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Evaluating the effect of viscous damper on improving the performance level of systems of steel structures with Chevron bracing in 10-storey constructions

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ABSTRACT

In the prevalent seismic design of structures, the optimal performance of a structure during an earthquake is based on the ability of the seismic load-bearing system to absorb and dissipate energy during numerous cycles of the earthquake. The aim of this study was to examine the effect of viscous damper on improving the performance of systems of steel structures with Chevron bracing in 10-storey constructions. In this examination, a 10-storey construction was designed based on the formula of FEMA356 regulation of viscous dampers, then the building under the accelerometer of Manjil, Tabas and Bam earthquakes was analyzed by time history analysis using sap2000 software version 14. Different responses were compared. After analyzing study group B, to compare the performance level of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Manjil earthquake record (10-storey construction with dampers) under the record of Tabas earthquake and (10-storey construction with damper) under the record of Bam earthquake, sample B-1 and sample B-2 were compared to the values of regulations. Based on the comparison of the performance level of sample B-1 and sample B-2, it was observed that by placing the performance level damper from the safety mode to the functional level, the uninterrupted usability has been enhanced.

Keywords: Viscous damper, Steel structures, Chevron bracing

Introduction

Experts and researchers have always searched to provide methods to decrease the damage caused by earthquakes, and have obtained some findings and methods in this field. Dampers are among the inactive control tools and increase the damping of the structure and response control and decrease the seismicity need. Their most conspicuous features are ease of control and construction because of the lack of much complexity in the shape and technology of construction, and being easily replaced in case of damage after an earthquake. Flowing metal dampers, by concentrating the damage on themselves, maintain the other components of the structure in the elastic range and decrease the dynamic responses of the structure (Najari Varzaneh et al., 2014). Viscous dampers are one of the safest energy dissipation devices that have been widely used around the world. These types of dampers do not cause a considerable change in the modal characteristics of the system due to the lack of added stiffness to the system and they also have the capacity to create significant damping (Lee, D., and Taylor, D, 2001). Viscous dampers, when correctly designed and manufactured, have zero leakage and do not require an accumulator (fluid accumulator) or external fluid storage device to keep the damper full of fluid, and they have almost complete sealing. In a properly designed and built-in viscous damper, there is nothing to wear out or deteriorate over time. Chevron frames, on the other hand, are a type of concentric brace frames. The behavior of such a system is controlled by the buckling of the braces. Generally, these systems do not have the ability to reproduce most of the forces after local failure in a storey and have not revealed good behavior in former earthquakes (Taghi Beklou, 2007).

Some research studies have also been done in this area. In a study, Landi et al (2012) examined one of the methods presented in articles on designing viscous dampers that should be installed in existing buildings and extended to 3D buildings outside the center. Palermo et al (2014), conducted a study entitled seismic design of torque-resistant frame structures equipped with viscous dampers, this method, which was originally created with reference to the design of shear structures, provided a method for easy identification of the mechanical properties of the produced viscous dampers. In a study, Khoshnoudian and Vosoughian (2014) indicated that the goal of building seismic improvement is to strengthen the members of structures and non-structural accessories in such a way that less damage is done to these components in the event of an earthquake. In a research study, Salehirad et al. (2016) revealed that the use of dampers in conventional steel frames, significantly decreases the structural responses such as base shear forces, reducing displacements and accelerations, reducing the amount of plasticization of the main members of the structure as well as a significant increase in the energy consumed as viscose in the structure. Noshiri and Hashemi (2014) in a study entitled evaluation of the seismic performance of steel frames with Chevron bracing and flowing metal dampers, displayed that the displacement and shear of the base has been decreased by about twenty percent. In a research study, Chayforosh et al. (2012) investigated the effect of viscous dampers in decreasing the seismic response of structures located in near-field earthquakes. The findings presented a reduction in base shear and roof displacement in structures equipped with viscous dampers. Pezeshki and Ziaeifar (2013) in a study, examined the effect of using nonlinear viscous dampers on isolated base structures located in the area near the fault. The results revealed that in some responses, such as base shift, nonlinear damping leads to a reduction of more than ten percent. Zarrin Ghalam and Yahyaei (2010) in a study examined viscous dampers in an 11-storey building, in the near and far areas of the earthquake by force methods, they used the base cut and drift of the storeys for comparison, and they found that this structure functions differently in the near and far areas of the earthquake. In a study, LJ Leo & JT Chang (2011) presented that by placing a special arrangement of viscous dampers, the drift of the storeys can be drastically decreased. Kandemie, et al, (2011) conducted a research study on arch bridges at Kumamoto University in Japan and found that installing viscous dampers on arched bridges is very efficient in the performance of structures. In a study, Bagheri and Fallah (2008), through using genetic algorithm, presented the optimal arrangement for viscous dampers. Considering the research studies, the purpose of the current study is to examine the effect of viscous damper on improving the performance level of steel structure systems with Chevron braces in 10-storey constructions.

