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THE EFFECTS OF LEAD RUBBER BEARING (LRB) SYSTEMS ON THE EARTHQUAKE RESPONSE OF HIGH-RISE BUILDING

The base isolation systems set sight on mitigating the effects of forces triggered by an earthquake through neutralizing the interaction between building and ground by means of earthquake isolators. This study aims to determine the effects of base isolation systems on the earthquake response of a high-rise building. In the content of the study firstly the high-rise building is designed for different sized isolators under the framework of earthquake isolator technique, and then scrutinize the earthquake response of the same building by comparing its configurations equipped with different sized isolators and fixed support. The building has 122.5 m tall and 35 stories and 16×20 m² habitable inner space, which is properly considered in line with vertical settlement movement widely seen in the world metropolises, is punctiliously designed and diffusively probed within the concept of fixed support. During the following stage, 2 different diameter size of 21 cm. tall lead rubber bearings are added to the structure, its unpredictable behaviors and forces transferred to the building under 1999 Kocaeli Earthquake highlighted from the study that LRB systems provide better structural response to building compared to fixed system, and then the critical parameters such as acceleration, lateral displacements, base and shear forces are compared with each other. Figs.: 9. Table 1. Refs.: 13 titles.

Keywords: base isolation; lead rubber bearing system; earthquake response; high-rise building.

Problem statement and literature analysis. The earthquake has been the most significant and hazardous disaster that is always kept in mind to avoid of its impacts when it comes to construct a building in the history of human being. There are a lot of factors and situations that may cause damage on the structures during an earthquake. In the low-rise structures with a lower natural period, there occurs a threat of resonance because of the adjacency of building period to base period, while in the high-rise buildings the rigidity of structure is critically affected by the increased bending moment and shearing force because of the nonlinear behavior of structure caused by the motions of lower and upper stories during the vibration of building [1].

Thanks to advanced construction technologies, there is a wide range of alternatives to absorb the energy of an earthquake nowadays. Today, it is possible to improve the seismic performance of a structure through absorbing some of the energy entering to architectonics by means of various components like base isolation systems added to the structure [2]. The

method of seismic isolation mitigates the interaction between building and ground, and separates the upper structure from the ground motions by placing certain equipment that are capable of displacement – vertically rigid but horizontally elastic – on the base of structure [3]. More often than not, the horizontal components of an earthquake are severer than its vertical components. To this respect, the seismic isolators used in the earthquake resistant design of structures are usually planned in a way to have a lower lateral stiffness but a higher vertical stiffness. Thus and so, an isolated structure behaves like a pendulum with a single degree of freedom on the horizontal direction.

With a meticulous design taking into account the relation of mass-rigidity-frequency in the single degree of freedom systems, it is possible to design a base-isolated structure with a certain mass in a way to have a natural frequency that is far enough from the dominant frequencies of ground motions [2].

Through the help of a seismic (base) isolation system, a structure is able to demonstrate both enough elasticity to make big displacements and a rigid motion at the upper structure, as it will be independent of the ground. Thanks to this characteristic added to structure by the isolators, the various effects such as story translations, story momentums, shear forces applied to structure, and bending moments are considerably limited. As the higher modes causing substantially cross-sectional effects in a fixed support structure would fail to go with the motion (structural behavior) because of base isolation, the structure will be less exposed to the cross-sectional effects caused by higher modes. In Fig. 1, the behavior of a structure with anisolated and fixed support base is schematically exhibited.

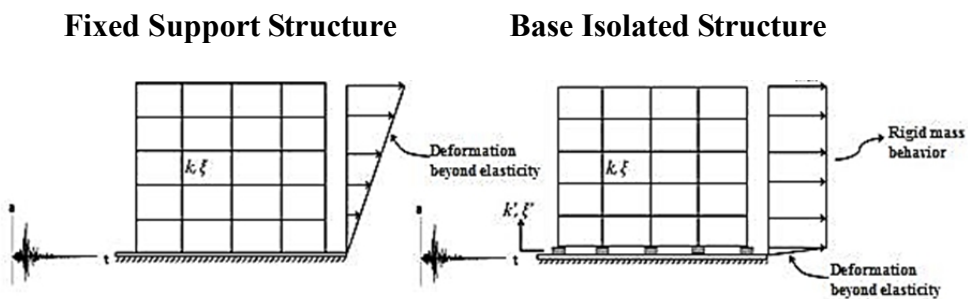


Fig. 1. The schematically exhibition of the behavior of a structure with fixed support and isolated base [4]

When fig. 1 is closely examined, it is seen that the internal forces in a structure with base isolation triggered by the effects of earthquake forces are likely to decrease in a businesslike manner.

