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Full Length Research Paper

Seismic performance of structures with pre-bent strips as a damper

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In this study, a new type of structural damper in the form of braces based on pre-bent strips has been proposed. In designing the structures, parameters that support the safety of structures like base shear, acceleration and displacement are so important. To create safe conditions in structures some new technologies like vibration control and isolation have been considered. Vibration control has been studied by dissipation of the seismic energy which contains vibration isolator like dampers. In this paper a new kind of energy dissipative devices has been utilized and simulated by FEM in ABAQUS. According to other studies, investigation on experimental methods to prove some features of pre bent struts as column, one of which was about per bent strips as damper on brace but as experimental study which contains parametric investigation about pre bent strips with simple prototype was studied. In this paper, pre bent steel strips have been studied by FEM in various structural models under different dynamic loading. Some seismic responses of structures like base shear, acceleration and displacement have been investigated to prove the efficiency of this damper. In order to compare the results for models with damper and without damper and achieve accurate result and approximation, a rational approach to the performance of pre bent steel strips in structure with various spans and stories, the average responses of 3 different dynamic loading like Palm Sprins, Northridge, Fruili has been demonstrated which functioned as a bilinear inelastic stress-strain model for mild steel simulation in ABAQUS.

Key words: Pre bent strips, response of structure, damper, energy-dissipation.

INTRODUCTION

Vibration control and energy dissipation which offer seismic protection with appropriate tools are important sources of this study for employing seismic dampers. The reduction and improvement of structural responses such as base shear, acceleration, displacement and velocity are the ultimate aim of this paper which is possible through the utilization of dampers structures without retrofitting each of the structural members. A new type of damper has been utilized and the idea has been expanded in this study with FEM using pre bent steel strips. According to the importance of structural safety, pre bent steel strips have been selected for this study as they are efficient and economical for civil structures.

Investigation of vibration control via isolation with pre bent struts and strips have been done by Plaut et al. (2008), Jeffers et al. (2008), Plaut et al. (2005), Narmashiri et al. (2010) and Ravari et al. (2011), all of whom have studied pre bent struts as a column for isolation. Virgin and Davis (2003) developed a vibration control system with parallel pre bent struts as a simply supported column and Chin et al. (2004) simulated pre bent strips as a vertical spring which controls excitation responses and reduces the effect of vibration on a 2D frame in the vertical stage. Plaut et al. (2008) considered vertical struts as pre bent strips for columns which support a 2D solid diaphragm as a uniform mass; the columns in that study had clamped support. Plaut et al.

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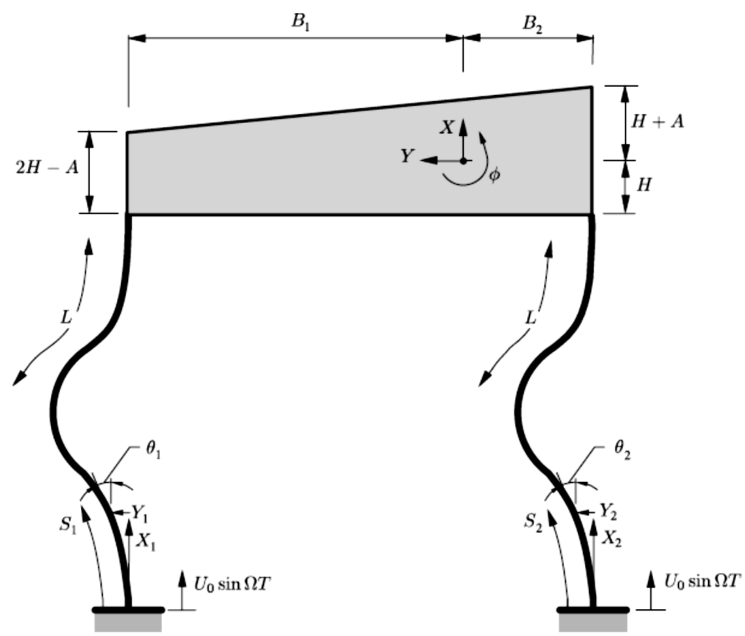

Figure 1. 2D solid diaphragm with pre bent column.

(2008) investigated another characteristic of pre bent strips as column in 2D systems (Figure 1). Furthermore, Jeffer et al. (2008) completed their study concerning isolation via pre bent struts by investigating pre bent strips as a column in a 3D system which contains a plate that was supported by 4 pre bent struts as a column. These studies have proved the efficiency of pre bent strips as columns in excitation which reduces the vibration to improve the structural responses of the frame.

The last study about pre bent strips was completed by Wang and Chien (2009). The capability of pre bent strips to dissipate energy under cyclic loading was tested and characteristics such as length of arch and slope were studied. At last pre bent steel strips have been set up with a brace in a 5 Storey frame as shown in Figure 2 which was set up on a shaking table to simulate Kobe and El-Centro acceleration. The seismic performance tests in this exploration proved the feasibility of pre bent steel strips as seismic energy dissipative devices. According to the series of investigations mentioned before on pre bent strips for vibration control, the idea of this paper was developed.

The main thought of this paper is to develop the idea of vibration control via pre bent steel strips by numerical simulation. This study which contains some phases to increase the accuracy of exploration is a series of simulations and numerical tests on various structural models by ABAQUS. The models have been loaded under cyclic loading Northridge, Palm Springs and Friuli. In the first stage the responses of structural models were assessed under cyclic loads, and then in next phase the average responses of three dynamic loads were evaluated. In the last stage the change procedure of responses was demonstrated by sums of squares which made it possible to realize the procedure in chart form for all models.

THE AVERAGE CHANGE TREND

Based on the investigations carried out in this study, and in order to increase the accuracy of results the average of structural responses under three accelerometer Northridge, Palm Springs and Friuli have been used to demonstrate the feasibility of structural model with damper (pre bent steel strips) versus without damper.

