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INVESTIGATING THE EFFECT OF LEAD-RUBBER BEARINGS IN CONCRETE BUILDINGS FEATURING DUAL MOMENT FRAME AND SHEAR WALL SYSTEMS

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Abstract. One method of improvement and safeguarding the ductility is making use of seismic base isolation system. Seismic isolation system effectively isolates the building from the horizontal components of earthquake. The shear walls at the side of the moment frames can provide for a soft, resistant and ductile behavior of the whole building and toleration of the highest quotient of the base shear force that brings about a considerable increase in the building's stiffness and a notable decrease in the damage to the nonstructural elements. The main objective of the present study is the investigation of the seismic behavior of the isolated concrete buildings and comparison of the results with those obtained for fixed base structures. The study's goal is actualized through nonlinear dynamic analyses using far and near-fault earthquake accelerographs assisted by ETABS V 9.6.0 and REFORM 3D software. The present study considers three seven-storey, twelve-storey and twenty-storey (representing short-, medium- and high-rise) structures featuring moment frame dual system with shear walls along the x- and y-axes and designs a lead-rubber base isolation system for them. On the other hand, the structure responses, including the floors' relative displacements, floors' shear forces and the components' internal forces have to also be made clear. The use of isolation systems in seven-storey and twelve-storey structures led to the reduction of responses and improvement of the structure behavior. As for the high-rise buildings with high alternating periods, the addition of isolation systems causes an increase in the structures' responses.

Keywords: concrete buildings with shear walls, lead-rubber bearings, time history analysis, near- and far-fault earthquake

Introduction. Seismic isolation system is a new method for reducing the relative displacement and acceleration of the storeys. Using this method brings about a reduction in the acceleration of the superstructure in contrast to the fixed base mode that will per se cause the mitigation of the inductive force imposed on the storeys' masses. The present study's primary objective of using isolation method is preventing the direct transferring of earthquake force from the foundation to the structure. Generally, isolation of a part or the whole structure from the ground parallel to reducing the ground motion response is called seismic isolation. Of course, the optimal implementation of base isolation is constrained due to the presence of inherent friction in the materials, control of the absolute structure displacement as well as for such reasons as executive shortfalls. Appropriate isolation, besides providing for proper lateral flexibility and damping, has to feature a large deal of stiffness in vertical direction to prevent the structure from swinging and moving in a cradle like motion [1].

The primary objective of the seismic isolation system is the transmitting of the structure's main frequency to a span away from the earthquake's frequency domain (preventing from the amplification phenomenon) through providing it with sufficient horizontal flexibility. Large displacements in isolation system causes a reduction in the seismic forces transferred to the superstructure. The mechanism used in this regard is in such a way that the gravitational loads are endured by the superstructure for its sufficient vertical stiffness; but, reductions are brought in the transferring of the horizontal loads. The structure's main frequency transmit is compensated by the base-isolation system's horizontal flexibility [2].

