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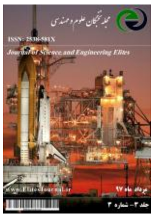

Seismic Performance of Low Rise Buildings with Elastic Materials Energy Absorbing System at the Foundation

Soroush Kherad [1*],Mahmood Hosseini[2], Ata Hojatkashani [3]

1- Ph.D. candidate of Earthquake Eng. & Seismology, Lecturer at Islamic Azad Univ., Tehran east Branch
2- Associate Prof., Int'l Inst. of Earthquake Eng. & Seismology (IIEES)
3- Assistant Prof., Islamic Azad Univ., Tehran South Branch

*sooroosh2010@yahoo.com

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ABSTRACT

The aim of current research is to design inexpensive natural materials, especially energy-absorbing slipping or sliding motion at the foundation of low rise buildings. Dimensions and kind of materials were input to the software and results were compared to the conventional and designed structure based on existing codes. The current system and method would cause structures built with conventional and existing codes, last during severe earthquakes and remain in safe position. The main goal is to provide a low cost base isolation system with natural materials available in the market and its formulation and specifications for a new system structural performance. After an earthquake, a new system structural performance would achieve to IO (immediate occupancy) level. Applications including overall objectives of the projects presenting organizations would involve in crisis management manuals used by contractors to provide innovative style design and construction of such structures. The research models were simulated by finite element and nonlinear dynamic softwares such as SAP and ABAQUS. Numerical and mathematical calculations and conclusions were compared to the results obtained from buildings with natural seismic isolation and conventional designs. In fact the aim is to propose seismic control of structure with the current system. The results have shown that this system would maintain seismic parameters such as drift, maximum roof acceleration and maximum stresses in main members at the optimum range.

Keywords: Repairable building, Structural fuse, nonlinear time history analysis, Near-field earthquake.

1. Introduction

In structural engineering, the mitigation of damage induced by large loads is of paramount interest. Especially in seismic regions, earthquakes pose a serious threat to human lives and the integrity of the infrastructure. Passive energy dissipating systems such as viscous dampers, tuned mass dampers and base isolation systems have been installed in new or existing buildings. Base isolation is one of the most widely used and accepted seismic protection systems. The philosophy behind most of seismic design codes implicitly accepts heavy damages of the building in case of large earthquakes, provided that the building is prevented against collapse. However, this philosophy, in case of large

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populated cities located at the vicinity of active faults, leads to unacceptable consequences, such as large number of people who lose their living or working places for a long time, very difficult demolishing work of the heavily damaged buildings, and very large volume of the required reconstruction works. To avoid such adverse consequences one approach is design of 'repairable structures' for buildings, by using the idea of 'Deliberate Directing of Damage' (DDD), introduced by (Hosseini and Alyasin 1996) [1], which means guiding the damage to some pre-decided parts or elements of the structural system, so that other parts do not experience any plastic deformation, and therefore, the structure can be easily repaired. Although this technique has been introduced basically for pipelines, researchers have introduced and worked on similar ideas for other types of structures, particularly building systems, among them using the energy dissipating devices or structural fuses can be mentioned, which have been introduced in late 70s to early 80s (Fintel and Ghosh 1981) [2], and have been developed more in recent years. It should be noted that in these studies, although the main idea is concentration of damage in energy dissipaters or fuses, and keeping the main structural members elastic or with minor easily repairable damages, in reality the building cannot remain in Immediate Occupancy (IO) Performance Level (PL), and needs to be evacuated, at least partially, for rehabilitation (R Vargas and M Bruneau) [3]. To overcome this shortcoming, the use of rocking motion of the building has been proposed by some researchers in recent. They used weak base plates, attached to the bottom of each steel column at the first story, to cause rocking vibration under appropriate control, and recently conducted an experimental study on a structural frame with rocking motion. Although their proposed rocking structural system (T Azuhata, M Midorikawa and T Ishihara) [4] was quite effective in seismic response reduction, their studies was limited to 2-dimensional systems. Recently, the first author of this paper has used the idea of rocking motion of building in combination with a central fuse, which works as a huge plastic hinge under the vertical load and the moment, induced by the lateral seismic load (Hosseini and Kherad 2013)[6]. In this study the DDD idea has been applied for design of regular steel multi-story buildings, which have rocking motion, by using inclined columns around the central main vertical column of the building at its base level. The inclined columns, which their bases have been shifted toward the center of the building plan, caused the building to move basically in rocking motion during an earthquake and were equipped with Double-ADAS (DADAS) devices (MG Gray, C Christopoulos and JA Packer)[5], which acted as the main role of energy dissipating devices or fuses. The inclined columns were connected to the strong beams of the first floor of the building, whose strength and relatively high stiffness helped the upper floors of the building to remain elastic, while the DADAS devices experienced large plastic deformations and absorb large amounts of seismic input energy In this way (N. Mansour, C. Christopoulos, R. Tremblay) [7], the building would have more reliably the IO or PL after major earthquakes. The efficiency of the proposed technique has been shown through implementation in some high-rise hybrid steel buildings. Details of the study are given in the following sections.