A. Palm Springs 1986.8.7 White water Tront farm 270
B. Northridge 1994.1.17 Jensen Filter Plant 292
C. Friuli Italy 6 May 1976

The sums of squares have been used as a numerical criterion to show the changes of procedures in the structural models responses (Figures 3 to 5).

In order to show the average change trend as well as answer diagrams of structural average, a numerical criterion is used to express changes of structural average answer; numerical criterion with squares title that is used in average answer of each model, so that coordinate of any point on an average graph is in square 2 and all of diagrams squares are collected and form sum of any answer square in average answers (Figures 6 and 7).

According to Figure 8, decrease rate for base shear

Figure 2. 5 Storey frame on shaking table.

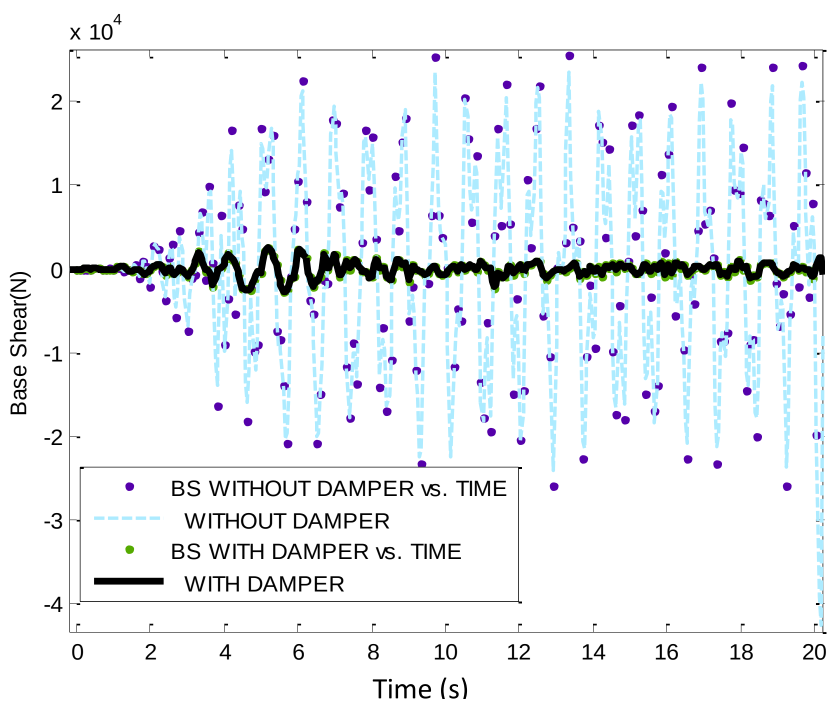

Figure 3. The mean of base shear in structural models 3 stories with 2 openings.

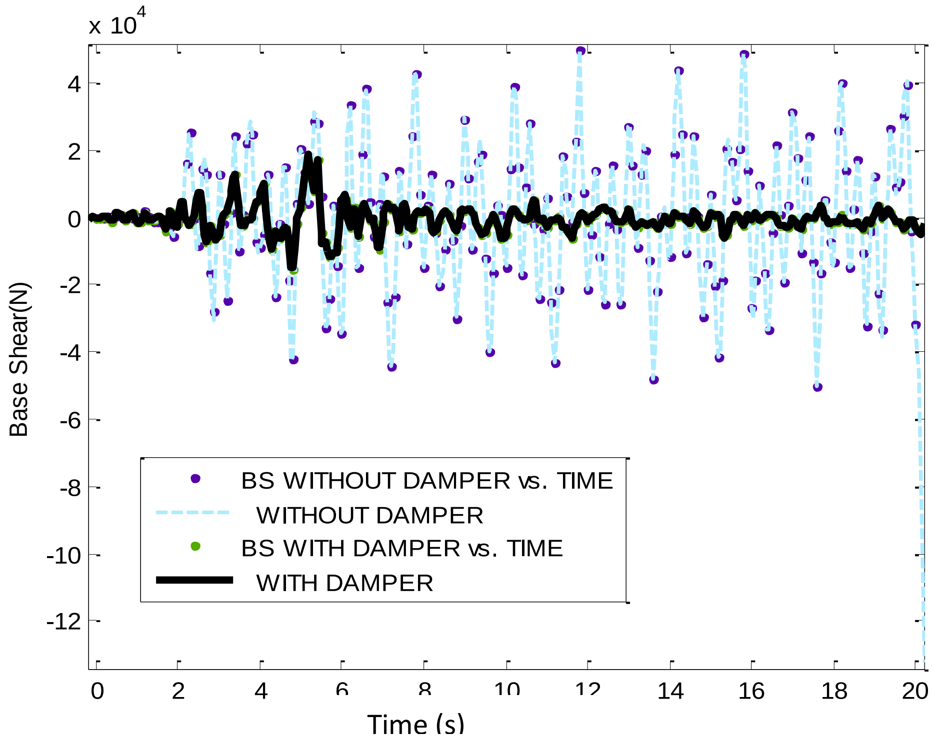

Figure 4. The mean of base shear in structural models 5 stories with 2 openings.

