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Seismic monitoring bridge decks with rotational friction dampers

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Abstract: *Safely and economically seismic energy dissipation is the most important way to deal with devastating effects of the earthquake. Classic seismic retrofitting techniques amortize the energy in the members and with their plasticity. In this way, in addition to compromising the structural members, capacity of structural members for subsequent energy absorption will decrease against the forces that their amounts are not known and the security of structure will also disappear. More appropriate method is the use of dampers that amortize the energy applied to the structure in themselves and maintain the structures. These absorber are offered in two permanent and switching forms. Rotational friction dampers are known as added yield moment of damper (displacement and reducer of base shear of structure). In this study, the properties of rotational friction damper have been examined and its function in the structure of a bridge with a length of 40 meters and four 10-meter spans and a height of 7 meter. 2000SAP software was used to model the structure of bridge and applying the rotational friction damper with Multi-linear plastic elements. After modeling and loading, the elements of damper were modeled in different positions of the structure under time history loading and its analysis through the menu of Link in software and in order to examine the function of installed elements in mentioned structure, modelling was performed in two modes (with and without damper) under time history loading. In order to determine the behavior of rotational friction dampers, various performance indicators such as structural displacement and base shear of structures were used. Firstly, the values of these indicators were extracted from the structures without damper and then, the maximum values of performance indicators were extracted from the structures with damper. These values were compared with each other and reduction in various performance indicators were provided by percentage.*
Keywords: *Seismic monitoring, bridge decks, rotational friction dampers*

1. INTRODUCTION

This study aimed to study the effects of rotational friction damper on the performance of the bridge structures. In this study, bridge structures were considered to be studied because many studies have been done on the effects of various types of dampers on buildings and other structures but the effects of dampers on bridge structure is a new topic and a few studies have been done on it. For this purpose, a hypothetical bridge with concrete-steel structure was used and 2000 SAP software was used for modelling. As you know, in order to examine the function of a structure, some performance indicators should be determined, these indicators should not only be measurable but also, be able to show the function of structure against external forces and lateral loads. Two major performance indicators are displacement of structure and base shear of structure. Firstly, the bridge structure is modelled and place under the accelerograph of studied earthquake to determine the values of mentioned indicators using SAP2000 software. After determining the values of indicators, the structure is mobilized with multi-linear plastic elements and then, placed under the same accelerograph. In this mode, the values of indicators will change. These changes (reductions) show the function of multi-linear plastic damper in bridge structures.

Bridge modelling

In this part, it is tried to completely describe the modelling, properties of materials and geometry of structures modelled in SAP2000 software.

Introduction of project

The bridge studied in this thesis consists of four 10m*40m spans that its 3D image is shown in figure 1. In this part, this structure is examined and analyzed. Its general properties are listed in table 1.

Table1. General properties of studied structure

Structure	Height of structure (m)	width of structure (m)	length of structure (m)	Lengh of span (m)
bridge	7	10	40	10

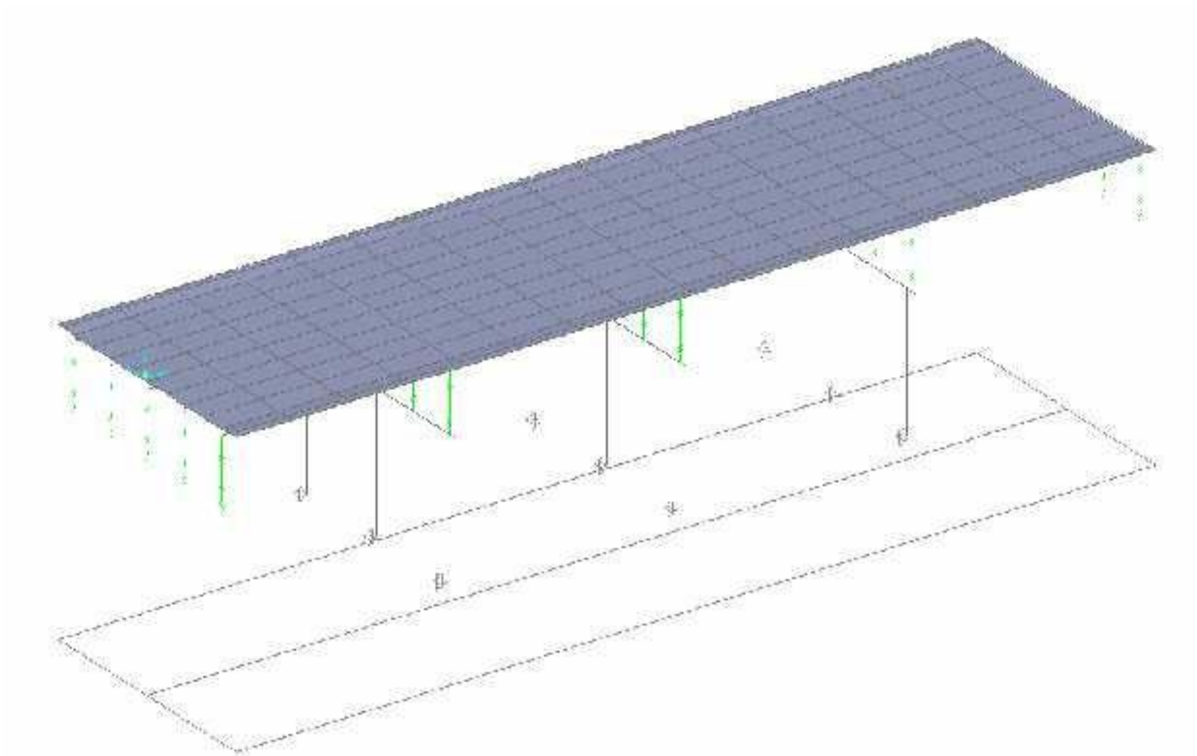


Figure 1. 3D image of studied structure

Used regulations

In this project, following regulations were used for gravity and lateral loadings in structure:
Gravity loading: Iran Regulations 519 (Second Edition) [3] and bridge loading Regulations (Issue 139, Iran planning and management organization) [4]
Lateral loading: Iran regulations 2800 (Third Edition) [2]

Materials

In studied structure, concrete and steel materials were used. Properties of materials are listed in table 2.

