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SEISMIC PERFORMANCE EVALUATION OF PILOTI-TYPE BUILDINGS AFTER AN EARTHQUAKE

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On November 15, 2017, the second strongest earthquake occurred in Korea, which was 5.4 in size on the Richter Scale. The duration of the earthquake was short, but the damage was serious. Two recent earthquakes have shown that our country is no longer safe from earthquakes. However, to date, Korean structures are showing a low earthquake resistance, and seismic retrofitting is necessary in preparation for a large-scale earthquake. In this study, reinforcing effect of steel slit damper was analyzed based on the dynamic test results of the previously studied reinforced concrete frame. After that, push over analysis and nonlinear time history analysis using OpenSees were selected for the residential piloti-type building as the target building. In the above Korean earthquake, the damage to the piloti-type building was conspicuous. Through analysis, the vulnerable part of the piloti-type building was identified and the seismic strengthening with the steel slit damper was carried out.

Keywords: Shaking table test, Steel slit damper, OpenSees, Nonlinear analysis.

1 INTRODUCTION

The Gyeongju earthquake that occurred on September 12, 2016 had a short duration of less than 10 seconds, but with a large number of 640 large aftershocks. Vibration was detected not only Gyeongju, Ulsan, Daegu and Busan, but also some parts of Seoul. On November 15, 2017, the second strongest earthquake occurred in Pohang city of 5.4 magnitude. The duration of the earthquake was short, from 4 to 6 seconds, but the damage was incomparable with the 9.12 Gyeongju earthquake. In this study, based on the results of the shaking table tests performed in the previous research (Shin *et al*. 2016), nonlinear static analysis and time history analysis were performed by modeling the test specimens using OpenSees, and the reliability of the steel slit damper modeling was verified by comparing with experimental results. After that, seismic performance evaluation was carried out for the residential piloti-type buildings located in Pohang city through nonlinear analysis of domestic and overseas earthquakes.

2 SHAKING TABLE TEST

2.1 Shaking Table Test Specimens

This study considered a 1-story 1-span RC frame specimen with a non-seismic (NS) design. Its detailed specifications are shown in Figure 1(a) and the specimen includes a column height of

2,750 mm and beam length of 3,700 mm. Its seismic performance was compared with the performances of various seismic reinforcement systems when a 22-ton mass was loaded on its top. Figure 1(b) portrays a specimen reinforced with a steel plate slit damper (NS-D), which was designed so that the stiffness of the damper was greater than of the frame.