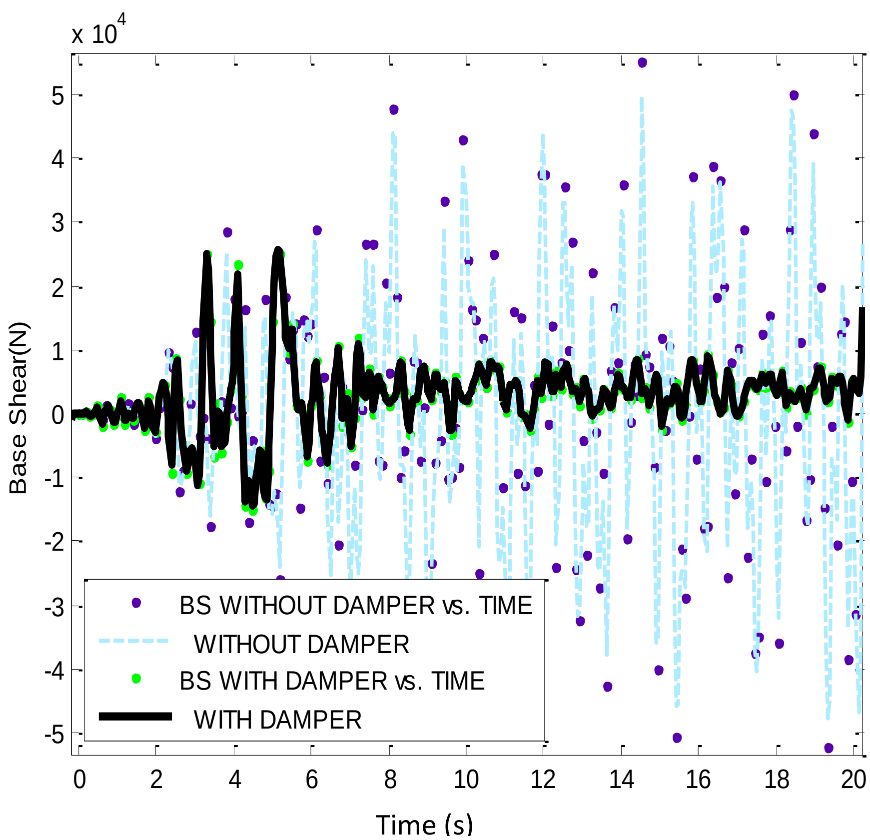

Figure 5. The mean of base shear in structural models 7 stories with 2 openings.

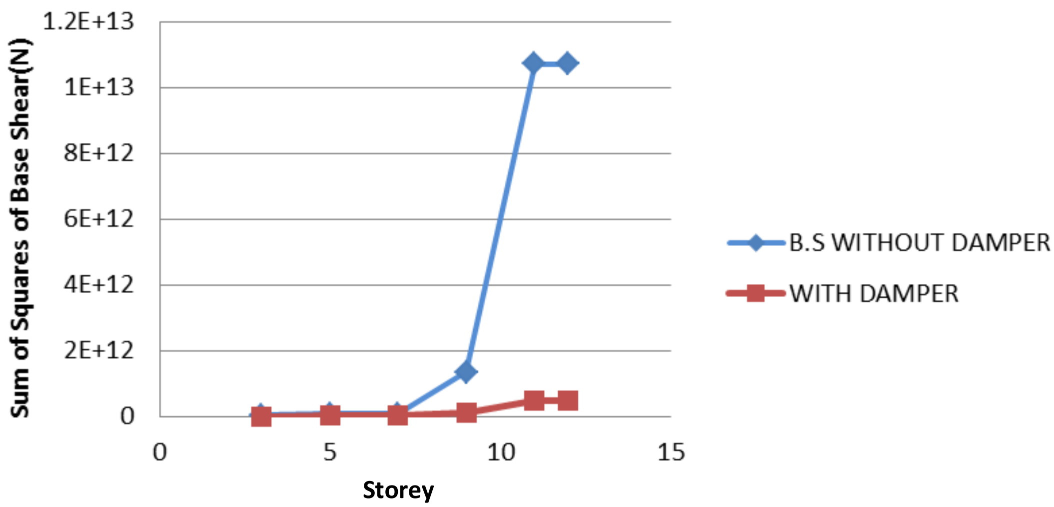

Figure 6. The sum of mean squares of base shear in structural models.

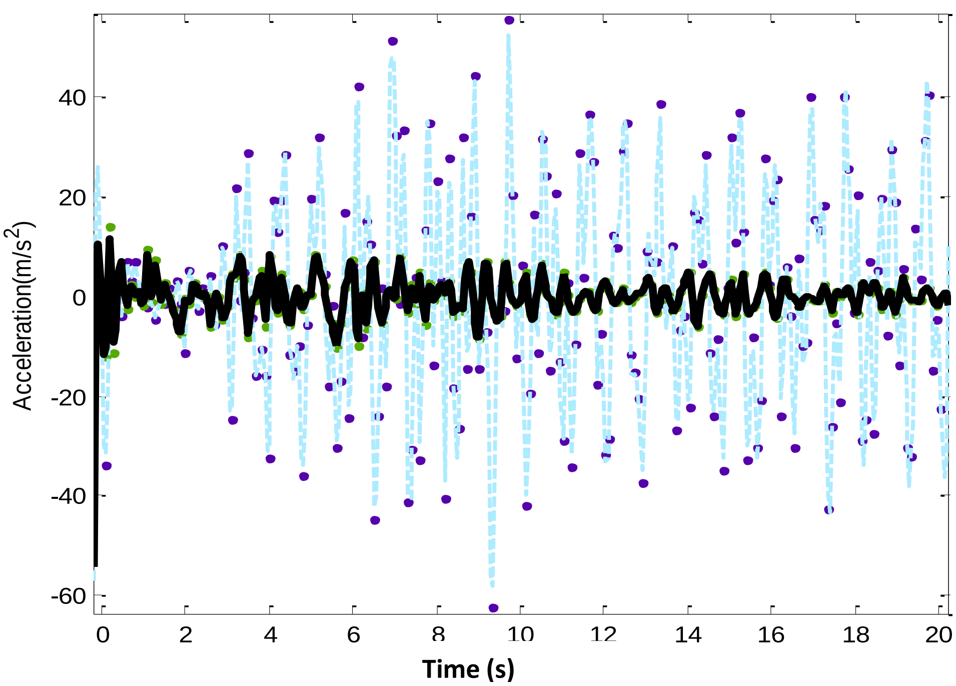

Figure 7. The mean of acceleration in structural models 3 stories with 2 openings.

average increases so that this difference is observed from 7 stories structure and this difference appears from 11 and 12 stories structures, that is sign of damping good function in 11 and 12 stories structures. In order to express the subject as shown in Figure 8, there is numerical expression of diagram.

