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Analysis of Reinforced Concrete Buildings with Different Location of Seismic Isolation System

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***Abstract:-* The technique of base isolation has been developed as an attempt to mitigate the effects on buildings and their contents during earthquake attacks. The most applicable location of isolators on the building structures is between the foundations and the superstructure of the building. Regarding the installation and monitoring of devices, this is the most acceptable location of the isolation system. Regarding seismic response analyses, isolators can be located in other levels such as on the first floor or in other intermediates storeys. Nowadays, in our country, the Box structures are preferable by some architects in order to design the facade with different forms and dimensions of openings. To analyze the effect of isolation location a ten storey reinforce concrete Box structure is considered. The structure is analysed in three different conditions: the first model is fixed base, the second model with isolators on the base and third model with isolators on the middle story. Elastomeric rubber bearings isolators are used. The dynamic properties and seismic behaviour of three models are provided by three dimensional finite element nonlinear time history analysis, using the SAP2000 computer program. Rubber bearing isolators are modelled as bi-linear elements. The analysis show the influence of isolators location on the dynamic properties of building structure and its influence on the displacement and internal forces of structural elements. Based on the analysis results, it has been concluded that the location of isolators can be selected in every story of the building based on the interested parameters to be modified.**

***Keywords- Base isolation, building structure, rubber bearing, bi-linear elements, time history*,**

1. INTRODUCTION

Based on the principle of the energy balance, the structure should be able to absorb energy so that the internal energy is equal to the external energy transmited to the structure. According to the traditional design philosophy, major earthquake effects are supported by increasing the resistance or the ductility of the structure. But under earthquake loads it is not effective to achive this balance through resistance increase, because the increase of strength is associated with system's stiffness increase. According to response spectrum, rigid structures coresponds to higher values of response spectrum. wich means higher forces indused to the structure. This is the case of Box type structures. By the second approch of the traditional design philosophy with increasing the ductility, the structure must behavie in nonlinear range wich at the same time means that some cracks and damages on structural elements are acepted to occur. As an alternative approach, base isolation, is a seismic design concept whereby adding flexible, energy absorbing elements between the foundation and the base of the structure, the reduction of seismic forces transmited from the ground to the structure is achieved. Many years of experience with the bearings used in these earlier engineering applications, have demonstrated the reliability, durability and resistance of bearings to many environmental conditions. In the past three decades, the number of applications of innovative technologies in earthquake-resistant construction has increased dramatically. In case of building structures, the isolation devices are located on the base, between the foundation and superstructure. On this study, we try to find the benefits in case of installing the isolators on the middle height of the building. Analyzing the building operation type (residential building, public service building, technological devices or special devices building), architecture and seismic response of different models, we would be able to choose the best location of isolators, considering not only the cost, but also other required parameters. Since inertial forces are bigger in rigid structures, special equipments installed in the building and structural or non-structural elements would suffer bigger accelerations and inertial forces during seismic action. Installing the isolation system under these storeys where special conditions are required will give the benefit of the isolator location.

2. ANALYSIS OF SEISMIC RESPONSE OF REINFORCE CONCRETE BOX-TYPE STRUCTURE

In order to study the effect of isolation location to the seismic behaviour of the structure, we will analyse the ten story box-type reinforce concrete building structure in three different conditions as shown in Figure 1:

- **Model 1.** Fixed base structure (SF),
- **Model 2.** Structure Isolated at the Base (SIB),
- **Model 3.** Structure Isolated in the Middle hight (SIM)

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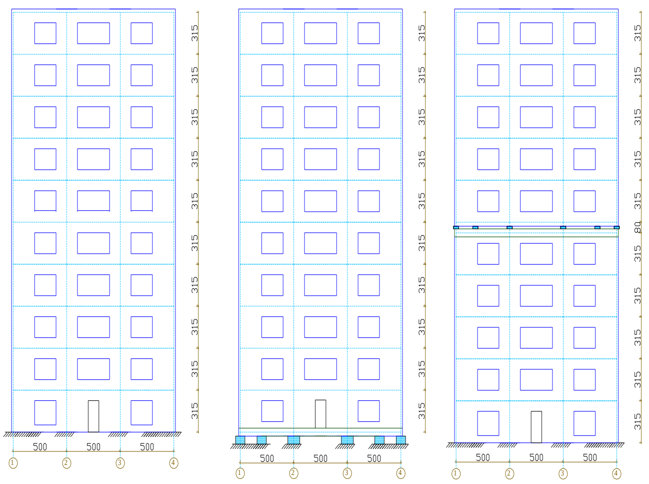

Fig. 1**:** Elevation plan and location of isolation system: **a)** Fixed base structure (SF), **b)** Structure Isolated at the Base (SIB), **c)** Structure Isolated in the Middle hight (SIM)

1.1 Building Structure and Input Data

Structural elements geometry- The analyzed structure is a ten story reinforce concrete structure with mixed structural elements: columns, beams and shear walls on the perimeter. The geometry of the structure elements of the structure are shown in Figure 2. The location of isolators in plan are shown in Figures 3a and 3b.

