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Seismic Behaviour Of Base Isolation System Using Lead Rubber Bearing

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Graphical abstract

Abstract

Nowadays the main cause of damage of reinforced concrete frames in the countries which are located on the seismic line area is earthquake even though they are designed due to the enactment of seismic codes. To provide a solution to these problems, Lead Rubber Bearing (LRB) system has been utilized in the construction of the buildings. Hence, the objective of this study is to determine 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. The 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, drifts frames and top level acceleration response of the LRB system with the Fixed Base System (FBS) using spectrum and time history analysis shows that the 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 and stiffness used in the Base Isolation System (BIS) and capable to be used for super structure located in the seismic line area. This system would help in reducing the cost in the long time and increase the safety of the structure.

Keywords: LRB system, seismic; fixed base system; base isolation system; response spectrum analysis; time history analysis

1.0 INTRODUCTION

Nowadays, earthquake is the main reason for damage of structures. Thus this study tries to define and propose a method to decrease the rate of damage. Base Isolation System (BIS) is one of the best methods to reduce the damage of the structures subjected to earthquake. BIS supports the concept of flexibility in horizontal surface, known as base-plate, and simultaneously causing factors in order to isolate the load associated with earthquake. The main idea behind the BIS is to control the period of structure against the earth movement's period since that reducing the frequency of structure along with increasing the period of structure equals to heightening the flexibility. BIS is responsible to push the structure back to its original place to minimize the permanent displacement of the structure in base.

From engineering perspective, BIS is one of the best ways to fight against the earthquake, a technology which is being considered widely today. However from the practical view, this system can be fully pragmatic if three items which are adequate built and implantation technology, proper operational system and high quality maintenance are followed. Regarding these profound factors lead to two more important features including immunization against the quake and also reducing computational weight in order to economize the projects' plan.

Past studies have shown that the BIS is one of the best techniques to improve the performance of super-structures and seismic structural response against the earthquake loadings. It can be seen in most of recent isolated buildings. In fact, isolators are very efficient tools in designing for isolated structures. To get these points, engineers need to know more about the main factors which decrease the structural response. The two most important parameters to decrease the structural response are the lengthening of the fundamental period of the super-structure and the deformation at the level of isolators.

The system namely Lead Rubber Bearing (LRB) selected for this study includes sample of materials such as plate, rubber and central core. It has been selected to establish an innovative simplified design procedure for isolators incorporated in multi-storey building structures. Recent studies have shown that most isolated buildings is important to use multi-layer Laminated Rubber Bearings with steel reinforcing layers as the load carrying component of the system.

Because of steel plates laminated in multi-layer, these isolators (LRBs) have got two factors under the seismic loads that are very stiff in the vertical direction and soft in the horizontal direction. However there are several reasons why this study focuses on LRBs as they are easy to produce, have no moving parts, unaffected by time and resist environmental degradation [1].

The study has shown simplified design procedures for LRBs for multi-storey buildings and been proposed to be included in International Building Code [2]. In this study Lead plug bearing is used and represented using bilinear force deformation behaviour. There are two main portions being discussed in this paper that are base isolators design and comparative study of the performances of fixed base condition and base-isolated condition. Static analysis on fixed base condition and reanalysis of dynamic analysis on base-isolated condition are used. The response spectrum analysis and linear time history analysis are also used on both of fixed base and base isolated buildings. Figure 1 shows the typical use of LRBs for all columns is common instead of mixing with Fixed-Base System (FBS).

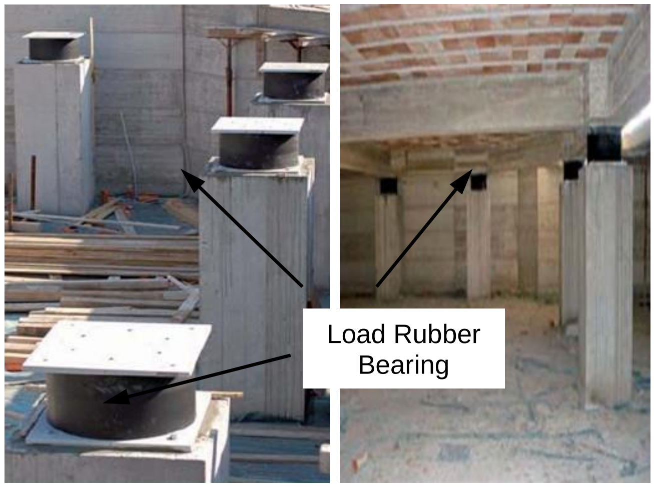


Figure 1 View of used LRB in all columns

The present problem mechanism in building structure that destroyed due to the load that exist during earthquakes came from near fault ground motion completely transferred from the base to the structure. In an attempt to solve and improve the mentioned problem, this study discovered through the existing literatures that more research is still needed in the following directions. Firstly reducing the deformation in the isolation system and suppressing any possible resonance at the isolation frequency Next, obtaining the best structural response by choosing one of Base Isolation system, Fixed-Base structure or mixing them (Mixed-Base). Finally, estimating the variation of optimum parameters of the LRB under different factors of super-structures and isolators is carried out.