Research Methods

In the current research study, in order to investigate the effect of viscous damper on improving the performance level of steel structural systems with Chevron bracing, study group B has been used. The study sample includes two study subsets. Generally, the geometric characteristics, the plan of the mentioned structures of the above-mentioned model have been presented in Figure (1).

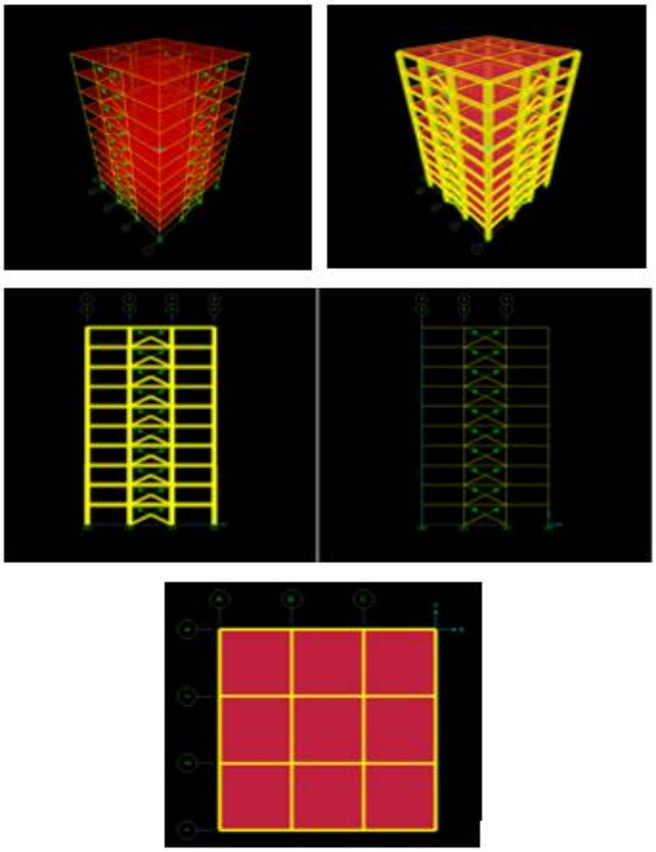


Figure 1: Schematic overview of the geometric sample of the study sample (B-1) with damper

Table 1: Geometric details of the structural model

Group name	Model name	Number of storeys	Effective parameters
GROUP B	B-1	10 storeys	Frame with Chevron brace + without damper
	B-2		Frame with Chevron brace + with damper

Table 2: Gravity loading

Type of gravity loading	Weight per unit length (kg / m2)
Dead (storeys)	450
Live (storeys)	250
Dead (roof)	450
Live (roof)	150

In this study, the parameters of damping coefficient and hardness, which have been presented in the reference (Ali Khan Sefid, 2013), were used. It is noteworthy that the design of the optimal viscous damping system for linear structures has been done. The parameters used in this study for a 10-storey construction have been presented in Table 3-3.

