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Shaking table test and numerical analysis of reinforcement concrete frame with a splice-type friction damper using high-frequency response seismic wave

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1. Introduction

Severely damaged cases of the concrete building were reported after the earthquake in Korea. Most damaged issues are mid- to low-rise reinforced concrete structures not designed to be earthquake resistant. It is necessary to properly evaluate and retrofit mid- to low-rise reinforced concrete buildings in Korea. One of the most effective retrofitting methods of the frame is to reinforce it with an X- or K-type brace. Splices using bolts are required in the brace member for construction purposes. The splice could be designed as a friction damper by controlling the bolt tension. A friction damper has a concept that dissipates seismic energy with friction and is economical, simple in structure, and also prevents the buckling of the brace.[1] In this study, the splice is designed as a shear friction damper. The pretension force of bolts are variables from which the retrofitting design is started. Before the shaking table test, the change of bolt tension by loading step and hysteresis behavior of friction damper was evaluated by performing a cyclic loading test.[2] After that, the reinforced concrete frames were retrofitted with diagonal bracing type and chevron bracing type friction dampers, and shaking table tests using artificial seismic waves were performed. Finally, an analysis model of the friction damper was proposed based on the experimental results.

2. Shaking Table Test

In order to understand the dynamic response characteristics of a reinforced concrete frame with non-seismic details and retrofitted with friction dampers, a dynamic test was performed at the Earthquake Disaster Prevention Research Center, which is certified by internationally accredited organizations KOLAS and KEPIC.

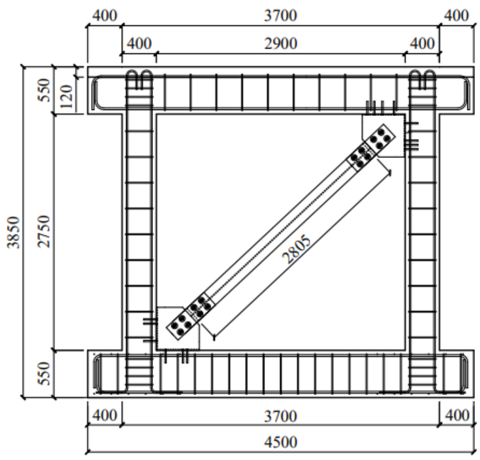
2.1 Test specimens

This study considered a 1-story and 1-span RC frame specimen with a non-seismic(NS) design. The net height of the column is 2750mm, and the net span of the T-beam is 2900mm. Table 1 is the list of specimens retrofitted with friction dampers. The friction dampers designed in this study are located at the lower part of the frame, considering maintenance. Figure 1 shows the details of retrofitted specimens. The steel grade of H-beam (H-200×200×8×12)and steel plate(10t) is SS275, and they were friction-bonded using high-tension bolts M20 (F10T).

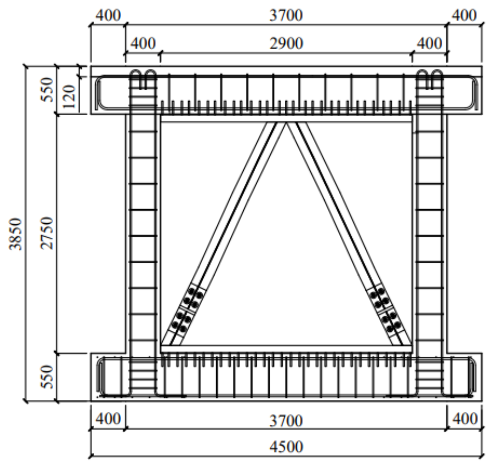
Table 1. List of specimens

No.	Specimens	Brace type	μ	T_i (kN)	N_s	$øR_n$ (kN)
1	NS	-	-	-	-	-
2	NS-DF-25%	Diagonal	0.4 (Mile scale)	40	2	195
3	NS-DF-40%			65		312
4	NS-VF-20%	Chevron		30		144 (2EA)