The aim of this study to investigate the effect of different dimension of materials in isolators includes rubber, plate, and lead core in order to protect the structure from the earthquake load. The effect of Mixed-Base structure by locating the supports Base Isolated system and Fixed-Base structure together is studied. Response of structure during the earthquake in terms of inter-story displacement, top level acceleration and top level drift of structure are also carried out.

■2.0 MODELLING THE BASE ISOLATED STRUCTURE

Base Isolated systems are one of the ways to confront with earthquake scientifically and in most countries the use of these systems is increasing. From application point of view, this system will be effective if the building have high quality of exploiting and conserving technology so that it is more than safe against the earthquake. It will have salient reduction of skeleton computational weight so much in order to advance the economical goal of this project. With this point of view, the designers decided to find a solution for reducing transmission that is caused by earthquake load to structure and also to estimate the structure details for load that caused by active earthquake forces.

For achieving these functions, several factors such as time history analysis, floor acceleration, and inter-story drift must be checked. In this study the isolation system was modelled as a bilinear hysteretic element. For the analysis of base isolated building, the following assumptions are made. Firstly, the super-structure is elastic and the non-linear behaviour is limited in isolation devices. Next, there is a diaphragm at each floor level to connect all frame substructures (rigid in its own plane). Then, for centre of mass (floor mass); each floor has got three degrees of freedom (two translations and one rotation). Finally, the isolators are assumed rigid in the vertical direction and have negligible torsion resistance as well.

2.1 Modelling Characteristics

With four spans in x-direction and three spans in y-direction, nine moment frame structure in Shiraz City (a cosmopolitan town in south of Iran) with distinctive spatial and total of nine story were selected in this analytical study. As for the structure spatial, the structure plan was 20 meters in x-direction by 18 meters in y-direction with exact size for each span through each direction.

Each floor rises to a height of 3.20 meters. From engineering point of view, for any building the overall seismic weight has to be identically distributed along all levels including the base floor and columns. Such presumption supports the idea of using the same isolation system for all columns within a particular structure. The exposed structure has 12 isolators and all chosen properties for column, beam and brace are selected from HE (European standard universal H beam), IPE (European standard universal I beam) and UNP (European Standard U channel) frame sections respectively.

Weight of structure comes into two parts as follows; live load (varying weight); 150 kg/m^{2}and dead load (intrinsic weight); 650 kg/m^2. These amounts are fixed for each floor; however live load on the roof level is 50 kg/m^2. Additionally, the area mass in each floor and the roof level are the same.

Then, the beam to column stiffness ratio is approximately the same for each floor (1/8) and only flexural deformations are considered. Figure 2 illustrates the structure plan and elevation for the selected structure used in this study.

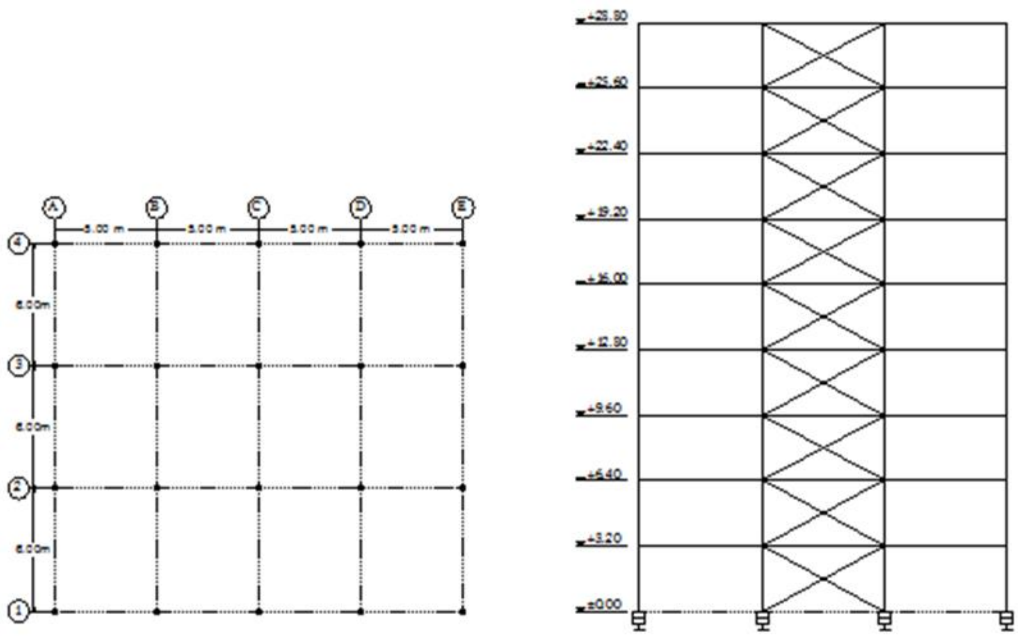


Figure 2 Plan and elevation of selected structure

2.2 Isolator Properties

Regarding to the shape of LRB, the used materials can be seen. The lead core used in LRB have an apparent yield level which is a function of the theoretical yield level of lead, 10.5 MPa and the degree of confinement of the lead. Figure 3 shows the LRB system used in the modeling.

