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SEISMIC RETROFITTING OF AN EXISTING RC BUILDING IN MEXICO CITY USING HYSTERETIC STEEL DAMPER “ADAS”

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ABSTRACT

One of the most devastating earthquakes in the history of Mexico was the earthquake of 1985. The seismic design code of Mexico City was urgently revised just after this earthquake. Furthermore, it was modified in 1987 and 2004, incorporating the earthquake damage analysis results and the latest knowledge on earthquake engineering.

In 2017, the Puebla Earthquake occurred and struck Mexico City. About twenty buildings collapsed, and more than 200 peoples died due to this earthquake. The survey results have found out that most of the buildings that collapsed in this earthquake were designed based on the old seismic code before 1985. Therefore, seismic performance evaluation and retrofit of these old buildings is still one of the significant issues.

In this study, the author investigated the ADAS's potential as dampers to retrofit existing reinforced concrete buildings. The ADAS, which means the "Added Damping and Stiffness," is one type of steel hysteretic dampers. This ADAS damper yields in bending during an earthquake and dissipates seismic energy by its plastic deformation. The original developer devised its shape so that plastic deformation occurs in a broader area without stress concentrating on a specific part.
The author took up one existing public office building and attempted to retrofit it using this ADAS. He carried out earthquake response history analyses and compared the building's dynamic behaviors before and after retrofitting. The results cleared that we could reduce inter-story drift angles by inserting the ADAS in the building.

Finally, the author considered a possibility of the damper's fatigue failure due to long-term earthquake ground motions.

Keywords: Seismic retrofit, Hysteretic steel damper, Inter-story drift angle, floor response acceleration, fatigue failure.

1. INTRODUCTION

On September 17, 2017, the Puebla Earthquake occurred in Puebla state of Central Mexico and caused heavy seismic damages even in Mexico City, about 120 km away from the epicenter. About 20 buildings collapsed, resulting in the death of more than 200 people.

After the well-known 1985 Mexico earthquake, they urgently revised the seismic code. Moreover, they expanded their seismic observation network and worked hard to research the earthquake ground motion characteristics, surface ground amplification, non-linear behavior of structures, etc.

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Based on these advanced research results, they furthermore revised the seismic design code in 1987 and 2004.

As a result of these revisions, the seismic design force has been dramatically increased compared to that before 1985. The zoning to evaluate surface ground application have become more detailed. Also, design standards have been established to ensure sufficient ductility for structural members. There can be a massive difference in seismic performance between buildings designed according to these revised standards and old standards. They reported that most of the buildings collapsing in the Puebla earthquake were such old ones. We can say that seismic performance evaluation and seismic retrofit of old existing buildings are remaining issues.

Based on this situational awareness, in this study, the author decided to examine a seismic reinforcement method for existing reinforced concrete structures by inserting dampers. He used the ADAS, one kind of the steel hysteretic dampers, for dissipating earthquake energy.

2. METHODOLOGY

2.1. Added Damping and Stiffness (ADAS)

The ADAS (Added Damping and Stiffness) is made up of a series of metal plates (generally ASTM grade A-36 steel) in the shape of an "X", connected in a way that has restriction at their ends. During an earthquake, its relative deformation must be close to that of the upper floor. As the upper part deforms laterally by a force perpendicular to its plane, these plates are subjecting to shear forces; the sheer force induces bending moments at the height of the plates. This bending occurs in the weak axis, giving a double curvature of equal radius. Figure 1 shows the shape of the ADAS, the deformation, the moment's distribution, the plate's width, and the curvature.

Making the plate's width coincide with the moment's distribution, as shown in this figure, can make the steel plate yield in bending simultaneously along the height. At that time, we can suppose the curvature as shown in the figure. We can derive the yield deformation and the strength capacity using this curvature with material and sectional properties: Young's modulus, the yield point of steel, the plate's height, width, and thickness.

This ADAS has the hysterical stability withstanding many cycles of the load without degrading. The X-shaped section leads to a uniform deformation throughout their its height, providing good resistance and deformation capacity for cyclic loads. By adjusting the number of plates and the dimensions of each plate, we can get required capacities of dampers relatively freely (Whittaker, 1989, Aguiar, Rodríguez, & Mora, 2016）.