Note : μ = coefficient of friction surface, T_i = pretension force of bolts, N_s = number of the shear surfaces, $øR_n$ = design strength of friction



(a) NS-DF specimen



(b) NS-VF specimen

Figure 1. Details of a retrofitted frame by splice-type friction damper

2.2 Seismic input

In order to evaluate the dynamic behavior of the test specimen for the seismic wave with high-frequency response characteristics, artificial seismic waves similar to the response spectrum for S4 ground, seismic grade 1 standard, and 5% damping ratio suggested by the KDS 41 17 Seismic Design Standard was created. The maximum PGA is 0.236 g, and the intense earthquake duration is about 20 seconds. The shaking table test was carried out in stages from 50% to 350% of earthquake acceleration, and in this paper, the excitation results of more than EQ 100% were summarized.

2.3 Experimental results

As can be observed in Figure 2, retrofitted frames have a large initial stiffness to prevent significant relative displacement. The NS specimen behaves nonlinearly, but all retrofitted specimens behave within the elastic range at the hysteresis loop for the 200% excitation. Figure 3 shows the frequency spectrum of the specimens. The initial natural frequency of the RC frame was 4.23Hz. Damage to the frame occurred after 80% excitation, and the natural decreased. The initial natural frequency of the retrofitted specimens was about 7.5Hz and dropped to about 4.8Hz after EQ 250% or 350% excitation.

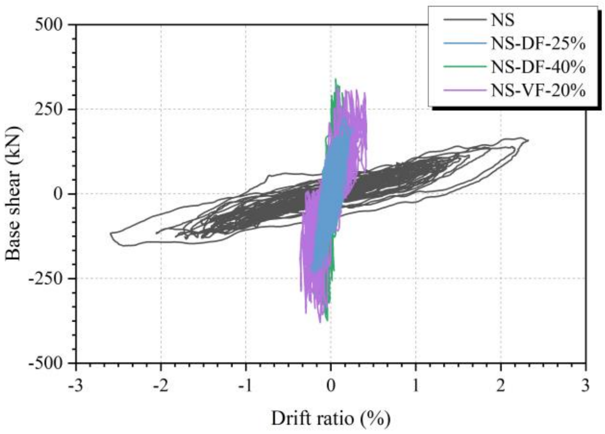


Figure 2. Dynamic test result at EQ 200%

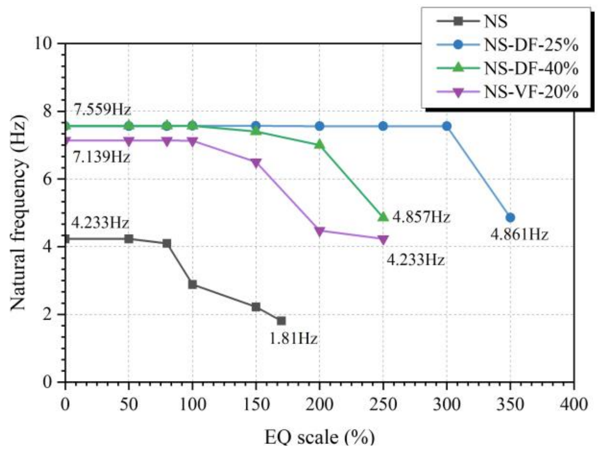


Figure 3. Response frequency of specimens

3. Numerical analysis

3.1 Modeling of specimens

For the numerical analysis model of the RC frame, the modeling method that has proven reliable in previous studies was applied in the same way, and it was performed as a two-dimensional analysis without out-of-plane buckling.[3] As the material model, Concrete02 and Steel02 materials provided by OpenSees were used and inputted in the same values as the material test results in Table 2, 3. The interaction between axial force and bending moment is reflected by entering the exact cross-section details using fiber section models.[4] The hysteresis loop of the friction damper is expressed by connecting BoucWen and steel 02 materials in parallel. [5]