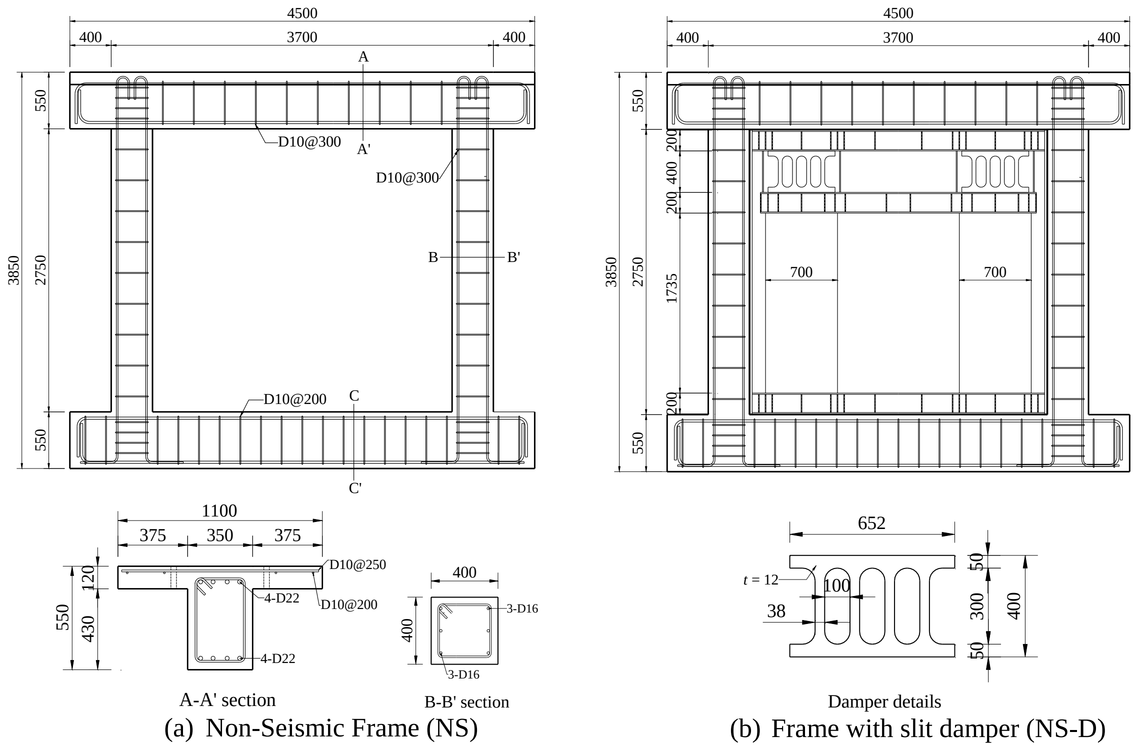


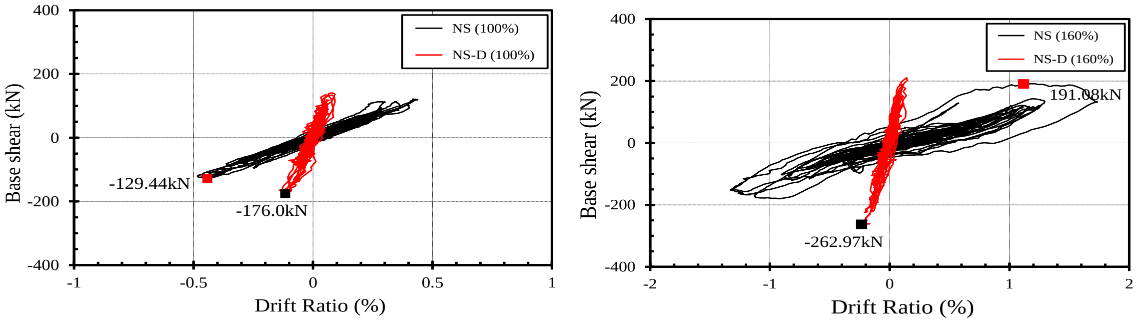
Figure 1. Detail of specimens (unit: mm).

2.2 Shaking Table Test Result

The shaking table test was carried out by shaking the specimens stepwise using a 10% to 300% acceleration scale based on the seismic wave data of the El Centro (1940) earthquake, which had a rating of 6.9 on the Richter scale, as listed in Table 1. Here, PGA is the peak ground acceleration, EPA is the effective peak acceleration, and Sa (1.0) is the acceleration in 1 second of the response spectrum. The test results for all the specimens are shown in Figure 2. The NS specimen, which is a non-reinforced frame, ended the experiment at 160% seismic excitation. Figure 2(a) shows the experimental results with 100% and Figure 2(b) shows the results with 160%.

Table 1. Characteristics of El Centro seismic wave.

Seismic wave	PGA (g)	EPA (g)	EPA / PGA	Sa (1.0) (g)	Sa (1.0) / PGA
El Centro	0.319	0.310	0.973	0.454	1.423



(a) 100% seismic excitation (b) 160% seismic excitation

Figure 2. Base shear force-drift ratio response curve of specimens.

3 OPENSEES ANALYSIS

3.1 Modeling of Specimens

OpenSees analysis modeling was performed with two-dimensional elements, as shown in Figure 3. The column and beam were modeled with nonlinear beam-column elements, and a fiber section was used to model the section (Mazzoni *et al*. 2006). In the case of the beam section, it was modeled not as a T-shaped beam but as a rectangular beam for the sake of convenience of the analysis. Boundary conditions of between column and ground are fixed. In the case of the steel slit damper, it was modeled by replacing each part with steel columns, as shown in Figure 3(b).

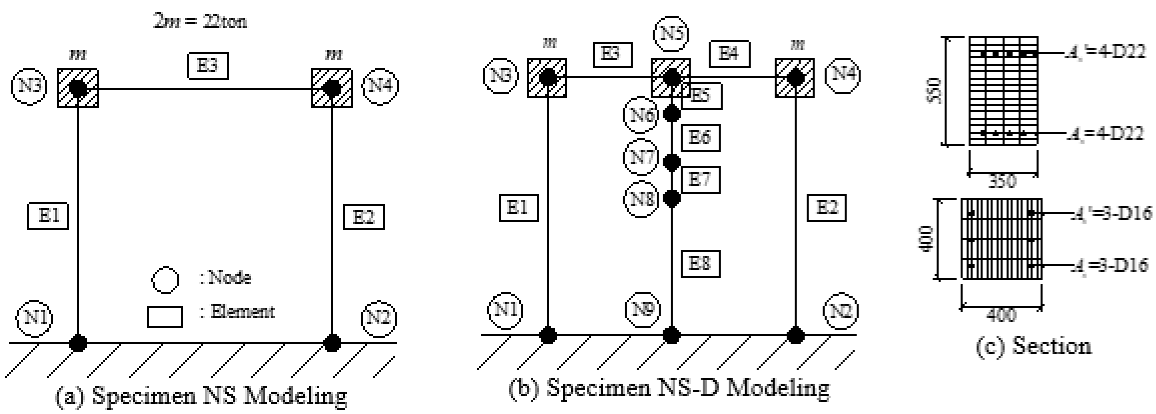


Figure 3. OpenSees modeling.