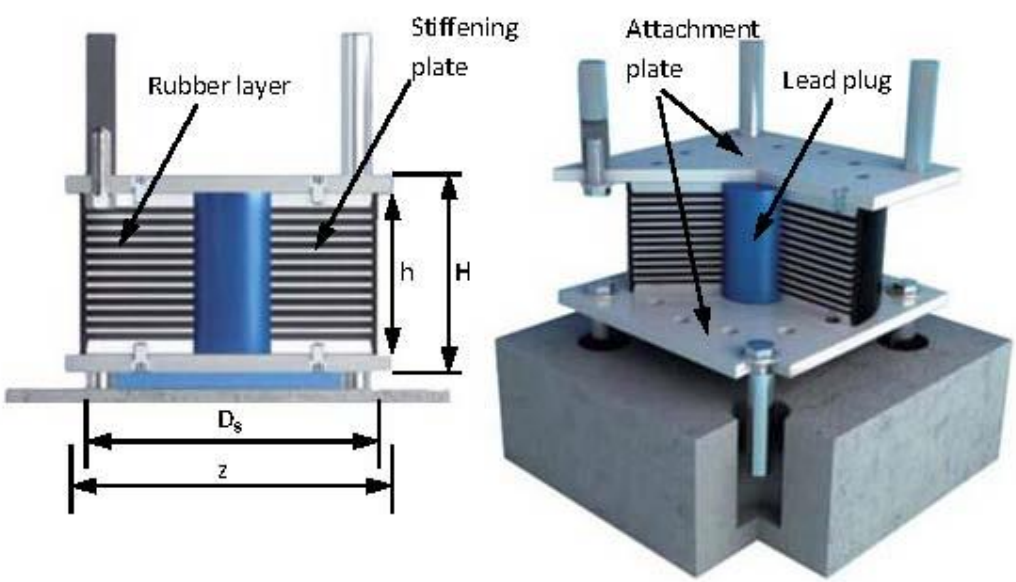


Figure 3 LRB system

The maximum lead core force is assumed to be 25% of characteristics strength, Q_d. The dimension of bearing isolator, D_g is very vital for incorporation after design and there are some constraints from which the optimum size of bearing being selected. The related work on the evaluation of the optimum dimensions are as follows [3,4,5,6,7]. Firstly, D_g is selected for the maximum gravity loads, and the increment of D_g for iterative design based on a Factor of Safety (F.S) of 3 in the design progresses equals 50 mm. Then, thickness of layer, t_i generally of 10 mm may be reduced to 8 mm or even 6 mm if vertical loads are critical and t_i should not exceed 10 mm for LRB. Thirdly, the number of layers define the flexibility of the system which to be set so that the isolated period is in the required range and the maximum shear strain is not exceed. Finally, ratio of the characteristic strength to weight, Q_d/W is in range of 3 to 10%.

In this study, the design structure is applied to a dynamic analysis. To analyse the structure using dynamic analysis, the frequency of seismic response spectra and time history of analysis must be check, because the dynamic analysis can only be performed by using the principle of dynamics.

2.3 Isolator Components Modelling

LRB is incorporated under 6 internal columns and 14 external columns in the buildings as shown in the Figure 4 layout plan. The diameter of isolator and number of layers required increases with the increase in number of stories in based-isolated building with thickness of 10 mm. The detail dimensions and other parameters of the isolator considered in the modelling is shown in Table 1. For all the models, the structural time period is below the unit value, seismic base shear is lesser than the wind induced shear and wind induced shear is less than ten percent of total seismic weight [3,4,5,6,7]. The values for vertical load (V), vertical service load (F_{zd}), diameter of isolator (D_g) and number of layers were obtained after the details of selected isolators was analysed.

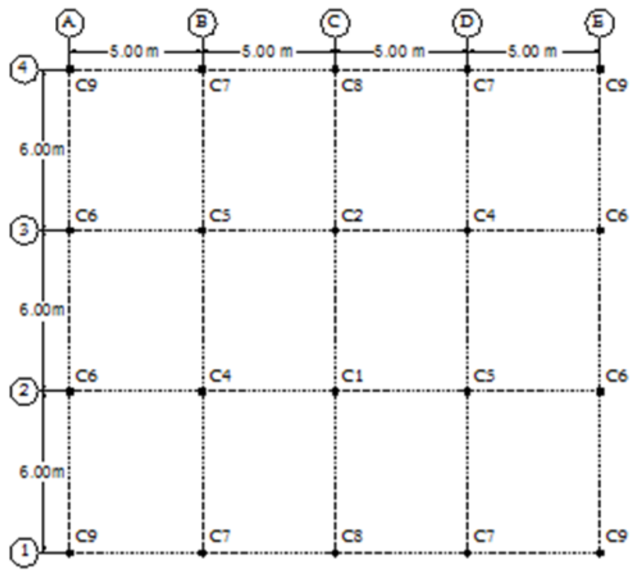


Figure 4 Plan of column number

Table 1 Dimension of isolators for each columns in LRB system

Column No.	V (kN)	F_{zd} (kN)	D_g (mm)	t_e (mm)	h (mm)	H (mm)	Z (mm)	No.of layer
C 1	2170	6980	750	190	337	397	800	15
C 2	2810	8050	800	180	322	382	850	15
C 3	3170	11480	750	193	337	397	800	15
C 4	3850	10350	750	180	322	382	800	15
C 5	4070	13160	800	180	322	382	850	15
C 6	4540	11250	800	198	345	395	850	15
C 7	4870	14320	800	190	337	397	850	15
C 8	5320	15440	800	190	337	397	850	15
C 9	5780	16910	850	180	322	388	900	15

3.0 MODELLING AND VERIFICATION OF RESPONSE SPECTRUM AND TIME HISTROY FUNCTIONS

A response-spectrum analysis is simply a list of period versus spectral-acceleration values. Generally, a linear response spectrum analysis will be carried out based on the response spectrum curve for specific soil condition of target location for a damping ratio of 0.05 [5]. In this case the response spectra are chosen from IBC2009 [2].