The purpose of the article is to study the behavior of high-rise buildings during earthquakes, depending on the type of seismic isolation.

Numerical application. Description of High-Rise Building and Finite Element Modeling.

Within the scope of this study, a high-rise building with 122,5 meters tall and 35 story concrete construction with a base area of $16 \times 20 \text{ m}^2$ is selected. The plan view of the structure is shown in the fig. 2 *a*. As seen in fig. 2 *a*, *b*, the structure is designed to have four spacing in both directions. The concrete curtains are located at each of the four corners (5, A-B; 5, D-E; A, 4-5; E, 4-5; 1, A-B; 1, D-E; A, 1-2; E, and between the axes of 1 and 2) and around the elevator shaft (4, C-D; 3, C-D; D, 3-4), and then the finite element model of structure is set up by the help of an SAP2000 software (Fig. 2 *b*).

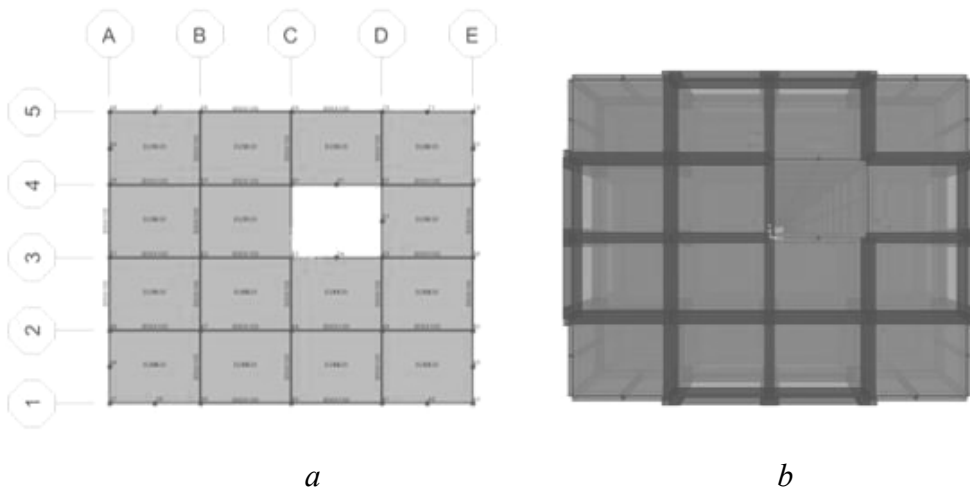


Fig. 2. *a* – Plan of selected concrete structure; *b* – Location of concrete curtains in finite element model

In this paper, it is targeted to determine the earthquake behavior of high-rise fixed support structures with seismic isolation. The blueprint of the model created for this purpose related with fixed support structure with seismic isolation is grounded on design spectrum (Fig. 3) – actually called as Uniform Building Code 1997 [5].

Accordingly, the columns with size of $80 \times 90 \text{ cm}^2$ and the beams with size of $50 \times 100 \text{ cm}^2$ are used, the floor height of 20 centimeters and the curtain width of 30 centimeters are selected, and C25-30 concrete as the material of construction and S420 steel as the reinforcement are preferred. There are 35 isolators placed between structure and ground as a result of design calculations of seismic isolated structure. According to the output of

calculations, the finite element models are formed through designing 2 different diameter size of 21 cm tall lead rubber bearings (74, and 90 centimeters).

