

Trends of Using Based Isolation System in High Seismic Regions

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Abstract

A lot of earthquakes were occurred around the world without any early warning which caused a lot of damages and casualties. The trends of using based isolation system in the buildings, bridges and heritage museums increases yearly due to their excellent performance during severe earthquakes. Even though, there are many types of earthquake protection system were invented by many researchers but the base isolation is still considered as the best option to protect the buildings from damaged. Basically, there are three types of base isolation system which are passive base isolation system, active base isolation system and hybrid base isolation system. The passive base isolation system is the cheapest cost among these systems with low maintenance cost but did not work effectively. Contradictory, the hybrid base isolation system becomes popular lately because it combines the advantages of using passive and active base isolation system assisted by the computer-controlled system.

Keywords: passive isolator, active base isolation, hybrid base isolation, fuse-bars, mechanical energy dissipating devices.

INTRODUCTION

The principle of a based isolation system was proposed in 1909 by J.A. Calantarients on the concept of "free joint" using a layer of fine sand, mica or talc to allow the building to slide during earthquake and reduce the seismic force transmitted to the building itself [1]. Therefore, the elementary school building in Skopje, Yugoslavia was built in 1969 using the first rubber isolation system to protect the structures from earthquakes [2]. The first application of a based isolation system was built in 1978 in New Zealand, United States in 1984 and Japan in 1985[4]. Furthermore, the first based isolation system building was constructed in the United States at the Foothill Communities Law and Justice Center, Los Angeles, United States in 1984. Successively, the largest based isolation building in the world was the West Japan Postal Computer Center, Kobe, Japan constructed in 1985 supported by 120 elastomeric isolators with additional of steel and lead dampers[5]. As a result of the superior performance of this building during the 1995 Kobe Earthquake, there has been increasing the usage of based isolation system especially for apartments and condominiums. Furthermore, Skinner and Robinsons [3] were scientists and seismic engineers from the Department of Scientific and Industrial Research, New Zealand had invented the lead rubber bearing (LRB) seismic

isolation device for bridges. Hence, the first structure in the world to be seismically isolated with lead rubber bearings was the Toetoe Bridge, completed in 1978 on the main highway which linking between Wellington and Auckland in New Zealand [6]. Based isolation is a method that can combat the vibration by essentially isolating the structure and its contents from dangerous ground motion simultaneously reduce the floor accelerations and inter-story drifts of the buildings[9]. Most of the historical heritage museums, libraries, government buildings and bridges in New Zealand used the based isolation system to protect the building's structure from damage and collapse during strong and great earthquakes. The museum of New Zealand is rich with artefacts and knowledge of past history was repaired and retrofitted using based isolation system. It is the largest based isolation structure weighted 64 000 tons in the Southern Hemisphere, which allow to move horizontally up to 50 cm and designed to withstand earthquake up to 7.5 Richter scale magnitude [7]. Presently, there are more than 80 based isolated buildings and 150 bridges in the United States, 1000 buildings and 500 bridges in Japan [8].

The trends of using the based isolation system as Earthquake Protection System (EPS) are increasing yearly due to its excellent performance during earthquakes which can reduce the structures damaged and casualties. Seismic isolation devices in the structures can be placed at the foundation and separated from its superstructure or specific section of the building. The kind of seismic isolation devices that are placed inside the buildings usually used the energy dissipating mechanisms such as fuse-bars, passive tuned mass damper, mechanical energy dissipation devices and others. A lot of research had been conducted on the usage of fuse-bars in precast hollow core wall and beam-column joint [10,11,12], tuned mass damper [13,14,15] and mechanical energy dissipation devices [16,17,18]. The mechanical energy dissipation devices are normally used to repair and retrofitting the building damaged by installing them at ground level or attached to wall panel [19, 20]. All the responses of earthquake protection system as mentioned above can be classified in accordance with their operation the principles as active, passive and hybrid system [9].