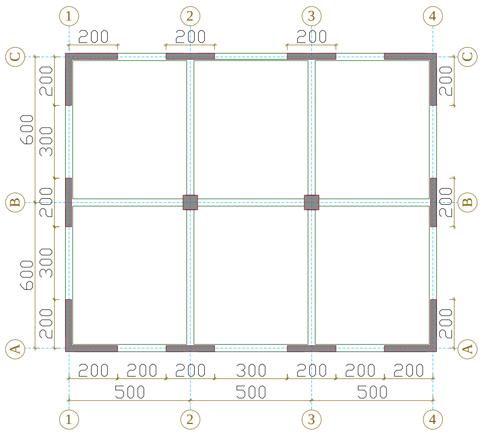

Fig. 2**.** Plan view of structure elements

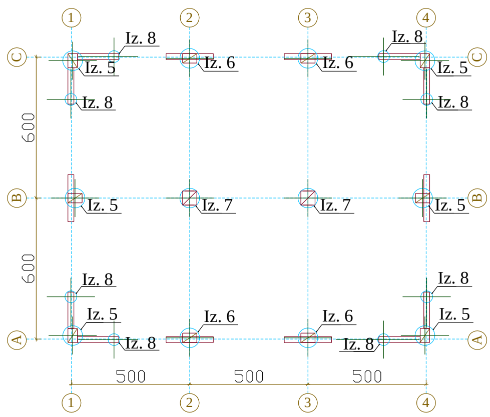

Fig. 3a. Plan view of isolators on Model-2

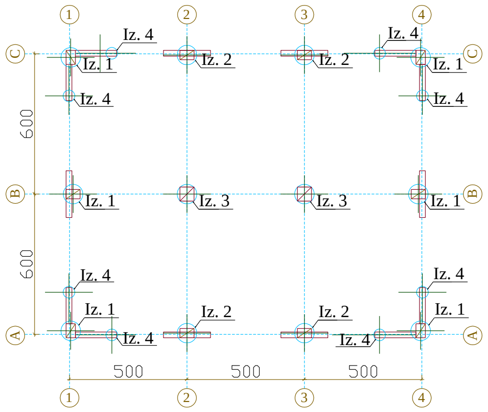

Fig. 3b. Plan view of isolators on Model-3

Class of Concrete: C25/30

Building elements dimensions:
Slab thicknes h_s=15 cm
Beam dimensions h_t=60cm, b_t=30cm,
Columns of storeys 1 to 5: peripheral columns b_k=50cm, h_k=80cm, central columns b_k=80cm, h_k=80cm
Columns of storeys 6 to 10: peripheral columns b_k=40cm, h_k=60cm, central columns b_k=60cm, h_k=60cm
Reinforced concrete shear walls of storeys 1 to 5: t_m=25cm,
Reinforced concrete shear walls of storeys 6 to 10: t_m=20cm.

Applied loads and seismic action- To calculate the dynamic parameters and to perform the seismic analyze, the loads applied to the structure are: dead loads g = 300 daN/m^2, live loads p = 200 daN/m^2 and earthquake loads. Earthquake load is applied through real earthquake accelerogram scaled for the chosen ground conditions, with maximum ground acceleration A_{max} = 0.25g. The applied accelerogram is that of El Centro earthquake with peak ground acceleration PGA = 0,349g, scaled with scale factor S = (0.25 / 0,349) x 10^{-3}= 0.716 x10^{-3}.
The input acceleration time history of El Centro is shown in Figure 4. These excitations are induced in both, X and Y, direction.

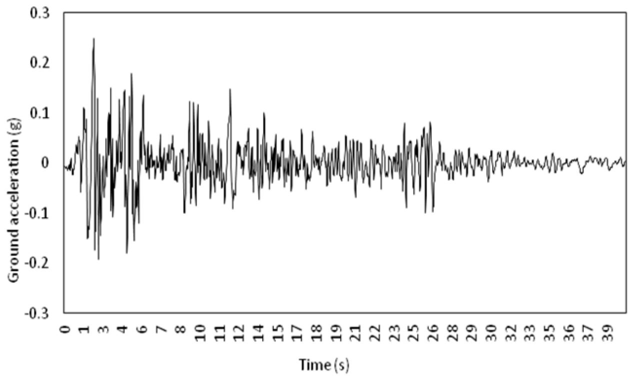

Fig. 4. El Centro accelerogram scaled for ground acceleration PGA = 0.25g

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1.2 Modeling of Building Structure

The building structure is modelled in space using frame and shell finite elements for the structure and "Link" element for the isolators. The labels of isolator elements are shown in Figure 3a and 3b.