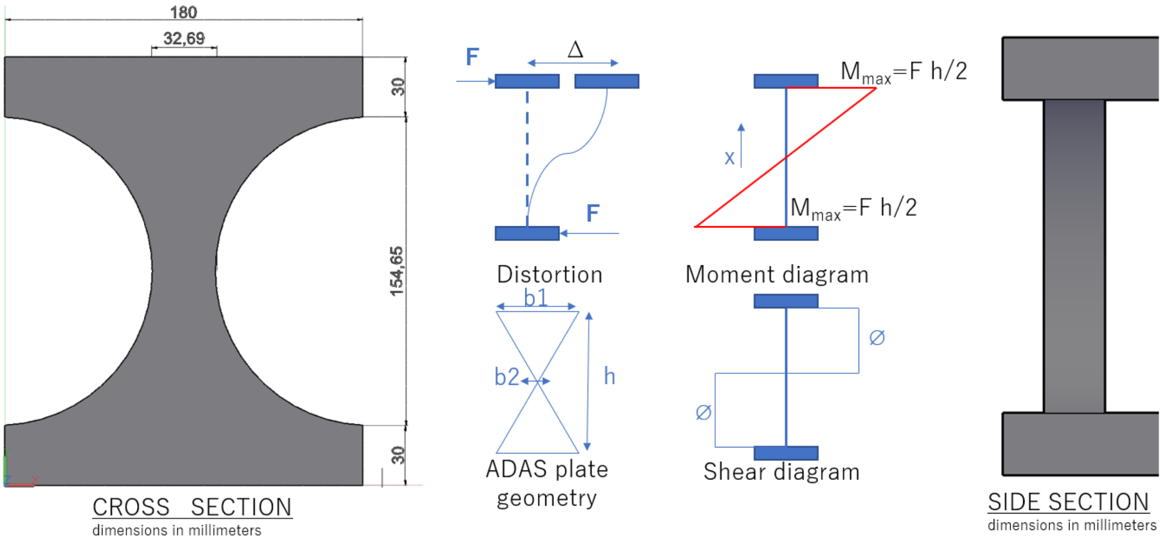

Figure 1. Moment and bending deformation of ADAS Steel Damper due to lateral force.

2.2. Target Building and Retrofitting Strategy

Figure 2 shows the plan of the building to be targeted in this study. Also, the author shows the locations of the ADAS dampers for seismic retrofit in this figure. The original building was designed based on the seismic code before 1985. Thus, we need to retrofit it. Figure 3 presents the conceptual strategy for the retrofit. The structure is composed of one central part and two side parts. Each side has nine stories: the central region has eleven stories. The author investigates the ADAS's potential for seismic retrofit by comparing the building's dynamic behaviors before and after the retrofit.

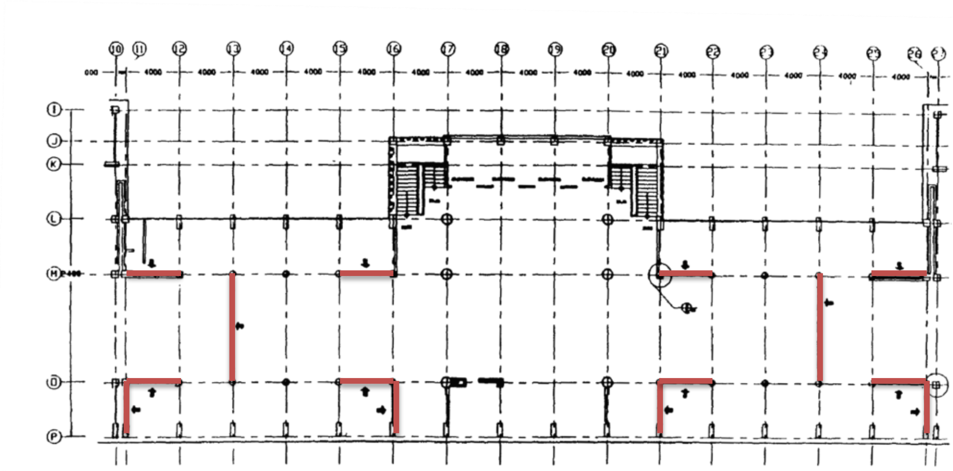

Figure 2. Plan of target building and arrangement of ADAS steel dampers.