3.2 Pushover Analysis of Specimens

A pushover analysis was performed with the OpenSees program to determine the approximate behavior and limit condition of the analytic model before performing a nonlinear time history analysis. Figure 4 shows a comparison of the test result of each specimen with the analytic result through OpenSees. The initial stiffness and maximum strength of the analytic model were very close to the test results.

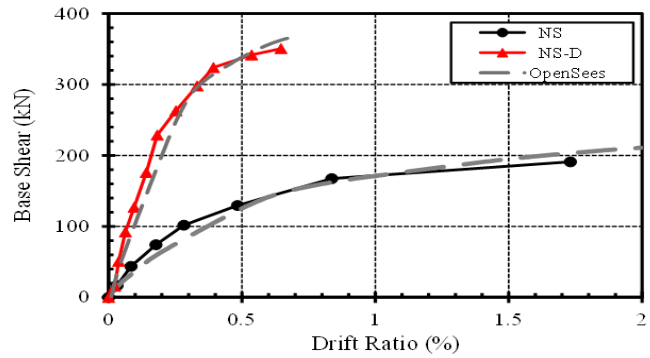


Figure 4. Comparison of experimental result and OpenSees analysis result.

4 SEISMIC PERFORMANSCE EVALUATION OF PILOTI-TYPE BUILDINGS

4.1 Target Building Overview

In order to evaluate the seismic performance of the piloti-type building, multi - family residential building located in Pohang city was selected as the target building. The target building is the 4-story RC ordinary shear wall structure constructed in 2011.

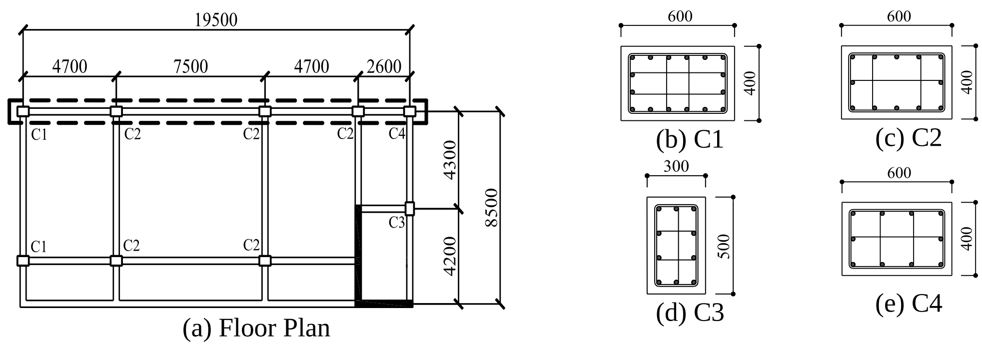


Figure 5. Detail of target building.

4.2 Modeling of Target Building and Reinforcement Overview

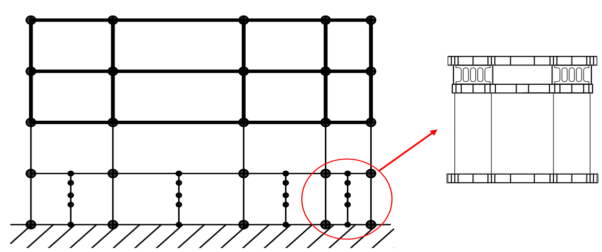


Figure 6. Modeling of piloti-type building and reinforcement overview.

Modeling was carried out to perform computational analysis of piloti-type buildings. In the case of the pillow type building due to the lateral force, the upper wall part behaves almost rigidly and most of the transverse strain is concentrated in the lower part of the frame (Go and Lee 2009). In order to reduce the analysis time and errors, the upper wall part, which is expected to be hardly damaged, is modeled as an Elastic Beam Column member, and the lower frame is modeled in detail with nonlinear beam members. The modeling of the upper wall as an elastic member for the piloti-type building has been proven by previous studies (Lee and Go 2013). Figure 6 is a visualization of the piloti-type modeling.