Here, the average change trend of stories acceleration answer is studied so that diminishing effect and decreasing trend are diagnosed.

Also, implicit description of the reasons for damping behavior of damper is studied and all of the diagrams of this section are sketched by MATLAB software and Smoothing method.

In order to show how change decreases in acceleration answer in Figures 7 to 9, sum of squares criterion is used, with change trend seen. For each answer in any model with sum of squares, a number is gained by using a diagram and related number that show the change trend. This is because what is seen in answer diagrams is decrease in answer and damping behavior; but in order

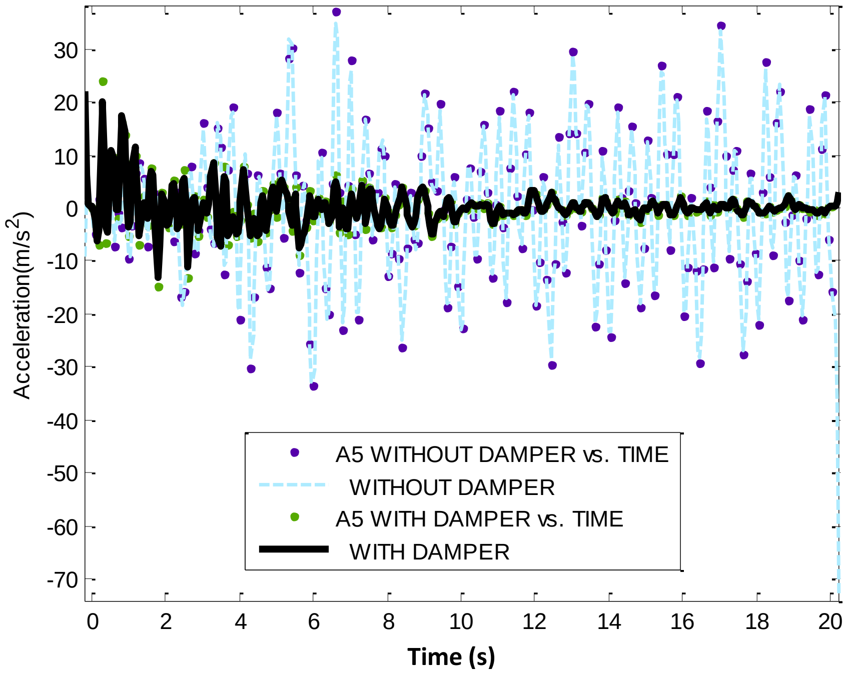

Figure 8. The mean of acceleration in structural models 5 stories with 2 openings.

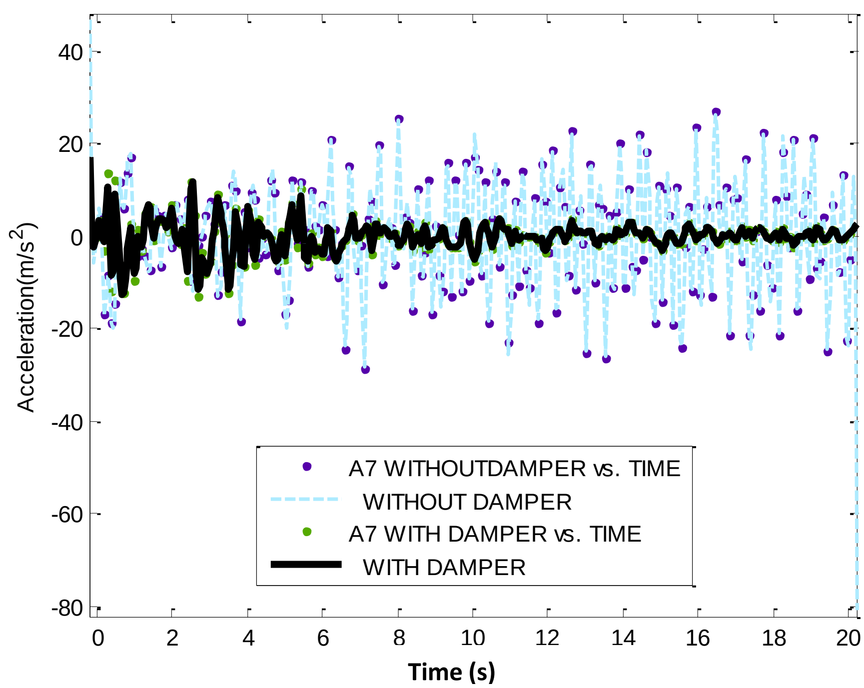

Figure 9. The mean of acceleration in structural models 7 stories with 2 openings.

to arrange answer diagrams and way of total behavior in damping behavior, we should use a criterion such as sum of squares so that one can view the trend of changes (Figures 10 and 11).

By total viewing of Figure 12, we can find that decrease in final stories average acceleration is from 3 stories structural model to 12 stories structural model, so that the last stories of the 3 stories structural model have the best