Table 3: Viscous damping parameters in 5 and 10 storey constructions

α	C(N.s/m)	K(N/m)	Type of structure
3162	2529.6	0.8	10 storeys

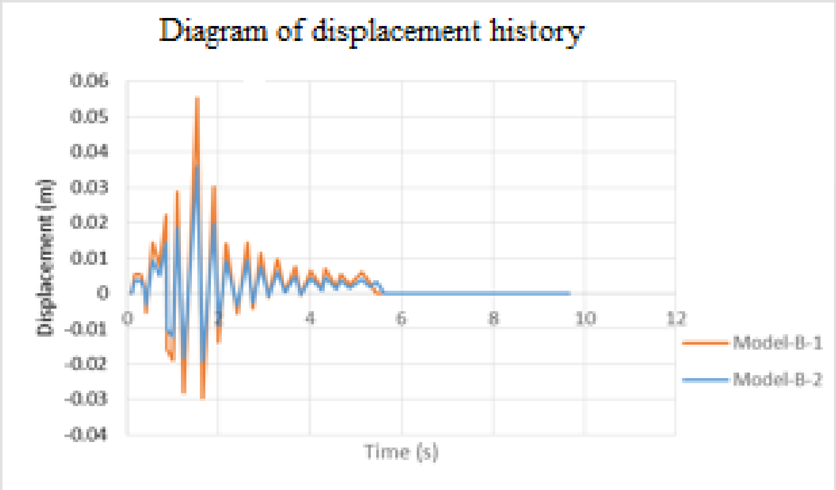
Findings

In this study, a 10-storey model in an area with a very high relative earthquake risk was used. In this model, for gravity loading of the construction, guidelines for gravity loading of the structure of Iran (Chapter 6 of the National Building Regulations). Seismic loading was also performed based on the fourth edition of Iranian Standard 2800. AISC 2010 regulations and SAP 2000 software have also been used for structural design. The final sections of Model B beams and columns after analysis and design by SAP2000 software have been presented in Table (4).

Table 4: Dimensions of beam-column of model B

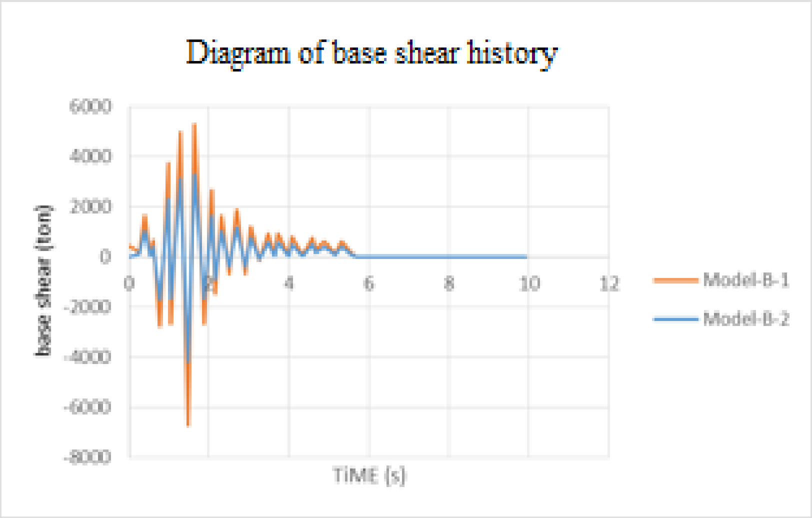
Storey number	Column specifications	Beam specifications
Storey 1-3	BOX 300X300X15	IPE 250
Storey 4-6	BOX 250X250X15	IPE 200
Storey 7-10	BOX 200X200X15	IPE 200

1- Dynamic response resulted from nonlinear dynamic analysis of 10-storey construction - without damper (Manjil earthquake record)