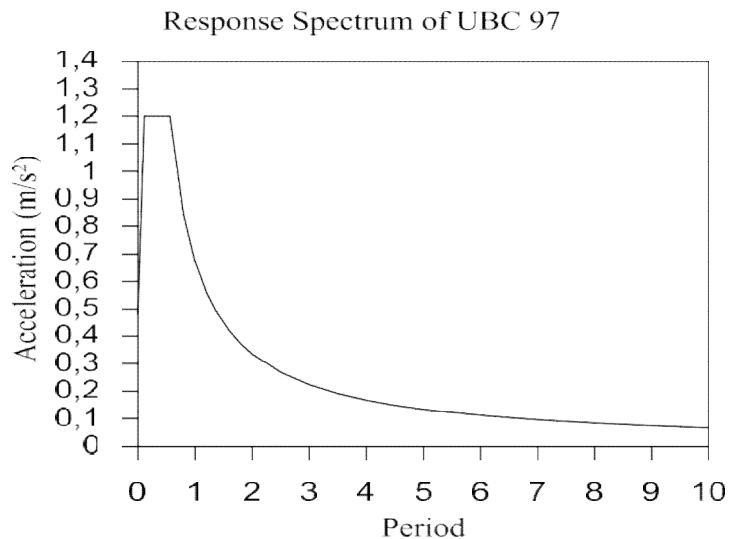


Fig. 3. Uniform Building Code 1997 earthquake design spectrum

In the design of isolators, the weights formed on structural bearings are obtained by the combination of 1,0 DL + 0,3 LL (1,0 Dead Load + 0,3 Live Load), and it is observed that the maximum of these values is 11871.29 kN, while the minimum of them is 4000.37 kN as seen in fig. 4. According to the findings of analysis, there are different sizes of support reactions formed at the base-column and base-curtain wall intersections. In compliance with the analysis, the structure effective period is realized as $T = 2.94$ s.

As the base layout is more limited and the interior constructional area should be used at maximum efficacy in the skyscraper style buildings like the structure in this study, there are far fewer number of columns standing on the ground. Thus, there will be pretty much vertical load on the base isolators to be placed. And, it will indispensably cause a compression pressure and a threat of torsion on the isolators. In order not to let that happen, it is mandatory to make designs by taking into account the isolator capacity, and vertical and horizontal loads during the calculation of structure, and consider the different types of base isolation systems instead of a single type of isolator in the case of design change is not an option.

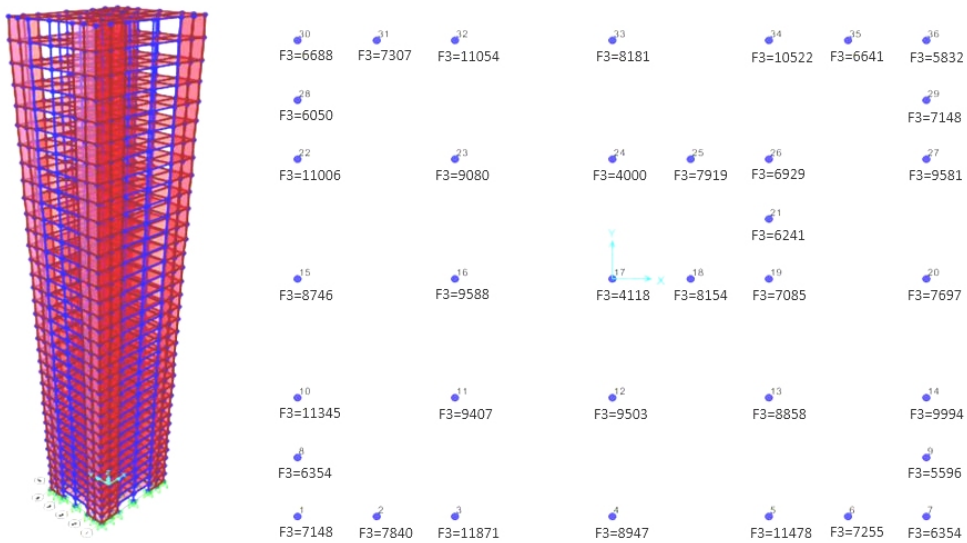


Fig. 4. The analysis findings at 0 (zero) elevation with respect to three-dimensional construction model and 1.0DL+0.3 LL combination of fixed support construction model

In the text and tables residing in the rest of study, the 21 cm tall isolator with 90 cm diameter will be denoted as KÇİ21.a, while the isolator with 74 cm diameter as KÇİ21.b (Fig. 5). In order to realistically evaluate the capacity and performance of the design and modeling conducted in this study, the information and tables subjected to experiment in the labs of California University, San Diego and delivered to the administration after the preparation of audit certificate within the concept of necessary items of IBC's [6] specification related with the structure's seismic isolation during the construction of Erzurum State Hospital are used [7].