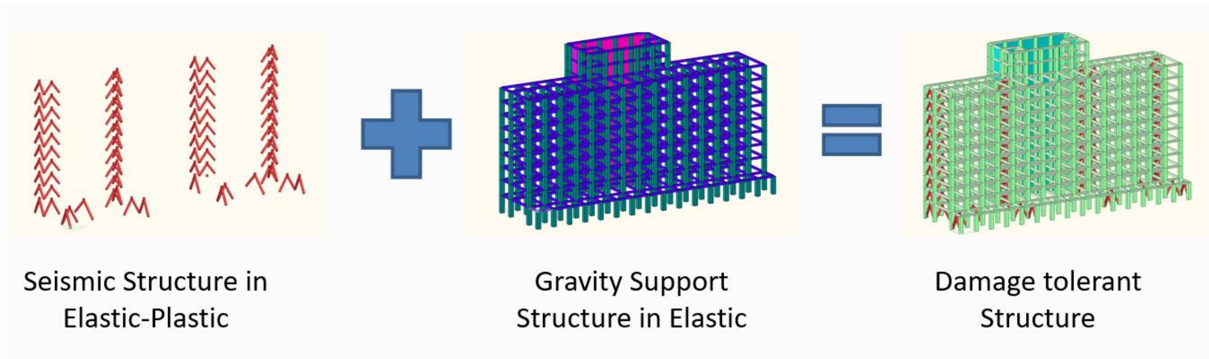

Figure 3. Retrofit Strategy using steel damper, ADAS.

3. RESULTS

3.1. Natural fundamental periods and static force-displacement relationships

In this study, the author inputs the ground motion record of the 1985 Mexico Earthquake to the building model for response history analyses. Figure 4 shows the response acceleration spectrum of the input ground motion and the fundamental natural periods of the model before and after the retrofit.

Figure 5 shows the relation between story drift angle and shear capacity for the original building model calculated by a push-over analysis. The author sets the retrofit design criterion for drift angle of each story as 0.015 to ensure the performance of “life-safety.” The yellow broken line shows this retrofit design criterion in the Figure 5.

Figure 6 shows the capacity curves, which are the relations between the base shar and the roof (PH) displacement of the target structure before and after retrofit. The base shear is normalized by the toral weight and revealed as the spectral acceleration, *Sa*. We can see the retrofit's effects in this figure. The ADAS inserted in each story makes the *Sa* increase from 0.7 G to 0.8G in x-direction: from 0.4 G to 0.5 G in the y-direction. These are the results against the monotonic loading calculated by static analyses. Furthermore, we can expect the damping effects of the ADAS in the case of dynamic repetitive loads.

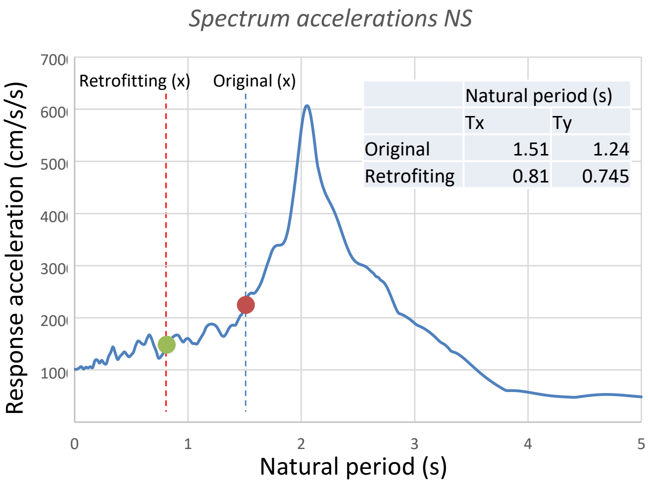

Figure 4. Response acceleration spectrum, and natural periods of target model before and after retrofit.