Table 2. Properties of used materials in modelled structure in 2000SAP

Properties of steel materials					
Yield stress(Fy)	Failure stress(Fu)	Mass of unit volume (M)	Weigh of unit volume (W)	Elasticity module (Ec)	Poisson's coefficient (v)
Kg/cm□	Kg/cm□	Kgf/m□	Kg/m□	Kgf/m□	-
2400	3700	800	7850	$2/1*10^{10}$	0/3
Properties of concrete materials					
(Fc)	Mass of unit volume (M)	Weigh of unit volume (W)	Elasticity module (Ec)	Poisson's coefficient (v)	
Kg/cm□	Kg/m□	Kgf/m□	Kgf/m□	-	
280	250	2500	$2/1*10^{9}$	0/2	

Sections of beams and columns

In order to design and analyze the structures, it is necessary that architect specifies the primary dimensions of sections. Since in this structure, a bridge consists of steel beams used in deck and concrete beams and columns used in pedestals, there is a restriction on the production of rolled sections for beams of deck. So, reinforced sections are used. The sections of columns and capitals used in modelling the bridge are 60*70 cm and the sections of used plate beams have a flange with width of 40 cm and thickness of 2 cm and height of 50 cm and web thickness of 1 cm and, also, a concrete slab with a thickness of 30 cm was used for bridge deck. In should be noted that since in this thesis, the aim is to estimate the maximum displacement and base shear of structure and not to design the bridge, the used sections in this study are primary and default sections and some of them may be changes in final design [8].

Loading

The loads on structure are divided into three groups of gravity loads, lateral loads and moving load and their details are explained below.

Gravity loading

Regulations 519 was used to estimate the gravity loads. Gravity load affect acts as dead load on the deck.

Moving loads (alive loads)

In order to estimate the moving loads, bridge loading regulations (Issue 139, Iran planning and management organization) (2nd edition) was used. 2000 SAP software includes both standard and non-standard moving loading for each type of regulations. Since, Iran loading regulations was used in this study, three types of non-standard loading, according to Iran regulations, were used.

1. A uniform load of 1.5 N/m in length and a width of 3 m was continuously applied on the deck.
2. A truck with the weight of 40 tons was used that 3m of it from its back and 3m of it from its front were empty.
3. A heavy vehicle was used for the place of tank which has 6 axles with total weight of 90 tons.

Lateral loading

In this part, loading of earthquake is done according to time history technique.

According to the descriptions of gravity loading, moving loading and lateral loading, following modes of load were used in modelling.

1. Dead load modes
2. Move load modes
3. Earthquake load modes in the direction of x (U1)

Type of analysis

In the studied structure, linear time history analysis was used to analyze the lateral loads. A typical static analysis was used to analyze the dead gravity loads and moving load analysis was used to analyze the moving load.

Modelling the structure

Modelling the structure is to shape the beams and columns and to assign the materials and sections to related elements. Positions of columns are exactly determined according to plan. Beam-to-column connection and column-to-pedestal connection are performed in such a way that the connections are quite rigid. And the sleeper beams used under the deck are quit rigid in connection to pedestal. In this part, explaining how modelling was done in 2000SAP software was ignored.

Time history analysis

After modeling and analyzing the model based on designing regulations, the modelled structure was placed under the time history loading related to EL Centro earthquake and Tabas earthquake. Accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration are shown in figures 2-5 and 3-5.

In this type of analysis, knowing earthquake acceleration must be applied to base level as a function of t. in time history analysis, center of mass and acceleration function applied to base level of structure is sufficient. One of the disadvantages of time history analysis, is that certain accelerographs should be used for different areas. Also, the probability of previous similar earthquakes, both in terms of intensity and duration of shaking, is low. Therefore, time history analysis is used only for additional control of structure and is not considered as a basis for designing structures. One of the biggest advantages of time history analysis is that it can be used as standard dynamic analysis in non-linear analysis. The method is linearly and nonlinearly usable.