In 2007, C. P. Providakis conducted a study on the effect of lead-rubber bearings and supplemental viscous dampers on the buildings' isolation subject to near-fault earthquakes. He selected two reinforced concrete, 6-storey and 5-sorey asymmetric, buildings with lead-rubber bearings and supplemental viscous dampers (beneath each column) and performed nonlinear time history analysis using ETABS. He concluded that it is necessary in near-fault regions to make use of lead-rubber bearing systems and supplemental viscous dampers to decrease the devastative effects of earthquakes; although the high damping of the isolation systems in regard of the far-fault earthquakes causes an increase in the buildings' stiffness through counteracting the structures' displacement and by transferring energy to the higher modes, the primary goal of using an isolation system, to wit reducing the superstructure's drift, is violated [3]. In 2008, Providakis carried out a research on the effect of supplemental damping on the lead-rubber and friction-pendulum isolation system under near-fault earthquakes. He analyzed two 5-storey and 6-storey reinforced concrete buildings with supplemental viscous dampers (placed in parallel to the isolation systems) using ETABS based on linear dynamic method and concluded that far-fault earthquakes, the existence of supplemental viscous dampers in the system for both of the lead-rubber and friction-pendulum isolation systems cause an increase on the lateral displacement of the floors and an increase in the absolute acceleration of the storeys. This is indicative of the idea that the seismic base isolation might be damaged due to the uncontrolled lateral displacement of the storeys for some damping amounts of the supplemental dampers; but, in near-fault earthquakes, this limits the storey's absolute acceleration in both of the isolation system. He figured out that in order it is necessary to use an isolation system accompanied by supplemental viscous dampers to reduce the supports' displacements. Of course, the supplemental damping has to be limited to a given value (for example to 20% at most) so that the storey's lateral displacement could be prevented in far-fault earthquakes [4]. It was shown in a separate study that was undertaken by Providakis in 2007 on a combined steel-concrete skeleton building through pushover analysis subject to near-fault earthquakes that the system ductility using composite frames is considerably increased when using seismic isolation system and that such a type of superstructures intensively neutralizes the earthquake inertia. The study was undertaken using ETABS 2000 and bilinear hysteretic cushion modeling and it was demonstrated that the structure exhibits more optimum behaviors in target displacement. Also, the system becomes subject to a higher level of base shear in case of seismic isolation system use in braced state than in an unbraced state and similar behaviors were documented for almost all of the lead core elastic buttresses featuring different physical characteristics. The seismic isolation systems that have always been effective in reducing the base shear showed relatively high displacement in the first floor subject to near-fault ground vibrations. Under such conditions, addition of the braces augments the structure's ductility and reduces the number of the plastic hinges in the overall structure system. Also, the braces could reduce the relative inter-floor displacement by 30% [1]. In 2011, Shayanfar and Torabi dealt with the effect of lead-rubber bearings on the buildings with steel moment frames in far- and near-fault excitations and linearly modeled the buildings in ETABS software. They run nonlinear time history analysis on three 4-storey, 10-storey and 15-storey moment frame lead-rubber isolated buildings subjected to twenty near-fault earthquakes and eight far-fault earthquakes and presented the mean values of the results in separate in tables and then discussed about them. They concluded that the reduced amounts of the structures' response (base shear, roof floor absolute acceleration and relative lateral displacement of the floors) are higher for near-fault earthquakes than for the far-fault earthquakes and the base isolation effect is reduced with the increase in the buildings' heights and that the increase in the displacement brings about an increase in the reduced response of the structures in buildings with moment frame system [5]. M. K. Sharbatdar et al performed a study in 2011 on seismic response of the lead-rubber and friction-pendulum isolated structures subject to near-fault earthquakes. They considered a 15-storey lead-rubber and friction-pendulum isolated building and nonlinearly analyzed it in a 3D model for five earthquake records. The numerical results obtained from the analysis subject to 4 Imperial Valley earthquake records are indicative of the idea that the maximum base displacement can become different up to 66% in a limited region within a 4-km distance from a disintegrated fault. Also, it was figured out that the highest higher floors' acceleration can be different up to 33% for this region [6]. In 2012, Shakery and Ja'afary in an article investigated the behavior of the behaviors of moment frame buildings with lead-rubber bearings. To do so, they selected two 5-storey and 10-storey buildings and designed isolation systems for them in three states, namely soft, normal and rigid. The studied samples were dynamically evaluated using nonlinear time history analysis subject to the effect of seven different earthquakes. The results are illustrative of the favorable behaviors of the structures isolated using soft isolation systems. They concluded that the use of base isolation system leads to the reduction in the acceleration caused in various floors in respect to the fixed base structures. It was also found out that the reduction in the base isolation system's lateral stiffness brings about a reduction in the relative inter-storey displacement but increases the isolated level's displacement and that , generally, the reduction in the base isolated system's lateral stiffness causes a reduction in the acceleration created in the various storeys [7]. Radmila B. Salic et al conducted a study in 2008 on the response of the lead-rubber isolated buildings. They selected a seven-storey residential symmetric building with shear walls in Scopia and measured the building's vibrations using GPS and seismograph in six points, i.e. in four corners and on every floor. The response of the locked-base structures was determined using environment response experiment (based on the Fourier's analysis of the recorded signals' domain spectrum) and modal identification software (ARTeMIS). They made use of four time histories for various earthquakes to compare the nonlinear response of the locked-base and lead-rubber isolated structure. The dynamic analysis of both of the models using ETABS (Nonlinear9.0.4) revealed the positive aspects of seismic isolation systems in structures' response to the external loads as given below:

1) **Increasing the Natural Alternation Time:** this causes the distancing of the system's alternation time from the earthquake's alternation time followed by an in increase in the system's flexibility.
2) **Reducing Base Shear:** the reduction in the base shear force is well evident in the seismic isolated model.
3) **Increasing Displacement:** the increase in the system flexibility leads to the increase in the total displacement for the elastic property of the isolation system.

4) **Reducing the Inter-**Floor Displacement: this reduction enables the structure to behave as an almost ideal rigid material in which case the damage to the structural and nonstructural elements will be minimized.
5) **Reducing the floors' acceleration.**
6) **Changing the Energy Depreciation Mechanism:** in classic structures, the energy depreciation was based on the plastic deformation of certain points of the structure. In isolated structures, the energy depreciation is concentrated on the isolated floor providing for simple design, control and contingent repairs [8].

Shayanfar and Torabi dealt with the amounts of the structure response in two concentric and eccentric braced systems for locked-base and lead-rubber isolated modes. They applied time history analysis on twenty near-fault earthquakes and eight far-fault earthquakes and came to the conclusion that the increase in the isolated design's displacement causes and increase in the reduced amounts of the structure response for locked-base and isolated structures and that the structures' responses undergo more reductions in concentric braced systems than in eccentric braced systems [9]. In another study, they also dealt with the effect of lead-rubber bearings in steel frame buildings with concentric frames. Using nonlinear time history analysis, they concluded that the increase in the isolation system's alternation period brings about a reduction in the absolute acceleration of the roof and shear base while the isolation system's displacement is increased; furthermore, it was made clear that the superstructure's drifting displacements do not follow a specific rule and that the number of the floors does not exert much of an effect on the superstructure's drift for identical alternation period of the isolation systems. They acquired a value about 10% for the ratio of isolation system's specific resistance to building's total weight that reduces the isolation system's displacement to a minimum value [10].

