optimize their system properties for a wide envelope of loading. Active Damping integrates three main components: a Monitor, which acquires data from sensors placed throughout the structure, a Controller, which is a data processing unit that decides on a course of action for the given circumstances and Actuator(s), which carry out the commands imposed by the Controller (Connor, 2003). Active control involves monitoring the system input and the structural response so that changes can be made to the input to optimize a system response for the real-time situation. The act of optimizing a system response can be achieved in many ways, depending on the design selected by the structure owner; actuators may be used to move a large mass or 9 masses on the structure, or even expand or contract cross-bracing elements in a structural framework to dissipate energy.

2.5 Semi-Active Damping

A semi-active system cannot increase the energy in the system (which includes the damping system and the structure) but has properties that can be dynamically varied. Semi-active damping systems are effective because of their mechanical simplicity, robustness, low power requirements and a level of effectiveness similar to fully active damping systems. There are an ever-growing number of semi-active damping devices and an even greater number of applications for those devices. One example is the magneto rheological damper, which functions similarly to viscous fluid dampers, with a fluid of a given viscosity absorbing energy in the form of heat as it is forced from one position in the damper casing to another by a plunger rod. The main difference between standard viscous dampers and magneto rheological dampers is that magneto rheological dampers utilize a damping fluid that contains very small particles suspended hydraulic oil that are reactive to magnetic fields. The damping characteristics of magneto rheological dampers can be quickly varied by changing the viscosity of the magneto rheological fluid by exposing them to magnetic fields of varying intensities.

3. COMPARATIVE STUDY OF BASE ISOLATION AND FIXED BASE

A fixed-base building moves with earthquake's motion and sustains extensive damage as a result. Base isolators work in a similar way like car suspension. Although it is designed for hard soil, it is not suitable for soft soil. Base isolated building is able to move horizontally relative to the ground, usually at least for 100 mm and in some instances up to 1 m (Ghodke and Admane, 2015). The analysis and observations of base–isolated buildings during earthquake have shown reduction in displacement of the building compared to fixed base buildings.

Prof.R.B.Ghodke and Dr.S.V.Admane have created 3-D models structure in SAP2000 software and have done modeling of the structures with and without base-isolation. A five storied reinforced concrete frame building situated in Zone IV, was taken for study. The plan area of building was 12 m x 10 m with 3.0m as height of each storey. It consisted of 2 bays of 6m each in X-direction and 2 bays of 5m each in Y-direction. The total height of the building was 15m. The building was considered as a Special Moment resisting frame. Sizes of the columns and beams were 400 mm X 400 mm, 345 mm X 500 mm respectively whereas the slab was 125 mm thick. Live loads were assigned as uniform area loads on slab elements as per IS 1893(PART 1)2002. Live load on all other floors was 3.0 kN/m^2. The following results were obtained in their analysis.

Table -1: Comparison of displacements of buildings with and without base isolation

Floor	Displacement of Building with Fixed Base (mm)	Displacement of Building with Base Isolation (mm)
1st Storey	25.9	3.6
2nd Storey	41.9	3.4
3rd Storey	53.2	3.3
4th Storey	61.3	3.2
5th Storey	69.3	3.1

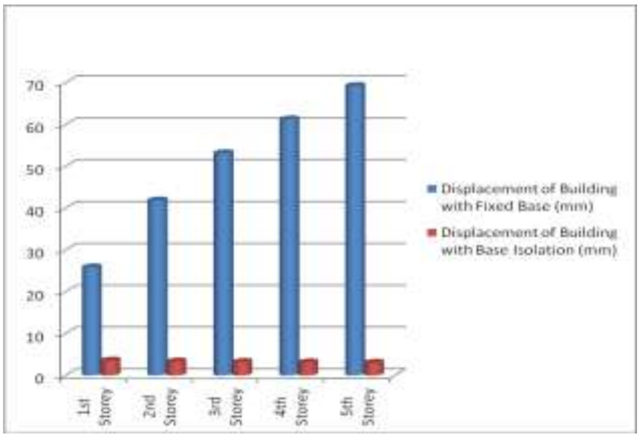

Chart -1: Displacements of buildings in base isolated buildings and fixed base buildings

Thus, it is derived from the analysis that for the base isolated buildings, the displacement of the stories decreases with the increase in height. For fixed base buildings, the displacement of stories increases with increase in the height of the building.