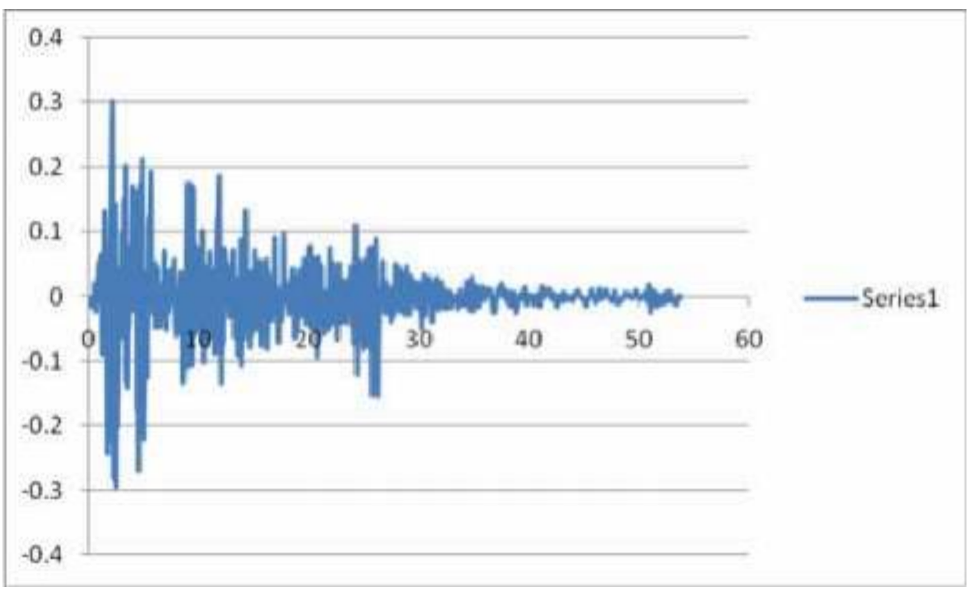


Figure2. Accelerograph of EL Centro earthquake with the scale of 0.3g

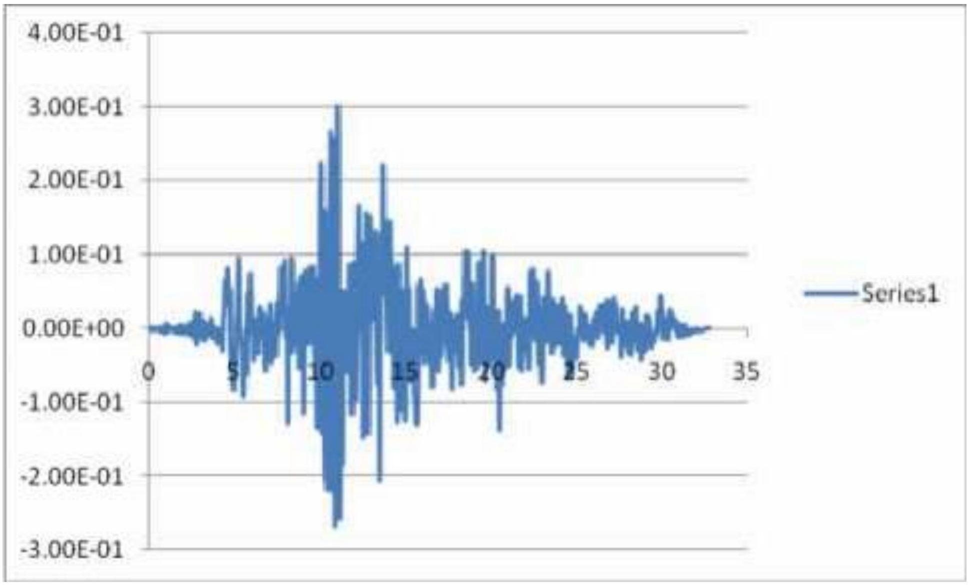


Figure3. Accelerograph of Tabas earthquake with the scale of 0.3g

Review of results

Results of final structure analysis can be shown with two types of outputs: text outputs and graphic output. In this part, the most important outputs of analysis, that can be called performance indicators, are examined. After reviewing the results of structure without damper, the structures are mobilized with multi-linear plastic damper and they are analyzed under the similar time history again and obtained results are compared with previous results.

Displacement of structure

One of the quantity which is examined in this study, is the displacement of bridge deck. The maximum created displacement of studied structure in the direction of x, which is estimated by 2000SAP software, is listed in table3.

Table 3. Maximum created displacement of bridge structure under the accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration

Name of earthquake	Height	Direction	Maximum replacement (cm)
EL Centro	Bridge deck level	**X**	**21.64**
Tabas	Bridge deck level	**X**	**21.52**

Base shear of structure

Another indicator that can be show the performance of structure is base shear. The value of base shear represents the need to strong columns which are the main factor in designing. Created base shear is one of the most important performance indicators of dampers that interesting results can be obtained by comparing the structure without damper with the structure with damper. Table 4-5 shows the maximum base shear created in the bridge under the earthquake in the direction of x which is estimated by 2000SAP.

Table 4. Maximum base shear created in the bridge structure under the accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration

Name of earthquake	Height	Direction	Maximum base shear (Kgf)
EL Centro	Pedestal support level	X	3.404E+04
Tabas	Pedestal support level	X	3.484E+04

Acceleration and vibration velocity of structure

Another indicators used to show the performance of structure are acceleration and vibration velocity. Maximum acceleration and maximum vibration velocity of bridge deck in the direction of x, estimated by 2000SAP software, are listed in table 5.

Table 5. Maximum acceleration and maximum vibration velocity created in the bridge structure under the accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration

Name of earthquake	Bridge deck level	X	Maximum acceleration (s/cm^2)	Maximum velocity(cm/s)
EL Centro	Bridge deck level	X	467	91.8
Tabas	Bridge deck level	X	410.6	90

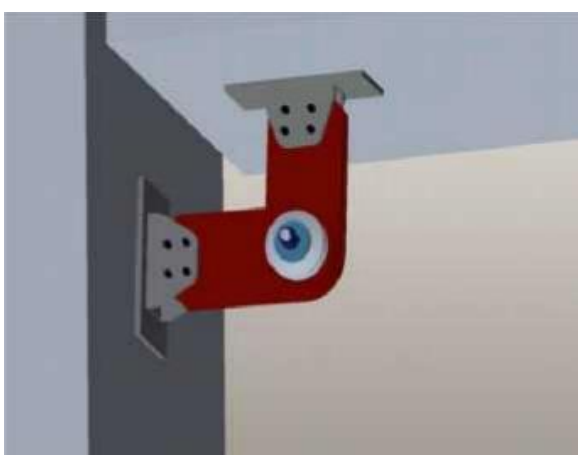
The use of Multi-linear plastic element

The properties of Multi-linear plastic element, including stiffness and yield moment, are provided with facilities titled "Link" in 2000SAP software. The software can model any type of device which has a function of Link (with certain stiffness and yield moment). Link model is built for Multi-linear plastic element using stiffness and non-linear yield moment.

In this thesis, the aim is to use rotational friction damper in base-to-deck connection to reach the minimum displacement and base shear of structure. Figure 4-5 shows this type of damper and base-to-deck connection which is built using Multi-linear plastic elements and Link model, applying stiffness and non-linear yield moment. This damper consists of 20*100 cm steel plates with the thickness of 2 cm. two steel plates are placed horizontally that are connected to base as hinged joint, and one plate is placed vertically that is connected to deck as hinged joint. These plated are connected to each other using Multi-linear plastic elements with the performance of Link model.

6 locations of Multi-linear plastic elements with similar number of elements are considered in the studied structure and placed under the accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration. Of course, in this study, minimum displacement and base shear are obtained by changing the value of yield moment of Link element and considering the constant value for stiffness of element. Figure 5-5 shows Multi-linear plastic elements distribution in the bridge structure.

