SHAKE TESTING OF FRAME STRUCTRES RETROFITTED WITH VISCOUS DAMPERS TO MITIGATE SEISMIC POUNDING

Yasser S. Salem[1] **and Maria Feng**[2]

[1] *Associate Professor, Dept. of Engineering Technology, California, State Polytechnic, Pomona. U.S.A*
[2] *Professor, Dept. of Civil & Environmental Engineering, University of California, Irvine, USA*
Email: ysalem@csupomona.edu, mfeng@uci.edu

ABSTRACT :

Many cases of structural damages were attributed to pounding during major seismic events. Pounding occurs when the gap between buildings are not wide enough to allow for their relative motions during seismic events] Viscous dampers, installed across the gap between buildings, were considered for seismic retrofit to mitigate pounding. Two steel frames representing a flexible building adjacent to a rigid building were tested in shake table using ground motions of varying intensities and varying gap widths between the frames. Results from shake table testing indicate that viscous damping devices significantly reduce the seismic pounding response without adding new seismic demands on any of the adjacent buildings. The damping devices were found to be more effective for the test cases in which frames were excited by high-intensity ground motions. It was also found that dampers work more efficiently for cases in which frames were separated by small gaps than for the cases in which frames are touching each other at rest condition.

KEYWORDS: Pounding, Viscous dampers, shake table testing

1. INTRODUCTION

The primary objective of this paper is to experimentally study the pounding response between framed structures and assess the effectiveness of viscous dampers installed across the gap between the frames in reducing the pounding response For this purpose, two steel-frame towers were designed and built as a test specimen. These frames represent a flexible frame adjacent to a rigid frame. All testing took place using recorded ground motions that were scaled based on the peak ground acceleration (PGA) levels of various intensities. After the pounding responses were determined, two types of viscous dampers were incorporated into the test specimens across the gap between the frames to study their effect in reducing the pounding response.