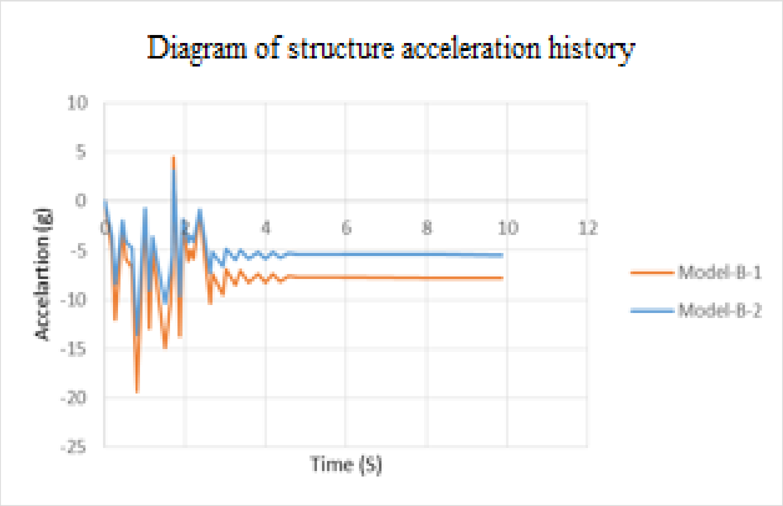
Graph 1: Diagram of displacement history of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey structure with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the base shear history diagram of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Manjil earthquake record was observed. By comparing the base shear history of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of the base shear of sample B-2 has reduced compared to sample B-1.



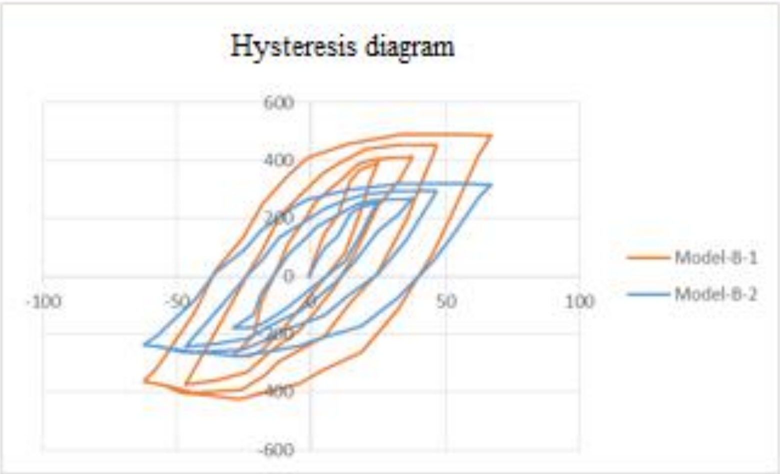
Graph 2: Diagram of base shear history of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B, sample B-1 and sample B-2, for making comparison, the roof acceleration diagram of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Manjil earthquake can be observed. Comparing the acceleration diagram of the base structure of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of acceleration of the structure of sample B-2 has reduced compared to sample B-1.



Graph 3: Diagram of acceleration history of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the Hysteresis diagram of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Manjil earthquake record was observed. Comparing the Hysteresis diagram of the base structure of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of Hysteresis diagram of sample B-2 has reduced compared to sample B-1.



Graph 4: Hysteresis diagram of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the performance level of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Manjil earthquake record was compared with the values of the regulations. Considering the comparison of the performance level of sample B-1 and sample B-2, it was observed that by placing the performance level damper from the life safety mode to the performance level, the uninterrupted usability has been enhanced.

Table 5: Drift ratio distribution specifications of storeys in sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

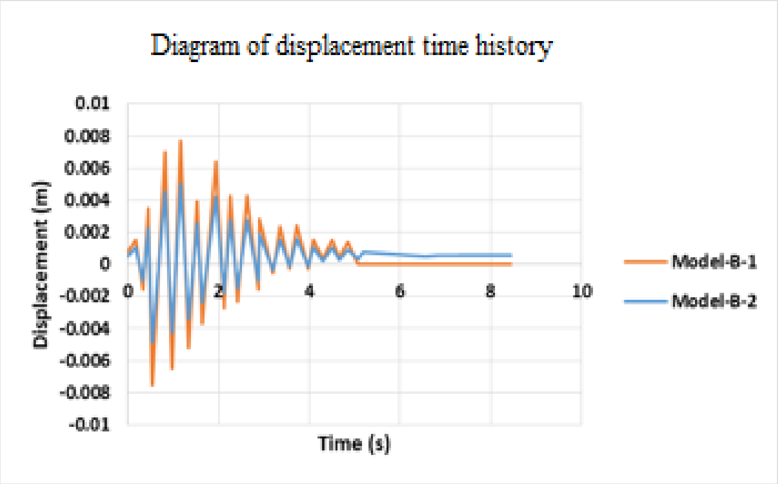
Drift ratio(٪) With damper	Drift ratio (%) Without damper	Storey number
1.18%	1.42%	Storey-1
1.38%	1.38%	Storey-2
1.27%	1.43%	Storey-3
1.34%	1.57%	Storey-4
1.12%	1.34%	Storey-5
1.23%	1.34%	Storey-6
1.35%	1.68%	Storey-7
1.34%	1.42%	Storey-8
1.26%	1.26%	Storey-9
1.21%	1.53%	Storey-10
1.38%	1.68%	Max Drift ratio (%)