Figure4. Rotational friction dampers used in the structure



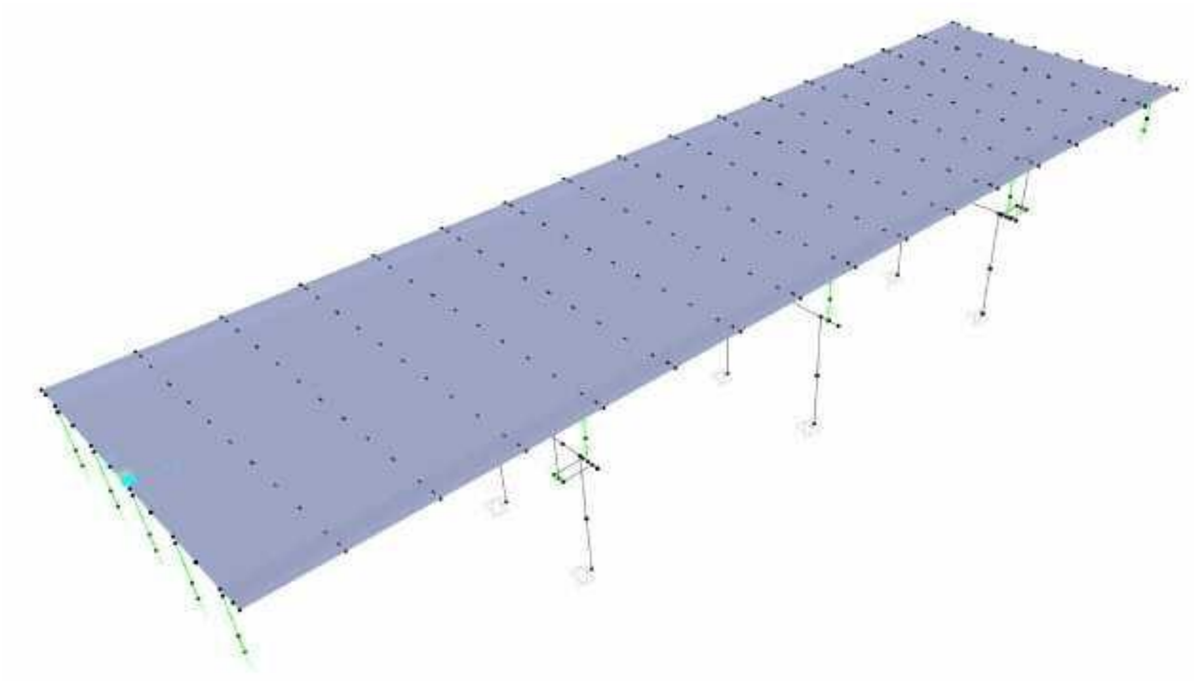


Figure 5. Distribution of dampers

Results of analysis

After installing damper in the structure, the obtained model is loaded by the same accelerographs of previous analysis (without damper) and non-linear time history analysis is applied to it due to non-linear behavior of dampers. The results of examined indicators in the structure with damper are listed in tables 6-5-a and 6-5-b. Then, the tables of different modes of Multi-linear plastic elements are provided. Displacement and base shear of structure and also acceleration and vibration velocity of structure are shown by curves.

Table 6-a. Distribution of Multi-linear plastic in bridge structure under the accelerograph of EL Centro earthquake with 0.3g of ground acceleration

Direction	Yield moment Kg.cm	Stiffness Kg/cm	Maximum displacement cm	Maximum base shear kgf	Maximum acceleration s/cm^2	Maximum velocity cm/s
X	1000	10E08	21.97	3.439E+04	437.6	93.05
X	10000	10E08	20.86	3.230E+04	448.8	87.63
X	50000	10E08	16.90	2.707E+04	425.3	70.36
X	100000	10E08	15.89	2.547E+04	404.6	67.11
X	150000	10E08	15.81	2.565E+04	397.3	66.92
X	200000	10E08	16.46	2.641E+04	410.7	69.61
X	250000	10E08	17.38	2.873E+04	403.7	72.91
X	300000	10E08	17.90	2.934E+04	396.9	75.60
X	400000	10E08	18.33	3.026E+04	397.9	77.06
X	500000	10E08	18.47	3.023E+04	397.9	77.09
X	1000000	10E08	18.47	3.023E+04	397.9	77.09

Table 6-b. Distribution of Multi-linear plastic in bridge structure under the accelerograph of Tabas earthquake with 0.3g of ground acceleration

Direction	Yield moment Kg.cm	Stiffness Kg/cm	Maximum displacement cm	Maximum base shear kgf	Maximum acceleration s/cm²	Maximum velocity cm/s
X	10E08	1000	21.48	3.458E+04	415.1	89.86
X	10E08	10000	20.43	3.233E+04	408.8	85.20
X	10E08	50000	16.67	2.705E+04	387.4	69.37
X	10E08	100000	14.38	2.410E+04	376.9	65.19
X	10E08	150000	13.90	2.384E+04	377.2	65.48
X	10E08	200000	14.12	2.502E+04	372.0	66.88
X	10E08	250000	14.61	2.543E+04	371.9	67.40
X	10E08	300000	15.46	2.558E+04	383.8	68.08
X	10E08	400000	16.64	2.766E+04	384.1	71.76
X	10E08	500000	16.66	2.768E+04	384.1	71.81
X	10E08	1000000	16.66	2.768E+04	384.1	71.81

