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# FULL SCALE SHAKING TABLE TEST OF A 3 SYORY STEEL FRAME WITH FRICTION DAMPERS

Chun Hee Bae*[1], Kyeong Hyeon Yang [1], Cheul Hwan Cho [1,] and Yeon Whan Kim [1]

[1] Korea Electric Power Research Institute, 103-16 Munji Dong, Yuseong Gu, Daejeon , Korea
chbae@kepri.re.kr

Energy dissipation devices can be considered as an alternative for the performance enhancement of existing structures based on the strengthened seismic design code. In this study, the seismic response mitigation effect of friction dampers is investigated through the shaking table test of a full scale 3 story building structure. First, the bilinear force-displacement relationship of a structure-brace-friction damper system and the effect of brace-friction damper on the increase of frequency and damping ratio are identified. Second the frequency, displacement , and torque dependences are investigated using harmonic load excited small friction damper. Finally. the shaking table test are performed for the full scale building. System identification results using random signal excitation indicate that brace-friction damper increases structural damping ratio and frequency, and EL Centro earthquake test show that brace-friction damper reduces the peak displacement and acceleration significantly . In particular the damping effect due to friction damping becomes obvious when the structure is excited by more intensive load causing frequent slippage of the friction dampers

## INTRODUCTION

Recently, the advanced design method of earthquake is required by the big loss of structure in earthquake at U.S.A, Twian, and Japan . The design report of earthquake based on the performances as ATC-40, FEMA-273, etc. present the various advanced method as like the strength increasing of structure, the improvement of strain capacity at structure, and the using of device of dissipating earthquake energy[1,2] . In these methods the using of device dissipating earthquake energy efficiently reduced the dynamic response as increasing the damping ratio of structure. Also because this method is easy and cheap to settle it largely is used to the established and new building[3-5]. The vibration level of the important facility of nationality as like power plant and electric tower must is limited to lower of safety level regardless of the vibration characteristic as like the wind and mechanical vibration. In particular,

because the damage of power plant is great by earthquake energy we must minimize its damage.
Consequently, the main contribution of this paper is applying friction damper, the device dissipating earthquake energy, to the vibration control of a built structure and new building including the power plant. In order to undertake this, the pulley friction damper is designed and manufactured. Subsequently, a lsrge-sized building in similar to real power plant is adopted and the performance test of the friction damper is worked as vibrating EL Centro earthquake to the structure with damper. As result of this test it is demonstrated that the earthquake response of building is greatly improved.

## SYSTEM OF STRUCTURE-BRACE-FRICTION DAMPER

### Relation of force-displacement

Figure 1 shows the relation of force-displacement in the combined system of structure, friction damper-brace, and structure-friction damper-brace. The structure is assumed in elastic state as showed in figure 1(a). Figure 1(b) shows the relation of force-displace -ment of structure with structure-brace. As we see in this figure the force delivered to the structure is worked by elastic restoration force when the friction damper don't slip and the constant force is worked to the structure after was happened to slipping to structure-brace system. And figure 1(c) shows that the the relation of force-displace -ment in the combined system of structure-brace-friction damper is hybrid motion[6,7] . Here $k_f$, $k_b$, $f_{slip}$ shows the structure stiffness, the brace stiffness, and the slip load of friction damper, respectively. The system with brace-friction damper increase the initial stiffness of system and can dissipate the input energy by earthquake by bilinear movement in case of working the more load than constant load. That is, as the system of brace-friction damper is installed to the structure, the structure can increase the natural frequency and the damping ratio according to the enlargement of its initial stiffness.

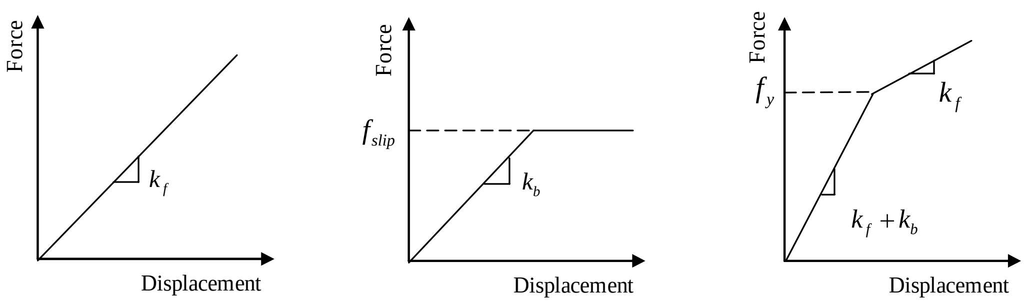


***Figure 1 Relation of force-displacement***

The equivalent strength of combined system , $f_y$, can show as follow

$$f_y = f_{slip} + k_f d_y = f_{slip} + k_f \frac{f_{slip}}{k_b} = f_{slip} + \frac{f_{slip}}{SR} \tag{1}$$

