



## Investigating the behavior of steel structures with honeycomb damper against blast and earthquake loads

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### Abstract

*Earthquake is one of the most important natural phenomena and humans have always been trying to control its adverse effects. In the past century, the development of cities and the high investment in them and many financial and life losses caused by earthquake and, on the other hand, the ever-increasing advances in science and technology that allow for more accurate knowledge of the factors causing the earthquake and how to control it have made humans reduce its financial and life losses by making suitable and earthquake resistant structures. Today, due to the increasing growth of terrorist activities, the risk of structures facing blast loads has also increased. The occurrence of various terrorist incidents in relation to important structures around the world has caused that in recent years, blast loads become the focus of special attention. This article examines the connection of steel structures with honeycomb damper by applying blast and earthquake loads in Abaqus finite element software. Three frame models with 6, 9 and 13 floors have been considered for the study. For air blast, 10 Kg of TNT have been used. To apply earthquake records, seven pairs of accelerograms have been employed. By examining the results of numerical modeling in Abaqus finite element software, it can be observed that as a result of applying blast load, the damper could not react. But due to applying earthquake records, the damper's behavior was very good so that at the beam-column joint, the highest amount of stress was created in the damper. Considering that applying the blast loading occurs in less than a few milliseconds and the structure does not have enough time to react to this load, blast load failure has been local and sectional.*

**Keywords :** Blast, honeycomb damper, Abaqus, moment frame.

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### I. Introduction

Various methods have been proposed so far by engineers to deal with the destructive effects of earthquakes so that many of these methods have been applied in the construction of structures. Among these methods, we can refer to the increased

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capacity of structural members to bear the earthquake loads. Many of the strategies used so far in this field are, indeed, based on an increase in load bearing capacity of structural elements while by increasing the capacity of structural members, the structure weight also increases and thus, the earthquake-induced force to the structure will increase. This process of increasing capacity should continue until the effect of capacity increase exceeds the effect of weight in producing the earthquake-induced force. In addition to increasing the structure weight, this increase in capacity can lead to the construction of very heavy and costly foundations, which is not normally desirable.

The occurrence of explosion caused by multiple factors such as unpredictable events and incidents like the terrorist attacks that take place today in various societies highlights the study of structural behavior influenced by blast loading. Explosions can cause progressive damage or complete failure in the structure while design of structures for large explosions may be expensive and impractical. Hence, explosive strength of the structure can be increased by taking advantage of a variety of depreciators.

Another way of dealing with earthquakes, which has been further considered by researchers in recent decades, is the control of structural response to earthquake force. In this approach, the main purpose of the structural design engineers is to either limit the energy from the earth to the structure in some way or depreciate this energy in the structure or change the structural frequency in a way that it has a lot of difference with the frequency of ground motion and thus reduces the structural response. In a large categorization, new methods for reducing seismic hazards can be divided into three general groups of active, semi-active and passive control.

Use of passive control systems (passive dampers) in structures to provide life and financial safety against seismic hazards is a method that has grown dramatically in recent decades. Among different types of passive dampers, yielding metallic dampers are more usable due to their ease of construction and lower costs. In structures equipped with these dampers, the incoming energy into the structure is spent on yield and creation of plastic strains in the consumed metal and energy depletion.

The first research projects in the field of metallic dampers were carried out by Kelly and Skinner in New Zealand and the United States in the early 1970s in order to depreciate part of the incoming energy into the structure by the earthquake [I, II]. In these studies, flexural and torsional non-elastic strains were created in steel beams and the idea of using devices in the structure which, by entering the plastic zone and absorbing energy, reduced the damage to the main structural members was raised for the first time.

After these investigations and especially in the last two decades, considerable research has been done in this area, among which we can refer to the experiments performed by Bergman and Goel in University of Michigan on X-shaped and V-shaped steel plates [III]. In another major research project in this regard, Wittaker and colleagues in Berkeley University carried out investigations on analyzing the behavior of X-shaped steel plates [IV]. Numerous studies have also been conducted on ADAS and TADAS metal dampers in recent years. But since the main purpose of this chapter is the introduction of newer types of metallic dampers, the studies conducted on other types of metallic dampers are more addressed.

In a laboratory work, Chan and Albermani investigated the behavior of slit metallic dampers [V]. In this project, by creating splits in rolled H-shaped steel sections, they built samples in which under a change in in-plane web shear shapes, steel strips between the slots undergo moment yielding and deprecate the incoming energy. It should be noted that the use of rolled sections to do this will eliminate the concerns about welding and the weakness of the welds. This type of dampers can be placed at the joint of the chevron braces to the beams. The results of experiments indicate that a drop in the strength of samples begins when some cracks are formed slowly in these areas because of stress concentration at the end of steel strips. This has happened, on average, after 27 loading cycles and the exact location of the crack start in different samples also varies. Figure (1) displays two samples from the samples tested in this study. Samples of very low weight (about 2.2 kilograms) have the ability to depreciate a significant amount of energy (8 to 10 kilojoules) and this suggests that with decreased steel strip slenderness (increased dimensions of slots), the energy absorption rate relative to the changed location increases and on the other hand, the cumulative displacement corresponding to the sample failure is reduced.

