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Seismic response of base isolated structure versus fixed based structure during strong ground motions

HARIS ALAM[1], MUHAMMAD FAHAD[2], KHAN SHAHZADA[3], NAVEED ALI[4], FASIH AHMED KHAN[4]
[1]Department of Civil Engineering University of Engineering & Technology, Peshawar, Pakistan
[2]Department Of Civil Engineering, CECOS University of IT and Emerging Sciences, Peshawar, Pakistan
Email: harisalam00@gmail.com, fahadkhan@uetpeshawar.edu.pk, khanshahzada@uetpeshawar.edu.pk , naveedali@cecos.edu.pk, fasih@cecos.edu.pk

Abstract: After 2005 Pakistan earthquake the damage to the structures were severe and different techniques were needed to be evaluated to increase seismic capacity of the buildings. Base isolation is one of such techniques, on which limited research has been carried out. This paper will presents a comprehensive description of the current stage of knowledge on the behavior of hardware used in seismic isolation and in seismic damping systems. Particularly the study deals with the description of fundamental behavior of fixed based and based isolated under both service-type of loading conditions and under high strain rates. Specific problems addressed in this study will include the estimation of design displacement using UBC-97 parameter for DBE. The response of building subjected to a set of seven time histories. The analysis result shows that UBC-97 predicts isolator's displacements successfully. On comparison of base isolated and a fixed based building, it was observed that inter story drift and floor Shear were significantly reduced. While the overall displacement in the building are amplified as a result of Base isolation. But the relative displacement in the structure are reduced as major portion of the displacement is produced in the isolation devices. Hence reducing the damages in the super structure of base isolated structure. The presented information may represent the basis for the development of modern Guide Specifications for Seismic Isolation Design in Pakistan.

Keywords: *Base Isolation, damping System, Time Histories, UBC-97, Displacement, Story drift, Story Shear.*

Introduction:

Earthquakes:

Earthquakes is shaking of ground which is caused by rapid release of strain energy stored in the earth's crust. The movement of tectonic plates in the earth's crust against each other results in production of stress. When these stresses exceed the capacity of plates, shifts of plates takes place. Resulting in release of stored strain energy. Figure 1 shows energy released and propagation of seismic waves.

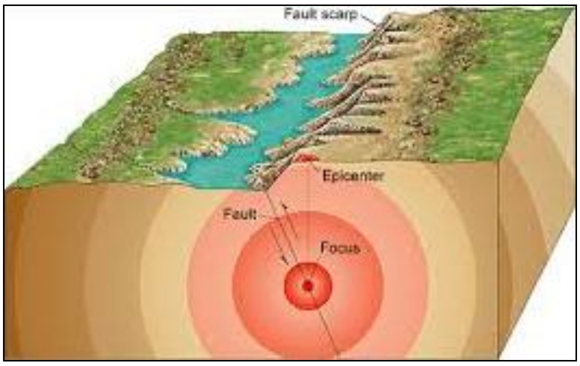

Figure 1 *Earthquake generation and propagation through different layers [Earthquake and plates]*

The energy released is partially consumed in pulverization and crack of rocks as two block of rock separated by fault grind past each other. The remaining part of energy speed through the rock as seismic waves. These seismic waves can travel far and cause damage at great distances. Seismic waves as a main mean, transfers the energy with in the earth crust from one spot to another. Different type of waves is recognizes by the seismologists, But the main two types we are interested in are P-waves (primary) and S-waves (secondary).P-waves are the fastest body waves and arrives before the S waves. The P-waves carry energy through the Earth as longitudinal waves, moving particles in the same line as the direction of the wave. While in S-waves material does not change volume but shears out of shape and snaps back. Particle motion is at right angles to the path of the wave. P-waves can travel through solids and liquids, whereas S waves can only travel through solids.