Abdullahzadeh and Ebrahimikhah dealt with the effect of elastomeric base isolation systems on the behavior of the 3D steel structure models with concentric braced systems. It was concluded in a dynamic spectrum analysis in SAP software of the 3-storey, 6-storey and 10-storey structures in fixed base and isolated base modes with different stiffness rates of the isolation systems that 1) the behaviors of the superstructures with fixed base and the structural deformities are considerable for all of the modes but the isolated structures behave like rigid objects for the first mode and they only exhibit structural deformations in other modes; 2) the modal mass participation coefficient of the isolated structures in the first mode is almost equal to unity and almost zero for the next modes, meaning that the entire energy of the ground motion is absorbed in the first vibration mode wherein the structural deformation is trivial; 3) the shear strength of the isolated floors undergoes smaller reductions in contrast to the similar locked structures with the increase in the number of the floors or reduction in the superstructure's stiffness, so the isolation systems exert far greater influences in stiffer structures, to wit the shorter structures for identical conditions; 4) due to the high stiffness of the concentric braced systems, the use of such a system that features a higher lateral stiffness in comparison to the moment frame will be followed by results closer to the considerations of UBC97 guidelines (assuming the superstructure equivalent to one degree of freedom); 5) according to the seismic isolation systems' performance, it is not appropriate and justifiable to use such systems in improving the seismic behavior of the high-rise buildings that spontaneously feature high alternation times [11]. Heaton et al investigated the seismic isolation systems subject to $7M_w$ earthquakes and concluded that the isolation systems undergo severe displacement when the dampers reach 25% of their critical damping which can result in isolation system's buckling or failure in strong seismic waves [12]. Kelly, as well, points to the need for high damping to reduce the isolation systems' displacement and concludes that high damping influences the superstructure forces leading to the increase in the lateral displacement of the floors [13].

Makris and Chang came to the conclusion through analyzing two single and double degree of freedom isolated buildings that the use of energy depreciation mechanisms alleviates the seismic response of the isolated buildings subject to near-fault earthquakes. They found out that the seismic isolated system is effective in fighting the effects of the near-fault earthquakes when it is devised with an appropriate energy depreciation mechanism [14]. In 2012, A. B. M. Saif Al-Islam et al dealt with the design of a combination of lead-rubber and rubber base isolation systems featuring high damping for four to ten-storey buildings in moderately earthquake-prone regions and investigated the buildings' seismic response using the combined model. Due to the high orthogonal stiffness of the rubber support with high damping and its ability to endure high loads of the structure, the internal columns were isolated using rubber isolation systems featuring high damping and the external columns were isolated using lead-rubber bearings. They carried out the linear static analysis and linear dynamic analysis and nonlinear dynamic analysis of the locked-base and isolated-base buildings through taking advantage of the finite element method of the SAP2000 software. They concluded that the seismic isolation technique brings about optimal reductions in structural damage caused in strong earthquakes. With the innovative composition of the isolation systems, the components of the multi-storey buildings experienced lesser amounts of shear stress, flexural moment and lateral displacement subject to lateral earthquake loads. The selected isolation system brought about reduction in the isolation system's frequency and then caused reduction in the acceleration of the isolated building's floors. They found out that the maximum reduction in the base acceleration subject to bilateral EQ waves in case of using isolation increases by ten times that of the non-isolated buildings in places wherein the soil ranges in its stiffness from soft to medium. Similar results were obtained for both of the soil types. However, the selection of the isolation system should be based on the comparison between the floors' acceleration reduction and the rigid building components' displacement with the objective of optimization.

However, for buildings constructed on soft soil that feature excitations with long alternation periods, the isolation system design should be carried out through exercising precision so as to avoid the amplification phenomenon [15]. Concrete is frequently used for different purposes in structures and it is the masonry preferred especially in highly humid areas to steel materials. There is a high resistance to fire in reinforced concrete structures. The shear walls are capable of tolerating the highest share of base shear force that causes a considerable increase in the buildings' stiffness and notable reduction in the damage to the nonstructural elements. Also, the shear walls are capable of enduring large gravitational forces even after developing numerous cracks but the columns lack such a property. The aforesaid properties have altogether made the dual systems with concrete shear walls more reliable than the moment frame systems [9]. It seems that the study of the effect of lead-rubber bearing on concrete buildings with dual moment frame and shear wall systems and the investigation of their responses subject to near- and far-fault earthquakes are amongst the cases that have not been dealt with previously. Moreover, it is more logical to make use of faster nonlinear analytical software such as PERFORM 3D due to the low speed of SAP software. The present study studies the relative floor displacement, components' internal forces and the shear forces of three seven-storey, twelve-storey and twenty-storey buildings using four far-fault seismographs and four near-fault seismographs.

Base Isolation system Modeling. Lead-core rubber supports are the most successful and most widely used seismic isolation systems around the globe. These isolation systems were invented in 1970s by Dr. Bill Robinson. These supports are currently considered as the most reliable and most efficient equipment used to provide various structures with protection against earthquakes and they have been used in more than 8000 structures worldwide since the day they were introduced to the market.

Lead-core rubber supports have exhibited a suitable performance in regard of the concomitant control of the weak and strong earthquake waves through displaying a bilinear behavior and softening subject to relatively severe seismic loads. The lead core of these supports alongside with the stiffness of the rubber segment that is very low in contrast to the lead part's stiffness provides for the initial stiffness required for these supports as demonstrated in the force-displacement diagram. The segment is taken to its yield limit with the increase in the loading and exhibits a very low stiffness against the lateral load. This stiffness along with the stiffness of the support's rubber part provides for the secondary stiffness as shown in the force-displacement diagram. The behavior is depicted below [16]:

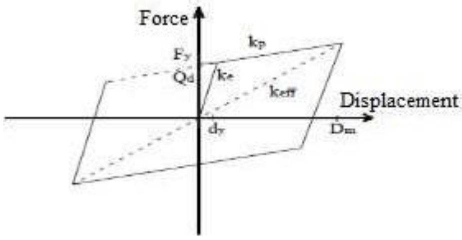


Figure (1): nonlinear behavior of the lead-core rubber isolation system

In practice, all of the isolation system buttresses are modelled in bilinear and based on K_e, K_p and Q_d parameters as displayed above. Elastic stiffness, K_1, can be obtained from the residual chains extant in the experimented elastomeric buttresses. The specific strength, Q, is obtained for the elastomeric buttresses from the residual chains and from the yield stress and lead area for the lead-core buttresses. The post-yield stiffness can be precisely estimated or predicted for both of the aforementioned buttress types.

