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A Review of the Seismic Isolation Studies

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Abstract

Seismic isolation system is an appropriate method for seismic design in a great many of the earthquake-prone regions around the globe. Every seismic isolation system effectively separates the building from the horizontal components of earthquake. The primary objective of the seismic isolation system is the transferring of the main frequency of the building to a span away from the earthquake frequency domain through providing it with sufficient horizontal flexibility. Large displacements in the isolation system causes reduction in the seismic forces transferred to the superstructure. There are numerous studies carried out in regard of seismic isolation. But, a comprehensive study of the studies and investigation of the results are yet to be conducted. The current paper reviews the seismic isolation studies covering two general sets of studies, namely studies on the isolated structures and the studies on the isolation systems' components. The effects of various parameters of structure and isolation system are discussed and an analysis will be presented of the information extant in various texts. General conclusions have been made even with the scattered and different nature of the data extant in the various studies reviewed.

Keywords: Seismic Isolation, Structure's Eccentricity, Stiffness And Mass Centers, Masonry Buildings, Near-Fault Earthquake, Far-Fault Earthquake.

Introduction

Seismic isolation system is a novel method for reducing the relative displacement and acceleration of the floors. The implementation of the method provides for the reduction in the superstructure's acceleration in contrast to fixed-base structures as a result of which the amount of force induced to the floors' masses will be decreased. The principle in seismic isolation system is the creation of flexibility in the structure's base on a horizontal plate and, in the meantime, depreciating components will be applied to limit the motion range of the earthquake(Asgary,2010). Equipping an existing structure with seismic isolation method against earthquake enables the limitation of the majority of the executive works to the level wherein the isolation plate has to be created; whereas, the common practices employs and reinforces the structural components in all of the building levels (Haqqollahi & Ardebili 2012). Therefore, the need for seismic isolation can come about in any of the following situations:

- Increasing the building's safety and efficiency in case of earthquake occurrence
- Reducing the design lateral forces
- Finding the existing structures unsafe against earthquake
- Requiring alternative forms of buildings featuring limited ductility (such as pre-stressed concrete) in quake-prone regions (Gokhale, 2006).

Due to the inelastic behavior of the base-isolation system, it is necessary to perform studies on the isolation systems and their effects on structures' behaviors. During the recent years, extensive studies have been carried out regarding seismic isolation systems. These studies are placed in two main sets: the first deals with the isolated structures and the second deals with the researches and experiments regarding the seismic isolation system.

The Effect of Isolation System and Structure's Eccentricity:

Different results have been obtained concerning the asymmetrical and irregular distribution of the bearings in the building's foundation:

Nagarajaiah et al concluded using a multi-storey model that the eccentricity of the isolation system and the dynamic characteristics of the superstructure are both effective on the torsion of the base-isolated structures. However, it is stated that the torsion decreases due to the isolation system (Nagarajaiah et al., 1993).

Also, Jangid and Datta concluded that the base isolation system exerts a low effect on the large eccentricity because the isolation system's displacement is increased as a result of the high amount of torsion involved (Jangid & Datta, 1994).

There are new studies carried out during the past few years in the multi-storey buildings:

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In 2002, Tena-Colounga A. and Gomez-Soberon L.A. compared the displacement responses of the asymmetrical base-isolated buildings with those of the symmetrical buildings. They found out that the base displacement is large for large eccentricity rate of the superstructure and it is highly dependent on the building's alternation period. They additionally concluded that the structure asymmetry causes reduction in the effect of seismic isolation system because the majority of the exposed isolation systems are inclined towards plastic deformation but the rest of the isolation systems remain elastic. They observed that the maximum base displacement pertains to the unidirectional eccentricity not bidirectional eccentricity (Tena-Colunga & Gómez-Soberón , 2002).

Also, in 2006, Tena-Colounga A. and Zambrana-Rojas C. investigated the effect of base-isolated system's eccentricity and figured out that the base-isolated system's large eccentricity exerts more negative effects on the base displacement in contrast to the superstructure's eccentricity and that a seismic isolation system with eccentricity should not be practically applied in buildings (Tena-Colunga & Zambrana-Rojas , 2006).

In 2007, Tena-Colounga A. and Escamilla-Cruz JL examined the torsion in isolated asymmetrical buildings. They came to the conclusion that the high torsion is more likely in buildings with mass eccentricity than in buildings with eccentricity in stiffness. They also figured out that the large torsional displacement of the base does not necessarily result from the large eccentricity of the superstructure (Tena-Colunga & Escamilla-Cruz , 2007).

One of the important studies regarding the lateral torsional hinges in base-isolated multi-storey buildings was conducted by Seguín CE et al in 2008. They concluded that the maximum response range occurs in the stiff edge for torsion-flexible isolation systems with low eccentricity of the base otherwise the maximum response range occurs in the flexible edge for the torsion-resistant isolation systems (Seguín et al., 2008).

In 2008, Vojko Kilar and David Koren performed a research regarding the investigation of the seismic behavior of base-isolated systems featuring asymmetrical distribution of lead-rubber bearings. They used SAP2000 Software to run a nonlinear dynamic analysis on a 3D four-storey building with reinforced concrete frame considering six different states of bearing distribution; they made use of ten earthquake records to examine the effect of earthquake variations in nonlinear dynamic analysis. They concluded that all states of bearing distribution mitigate the unfavorable effect of torsion transmitted in various methods from superstructure to base-isolation system and that the distribution in the form of mass center superimposed on isolation system center is the best state for the moderating the effect of torsion on seismic isolation system as specified in the building guidelines and, of course, this type of distribution might bring about higher damage in the flexible side of the frame.