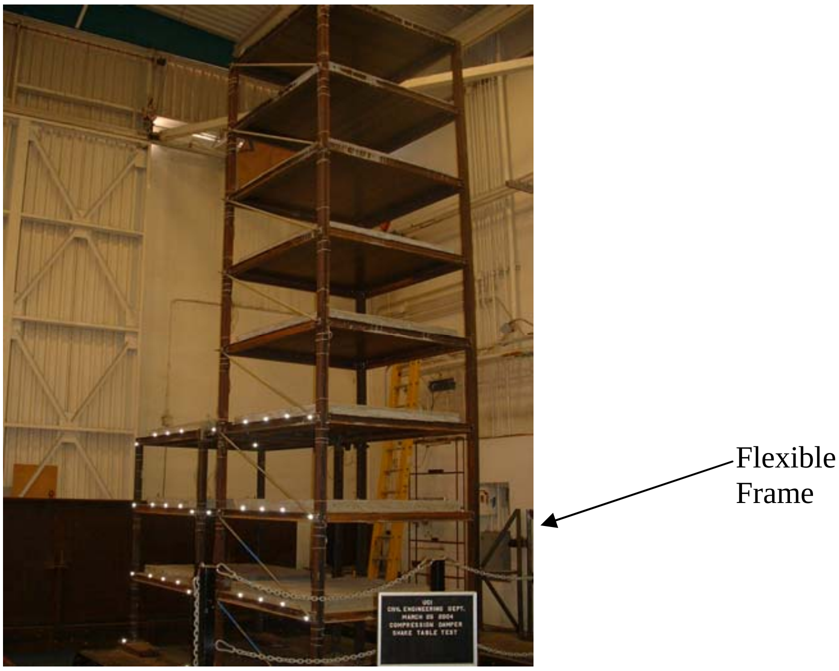

Figure 1. Test Frame

2. EXPERIMENTAL SETUP

2.1. Description of Test Specimens

Two adjacent 1/6-scale, single-bay moment-resisting steel-frame models were built to be tested in this study. The first frame represents a flexible building eight stories high and is adjacent to a second frame that represents a rigid building three stories high[11]. At each floor, an 11-gauge steel plate is bolted to the top of the steel beams to represent rigid diaphragm action. The masses of the models are represented by reinforced concrete blocks each measuring 3½ by 54 by 43 inches. The testing was performed on the biaxial shake table in the structural laboratory at the Henry Samuel School of Engineering at the University of California, Irvine. The shake table has plane dimensions of 10 by 12 ft with horizontal and vertical degrees of freedom. Floor acceleration at each floor level was measured by using piezoelectric accelerometers. Diagonal linear variable differential transformers (LVDTs) were installed at each floor bay of the flexible frame to measure the story drift. Separate horizontal LVDTs were installed between the flexible frame and the rigid frame to measure their relative displacements during testing. Impact forces were measured using a compression-only load cell.

Collision between the frames was controlled so that it occurred only at the top of the rigid the gap between the frames could be configured to simulate three main conditions:

Zero gap: the two frames that are touching each other are at rest, Large gap: the frames are separated sufficiently to allow them to vibrate freely under strong earthquakes without colliding

Small gap: a case between the zero and the large gaps.

2.3. Supplemental Damping Devices

Two types of viscous dampers were used in this study. Type I is a tension compression damper with a constant damping coefficient and is manufactured by Taylor Devices®. Type II is a compression-only shock absorber with a variable damping coefficient and is manufactured by ENIDINE®. Figure 2 shows a schematic diagram of the type I damper and its installation fitting to the test frames. For device type II, the damping coefficient was changed under the same ground motion input to determine how the changing damping magnitude reduced the pounding response.

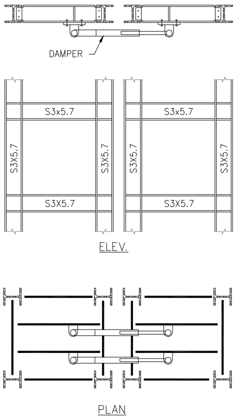

Figure 2. Supplemental Damping Devices Installed Across Gap between Frames

2.4. Earthquake Records

Two earthquake records scaled linearly with different intensities based on the PGA were used as input records in this study: El Centro Earthquake (NS-components, 1940), with a PGA of 0.34g (Figure 4); and Northridge Earthquake (NS-components, Whiter school, 1994), with a PGA of 0.8g (Figure 5). Earthquake records were chosen based on their frequency content characteristics. The PGAs for both records were linearly scaled to range from 0.04g to 0.24g

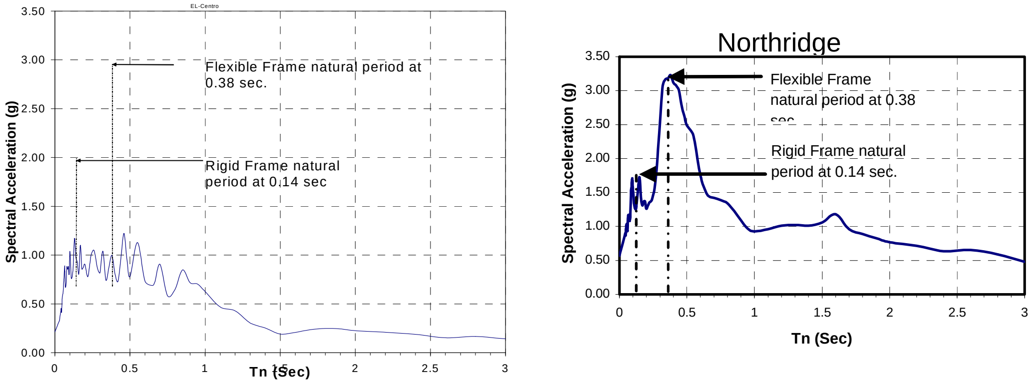

Figure 3. Response Spectra at 2% Damping PGA (0.8g)