1. Specifications of the Base Isolation System:

Based on the considered masses, 24 elastomeric buttresses were designed and used in three 1, 2 and 3 types in every structure. The type one isolation systems are corner isolation systems, the type two isolation systems are middle isolation systems and the type three isolation systems are side isolation systems of the structure. The specifications of all three isolation system types used for each of the buildings are summarized in the following tables.

Table 1: types of the isolation systems used in the seven-storey isolation systems

Isolation system Type	Qd (ton)	Kd (ton/m)	Ku (ton/m)	Dm (m)
1	4.3	39.26	392.6	0.17
2	6.6	60.02	600.2	0.17
3	5.75	52.39	523.9	0.17

Table 2: types of the isolation systems used in the twelve-storey isolation systems

Isolation system Type	Qd (ton)	Kd (ton/m)	Ku (ton/m)	Dm (m)
1	8.66	68.01	680.1	0.197
2	11.67	91.67	916.7	0.197
3	11.13	87.42	874.2	0.197

Table 3: types of the isolation systems used in the twenty-storey isolation systems

Isolation system Type	Qd (ton)	Kd (ton/m)	Ku (ton/m)	Dm (m)
1	18.3	132.78	1327.8	0.213
2	22.4	162.75	1627.5	0.213
3	21.1	153.29	1532.9	0.213

2. Specifications of the Studied Buildings:

The studied structures are three 7-storey, 12-storey and 20-storey structures the lateral load-bearing system of which is composed of a moment concrete frame and moderately-reinforced concrete shear wall. These three structures have three spans along the x-axis and five spans along the y-axis. All the floors have identical height, 3.2m. The structures have been designed based on ACI 318-99 guidelines.

Table 4: summary of the gravitational loads imposed on the building

Position	Dead load (kg/m^2)	Live load (kg/m^2)
Storey's floors	555	400
Roof floor	615	150
Invisible lateral walls	215	-
Visible lateral walls	215	-
Shelter walls	215	-

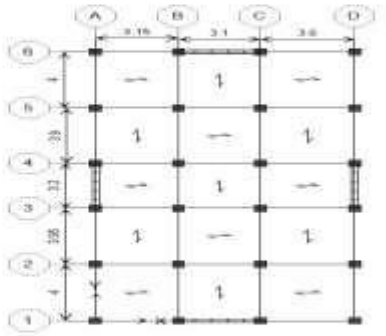


Figure (2): the plan of the studied structure

ETABS V.9.5.0 software was used to perform the preliminary analysis and design of the structure that is capable of 3D analysis and designing of the structures corresponding to the credible procedures. After the determination of gravitational and seismic loads, the intended model was subjected to force analysis and the structure components were designed in the software based on ACI 318-99 standards. The studied structures were remodeled in PERFORM-3D and subjected to nonlinear time history analysis. It is worth mentioning that PERFORM-3D software is capable of running nonlinear analysis but incapable of designing and the obtained cross-sections were translocated from ETABS to PERFORM-3D. Fiber Element was used to model the shear wall.

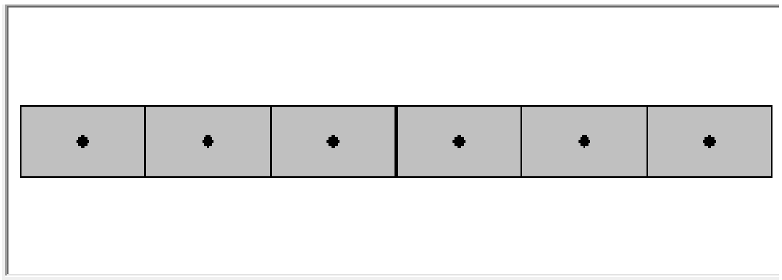


Figure (3): fiber cross-section model

The specifications of the four near-fault and the four far-fault earthquakes are as tabulated below:

Table 5: structural specifications of the studied locked-base buildings

	Height (m)	Mass (kg)	Alternation time along x-axis	Alternation time along y-axis
7-storey building	22.4	2637.7	0.514	0.514

12-storey building	38.4	5080	0.771	0.771
20-storey building	64	9792	0.131	0.131

Table 6: specifications of the four far-fault earthquake

Row	Occurrence location	Station	Occurrence year	Soil	Distance	PGA
1	Irpinia,Italy	ENEL 99999	1980	B	46.16	0.2137
2	Northridge	CDMG 24278	1994	B	40.68	0.4898
3	LomaPrieta	VSGS1601 PaloAlto	1989	B	51.2	0.2281
4	Chichi, Taiwan	CWB 9999936	1999	B	33.15	0.2565

Table 7: specifications of the four near-fault earthquake

Row	Occurrence location	Station	Occurrence year	Soil	Distance	PGA
1	Newzealand	99999Matahina Dam	1978	B	24.23	0.2926
2	LomaPrieta	VSGS 1652 Anderson Dam	1989	B	26.57	0.2385
3	SanFernando	CDMG24278 Castic	1971	B	25.36	0.2994
4	Northridge	CDMG 24283Moorpark	1994	B	31.45	0.2291

Nonlinear time history analysis serves the determination of the dynamic response of a structure subject to the effect of time-dependent forces. The calculated response is largely sensitive to the characteristics of the ground motion. Each pair of the seismograph features two perpendicular horizontal indicators that simultaneously influence the structure along the x- and y-axes. Since the mathematical model used in this method directly7 takes into account the inelastic response of the masonry, the internal forces obtained based on this method are approximately equal to the forces created in the structure during earthquake.