The buildings have small natural vibration period are the best structures in using the isolated systems where the time period is not be greater than 1 s [8]. Generally, the natural period should not be greater than 2 s for the buildings subjected to design of more than 10 stories [9]. The structures do not need to the isolation system, if the time period of the structure is in the range of 1.5 to 3.5 s. Practically, isolation systems will be used if these structures cannot afford an infinite period but they transfer the period to the range of 1.5 to 3.5 s. In order to get the response of the fixed base system and isolated system, the earthquake ground motion should be investigated under X-direction and under excitation of real earthquake ground motion. Table 2 indicates the specific components of Japan ground motion. Figure 5 indicates the acceleration time history to show the ground motion for each earthquake of Japan with proposed modelling is the same approximately.

Table 2 Basic information of Japan ground motions

Earthquake Name	Station	Year	PGA (g)	PGD (cm)
Japan	Tokyo	2011	0.35	91.623

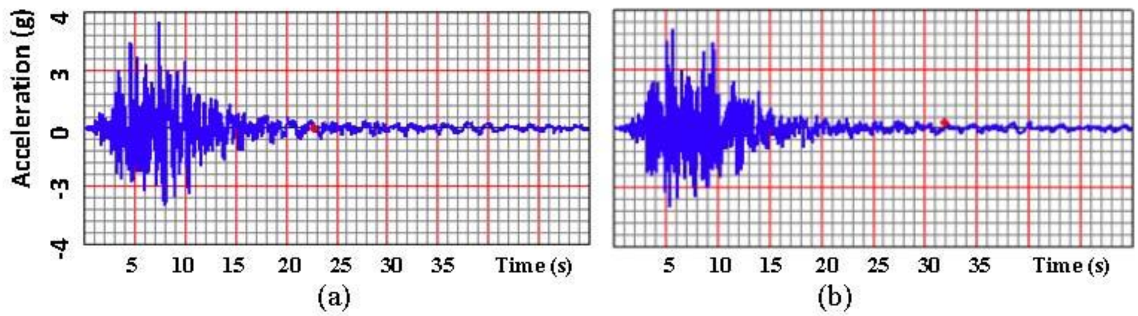
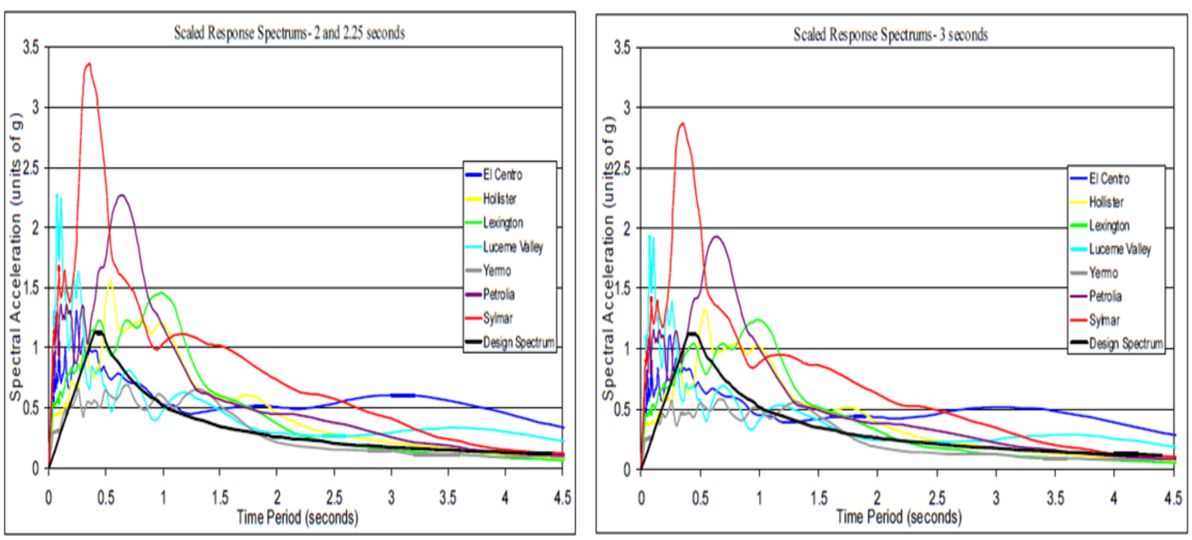


Figure 5 Comparing (a) the acceleration time history of present study with (b) the acceleration of Japan ground motion

It can be seen that the occured earthquake in Japan earthquake occurred in 2011 has approximately the same acceleration time history. Hence, in case of BIS, Japan earthquake (2011) is selected as the specific component for comparing ground motion displacement and acceleration time history with present study analysis. The proposed model were compared with eight known earthquakes value from El Centro, Hollister, Lexington Dam, Lucerne Valley, Yermo Fire Station, Petrolia, Sylmar and Japan Tokyo Earthquake the acceleration of base isolated structure in various time periods as shown in Figure 6 in order to find the response of structure. Eight known earthquakes which most of them (for instance; Yermo fire station with BIS and Sylmar without BIS) did not use BIS in their structure. The current spectrum shows the close pattern with Yermo response spectrum indicating the agreement of spectrum for BIS.