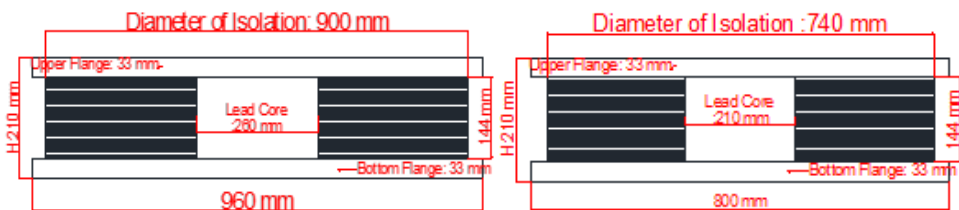


Fig. 5. The 21 centimeters long lead rubber bearing with diameters of 74 and 90 centimeters

The formulas and tables given in UBC 97 (Uniform Building Code, 1997) are used to determine the specifications of isolator. The earthquake zone is selected as No. 1 earthquake zone, and $A_0 = 0.40$ (UBC 97 $Z = 0.40$). $S_c -$

dense sand and soft rock – is selected as the soil profile type UBC 97. By considering the near fault effect, equations of $N_a = 1.2$ and $N_v = 1.2$ are assumed.

During the estimation of damping ratio, there is no need to use high damping rubber in the lead rubber bearing as enough dumping will be acquired due to the lead core at the heart of isolator. Therefore, the dumping ratio is taken as 20%, and the corresponding damping coefficients BD and BM are assigned the value of 1.5 [2].

The coefficients are assigned values as: lateral load coefficient, $RL = 2$, fixed in structure lateral load coefficient, $R = 8$, and the building significance coefficient, $I = 1$.

Earthquake Response of the High-Rise Building. In order to identify the earthquake behavior of the building, the spectrum obtained for 5% of damping ratio in the accelerogram produced from İzmit Meteorological Station about 1999 Kocaeli earthquake is applied to the structure in X and Y directions. The time histories of the acceleration record are given fig. 6 *a*, while the spectrum graph of record in fig. 6 *b*.

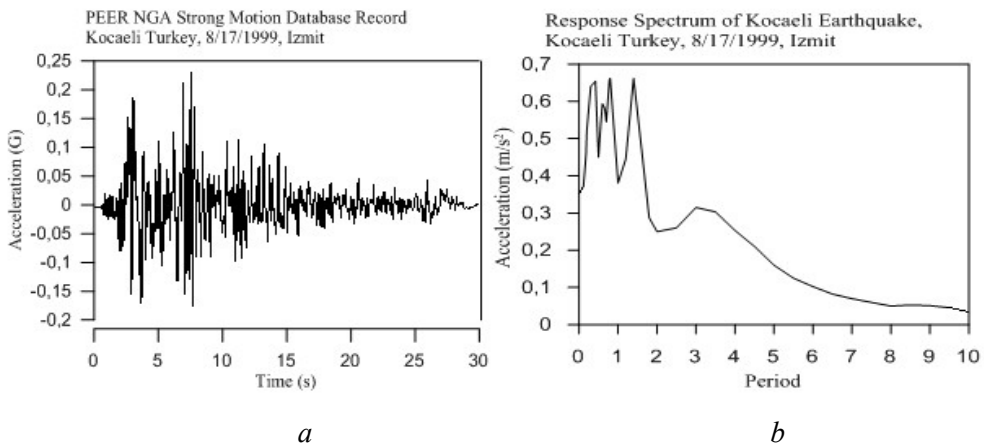


Fig. 6. *a* – Time histories of acceleration record; *b* – Response spectrum graph

According to the analysis results of fixed support structure subjected to vertical load, there is a difference of value up to 2 – 3 times between maximum and minimum normal force that are calculated at the level of structural bearing. In terms of structure cost and factualness of study, No. 1 and 2 nodal points (fig. 4) are assigned two isolator designs with the same height but different diameters with respect to the vertical load values of 7840 kN and 11871 kN respectively.

According to the modal analysis results of fixed support model, the structure effective period is calculated as $T = 2.94$ s. If a structure with that

period is subjected to a seismic isolation to pull up the structure period to the levels of 4.5 – 5 s, then it is assumed that the isolators designed in this way will have a higher degree of average excess strength than the isolators designed for 4 – 7 storied structures.

The fixed support structure model is attached 21 centimeters long isolators with diameters of 90 and 74 centimeters, and the forces of acceleration, displacement, and shear forces are obtained by iterating the analysis. Accordingly, the new value of period has changed as $T = 4.99s$.