3. The Results Obtained from the Investigation of the Floors' Relative Displacements to Floors' Heights:

Floor drift is one of the main indices in evaluation of the seismic damages and it is estimated to determine the separation joint in order to prevent the structures from impacting one another. Drift is the most important controlling factor in structures' vibration system. The maximum ratio of the floors' relative displacements to floors' heights has been obtained as shown in the following diagrams through modeling three isolation system types for each of the studied structures. It is worth mentioning that the blue curve illustrates the locked-base structure response and the red curve demonstrates the isolated-base structure response.

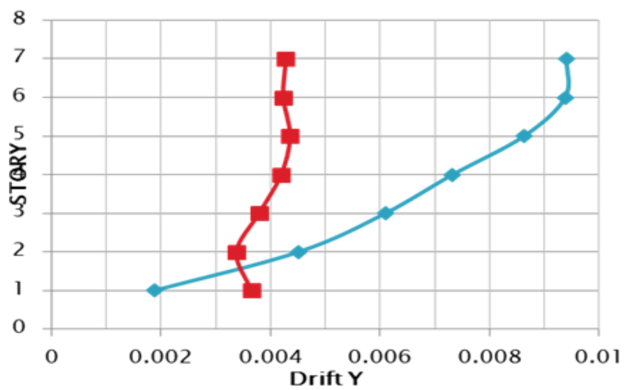


Figure (4): relative displacement of the seven-storey structure subject to near-fault earthquake

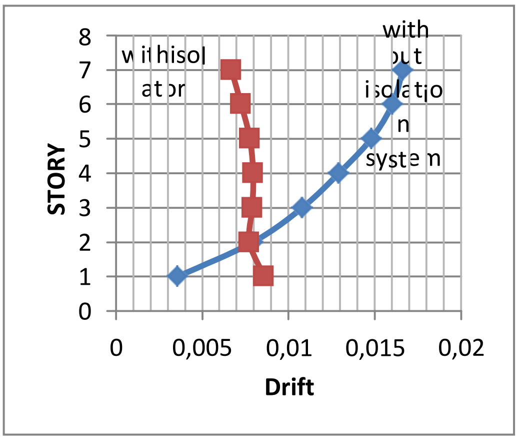
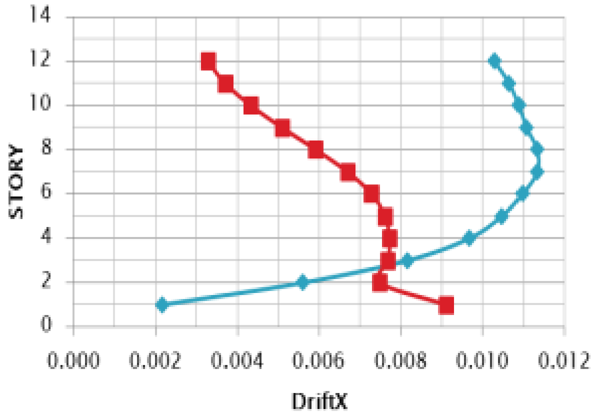


Figure (5): relative displacement of the seven-storey structure subject to far-fault earthquake



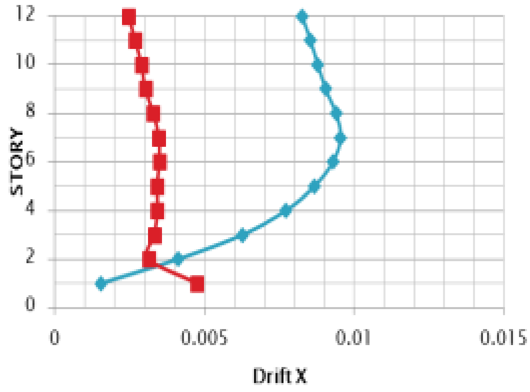
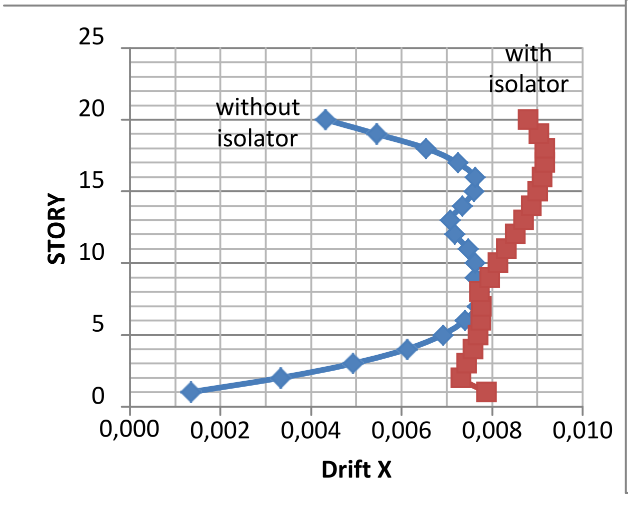