(a) (b)

Figure 6 The scaled response spectra's for (a) T = 2 s and (b) T = 3 s

■4.0 RESULT OF ANALYSIS

There are different methods for finding out the accuracy of the model. In this study the obtained results i.e. the ground motion, acceleration of top storey and inter-storey drift of proposed method (LRB) are compared with the output results with the fixed-base system (FBS). The analysis is carried out through response spectrum analysis and time history analysis and the building is assumed to be in elastic linear range. Figure 7 indicates the comparison results for inter-storey displacements by response spectrum between both fixed base system and base isolated system. It can be seen that base isolation decreases the inter-storey displacement by response spectrum in about 14% approximately. The results of isolation which are shown in Table 3 indicates that the value of natural period reduces by 70% for both value of fixed base and base isolated Systems by using the response spectrum analysis. Figure 7 shows inter-story displacement by response spectrum analysis. This indicate that the LRB system control the period of structure against the earth movement's period since that reducing the frequency of structure along with increasing the period of structure. While through time history analysis of the structure for fixed-base system and base-isolated system have shown an increment of 68% for inter-story displacement which as shown in Figure 8.

Table 3 Comparison of natural period for fixed base and base isolated system by response spectrum

T at each floor	Fixed-Base System, T (sec)	Base Isolated System, T (sec)
1st floor	2.25	1.87
2nd floor	1.76	1.55
3rd floor	1.28	1.09
4th floor	0.98	0.76
5th floor	0.7	0.65
6th floor	0.55	0.48
7th floor	0.45	0.27
8th floor	0.18	0.17
9th floor	0.09	0.05