2. The Proposed Structural System

In the proposed structural system for regular multi-story steel buildings and missionary buildings, creation of possibility of sliding motion has been carried out by using a space resting on a low layer at the base level with a series of elastic deformation at that base level. Elastic deformation device (EDD) is the base layer by elastic deformation that is called natural elastic deformation device, which is installed at the bottom of the building foundation as shown in Figure 1.The introduction should show the background of the subject and main contributions. It is necessary to explain clearly the novelty and contribution of present work in the last paragraph of introduction.

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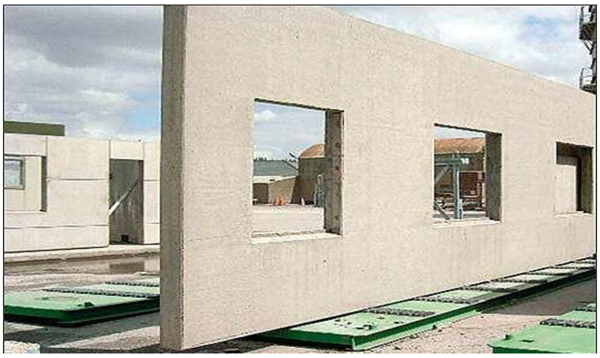

Fig. 1- The EDD device used at the bottom of the circumferential foundation building's base level

each EDD device consists of elastic layer of new pan polymer by two rigid plate that the force of foundation is taken there, and a set of lowest foundation which is connected to the outer plate and their outer sides fixed by rigid plate that is set at the button of buildings. During an earthquake, horizontal movement of the buildings which would in fact occur at the lower part of the column element, causes week and plastic deformation to develop at the majority of their body, leading to a remarkable energy dissipation and creating a type of hysteretic behavior in shear deformation of foundation, as shown in Figure 2. Figure 2 shows a section of deformed shape of the EDD device by ABAQUS software, and a sample of its hysteretic curves.

