Base Isolated Structure: A Review

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Abstract- **The structures constructed with good techniques and machines in the recent past have fallen prey to earthquakes leading to enormous loss of life and property and untold sufferings to the survivors of the earthquake hit area. Base isolation concept was coined by engineers and scientists as early as in the year 1923 and thereafter different methods of isolating the buildings and structures from earthquake forces have been developed world over. Controlling seismic behaviour is possible only through faithful design that ensures all behavioural actions considered in buildings during analysis. In keeping with the key characteristics of buildings, structural design of buildings can be stiffness-based, strength-based, deformation-based and energy-based. In this paper a review has been done for the base isolated structure with different techniques, parameters and components.**

Keywords: Earthquake, Base isolation, Stiffness, Deformation

I. INTRODUCTION

The destruction caused by an earthquake is highly unpredictable and sometimes beyond repair. Though it is not possible to avert this natural disaster, but it is possible to minimize and reduce the effect caused by it. Innovative methods of seismic analysis of structures play an important role in its mitigation. The loss of life and damage to property due to the disaster can be reduced by adoption of improved prevention and preparedness measures. This is usually accomplished by using permanent controls i.e.; structural or non- structural designed and developed [Housner, G.W. et al, 1997] in advance of the disaster or by using temporary measures.

One of the most widely implemented and accepted seismic protection systems is base isolation. Seismic base isolation [Skinner et al. 1993; Naeim and Kelly 1999] is a technique that mitigates the effects of an earthquake by essentially *isolating* the structure and its contents from potentially dangerous ground motion, especially in the frequency range where the building is most affected. The goal is to simultaneously reduce interstory drifts and floor accelerations to limit or avoid damage, not only to the structure but also to its contents, in a cost-effective manner.

Base isolation concept was coined by engineers and scientists as early as in the year 1923 and thereafter different methods of isolating the buildings and structures from earthquake forces have been developed world over. Countries like US, New Zealand, Japan, China and European countries have adopted these techniques as their normal routine for many public buildings and residential buildings as well. Hundreds of buildings are being built every year with base isolation technique in these countries.

As of now, in India, the use of base isolation techniques in public or residential buildings and structures is in its inception and except few buildings like hospital building at Bhuj, experimental building at IIT, Guwahati, the general structures are built without base isolation techniques. Many significant advantages can be drawn from buildings provided with seismic isolation. The isolated buildings will be safe even in strong earthquakes. The response of an isolated structure can be ½ to 1/8 of the traditional structure. Since the super structure will be subjected to lesser earthquake forces, the cost of isolated structure compared with the cost of traditional structure for the same earthquake conditions will be cheaper. The seismic isolation can be provided to new as well as existing structures. The buildings with provision of isolators can be planned as regular or irregular in their plan or elevations.

A. Base Isolation Techniques

The seismic energy forces entering the structure can be controlled by two basic approaches:

a) Structural Design that can accommodate the input seismic energy.
b) Isolate the seismic energy to reduce or divert it, before it enters the structure.

Seismic isolators function based on the second approach, in which energy is limited by using energy absorbing or dissipating devices. These devices isolate only horizontal forces. These isolators come in various shapes, forms and sizes (The Hartford loss control department, 2002). Seismic isolated structures are currently difficult to analyze, design and implement due to complex code requirements. Base isolation is an approach to earthquake-resistant design that is based on the concept of reducing the seismic demand rather than increasing the earthquake resistance capacity of structure. This technology was first developed for bridge construction to protect against thermal movement in the bridge deck. Isolators are of many types depending upon their sizes, shapes and advantages. They can be elastomeric based systems, high damping natural rubber systems and sliding systems etc.

The isolation mechanisms are designed so that only a small portion of the energy of the earthquake is left to be dissipated by the super-structure. Elastomeric bearings and frictional sliding mechanisms installed in the foundations of seismically isolated structures are some of the examples of seismic isolation systems which protect the structures from strong earthquakes through a reduction of stiffness and an increase in damping. The purpose of this paper is to provide a brief overview of many new technologies that are rapidly becoming more prevalent in the seismic design of structures. All these technologies involve the use of specific devices to alter or control the dynamic behavior of buildings.