Recently, a lot earthquakes occurred around the world with huge damaged to the structures and numerous casualties. This is due to the fact that these structures are still design using the conventional method by considering the gravity load (dead load and imposed load) and ignoring the earthquake load. It is evident that the non-seismic code of practice for these

buildings did not survive under earthquake excitations where the structures suffer severe damages or partial/collapse of the buildings [21, 22, 23]. The worst scenario occurred when the emergency buildings such as hospital, police station and fire station cannot be functional after ground shaking. In order to have a safe building under seismic loads, installation of based isolation systems in these buildings should be implemented. Moreover, based isolation system is used to mitigate the effects of an earthquake by isolating the building from possibly dangerous ground motion by providing flexibility and energy dissipation capability through the isolating devices. Many researchers and engineers proved that based isolation system is the best way to control the earthquake vibration, reduce the earthquake force transmitted to the structures and lessen the structural damages [28, 27, 24, 25, 26]. Practically, the designed and usage of based isolation systems depends on some factors which are accurate calculation, build technology, control operating system, good quality of product, total maintenance cost and the amount of damping which can be provided during earthquake [29]. By adopting the based isolation system in the building, the earthquake forces that transfer to the structure can be reduced due to the based isolation flexibility that move vice versa from the ground motions. Consequently, this mechanism is not only save for human life but also save the buildings from crack or damage and the building can be remained functional after the earthquake especially the emergency buildings. The new trends of using the based isolation system may vary in ways and using different materials to improve its characteristic damping. The main objective of this paper is to have an overview of using the based isolation system as earthquake protection system and to discuss various numbers of earthquake protection system to suit with the customers' choices, installations and maintenance costs.

The isolator can be classified in two difference types as shown in Figure 1. The two types of isolator are isolator sliding bearing and laminated bearing. Currently, laminated bearing is commonly used as compared to the sliding bearing because rubber from the laminated bearing can produce higher shearing and flexibility as compared to the sliding bearing [52]. Sliding bearing consists of rigid sliding bearing and elastic sliding bearing. Meanwhile, laminated rubber bearing comprises of natural rubber bearing, lead-plug rubber bearing and high-damping rubber bearing. Rubber bearings are manufactured by binding sheets of vulcanized rubber to thin reinforcing plates made of steel tend to be supple horizontally, while being very stiff in the vertical direction. During the seismic action, the sheet of bearings isolated which attached to structure moves horizontal in the opposite direction of ground motion and the vertical load transfers to the building remain intact. The cost of the based isolation is very high during installation but for the long term services, it will benefit people in term of safety and properties of the building.

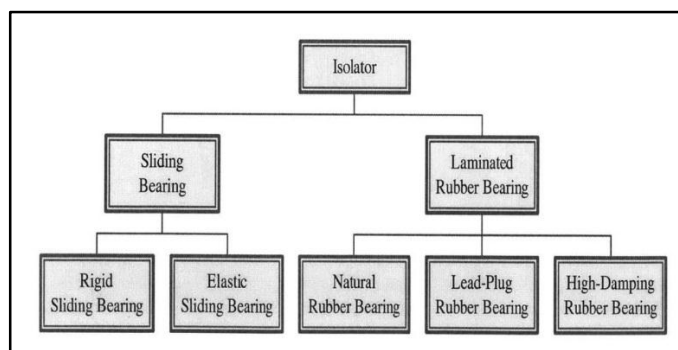


Figure 1: The Classification of Isolators [52].

OVERVIEW OF BASE ISOLATION SYSTEMS

Most of the reinforced concrete buildings in the world are usually designed using non-seismic code of practice without any provision of the seismic loads. In non-seismic standard, only gravity load such as dead load and imposed load are considered by ignoring the lateral load such as wind load, hydrodynamic load and earthquake load. The main issue is regarding about the safety of these buildings where the buildings will suffer severe damage, partial collapse or fully collapses under these natural disasters. Certainly, these buildings need to cater for high lateral load, behave under elastic region and remain standstill after the disaster. Unfortunately, strong RC structures with the monolithic conventional method of construction did not secure that they survive under moderate or strong earthquake. Therefore, based isolation system can be installed in these buildings to allow bigger drift at the foundation and reduce the structures damages. The trend of using the based isolation system in high rise building is increasing yearly. The based isolation system is like the energy absorber that can captivate the extra energy such as earthquake by isolated the building from the ground and it is believed to handle the structures and resist an earthquake tremor [30].