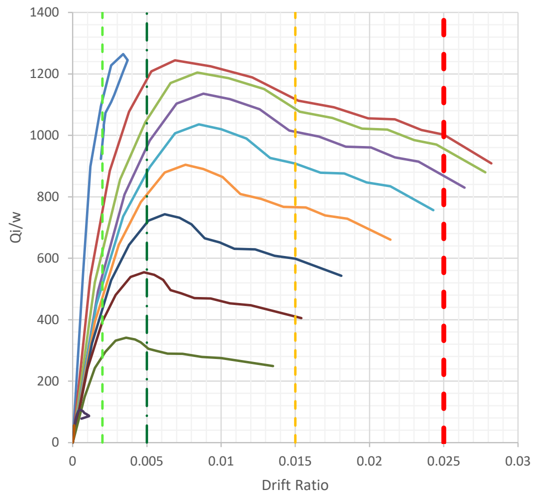

Figure 5. Shear force - story drift angle (Before retrofit).

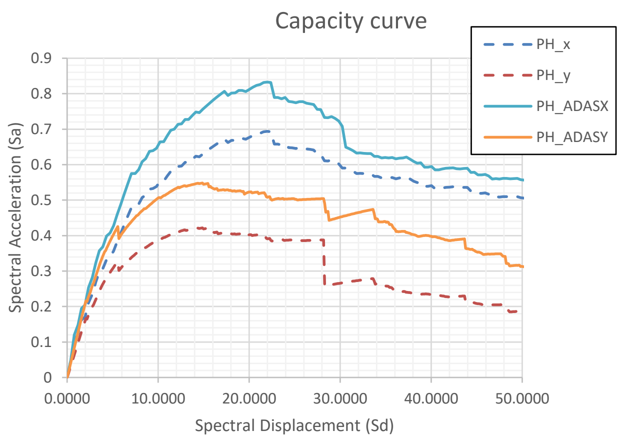

Figure 6. Capacity curves of target model before and after retrofit.

3.2. Results of response history analyses

Figure 7 presents each story's maximum story drift of the target model before and after the retrofit. Before retrofitting, the story drift from the second to the ninth story exceeds the limit drift angle for "pre-collapse." On the contrary, after retrofitting, all stories' drift angles fall below this limit drift angle. Some of them exceed the limit angle for "fully-operational", but all of them fall below that for "life safety", which is 0.015, in both x and y directions. Figure 8 and 9 respectively show the time history of the shear deformation and the hysteresis loop of the ADAS arranged in the second story. The ADAS repeated oscillation a lot. We can say that the dampers effectively dissipated the earthquake energy due to these cyclic behaviors and successfully reduced the earthquake responses of the target model.

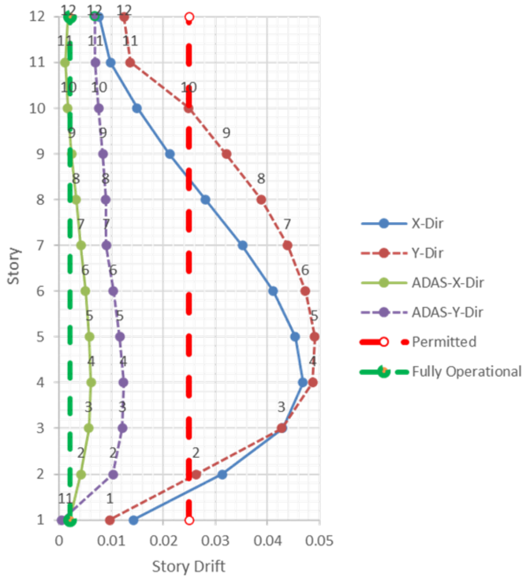

Figure 7. The maximum story drift of target model before and after retrofit.

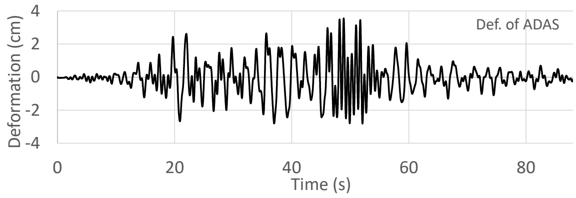

Figure 8. Time history of ADAS's deformation.