As a result, the following values are obtained: the maximum acceleration value of structure: $3,874 \text{ m/sn}^2$, the maximum displacement in the direction of U1: 1.23 meters, and U2: 1.352 meters, and the shearing forces F1, F2, F3: 2685 kN, 2510 kN, 66390 kN respectively.

In the Table 1, the analysis result and comparison of fixed support system and the systems with KÇİ21.a and b are shared.

Table 1

Comparison of the values of Acceleration, Displacement, and Shearing force belonging to fixed support and seismic isolated models of structure.

	ACCELERATION (m/sn ²)			DISPLACEMENT (m)			SHEARING FORCE (kN)		
	U1	U2	U3	U1	U2	U3	F1	F2	F3
Fixed Model	10,140	9,910	2,740	0,701	1,036	0,102	7799,58	8314,14	74286,04
h=21cm Iso.	3,066	3,874	0,498	1,230	1,352	0,096	2684,36	2510,88	66388,40
Reduction Percent	69,76%	60,91%	81,82%	-75,47%	-30,47%	5,45%	65,58%	69,80%	10,63%

As compared with the fixed support system, the maximum accelerations occurred in the directions of U1, U2, and U3 on the floors of structure for KÇİ21 decrease by 68%, 59%, and 81% respectively. And, it means that the felt magnitude and motion of an earthquake are mitigated by the absorption of energy to a great extent during an earthquake motion.

As can be seen in the Table 1, the maximum acceleration values acting on the structure decrease by 61% and 81%. When looked at the acceleration graph related to story height in the fig. 7, it is recognized that the higher acceleration differences among the stories are eliminated by the implementation of seismic isolation. In the fixed root model, the average acceleration acting on the structure has seriously faltered, and the amounts of increase and decrease in acceleration have been at pretty low level as the height scales up

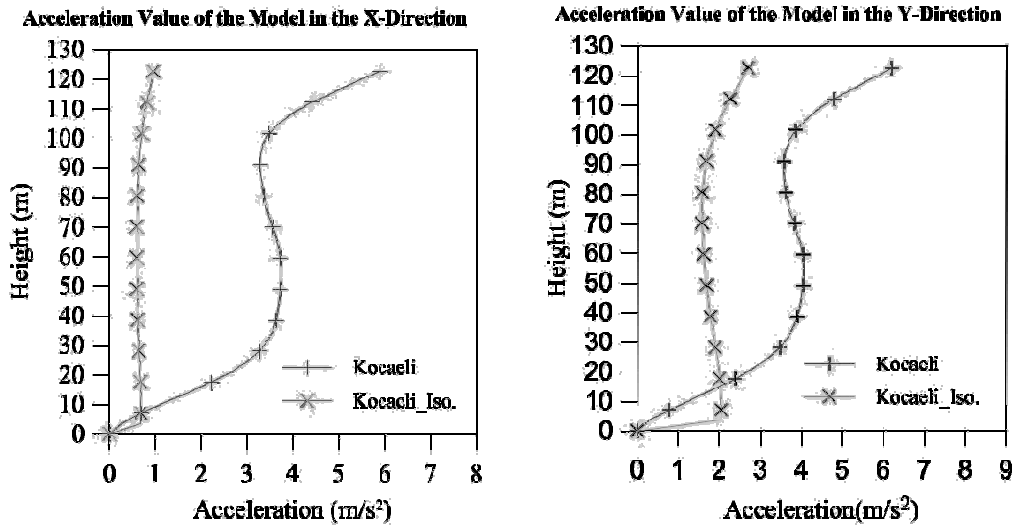


Fig. 7. Comparison of fixed support model with the acceleration values of KÇİ.21 isolator in X and Y directions

In the fig. 8, the displacement graph of fixed root and base isolated system dependent on the structure height is given. Accordingly, it is observed a rise in the amount of displacement in the structure by 75%, and 30% in the directions of U1 and U2 respectively. When it is probed with that point of view, it is concluded that the existing seismic isolator implementation designed has no positive impact on the displacement performance of structure. For a better performance, it might be tried to increase the height of isolator, or choose a rubber material that is capable of making a higher rate of shift unit displacement, or refer a design that the seismic isolation implementation is supported by dampener devices.