Normally, based isolation system is used in the buildings, bridges, historical structures and machinery. The based isolation system affects the global structural behavior because it is an additional element providing sufficient stiffness in series with respect to the superstructure with its stiffness base. The isolation layer is more flexible than the rest of the structure, hence absorbs a large part of the displacement demand [31]. Therefore, based isolation system can be categorized into three parts as illustrated in Figure 2. There is passive based isolation, active based isolation and hybrid based isolation. Passive based isolation is the pioneer of the based isolation system which responds in the opposite direction of earthquake excitations and require low cost of maintenance. Active based isolation is defined by using a hydraulic actuator to provide the dampening to the based isolation system [34]. The hybrid based isolation combines the attractive attributes of active and passive systems as well as it has high stiffness-weight ratio, a high frequency bandwidth, and low power consumption [33]. But lately, researchers focus their studies on hybrid based isolation by combining the active base isolation and passive based isolation system to get the optimum service of insulator when the high ground motion occurred with relative minimum inter-storey drift.

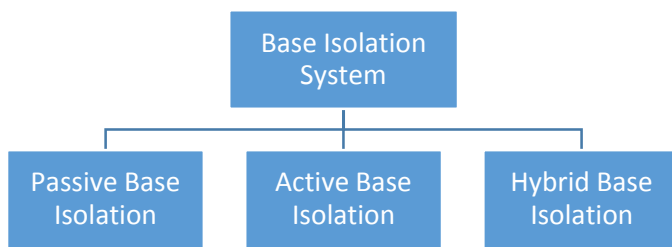


Figure 2: Three types of base isolation system [32].

The passive base isolation system

Jalali et al. [37] had conducted the comparison between a base isolation system, multi-story structure and fixed base structure. The model of the building was created using ETABS (8.5.0) and nonlinear time history analysis was performed. The result showed that based isolation multi-story building is more efficient as compared with the fixed based structure. Natural period in based isolated building is 2.3 times longer than fixed-based building. Modal participation factor of the fundamental structural mode of base-isolated building is 0.4 times lesser than fixed-based building. The characteristics of superstructures have different effects on the isolation performance in low-rise buildings, medium-rise buildings and high-rise buildings. High-rise building produces an effective based isolation system when the damping is increased and structure becomes more stiff as compared with conventional buildings. For low-rise buildings, a simple based isolation produces better performance while medium-rise building is better to have a base-mass and high damping. Pradeep et al., [38] had carried out experimental work using lead rubber bearing isolator and seismic damper which had been designed and modelled based on basic parameter such as characteristic strength, lower stiffness and initial stiffness. The use of isolator is believed to increase natural period of structure under earthquake while damper function to absorb energy of the seismic force. After experimental work, it is found that the lead rubber bearing has a little strain-rate dependence for wide frequency range that usually happen in typical earthquake bearing design.

Di Sarno et al., [39] had investigated the complex irregular multi-storey RC frame hospital building using circular high damping rubber bearing (HDRB). They designed the hospital using Eurocode 8 which required certain size of the diameter of insulator to resist against earthquake vibrations. The framed system of the hospital building was modelled using finite elements (FEs) as implemented in the computer program SAP2000. The results of their investigation reveal that based isolation HDRB is an effective strategy to improve the seismic performance of relatively flexible framed structures. It also can be concluded that the relatively high horizontal flexibility of the superstructure apparently reduces the beneficial effects of the based isolation system. About 40% savings were estimated

for the amount of percentage of steel reinforcement used for the columns and beams if used based isolation system.

Salic et al., [40] demonstrated that the effects of dynamic response of the seven-story residential building under different level of ground motions. The type of the isolator used is lead rubber bearing and the result has been compared with the fixed based building. The model of the seven-storey residential building was modelled using ETABS (9.0.4) for the based isolation building. The dynamic properties of fixed-based building such as damping ratios, natural frequencies and mode shapes were obtained from ARTEMIS (Ambient Response Testing and Modal Identification Software). The time history analysis was conducted by using four types of the real earthquakes at different frequencies. The result produces an increasing of natural period and flexibility of the structures. Flexibility has increased the total displacement due to the elasticity of based isolation, reduce the inter-story drift and acceleration of the buildings subjected to ground motions.

Kilar et al., [41] had designed four-storey building according to Eurocode 8 and tested for seismic analysis and dynamic performance. Two samples of four-storey building were constructed with simple rubber bearing and lead rubber bearing as a based isolation system. Different percentages of damping value were used for these samples. Non-linear pushover analysis and data were compared with analysis software SAP 2000. At the end of the study, they concluded that high damping value gives smaller target based displacement as compared with lower damping. It also can be concluded that damping has an inverse proportional to target lateral displacement and higher damping can protect the structures from damage and collapse.