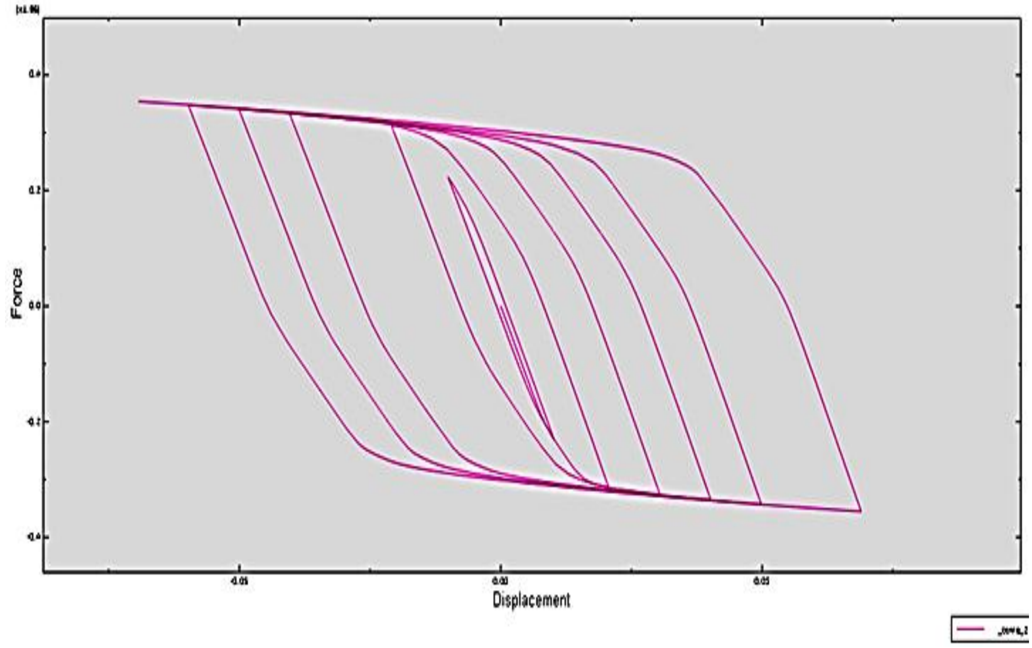

Fig. 2- a sample of hysteretic curves of EDD device

In Figure 3 the circumferential layer of the base level is shown as multi-linear links with hinge connection at their both ends. It can be observed in Figure 1 that the building structure above the lowest level, which can be called the superstructure, is of concentrically braced frame (CBF) type. In fact, for higher efficiency of the sliding motion in decreasing the seismic response of the superstructure, it should be relatively stiff to facilitate limiting the inter-story drifts. Therefore, moment resisting frames, CBFs and frames with applied shear walls does not seem to be appropriate for such purpose.

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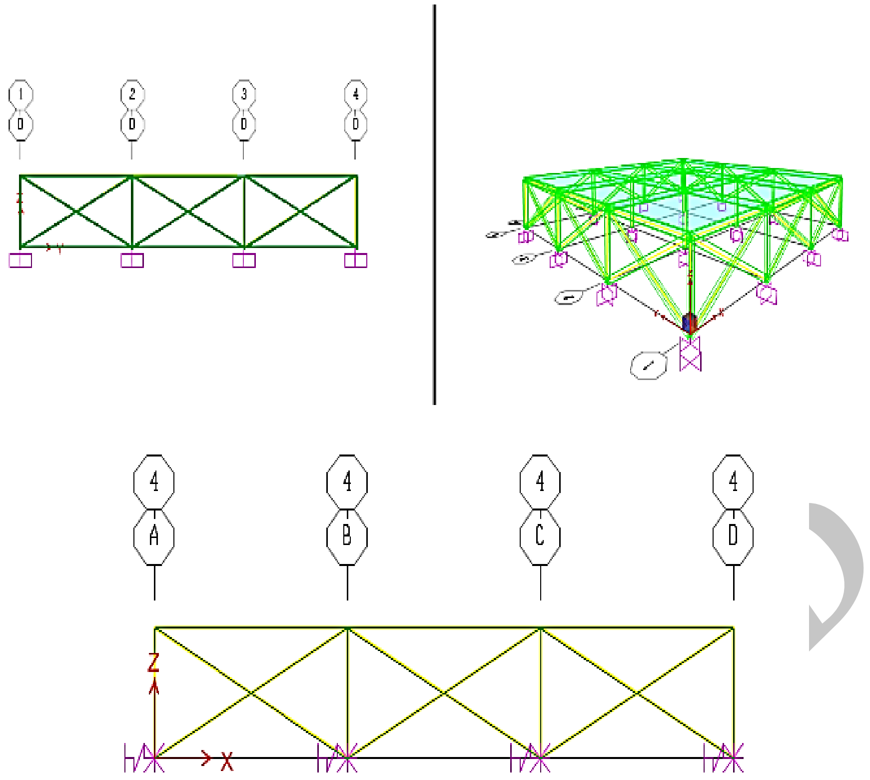