They found out that the asymmetrically isolated building's displacement and rotation is less than the locked-based buildings. Kilar and Koren concluded that the seismic isolation system distribution cannot be stated within the format of a general law. Of course, they suggested, due to the haphazard and random eccentricity, that the intended building can be investigated in a case-specific and particular manner in case that those states are used in seismic improvement of the buildings (Kilar & Koren, 2009).

Jia Yia Yen et al performed a special evaluation in 2008 in designing an isolation system based on chaos. They carried out their studies considering the histories of ten earthquakes to obtain the optimum state of building response to earthquake based on chaos distribution and concluded that the building's final responses are not documentable and it is only the selection range of the bearings that can be determined and the optimum behavior of the chaos-based isolation system cannot be expressed in a general conclusion (Haqqollahi & Ghiami Ardebili, 2012).

The Effect of Near- and Far-Fault Earthquakes:

The seismic response of the buildings close to a fault causing earthquake can be largely different from that of the buildings distant from earthquake's epicenter. In regions close to the fault, land movements are subject to the failure mechanism and slide orientation and continuous displacement of the locality (resulting from the ground's tectonic movements). Seismologists know the preliminary characteristics of the near-fault earthquakes as being thrown forward following the ground's tectonic movements. Due to the special attributes of the near-fault earthquakes and the structural damage potential, the investigation of the seismic response of the base-isolated structure subject to near-fault earthquake is necessary.

The phenomenon "pulse" in velocity, displacement and acceleration waves can change the seismic response of the base-isolated buildings in near-fault earthquakes' responses (Sharbatdar et al., 2011).

The isolation system gives an acceptable deformation in far-fault ground motions; but, the isolation system's displacement is considerable in near-fault earthquakes. Therefore, isolation systems featuring very large dimensions are required for the buildings extant in near-fault regions. The large dimensions of the isolation systems contradict the primary goal of the use of seismic isolation systems, to wit achieving a cost-effective and practical solution. But, knowing that the vibration waves can reach a velocity maximum of 0.5m/s within one to three seconds, the importance of doing research on near-fault earthquakes becomes more evident (Providakis, 2008).

Seismic isolation system presents an appropriate performance in far-fault earthquakes. As for the near-fault ground motions, the high seismic needs urge the use of isolation systems featuring large dimensions that will be accompanied by large costs. The near-fault earthquakes have such properties as large domain, long alternation period and being pulse-like that necessitates isolation systems featuring considerable dimensions and this entails the spending of extravagant costs rendering the seismic isolation system infeasible.

One way to cope with strong earthquakes is making use of lead-rubber isolation systems (LRB) or friction pendulum systems (FPS) plus supplemental dampers for limiting the bearing's displacement, although the increase in damping in such states might bring about an increase in the internal deformation and absolute acceleration of the superstructure and many of the objectives of seismic isolation system's application might be left unaccomplished (Providakis, 2009).

One issue that is posited regarding the far-fault earthquakes is the low frequency of the waves. As an eye witness, the earthquake in Rasht can be exemplified in which heavy damages were caused to the concrete and steel skeletons of the buildings even with their large distance (65 kilometers away from Manjil) from the earthquake's epicenter while the one- or two-storey buildings with no skeleton and low-grade construction materials were not damaged and this seems natural considering the closeness of the alternation period of the majority of the earthquakes in Rasht to the alternation of the high-rise buildings.

Molla Reza'ei and Ghal'eh No'ei investigated the seismic behavior of isolated moment frames subject to near-field earthquakes in 2011. In their study, they investigated the existence of isolation systems on the behavior of the near-fault moment frame steel structures (three 12-storey, 7-storey and 20-storey structures with similar plans) and concluded that the application of isolation system in the structures leads to the increase in the structure's alternation period as well as decrease in the responses and improvement of the structure behavior. This was the case for the 7-storey and 12-storey structures. Moreover, the addition of isolation system to the high structures with high alternation periods does not have any effect on their behaviors and responses and it might even cause an increase in their responses (Molla Reza'ei et al., 2011).

Heaton et al examined the seismic isolation system subject to a $7M_w$ earthquake and concluded that the isolation system exhibits large displacement in case that the damping reaches 25% of the critical damping and this can result in buckling or isolation system failure in strong earthquake waves (Heaton et al., 1995).

Kelly, as well, points to the need for large damping to reduce the isolation system's displacement and concludes that large damping plays a part in forces imposed on the superstructure providing for the lateral displacement of the floors (Kelly, 1997).

Makris and Chang analyzed two base-isolated building models with one and two degrees of freedom and concluded that the use of energy dissipation mechanisms is effective in reducing the seismic response of the base-isolated buildings subject to near-fault earthquakes. They figured out that the seismic isolation system can be effective on coping with near-fault earthquake when it is provided with an energy dissipation mechanism (Makris & Chang, 1998).