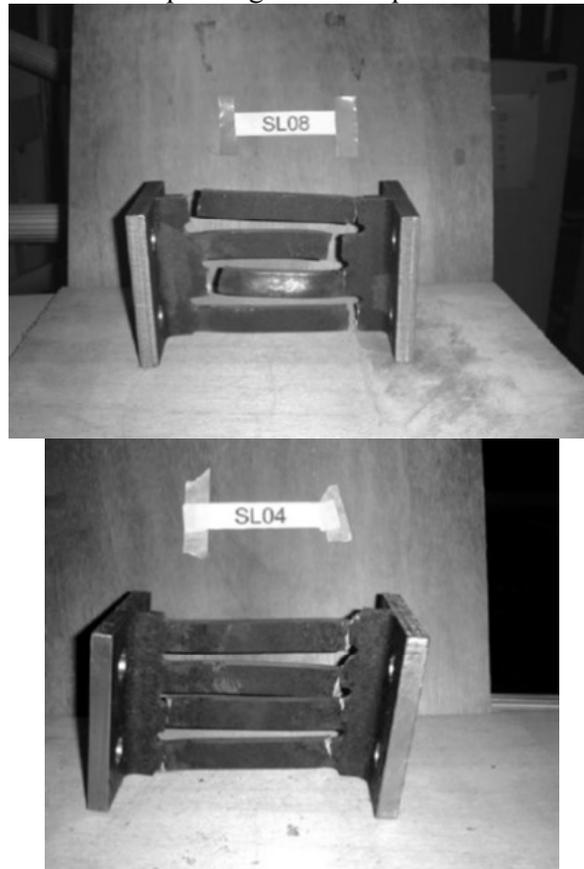


Figure 1: Two samples of the dampers tested in Chan and Albermani's work [V]

By presenting an interesting idea, Benavent has proposed a new type of metallic dampers that, like diagonal bracing, are embedded in the structure and depreciate the incoming energy through steel flowing while increasing structural strength and

stiffness [VI]. To build this type of damper, there is a need for two box sections with different dimensions that are put inside each other. On two opposite flanges of the outer section, elliptical cavities are created with distance from each other and two profiles are welded in the points between these cavities. Now, if this element is under reversible axial loads, the strips on the flange with cavity will have a plastic deformation and the incoming energy can be depreciated in this way [VI].

Koetaka and colleagues studied a kind of dampers that connects the flange of wide flange beams to the web of I-section columns [VII]. In this innovative method, two plates are placed at the top and bottom of the upper flange of the beam and connect this flange to the plate that is itself connected to the column web. The beam lower flange is also connected to the column web through one or two  $\pi$ -shaped dampers. All connections are bolted and the only welded section is related to the plates to column web connection. In this research, 6 samples of these connections have been tested. The hysteresis curve of these 6 samples represents the stable and ductile hysteretic behavior of the sample even up to 4% drifts. However, in some of the samples, due to the occurrence of slip in the bolts connecting the dampers to the frame, pinching phenomenon can be seen to some extent, which is not observed in samples designed and studied specifically for non-slip. One of the samples, because of stress concentration in the middle of the U-shaped part of the damper, had failure in this area before starting loading cycles with a drift range of 4% and could not bear the mentioned drift; this is due to less thickness of this sample compared to other samples. Therefore, the thickness of this type of dampers in the U-shaped area should observe some minimums and this is an important point when designing this type of dampers. Overall, it can be said that this type of connections including  $\pi$ -shaped dampers will have very good seismic behavior if appropriate materials and geometry are chosen for the damper, and the use of two dampers at the top and bottom of the the beam lower flange instead of one can have a desirable effect on energy absorption. Additionally, attention to the proper design of the bolts to prevent slip is very important in designing this type of connections [VII].

Oh and colleagues, with the aim of designing ductile connection in moment frames and putting metallic slit dampers under the beams at the junction with the column, examined the seismic behavior of this type of connections [VIII]. In this laboratory work, by placing the metallic slit dampers below the lower flange of the I-shaped beams, they designed a connection so that when creating the lateral displacement of the frame, plastic deformations were created in the metallic damper and the incoming energy was depreciated in this way and thus, with damage concentration in dampers, the main members of the frame (beam and column) are not damaged. However, it should be noted that this becomes possible by designing damper geometry in a way that it is weaker than the beam and column. This type of damper can be easily replaced after the occurrence of earthquake and the damage caused to it. In this study, they tested four samples of connection and to compare the proposed connection behavior with the behavior of conventional welded moment connections, they also tested a sample of welded connection. The results indicate the stable and ductile behavior of samples and thus their high energy absorption capacity [VIII].

Nakata and colleagues, by providing a new idea entitled arc-shaped dampers, investigated the behavior of metal arcs of quarter circles to be used as metallic dampers [IX]. These metal arcs can be embedded in corners of steel or concrete

frames and absorb energy through plastic deformations under the frame lateral displacements. In their investigations, they initially studied the behavior of their proposed metallic dampers and for this purpose, they tested several samples of these dampers made of steel and aluminum. These experiments demonstrated that this form of dampers has high energy absorption capacity, particularly aluminum samples that have damping twice as much as steel samples. After performing these tests and evaluating the behavior of the proposed dampers as appropriate, in another research work, the application of these dampers in the reinforcement of valley railway bridge was examined [X]. A series of numerical studies determined that by adding dampers to the frame, shear failure mode can be converted to flexural failure mode and thus, structural ductility can be increased. Moreover, in 3% to 6% drifts, the proposed arc-shaped dampers will have the ability to provide 30% to 40% of the equivalent damping. After conducting these analytical studies, in a laboratory work, four samples of these concrete frames with a one-fifth scale were tested under reversible loads, three of which were improved by arc-shaped dampers and one sample was only a frame [XI]. The difference between the three improved samples was in the percentage of shear steels of their concrete members and the results of these experiments indicated high effectiveness of arc-shaped dampers in energy depletion and reduced failure in the main frame.

One of the most important laboratory works on the study of structural behavior including passive dampers is the experiments performed by Kasai and colleagues, in which a real scale 5-storey steel structure was constructed with various (metallic, oily, viscous and viscoelastic) dampers and its seismic behavior was examined under Kube earthquake on the largest shaking table of the world [XII, XIII]. This project aims to investigate the behavior of steel buildings of medium height, in which passive seismic control systems have been used. It should be noted that many office buildings in Japan have such features.