3. TEST RESULTS

3.1.Floor Accelerations

Figure 4 shows the absolute floor acceleration at the third floor of the rigid frame for the El Centro record. The graph indicates that, for the small gap, the floors are subjected to impulsive acceleration each time impact occurs. For the large gap, the amplitude of the maximum floor acceleration is almost six times the maximum amplitude. When the gap width is reduced to zero, allowing the two frames to be in direct contact at rest, the acceleration amplification is significantly higher than in the case of a small gap. The amplitude of the maximum acceleration is 36 times greater than for the large gap. When viscous dampers were installed across the gap between the frames, the peak floor acceleration was reduced and then reached a level similar to that of the large gap. This data suggests that the viscous dampers were successful in reducing the impulsive floor acceleration that occurs during impact. The results of the Northridge record (Figure 5) show similar trends with a maximum floor acceleration level slightly less than that for the El Centro record.

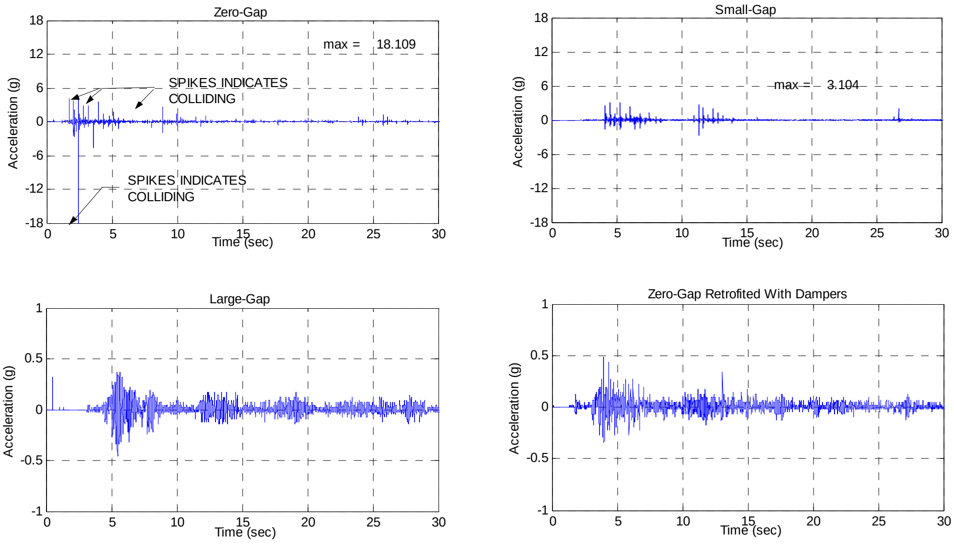

Figure 4. Third Floor Acceleration at Rigid Frame for El Centro Record

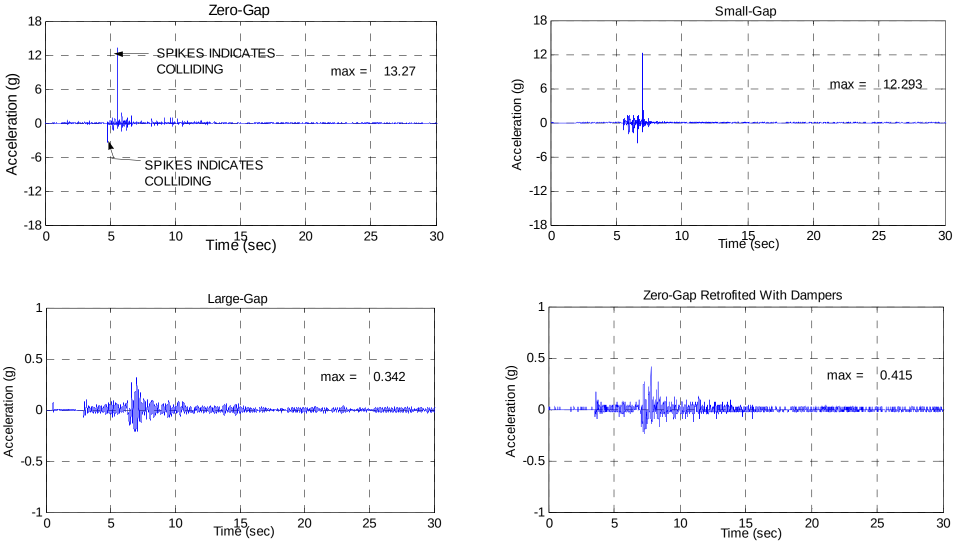

Figure 5. Third Floor Acceleration at Rigid Frame for Northridge Record

Figure 6 shows the envelopes of the maximum floor acceleration at each floor of the two frames for all tested cases. These graphs indicate that the third floor of the rigid frame is subjected to large acceleration amplification compared to the third floor of the flexible frame. The acceleration level in the case of a zero gap is