II. ENERGY DISSIPATION DEVICES

The structural systems that utilize seismic isolation technologies can be broadly categorized as passive, active or hybrid control systems [Kelly, 2001; Naeim and Kelly, 1999; Skinner et al., 1993]:

(1) Passive control systems: These systems are designed to dissipate a large portion of the earthquake input energy in specialized devices or special connection details that deform and yield during an earthquake [C. Alhan, H.Gavin, 2003]. Since the deformation and yielding are concentrated in the device, the damage to other elements of the building is reduced. These systems are passive because they do not require any additional energy source to operate and are activated by the earthquake input motion. Seismic isolation and passive energy dissipation are both examples of passive control systems. Generally, these devices are used at the base of a structure as a part of an isolation system or in combination with braced frames or walls as energy dissipation devices [M. D. Symans et al, 2008].

A study was made on isolation system consisting of Sliding Teflon bearing and displacement control devices for seismic protection of bridges [M.C. Costantinou et al, 1991]. The system utilizes multidirectional Teflon bearing for accommodating thermal movements and for providing the isolation mechanism and displacement control devices which exhibit bilinear behaviour with controlled stiffness and characteristic strength. The devices provide rigidity for service loads below their characteristic strength and restoring force and energy dissipation for strong earthquake forces.

a) Seismic isolation systems: The objective of these systems is to decouple the superstructure from the damaging components of the earthquake input motion i.e. to prevent the superstructure of the building from absorbing the earthquake energy. The entire superstructure was supported on discrete isolators whose dynamic characteristics were chosen to uncouple the ground motion. Some isolators were also designed to add substantial damping. Displacement and yielding were concentrated at the level of the isolation devices and the superstructure behaved very much like a rigid body.

A study on 3D nonlinear analysis procedure of base isolated building [Deb, Sajal Kanti, 2004] discussed the (i) effects of soft soil on performance of base isolated building, (ii) effects of near fault motion, and (iii) soil-base isolated building interaction.

(b) Passive energy dissipation systems: The objective of these systems is to provide supplemental damping in order to significantly reduce structural response to earthquake motions. This may involve the addition of viscous damping through the use of viscoelastic dampers, hydraulic devices, lead extrusion systems or the addition of hysteretic damping through the use of friction-slip devices, metallic yielding devices or shape-memory alloy devices. Using these systems, a building will dissipate a large portion of the earthquake energy through inelastic deformations or friction concentrated in the energy dissipation devices thereby protecting other structural elements from damage.

An investigation on semi active damping system was carried out using variable amplification for base isolation [K.K Walsh; M.M. Abdullah, 2006] of structures. It used novel variable amplification devices (VAD) connected in series with a passive damper. The VAD is capable of producing multiple amplification factors each corresponding to a different amplification state. To demonstrate the effectiveness of VAD damper, numerical simulation conducted for three and seven storey base isolated building. The results indicate that the system can achieve significant reduction in response compared to the base isolated buildings with no damper. The proposed system was also found to perform well compared to a typical semi active damper.

(2) Active control systems: These systems provide seismic protection by imposing forces on a structure that counter balance the earthquake induced forces. These systems are active in the sense that they require an energy source and computer-controlled actuators to operate special braces or tuned-mass dampers located throughout the building. Active systems are more complex than passive systems since they rely on computer control, motion sensors, feedback mechanisms and moving parts that may require service or maintenance.

(3) Hybrid control systems: These systems combine features of both passive and active control systems. In general, they have reduced power demands, improved reliability and reduced cost when compared to fully active systems. In the future, these systems may include variable friction dampers, variable viscous dampers and semi-active isolation bearings.

III. RESEARCH WORK ON BASE ISOLATED TECHNIQUES

Base isolation is an area in the field of passive vibration control of the structure, which attracted lot of researchers to explore it. Practical systems for earthquake base isolation began to appear in the last quarter of the 20th century. Seismic isolation research in the middle and late 1970s was largely predicated on the observation that most strong-motion records recorded up to that time had very low spectral acceleration values (2 sec) in the long-period range. Records obtained from lakebed sites in the 1985 Mexico City raised concerns of the possibility of resonance, but such examples were considered exceptional and predictable. One of the early examples of the earthquake design strategy is the one given by Dr. J.A. Calantariens in 1990. It was proposed that the building can be built on a layer of fine sand, mica or talc that would allow the building to slide in an earthquake, thereby reducing the forces transmitted to building.

A detailed literature review of semi-active control systems **Michael D. Symans et. al (1999)** provides references to both theoretical and experimental research but concentrates on describing the results of experimental work. Specifically, the review focuses on descriptions of the dynamic behavior and distinguishing features of various systems which have been experimentally tested both at the component level and within small scale structural models. The semi-active systems which are reviewed include stiffness control devices, electro rheological dampers, magnet orheological dampers, friction control devices, fluid viscous dampers, tuned mass dampers and tuned liquid dampers. The review clearly demonstrates that semi-active control devices have the potential for improving the seismic behavior of full-scale civil structures.