4. VISCOUS DAMPING SYSTEMS FOR HIGH RISE BUILDINGS

Vibrations induced by strong winds and earthquakes are decreased by viscous dampers (VD), when used in high-rise buildings in seismic areas. The optimal behavior of viscous dampers is not the same in two situations, thus the viscous dampers exhibit different behaviours in the different velocities corresponding to wind and earthquake and also have different design requirements. Often viscous dampers are used to control the motion of the Tuned Mass Dampers (TMD). TMD provides the necessary reduction in wind-induced accelerations. (Infanti et al., 2008)

The dampers have two main effects on the wind response. The first is the reduction of the dynamic amplification of the wind loading used for strength design. The second is to reduce the accelerations felt by the building occupants to acceptable levels.

As a building undergoes dynamic sway motion, there is relative vertical motion between the perimeter columns and the ends of stiff outrigger elements cantilevering from the core. A damper is inserted across this structural discontinuity, dissipating energy during the cyclic motion, and resulting in an increase in the overall damping of the building. The use of viscous dampers directly incorporated into the superstructure of the building has a number of significant advantages, when compared with a simple pendulum TMD 1) they take up less space; 2) they are usually placed away from the top of the building (the most valuable space); 3) they can supply higher levels of damping;

4) they are not as sensitive to a potential variation between the predicted and as-built building frequencies; 5) by using a number of different units, there is inherent redundancy; 6) with strategic positioning to ensure adequate damper stroke is achieved, they can be used over a range of amplitudes from low winds to earthquakes (Infanti et al.,2008).

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5. COMPARATIVE STUDY OF BUILDINGS WITH VISCOUS DAMPER AND FIXED BASE BUILDING IN SEISMIC ZONE

There are several types of seismic protection when included in a structure improve the seismic behavior classified as active and passive protection system depending upon whether or not it is necessary to provide energy for its operation. In non-conservative system damping forces are present which dissipate energy from the system and to maintain the energy at constant level, an external source must supply energy to the system at a rate equal to the rate of energy loss or dissipation(Maurya and Singh, 2018). In general, damping is a phenomenon in which the energy of the system is gradually reduced or the amplitude of vibration goes on decreasing & finally the vibration of the system is completely eliminated and the system is brought to rest. Earthquake protective system is of three types:

5.1 Passive control system

These systems have significant to buildings, bridges and industrial plants. The basic concept of passive system is –

- Reducing the stiffness
- Increasing the natural period of the system
- Provision of increased damping to increase the energy dissipation in the system.

Following are the examples of passive control system: - Energy dissipation devices- These devices are specially designed mechanical systems to dissipate a large portion of the earthquake input energy in specialized devices or special connection details which deform or yield during earthquakes. Energy dissipation devices operate on the principle such as frictional sliding, yielding of metal, phase transformation in metal, deformation of visco-elastic solids or fluid in fluid viscous dampers (Maurya and Singh, 2018). Accordingly, there are following types of energy dissipation devices-

- Friction dampers
- Metallic yielding dampers
- Visco-elastic dampers
- Fluid viscous dampers

Fluid viscous damping is a way to add energy dissipation to the lateral system of a building structure. A fluid viscous damper dissipates energy by pushing fluid through an orifice, producing a damping pressure which creates a force. These damping forces are 90 degrees out of phase with the displacement driven forces in the structure. This means that the damping force does not significantly increase the seismic loads for a comparable degree of structural deformation.

5.2 Active protective system

In these systems mechanical devices are incorporated into the building which actively participates in the dynamic behavior of the building in response to the measurements of its behavior during the earthquake ground motion. Thus, in these systems, the structure's characteristics are modified according to seismic input to the building.

5.3 Hybrid (semi active) protective systems

These systems are implying the combined use of passive and active control systems. For example, a base isolated structure is equipped with actuators.