Table 2. Result of compressive test

Cylinders	Compressive strength (MPa)
A	16.8
B	16.4
C	16.9
D	17.3
E	16.7
F	17.0
Average	16.9

Table 3. Result of tensile test

Coupon	Yield strength (MPa)		Tensile strength (MPa)	
	Measured	Average	Measured	Average
D10	410.5	403.4	516.5	514.5
	408.9		514.9	
	390.9		512.1	
D16	518.7	521.2	649.6	650.5
	523.2		650.5	
	521.7		651.5	
D22	503.0	503.3	639.8	638.1
	492.2		628.7	
	514.8		645.8	
H-beam (12t)	282.4	282.2	427.4	428.0
	282.2		428.6	
	282.1		428.1	
Steel plate (10t)	275.3	274.6	443.5	441.5
	280.6		445.3	
	268.0		435.8	

3.2 Nonlinear static analysis

Push-over analysis was performed to evaluate the reliability of the analysis model and to identify the limit state of each specimen. A comparison of the results of the nonlinear static analysis and the back-bone curve obtained through the experiment is depicted in Figure 4. The initial stiffness and maximum strength of the analytic model were very close to the test results.

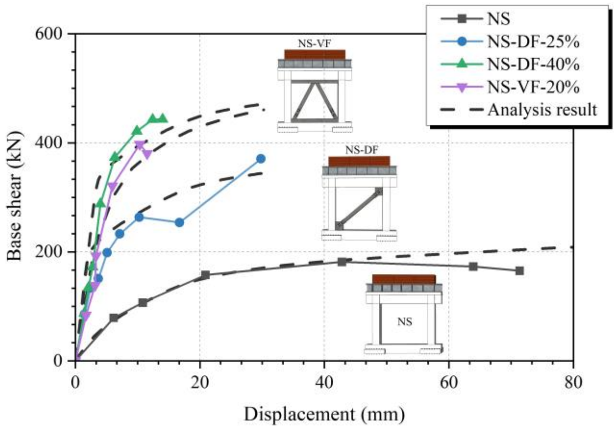


Figure 4. Comparison of back-bone curve and push-over analysis result

4. Conclusions

In this study, a shaking table test was performed to analyze the dynamic response characteristics of the RC frame with a splice-type friction damper at a high-frequency seismic wave, which has a similar response to Korean seismic waves. After that, the reliability of numerical models was evaluated by comparing them with the experimental results. The RC frame retrofitted with friction dampers had sufficient stiffness and strength retrofit effects. However, for the effective behavior of the friction damper, it should be designed that the appropriate section of steel brace and pretension force of bolts according to the strength of the RC frame.

Acknowledgments

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REFERENCES

[1] Pall A.S., Marsh C. (1982) Response of friction damped braced frames, Journal of Structural Engineering, Vol. 108, Issue 6, pp.1313-1323.

[2] Shin, H.M., Lee, H.D., and Shin, K.J. (2019) Measurement of Bolt Tension of Friction Damper Using Manufactured Load Cell, *Journal of Korean Society of Steel Construction*, KSSC, Vol.31, No.3, pp.171-178 (in Korean).

[3] Shin, K.J., Lee, S.-H., Lee, H.-D., and Kwon, H.-S. (2016) Seismic-Strengthening Effect of Steel Shear Wall with Circular Opening Through Shaking Table Test on Reinforced Concrete Frame, *Journal of the Architectural Institute of Korea – Structure & Construction*, AIK, Vol.18, No.2, pp.107-114 (in Korean).

[4] Pacific Earthquake Engineering Research Center (2009) *Open System for Earthquake Engineering Simulation (OpenSees)*, http://opensees.berkeley.edu.

[5] Tirca L. (2015) Friction Dampers for Seismic Protection of Steel Buildings Subjected to Earthquakes: Emphasis on Structural Desing, Encyclopedia of Earthquake Engineering, Springer, pp.1058-1070.