4.3 Nonlinear Analysis using Seismic Wave

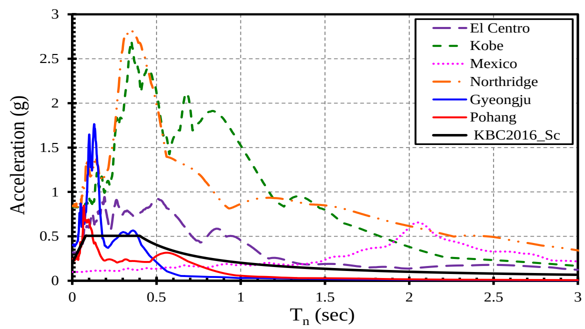


Figure 7. Response spectra of seismic waves with 5% damping ratio in comparison to design response spectrum in Korea (Sc).

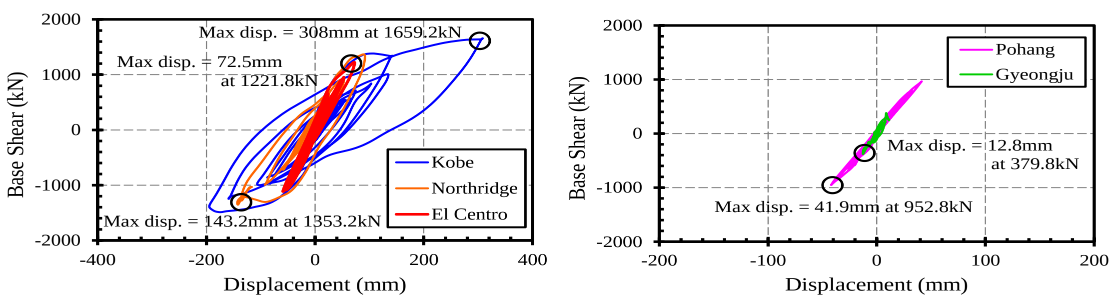


Figure 8. Base shear force- Roof displacement of Piloti-type building.

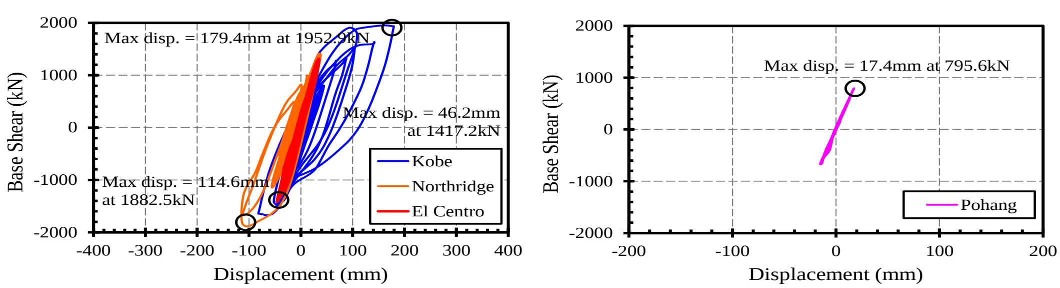


Figure 9. Behavior after reinforcement of piloti-type building.

Recently, the Gyeongju and Pohang earthquakes that occurred in Korea have short - period high frequency characteristics and are different from the earthquake that was used in the study. Figure 7, the response spectra of the Gyeongju and Pohang earthquakes were compared with those of the other earthquake. The nonlinear time history analysis was performed using the Gyeongju earthquake, the Pohang earthquake and the oversea earthquake. Figure 8 is a roof displacement graph for the base shear force of a Piloti-type building with seismic waves. The results of the nonlinear analysis after reinforcement with the steel slit damper are shown in Figure 9. As a result of the reinforcement, the displacement due to the Gyeongju earthquake hardly occurred and the effect of the large displacement was also reduced for the other earthquakes.

5 CONCLUSIONS

1) OpenSees, a structural modeling and analysis program, was used to carry out modeling of the specimen in the same manner as the previous research by Shin *et al*. (2016) and to perform nonlinear static analyses and dynamic analyses.
2) As a result of the response spectrum of Korean seismic waves, it was considered that it will have a short period high frequency characteristic and affect the middle-low story structure.
3) After conducted nonlinear analysis of the piloti-type building, large displacement occurred and reinforcement was performed by using a steel slit damper. As a result of nonlinear time history analysis after reinforcement, the displacement reduction effect was more than 50%.
4) As a result of the analysis, it is judged that proper reinforcement has been done, and additional studies on the modeling method of the slit damper and the seismic strengthening method applicable to the piloti-type building will be need.

Acknowledgments

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