As shown in tables 6-5-a and 6-5-b, different element of Link with constant stiffness and different yield moments were used. The reason for it is to obtain the minimum displacement and base shear of structure and to use the most optimal one. According to table 6-5-a, accelerograph of EL Centro earthquake with 0.3g of ground acceleration was used for analysis and with a constant stiffness of 100000000 and different yield moments, different results were obtained. With the increase in yield moment from 1000 to 150000 and considering the constant stiffness, the displacement was reduced but with the increase in yield moment from 150000 to 500000, the displacement was increased and with the change in yield moment from 500000 to greater values, the value of displacement remained constant. About the base shear, with the increase in yield moment from 1000 to 150000 and considering the constant stiffness, it was reduced but with the increase in yield moment from 150000 to 500000, it was increased and with the increase in yield moment from 500000 to greater values, the value of base shear remained constant. About the acceleration related to structure vibration, with the increase in yield moment from 1000 to 200000, there were swings in the acceleration. With the increase in yield moment from 10000 to 150000, sharp decline was observed in acceleration and with the increase in yield moment to 200000, a small increase was observed in it and with the increase in yield moment from 200000 to 300000, decline in acceleration was observed and with the increase in yield moment from 300000 to 400000, increase in acceleration was observed and with the increase in yield moment from 400000 to greater value, no changes was observed in acceleration and its value remained constant. About the velocity related to structure vibration, with the increase in yield moment from 1000 to 150000, reduction in velocity was observed and with the increase in yield moment from 150000 to 400000, increase in velocity was observed and with the increase in yield moment from 400000 to greater value, no changes was observed in velocity and its value remained constant.

According to table 6-5-b, accelerograph of Tabas earthquake with 0.3g of ground acceleration was used for analysis and with a constant stiffness of 100000000 and different yield moments, different results were obtained. With the increase in yield moment from 1000 to 150000 and considering the constant stiffness, the displacement was reduced but with the increase in yield moment from 150000 to 500000, the displacement was increased and with the increase in yield moment from 500000 to greater values, the value of displacement remained constant. About the base shear, with the increase in yield moment from 1000 to 150000 and considering the constant stiffness, it was reduced but with the increase in yield moment from 150000 to 500000, it was increased and with the increase in yield moment from 500000 to greater values, the value of base shear remained constant. About the acceleration related to structure vibration, with the increase in yield moment from 1000 to 200000, there were swings in the acceleration. With the increase in yield moment from 10000 to 150000, sharp decline was observed in acceleration and with the increase in yield moment to 200000, a small increase was observed in it and with the increase in yield moment from 200000 to 300000, decline in acceleration was observed and with the increase in yield moment from 300000 to 400000, increase in acceleration was observed and with the increase in yield moment from 400000 to greater value, no changes was observed in acceleration and its value remained constant. About the velocity related to structure vibration, with the increase in yield moment from 1000 to 150000, reduction in velocity was observed and with the increase in yield moment from 150000 to 400000, increase in velocity was observed and with the

increase in yield moment from 400000 to greater value, no changes was observed in velocity and its value remained constant.
The damper hysteresis diagram is as three-bar chart as following.

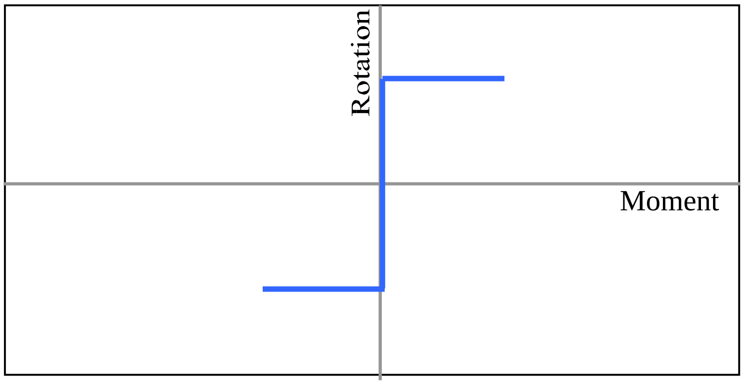


Figure 6. Damper hysteresis diagram

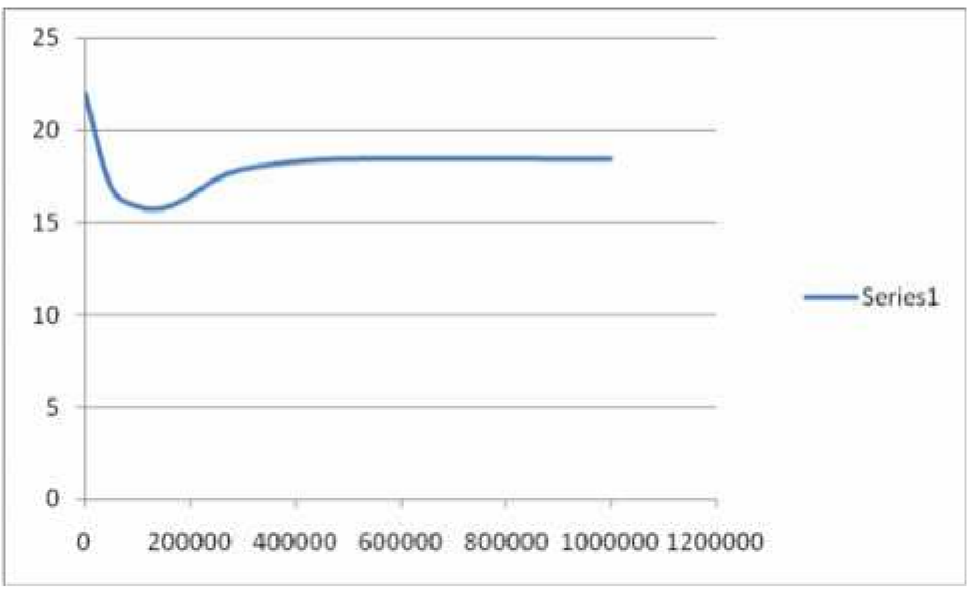


Figure 7. Displacement-moment curve under accelerograph of EL Centro earthquake

According to table 6-5-a and figure 7-5, the greatest reduction in displacement, under accelerograph of EL Centro earthquake with 0.3g of ground acceleration, is related to the yield moment of 150000. Also, it can be seen that the increase in yield moment from 500000 to greater value, increase in yield moment has no impact on the displacement of structure and percentage of reduction in displacement remains constant.