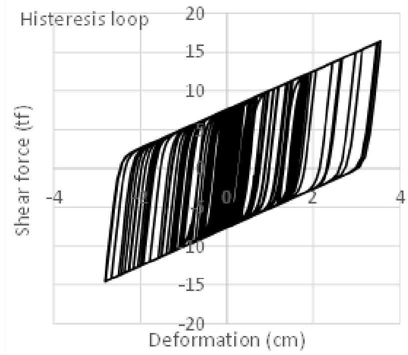

Figure 9. Hysteresis loop of ADAS.

3.3. Discussion on a risk of fatigue failure

The latest seismic code of Mexico City was published in 2017. This year, the Puebla Earthquake occurred. However, regardless of this earthquake, they had previously planned to revise the seismic code to introduce the newest knowledge about seismology and earthquake engineering. This latest code stipulates that they should consider two types of earthquakes to design building structures in Mexico City. One is the subduction earthquake, and the other one is the intermediate-depth earthquake. We generally think that the duration of a subduction earthquake is longer than the other one. The seismic code of Mexico City supposes that the duration of the former one is 80 s: that of the latter one is 40 s. When designing structural steel members against such a long-duration earthquake, we need to check if there is a risk of fatigue failure.

We can predict the risk of fatigue failure for cyclic loading with constant amplitude by using the *S-N* curve. For example, the following curve is used for the structural design of beam ends of high-rise steel buildings in Japan.

$$\mu = C \cdot N_f^{-1/3} \tag{1}$$

where, μ: ductility factor, C: Coefficient derived from cyclic loading tests and N_f: the number of load's cycles when the structure fractures.

The coefficient C ranges from 2.0 to 10.0 for the beam ends of steel structures. To apply Eq, (1) to a random response due to earthquake ground motions, we generally use the well-known Miner's rule as shown below.

$$D = \sum \frac{n_i}{N_{fi}} \tag{2}$$

where, D: Failure index, n_i: the number of load's cycles in the specified deformation range and N_{fi}: N_f for the specified deformation range.

If the index D surpass 1.0, we should judge the structure will fracture. The author counts n_i in Eq. (2) from the results shown in Figure 8 by using the rain-flow method. Figure 10 shows the result of counting.

As long as the author knows, there is not sufficient test data to determine the coefficient C. If we assume C = 43, the failure index D becomes 1.01, which is almost equal to 1.0. And this case almost meets the design criterion. This *C* value is relatively high, comparing those of the beam ends. However, we should consider the characteristics of ADAS again. It has an X-shape section, which makes the steel plate yield through the height uniformly. This feature brings stable performance against cyclic loadings. We can reasonably assume that the ADAS has a higher coefficient *C*. To improve the ADAS dampers' reliability, the author considers that we need to acquire their test data against cyclic loading more and analyze them to reduce fatigue failure risk.

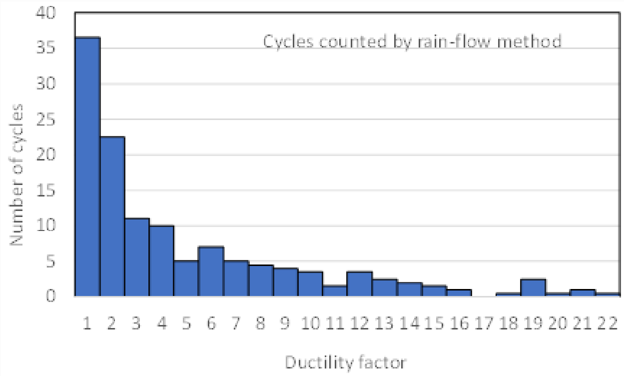

Figure 10. Cycles counted by rein-flow method.

4. CONCLUSIONS

The author investigated the ADAS's potential as an energy dissipation device used to retrofit existing buildings through the case study. The results of earthquake response analyses for the model retrofitted using the ADAS presented their excellent performance to reduce displacement responses. We can also expect stable performance even against cyclic loading with a long duration because of its mechanism due to the X-shaped section. The author thinks that we need to acquire more test data and analyze them to demonstrate such a good performance for the cyclic loading by more quantitative evaluation scales like the S-N curve.

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