Fig. 3- The 3-D view of the sliding building and the grid consisted of orthogonal girder and its supporting space truss

3. Numerical Modelling of the EDD Device and the Proposed sliding Building

To assess the realistic hysteretic force-displacement curve of the proposed EDD devices, a powerful finite element (FE) program was used, and for the verification of numerical modelling process the results of cantilever beam in large plastic deformation were used as explained in the main report of the study (Alavi 2014) [9]. After the verification, by performing a set of FE analyses on EDD devices with different sizes of the initial (initial) and post-yield (secondary) stiffness values as well as their yielding strength were obtained. The appropriate values of initial and secondary stiffness's for the EDD device may be found by a series of trial and error analysis for each building system. For this purpose, the EDD devices were modelled as the multi-linear plastic springs in the numerical model of the whole building structure as shown in Figure 3. The initial stiffness of the device affected remarkably the modal periods of the rocking building, and its yield strength and post-yield stiffness controlled the energy dissipation potential of the system. EDD device stiffness values also affected the values of stress ratio in the superstructure elements, which was on the other side under the effect of the relative stiffness of the grid of the orthogonal strong girders. By assigning different structural properties to both EDD device and the grid elements, and observing the stress ratios under the dead and live load of the building decision could be made on the desired values.

4. Nonlinear Time History Analyses of the Conventional and the Proposed sliding Buildings

For seismic response evaluation of the two designed counterpart buildings, a series of nonlinear time history analysis (NLTHA) were performed by using three-component accelerograms of a set of selected earthquake based on their frequency content to be compatible with the considered site

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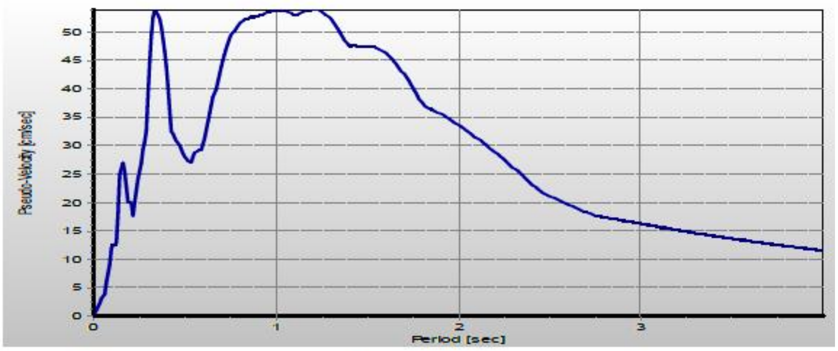
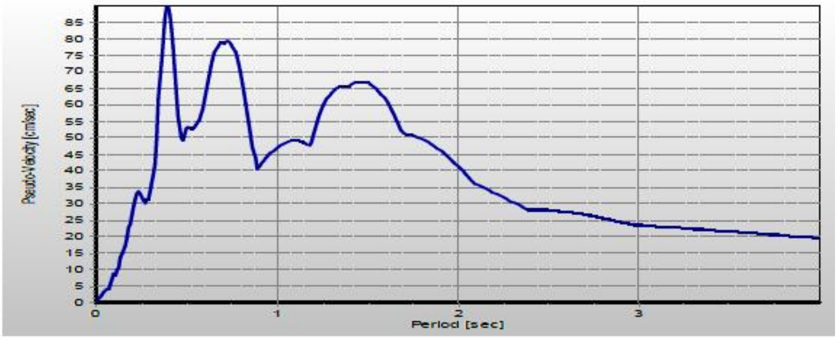
condition and the natural periods of conventional, sliding buildings. Specifications of the selected earthquakes are given in Table 1, and sample of their response spectra are shown in Figure 4.