5.4 Study of models of buildings

In the study carried out by Abhishek Maurya and V.K. Singh, a multi-story G+10 RC framed building was taken into account. Three models were designed to study the behavior of viscous damper on the structure in zone V. These models were as follows:

1. Building with Fixed Base(No damper)
2. Building with Viscous Damper at middle bays of each story
3. Building with Viscous Damper at corner bays of each story

All the models were analyzed to study their seismic performance while considering the parameters such as Story displacement, Story drift and Model period. Modelling and analysis was done on ETABs 2016.

The models are subjected to analyses for Gravity and Seismic loads. Dynamic analysis is carried out by Time History Method according to Indian standard code by using ETABs 2016.
The observations of the analysis were as follows:-

Table -2: Maximum Natural Time Period

Model	Natural Time Period
Building with No damper	2.638 s
Building with Middle damper	1.76 s
Building with Corner damper	1.305 s

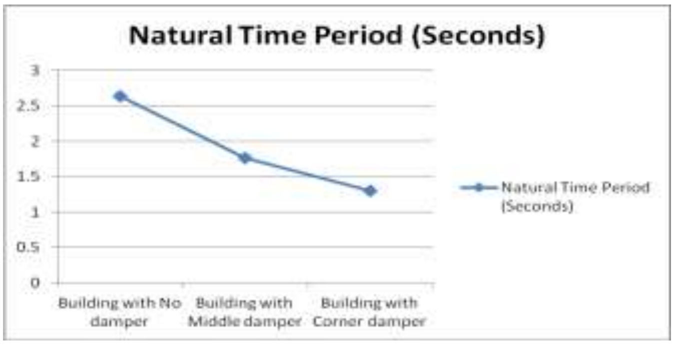

Chart -2: Variation of modal periods for all the models

Table -3: Maximum Story Drift

Model	Maximum Story Drift (mm)
Building with No damper	37.019
Building with Middle damper	15.996
Building with Corner damper	9.922

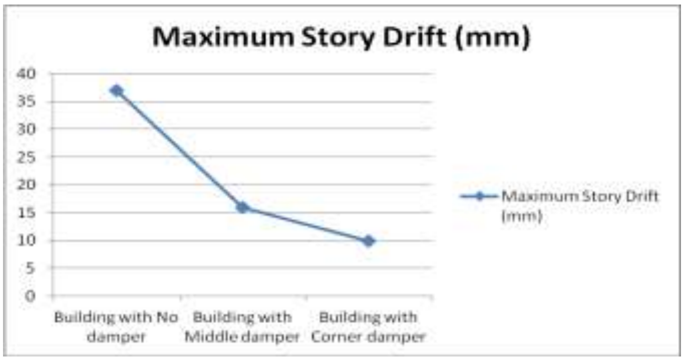

Chart -3: Variation of Story Drift for all the models

Model	Maximum Story Displacement(mm)
Building with No damper	168.75
Building with Middle damper	146.78
Building with Corner damper	105.36

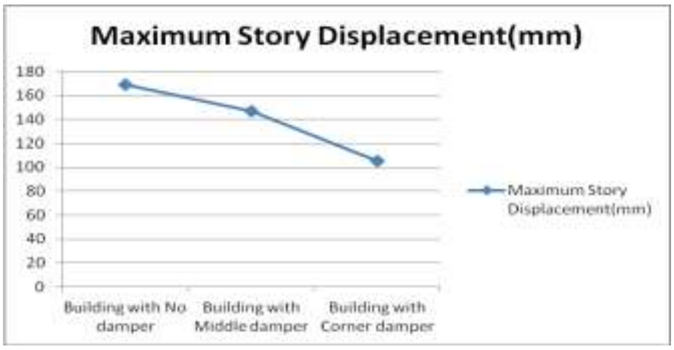

Chart -4: Variation of Story Displacement for all the models

The maximum time period of the building without damper is more than both the damped models and The Viscous damper substantially decreases the time period for structures by more than 50% when compared to fixed base structure without damper building. Building without damper fails under permissible story drift condition and also when the damper is located at middle. Building with damper at corner location gives good response under seismic condition and also graph shows that without damper building, the displacement reached to its peak limit. Hence, Damper at corner gives satisfactory result under seismic condition (Maurya and Singh, 2018).