C. P. Providakis conducted a research in 2007 on the effect of lead-rubber isolation systems and supplemental viscous dampers on the base-isolated buildings subject to near-fault earthquakes. He identified two 3D reinforced concrete 6-storey and 5-storey plan-asymmetrical buildings with lead-rubber isolation and supplemental viscous dampers (underneath every column) and performed nonlinear time history analysis for them using ETABS software. He concluded that it is necessary to make use of lead-rubber isolation systems and supplemental viscous dampers in near-fault regions so that the devastative effects of earthquakes can be reduced; however, the large damping of the isolation systems in far-fault earthquakes causes an increase in building's stiffness through controlling the structure displacement and the subsequent energy transfer to higher modes might contradict the primary reason, the very superstructure drift reduction, for making use of isolation system (Providakis, 2008).

Providakis performed a study in 2008 regarding the effect of supplemental damping on lead-rubber isolation systems and friction pendulum isolation systems subject to near-fault earthquakes. He run linear dynamic ETABS-assisted analysis on two 5-storey and 6-storey concrete buildings with supplemental viscous dampers (placed in parallel to the bearings). He concluded that the existence of supplemental viscous dampers in both of the lead-rubber and friction pendulum isolation systems causes an increase in the lateral displacement of the floors as well as in absolute acceleration of the floors in far-fault earthquakes; this is indicative of the idea that the seismic isolation system might be damaged due to the floors' lateral displacement being left uncontrolled for some damping values of the supplemental dampers. He reasoned that it is necessary to make use of an isolation system along with supplemental viscous damping so that the supports' displacements can be reduced and that the supplemental damping has to, of course, be limited to a certain amount (for example 20%) so that the floors' lateral displacement in far-fault earthquakes could be prevented (Providakis, 2009).

In a separate study in 2007, Providakis showed for a composite steel and concrete skeleton building through pushover analysis subject to near-fault earthquake that the ductility of the system with composite frame is intensively increased when using seismic bearing and that this type of superstructures extremely neutralize the earthquake's inertia forces. The study was undertaken through taking advantage of ETABS 2000 Software and bilinear hysteretic cushion modeling and it was indicated that the structure behaves more optimally in the target displacement. It was also pointed out that higher base shear is exerted onto the system in case of making use of seismic isolation system in an unbraced compared to braced state and that almost all the elastic lead-core buttresses featuring different characteristics exhibited similar behaviors. The seismic isolation systems, always effective on base shear reduction, now, had relatively high displacement rates scored for the first floors subject to near-fault ground motions. Under such conditions, addition of braces brings about an increase in the structural ductility and a decrease in the number of plastic hinges therein. It was also found capable of reducing the relative inter-storey displacement by 30% (Haqqollahi & Ghiami Ardebili, 2012).

In 2011, Shayanfar and Torabi studied the effect of lead-rubber isolation systems on the buildings with steel moment frames subject to near- and far-fault excitations and modeled the buildings linearly in ETABS Software. They run nonlinear time history analysis on three 4-storey, 10-storey and 15-storey steel buildings with moment frames and lead-rubber isolation system and used the data extant on twenty near-fault earthquakes and eight far-fault earthquakes to do their research. The mean results were separately drawn in diagrams and subjected to discussion and examination. It was concluded that the structures' reduction in response (base shear, absolute roof floor acceleration, relative displacement of the floors) is higher in near-fault earthquakes than the far-fault ones and that the increase in building height causes a reduction in the base-isolation system's effect and the structure's response reduction is increased in buildings with moment frame systems with the increase in the proposed displacement (Shayanfar &Torabi, 2011).

M. K. Sharbatdar et al performed a study in 2011 concerning the seismic response of the lead-rubber and friction-pendulum base-isolated structures subject to near fault earthquakes. They considered a 15-storey building with lead-rubber and friction-pendulum base-isolated systems and carried out nonlinear analysis in 3D for five near-fault earthquake records. The numerical results obtained from the analyses subject to four Imperial Valley Earthquake records showed that the maximum amount of base displacement can be variable up to 66% in a limited region within a 4-km distance from the disintegrated fault. Also, the maximum amount of the upper floor's acceleration can be varying up to 33% in this region (Sharbatdar et al., 2011). The earthquakes specifications have been summarized in table (1).

Table 1: the specifications of the earthquake records used (Sharbatdar et al., 2011).

Closeness to fault (km)	Station	Mw	Date	Place
0.1	C02	6.19	27th of January, 1966	Park field, USA
4.2	E04	16.53	15th of October, 1979	Imperial Valley, USA
1	EO5			
1	E06			
0.6	E07			

In 2012, Shakeri and Ja'afary investigated the behavior of the rubber-lead base isolated buildings with moment frames. To do so, they selected two 5-storey and 10-storey buildings and designed isolation systems for them in three soft, normal and stiff states. Nonlinear dynamic time history analysis was run on the studied specimens subject to the effect of seven various earthquakes. They concluded that the use of base isolation system leads to the reduction in the acceleration created in various floors in respect to fixed-base structures. It was also found out that the decrease in the lateral stiffness of the base-isolated system brings about a reduction in the relative inter-floor displacement but an increase in the isolated level's displacement and that generally the acceleration created in various floors is reduced with the reduction in the lateral stiffness of the base isolation system (Ja'afary & Shakery, 2012).