Surnayati [42] has studied the seismic response of steel structures with rubber bearing based isolators under low intensity earthquakes. Three identical steel frame structures with simple structural configurations were analysed using Finite Element Analysis under different earthquakes time history data. These earthquakes were the 1940 El Centro Earthquake, the 1995 Northridge Earthquake and the 1994 Kobe Earthquake. The analysis of steel frame structure was conducted using three different types of based isolation system. These types were fixed based system (FBS), based isolation system with solid rubber bearing (BISRB) and hollow rubber bearing (BIHRB). The numerical modelling analyses were validated by putting the steel structures with different based isolation system on a shake table using different level of earthquake accelerations. From their study, the maximum accelerations of isolated structures can be reduced nearly 30% of ground acceleration values and reduce the damage of the structures.

Saiful et al [43] had explored and studied two different types of isolators which were high damping rubber bearing (HDRB) and lead rubber bearing (LRB) in soft-storey buildings which have a lot of open spaces under seismic loading. From their exploration, each level of building was equipped with isolators and different damping values were investigated. By designing soft-storey building can create a lot of major problem under earthquake excitations, especially when utilizing weak column strong beam design concepts. One of

the significant findings of their study is that the soft-storey building equipped with based isolation system can survive under strong earthquake excitations. The lead rubber bearing can perform better than high damping rubber bearing in term of period, frequency, ductility, equivalent viscous damping and energy absorption. Their study also deals with the main requirement for installation of isolators in soft-storey buildings. It can be concluded that the flexibility, damping and resistance to cater for lateral load are the main parameters which affects the practical isolation system to be incorporated into building structures. Other additional requirements such as durability, cost, ease of installation and specific project requirements influences device selection, but all practical systems should contain these essential elements.

Islam et al., [44] had conducted the analysis of the based isolators for a RC building which located in Dhaka, Bangladesh and then compared with fixed based RC structure buildings under difference level of earthquake excitations. A time history analysis and response spectrum curve generated from the structure building in Dhaka and peak ground acceleration (PGA) was selected from a nearby recorded earthquake. The analysis showed that the based isolator structure is capable to reduce the seismic force from low to medium level of ground shaking. Not only that, the buildings that used based isolation system can save about 5% to 10% of the total structural cost even though based isolator system can increase the installation cost and maintenance cost.

Hadian and Mutalib [29] explored on seismic behaviour of based isolation system using lead rubber bearing and compare it with the normal fixed-based structure. The type of structure used in this research is reinforced concrete frame. They determined the best configuration of the LRB in the structure by calculating the response of the structure, roof level acceleration and inter-story displacement based on the ground motion records. Their study consists of determining the structure, calculating the weight of structure, modelling the LRB in the structure and obtaining the output from the dynamic analyses. The comparison of the inter-story displacement, inter-storey drifts frame and top level acceleration response of the LRB system with the fixed based system. They used the spectrum and time history analysis and the results showed that base shear reduces by 65–75% in response spectrum analysis, while in time history analysis base shear reduces by 75–85%. The proposed method is based on the LRB system that reduces the response of the structure because of high damping ratio, stiffness used in the based isolation system and capable to resist lateral load for super structure which located in high seismic regions. This system would help in reducing the cost in the long time and increase the safety of the structures.

Tiong et al., [45] had carried out the finite element analysis using SAP2000 for two-storey precast wall panel with HDRB at foundation under difference level of peak ground acceleration (PGA). This analysis was carried out to investigate the effectiveness of based isolation system in seismically non-ductile precast wall structure from the earthquake vibration. Difference types of ground acceleration from three classification of acceleration history were used based on a/v ratio. A simple concrete frame and two wall

structures were modelled using the commercial finite element software, SAP2000. The difference between Wall Structures 1 (WS-1) and 2 (WS-2) was only the direction of earthquake ground excitations. For WS-1, the simulated seismic loading was acting towards the structure in the direction parallel to the wall panels' alignment as shown in Figure 3. Time history data loading from the real 1980 Irpinia earthquake data in Italy, with peak ground acceleration value (PGA) of 0.202g was simulated in SAP2000 as the seismic induced forces towards the three structures and two other strong motion data having PGA/PGV ratio of 1.078 and 1.250 $g/m.s^{-1}$ were selected in addition to the Italy's. The results showed that the based isolation system was successful reduce the critical structure response such as base shear demand, inter-story drift and floor acceleration as compared to the fixed base structure. However, there is no experimental work conducted to validate the model of two storey precast wall panel with HDRB and the structural engineer and designer will not confident to use this product.