Here, the biggest question for KÇİ21 is whether the structure will meet the average maximum displacement of 50 centimeters at the isolator level. When the displacement ratio of %238 in Table 1 is taken as a reference, the isolator of KÇİ21 might exactly meet a displacement of 49.38 centimeters. However, that would be quite on the fringe. Although our structure design can meet the energy that the isolator fails to absorb, choosing an isolator with height in the range of 35 – 40 centimeters would both meet the translation at the isolator level and make sure to produce a more economical solution in order not to take the risk of breaking the isolator and adherence of isolator-base and isolator-column and decreasing the amount of horizontal displacement to make sure that the earthquake isolator exactly achieves its mission.

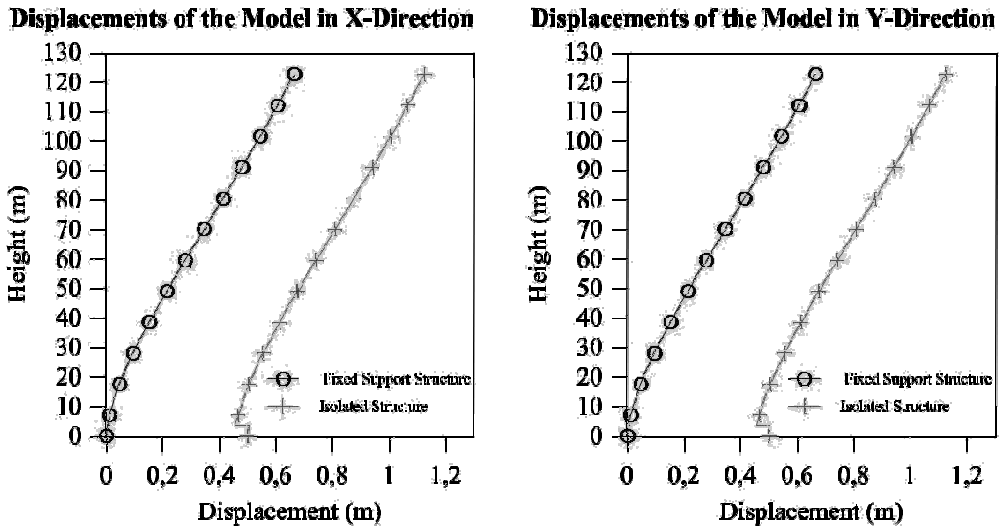


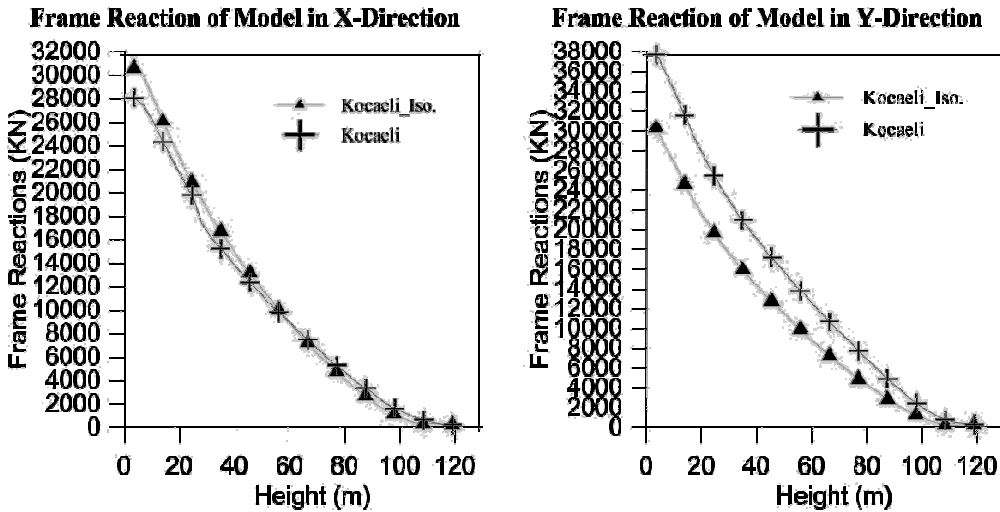
Fig. 8. Comparison of fixed support model with the displacement values of KÇİ.21 isolator in X and Y directions

The systems analyzed are sifted through, it is comprehended that the shearing forces that on the joints applied to the floors in the base isolated structures tend to exhibit lower values in the directions of F1, F2, F3 at the ratios of 65.58 %, 69.80 %, and 10.63 % respectively than that of fixed support structures. The reason is that the earthquake motion including different displacements between columns is largely absorbed through cutting the connection between structure and ground via seismic isolators.