One of the theoretical studies conducted in this field is the research by Inoue and Kuwahara, in which they carried out an analytical work and examined the optimal ratio of the strength of hysteretic dampers to the strength of the main frame of the structure in order to minimize the failure created in the main frame [XIV]. By dividing the structure into two parts of the main frame and the damper system and introducing parameters  $k$  and  $\beta$  and then performing analysis on structures of one and several degrees of freedom, they studied parameter  $\beta$  and its effect on the total behavior of the structure. First, by considering the relationship related to calculating the equivalent viscous damping ratio, they wrote this ratio based on parameter  $\beta$  and obtained a relationship to determine the optimal value of this ratio ( $\beta_{opt}$ ) based on parameter  $k$ . After presenting this relationship, structures of one and several degrees of freedom under four different earthquakes were studied and the desired responses of the structure were analyzed. In this work, the energy absorbed by the main frame is regarded as a measure of the damage inflicted on it. In the following, it has been demonstrated that in all states, there is a specific  $\beta$ , for which the ratio of the energy absorbed by the main frame has the minimum value and on the other hand, this specific  $\beta$  is approximately equal to the  $\beta_{opt}$  obtained from analytic relations. This result is of great importance since it reminds us of the need to consider  $\beta_{opt}$  in the design of structures including these dampers and also the usability of providing a simple analytical relationship in this study to calculate  $\beta_{opt}$  [XIV].

In a series of other theoretical studies conducted by Mazza and Vulcano, in addition to offering a method for designing metallic and viscoelastic dampers in structures including them, they examined the effects of these dampers on structural behavior [XV]. In this work which has been performed by writing a computer program and doing a nonlinear dynamic analysis on the structure, the impact of applying metallic and viscoelastic dampers on ductility demand of the main frame and its members has been investigated. The structure under study in this research is the middle frame of a 6-storey concrete structure. To perform nonlinear dynamic analyses, 7 real accelerograms (group A) and 3 artificial accelerograms (group B) have been employed. Comparison of the average ductility demand in beams and columns of storeys in two modes of the structure with and without dampers displays that significant reduction in these values in the frame members is due to the use of metallic dampers. Reduced ductility demand can be a criterion for decreasing the level of damage or failure in structural members. The figure properly shows the positive effects of metallic dampers in this regard [XV].

Another way to deal with earthquakes, which has attracted the attention of researchers in recent decades, is the control of structural response to earthquake force. In this approach, the main purpose of the structural design engineers is to either limit the energy from the earth to the structure in some way or depreciate this energy in the structure or change the structural frequency in a way that it has a lot of difference with the frequency of ground motion and thus reduces the structural response. In a large categorization, new methods for reducing seismic hazards can be divided into three general groups of active, semi-active and passive control. Given the obstacles such as financial constraints, weaknesses in manufacturing technology and lack of sufficient knowledge in developing countries, the use of new methods for structural reinforcement is not pervasive while several decades have passed since the beginning of research, development and application of these methods in developed countries, especially in the United States and Japan. Among the three general groups mentioned, the third group, i.e. passive energy depletion systems, can be considered as a more appropriate option with respect to the constraints in developing countries. In this group, friction dampers and yielding metallic dampers are more capable of being developed and applied in these countries due to lack of the need for sophisticated manufacturing technologies. In this article, by introducing a kind of damper, attempt has been made to examine its behavior under applying blast loading and earthquake records.

## **II. Descriptions of models**

In this article, the effect of explosion and earthquake on 3D structure model under consideration has been investigated.

The structure under study is a 6-, 9- and 13-storey structure. The height of all storeys has been considered to be 3 meters. The studied frame is residential. The soil considered for the structure is the soil type III. The steel used is of ST37 type for all beams and columns. To consider the effect of soil and structure interaction, the soil has been also modeled as a separate section. Then, the structure is placed on the soil and is tied to the soil by a fixed Support. In Figure (2), the structure modeled in Abaqus software has been displayed.

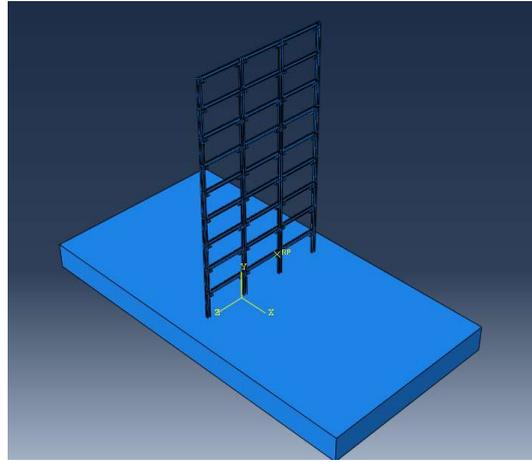


Figure 2: Model under study

The frames under study have 3 spans and the length of each span is 5 meters. In Table (1), the specifications of the steel used in this study have been presented. Soil type III is considered for the site of this structure.

Table 1: Specifications of the used materials

Special Weight	7796	kg/m <sup>3</sup>
Modulus of elasticity	2.01×10 <sup>10</sup>	kg/m <sup>2</sup>
Poisson's ratio	0.3	
Shear modulus	8.077×10 <sup>9</sup>	kg/m <sup>2</sup>
Yield stress	2.4×10 <sup>7</sup>	kg/m <sup>2</sup>
Ultimate stress	3.7×10 <sup>7</sup>	kg/m <sup>2</sup>

The equation provided by Johnson and Cook to express the effects of plastic work, plastic strain rate and temperature on yield stress is as follows [16, 17]:

$$\sigma = [A + B \varepsilon^n][1 + C \ln \dot{\varepsilon}^*][1 - T^{*m}]$$

In which, A, B, C, n and m are material constants,  $\varepsilon$  is equivalent plastic strain and  $\dot{\varepsilon}^*$  is the dimensionless parameter of plastic strain rate which has been defined as

$$\dot{\varepsilon}^* = \frac{\dot{\varepsilon}}{1.0s^{-1}} \cdot T^{*m} \text{ is dimensionless parameter of temperature which is calculated}$$

through the following equation [XVI, XVII].