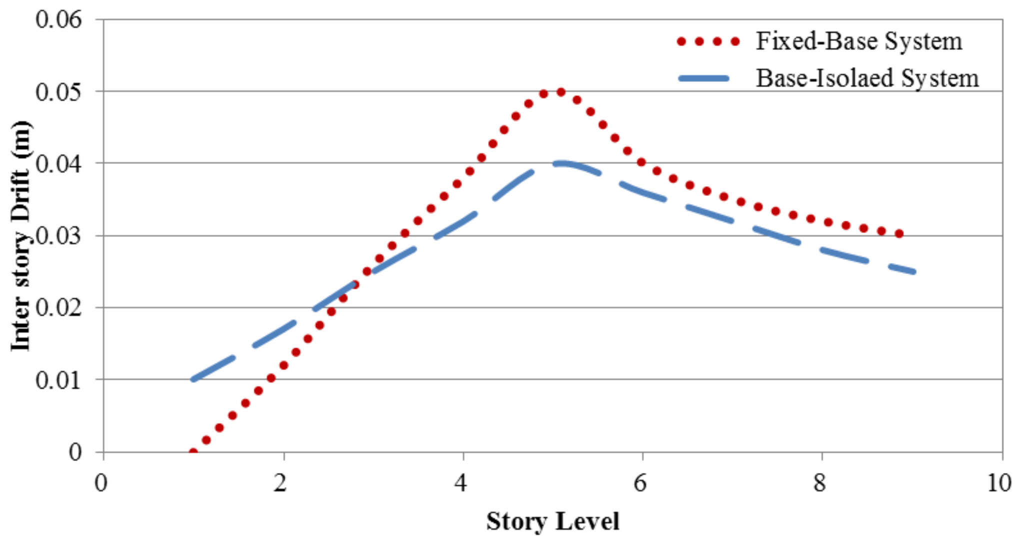


Figure 7 Inter story displacement by response spectrum analysis

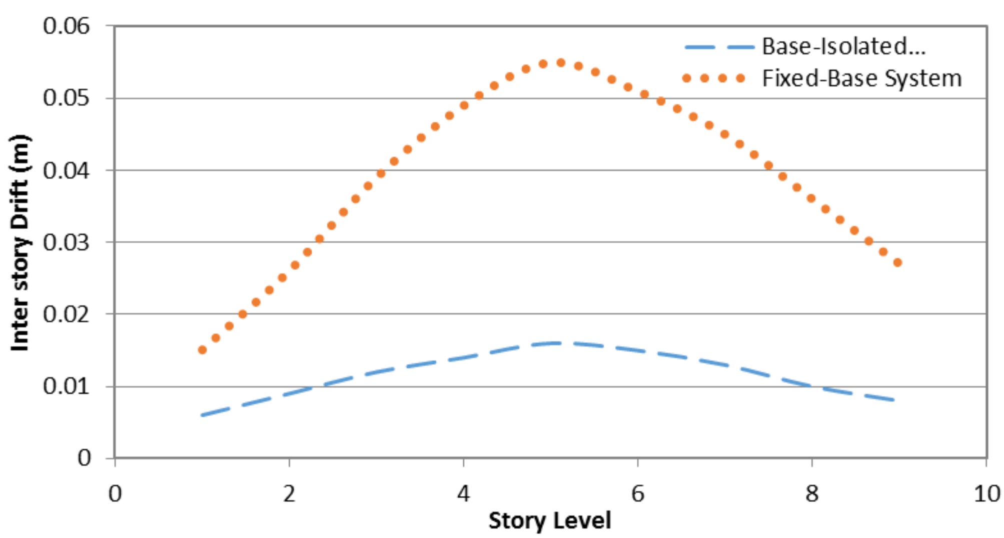


Figure 8 Inter-story displacements by time history

By comparing the roof level acceleration in both systems, it can be seen that the reduction of 81% of roof level acceleration for base isolated system which as shown in Figure 9. It can be seen that the beginning value of acceleration in base isolated system are at least a half of fixed base acceleration values. This showing the LRB is efficient to absorve more energy during the excitation of the structures.

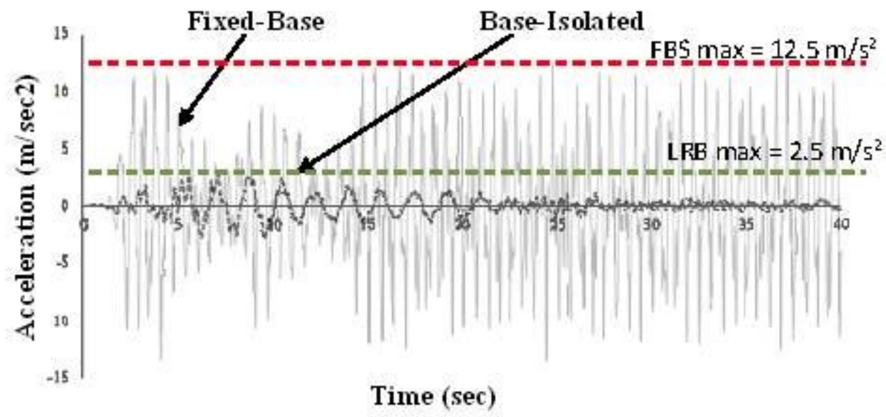
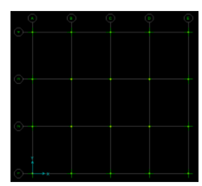
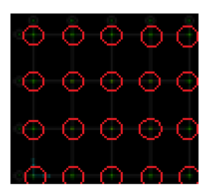
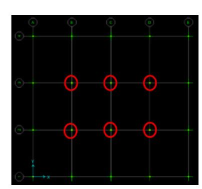
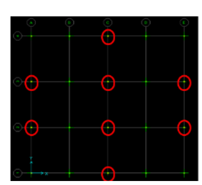


Figure 9 Comparison of roof level acceleration in both systems

■5.0 PARAMETRIC STUDY ON MIXED BASE-SYSTEM CONDITION

According to the results of this study which are concentrating on fixed-base system and base-isolated system, mixing of both systems for the best responces of top level acceleration and displacement were also considered. In this study, finding the way to mix both system (FBS & BIS) is an important factor to decrease the rate of damaging of building and cost of structure as well. Table 4 shows the proposed design of mixed base system for the same plan.

Table 4 Systems with different type of locating support

System with type of support	No. of Column	No. of LRB	No. of Pin support(FBS)	Figure of plan
FBS	20	0	20	
LRB	20	20	0	
Mix Base 1 (MB1)	20	6	14	
Mix Base 2 (MB2)	20	8	12	

According to the results of this study, mixed both systems to get the best consequences for top level acceleration and displacement is considered. The simulation result of top level acceleration for different system as proposed in Table 4 are shown in Figure 10.