In the fig. 9, the graph of frame reaction that fixed root and base isolated system dependent on the structure height is given. Accordingly, it is observed probably a same in the amount of frame reaction in X- Direction in the structure, when looked at the graph of frame reaction of model in Y- Direction related to story height in the fig. 9, it is recognized that the higher frame reaction differences among the stories are eliminated by the implementation of seismic isolation.

As can be seen in the comparison of fixed support model, the amount of displacement increases by 75% and 30% in the directions of U1 and U2 respectively. Actually, this is an expected behavior model for a high-rise structure that is enabled to move and separated from the base, which permanently interacts with the ground. When the model mentioned in the study is analyzed with respect to its compliance with seismic isolation, we face with a less number of spacing and a smaller footage of housing space than that of a 35-story structure, and we also face with greater displacements than that of fixed support structures when this case is coincided with releasing

the columns and curtain walls from the ground. Depending on the height and material specs, the isolator has a capability of damping the displacement motion. And, this means that the relative floor adding in the seismic isolated models is likely to realize less than the fixed support structure model.



Frame Reaction of Model in X-Direction Frame Reaction of Model in Y-Direction

Fig. 9. Comparison of fixed support model with the frames shearing forces that values of KÇİ.21 isolator in X and Y directions

The structure is never exposed to over internal forces, because 35 individual structural bearings on which the structure is seated are all independent from the ground. That is to say, the structure behaves in a nonlinear way when an earthquake motion is detected in a fixed root system. In other words, there occur different internal forces and displacements in different floors. In this case, a rigid structure tied to the ground is subjected to higher shearing force and torsional moment. When we separate our structure from the ground by means of isolators, then the great majority of those different displacements and the horizontal motions of earthquake are absorbed by isolators, and our upper structure tends to show a rigid behavior as a whole, and it is observed serious increments in the absorption capacity of structure. The high rate of decrease in the shearing force is likely to provide an extra endurance to our structure against the axial tensions stemmed from overturning moment.

Conclusions. In line with the primary objective of the study, it is aspired to investigate the functionality of seismic isolation implementation in

the structures with a period of 3 and above at the design of high-rise and fixed support structure. The following conclusions obtained from the study are summarized as:

1. The acceleration obtained due to earthquake on the x and y direction of the building are generally increased through the bottom to top for fixed system. However, accelerations are similar to each other from bottom to top of the isolated system. Also the maximum acceleration values are obtained on the isolated system as 3 – 4 times smaller than those of fixed system.

2. The displacements obtained for both fixed and isolated systems are increased from the bottom to top of the building in x and y directions. Also, relative displacements are similar for both fixed and isolated system. This mean that isolated system behaves as fixed system, because the height of the isolators (21 cm) are not suitable such a high rise building (122,5 m) when considered displacement changes.

3. The frame reaction obtained due to earthquake on the x direction of the building is probably same through the bottom to top for fixed and isolated system. However, for isolated system the frame reaction obtained due to earthquake on the y direction of the building is smaller than those fixed system. Also the frame reaction values are obtained on the isolated system is little bit smaller than those of fixed system.

4. Should we evaluate the study as a whole, the seismic isolators placed in the fixed support structure model seriously improve the performance of structure through decreasing floor shearing forces and floor accelerations. Thus, the cross-sections inside the structure will be exposed to pretty lower level of strains following a possible earthquake, the risk of torsion will be largely avoided, and the structure will display a more robust performance against axial tensions. Besides, the structure gaining freedom as a result of disengagement with ground has achieved a higher displacement as compared to the fixed support model. Among the reasons of this displacement performance is the structure geometry, working on a model with a pretty higher structure than that of recommended for a seismic isolation implementation, choosing an isolator with lower height, and few number of spacing in both of the directions.

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Вплив систем освінцованих амортизаторів (COA) на поведінку висотної будівлі під час землетрусу / *Sağlam Doğan, Sevim Barış* // Вісник НТУ "ХПІ". Серія: Інформатика та моделювання. – Харків: НТУ "ХПІ". – 2017. – № 21 (1243). – С. 14 – 27.