almost four times the acceleration magnitude of the small gap in the El Centro record. However, in the Northridge record, both the small- and zero-gap configurations show similar acceleration levels, indicating that the floor acceleration between the frames depends on the frequency of the input ground motions. In both records, when the viscous dampers were installed between the frames, they were successful in reducing the acceleration level (especially at the rigid frame) to a level similar to that of the large gap.

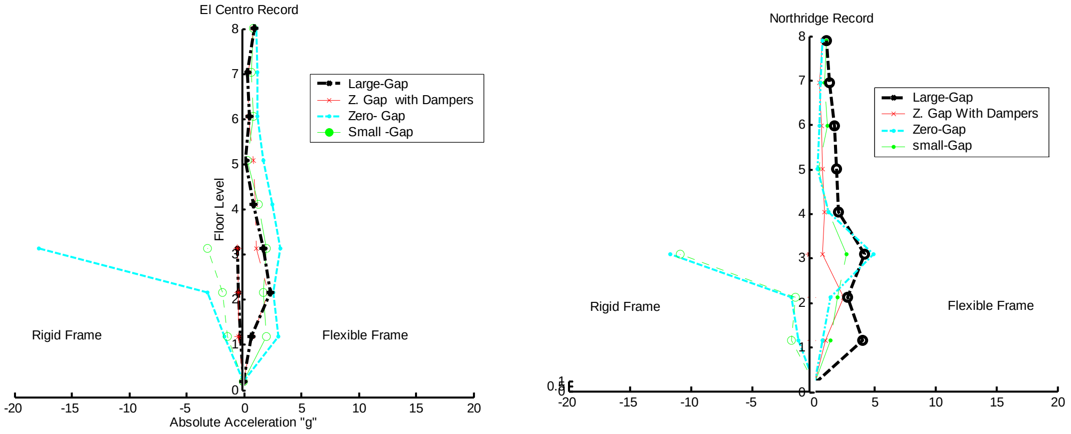

Figure 6. Envelope of Maximum Floor Acceleration for El Centro Record

Figure 7 shows the envelope of the maximum floor acceleration for the various damping coefficients that were used with the type II damper for both the El Centro and Northridge records. Increasing the damping coefficients by 20 percent and reducing the acceleration level of the third floor of the rigid frame to the original acceleration level increases the acceleration at the third floor of the flexible frame, but there is less noticeable reduction of floor acceleration in the case of the flexible frame. The supplemental damping devices were successful in reducing the demands for both the El Centro and Northridge records. It should be noted that the Northridge record showed a significant reduction in floor acceleration as the damping coefficient increased. However, for the El Centro record, increasing the damping coefficient beyond 40% did not significantly reduce the floor acceleration. This is another indication of how the damper and the structural response are sensitive to the frequency contents of the input ground motion;