T.T. Soonga et. al (2002) studied about passive systems encompass a range of materials and devices for enhancing structural damping, stiffness and strength. Also for a specific level of seismic intensity, a designated performance level of the structure is proposed by **Fabio Mazza, Alfonso Vulcano (2008)** which assumes the elastic lateral storey-stiffness due to the braces proportional to that of the unbraced frame, is combined with the Direct Displacement-Based Design, in which the design starts from a target deformation. Various studies has been done by **Fabio Mazza, Alfonso Vulcano** on base isolated structure in which they have studied different parameters eq. studied the two and multi-degree-of-freedom systems, representing medium-rise base-isolated framed buildings according to Euro code 8 assuming ground types A (i.e., rock) and D (i.e., moderately soft soil) in a high-risk seismic region. The overall isolation system, made of in-parallel high-damping laminated- rubber bearings (HDLRBs) and supplemental viscous dampers, is modeled by an equivalent viscoelastic linear model. **Fabio Mazza and Alfonso Vulcano (2011)** analyzed that the insertion of steel braces equipped with viscoelastic dampers (VEDs) is a very effective technique to improve the seismic or wind behaviour of framed buildings. Overview of the present state of base isolation techniques with special emphasis and a brief on other techniques developed world over for mitigating earthquake forces on the structures is discussed by **S.J.Patil1, G.R.Reddy (2012)** in which dynamic analysis procedure for isolated structures is briefly explained. The provisions of FEMA 450 for base isolated structures are highlighted. The effects of base isolation on structures located on soft soils and near active faults are given in brief by **Gordon P. Warn et. al. (2012)** and summarizes current practices, describes widely used seismic isolation hardware, chronicles the history and development of modern seismic isolation through shake table testing of isolated buildings and reviews past efforts to achieve three-dimensional seismic isolation. The review of current practices and past research are synthesized with recent developments from full-scale shake table testing to highlight areas where research is needed to achieve full seismic damage protection of buildings. **Fabio Mazza, Alfonso Vulcano et. al. (2012)** studied design of base-isolated structures located in a near-fault area, base-isolated five-storey r.c. framed buildings with elastomeric bearings acting alone or combined in parallel or in series with sliding bearings ("Base Isolation and in-Parallel Sliding", BIPS, or "Base Isolation and in-Series Sliding", BISS, systems). **C C Patel, R S Jangid (2012)** examined the dynamic response of two adjacent single-degree-of-freedom (SDOF) structures connected by viscous damper under base acceleration. The base acceleration is modeled as harmonic excitation as well as stationary white noise random process. The governing equations of motion of the coupled structure are derived and solved for relative displacement and absolute acceleration responses. The viscous damper is found to be effective for response control of adjacent structures by connecting with appropriate damping coefficient of damper.

Fabio Mazza and Mirko Mazza (2012) designed a six and twelve storey r.c. spatial frames according to the provisions of the Italian seismic code, considering horizontal and vertical seismic loads in a high-risk seismic region and assuming low and high ductility classes. The nonlinear dynamic response of the test structures is studied with reference to the horizontal and vertical components of near-fault records. The occurrence of a directivity effect at arbitrary orientations is checked rotating the horizontal components of the selected motions, rather than considering only fault-normal and fault-parallel orientations. **Fabio Mazza, Alfonso Vulcano (2013)** focused on the modeling and nonlinear seismic analysis of framed structures equipped with friction, metallic yielding, viscoelastic and viscous dampers. A design procedure is proposed for proportioning damped braces in order to attain, for a specific level of seismic intensity, a designated performance level of the structure. **Faramarz Khoshnudian et. al. (2013)** studied a four-story building with different eccentricities supported on elastomeric isolators with different vibration periods and damping ratios as well as three different records is used to study the effects of vertical component of earthquakes on the seismic behavior of asymmetric steel isolated structures.

Andre Filiatrault1et. al. (2014) review paper summarizes current knowledge on the seismic design and analysis of nonstructural building components, identifying major knowledge gaps that will need to be filled by future research. Furthermore, considering recent trends in earthquake engineering, the paper explores how performance-based seismic design might be conceived for nonstructural components, drawing on recent developments made in the field of seismic design and hinting at the specific considerations required for nonstructural components.