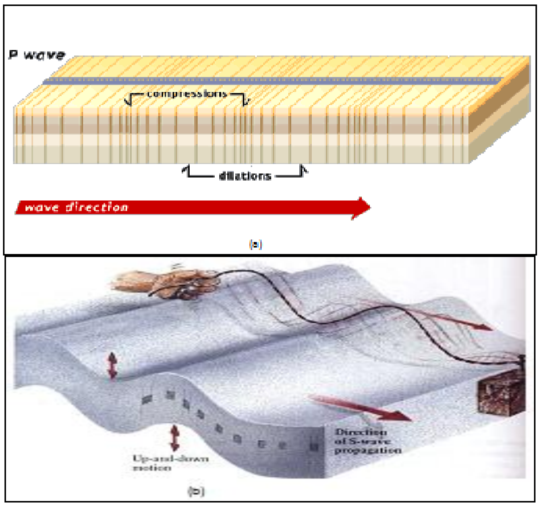

Figure 2 *Type of Surface waves (a) P-waves and (b) S-waves*

The Speed of the earthquake is not constant but varies with many factors. The variation in speed is due to rock type through which is traveling and the depth at which rupture has occurred. P waves travel between 6 and 13km/sec. S waves are slower and travel between 3.5 and 7.5 km/sec. [1]

Lateral Force Resisting System:

Engineer normally design structures by apply one of the two approaches to resist the lateral force which is produce as a result of earthquakes in structures. Designing the lateral force resisting system to be very stiff (a), which result in short natural period and high natural frequency of the structure. Designing such structure will protect displacement/drift sensitive modules. While the other is designing a flexible lateral force resisting system (b). Which results in a structure with high natural period and low natural frequency. As a result of this approach, Earthquake induced horizontal accelerations and forces are relatively reduced.

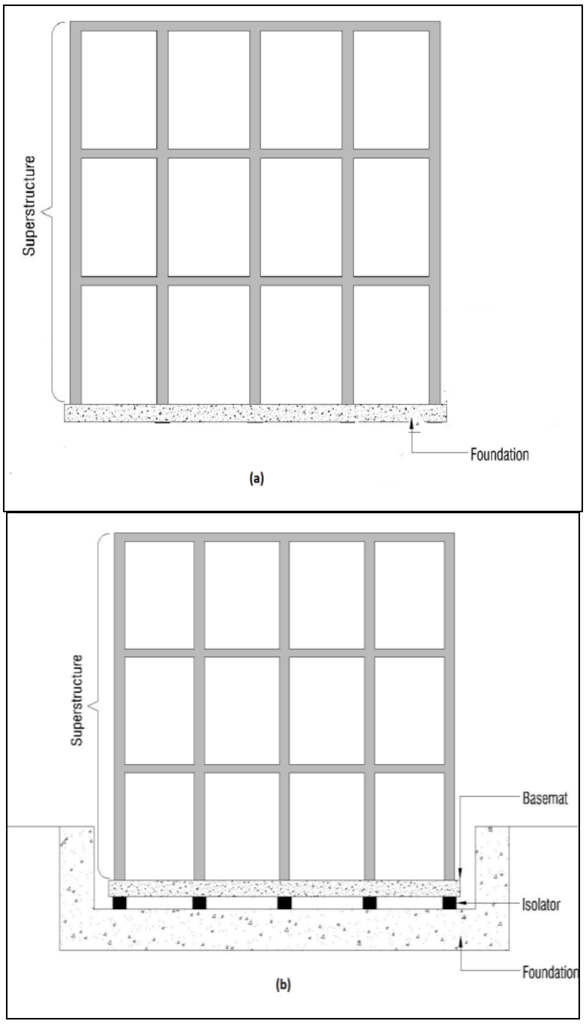

Figure 3 *Lateral Force Resisting Systems*

Base Isolation:

Base isolation is a design technique to decrease the destruction potential of the earthquakes. It comprises of basically inducing a mechanism which decouples the sub-structure from the super structure resulting in decreased response of the structure [2]. The main feature of base isolation is that it increase flexibility and shift the Time Period of the structure. The basic three properties that an isolation system must contain are:

i. Horizontal flexibility to increase structural period and decrease Acceleration demands (except for very soft soil sites),
ii. Dissipation of Energy (also known as damping) to decrease displacements.
iii. Adequate stiffness at small displacements to provide tolerable rigidity for service-level loadings.