$$T^{*m} = \frac{T - T_{Room}}{T_{Melt} - T_{Room}}$$

In this model, the effects of plastic strain rate in relation to time over yield stress are considered but are ignored in Steinberg model. The reason is the difference in the scope of using these models. In experiments conducted by Johnson and Cook to calculate the coefficients used in this model, the highest plastic strain rate was equal to 400s<sup>-1</sup>. But in Steinberg's experiments, because of their attention to blast loading and collision at very high speeds, the plastic strain rate was more than 10<sup>5</sup>S<sup>-1</sup>. Equivalent plastic strain is obtained from the following equation.

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$$\varepsilon = \sum \dot{\varepsilon} \Delta t$$

In the above equation,  $\dot{\varepsilon}^*$  is expressed as the following equation.

$$\dot{\varepsilon} = \left\{ \frac{2}{9} [(\dot{e}_r - \dot{e}_z)^2 + (\dot{e}_z - \dot{e}_\theta)^2 + (\dot{e}_\theta - \dot{e}_r)^2] + \frac{1}{3} \dot{\gamma}_{rz} \right\}^{\frac{1}{2}}$$

In the equation,  $\dot{e}_z$ ,  $\dot{e}_\theta$  and  $\dot{e}_r$  are deviant plastic strain rates and  $\dot{\gamma}_{rz}$  is plastic shear strain rate.

Dead and live surface loads have been considered to be 600 and 200 kilograms per square meter, respectively. According to the plans of Figure (3), the dead load and live load exerted on the beams will be calculated to be 2400 kg/m and 800 kg/m, respectively.

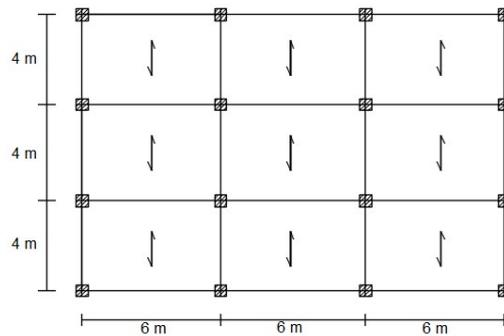


Figure 3: The plan considered for studied frames

For the design of structures, the tenth chapter of the National Building Regulations of Iran has been used [XVIII].

Additionally, the beams and columns have been modified such that the strength of the beams is weaker than the strength of the columns functionally and in this way, the philosophy of strong-column-weak-beam is also observed.

IPE sections for the beams and IPB sections for the columns have been considered. In Table (2), the examined models with the sections used for each of the elements are displayed.

The studied damper is 55 cm long and has two honeycomb holes embedded inside it. In Figures (4) and (5), full specifications of the honeycomb beams are displayed. This damper has been used for all studied frames and under all the beams.

Table 2: The sections applied in each of the frames

Structure type		Flo or 1	Flo or 2	Flo or 3	Flo or 4	Flo or 5	Flo or 6	Flo or 7	Flo or 8	Flo or 9	Flo or 10	Flo or 11	Flo or 12	Flo or 13	Flo or 14
6 stor eyes	IPE beam	320	320	320	320	300	300								
	IPB column	360	360	360	360	330	270								
9	IPE	34	34	34	34	34	32	32	30	30					

stor eys	bea m	0	0	0	0	0	0	0	0	0					
	IPB colu mn	36 0	40 0	40 0	40 0	40 0	36 0	30 0	30 0	27 0					
14 stor eys	IPE bea m	50 0	50 0	50 0	50 0	50 0	45 0	45 0	40 0						
	IPB colu mn	30 0	40 0	40 0	45 0	45 0	40 0	40 0	40 0	40 0	36 0	33 0	33 0	33 0	30 0

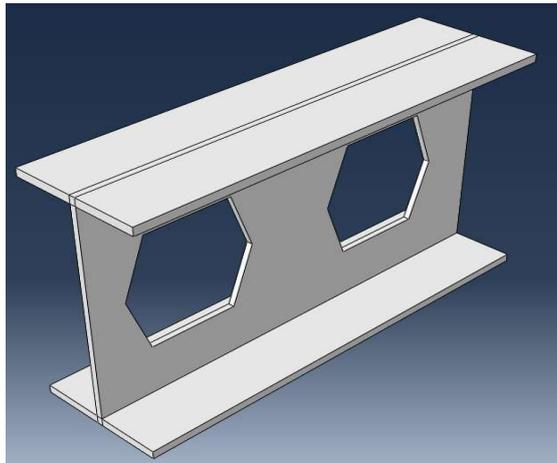


Figure 4: The honeycomb damper used in this research

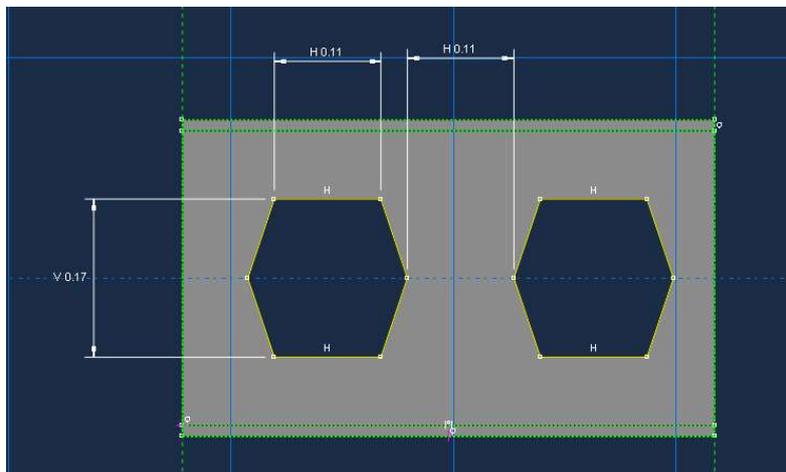


Figure 5: The honeycomb damper used in this research (dimensions in meter)