Manuela Cecconi et. al. (2014) presents a paper on application of the seismic design method named "Direct Displacement Based Design" (DDBD), first introduced in 1990s in the field of earthquake structural engineering, and gaining due attention in the recent years with considerable discussion on its applicability to flexible earth retaining structures in coarse grained-soils. Particular attention is given to the evaluation of the equivalent damping ratio of the wall/soil system, since it sensibly affects the results of the procedure. A simplification of the design process is proposed in order to provide a seismic demand curve, in terms of active/passive thrust, which is dependent on the system ductility. A numerical example of application of the method is also provided in the paper.

Stefano Sorace, Gloria Terenzi (2014) presented a study on the evaluation of seismic response of statues exhibited in art museums, and a base-isolated floor strategy for their enhanced protection. Attention is particularly focused on statues made of small tensile strength materials, whose behaviour is simulated by a smeared-crack finite element approach. **Angelo D'Ambrisi, Marco Mezzi (2014)** studied a paper on energy-based method for nonlinear static analysis that allows to overcome these assumptions.

Fabio Mazza, Alfonso Vulcano (2014) also analyzed expressions of the equivalent damping which obtained considering the energy dissipated by the HYDBs and the framed structure. Also they studied a displacement-based design procedure for proportioning hysteretic damped braces (HYDBs) in order to attain, for a specific level of seismic intensity, a design at the performance level of a reinforced concrete (r.c.) in-elevation irregular framed building which has to be retrofitted. **George D., Hatzigeorgiou et.al. (2014)** examines the inelastic response behaviour of structures with supplemental viscous dampers under near-source pulse-like ground motions. **Amir Soltani et. al. (2014)** introduces a simple approach to determine optimum parameters of a nonlinear viscous damper for vibration control of structures. A MATLAB code is developed to produce the dynamic motion of the structure considering the stiffness matrix of an SDOF frame and the non-linear damping effect.

Fabio Mazza, Alfonso Vulcano (2015) studied Displacement-Based Design (D.B.D.) procedure which is adopted for the retrofit of framed structures by inserting hysteretic damped braces (HYDBs) **Julián M., Londoño et.al. (2015)** examines the effects of amplifying the displacements transferred to a non-linear damper, to increase the effectiveness of the damper in a range of situations commonly encountered in civil engineering structures. These include, (i) the ability to ‘‘fine tune’’ the required damping for a particular size damper, (ii) the ability to have a set of the same size dampers, but with different amplification factors to achieve a specific damping task, and (iii) to increase the sensitivity of the damper to small movements which effectively extends the range over which the damper works.

Mehdi Ezati Kooshki et.al. (2015) studied an effective way to protecting of structures against grand motions by new method (semi base isolation system). In the new way structures isn't completely decouple of bases and it changed natural frequency of structures due earthquake by changing horizontal stiffness. The proposed semi base isolation (SBI) system were applied to a one story frame and compared with end fixed frame and the time history analysis was conducted on record of Kobe earthquake (1995), San Fernando (1971) and Santa Barbara (1978), by used finite element software (ABAQUS 6-10-1). The analysis results can shows that the efficiency reduced the floor acceleration and displacement and velocity. This study shows that (SBI) system has great potential in future application of seismic isolation technology.

Alaa Barmo et. al. (2015) examined the response of buildings isolated using isolation system hybrid consisting of Lead-Rubber Bearings (LRB), Flat Sliding Bearings (FSB), with the addition of Rotation Fiction Damper (FD) at the base, then compare the results with buildings that have traditional foundation, in terms of the (period, displacement and distribution shear force and height of the building).

IV. FUTURE SCOPE

In recent years, considerable attention has been paid for the development of structural control and become an important part of designing new structures to resists the hazardous forces. There have been significant efforts by researchers to investigate the possibilities of using various control methods to mitigate earthquake hazards. Controlling seismic behaviour is possible only through faithful design that ensures all behavioural actions considered in buildings during analysis. Also, there is a need to work on the following areas to overcome the gap areas.

- National level guidelines and codes are not available presently for the reference of engineers and builders.
- Engineers and scientists have to accelerate the pace of their research work in the direction of developing and constructing base isolated structures and come out with solutions which are simple in design, easy to construct and cost effective as well.
- Researchers have to work on techniques like tuned mass dampers, dampers using shape memory alloys etc. Tuned mass dampers are additional mass on the structure provided in such way that the oscillations of the structure are reduced to the considerable extent.

Dampers using shape memory alloys can be tried as remedy to earthquake forces. In this system, super elastic properties of the alloy is utilized and there by consuming the energy in deformation at the same time the structure is put back to its original shape after the earthquake.

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