The Effect of Various Seismic Isolation System:

Radmila B. Salic et al carried out a research in 2008 regarding the responses of the lead-rubber base isolated buildings. They selected a seven-storey building with shear wall and symmetrical plan in Scopia and measured the building's vibration using six GPS and seismograph devices placed in four corners on every floor. The responses of the locked-base structure were obtained through environment response experiment (based on Fourier analysis of the recorded signals' domain) and Modal Identification Software (ARTeMIS). They run four time history analyses on the various earthquakes to compare the nonlinear response of the locked-base structure and lead-rubber base-isolated structure. They conducted dynamic analyses on both of the models using ETABS (Nonlinear9.0.4) and listed the positive aspects of the seismic isolation system's effects on structural response as below:

1) Increase in the natural alternation time: this causes the system's alternation time to get distant from the earthquake's alternation period hence increasing the system's flexibility.
2) Reduction in the base shear: the reduction in base shear force is evident for the seismic isolation model.
3) Increase in the displacement: the increase in system flexibility leads to the increase in the total displacement for such a reason as the elastic characteristic of the isolation system.
4) Reduction in the inter-floor displacement: the decrease in the inter-floor displacement enables the structure to behave as an approximately ideal hard matter in which case the structural and nonstructural element's damages are reduced to a minimum.
5) Reduction in the floors' acceleration
6) Change in the energy dissipation mechanism: in classic structures, energy dissipation was based on plastic deformation of certain points of the structure. But, the energy dissipation mechanism of the base-isolated structures is concentrated on the isolated floor and this provides for simple design, control and possible repairs (Salic et al., 2008).

Shayanfar and Torabi compared the structural responses of two concentric and eccentric braced systems for locked-base and lead-rubber base-isolated modes. They run time history analysis on twenty near-fault earthquakes and eight far-fault earthquakes and concluded that the increase in the proposed isolation system's displacement causes the decrease in the structural response in locked-base state and base-isolated state to be increased and that the structures' responses are more reduced in concentric braced systems as compared to eccentric braced systems (Shayanfar & Torabi, 2011). They also carried out a research to investigate the effect of lead-rubber isolation systems in steel buildings with concentric braces. They run nonlinear time history analysis and concluded that the increase in the isolation system's alternation period causes a decrease in the absolute acceleration of the roof and base shear while the isolation system's displacement is increased; it was further indicated that the superstructure's drift variations do not follow any certain rule and that the number of the floors does not have much of an effect on the superstructure's drift during identical alternation drift periods. They obtained a value equal to 10% for the ratio of the isolation system's specific resistance to the total weight of the building which minimizes the isolation system's displacement (Shayanfar & Torabi, 2011).

Abdullahzadeh and Ebrahimikhah investigated the effect of elastomeric base-isolation systems on the behavior of the 3D models of steel structures with concentric braces. In a dynamic spectral analysis of the 3-storey, 6-storey and 10-storey structures for two fixed-base and isolated-base modes with different stiffness of the bearings in SAP software, they came to the following conclusions: 1) the superstructures with fixed base show considerable structural deformations for all of the modes but the base-isolated structures behave like rigid objects in the first mode and they only exhibit structural deformations for the next modes; 2) the participating factor of the base-isolated structures' modal mass is nearly equal to unity for the first mode and almost zero for the next modes, meaning that all the earthquake energy is absorbed in the first vibration mode wherein the structural deformation is trivial; 3) the increase in the number of the floors, to wit the decrease in the superstructure stiffness, causes lower decrease in the isolated-base structures' shear force in contrast to the similar locked-base structures, so the isolation systems are more effective in harder structures, i.e. in short structures, for similar conditions; 4) due to the high stiffness of the concentric braces, the use of this system that enjoys a higher lateral stiffness as compared to the moment frame systems provides for results closer to the standards mentioned in UBC97 (assuming superstructure with an equivalent one degree of freedom); 5) according to the seismic isolation system's method of performance, the use of these systems for improving the seismic behavior of high-rise buildings that per se feature high alternation periods is inappropriate and unjustifiable (Abdullahzadeh & Ebrahimikhah, 2012).

In 2009, Beom-Soo Kang, Le Li and Tae-Wan Ku in a separate study investigated the specifications of the base-isolated buildings. They dynamically analyzed three different short building models, including locked-based, steel-reinforced elastomeric (SRE) base-isolated and fiber-reinforced elastomeric base-isolated (FREI) structures. It was found out in the results that the base-isolated buildings outperform the locked-base buildings in seismic terms. They figured out that fiber-reinforced elastomeric isolation system effectively absorbs seismic energy and reduces the devastative effects of earthquake's horizontal motions on the structure. Therefore, the important result will be that the fiber-reinforced elastomeric isolation presents better seismic performance than the steel-reinforced elastomeric isolation system(Kang et al., 2009).

In 2012, A. B. M. Saif Al-Islam et al designed an isolation system composed of lead-rubber bearing with rubber featuring high damping properties for four- to ten-storey buildings in earthquake-prone regions and studied their seismic response with the use of such a combined system. Due to the high orthogonal stiffness of the rubber support with high damping and the structure's capability of tolerating a large deal of loads, the internal columns were isolated using rubber bearings featuring high damping and the external columns were isolated using lead-rubber bearings. They carried out linear dynamic analysis and nonlinear dynamic analysis for the locked-base and isolated-base buildings through taking advantage of finite element software, SAP2000. They concluded that the seismic isolation technique brings about optimal reductions in the structural damage subject to strong earthquakes. With this innovative combination of the bearings, the multi-storey building components experience lower shear, moment and lateral displacement subject to lateral earthquake loads. The selected isolation system causes reductions in the bearing's frequency following by decreasing the acceleration of the isolated building's floors. They found out that the reduction in maximum base acceleration in places with soft to medium soil (in hardness) is up to ten times in base-isolated structures as compared to the otherwise subject to EQ bilateral earthquakes. Similar results were obtained for base in any soil type. However, the designing of the bearings for buildings constructed on soft soil featuring excitations with long alternation periods has to be carried out cautiously so as to avoid amplification phenomenon (Saiful et al., 2013).