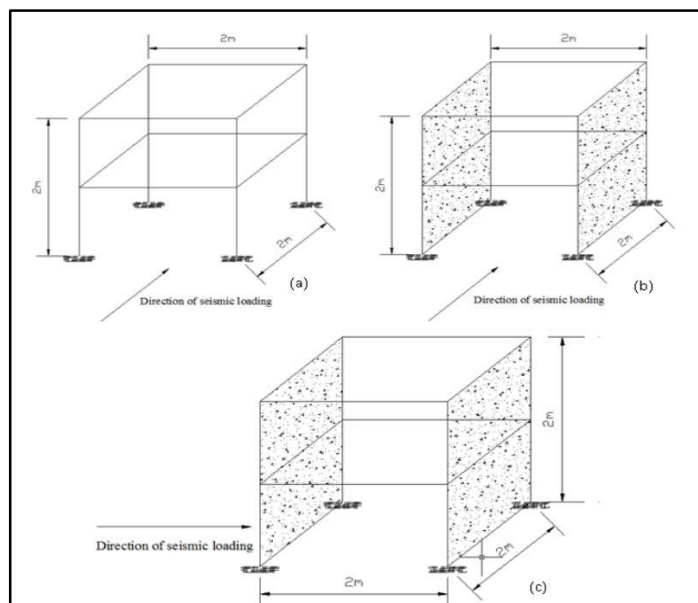


Figure 3: (a) Frame Structure (b) Wall Structure 1, WS-1 and (c) Wall Structure 2, WS-2 [45]

Shu-Lu Wang et al. [35] investigated the common problem of the normal isolator that usually produce to cater high vibration and suggested a new type of isolator with strong metal rubber isolator. Their study proposed three aspects of passive based isolation system including experimental study, dynamic modeling, parameter identification and research of vibration isolation system response. The experimental results have good agreement with the dynamic modeling of this system. According to Li Yu-Yan [36], the metal rubber vibration isolator can solve the problem of vibration isolation because it has a superior performance under extreme earthquake excitations. Its stable performance and long service life has a practical significance to strengthen the maintainability and improve the reliability of the equipment even under normal environment. Other aspects properties of metal rubber isolator are conducted experimental in the laboratory to get a better and

optimum results of damping and flexibility of base isolation system.

The active base isolation system

The active based isolation comprises of a passive isolation system and combined with control actuators. It has been proposed as an alternative solution to overcome the disadvantages of passive base isolation systems. In active isolation systems, the control actuators are used to reduce drifts and floor accelerations. Many small-scale experiments of active based isolation systems have been performed and the effectiveness of such systems had proved tremendously. The combination of based isolation with active control system can create the possibility of achieving a balanced level of control performance in reductions of either floor accelerations or base displacements.

Nagarajaiah et al., [47] have presented an experimental and analytical study of hybrid control of bridges using sliding bearings, with re-centering springs and servo-hydraulic actuators. Their study produced the control algorithm based on instantaneous optimal control laws. It showed that by using hybrid control, the accelerations were reduced substantially, while sliding displacement was confined within an acceptable range post-earthquake permanent offsets were eliminated almost complete.

Chan and Spenser [46] had developed and conducted experimental verification of an active based isolation system for a seismically excited building. First, the general problem formulation and control design procedure were provided. Subsequently, the experimental setup was described; unique features include low-friction pendular bearings and custom-manufactured low-force hydraulic actuators. A new system identification procedure that can effectively capture the phenomena of control structure interaction (CSI) was presented and used to realize control-oriented models of the system. The control strategies employing different performance objectives by evaluating a six degree-of-freedom of shaking table in the Smart Structures Technology Laboratory, University of Illinois, Urbana-Champaign, United States. The proposed control strategies showed excellent seismic performance under various ranges of seismic excitations.

Gandelli [48] used sliding isolator together with conceptual design to develop a new tool for the designing the seismic retrofitting interventions of hospital using high technology of sliding isolation systems. The cornerstones of his study are the establishment of a FEM approach for the assessment of the frictional heating in sliding isolators, the numerical investigation of the re-centering capability and the improvement of an existing finite element formulation of the "isolator" element. In order to reproduce resistance for sliding at breakaway, the proposal of a "step by step" procedure was implemented for retrofitting interventions strategic buildings. He recommended to use sliding isolators and apply it in a real case-study of the hospital which located in high seismic regions.