The characteristics of isolators- The type of isolators is selected to be rubber bearings with be-linear diagram as shown in Figure 5.

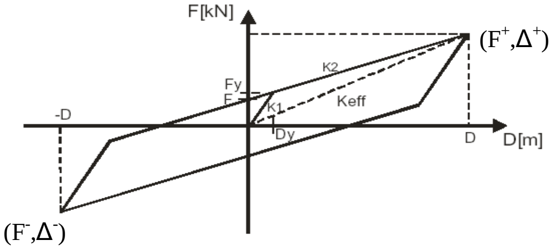

Figure 5. Bi-linear Link isolator

First we calculate the vertical load on isolators with the combination 1.35G + 1.5P. In order to select a few type of isolators, analyzing the forces applied on each isolators of the structures, two groups of isolators are used:
First group, in total four isolators, identified with numbers Iz 1 to Iz 4, used for Model-3. The vertical loads used to calculate the isolators characteristics are given in Table I.
Second group, in total four isolators, identified with numbers Iz 5 to Iz 8, used for Model-2. The vertical loads used to calculate the isolators characteristics are twice bigger than Model 3 and are presented in Table II.

TABLE I. VERTICAL FORCES ON ISOLATORS OF STRUCTURE MODEL-3

Isolator	**1**	**2**	**3**	**4**
Vertical force (kN)	800	1220	2380	400

TABLE II. VERTICAL FORCES ON ISOLATORS OF STRUCTURE MODEL-2

Isolator	**5**	**6**	**7**	**8**
Vertical force (kN)	1600	2440	4760	800

To calculate the isolators characteristics we have accepted the following parameters:

- first period of both models of isolated structure (Model-2 and Model-3) to be around T = 2.5 s,
- damping ratio β = 10%,
- design displacement D = 10 cm
- stiffness ratio $r = K_2/K_1 = 0.2$

The calculated characteristics of the isolators are given in Table III and Table IV.

TABLE III. THE ISOLATOR'S CHARACTERISTICS OF STRUCTURE MODEL-2

Isolator	**5**	**6**	**7**	**8**
Effective stiffness, K_{eff} (kN/m)	1030	1570	3065	515
Elastic stiffness, K_1 (kN/m)	4300	6560	12800	2150
Post yield stiffness, K_2 (kN/m)	860	1310	2560	430
Characteristic force, Q (kN)	17	25.95	50.62	8.5
Yield force, Q_y (kN)	21.3	32.4	63.30	10.6
Yield displacement, D_y (m)	0.005	0.005	0.005	0.005
Vertical stiffness, $K = 100 \times K_{eff}$ (kN/m)	103000	157000	306500	51500

TABLE IV. THE ISOLATOR'S CHARACTERISTICS OF STRUCTURE MODEL-3

Isolator	**1**	**2**	**3**	**4**
Effective stiffness, K_{eff} (kN/m)	515	785	1532	260
Elastic stiffness, K_1 (kN/m)	2150	3280	6400	1075
Post yield stiffness, K_2 (kN/m)	430	655	1280	215
Characteristic force, Q (kN)	8.50	12.97	25.31	4.04
Yield force, Q_y (kN)	10.6	16.2	31.6	5.32
Yield displacement, D_y (m)	0.005	0.005	0.005	0.005
Vertical stiffness, $K = 100 \times K_{eff}$ (kN/m)	51500	78500	153200	26000

Using the features of SAP2000 program the base isolated structures will be modelled with "Link" elements for the isolators. So, the dynamic analysis will be linear for the structural elements and non-linear for the bearing elements.

3. RESULTS OF ANALYSIS

All the interesting results from the dynamic and seismic analysis of three Models of structure are presented.

3.1 Dynamic Properties of Structure

The first six periods of vibrations for three models of structure are presented in Table V.
From the mode shapes, it can be noted that for all three models, the first mode shape is translational in Y direction, the second mode shape is translational in X direction, and the third mode shape is torsional around Z direction.

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TABLE V. THE PERIODS OF VIBRATIONS

Mode	Period			
	Fixed base structure Model-1 (SF)	Base isolated structure Model- 2 (SIB)	Mid isolated structure Model- 3 (SIM)	Ratio T_{SIM} / T_{SIB}
1	0.36	2.84	2.79	0,98
2	0.33	2.81	2.78	0,99
3	0.17	2.46	2.46	1,00
4	0.12	0.59	0.40	0,68
5	0.11	0.55	0.39	0,71
6	0.05	0.09	0.07	0,78

Based on these result of the vibration periods we can note that the two isolated systems have an increase of the period value by 8 times. Periods difference between the isolated system in the middle storyes (SIM) and base isolated structures (SIB) shows that for first three periods (which has the greater influence on structure response) is by 10%. This means that isolation of structures in the middle storeys has the same influence as base isolation, according to vibration periods results.