Molla Reza'ei and Ghal'eh No'ei evaluated the seismic behavior of metal moment frame lead-rubber base-isolated buildings. They dynamically analyzed three 7-storey, 12-storey and 20-storey metal structures and concluded that the use of isolation system in the structure generally leads to the increase in the structure's alternation period. But, the use of isolation system results in the reduction in the responses and improvement of the behaviors of the structure in case that it features low or medium alternation period; but, for buildings with high alternation periods, the addition of isolation system does not have any effect on structure's behaviors and it might bring about an increase in the responses. So, it is not cost-effective to use base-isolation for structures with high alternation period or the high-rise buildings (Molla Reza'ei et al., 2011).

The rubber supports with vertical stiffness a hundred times higher than the horizontal stiffness seem to be very stable; but, they occasionally happen to undergo buckling due to the reduction in their shear stiffness. Some standards require the imposition of some tensile force on the support. Several studies have demonstrated that the compressive buckling analysis leads to predictions for the tensile buckling occurrence subject to a certain load close to the compressive buckling. It has been discussed sometimes that the tensile buckling might be artificially created using the model and not the bearing; but, the results of the finite element analysis of the lead-rubber base-isolation system indicated that the tensile buckling prediction using linear elastic theory is a taut not artificial reality. The materials are constrained in all three directions in the center of the support as a result of which hydrostatic stress comes about. The damage is developed in the central section as a result of cavitation (due to high hydrostatic tensile stress); under such a tri-axial tensile force, the internal failures continue in the rubber and rupture occurs followed by the formation of cracks and eventually the reduction in the bulk and shear moduli.

In 2012, James M. Kelly, Maria Rosaria Marsico examined tensile buckling of the rubber bearings subject to cavitation and made use of an analytical model to investigate the cavitation effects on the compressive stiffness and flexural stiffness of the rubber isolation system. In order to take into account all the cavitation effects in buckling theory, they modeled the gradual decrease in the rubber's bulk modulus using an exponential form that was envisaged as an acceptable estimation. They concluded that the instability upon being strained is influenced by the introduced alpha coefficient that reduces the bulk modulus and affects the critical tensile load in the presence of cavitation (Kelly et al., 2013).

In 1991, C. Mattheck and D. Erb evaluated the form optimization of rubber isolation systems with axis symmetry using ABAQUS finite element and combined element software. In fact, the main issue was avoiding fold in rubber supports subject to axial compression between two symmetrical conical torsional steel pipes. The fold causes large deformation in rubber support followed by its rupture and failure. They made use of the novel computer-aided optimization (which is based on stress reduction in the rupture resulting from small deformations so that the fold could be prevented from inflammation). They concluded that the rubber support's inflammation of support emerges in large deformations and ruptures with large stress and large displacement and that the maximum stress can be decreased through form optimization within the limits of linear elastic theory with small displacement. Of course, they figured out that the large deformation provides for the optimization success and the fold inflammation will disappear in optimized design and also that this example does not generally hold for the small displacements and does not prevent fold inflammation via making reductions in rupture stress (Mattheck & Erb, 1991).

The blowing of the wind brings about a considerable increase in the ductility of the base-isolated buildings in comparison to the locked-base buildings and this contributes to the increase in the bearings' displacement and floors' acceleration.

In 1998, Alfonso Vulcano carried out a comparative research to investigate the dynamic response of the base-isolated structures against earthquake and wind. He selected two three-storey and five-storey concrete buildings featuring symmetrical plans and rubber isolation system with high damping and introduced the isolation system's coefficient:

$$\boldsymbol{\alpha} = \mathbf{T_1}/\mathbf{T_F} \qquad (1)$$

Where, T_1 is the locked-base building's alternation period and T_f is the primary alternation period of the base-isolated building's vibration.

The results of the experiments on the buildings subject to earthquake were indicative of two different types of behaviors highly dependent on strength: when the strength is higher than the earthquake intensity, the structure behaves elastically otherwise the ductility demand of the base-isolated building for stronger earthquakes can increase more than that of the locked-base buildings. The intended buildings were designed in such a way so as to endure strong earthquakes but they were found remaining elastic subject to strong winds, as well; but, the acceleration of the storey's floors was found increased to critical amounts, especially when the isolation system is very flexible. He found out that the isolation system's displacement trend should be increased for earthquake like for wind so that the isolation system's coefficient can be increased. It was also figured out that the acceleration trends of the storeys' floors are different: reduction subject to earthquake and increase in wind; of course, the acceleration of the storeys' floors and isolation system's displacement are higher in earthquake than in wind.

He also came to the conclusion that proper limits have to be selected for checking the final status (such as ductility demands) subject to strong earthquakes and serviceability subject to wind so as to choose the optimum range of the bearing's coefficient (Vulcano , 1998).