Table 6: Performance level of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

Sample name	Earthquake record	Displacement member type	Sample performance level		
			Values of Regulations		
			Uninterrupted usability	Life safety	Collapse threshold
		Transient lateral displacement	0.5%%	1.5%	2%
		Displacement member type	Calculated values	performance level	
Sample B-2	Manjil	Transient lateral displacement	1.68% percent	(Life safety)	

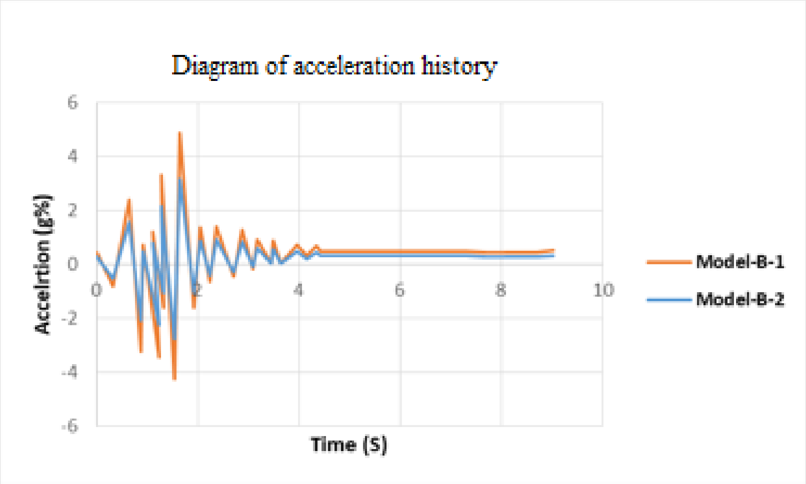
2- Output of the results of dynamic analysis of time history (Tabas record) of a 10-storey construction with and without dampers

By comparing the displacement time history chart of sample B-1 and sample B-2, it can be seen that by placing the damper, the amount of displacement of sample B-2 has reduced compared to sample B-1.



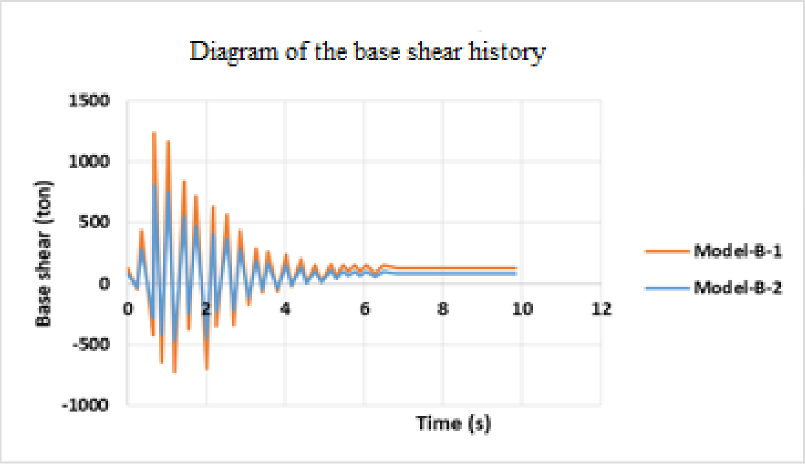
Graph 5: Diagram of displacement time history of sample B1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the base shear history of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Tabas earthquake record was observed. Comparing the base shear history diagram of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of base shear of sample B-2 has reduced compared to sample B-1.