The horizontal flexibility common to all practical isolation systems is induced in system by providing flexible bearing which helps to decouple the structure from the effects of high frequency earthquake shaking. Energy dissipation in an isolation system, in the form of either hysteretic or viscous damping, helps to decrease the displacement response of an isolation system. Different types of isolators which comprises of i) Laminated Rubber Bearing (LRB) ii) High Damping Rubber Bearing (HDRB) iii) Lead Rubber Bearing (LRB) iv) Friction Pendulum System (FPS) Bearing are used to achieve the goals. In this study HDRB are used.

High Damping Rubber Bearing (HDRB):

HDRB is a type of elastomeric bearing. The bearing consists of laminated rubber of high damping capacity with alternate layer of steel plates called shims. The rubber gives lateral flexibility to the system while the steel shims are used to support the vertical load. The vertical stiffness is very high as compared to the horizontal stiffness.

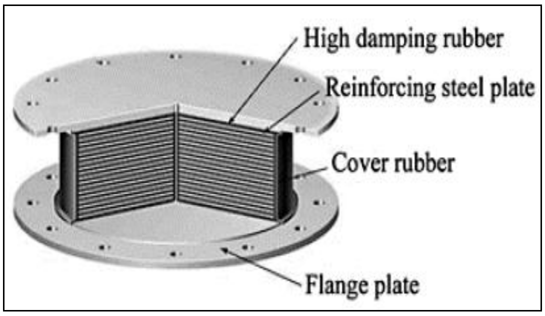

Figure 4 *High Damping Rubber Isolator (Masahiko & Shin, 2006)*

The horizontal stiffness is regulated by the low shear modulus while vertical stiffness is achieved through steel shims, Shims also prevent lateral bulging of the rubber. Structures are supported by the rubber reinforced with steel to provide stable support. Due to use of high damping rubber the effective damping increases to the range of 10% to 20% [3], which eradicate the use of Supplementary devices that would have been needed to damp out the excitation by cumulating the intrinsic damping of the rubber. The damping property of the isolator is amplified by adding resins or oils, very fine carbon blocks, and other proprietary fillers.

Modeling & Analysis:

A Response Spectrum Analysis (RSA) was carried out in finite element based software ETABS, in which seven different earthquakes were considered according to site specific condition (Soil type and Seismic zone) Table *1*. These earthquakes considered were scaled/adjusted to seismic excitation level of the site (as per site specific condition), and then Square Root of Sum of Squares (SRSS)of these earthquakes were along with Design Bases Earthquake (DBE) in accordance with UBC-97 & Maximum Considered Earthquake (MCE) [4]. Selected earthquakes are shown in

applied to both base isolated and fixed based structure to measure the response [5,7]. The SRSS of earthquakes used are shown in Figure 5

Table 1 *Selected earthquakes and the Scale Factors used in analysis*

S.No	Earthquake Name	Recording Station	Scale Factor, F_j
1	1976 Gazli, USSR	Karakyr	0.8900
2	1989 Loma Prieta	LGPC	0.5789
3	1989 Loma Prieta	Saratoga-W. Valley Coll.	1.1655
4	1994 Northridge	Jensen Filter Plant	0.7309
5	1994 Northridge	Sylmar-Coverter Sta.East	0.6628
6	1995 Kobe, Japan	Takarazuka	0.7865
7	1999 Duzce, Turkey	Bolu	0.9774

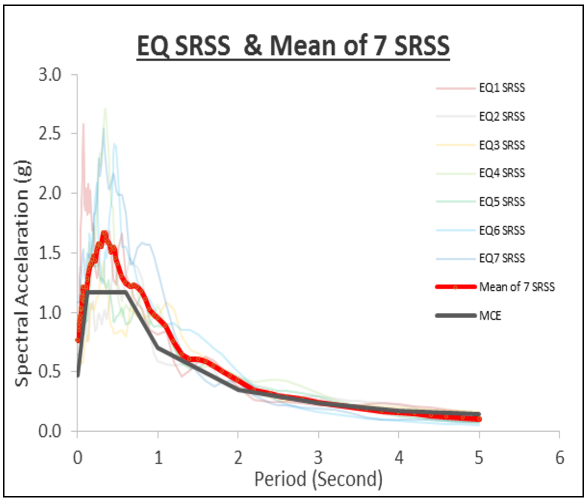

Figure 5 *SRSS of Earthquakes Considered for RSA*

Model Description:

The models considered for the study are symmetric four stories building with a lift core located at Zone 3.The building consists of identical square columns with dimension of 18inches x 18inches, all the beams with dimension of 12inch x 24 inches. The floor slab are taken as 7inches. The story height is kept 12feet.The compressive strength of concrete for slabs, beams and Shear wall (lift core) is considered to be 3000psi while that of footing and column is 4000psi.The steel used in slabs, beams and Shear wall (lift core) is considered to be Grade40 while that of footing and column is Grade60. Two different type of isolators are used. Type-I with vertical load capacity of 700 kips, Shear modulus of 130.5psi and effective damping of 12% while the Type-II with vertical load capacity of 1400 kips, Shear modulus of 236.64psi and effective damping of 20%. Figure 6 shows the configuration of both base isolated and fixed based structure.

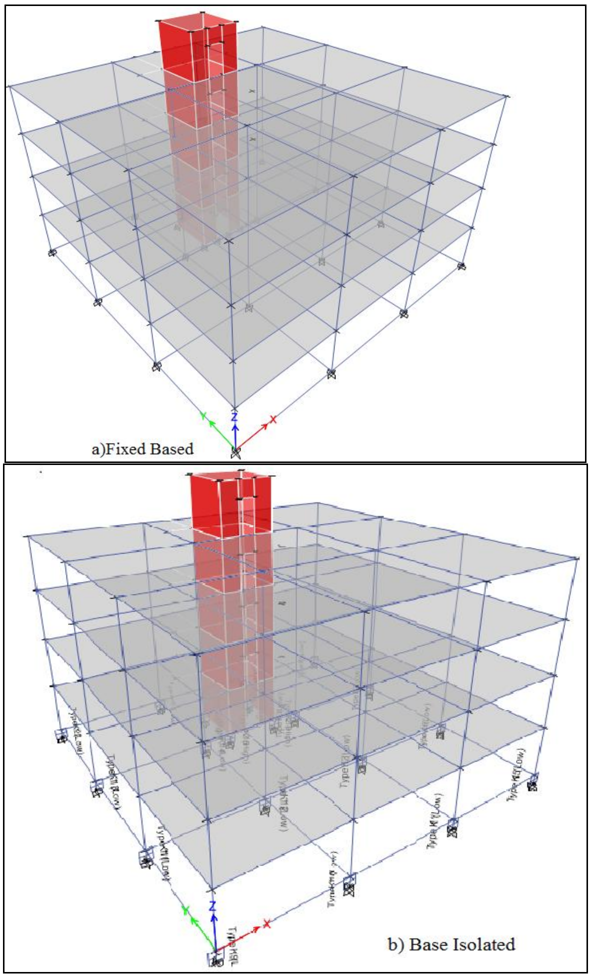

Figure 6 *3D models of fixed based and base isolated structure*

Results:

The results of this study are categories in three different categories. Which includes displacements, story drifts and story shears for both isolated and fixed based structures.

Displacements:

On Comparison of overall story displacement, it is concluded that the overall displacement in base isolated structure increases. The displacement of the structure with respect to base are shown in Figure 7. The study also concluded that the maximum combined displacements (SRSS of the orthogonal direction) for fixed based structure varies with in the range of 7-12 inches. While for base isolated the range is 7-14 inches. Moreover, it was also observed that the relative displacement of the stories with respect to base decrease in the base isolated structure, resulting in reduction of inertial force on the structural members of the structure. The average relative displacement with respect to base for conventional fixed based structure was observed to be 8.40 inches, while it reduced to 3.42 inches in case of base isolated structure. As a whole the displacement in base isolated structure were found to increase but the maximum of them was taken by the HDR isolator.