The hybrid base isolation system

Hybrid based isolation system combines the features of passive and active seismic control system. Usually, it can reduce power demands, improved reliability and reduced cost when compared with fully active systems. Based isolator is used in conjunction with computer-controlled actuators to operate the tuned-mass dampers located through the building. Hybrid based isolation system utilizes the advantages of passive based isolation and active based isolation systems.

Madden et al., [50] investigated the ability of seismic based isolation system to protect structures against the difference earthquake ground motions. The type of isolator used is the combination of sliding isolation bearing and hydraulic damper which can be changed to respond towards the ground motion acceleration. Their study had concentrated on an experimental study of the seismic response of a scale-model, steel building frame outfitted with an adaptive hybrid seismic isolation system consisting of sliding bearings combined with semi-active fluid viscous dampers. Figure 4 shows the steel structures mounted with seismic isolator and fluid viscous damper and tested under different level of earthquake excitations.

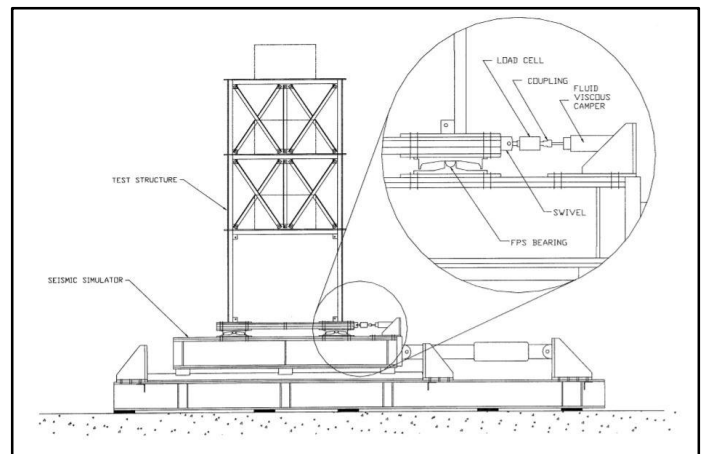


Figure 4: Test Structure Mounted on Seismic Simulator and Retrofitted with Adaptive Base Isolation System (Madden et al., 2002).

Ramallo et al., [51] studied on the effectiveness of "smart" base isolation system using difference materials and techniques. Smart or hybrid based isolation using lead rubber bearing together with the semi-active or controllable passive dampers. This smart hybrid system uses magnetorheological fluid and lead rubber bearing. They found that smart controllable semi-active dampers or hybrid based isolation effectively can protect the structures under strong tremor of earthquakes events. It uses lead rubber bearing together with the semi-active or controllable passive dampers. The result of this technique prove smart dampers provides good protection to the structure against ground motion as compared to lead rubber bearing. The two and six degrees of freedom models of based isolated and fixed based are shown in Figure 5. **Error! Reference source not found.** They strongly agreed that smart

dampers can be used in base isolation applications and performed very well under extreme earthquake excitations. But the complex technique of smart dampers as a based isolation system cannot be avoided. Thus, the adaptable nature of the smart damper system allows a structure to be protected against extreme earthquakes, without sacrificing performance during frequent and moderate seismic events. Previous earthquake data which classified as moderate and severe earthquakes (the 1940 El Centro Earthquake, the 1968 Hachinohe Earthquake, the 1995 Kobe Earthquake and the 1994 Northridge Earthquake) were used to simulate the model. Figure 6 shows the peak response of the based isolation building under moderate and severe events of earthquakes using lead rubber bearing as smart based isolation system. Therefore, it can be concluded that smart based isolation system can reduce the base drifts significantly as compared with passive systems with no increase in base shear or acceleration of the superstructure.

Donata et al., [49] performed the experimental work on multi-storey building design using Eurocode 8 with based isolation system. The type of isolator used was Friction Slider (FS) combined with Lead Rubber Bearing (LRB) called high damping hybrid seismic isolator (HDHSI) and tuned mass dampers. The sample of building structure was tested under different ground motion acceleration recorded according using accelerogram. The results between both isolator was compared in term of the response and behaviour of both building structure with isolator and normal fixed based structure. The comparative result shows that HDHSI provide better protection for severe seismic activity then others.