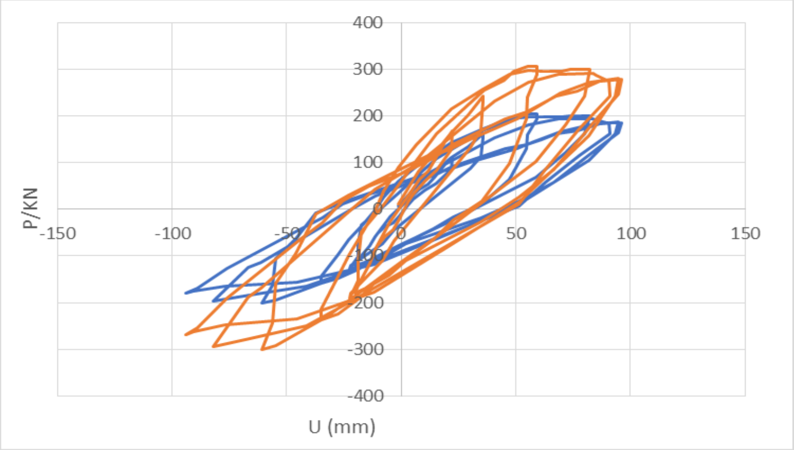
Graph 6: Diagram of the base shear history of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the roof acceleration of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Tabas earthquake record was observed. Comparing the base acceleration structure diagram of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of structure acceleration of sample B-2 has reduced compared to sample B-1.



Graph 7: Diagram of acceleration history of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the Hysteresis diagram of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Tabas earthquake record was observed. Comparing the Hysteresis diagram of the base structure of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of Hysteresis diagram of sample B-2 has reduced compared to sample B-1.



Graph 8: Hysteresis diagram of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the performance level of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Tabas earthquake record was compared with the values of the regulations. Considering the comparison of the performance level of sample B-1 and sample B-2, it was observed that by placing the performance level damper from the life safety mode to the performance level, the uninterrupted usability has been enhanced.

Table 7: Drift ratio distribution specifications of storeys in sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

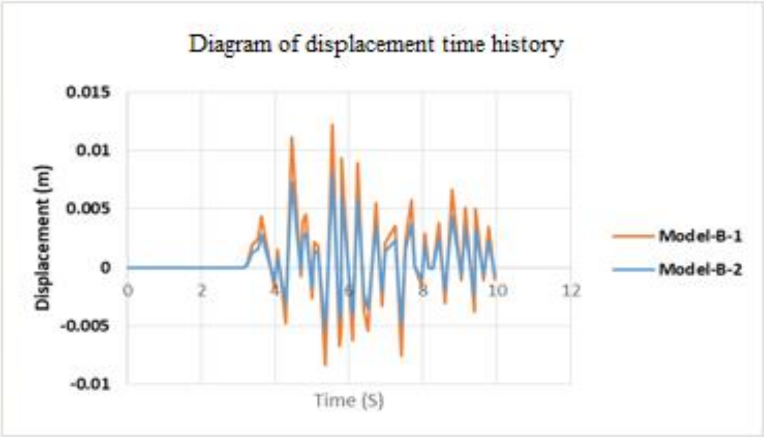
Drift ratio(٪) With damper	Drift ratio (%) Without damper	Storey number
1.28%	1.39%	Storey-1
1.31%	1.61%	Storey-2
1.34%	1.43%	Storey-3
1.42%	1.75%	Storey-4
1.23%	1.63%	Storey-5
1.35%	1.85%	Storey-6
1.28%	1.78%	Storey-7
1.31%	1.81%	Storey-8
1.34%	1.64%	Storey-9
1.28%	1.75%	Storey-10
1.42%	1.85%	Max Drift ratio (%)

Table 8: Performance level of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