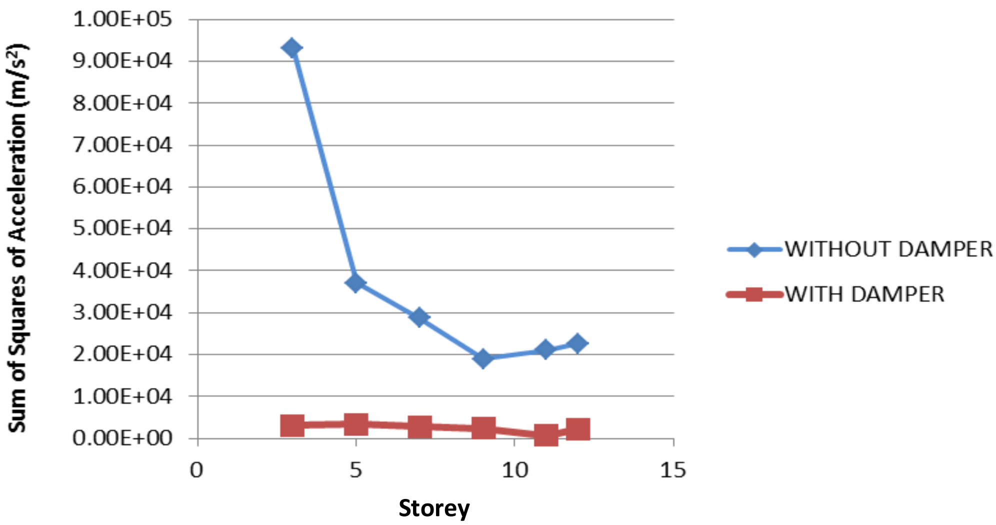

Figure 10. The sum of mean squares of acceleration in structural models.

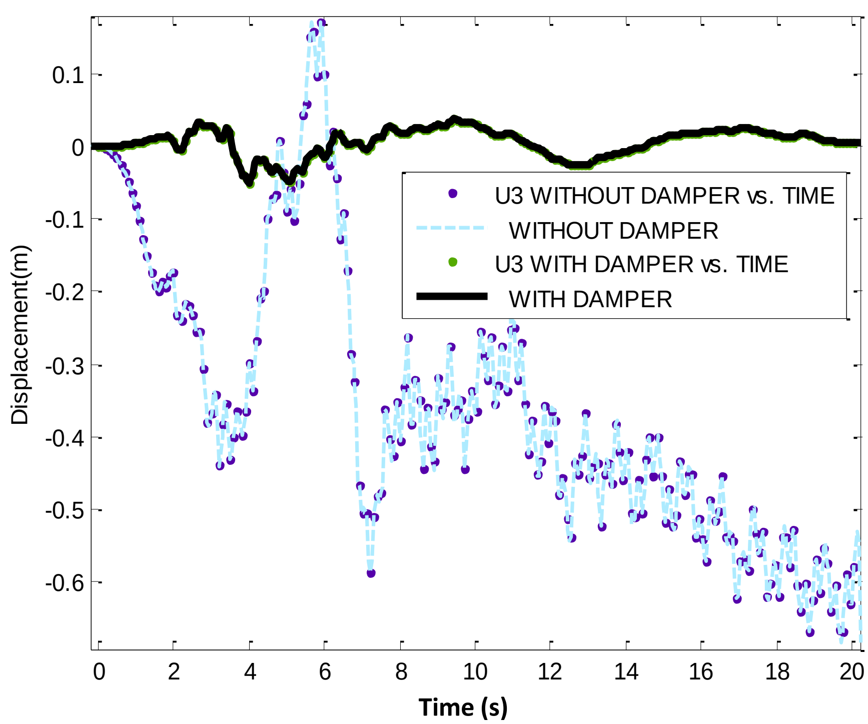

Figure 11. Average displacement of the 3rd storey of 3 stories model with two openings.

relative function. This makes difference between amount for damping mood and without damping a sign of decrease on the last stories model average answer. There is decline rate in answer of last stories average acceleration by decreasing of 3 stories model to 12 stories model. But we can say in details that in 9 stories structural model, there is the least amount of relative difference (Figures 13 and 14).

In order to view the damper behavior on last stories displacement, we study displacement average answers under effect of momentum mapping in this section.

Damping decreasing behavior of displacement answer can be found in Figures 11 to 13, but we can use sum of squares criterion in order to understand change trend of

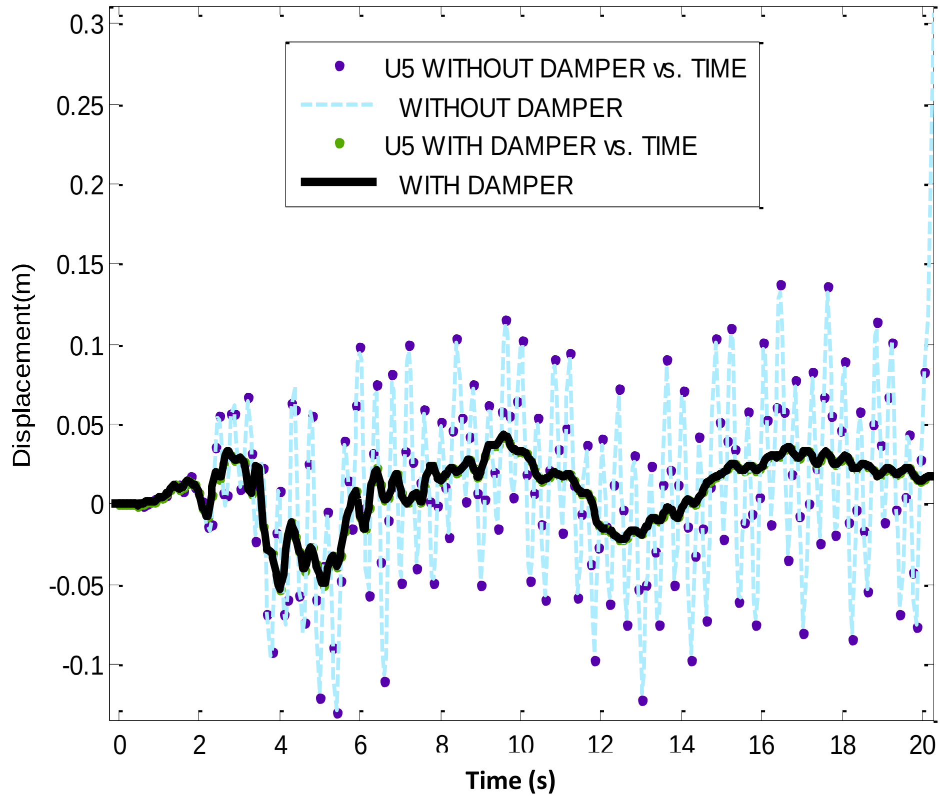

Figure 12. Average displacement of the 5th storey of 5 stories model with two openings.