The First mode shapes of the three models are given in Figure 6.

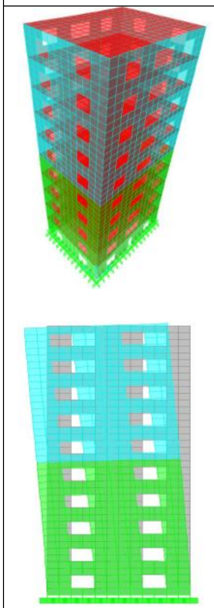
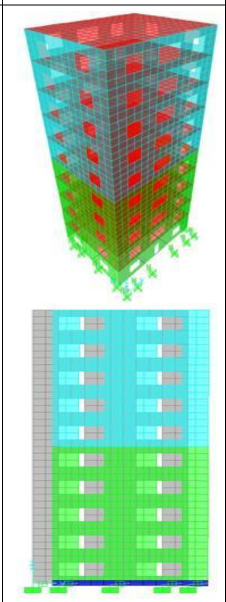
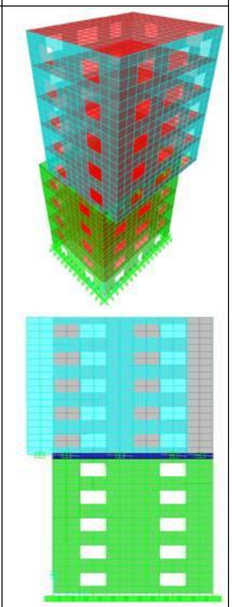
10 Storey building structure, Type "BOX"		
Model 1 - SF	**Model 2 - SIB**	**Model 3 - SIM**
		
Mode 1 (T=0.36 s)	Mode 1 (T=2.84 s)	Mode 1 (T=2.79 s)

Fig. 6. First mode shape os three models of structures

From the sixth mode shapes of vibrations of structure is shown that for first three modes of isolated models, only the isolation system is deformed, while the superstructure moves like a rigid disk, thus its deformations are really small. These modes has the longer periods compared with fixed base model.

3.2 Seismic Response Results:

Seismic response of all three models of the structure (SF, SIB and SIM),), is numerically given in Tables VI, VII, VIII and IX. The chosen parameters are the maximum values in X and Y directions of the displacements (MaxUx, MaxUy), accelerations (MaxAx, MaxAy), base shear force (BShear-x, BShear-y), first and last floor column shear forces (Qx, Qy) and bending moments on beams of the first and last floor Mx for the Y direction and My for the X direction of the earthquake. Also vertical stresses S22 and horizontal stresses S11 of the first floor shear walls are presented. The position of chosen elements used for introducing the seismic response results are schematically shown in Figure 7.

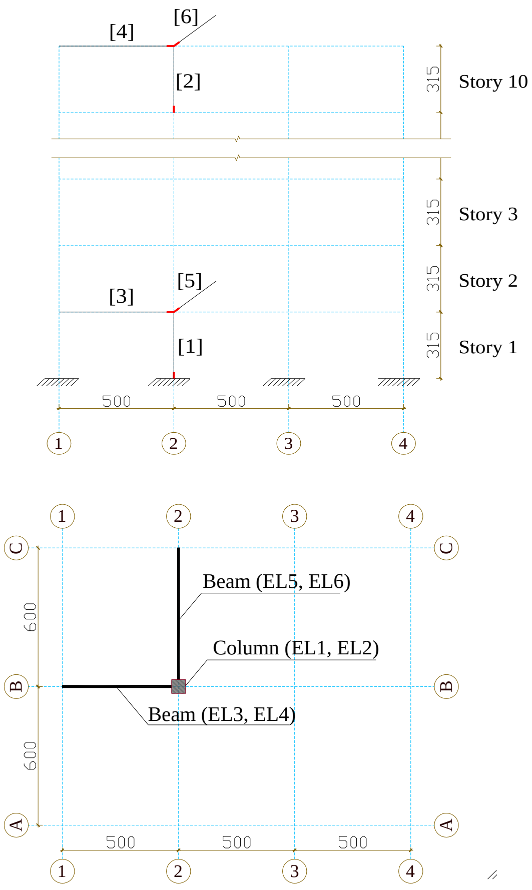


Fig. 7. Position of chosen elements for introducing seismic response results

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TABLE VI. ACCELERATION RESULTS (M/S^2) OF STRUCTURE

Location	Fixed base structure Model 1 (SF)		Base isolated structure Model 2 (SIB)		Mid isolated structure Model 3 (SIM)	
	X	Y	X	Y	X	Y
Base, below isolator (joint 0)	2.45	2.45	2.45	2.45	2.45	2.45
Base, above isolator (joint 0')			1.1	1.4		
First floor, below isolator (joint 1)	1.54	1.80	1.1	1.20	2.22	2.20
First floor, above isolator (joint 1')						
Mid, below isolator (joint 5)	2.29	2.29	0.6	0.6	5.3	4.2
Mid, above isolator (joint 5')					0.6	0.64
Në tarracë (joint 10)	5.88	5.40	1.20	1.20	0.64	0.66