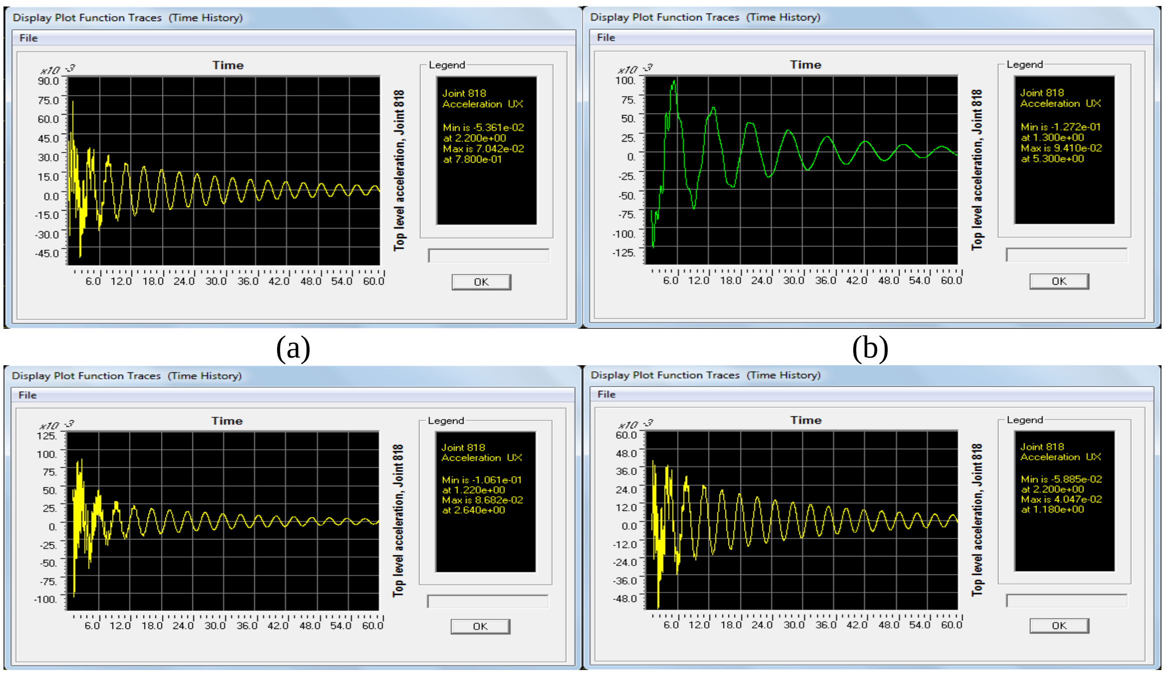


Figure 10 Maximum plot of acceleration in (a) FBS, (b) LRB, (c) MB1 and (d) MB2

Figures 11-15 show the comparison result of the inter-story displacement, total drift and top level acceleration in time history and response spectrum analysis. The comparison results are presented for all different systems. The comparison of top level drift and top level acceleration in all structures is shown in the following part which shows the accuracy of LRB system compared to others. If maximum of top level drift and acceleration lower, the accuracy is increased. Obtaining the ratio of all systems illustrate the reduction of LRB values compared to other modelled structures. It also can be observed that the peak displacements obtained by the time history analysis are less than those of the response spectrum method of analysis [10]. This is caused by damping due to the hysteretic effect is more than the equivalent damping considered in the response spectrum method of analysis.