Thus, in this study, a set of natural accelerograms of the event in Iran and the world has been selected and used based on the following criteria:

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- Selection of accelerograms recorded in earthquakes with a magnitude of greater than 6 on the richter scale.
- Compliance of soil type of accelerogram record station with soil type III based on Iran earthquake regulations.
- The shear wave velocity of the accelerogram record site is between 102 and 362 m/s.
- Maximum acceleration of at least 0.2 g to prevent excessive increase in the scale factor of accelerograms.
- The effective time of the movement of all accelerograms is greater than three times as much as the structural period and is also more than ten seconds.
- All accelerograms from 0.1 to 25 Hz are filtered in terms of frequency content.

Natural records selected for analysis include Manjil earthquake at Abbar station, Bam, El Centro, Kube, Taft, Tabas and Tarzana. All accelerograms have been filtered in terms of frequency content such that their properties are consistent with soil type III in the 2800 regulations [XIX].

The scaled real accelerograms are consistent with the design spectrum of IS 2800-4th edition, whose specifications have been provided in Table (3).

Table 3: Specifications of the scaled real accelerograms

<i>Record Name</i>	<i>Max PGA (g)</i>	<i>Duration (Sec)</i>	<i>Time Step dt (Sec)</i>	<i>Predominant Period (Sec)</i>	<i>Mean Period (Sec)</i>	<i>M<sub>w</sub></i>
Abar	0/55 □ □	53/5	0/02	0/18	0/838	7/3
Bam	0/50 □ □	66/54	0/005	0/20	0/818	6/6
El Centro	0/44 □ □	40	0/01	0/46	0/826	6/53
Kube Kjma	0/37 □ □	48	0/02	0/34	0/933	6/9
Taft 69	0/58 □ □	54/4	0/02	0/44	0/914	7/4
Tabas	0/45 □ □	32/84	0/02	0/24	0/848	7/7
Tarzana	0/44 □ □	40	0/02	0/58	0/891	6/52

In Table (4), types of the models under study have been displayed.

Table 4: Models under study

No.	Model name	Blast distance (m)	Amount of explosives (Kg)	Number of floors
1	M1	5	10	6
2	M2	5	10	9
3	M3	5	10	13
4	M4	Earthquake record	Abbar	6
5	M5	Earthquake record	Bam	6
6	M6	Earthquake	El Centro	6

		record		
7	M7	Earthquake record	Kube	6
8	M8	Earthquake record	Taft	6
9	M9	Earthquake record	Tabas	6
10	M10	Earthquake record	Tarzana	6
11	M11	Earthquake record	Abbar	9
12	M12	Earthquake record	Bam	9
13	M13	Earthquake record	El Centro	9
14	M14	Earthquake record	Kube	9
15	M15	Earthquake record	Taft	9
16	M16	Earthquake record	Tabas	9
17	M4	Earthquake record	Abbar	13
18	M5	Earthquake record	Bam	13
19	M6	Earthquake record	El Centro	13
20	M7	Earthquake record	Kube	13
21	M8	Earthquake record	Taft	13
22	M9	Earthquake record	Tabas	13

### III. Results

In this section, the results obtained from numerical modeling on the studied frame are examined. The results are analyzed in two separate sections. In the first section, the blast effect on the model is studied and in the second section, numerical results from earthquake records are addressed.

#### **Numerical results from applying blast loading to the model**

In this model, 10 kilograms of TNT explosives are applied at a distance of 5 meters from the structure and in the middle of the frame on the second floor. The number of the storeys of the structure is 6. In the following, the results obtained from the numerical analysis are stated. In Figure (6), the stress created in the structure is shown.

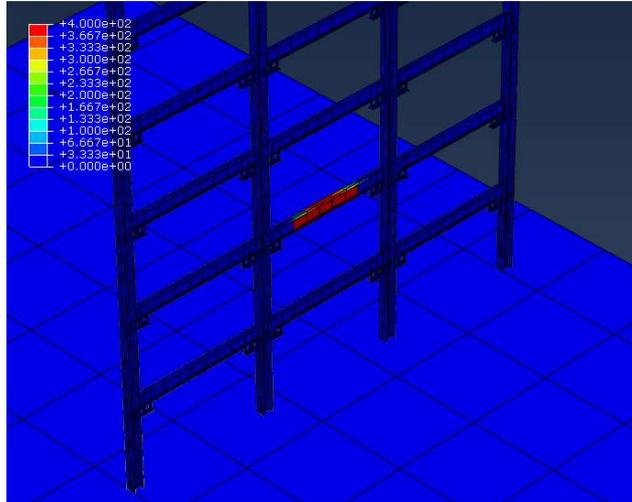


Figure 6: Von Mises stress created in the structure as a result of the explosion of 10 kilograms of TNT

The beams exposed to the explosion of the structure have entered the plastic stage, and plastic strain of the structure has occurred in the middle of the beam.

The amount of the base shear force of the structure and the overall displacement of the structure due to this load has been almost negligible and only led to displacement in the beams. The maximum displacement during the explosion is equal to 13 mm and the maximum stress in the beams is also equal to 400 N/m<sup>2</sup>.

Figure (7) displays the equivalent plastic strain (PEEQ).