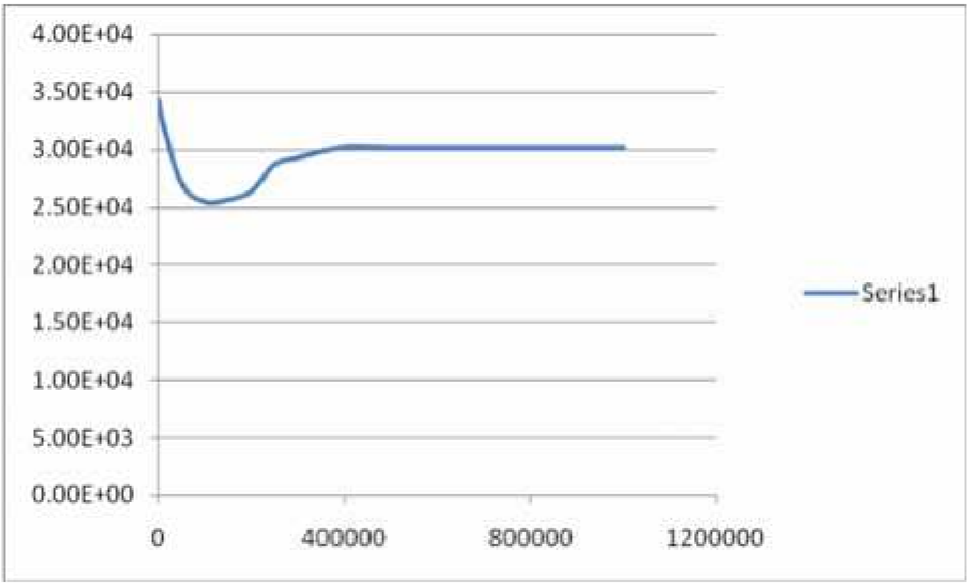


Figure 8. Base shear- moment curve under accelerograph of EL Centro earthquake

According to table 6-5-a and figure 8-5, the greatest reduction in base shear, under accelerograph of EL Centro earthquake with 0.3g of ground acceleration, is related to the yield moment of 100000. Also, it can be seen that the increase in yield moment from 500000 to greater value, increase in yield moment has no impact on the base shear of structure and percentage of reduction in base shear remains constant.

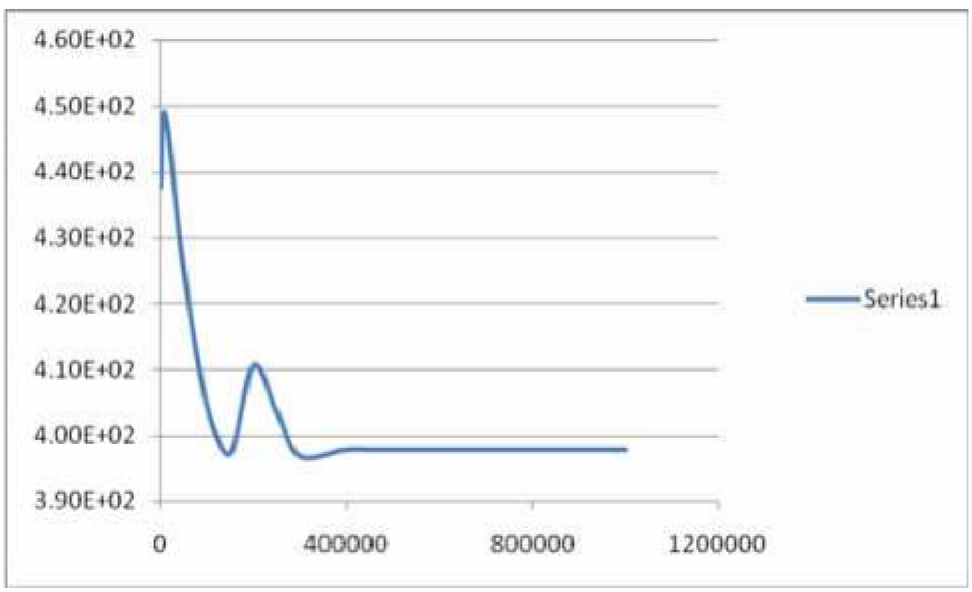


Figure 9. Acceleration-moment curve under accelerograph of EL Centro earthquake

According to table 6-5-a and figure 9-5, the greatest reduction in base shear, under accelerograph of EL Centro earthquake with 0.3g of ground acceleration, is related to the yield moment of 300000. Also, it can be seen that the increase in yield moment from 400000 to greater value, increase in yield moment has no impact on the acceleration of structure and percentage of reduction in acceleration remains constant.