Table 1- Selected earthquakes used for NLTHA and their PGA Values in three main directions

Earthquake	PGA (g)		
	In X direction	In Y direction	In Z direction
Imperial Valley	0.351	0.238	0.145
Coyote Lake	0.339	0.211	0.166
Loma Prieta	0.367	0.322	0.294
North Ridge	0.357	0.267	0.127



Coyote Lake



Loma Prieta

Fig. 4- Pseudo velocity response spectra, with 5% damping, of the used Earthquakes

Responses considered for comparison include base shear, roof displacement and acceleration, and inter-story drift of the conventional, sliding buildings as well as the hysteresis of the EDD devices in the sliding building. The joint at which the aforementioned responses have been extracted from NLTHA, are shown in Figure 5.

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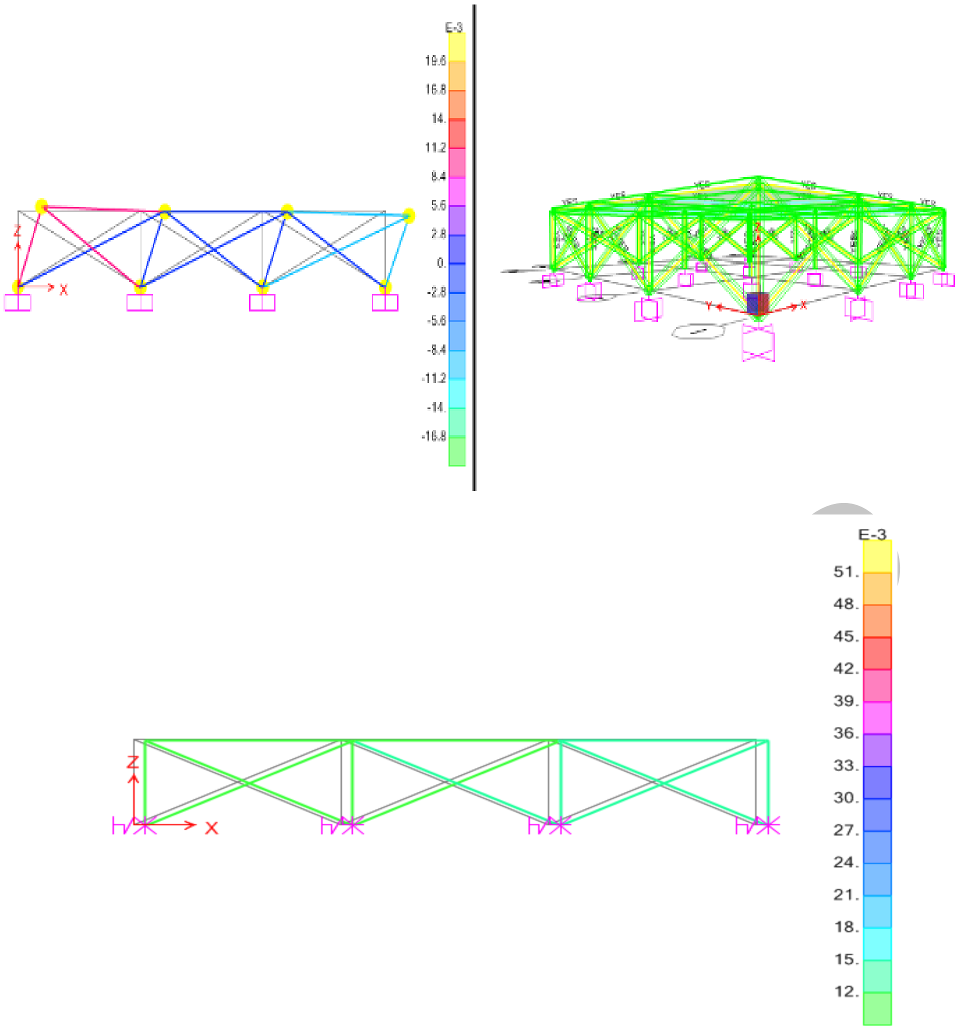