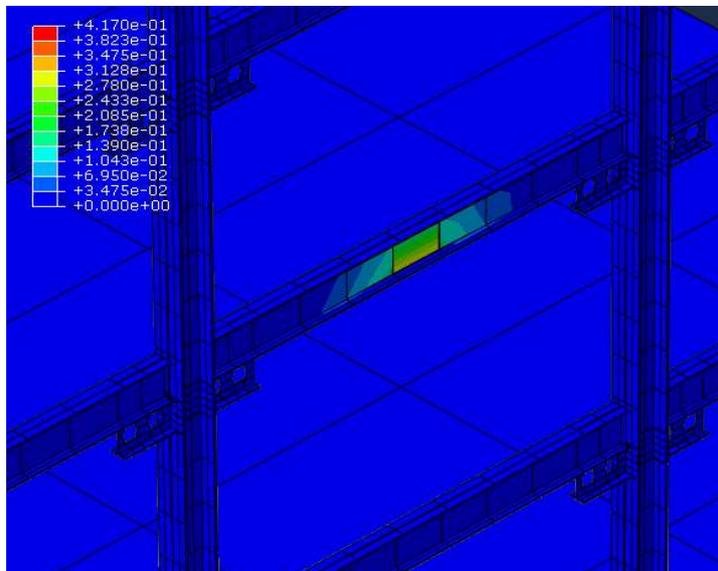


Figure 7: Equivalent plastic strain in the studied structure

In the M2 model, the amount of the base shear force of the structure and the overall displacement of the structure due to this load has been almost negligible and only led

to displacement in the beams. The maximum displacement during the explosion is equal to 11.3 mm and the maximum stress in the beams is also equal to  $400 \text{ N/m}^2$ .

In the M3 model, the amount of the base shear force of the structure and the overall displacement of the structure due to this load has been almost negligible and only led to displacement in the beams. The maximum displacement during the explosion is equal to 10 mm and the maximum stress in the beams is also equal to  $400 \text{ N/m}^2$ .

When the amount of explosive is more than 10 kilograms, the second floor beam is strongly damaged because its power is high and the beam is twisted and the software is not able to continue the analysis to the end. Therefore, the maximum amount of explosive in this situation is 10 kilograms.

By examining the results of applying the blast load to the frames, it is found that failure is local and near the beam located at the site of the explosion.

### **Results obtained from applying earthquake records**

Below, the results of numerical analysis obtained from applying earthquake records are presented. Given that the number of hysteresis graphs is high, only a few models of the hysteresis graph are displayed in this section. In Figures (8) to (10), the hysteresis graphs resulting from applying El Centro earthquake records to 6-, 9- and 13-storey structures are shown.

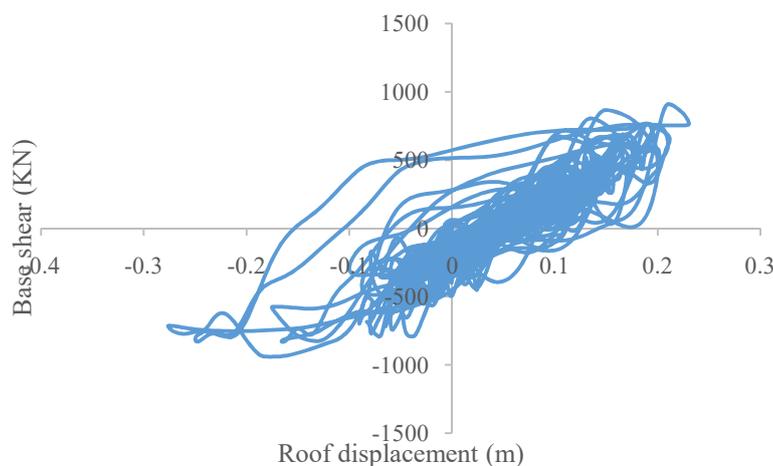


Figure 8: Hysteresis diagram of a 6-storey structure under the influence of El Centro earthquake record

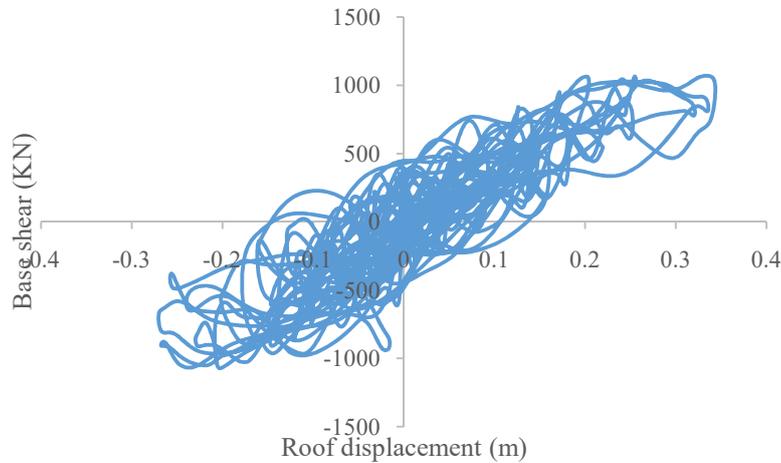


Figure 9: Hysteresis diagram of a 9-storey structure under the influence of El Centro earthquake record

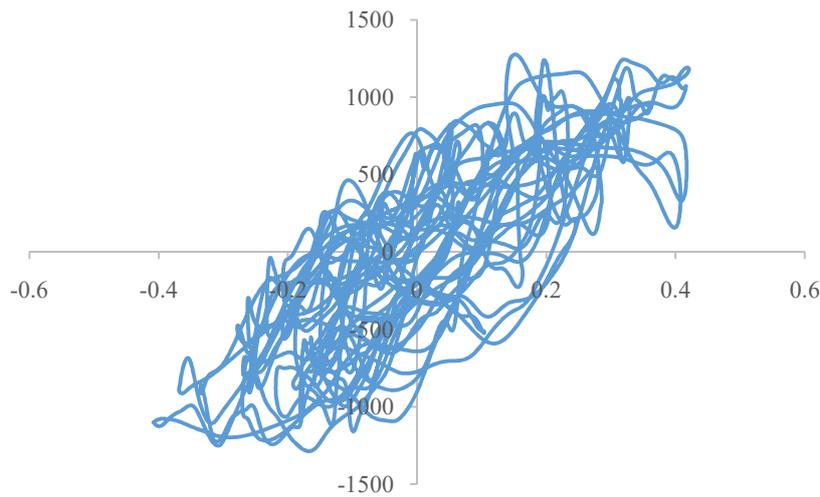


Figure 10: Hysteresis diagram of a 13-storey structure under the influence of El Centro earthquake record