TABLE VII. STOREY DISPLACEMENT RESULTS (CM) OF STRUCTURE

Storey	Fixed base structure Model 1 (SF)		Base isolated structure Model 2 (SIB)		Mid isolated structure Model 3 (SIM)	
	X	Y	X	Y	X	Y
Base 0	0	0	0	0	0	0
Base 0'			11.68	11.56		
Storey 1	0.08	0.11	11.72	11.62	0.04	0.04
Storey 1'						
Storey 2	0.22	0.27	11.77	11.68	0.10	0.09
Storey 3	0.39	0.45	11.82	11.74	0.15	0.14
Storey 4	0.56	0.64	11.87	11.80	0.19	0.18
Storey 5	0.74	0.85	11.92	11.86	0.21	0.19
Storey 5'					11.31	11.33
Storey 6	0.93	1.06	11.97	11.92	11.34	11.38
Storey 7	1.11	1.27	12.02	11.98	11.37	11.43
Storey 8	1.27	1.46	12.06	12.03	11.40	11.48
Storey 9	1.42	1.64	12.10	12.09	11.42	11.53
Storey 10	1.54	1.80	12.13	12.14	11.44	11.58

TABLE VIII. STOREY DEFORMATION (DRIFTS) RESULTS (CM)

Storey	Fixed base structure Model 1 (SF)		Base isolated structure Model 2 (SIB)		Mid isolated structure Model 3 (SIM)	
	X	Y	X	Y	X	Y
Baza 0'	0	0	11.68*	11.56*	0	0
Storey 1	0.08	0.11	0.04	0.06	0.04	0.04
Storey 1'						
Storey 2	0.14	0.16	0.05	0.06	0.06	0.05
Storey 3	0.17	0.18	0.05	0.06	0.06	0.05
Storey 4	0.17	0.19	0.05	0.06	0.04	0.04
Storey 5	0.18	0.21	0.05	0.06	0.02	0.01
Storey 5'					11.1*	11.14*
Storey 6	0.19	0.21	0.05	0.06	0.03	0.05
Storey 7	0.18	0.21	0.05	0.06	0.03	0.05
Storey 8	0.16	0.19	0.04	0.05	0.03	0.05
Storey 9	0.15	0.18	0.04	0.06	0.02	0.05
Storey 10	0.12	0.16	0.03	0.05	0.02	0.05

TABLE IX. THE FORCES RESULTS OF STRUCTURE

Parameter	Location	Fixed base structure Model 1 (SF)		Base isolated structure Model 2 (SIB)		Mid isolated structure Model 3 (SIM)	
		X	Y	X	Y	X	Y
Column shear force (kN)	On base (EL1)	94	134	11	8.7	51	50.7
	On roof (EL2)	19	14	8.4	2.4	4.8	2.7
Beam moment (kNm)	On base (EL3-EL5)	53	57	13	13	26.5	18.3
	On roof (EL4-EL6)	8	13	13.5	9.8	6.4	2.2
Base shear force (kN)	Base	11170	11650	2390	2370	5860	4400
Reinforced concrete shear wall stresses (kN/m^2)	Vertical	6005	7500	1300	1200	1800	1700
	Horizontal	1500	1600	700	600	800	700