Aung Chan Win designed and analyzed isolation systems for high-rise buildings. He ran time history analysis using ETABS software on a 16-storey concrete building with shear wall. He concluded that the size of the seismic isolation system can be changed through regulating the rubber hardness and that the floor acceleration is effectively reduced in base-isolated in contrast to locked-base buildings. It was also made clear that the increase in alternation period brings about a reduction in floor acceleration and an increase in the lateral displacement of the building above the seismic isolation following which the overall displacement is increased. The base shear was found reduced in all directions for the entire studied modes, especially in base-isolated buildings featuring a 3.7-second alternation period in comparison to the locked-base buildings (Saifi, 2010).

In 2013, Zhifei Shi et al used ANSYS 10.0 to investigate novel bearings comprised of concrete layers and rubber blocks in 6-storey buildings with three different types of foundations (ground-fixed base, rubber base-isolated and periodic foundation) in attenuation zones. Based on alternation theory in solid-state physics, they proposed a novel form of base isolation system in which the concrete layers and rubber blocks installed in certain intervals cause the creation of periodic foundations. Periodic foundations feature special dynamic properties called attenuation zones wherein the waves and vibrations are blocked and the primary frequency region of the seismic vibrations and the frequency characteristics of the superstructure are covered making for a reduction in the input seismic energy and superstructure's seismic response. The attenuation zones prevent the upward dissipation of earthquake waves with frequencies ranging from 2.15Hz to 15.01Hz from foundation.

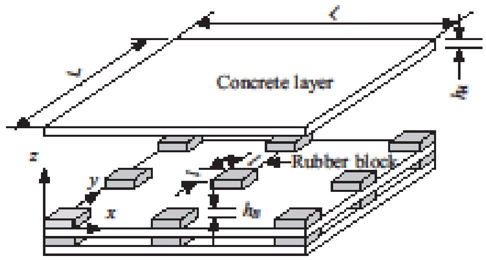


Figure 1: periodic foundation

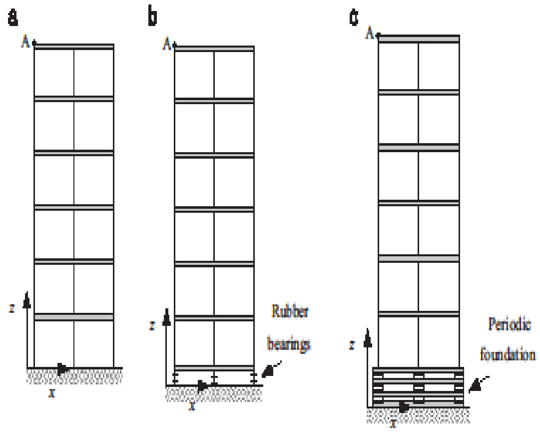


Figure 2: six-storey frame with three different types of foundations: a) locked-base, b) rubber bearing and 3) periodic foundation

They concluded that the seismic response of the periodic foundation building has been attenuated more than the other two studied buildings; foundation with periodic bearing can produce very low frequency and wider attenuated zones rendering it more appropriate to civil engineering considerations. They figured out that it is not so much easy to use of proposed foundation for the improvement of other structures and some additional measures should be taken to reduce the superstructure’s displacement (Shi et al., 2014).

The Earthquake and Structure Engineering Research Center has proposed the cellular seismic isolation system for the reduction of the horizontal stiffness of the bearing and increase of its initial effect. The existing advanced computer programs utilize finite element method (which is based on the mechanical behavior of the elastomeric supports subject to compressive and shear loads). The previous programs assume bearings as being an elastic material. Contrarily, the bearing is made of an elastomeric rubber that is not elastic. Therefore, the previous programs have to be deleted or corrected so that realistic results could be obtained.

In 2005, Jetty Sunaryati et al examined the mechanical behavior of the cellular elastomeric seismic isolation system based on finite element method. Their attention focus was on the elastomeric rubber bearing and they compared the cellular seismic bearing with the ordinary seismic bearing both of which made similar in their dimensions and characteristics but different in their steel shapes. The seismic bearings were analyzed using SAP in both horizontal and vertical directions.

The results indicated that the change in the base isolation system’s geometry causes the stiffness values to be changed and it was found out that the cellular seismic bearing’s ratio of horizontal to orthogonal stiffness is higher than that of the ordinary rubber bearing (Sunaryati et ai., 2004).

During earthquake, some of the elastomeric and lead-rubber bearings are simultaneously influenced by large compressive axial loads (created by overturning and gravitational forces) and large lateral displacement). However, the reduction in the critical load capacity of the elastomeric support occurs at the same time with the increase in the lateral displacement. The design of the isolation system for this type of the supports is needless of supplying stability in terms of maximum displacement. The common method of stabilization using the ratio of area that is pertinent to the surface overlapping method of the critical load capacity determination is better for a given lateral displacement than combining the support’s axial forces. Although the surface overlapping is a simple method for the calculation of critical load for a given lateral displacement, it lacks a robust basic theory and it is not generally justified in practice for supports with specified coefficient of form that are applied for isolation (using lead-rubber supports).

In 2012, Jared Weisman and Gordon P. Warn investigated the stability of elastomeric bearings and lead-rubber bearings. They made use of practical experiments and details of nonlinear finite element analysis to evaluate the elastomeric and lead-rubber supports’ critical load capacity with form coefficients equal to 10 and 12, respectively, in regard of large displacement). The study results indicated that the lead core exerts a negligible effect on the critical load (whose displacement is in a range higher than 150%-280% of the compressive shear strain with lead-rubber support). It was also pointed out that the surface overlapping is a conservative method for estimating the critical load capacity of these supports as compared to the practical results (Weisman &Warn, 2012).