By studying the graphical results of numerical analysis in Abaqus finite element software, it is observed that the damper placed in the models has had good behavior so that as a result of applying the records, the highest amount of stress has been observed in the dampers. Hence, it has absorbed the force from earthquake at the junction and has caused less damage to the beam. In Figure (11), a sample of Von Mises stress created in the 6-storey frame as a result of applying El Centro earthquake record is shown. Further, in Figure (12), the plastic stress created in the 6-storey frame model as a result of applying the same earthquake record (El Centro) is displayed.

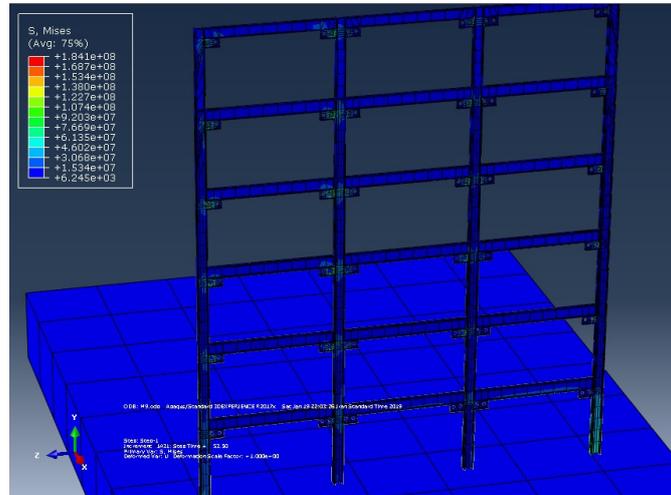


Figure 10: Von Mises stress created in the 6-storey frame model as a result of applying El Centro earthquake record

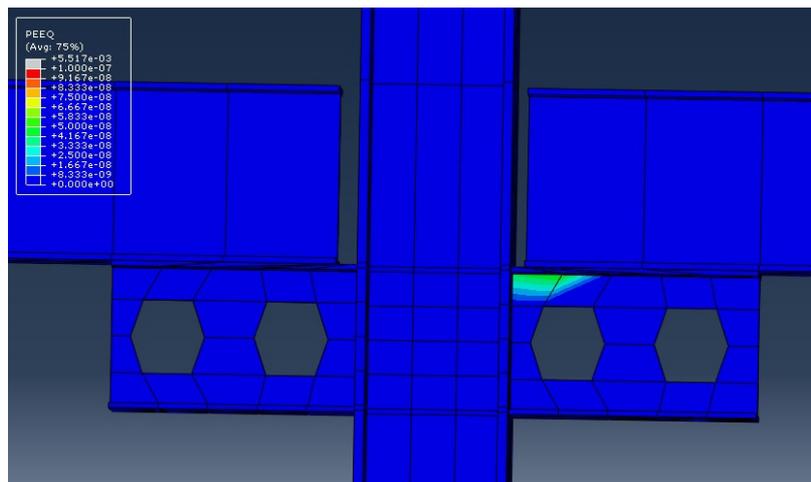


Figure 11: PEEQ stress created in the damper of the 6-storey frame as a result of applying El Centro earthquake record

In all the studied models (6, 9 and 13 storeys), by investigating the graphical results, it is observed that more stress has been created in the dampers placed under the beams, which suggests the proper behavior and function of this damper. As a result of applying the earthquake record, this damper has initially engaged and has absorbed the force and then, stress has also increased in the column.

By analyzing the graphical results of the frames under study in this section, the results of numerical analysis in Abaqus software are examined and summarized. In Table (5), all the results of numerical analysis based on earthquake records are displayed with regard to the maximum and minimum values obtained from the graphs. Besides, by studying the graphical results, including plastic stress and strain, it can be seen that the entire capacity of the damper has been used in none of the records and plastic

strain has occurred only in part of the dampers. In another investigation, it has been observed that dampers which have reached plasticity still possess load-bearing capability and the total capacity of the damper has not been used.

Table 5: Results of maximum and minimum values obtained from numerical analysis based on applying the accelerogram record

Accelerogram record	6 storeys		9 storeys		13 storeys	
	m	KN	m	KN	m	KN
EL Centro	0.23	907.93	0.34	1070.17	0.42	1286.90
	-0.28	-940.46	-0.27	-1069.12	-0.41	-1274.99
Kube	0.18	816.33	0.43	1038.31	0.52	1208.94
	-0.29	-908.98	-0.35	-1157.05	-0.28	-1227.41
Manjil	0.24	850.04	0.44	1147.96	0.30	1291.03
	-0.20	-841.76	-0.29	-1118.73	-0.56	-1278.94
Tabas	0.18	842.06	0.17	1232.48	0.26	1351.26
	-0.32	-944.25	-0.36	-1076.20	-0.43	-1302.96
Taft	0.14	826.64	0.21	1205.42	0.29	1357.30
	-0.33	-917.50	-0.42	-1145.18	-0.60	-1195.74
Tarzana	0.26	828.37	0.25	1255.72	0.33	1298.66
	-0.19	-888.00	-0.44	-1140.32	-0.39	-1317.00
Bam	0.14	813.75	0.21	1180.35	0.25	1302.90
	-0.39	-971.33	-0.51	-1016.67	-0.60	-1033.97

In Figure (12), the results of the maximum displacement based on the studied records have been provided.