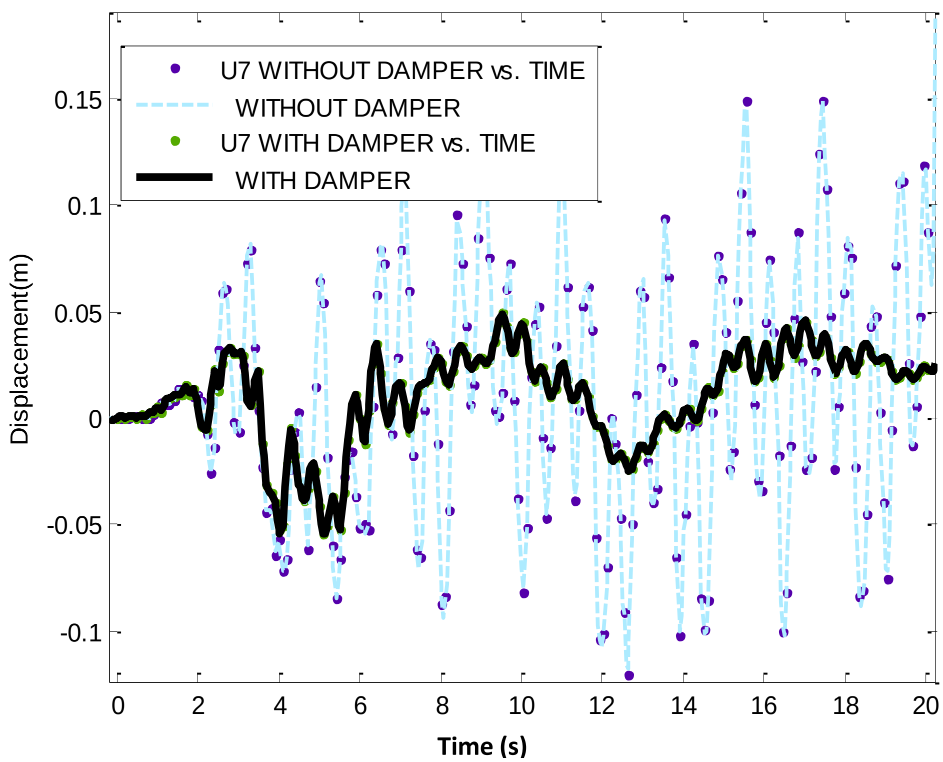

Figure 13. Average displacement of the 7th Storey of 7 stories model with two openings.

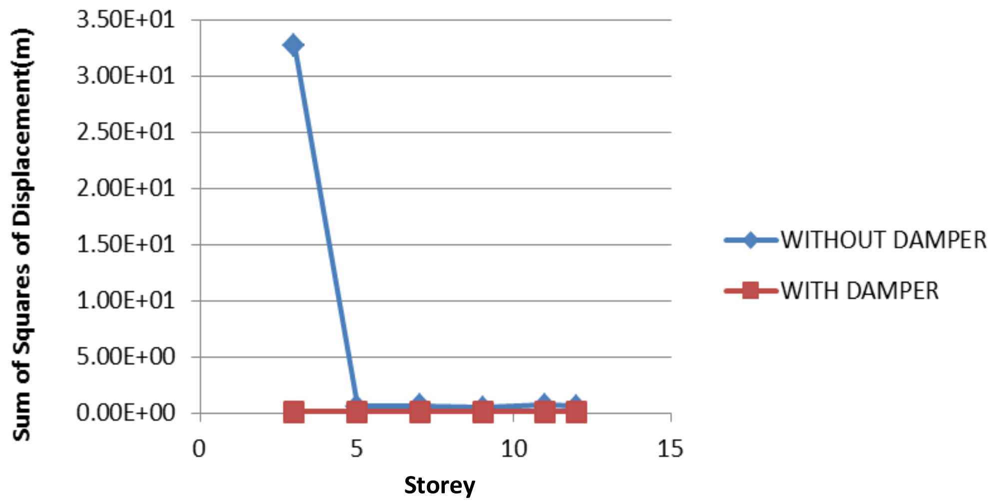

Figure 14. The sum of mean squares of last stories displacement in structural models