In 2012, Moradi Shaghaghi and Kaivani investigated the performance of seismic isolation system featuring different damping percentages and various alternation periods in 5-storey and 7-storey buildings with lateral load-bearing concrete moment frames. To do so, they carried out nonlinear dynamic time history analysis for Tabas earthquake using SAP2000. They concluded that the isolation system causes a considerable reduction in the base shear and relative displacement of the floors and that the increase in the alternation period of the bearing base for the 5-storey building brings about an increase in the percentages of the response reduction and the increase in damping in higher alternation periods provides for an appropriate performance in reducing the maximum response. But, an inappropriate performance was observed in the response reduction with the increase in alternation period for the 7-storey buildings; however the increase in damping caused reduction in the structure's seismic response.

Therefore, the use of the relative displacement and base shear concept is considered as a precise scale for the evaluation of the seismic performance of the isolation system (Moradi et al., 2012).

The Effect of the Buildings with Different Mass and Stiffness Centers:

In the past earthquakes, the asymmetrical buildings suffered more damages than the symmetrical buildings. These cases have made for the enactment of particular design criteria in the guidelines for the asymmetrical buildings. In 1958, Hazner and Atinen showed that the results obtained from the static analysis of the buildings wherein the estimated shear force possesses eccentricity equal to the distance of the stiffness center from the mass center (static eccentricity) do not have the required margin of reliability and that the floors' mass moment of rotational inertia and their torsional dynamic behaviors cause large torsional moments in contrast to their static torsional moment (Housner & outinen, 1958).

During 1960 and later years, the researchers' success in defining dynamic eccentricity enabled them to take advantage of dynamic analysis results of the structures and their calibration with the static analysis results so as to become capable of specifying the estimated eccentricity based on the static eccentricity intensification. This led to the introduction of relations that are currently being used for the estimated eccentricity.

The study of the nonlinear behavior of asymmetrical structures was suggestive of the idea that the amount of the stiffness center's eccentricity in comparison to the amount of mass center's eccentricity exerts a considerable influence on the ductility demand intensity and that the way the strength is distributed has a considerable effect on the control of the maximum ductility need of the structure member's lateral load-bearing. Thus, it was concluded that the eccentricity of the stiffness center and strength center are parameters that have to be taken into consideration in the designing of the asymmetrical structures (Rutnberg, 1992).

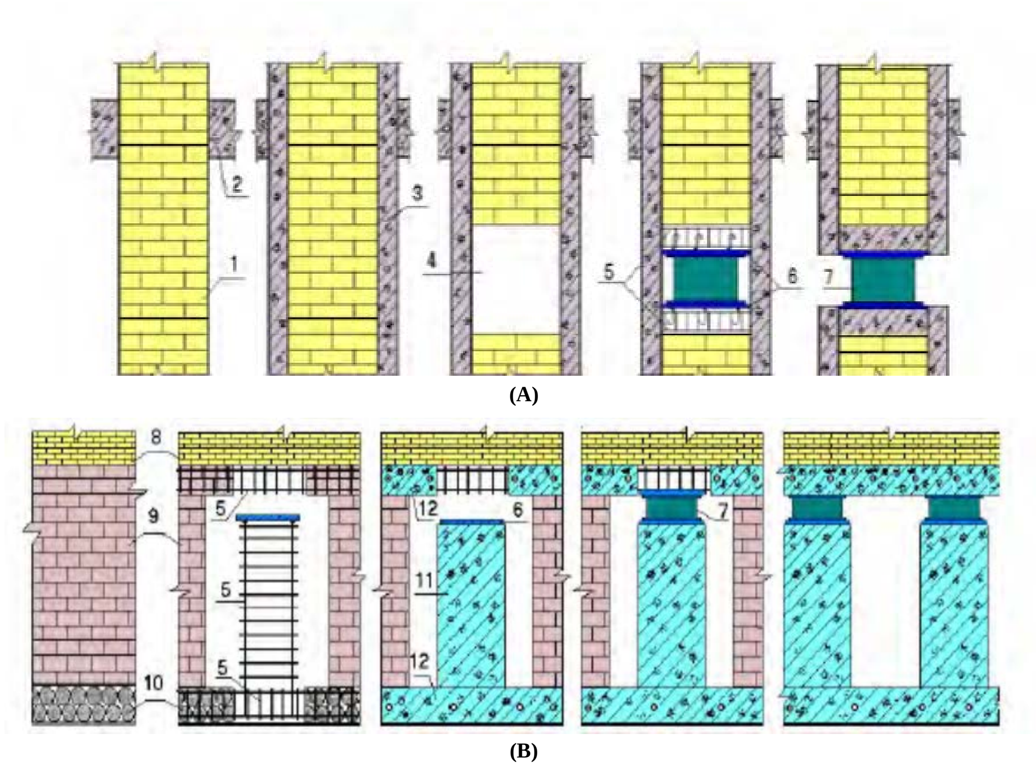
Su and Ying realized strength eccentricity as a parameter having less influence on the systems with asymmetrical mass distribution and suggested that it is better to get the strength center closer to the mass center to the maximum extent possible so that the ductility demand could be reduced on the soft side of the buildings with asymmetrical distribution of stiffness (Tso & Ying, 1992). On the contrary, Mittal and Jin defined effective strength eccentricity to put it forth as a parameter influencing both the asymmetrical mass and stiffness systems (Mittal & Jain, 1995).