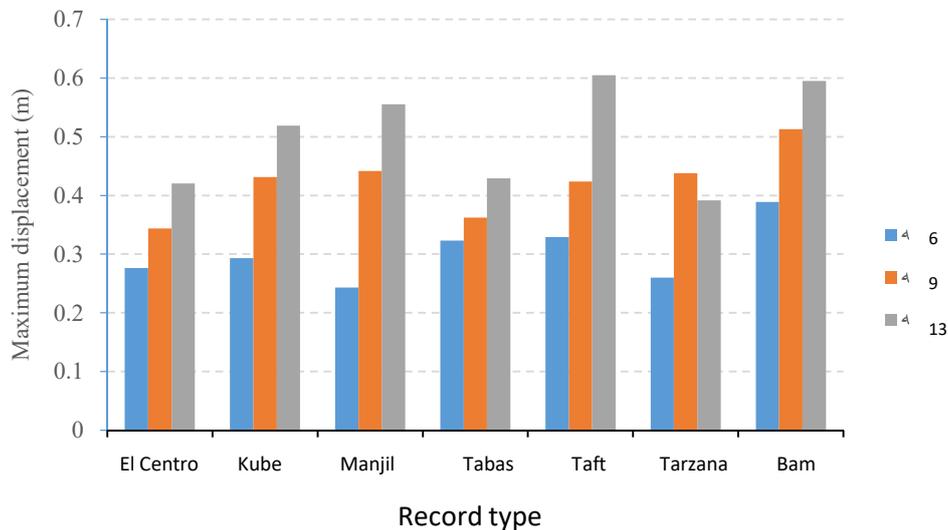


Figure 12: Maximum displacement obtained from earthquake records

Considering the above figure, it is observed that with increased height, the amount of displacement of the structure has increased. Bam, Taft and Tabas earthquake records

have produced the greatest amount of displacement in all three studied structures. The lowest amount of displacement is related to Manjil and Tarzana earthquake records. The average amounts of displacement in 6-, 9- and 13-storey structures have been obtained to be 0.3 m, 0.45 m and 0.55 m, respectively.

In Figure (13), the maximum base shear for the studied records has been presented.

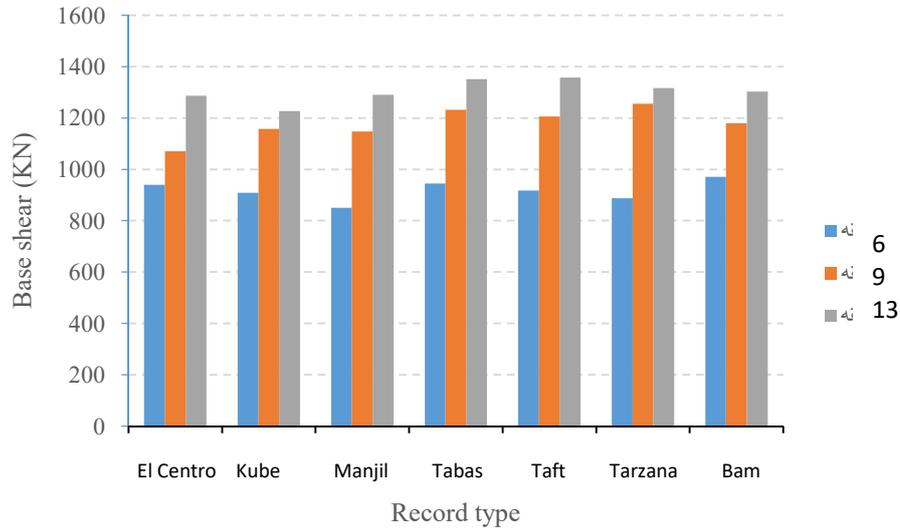


Figure 13: Maximum base shear based on the studied records

Given the above figure, it is observed that with increased height, the amount of the base shear of the structure has increased. Bam, Taft and Tabas earthquake records have had the greatest amount of base shear in all three studied structures. The lowest amount of base shear is related to Manjil and Tarzana earthquake records.

#### IV. Conclusion

In this article, the effect of explosion and earthquake records on short-order steel structures is evaluated. Abacus software has been used to consider and model. Johnson-Cook behavioral model has been employed to apply the blast load. The blast load has been selected based on TNT material. The amount of the explosive was 10 kg. The distance of the explosive was 5 meters from the frame and the blast occurred in the air. To model the effect of earthquake records, seven pairs of accelerograms have been used. To consider the effect of soil and structure interaction in this model, the obtained soil based on the specifications of soil type III was considered to be in accordance with the 2800 standard. For the intended structure, a damper with honeycomb holes has been used in the beams. The results obtained from this study are as follows.

- In the studied models, the use of an explosive has caused failure of the beam close to the explosive and as a result of this failure, force and stress have been created only in the desired beam while the amount of base shear and roof displacement of the structure under study was negligible. Since the explosive

affects the structure in a very short time, the structure does not have enough time to react to the blast loading.

- In the models under investigation, because the nature of the explosion was very fast, the damper mounted on the structure did not have enough time to react and according to the results, it was observed that failure has occurred in the beam exposed to the explosion.
- As a result of applying earthquake records, it has been observed that the damper mounted on the structure has engaged. The greatest plastic damage and failure has occurred in the damper and no damage has been detected in the installed beams. Thus, it can be seen that the installed damper has been functioning properly.
- Bam, Tabas and Taft earthquake records have had the highest impact on the structure.
- In the studied structures, it has been observed that because the structure has had enough time to react in the earthquake, the damper installed at the beam joint has engaged and has caused absorption of more energy and application of less force to the beams.

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