* Deformation of Isolators

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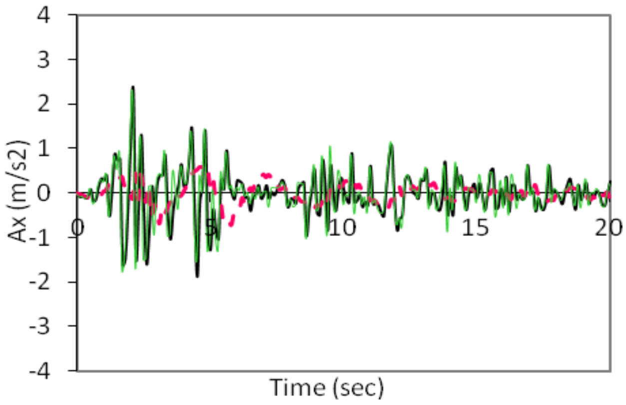
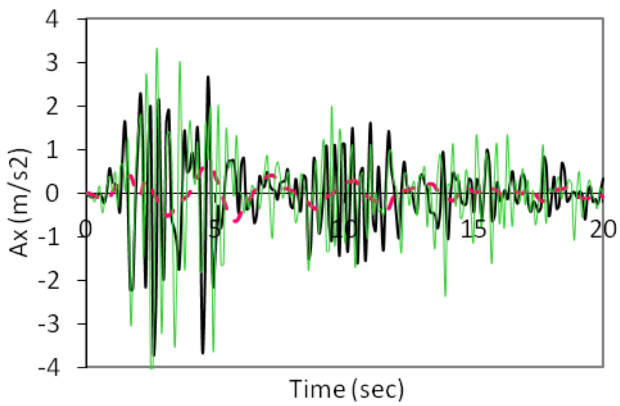
The comparative time history responses between three models of structures are plotted in the Figure 8 to 14. In the Fig. 8a and 8b are shown the time history response of the acceleration for joint 1' and joint 5 respectively. In the Fig. 9a and 9b are shown the time history response of the acceleration for joint 5' and joint 10 respectively. In the Fig. 10a and 10b are shown the time history response of the displacement for joint 1' and joint 5 respectively. In the Fig. 11a and 11b are shown the time history response of the displacement for joint 5' and joint 10 respectively. In the Fig. 12a and 12b are shown the time history response of the relative displacement between joint 5 and 1' and between joint 10 and 5' respectively. In the Fig. 13a and 13b are shown the time history response of the shear forces on column in first and top story respectively. In the Fig. 14 and are shown the time history response of the base shear

The line types of all the graphics selected for three models are presented by this legend:

- Model 1 – SF
- Model 2 – SIB
- Model 3 – SIM

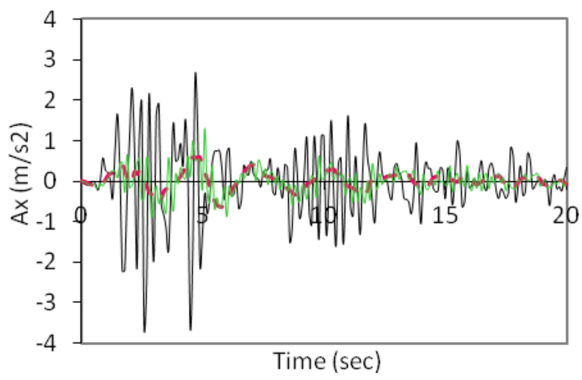


a)

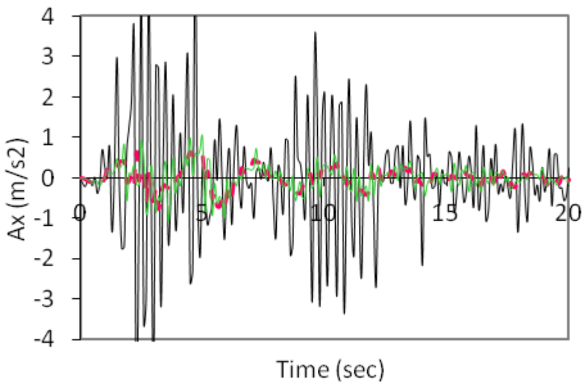


b)

Fig. 8. Time history of Acceleration: a) for joint 1'; b) for joint 5

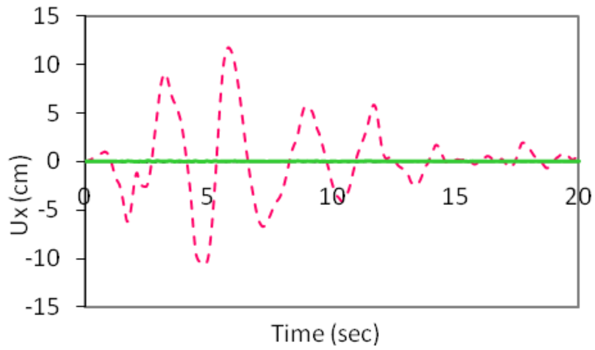


a)

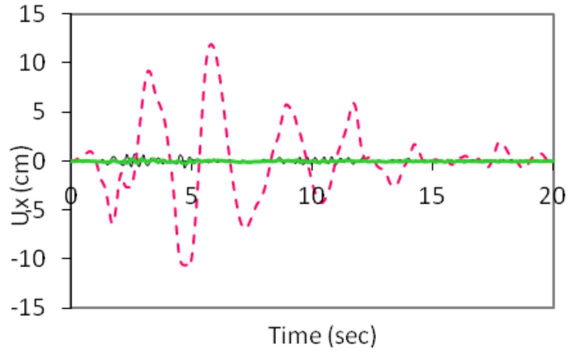


b)

Fig. 9. Time history of Acceleration: a) for joint 5'; b) for joint 10



a)



b)

Fig. 10. Time history of Displacement in X direction: **a)** for joint 1'; **b)** for joint 5