<table>
<tr><td rowspan="5">Sample name</td><td rowspan="5">Earthquake record</td><td rowspan="3">Displacement member type</td><td colspan="4">Sample performance level</td></tr>
<tr><td colspan="4">Values of Regulations</td></tr>
<tr><td>Uninterrupted usability</td><td colspan="2">Life safety</td><td>Collapse threshold</td></tr>
<tr><td>Transient lateral displacement</td><td>0.5%%</td><td colspan="2">1.5%</td><td>3%</td></tr>
<tr><td>Displacement member type</td><td colspan="2">Calculated values</td><td colspan="2">performance level</td></tr>
<tr><td>Sample B-2</td><td rowspan="2">Tabas</td><td rowspan="2">Transient lateral displacement</td><td colspan="2">1.85% percent</td><td colspan="2">(Life safety)</td></tr>
<tr><td>Sample B-2</td><td colspan="2">1.43% percent</td><td colspan="2">(Uninterrupted usability)</td></tr>
</table>

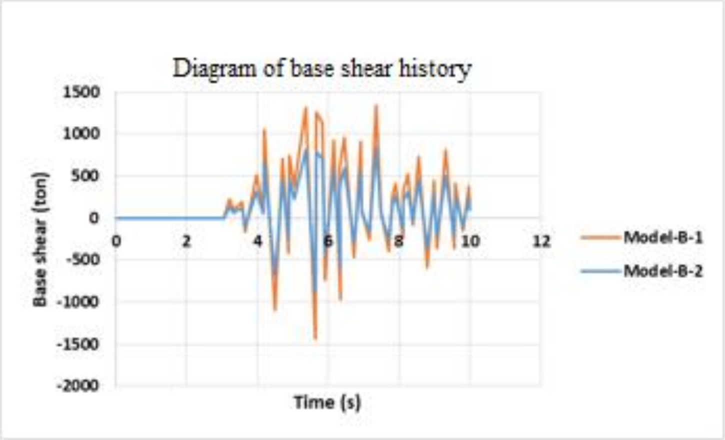
3- Output of the results of dynamic analysis of time history (Bam record) of a 10-storey construction with and without dampers

By comparing the displacement time chart of sample B-1 and sample B-2, it can be observed that by placing the damper, the amount of displacement of sample B-2 has reduced compared to sample B-1.



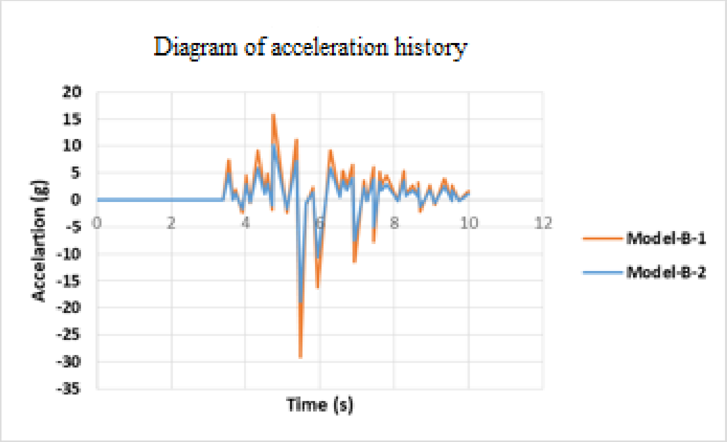
Graph 9: Diagram of displacement time history of sample B1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the base shear history of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Bam earthquake record was observed. Comparing the base shear history diagram of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of base shear of sample B-2 has reduced compared to sample B-1.



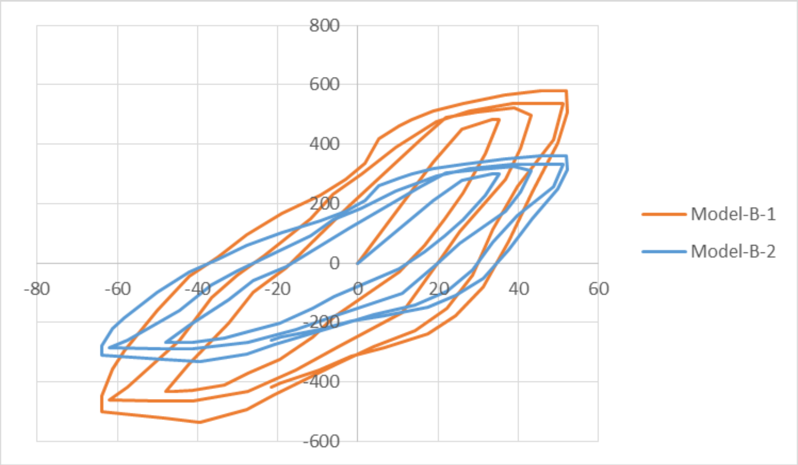
Graph 10: Diagram of the base shear history of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the roof acceleration of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Bam earthquake record was observed. Comparing the base acceleration structure diagram of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of structure acceleration of sample B-2 has reduced compared to sample B-1.