The majority of the studies concerning the asymmetrical structures are concentrated on the models that have only been subjected to single-component mapping and there is paid less attention to the models the elements of which have been subjected to earthquake components in both the primary directions. This is while the structure is in fact subjected to earthquake from both directions and the building resists the torsional loads assisted by its lateral load-bearing elements in practice. In 1985, Siamal and Picao investigated the models that are subjected to sinus excitations in both primary directions of the building. They concluded that stiffness eccentricity has a considerable influence on the ductility demand of the lateral load-bearing elements (Syamal & Pekau, 1985). In another study that was conducted in 1990, Goel and Chopra studied the behavior of the asymmetrical models with resistant elements in both the primary directions of the structure. They concluded that the elements perpendicular to the earthquake plane exert much of an effect in maximal reduction of ductility demand and maximum displacement of the structure; also, it was pointed out that these elements have effects greater in models with low alternation period than in models with medium and high alternation periods (Housner & outinen, 1958).

Base-Isolated Masonry Buildings:

Corresponding to the results obtained from the past earthquakes, the use of ordinary constructional materials with low seismic resistance causes the creation of fundamental damages or collapse of building and death of thousands of residents. To prevent the occurrence of such damages in masonry buildings and take advantage of these buildings, the new masonry buildings have been extensively built with seismic isolation system in the various spots of the world. The use of seismic isolation system in masonry buildings is a useful and effective method for improving them. The use of this technique renders the continuation of the masonry building exploitation feasible. In contrast to the new buildings, such considerations as the ease of implementation and economic costs have to be attended to in equipping the extant structures with seismic isolation systems. Due to the fact that no changes are brought about in the exterior or interior of the buildings, the method is very useful for the historical or valuable edifices.

An example of seismic isolation system implementation in a masonry building has been demonstrated in the following figure. This irregular 5-storey building belongs to a bank in Cyberia. The load-bearing system of the building is consisted of an external brick wall, transversal internal walls, two rows of brick columns and a concrete frame composed of circular columns. The entire foundations including the strip footing of the brick walls or the singular foundations of the brick and concrete columns are made of ballast. Also, the walls of the ground floor are made of stone. The building is composed of three blocks. With the shutting down of a block of the bank, the seismic isolation works were commenced under the block and this was kept on for the other two blocks. The stages of the work have been shown in the following figure (Rutnberg, 1992).



(1) Brick wall; (2) reinforced concrete beam; (3) exterior cover of the reinforced concrete (4) part of the cut masonry column (5) steel rebar (6) steel plate (7) seismic bearing (8) first floor's brick wall (9) the wall under column (10) strip footing made of concrete and stone (11) reinforced concrete foundation (12) upper and lower sections of beam

Figure 3: the stages of seismic isolation system creation in a bank in Cyberia; (A) brick wall (B) external stone wall

Nonlinear static analysis of the masonry buildings with fixed base and locked base indicates that the isolated systems lead to the reduction in base shear and increase in the system's performance area. In masonry buildings with low number of floors, the effect of seismic isolation system is considerable in the improvement of the responses but the increase in the building height brings about a reduction in the effect of seismic isolation in the superstructure. The reduction comes about because the alternation period of the multi-storey structures is inherently high and the increase in the alternation period resulting from the seismic isolation system will not become as big as the structures of a storey.

Radhikesh P. Nanda et al posited a new idea in an article regarding the seismic improvement of the masonry buildings. Through placing artificial stone and green marble on one another, they could create an isolated layer featuring a friction ranging from 15% to 50%. In their study, the isolating layer was placed under the wall on the building's foundation. This way, it was shown in the results that this recent method can lower the building's absolute acceleration by 50% in an earthquake with an acceleration maximum of 0.36g (Haqqollahi & Ardebili, 2012).

Conclusion:

A review of the studies on the seismic isolation system was presented herein. The results of the studies and the effect of various parameters on the isolation system's behavior were discussed. The following points have to be taken into consideration in the design of isolation systems: (1) isolation systems work more effectively in symmetrical buildings; (2) isolation systems with eccentricity should not be applied in buildings and, as specified in the standards, the isolation system distribution should be in the form of mass center equal to the isolation system's mass which is the best mode of moderating the effect of torsion in seismic isolation system; (3) seismic isolation system is effective for coping with the near-fault earthquakes if it is equipped with an appropriate energy dissipation mechanism; (4) the isolation systems are more effective in stiffer structures, to wit shorter structures, and the application of seismic isolation system in the high-rise buildings cannot be justified; (5) for buildings constructed on soft soil, the design of the isolation system should be carried out with precision (so as to counteract intensification); and (6) in masonry buildings with low number of floors, the effect of isolation system is considerable in response improvement.

Many of the experts of our country underline the infeasibility of seismic isolation system for its being costly. But, the systems that are both less expensive and most efficient are applied in such countries as India and Indonesia, particularly in brick and masonry buildings constructed in rural areas. It is now known that the majority of the deaths and financial and life losses have occurred in the villages in the recent earthquakes of our country. Therefore, it is necessary to design native seismic isolation systems for our country

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