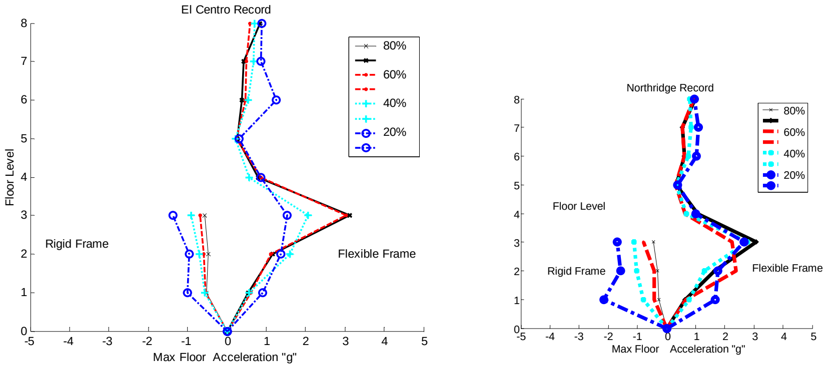

Figure 7. Maximum Floor Acceleration at Various Percentages of
Maximum Damping Values

3.2.Story Drifts and Ductility Demands

Figures 8 and 9 show the envelopes of the maximum story drift for zero and small gaps between the frames with and without dampers installed between the frames. As can be seen from these graphs, the dampers succeed in reducing the overall maximum relative floor displacements for both frames in both the El Centro and Northridge records.

The maximum floor displacements are proportional to table peak accelerations. The benefit of the viscous dampers in reducing the floor displacements is more pronounced for the small-gap than for the zero-gap configuration.

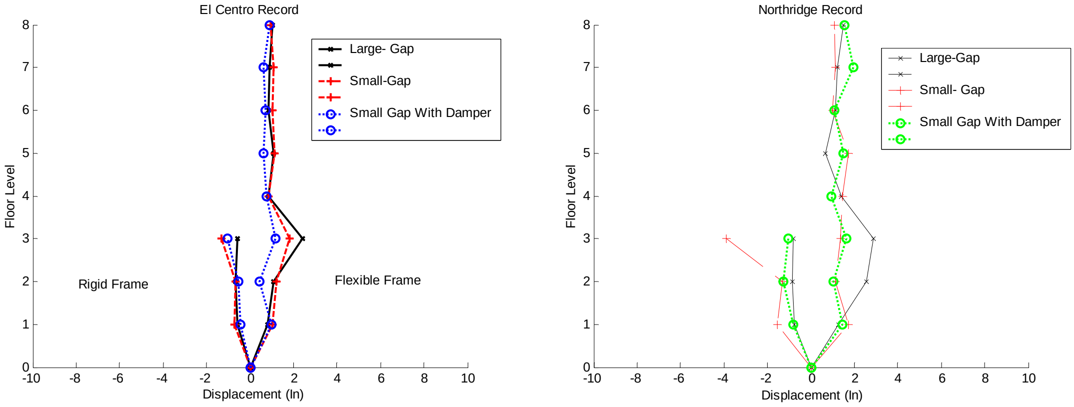

Figure 8. Envelope of Third-Floor Story Drift at Rigid Frame for El Centro Record