Система ізоляції бази призводить до зменшення впливу сил, викликаних землетрусом, за допомогою нейтралізації взаємодії між будівлею і землею за допомогою сейсмоамортизаторов. Мета цього дослідження – визначити вплив систем ізоляції бази на реакцію висотної будівлі під час землетрусу. Досліджуються висотна будівля з амортизаторами землетрусів різних розмірів, які призначені для ізоляції землетрусів, а потім ретельно вивчають реакцію на землетрус в цьому ж будинку, порівнюючи її при використанні ізоляторів різних розмірів і нерухомих опор. Будівля має 122,5 м в висоту і 35 поверхів, а також житловий простір розмірами 20×16 м², для якого виконані розрахунки вертикального руху, прийняті для висотних будівель мегаполісів. Ці розрахунки детально розроблені і поширені в рамках концепції нерухокої опори. Досліджуються діючі на будівлю сили землетрусу, яке мало місце в Коджаелі в 1999 році. У дослідженні підкріплюється, що система з освінцованими амортизаторами забезпечує кращу структурну реакцію сродня в порівнянні з нерухомими опорами. Порівнюються між собою такі критичні параметри як прискорення, бічний зсув, базисні і поперечні сили. Іл.: 9. Бібліогр.: 13 назв.

Ключові слова: ізоляція бази; система освінцованих амортизаторів; реакція на землетрус; висотна будівля.

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Влияние систем освинцованных амортизаторов (COA) на поведение высотного здания при землетрясении / *Sağlam Doğan, Sevim Barış* // Вестник НТУ "ХПИ". Серія: Інформатика та моделювання. – Харків: НТУ "ХПІ". – 2017. – № 21 (1243). – С. 14 – 27.

Система ізоляції бази приводить к уменьшению воздействия сил, вызванных землетрясением, посредством нейтрализации взаимодействия между зданием и землей с помощью сейсмоамортизаторов. Цель этого исследования – определить влияние систем изоляции базы на реакцию высотного здания при землетрясении. Исследуется высотное здание с амортизаторами землетрясений различных размеров, предназначенное для изоляции землетрясений, а затем тщательно изучают реакцию на землетрясение в этом же здании, сравнивая ее при использовании изоляторов различных размеров и неподвижных опор. Здание имеет 122,5 м в высоту и 35 этажей, а также жилое пространство размерами 16×20 м², для которого выполнены расчеты вертикального движения, принятые для высотных зданий мегаполисов. Эти расчеты детально разработаны и распространены в рамках концепции неподвижной опоры. На следующем этапе два различных по высоте амортизатора из освинцованной резины диаметром 21 см добавляются в структуру здания. Исследуются действующие на здание силы землетрясения, которое имело место в Коджаели в 1999 году. В исследовании подчеркивается, что система с освинцованными

амортизаторами обеспечивает лучшую структурную реакцию строения по сравнению с неподвижными опорами. Сравняются между собой такие критические параметры как ускорение, боковое смещение, базисные и поперечные силы. Ил.: 9. Библиогр.: 13 назв.

Ключевые слова: изоляция основания; система освинцованных амортизаторов; реакция на землетрясение; высотное здание.

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The effects of lead rubber bearing (LRB) systems on the earthquake response of high-rise building / Sağlam Doğan, Sevim Barış // Herald of the National Technical University "KhPI". Subject issue: Information Science and Modelling. – Kharkov: NTU "KhPI". – 2017. – №. 21 (1243). – P. 14 – 27.

The base isolation systems set sight on mitigating the effects of forces triggered by an earthquake through neutralizing the interaction between building and ground by means of earthquake isolators. This study aims to determine the effects of base isolation systems on the earthquake response of a high-rise building. In the content of the study firstly the high-rise building is designed for different sized isolators under the framework of earthquake isolator technique, and then scrutinize the earthquake response of the same building by comparing its configurations equipped with different sized isolators and fixed support. The building has 122.5 m tall and 35 stories and 16×20 m² habitable inner space, which is properly considered in line with vertical settlement movement widely seen in the world metropolises, is punctiliously designed and diffusively probed within the concept of fixed support. During the following stage, 2 different diameter size of 21 cm. tall lead rubber bearings are added to the structure, its unpredictable behaviors and forces transferred to the building under 1999 Kocaeli Earthquake highlighted from the study that LRB systems provide better structural response to building compared to fixed system, and then the critical parameters such as acceleration, lateral displacements, base and shear forces are compared with each other. Figs.: 9. Refs.: 13 titles.

Keywords: base isolation; lead rubber bearing system; earthquake response; high-rise building.