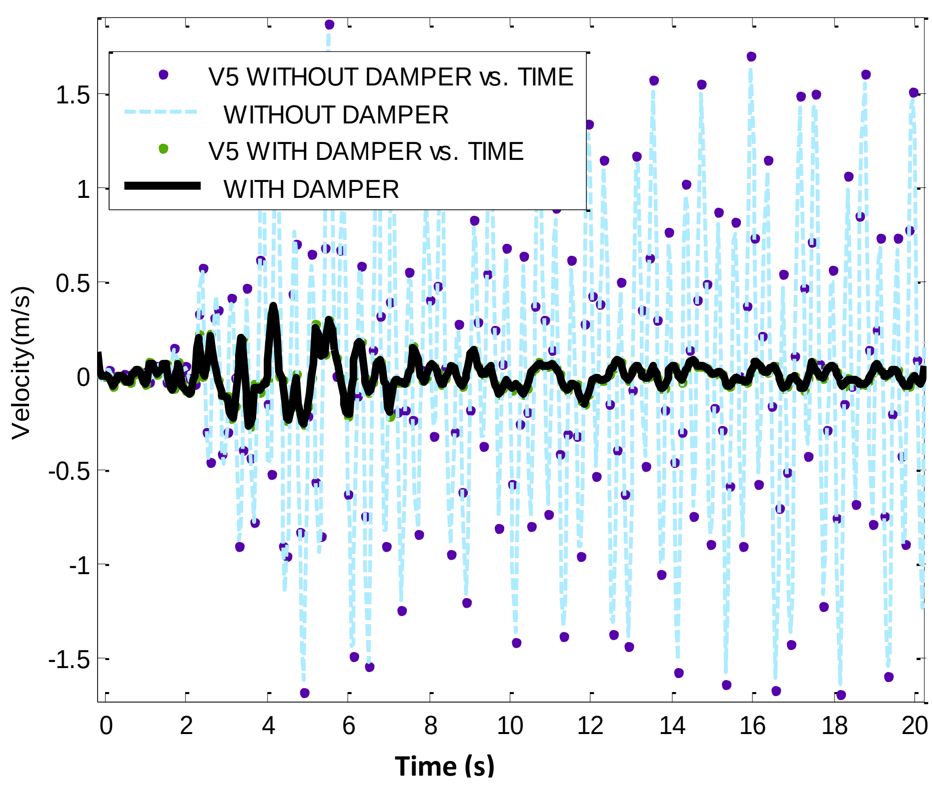

Figure 15. Average velocity of the 5th storey of 5 stories model with two openings.

models answers. This is to enable the obtaining of better understanding of damping decreasing function in models by increasing stories from 3 to 12 stories model.

What is obtained from Figure 16 is that decrease trend decreases in displacement of last stories of 3 stories model to 12 stories. This makes difference amount between damping mode and without damping in 3 stories model with 2 openings has the most relative limit. Descending trend of relative intensification to 5 stories model has begun and decreasing trend from 5 stories model to 12 stories has fixed trend (Figure 17).

In this stage, we study damping behavior on average answer of the last stories acceleration of structural models so that damping role is shown in these models by

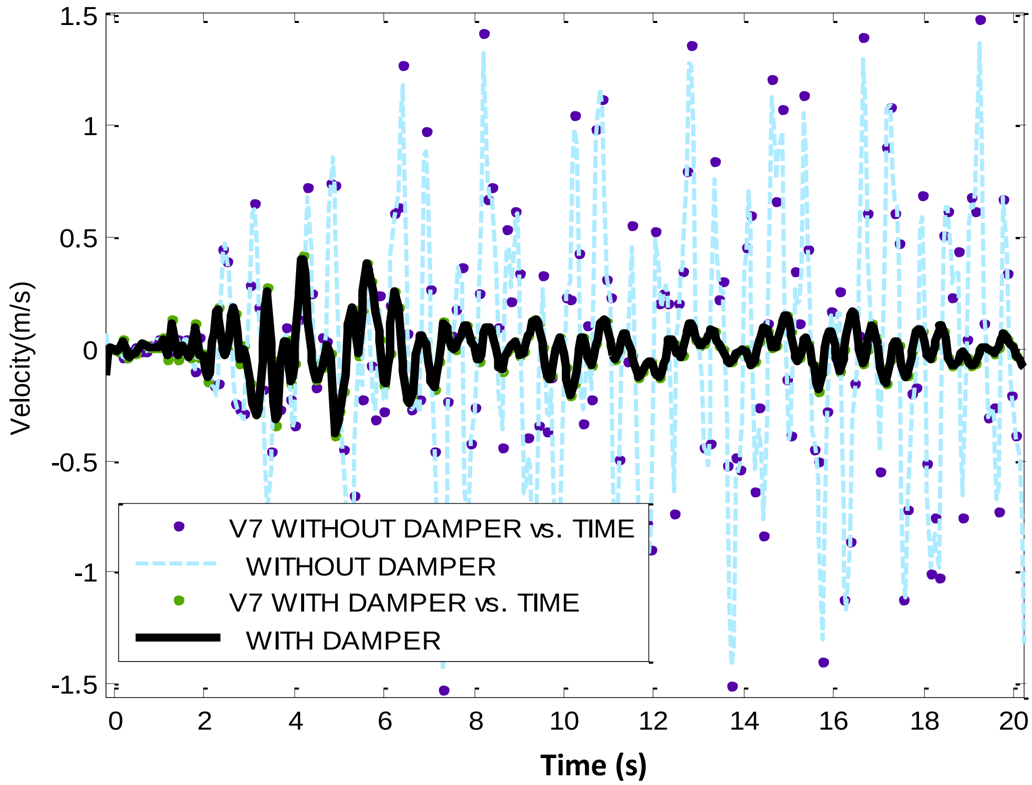

Figure 16. Average velocity of the 7th storey of 7 stories model with two openings.

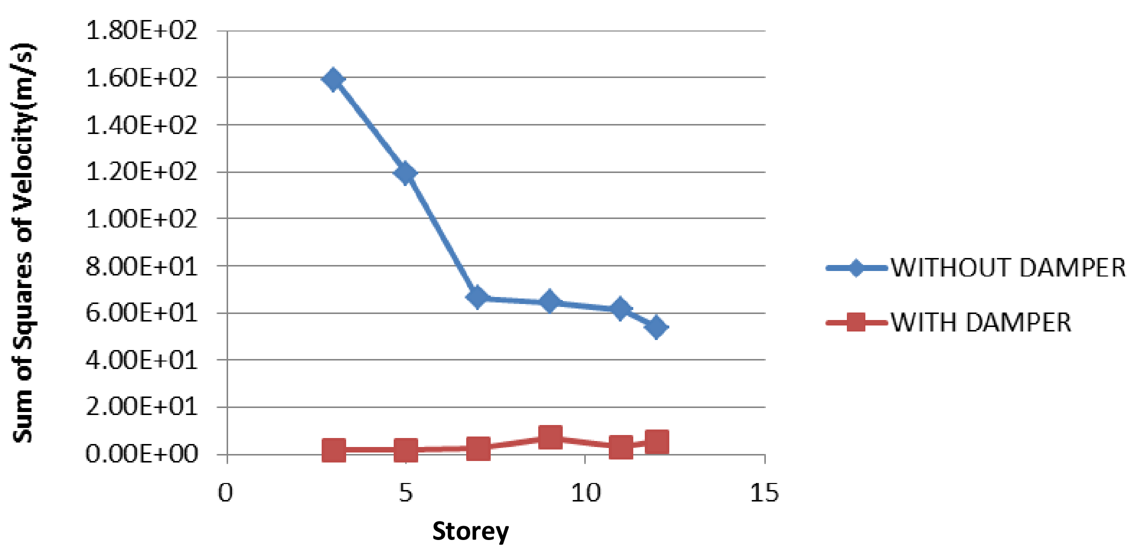

Figure 17. The sum of mean squares of last stories velocity answer in structural models.

using related diagrams. According to last stories acceleration of average answers, we find that because it will be mentioned in next section and because damping behavior is nonlinear and enters plastic phase, it leads to decreasing mode in acceleration answer. In order to study average change trend in above diagrams, we use sum of squares that shows damper behavior in different models.