Figure (6): relative displacement of the twelve-storey structure subject to far-fault earthquake

Figure (7): relative displacement of the twelve-storey structure subject to near-fault earthquake



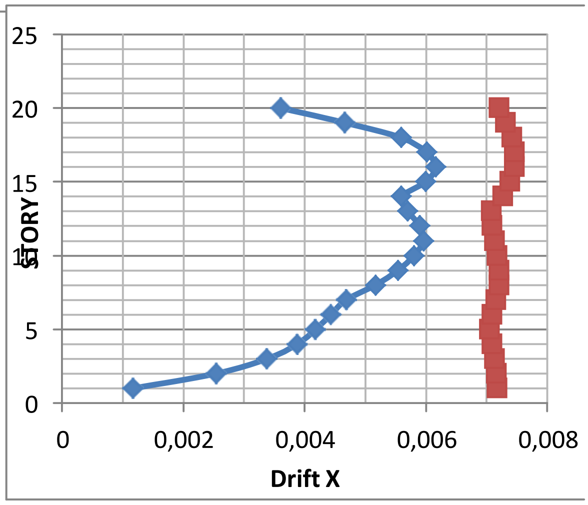


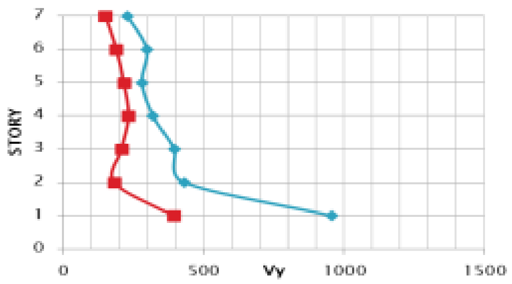
Figure (8): relative displacement of the twenty-storey structure subject to far-fault earthquake

Figure (9): relative displacement of the twenty-storey structure subject to near-fault earthquake

As it is observed, the highest relative displacement of the isolated seven-storey and twelve-storey structures occurs in the first floor and the highest relative displacement of the isolated twenty-storey structure, as well, has been found occurred in the first floor. Therefore, it can be stated that the existence of the isolated-base system causes the smoothing of the structural system responses. It can also be seen that the isolated seven-storey and twelve-storey systems have undergone considerable reduction in the relative displacement of the floors as compared to the locked-base structure but the results are different for the isolated twenty-storey structure in which the relative displacements are greater than those of the locked-base structure. Therefore, the use of such controller systems as base isolation brings about reductions in the relative displacement of the short to medium-height structures in an effective manner and this is well indicative of the importance of control systems in these structures. Also, the relative displacement created in the lower floors of the isolated building is higher subject to far-fault earthquake than to near-fault earthquake. In remote earthquakes, it was evidenced that the structure finds an opportunity to enter the nonlinear region following which the structure's flexibility is increased and the plastic joint's load-bearing is dispersed along the whole building.

4. The Results Obtained from Base Shear Evaluations of the Building storeys:

The following diagrams display the maximum shear stress of the storeys subject to far- and near-fault earthquakes in ton. It was found out in the investigation of the entire shear forces exerted onto the structures that the shear loading is decreased almost in all the floors for seven- and twelve-storey buildings with isolation systems but the addition of an isolation system to the twenty-storey building causes an increase in the shear stress of some storeys and reduction in that of the others.



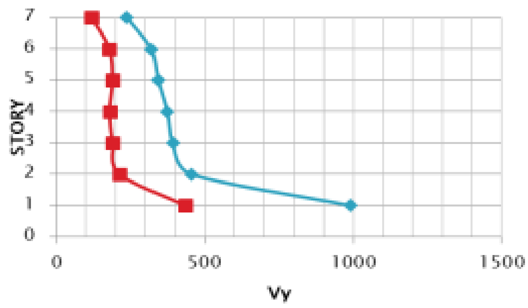
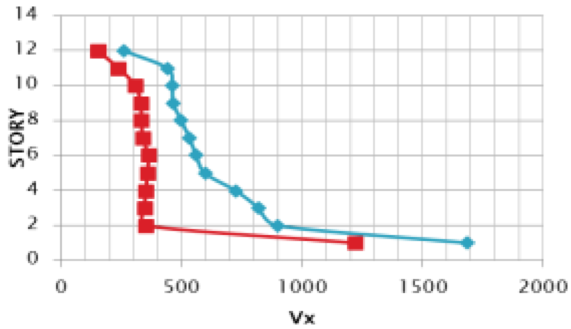


Figure (10): shear stress of the seven-storey structure subject to far-fault earthquake

Figure (11): shear stress of the seven-storey structure subject to near-fault earthquake



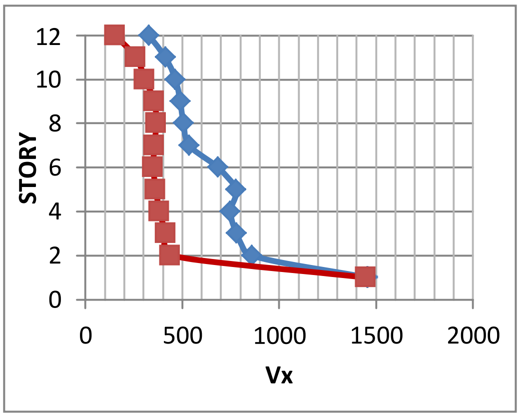
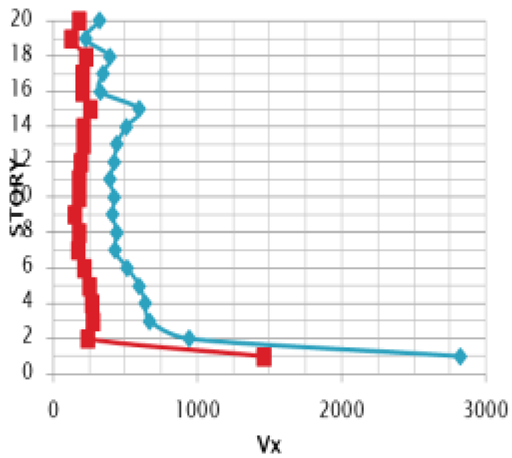