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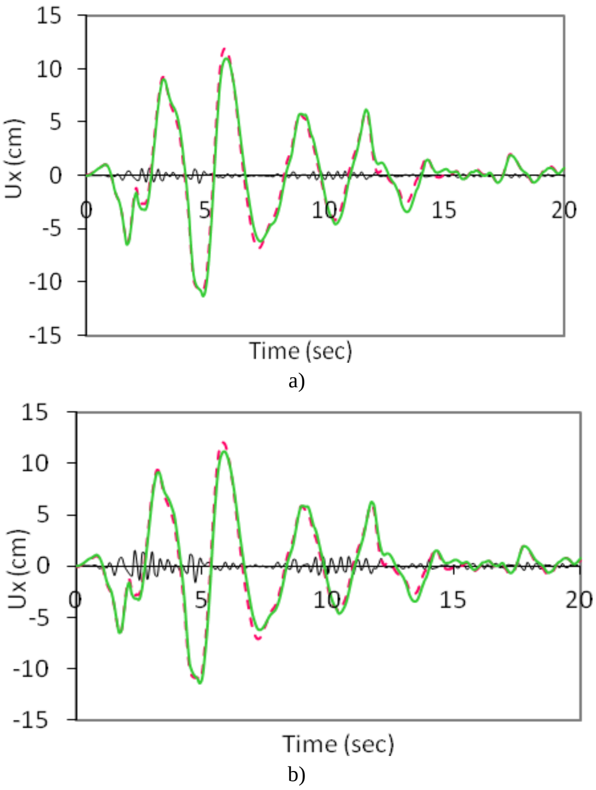

Fig. 11. Time history of Displacement in X direction: a) for joint 5'; **b)** for joint 10

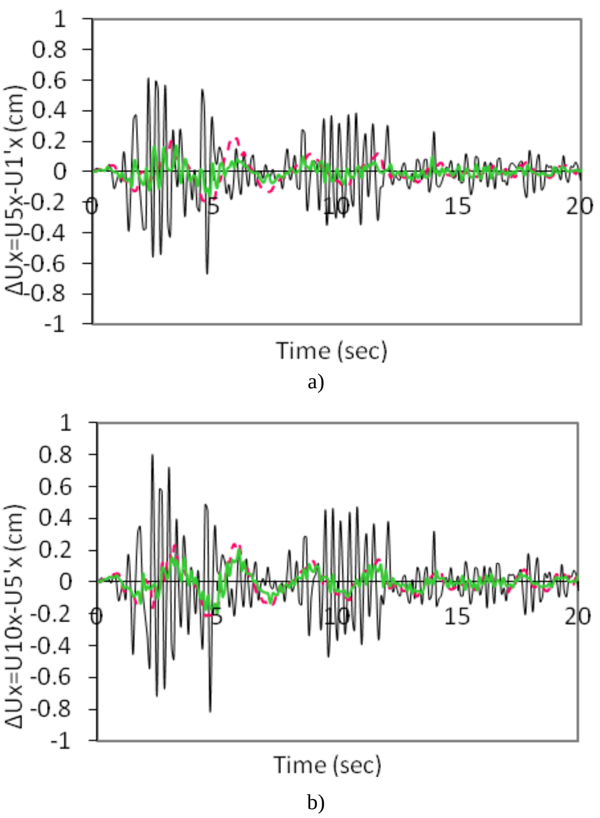

Fig. 12. Time history of Relative Displacement in X direction: a) between joint 5 and 1'; b) between joint 10 and 5'

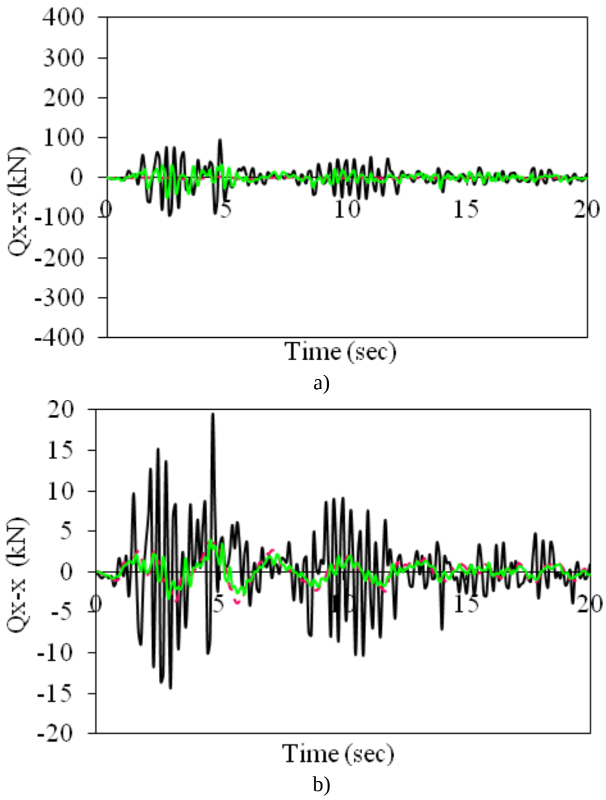

Fig. 13. Time history of shear force in column in X direction: **a)** shear force in element EL - 1; **b)** shear force in element EL - 2