6. RECENT DEVELOPMENT OF DAMPING SYSTEMS

More than 23,000 structures in the world have been protected by passive anti-seismic techniques, such as seismic isolation or energy dissipation systems, shape memory alloy devices, or shock transmitter units. They are located in more than 30 countries concerning both new constructions and retrofits of existing structures of all kinds: bridges and viaducts, civil and industrial buildings, cultural heritage and industrial components and installations, including some High Risk nuclear and chemical plants and components. Buildings are made of all types of materials: reinforced concrete (r.c.), steel and even wood. Japan is the leading country for the overall number of applications of the anti seismic systems; it is followed by the Peoples' Republic (P.R.) of China, the USA, the Russian Federation and Italy. The use of the anti seismic systems and devices in a civil context already includes not only the strategic structures (civil defence centres, hospitals) and the public ones (schools, churches, museums, commercial centres, hotels, airports), but also residential buildings and even many small and light private houses. Everywhere, the number of such applications is increasing, although it is strongly influenced by earthquake lessons and the availability and features of the design rules used (Martelli et al., 2014).

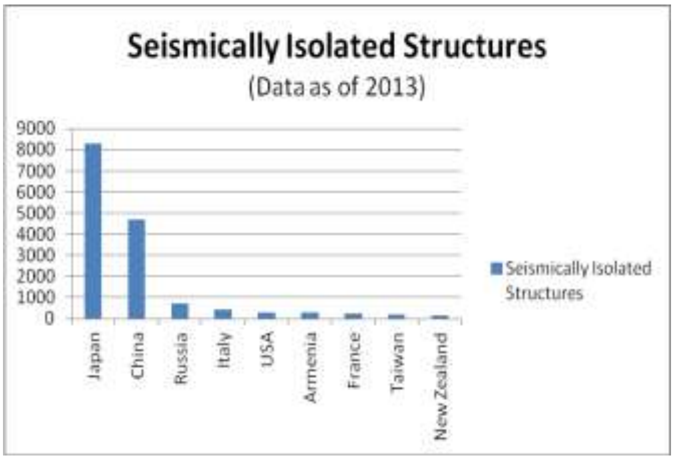

Chart -5: Numbers of seismically isolated buildings in the most active regions

7. COST ANALYSIS AND BENEFITS

A report on the findings of a study on the effects of damping on the life-cycle cost of buildings [in a seismically active area] stated that retrofitting a structure with viscous dampers would lead to a 22% reduction of the total life-cycle cost of the structure without dampers. The quantitative results of the simulation-based, probabilistic study of life-cycle costs of a building in a seismic hazard zone with and without dampers installed where the total cost without dampers was $555,700 and the total cost with dampers was $115,710, which represented an 80% savings in the total life-cycle costs for the structure, totaling $440,000 (Taflanidis & Gidaris, 2013). Damper life-cycle cost is dependent on the type of damper selected for use, but costs can be generated by factors like fluid seal leakage, possible debonding of solid damper layers due to limited deformation capacity and temperature dependency and degradation of materials (Symans, et al., 2008).

8. CONCLUSION

The displacement of the building is less under seismic forces where base isolation technique is adopted compared to a building with fixed base. The displacement of the building goes on reducing as the number of stories increases. The time period for structures decreases when compared to fixed base structure without damper. Maximum storey drift and maximum storey displacement is least for a building with damper at corner location. Viscous dampers and base isolation can be effectively used in different configurations to reduce the response of high-rise buildings to wind and earthquake. Seismic isolation and the other anti seismic systems have already been widely used in over 30 countries and their application is increasing more and more, for both new constructions and retrofits, for all kinds of structures and their materials. The features of the design rules used, as well as earthquake lessons, have plaid a key role for the success of the aforesaid technologies. While the possible savings from damping solutions can be significant, there are many factors that influence the available savings. Structure size and level of importance, seismicity of the region, and socioeconomic costs involved in repair of the structure heavily influence possible benefits of a damping system.

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BIOGRAPHIES

Er. Omkar Shelar
B.E. (Civil), MIT, Pune
Structural Design Engineer,
Altron Consultants, Pune