Graph 11: Diagram of acceleration history of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the Hysteresis diagram of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Bam earthquake record was observed. Comparing the Hysteresis diagram of the base structure of sample B-1 and sample B-2, we can observe that by placing the damper, the amount of Hysteresis diagram of sample B-2 has reduced compared to sample B-1.



Graph 12: Hysteresis diagram of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

After analyzing the study group B and sample B-1 and sample B-2, for making comparison, the performance level of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Bam earthquake record was compared with the values of the regulations. Considering the comparison of the performance level of sample B-1 and sample B-2, it was observed that by placing the performance level damper from the life safety mode to the performance level, the uninterrupted usability has been enhanced.

Table 9: Drift ratio distribution specifications of storeys in sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

Drift ratio(٪) With damper	Drift ratio (%) Without damper	Storey number
1.34%	1.39%	Storey-1
1.38%	1.61%	Storey-2
1.29%	1.43%	Storey-3
1.45%	1.75%	Storey-4
1.31%	1.47%	Storey-5
1.39%	1.85%	Storey-6
1.25%	1.73%	Storey-7
1.27%	1.96%	Storey-8
1.41%	1.63%	Storey-9
1.34%	1.85%	Storey-10
1.45%	1.96%	Max Drift ratio (%)

Table 10: Performance level of sample structure B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper)

<table>
<tr><td rowspan="5">Sample name</td><td rowspan="5">Earthquake record</td><td rowspan="3">Displacement member type</td><td colspan="3">Sample performance level</td></tr>
<tr><td colspan="3">Values of Regulations</td></tr>
<tr><td>Uninterrupted usability</td><td>Life safety</td><td>Collapse threshold</td></tr>
<tr><td>Transient lateral displacement</td><td>0.5%%</td><td>1.5%</td><td>2%</td></tr>
<tr><td>Displacement member type</td><td>Calculated values</td><td colspan="2">performance level</td></tr>
<tr><td>Sample B-2</td><td rowspan="2">Bam</td><td rowspan="2">Transient lateral displacement</td><td>1.96% percent</td><td colspan="2">(Life safety)</td></tr>
<tr><td>Sample B-2</td><td>1.45% percent</td><td colspan="2">(Uninterrupted usability)</td></tr>
</table>

Conclusion

The aim of this study was to examine the effect of viscous damper on improving the performance level of steel structures systems with Chevron bracing in 10-storey constructions, which was performed by analyzing the time history in sap2000 software. After analyzing study group B, sample B-1 and sample B-2, for making comparison, the performance level of sample B-1 (10-storey structure without damper) and sample B-2 (10-storey structure with damper) under the Manjil earthquake record was compared to the values of regulations, based on the comparison of the performance level of sample B-1 and sample B-2, it was observed that by placing the performance level damper from the life safety mode to the performance level, the uninterrupted usability has been improved. After analyzing the study group B, sample B-1 and sample B-2, for making the comparison, the performance level of sample B-1 (10-storey construction without damper) and sample B-2 (10-storey construction with damper) under the Tabas earthquake record was compared to the values of the regulations, based on the comparison of the performance level of sample B-1 and sample B-2, it was observed that by placing the performance level damper from the life safety mode to the performance level, the uninterrupted usability has been enhanced. After analyzing the study group B, sample B-1 and sample B-2, for making the comparison, the performance level of sample B-1 (10-storey structure without damper) and sample B-2 (10-storey structure with damper) under the Bam earthquake record was compared to the values of the regulations, by comparing the performance level of sample B-1 and sample B-2, it was seen that by placing the performance level damper from the safety mode to the functional level, the uninterrupted usability has been enhanced.

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