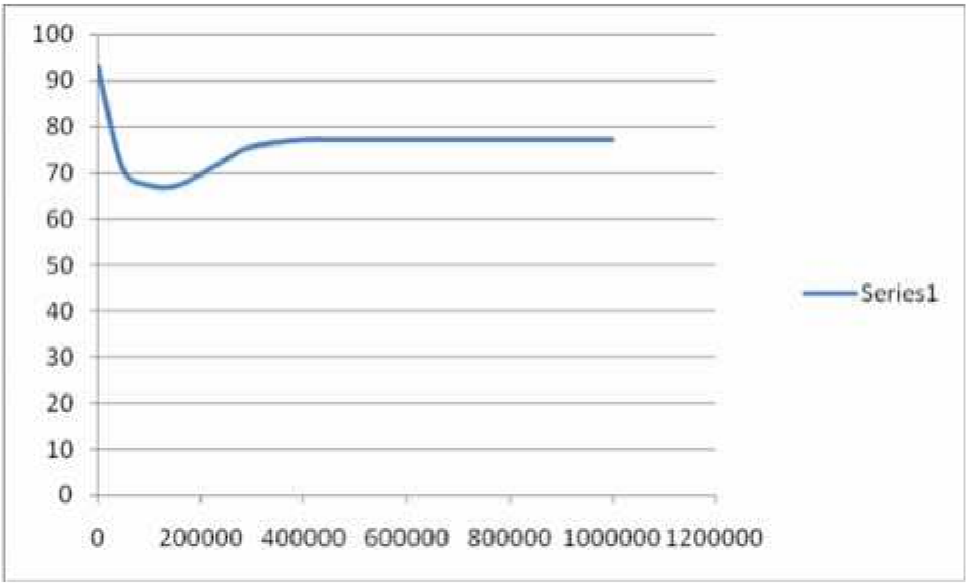


Figure 10. Velocity-moment curve under accelerograph of EL Centro earthquake

According to table 6-5-a and figure 10-5, the greatest reduction in vibration velocity of structure, under accelerograph of EL Centro earthquake with 0.3g of ground acceleration, is related to the yield moment of 150000. Also, it can be seen that the increase in yield moment from 500000 to greater value, increase in yield moment has no impact on the vibration velocity of structure and percentage of reduction in acceleration remains constant.

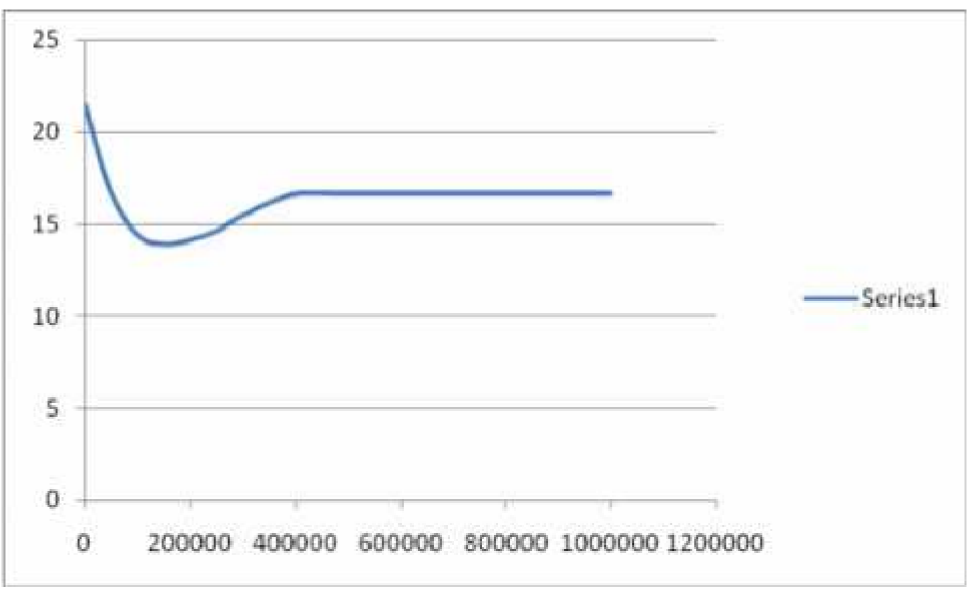


Figure11. Displacement-moment curve under accelerograph of Tabas earthquake

According to table 6-5-b and figure 11-5, the greatest reduction in displacement, under accelerograph of Tabas earthquake with 0.3g of ground acceleration, is related to the yield moment of 150000. Also, it can be seen that the increase in yield moment from 500000 to greater value, increase in yield moment has no impact on the displacement of structure and percentage of reduction in displacement remains constant.

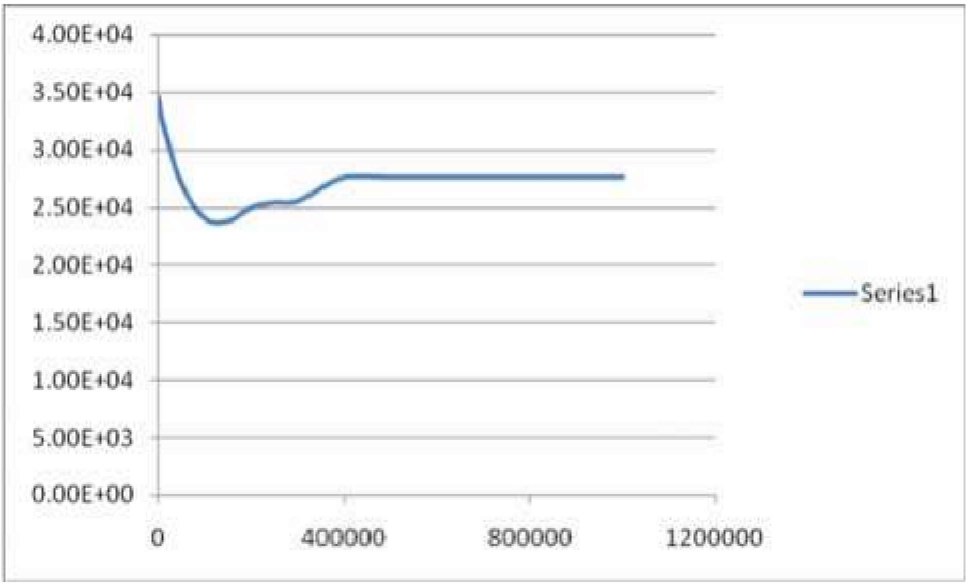


Figure 12. Base shear- moment curve under accelerograph of Tabas earthquake

According to table 6-5-b and figure 12-5, the greatest reduction in base shear, under accelerograph of Tabas earthquake with 0.3g of ground acceleration, is related to the yield moment of 150000. Also, it can be seen that the increase in yield moment from 500000 to greater value, increase in yield moment has no impact on the base shear of structure and percentage of reduction in base shear remains constant.