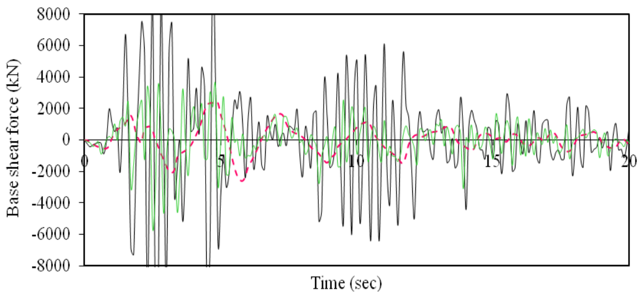

Fig. 14. Time history of Base shear force in X direction

4. CONCLUSION

Based on the above analyses and results the following conclusions can be derived:.

1. The accelerations of structure isolated at the base are reduces about 4 times for all storeys compared to the fixed base structure, while for the structure isolated in the middle storey, accelerations of storeys 1 to 5 are increased compared to the fixed base structure and accelerations for storeys 6 to 10 are reduced by 2 compared to the base isolated structure and by 8 for the fixed base structure. This shows that if it is required the reduction of seismic accelerations on upper floors of buildings than the isolation of these structures in the

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middle storeys would be more effective than structure isolated at the base.

2. Storey displacements of structure isolated at the base are bigger compared to fixed base structures, but these displacements are result of isolators deformations. For the structure isolated in the middle storey, displacements of storeys 1 to 5 are 3 times smaller compared to the fixed base structure, while displacements of storeys 6 to 10 are almost the same as the base isolated structure displacements for the respective storeys. This is because displacements are result of isolators deformations and not result of structure elements deformations despite the location of isolators. Since characteristics of each isolator where chosen to have the same maximum deformation, displacements of all storeys above the isolation systems, for the two models, are equal to the isolators deformations.
3. Deformations of all storeys of both isolated structures are about 3 to 4 times smaller compared to the fixed base structures. Deformation ratio between the structure isolated in the middle storey and the base isolated structure shows that from the first floor to the fifth the reduction of deformations are almost the same, meanwhile for the sixth to the tenth storey this reduction is bigger for the middle storey isolated structure. The influence of higher modes on structure deformations (of course to the entire seismic response parameters) is bigger for the base isolated structure compared to the middle isolated structure. Moving the isolation system from the base to the middle storeys, the influence of higher modes on storeys above the isolation system becomes less sensitive.
4. Compared to fixed base structure, shear forces of the first floor are reduced by 10 times for the base isolated structure and by 3 times for the middle storey isolated structure. Shear forces of the top floor columns are reduced by 3 times for both isolated models.
5. Bending moments on the beams are reduced by 4 times in the case of base isolated structures and by 2 times for the middle storey isolated structure, compared to the fixed base structure. Bending moments of top floor beams are reduced by 3 times only for the case of middle storey isolated structure.
6. Base shear forces are reduced by 5 times for the base isolated structure and 2.5 times for the middle storey isolated structure, compared to the fixed base structure.
7. First floor shear wall vertical stresses are reduced by 5 times for the base isolated structure and by about 3.5 for the middle storey isolated structure, compared to the fixed base structure. Meanwhile the horizontal stresses are reduced by 2 times for both the isolated structures, always compared to the fixed base structure.
8. Considerable reduction of internal forces of structural elements, columns and beams, is achieved by isolating only the upper 5 storeys of the structure (SIM).

Moving the isolation location towards upper floors affect the required characteristics of the isolators to be used (smaller isolators are needed, leading to lower cost). For the studied cases, isolators characteristics for the middle isolated structure refers to the isolation of only 5 storeys

above them. On the other hand, isolators used for the base isolated structure need to isolate 10 storeys above them thus they are bigger. Considering all these factors we should search for the optimum values of isolators characteristics according to their locations on the structure.

Summarizing the above we conclude that the isolation system can be located not only to the base but also to upper storeys. The selection of this location depends on different factors such as:

1. The seismic isolation purpose, referred to the required parameters according to the isolated storeys;
2. Building function, considering technological devices sensitivity and providing isolators protection against natural and chemical actions;
3. Structural irregularities along the building height, such as the cases when it is needed to discontinue rigid elements (shear walls);
4. Storey plan irregularities. Isolation can be used to separate irregular parts of the structure, with the installation of isolators at the floors that these irregularities appear.

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