In Figure 18, we find that change trend of 3 stories model to 12 stories is descending, that 3 stories model

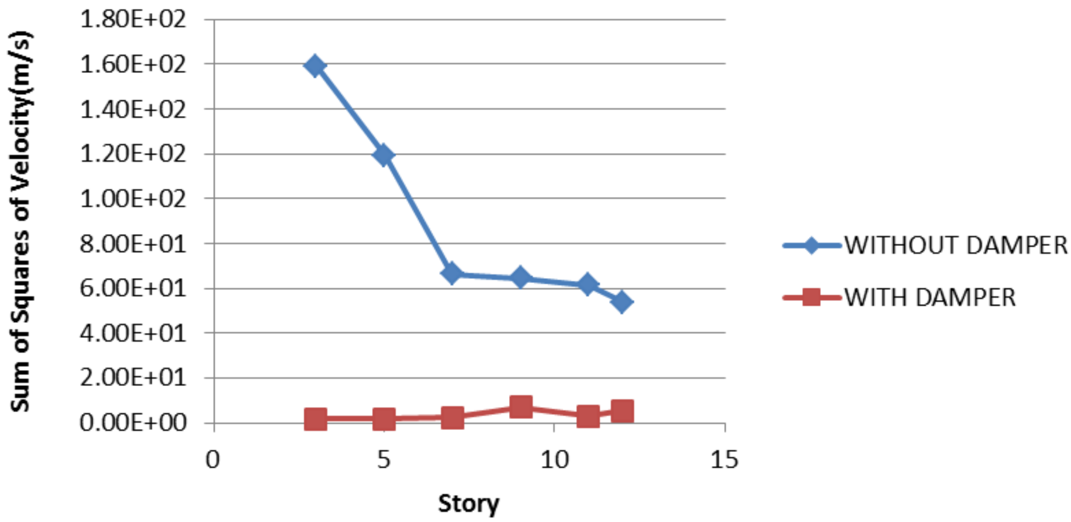

Figure 18. The sum of mean squares of last stories velocity answer in structural models.

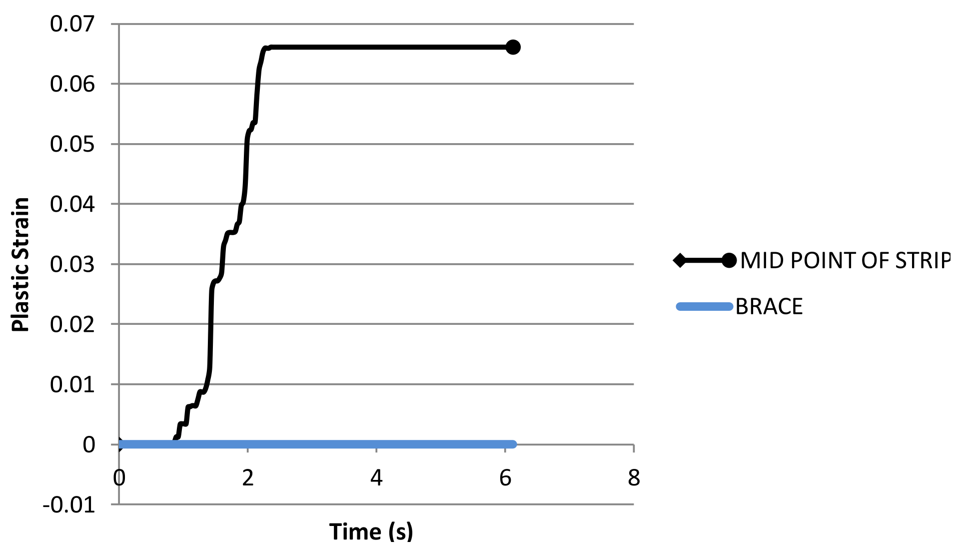

Figure 19. The responses of damper vs. to brace.

with 2 openings has the most relative limit for difference between damping and without damping mode.

DAMPING PERFORMANCE

The mean of the responses has been affected by pre bent steel strips damping behavior obviously. For explaining the damping performance of pre bent steel strips, inelastic behavior of the nonlinear spring (pre bent steel strip according to Equation 3) is used. Figure 19 shows the performance of pre bent steel strips. The figure shows the damping response of pre bent steel strips which resulted from inelastic performance of pre bent steel strips. Equation 1 demonstrates axial force which shows the nonlinear option for the pre bet strips as a damper (spring) which reacts with this nonlinear stiffness:

$$K = \frac{P(q_0\,, u\,, \beta)}{u}$$

Therefore, according to above, it can be concluded that the combination of nonlinear stiffness and inelastic performance is the reason for the damping response of pre bent steel strips.

Conclusion

In this study, a new type of seismic damper has been utilized and simulated on the various structural models which have been tested under cyclic loads and bench mark earthquakes. The summary of the mean responses of this numerical investigation has been demonstrated in this paper. The seismic tests with FEM in this numerical study confirm the feasibility and effectiveness of pre bent steel strips as seismic damper which reduces the important responses of structural model effectively.

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