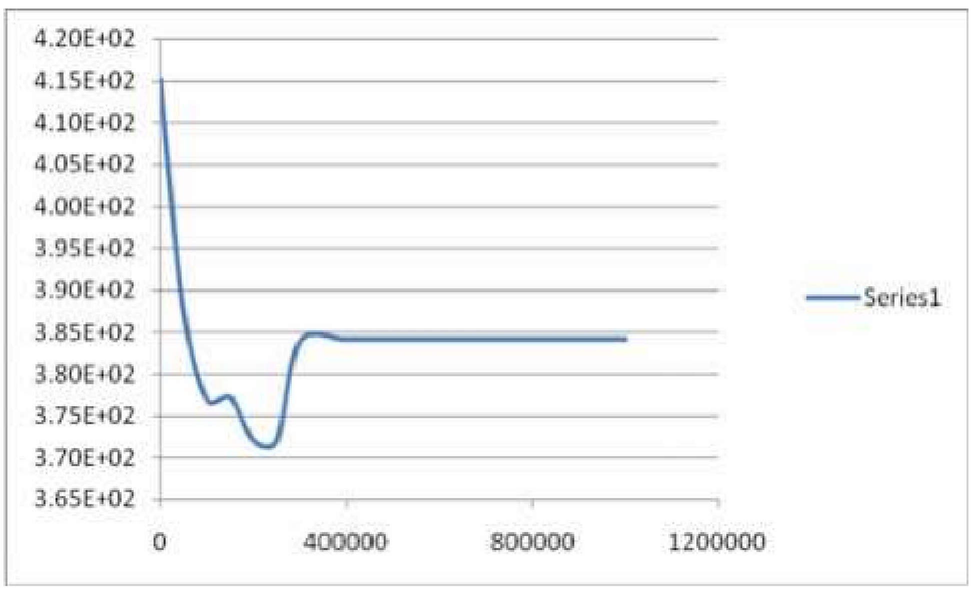


Figure 13. Acceleration-moment curve under accelerograph of Tabas earthquake

According to table 6-5-b and figure 13-5, the greatest reduction in base shear, under accelerograph of Tabas earthquake with 0.3g of ground acceleration, is related to the yield moment of 250000. Also, it can be seen that the increase in yield moment from 400000 to greater value, increase in yield moment has no impact on the acceleration of structure and percentage of reduction in acceleration remains constant.

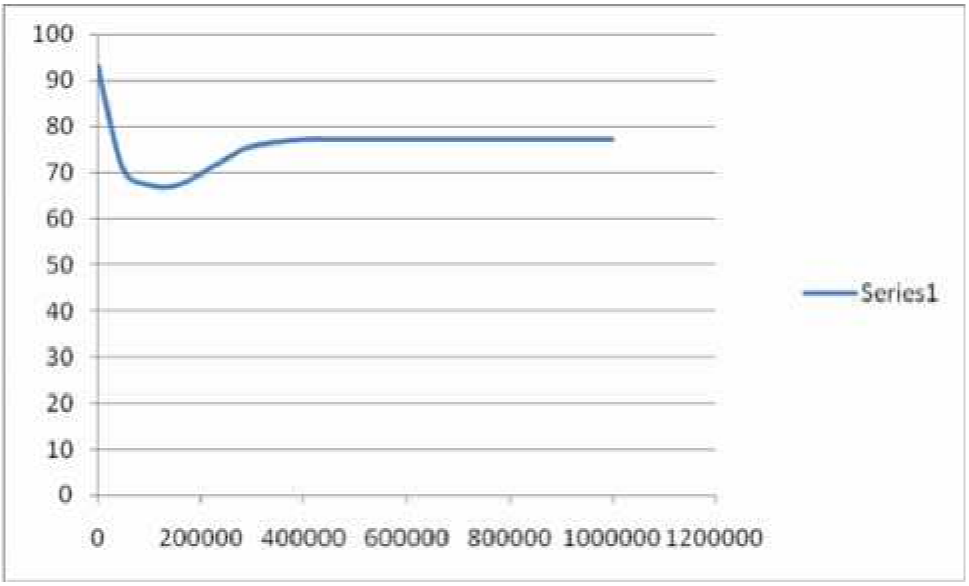


Figure 14. Velocity-moment curve under accelerograph of Tabas earthquake

According to table 6-5-b and figure 14-5, the greatest reduction in vibration velocity of structure, under accelerograph of Tabas earthquake with 0.3g of ground acceleration, is related to the yield moment of 100000. Also, it can be seen that the increase in yield moment from 500000 to greater value, increase in yield moment has no impact on the vibration velocity of structure and percentage of reduction in acceleration remains constant.

Comparison of results

The results are compared in terms of following performance indicators:

1. Displacement
2. Base shear
3. Acceleration
4. Velocity

Displacement

According to table 3-5 and tables 6-5-a and –b related to the results of analysis under accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration, it can be found that significant reduction in displacement of deck under both accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration, was observed in the structure mobilized with damper compared to the structure without damper. By comparing the structure with damper with the structure without damper, it was observed that the reductions in displacement under the accelerographs of EL Centro earthquake and Tabas earthquake were %26.9 and %35.4, respectively.

Base shear

According to table 4-5 and tables 6-5-a and –b, it can be found that significant reduction in base shear under both accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration, was observed in the structure mobilized with damper compared to the structure without damper. By comparing the structure with damper with the structure without damper, it was observed that the reductions in base shear under the accelerographs of EL Centro earthquake and Tabas earthquake were %25.2 and %31.6, respectively.

Acceleration

According to table 5-5 and tables 6-5-a and –b, it can be found that significant reduction in vibration acceleration of structure under both accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration, was observed in the structure mobilized with damper compared to the structure without damper. By comparing the structure with damper with the structure without damper, it was observed that the reductions in base shear under the accelerographs of EL Centro earthquake and Tabas earthquake were %15 and %9.4, respectively.

Velocity

According to table 5-5 and tables 6-5-a and –b, it can be found that significant reduction in vibration velocity of structure under both accelerographs of EL Centro earthquake and Tabas earthquake with 0.3g of ground acceleration, was observed in the structure mobilized with damper compared to the structure without damper. By comparing the structure with damper with the structure without damper, it was observed that the reductions in base shear under the accelerographs of EL Centro earthquake and Tabas earthquake were %27.1 and %27.6, respectively.

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