DISCUSSIONS

The stiffness of the damping rubber and materials used for based isolation system are very important issue to be considered while other factors such as ground condition, geometry of structure and height also plays vital role on the performance of structure building during ground motions. The trend of using base isolation system in buildings, bridges and heritage buildings had changed tremendously in the past decades. From passive base isolation alone has moved to the active based isolation system to recently the hybrid base isolation system. By combining the isolator with active or semi-active based isolation system together with computer-controlled system will reduce the structural damages and collapse of building under wide range of earthquake excitations. Nevertheless, by adoption of based isolation system together with active mechanical dissipating devices in real building can save the buildings from collapse and casualties. However, based on the literature review, around 5% to 10% cost of structure can be reduced, the building can survive and function well after the earthquake are among enormous benefits for high seismic regions. Moreover, lead rubber bearing isolator are the most commercial isolator as compared to other types of high damping rubber bearing.

CONCLUSIONS

From the past literature review of the base isolation systems, it is notified that the trendson usingbase isolation system for structures and infrastructures are increasing yearly in country that involve a lot of earthquake activities such as Japan, Turkey, Indonesia, Philippines, Taiwan, China and other parts of the world which located in “Pacific Ring of Fire”. Starting from 2015, many researchers started to combine the different isolator as one application but the methodology and result obtained still under discussion and not clearly clarify. For non-seismic regions, the application of based isolation system is still minimal due to the cost of construction and maintenance of the devices. Regarding the passive based isolation using elastomeric bearing shows the increasing in numbers of research and publication especially on lead rubber bearing (LRB). The research on high damping rubber bearing on structure still limited as comparedtoother types of based isolation that available in markets. Therefore, it can be concluded that based isolation system is an effective way to protect structure against the earthquake especially using

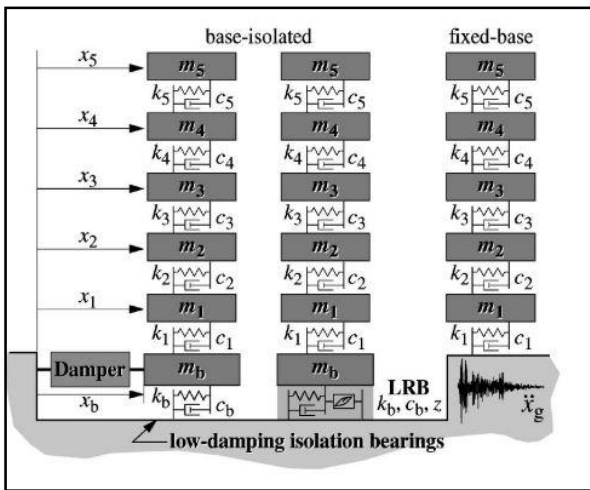


Figure 5: Multi-degree-of-freedom (MDOF) models

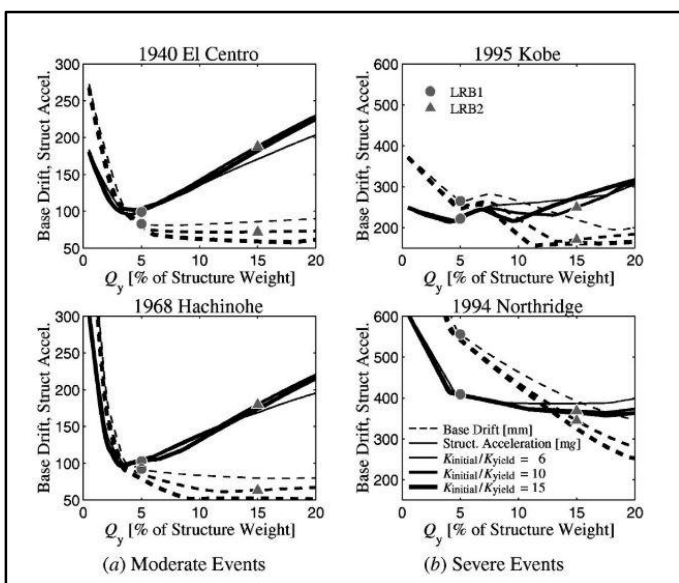


Figure 6: Peak response of lead rubber bearing under (a) moderate and (b) severe seismic action [51].

elastomeric bearing isolator that has excellent stiffness, flexibility, percentage damping and superb seismic performance under severe ground motions. Hopefully, by implementing based isolation system in existing buildings can provide high level of survival and safety for society especially in rural area whom are faced with unpredictable earthquake.

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