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Evaluation of the seismic behavior of SAC steel frame buildings retrofitted with viscous dampers affected by far and near fault earthquakes

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ABSTRACT: Researchers have recently considered ways to increase the strength of and damping of the structures against earthquake loads so as to reduce maintenance and maintenance costs while enhancing safety. These solutions include the combination of steel frames with viscous dampers as the most vital part. Additionally, one of the most powerful tools in passive control is viscous dampers, which absorb earthquake energy and reduce the structure's response to earthquakes. Therefore, we have undertaken this study to investigate the response of standard SAC frames, built-in three, nine, and twenty floors, by applying this structural system to seismic loadings. The issue was first investigated using the Abaqus software package's numerical model of the viscous damper. Then, the effect of applying acceleration of faults of far and near-field Imperial Vali, Lomaprita, and Northridge earthquakes on the behavior of this structural system is evaluated separately. The results include floor drift, load-carrying capacity (as maximum base shear), and energy absorption of the structure (in two External working modes and strain energy) are discussed. Applied viscous dampers resulted in an average 200% decrease in drift, a 30% increase in load-carrying capacity, and a 35% increase in energy absorption in SAC standard steel structures after the application of these dampers

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1- Introduction

Passive control systems such as viscous dampers are utilized and located in the bracing elements and absorb some of the seismic energy applied into the structure, ensuring that the structural energy dissipation capacity is reduced to mitigate structural induced damages [1]. Conventional structures absorb energy through the surrender or rupture of building materials. For example, concrete structures absorb seismic energy through cracks, while steel beams and columns form plastic joints to absorb energy. Viscous dampers are a solution for yielding and rupturing [2, 3]. A damper gives a constant resistance to the movement of a structure. The force between the two ends of the damper is proportional to their relative velocities [4]. There has been extensive research on viscous dampers in recent years, but there still remains a research gap in previous studies. The answer can fill the gap to the fundamental question of "how much will the use of viscous dampers affect the behavior of short-range, medium-grade, and high-grade steel structures as a practical step in this regard against various ground motions. This study, therefore, investigates how adding viscous dampers affects the performance of different steel buildings. This damper allows the structure to dissipate energy while also reducing the drift caused by earthquakes, thereby reducing damage to non-structural components [5, 6]. Making optimal use of the capacity of these systems allows for a reduction of earthquake response and damages caused by earthquakes.

2- Methodology

Three buildings of 3, 9, and 20 stories of SAC standard have been designed and implemented in Los Angeles, Seattle, and Boston, respectively, according to FEMA355 to conduct this research [7, 8]. Then an external frame of the mentioned structures is modeled in Abaqus finite element software in states with and without using viscous dampers elements under near and far-field earthquakes. Using time history analysis, the amount of changes in the dynamic indicators of the structure, such as floor drift, load capacity, and energy absorption created in the whole structure, has been studied. These earthquakes used to conduct the time history analysis, as near and far-field ground motion data are the Imperial Uli, Lomaprita, and Northridge earthquakes.

3- validation

For validation, the numerical modeling of an experimental structure model equipped with a damper is employed [9]. The experimental model is a three-story frame, two-thirds of the actual scale, rehabilitated with a nonlinear viscosity damper

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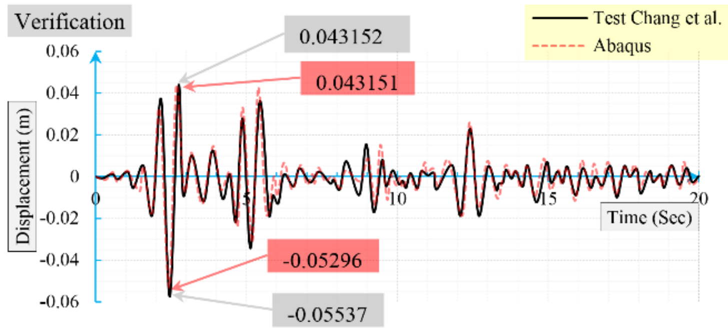

Fig. 1. Comparison of roof displacement in both experimental and numerical models

and placed on a shaking table under the north-south seismic component of the El Centro earthquake with a maximum ground acceleration of 0.34 g. The dimensions of the tested frame are 3 meters by 2 meters in the plan, and the height of floors 1, 2, and 3 are 2 meters, 1.75 meters, and 1.75 meters, respectively. The weight of the floors is 32.9 kN on the first floor, 32.9 kN on the second floor, and 22.7 kN on the third floor, respectively. The following laboratory and numerical results for roof displacement under 100% of the centrifugal earthquake can be seen in Figure 1.

As can be seen from Figure 1, the results are well correlated. The maximum displacement in the experimental study in the worst case in the negative part of the plot in the experimental study was 53.37 mm, which was obtained in the numerical model with a difference of 4.25% to 52.96 mm. Validation results indicate that the answers obtained in the present study can be relied upon with high accuracy.

4- Results and Discussion

According to the SAC project, three moment-resisting building frames as 3, 9, and 20-level steel bending frames, were simulated using the software package ABAQUS with and without dampers. These structures were then subjected to three earthquakes named; (1) Imperial Valley, (2) Lomaprita, and (3) Northridge, recorded as far and near-field ground motion. We discuss three structural models with and without viscous dampers subjected to six earthquakes to understand this structural system's behavior. Accordingly, 36 different models were developed and analyzed, and the results are presented as follows. The results also include the following three main sections:

Analysis of the effect of damper applications on the drift rate of SAC benchmark structures

Analysis of the effect of damper applications on the bearing capacity of SAC benchmark structures

Analysis of the effect of damper applications on the energy absorption of SAC benchmark structures

5- Conclusions

Results indicate that the behavior of the system is significantly dependent on earthquake acceleration amplitude. As a general observation, we can mention that the base-shear in all three structures is higher under near-field earthquakes than under far-field earthquakes. Due to this phenomenon, the capacity of structural materials is more taken into account for induced loads, and the bearing capacity for structures subjected to seismic loads increases for near-field earthquakes. As the story height increases, the induced displacements and drifts significantly increases. Therefore, resultant displacements are observed to be higher in the 20-story structure. The displacements subjected to the structure under near-field earthquakes have also been observed to be significantly larger than those caused by far-field earthquakes in many cases. Identifying and predicting the location of the damages in the structure is a very important aspect of the behavior of structures, which is often ignored in many studies. Following the drifts obtained from the different analyses, it was observed that the majority of damages in the frame were located on the first floor by the drifts. Therefore, the mentioned damage states on the first floor of the structures are more prone to strengthening and must be carefully considered. Another significant issue has been the reduction of drift, increasing bearing capacity, and increasing energy absorbed in structures equipped with dampers. With the use of viscous dampers, the drift ratio was more than two times lower in three frames of 3, 9, and 20 floors. Also, the bearing capacity of the three frames has increased by an average of 30% after using the damper. Total kinetic energy and internal energy also increased by 28% and 43% on average after utilizing dampers, respectively.

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