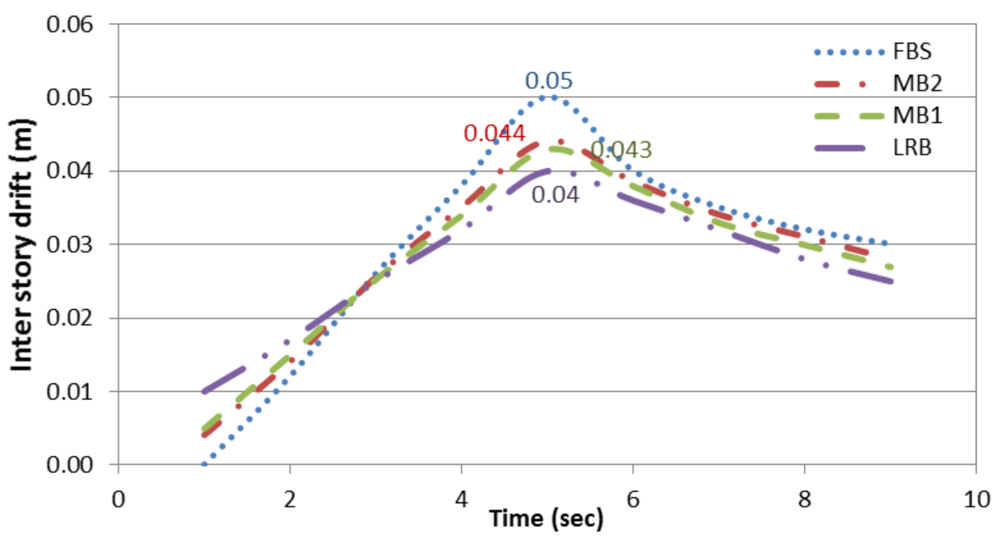


Figure 11 Inter-story displacements by response spectrum analysis

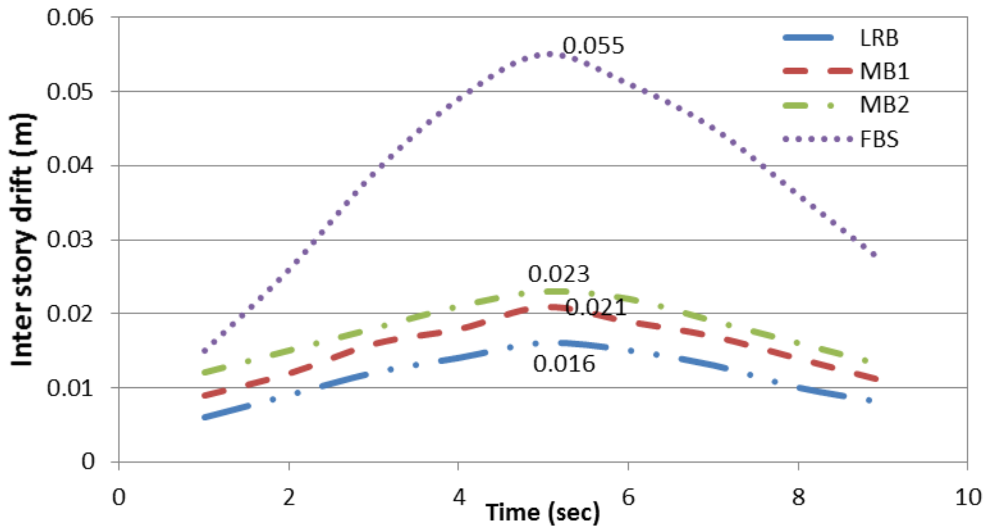


Figure 12 Inter-story displacements by time history analysis

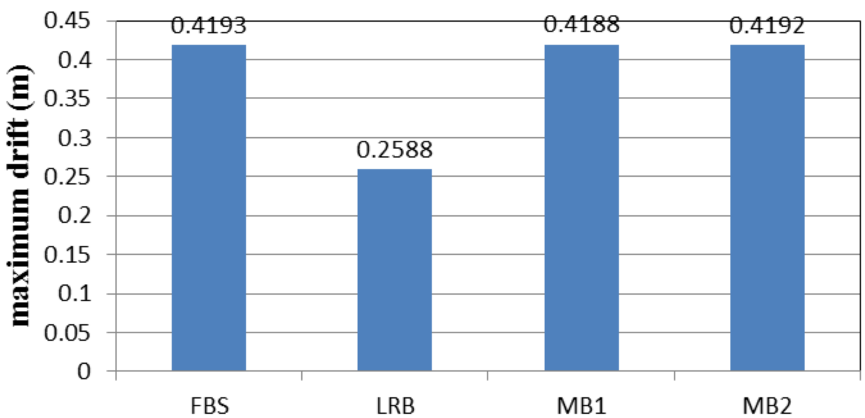


Figure 13 Maximum of top level drift by response spectrum analysis

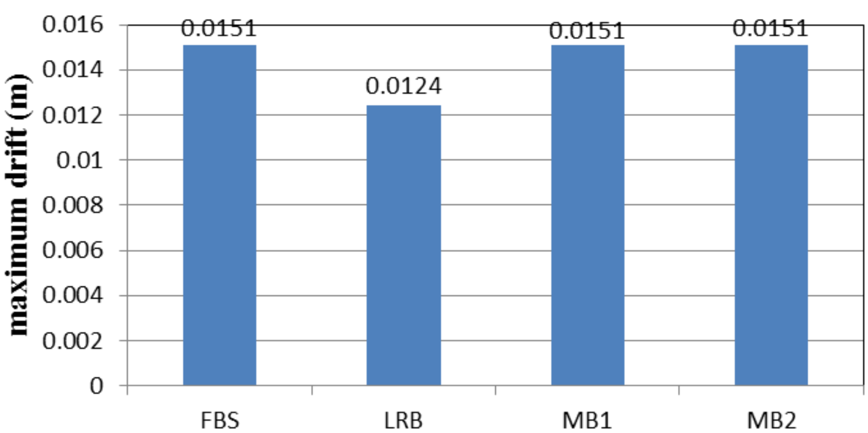


Figure 14 maximum of top level drift by time history analysis

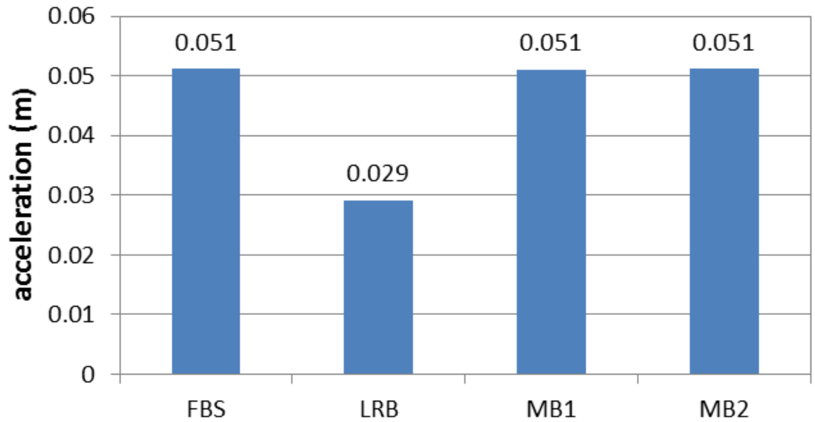


Figure 15 Maximum of top level acceleration

■6.0 CONCLUSION

Regarding to the results of the analysis of the study, the proposed study is more reliable and safer than the fixed-based structure. Significant influences by using the different dimension of materials in isolator reduces the response of structure. The acceleration becomes in lower value for the shear and bending due to the higher time period occur but it causes the increasing in damping. The comparison of acceleration and time period also are carried out between the response spectrum analysis and time history analysis in both fixed-base system and base isolated system to find the optimum seismic response while the dynamic analysis is selected. In this study, it can be seen that the base shear is reduced by 65-75 % in Response Spectrum Analysis, while in Time History Analysis base shear is reduced by 75-85%. The reduction in response of structure also can be obtained by using the best properties values for LRB such as number of layers, size, stiffness and damping. The model is capable to reduce the seismic structural response. The accuracy of the result of the validation shows that the model is capable to use by the designers and engineers.

Acknowledgements

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