Fig. 5- Comparison of created system in the central frames of the three counterpart buildings subjected to Imperial Valley earthquake

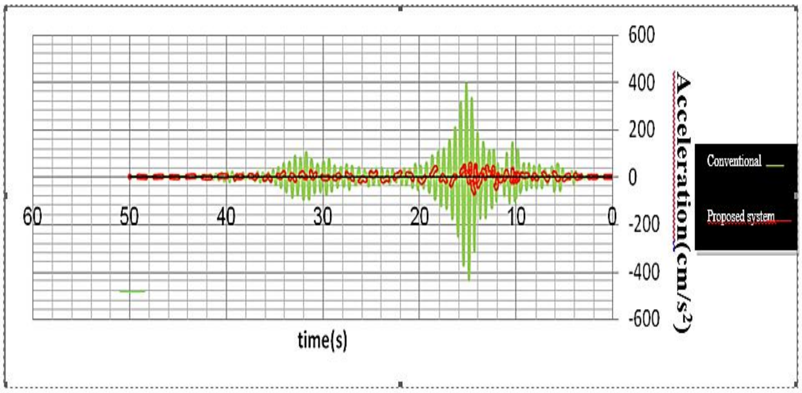

Fig.6- Comparison of roof acceleration time histories of the two Counterpart buildings at roof subjected to Imperial Valley earthquake

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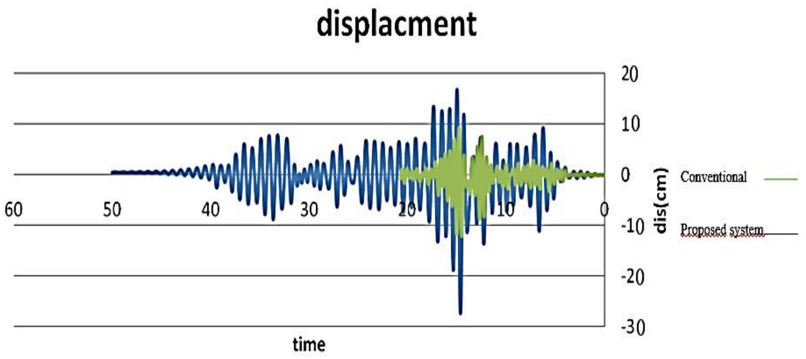

Fig.7- Comparison of roof displacement time histories of the two Imperial Valley earthquake

From the previous Figures it can be seen that in the central frame of the conventional building several PHs in the collapse prevention (CP) PL have been formed, while in the counterpart frame of the sliding building no PH has been formed. Also it can be seen in Figures that in the other sample frame of the fixed-base building PHs beyond the CP PL have been formed in several bracing elements, which indicates collapse of the building. This phenomenon is due to the fact that in the counterpart frame of the sliding building only some PHs in immediate occupancy IO PL, and few one in life safety (LS) PL has been formed, and this means that the sliding building can be easily safe after the earthquake.

5. Conclusion

Based on the numerical results obtained from NLTHA of the conventional building and its counterpart sliding building, subjected to several two-component earthquake records, it can be concluded that:

- The suggested structural system is very safe and inexpensive method by using material for arrive the good seismic performance for short and sample rise buildings.

- The suggested structural system leads to a more reliable seismic behavior of buildings.

- Plastic deformations not happen mainly in the EDD devices at ground floor, and therefore, in most cases only a few hinges at the IO or LS performance levels appear in other parts of the building structure.

- Considering the advantages of the proposed sliding and energy-dissipating structural system in seismic reduction of short-rise buildings, and particularly the easiness of manufacturing and installation of the EDD devices, the use of this system can be strongly recommended for buildings in the vicinity of active faults, particularly in large populated cities.

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