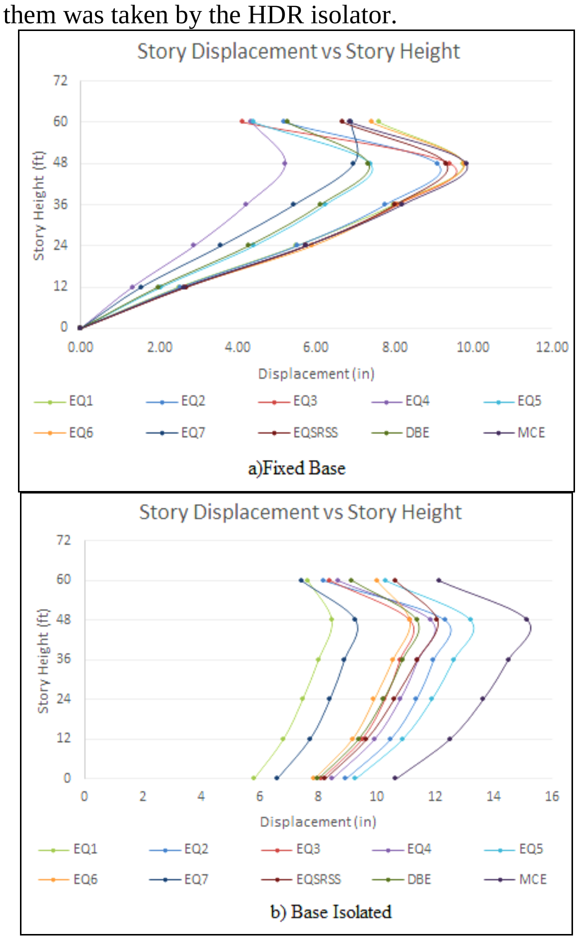

***Figure 7** Displacements comparison of Base Isolated versus Fixed Based Structure.*

Story Drifts:

In this study, the inter story drift ratio is categorized into four groups, the inter story drifts ratios of 0.25-0.5% corresponds to nonstructural damage, 0.5%-1.5% to moderate structural damage and 1.5%-3% to severe structural damage, while structural damage greater than 3% correspond to collapse story [6]. The results in Figure 8 shows that inter story drifts in isolated structures are less as compared to the fixed based building. The major damages in base isolated structure are in a range of 0.5%-1.5% which corresponds to moderate structural damages, while the damage range for traditional building fall in the range of 1.5%-2.5% corresponding to severe structural damages.

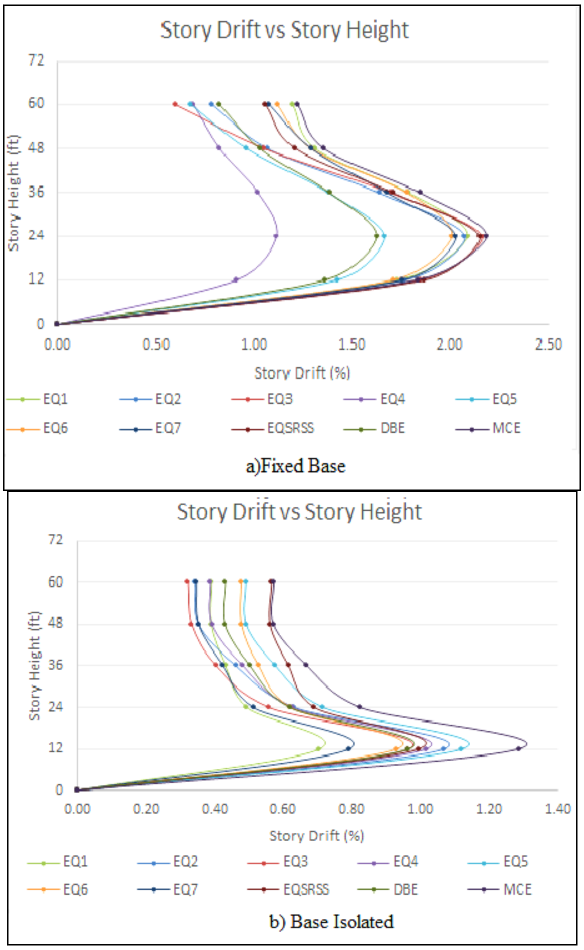

***Figure 8** Story Drift comparison of Base Isolated versus Fixed Based Structure.*

Story Shear:

The story shear taken by a building mainly depends on the lateral force resisting system of the structure. The stiffer the system the greater will be Stiffness (resistance) and so will be the story shear taken by the structure. The flexible the structure, means greater is the ductility of the structure, less will be the story shears and greater will be the story drift. During an earthquake, lateral loads are transferred to the structure at the base these are then resisted by the structure due to the stiffness members i.e. walls, columns and bracings if any. Greater the inertial mass of a story greater will be the lateral load and thus greater story shear. Hence more stiffness is needed to withstand the story shear [8-9]. From the study it was inferred that the structure with isolation system reduce the story shear by 17%.The Story shear in fixed based structure was very high in the three story but drastically reduced in next story, while the distribution of story shear is uniform in case of base isolated structure. Figure 9 shows the story shear for the structures.

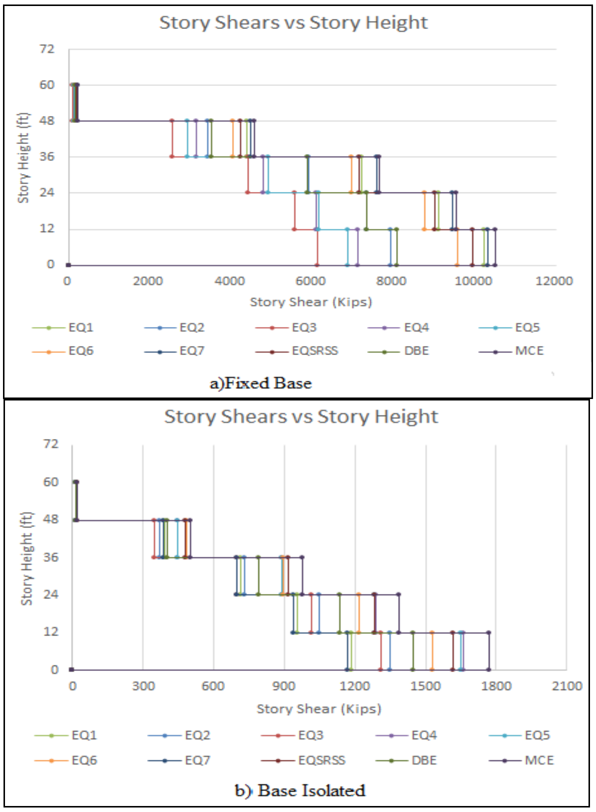

Figure 9 *Story Shear comparison of Base Isolated versus Fixed Based Structure.*

Time Period:

The seismic responses of the structure are reduced by using the technique of base isolation. Base isolation lengthens the natural period of vibration of structure via use of HDR, hence reducing the frequency of vibration of the structure, which results in reduction of response parameters like relative displacements, story drifts and story shear. Table 2 shows the comparison of time period of the base isolated and fixed based structures.

Table 2 *Time Period of Base Isolated Versus Fixed Based Structure.*

Mode Shape	Time Period Fixed Based (Sec)	Time Period Base solated (Sec)
Mode 1	0.891	2.388
Mode 2	0.538	2.285
Mode 3	0.440	1.979
Mode 4	0.305	0.523
Mode 5	0.194	0.406

Conclusion:

The seismic response of four story fixed based (Conventional) and base isolated structure during seven different earthquakes along with DBE and MCE were investigated in this study. The results of the study demonstrate that the response of the structure can be reduced dramatically using base isolation. The relative story displacement and story drifts of structure element were decreased, subsequently causing reduction in the inertial force in beams and columns. Due to decrease in lateral force of the stories, the acceleration of the stories are also reduced resulting in low inertial force thus reducing the level of damage in the super structure which would otherwise be there in fixed based structure. The time period of the structure increases significantly by using base isolation. This shifts structure from acceleration sensitive region to displacement sensitive region. The story shears and drifts of isolated structure were promising when compared with those of conventional concrete. The Story shear was reduced to approximately 17% of fixed based conventional structure.

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