Figure (12): shear stress of the twelve-storey structure subject to near-fault earthquake

Figure (13): shear stress of the twelve -storey structure subject to far-fault earthquake



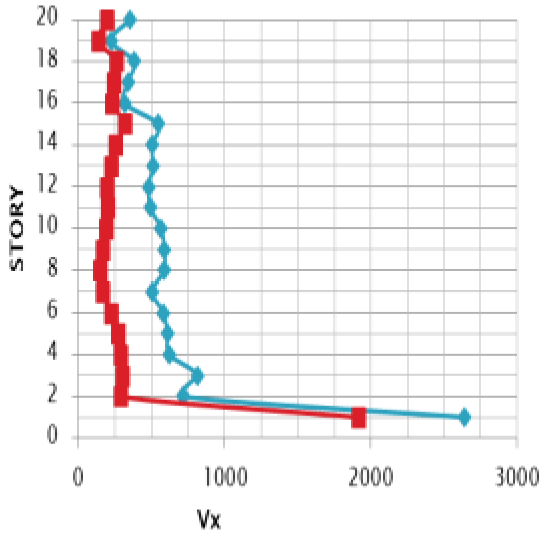


Figure (14): shear stress of the twenty-storey structure subject to near-fault earthquake

Figure (15): shear stress of the twenty-storey structure subject to far-fault earthquake

5. The Results Obtained from the Investigation of the Structure Components' Internal Forces:

The reduced amounts of the components' internal forces are given in percentage for the isolated structures in respect to the locked-based structures. The studied columns are the corner columns situated in the A and 6 axes intersection and the internal column positioned in the B and 3 axes intersection.

Table 8: the percentage of change in the internal forces of the isolated building first floor's corner column in respect to the changes in that of the locked-base structure subject to far-fault earthquake

Structure	Flexural moment reduction percentage	Shear force reduction percentage	Axial force reduction percentage
7-storey	-98.1	-65.9	-7.2
12-storey	-98.9	-61.5	-8.3
20-storey	-97.4	-71.4	-59.2

Table 9: the percentage of change in the internal forces of the isolated building first floor's corner column in respect to the changes in that of the locked-base structure subject to near-fault earthquake

Structure	Flexural moment reduction percentage	Shear force reduction percentage	Axial force reduction percentage
7-storey	-98.2	-60.5	-14.5
12-storey	-98.6	-67.7	-12.6
20-storey	-97.8	-79.05	-60.8

Table 10: the percentage of change in the internal forces of the isolated building first floor's internal column in respect to the changes in that of the locked-base structure subject to far-fault earthquake

Structure	Flexural moment reduction percentage	Shear force reduction percentage	Axial force reduction percentage
7-storey	-97.5	-72.4	-13.5
12-storey	-98.5	-66.6	-11.4
20-storey	-96.5	-89.8	-85.3

Table 11: the percentage of change in the internal forces of the isolated building first floor's internal column in respect to the changes in that of the locked-base structure subject to near-fault earthquake

Structure	Flexural moment reduction percentage	Shear force reduction percentage	Axial force reduction percentage
7-storey	-97.4	-75.7	-18.1
12-storey	-98.3	-71.7	-17.8
20-storey	-97.45	-92.1	-85.2

It can be stated according to the reduced amounts of the internal forces in the structure members that the use of base-isolated structures causes an optimal and favorable improvement in the structure behavior and the structural responses are considerably reduced through absorption and depreciation of energy.

6. Summarization:

The present study investigated the effect of bilinear hysteretic elastomeric isolation system on the response created in the superstructure considering the near- and far-fault earthquake excitations using nonlinear time history analysis. In line with this, three seven-storey, twelve-storey and twenty-storey buildings with shear walls were proposed because of being an appropriate pattern for the evaluation of structures' behaviors in earthquake. The investigation and comparison of the results were conducted in two stages for locked-based structures and isolated structures.

Considerable reduction in the floors' relative displacement was evidenced in the seven- and twelve-storey isolated system in contrast to the locked-base structure. The reason for such a finding can be the idea that the buildings act like rigid structures upon being built in with an isolation system in which case the column base will enjoy degrees of freedom that provide for large relative displacement in the column base and bar the transmit of the earthquake force to the upper floors and the relative displacement of the floors will be reduced resultantly. The results are different for the twenty-storey building. The relative displacements are higher in isolated buildings in comparison to in locked-base structures and this is indicative of the idea that the isolation system's performance is not favorable in twenty-storey buildings. Reducing the relative displacement of the floors in short- and medium-height structures, the isolation system minimizes the damage to the structural and nonstructural members.