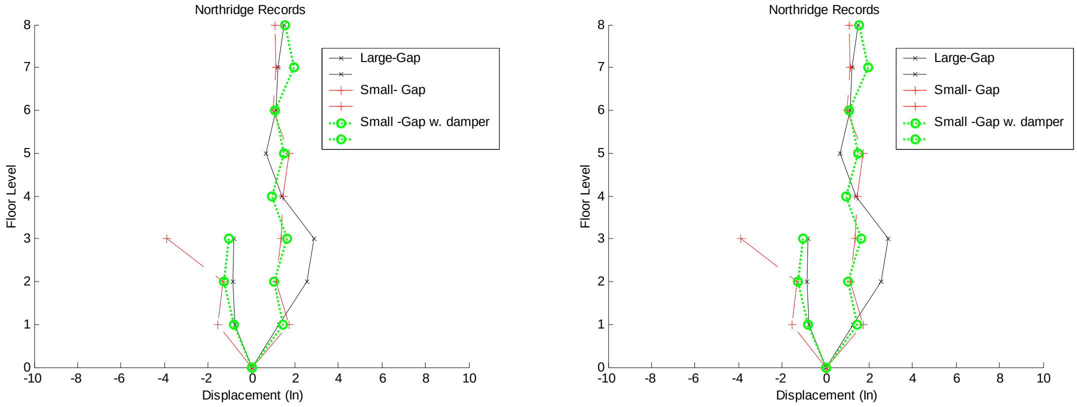

Figure 9. Envelope of Third-Floor Story Drift at Rigid Frame for Northridge Record

3.3.Impact Force Between Frames

The magnitude of the impact force transmitted between frames during pounding is proportional to the PGA level in the input record. By comparing Figure 10 to Figure 11, it is evident that viscous dampers effectively reduced the maximum impact force from 833 lb to 327 lb with a 60% reduction in the case of EL Centro record. Similar trend was observed in the Northridge record, where the impact force was reduced from 875 lb to 357 lb with a 59% reduction which clearly show the effectiveness of viscous dampers in eliminating these forces

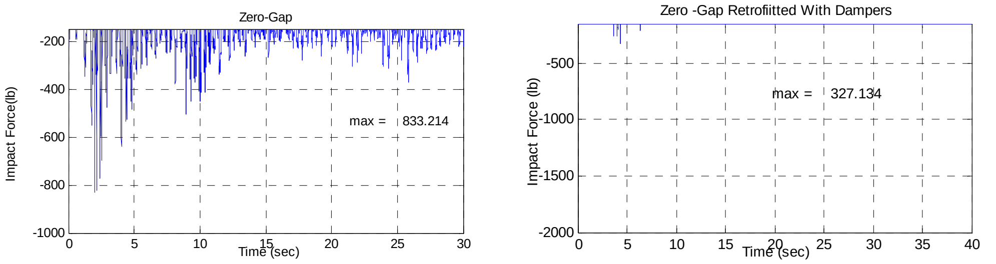

Figure 14. Floor Impact Force with Zero Gap Subjected to El Centro Ground Motion

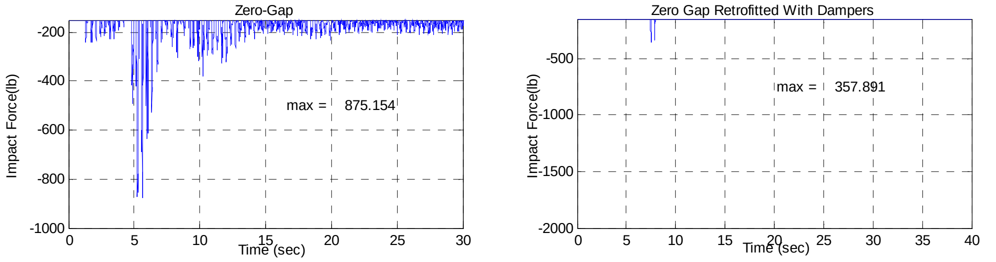

Figure 15. Floor Impact Force with Zero Gap Subjected to Northridge Ground Motion

4. SUMMARY

For the zero-gap configurations, the acceleration amplification is higher than for the small gap. When dampers are installed between the frames, they reduce the acceleration to a level comparable to that of a large gap. Frames with a zero gap were subjected to less impact force than frames that were separated by a small gap. The story drift at the third floor of the rigid frame was more amplified for the small-gap than for the zero-gap configuration. Viscous dampers succeeded in reducing the story drift for both frames. The reduction was more pronounced in the rigid frame than in the flexible frame.

The impact force was found to be proportional to the simulator peak acceleration. By increasing the damping values, the impact force gradually decreased until it vanished when the dampers were fully used. The supplemental damping devices were more efficient in reducing impact forces for the small-gap than for the zero-gap configuration.

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