According to the reduction in the shear force for the isolated mode as compared to the locked-base mode, it can be stated that the structural response is significantly lowered upon the insertion of base isolation system. The reason for such a subject is the energy depreciation in the base part through rubber layers of the isolation system. It was also figured out that the reduction in the structure's shear stress subject to near-fault earthquakes is more than the reduction in the shear stress subject to far-fault earthquakes and the shear force of the near-fault earthquake spans over a limited area. Generally, the responses obtained from the buildings subject to near-fault earthquakes span over a limited area than subject to far-fault earthquakes and this can be well justified through accelerograph readings indicating lower responses of the isolated structures due to entering the nonlinear region in near-fault earthquakes.

The use of isolation system largely influences the reduction of the internal forces of the seven-storey, twelve-storey and twenty-storey buildings' members in such a way that it causes reductions in the flexural moment up to 98%. Besides reducing the structure response, the elastomeric isolation systems distribute the imposed loads more evenly in the building floors in contrast to a non-isolated building. Therefore, the dimensions and capacities of the designed cross-sections can be reduced in designing works and bring about notable savings in the implementation of the structure system. Therefore, the use of isolation systems in structures with dual systems of concrete moment frame and shear wall positively influences the structure response reduction for buildings with alternation times below 1.5 s and some of the structure's responses might undergo reductions and some others might be increased for structures featuring alternation times up to about 2 seconds but the structure responses will be amplified most probably for alternation times above two seconds.

The following cases are suggested and recommended to supplement the researches extant on the seismic isolation of the structures:

1) Investigation of the irregularity effects subject to tri-component earthquake excitations in isolated concrete buildings
2) Evaluation of the effect of roof seismic isolation systems on the improvement of the tall buildings' behaviors
3) Investigation of the concomitant effect of plan irregularity and height on the isolated structures
4) Study of the smart base-isolated systems in concrete and steel structures
5) Survey of the base-isolated systems in buildings constructed using ordinary construction materials
6) Combining active and passive control of the irregular structures' behaviors in plan and height
7) Assessment of the dynamic behavior of the irregular isolated structures in height

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Appendix A: defined cross-sections of beam, column and shear wall

Table 1: cross-sections obtained for the beams

floor	Beam cross-sections: Cross-section dimensions (cm^2)	Moment reinforcement	Shear reinforcement
20-storey buildings	60×55	8Φ28	Φ12@15cm
12-storey buildings	50×45	6Φ28	Φ10@15cm
7-storey buildings	45×35	6Φ22	Φ8@15cm

Table 2: cross-sections obtained for the twenty-storey building's columns

floor	column cross-sections of the twenty-storey building: Cross-section dimensions (cm^2)	Moment reinforcement	Shear reinforcement (three way)
1-6	110×110	20Φ40	Φ12@15cm
7-15	100×100	20Φ36	Φ10@20cm
16-18	80×80	16Φ36	Φ10@25cm
19-20	60×60	12Φ28	Φ8@20cm

Table 3: cross-sections obtained for the twelve-storey building's columns

floor	column cross-sections of the twelve-storey building: Cross-section dimensions (cm^2)	Moment reinforcement	Shear reinforcement (three way)
1	95×95	18Φ40	Φ10@15cm
2-5	85×85	16Φ36	Φ8@15cm
6-7	65×65	12Φ30	Φ8@15cm

Table 4: cross-sections obtained for the seven-storey building's columns

floor	column cross-sections of the seven-storey building: Cross-section dimensions (cm^2)	Moment reinforcement	Shear reinforcement (three way)
1-4	60×60	16Φ34	Φ8@10cm
5-7	45×45	8Φ18	Φ8@20cm

Table 5: specifications of the obtained cross-sections for the seven-storey buildings shear walls

Floor	Seven-storey building's Shear wall cross-sections: x-axis (3.1m)			y-axis (3.2m)		
	Thickness (cm)	Vertical reinforcement	Shear reinforcement	Thickness (cm)	Vertical reinforcement	Shear reinforcement
1-4	30	Φ26@15cm	Φ10@20cm	30	Φ32@30cm	Φ10@20cm
5-7	30	Φ28@15cm	Φ10@20cm	30	Φ32@30cm	Φ10@20cm

Table 6: specifications of the obtained cross-sections for the twenty-storey buildings' shear walls

Floor	Twenty-storey building's Shear wall cross-sections: x-axis (3.1m)			y-axis (3.2m)		
	Thickness (cm)	Vertical reinforcement	Shear reinforcement	Thickness (cm)	Vertical reinforcement	Shear reinforcement
1-6	100	Φ32@10cm	Φ16@30cm	100	Φ32@10cm	Φ16@30cm
7-15	90	Φ34@10cm	Φ16@30cm	90	Φ28@10cm	Φ16@30cm
16-18	70	Φ26@10cm	Φ16@30cm	70	Φ26@10cm	Φ16@30cm
19-20	50	Φ20@10cm	Φ16@30cm	50	Φ20@10cm	Φ16@30cm

Table 7: specifications of the obtained cross-sections for the twelve-storey buildings' shear walls

Floor	Twenty-storey building's Shear wall cross-sections: x-axis (3.1m)			y-axis (3.2m)		
	Thickness (cm)	Vertical reinforcement	Shear reinforcement	Thickness (cm)	Vertical reinforcement	Shear reinforcement
1	60	Φ32@15cm	Φ14@30cm	60	Φ32@15cm	Φ14@30cm
2-5	55	Φ32@15cm	Φ18@30cm	55	Φ32@15cm	Φ18@30cm
6-12	55	Φ28@10cm	Φ14@30cm	55	Φ28@10cm	Φ14@30cm