Here, SR is the ratio of brace stiffness to structure stiffness. Equation (1) shows that the yield-load of combined system approach to the slip-load of friction damper and the yield-displacement is small as the brace stiffness increase .

## Harmonic load analysis

Figures 2 and 3 show the peak displacement and absolute acceleration under sine exciting SDOF system with one second period and 5% damping . Figure3 indicates that the natural frequency of structure increase with the added stiffness by brace. Also figure 3 show that if SR, the ratio of brace strength to structure strength increase the natural frequency of system increase as showed figure 2. But the brace system without increasing damping is not effect to the acceleration response. Instead it increase the maximum acceleration response in resonance field. But the brace system with friction damper reduce the acceleration response in resonance field in addition to varying forcing frequency as dissipating the energy of system.

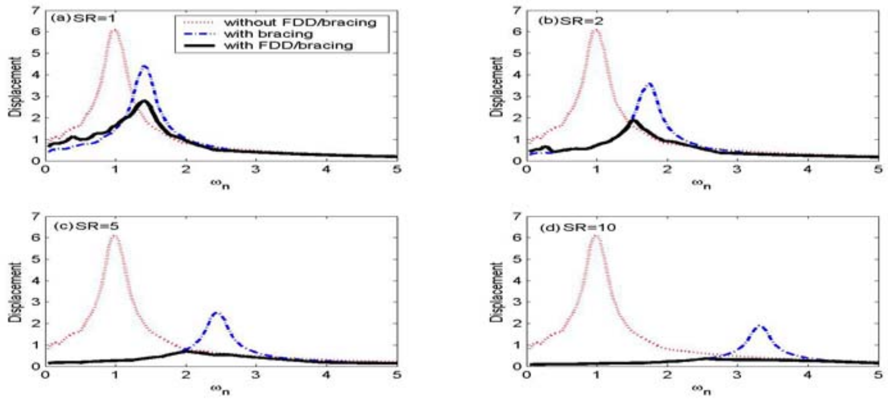


***Figure 2 Maximum displacement response under harmonic load***

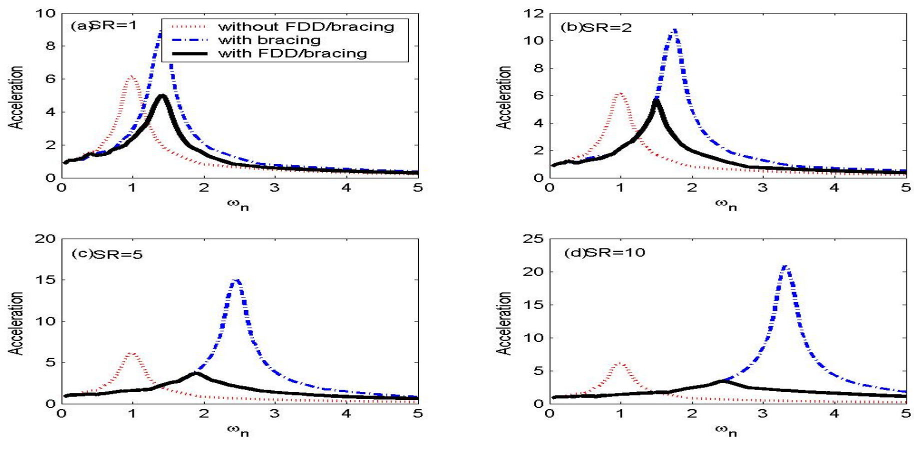

*Figure 3 Maximum acceleration response under harmonic load*

## LABORATORY TESTS

Figure 4 displays laboratory cyclic test of a damper device with a basic configuration at the KEPRI in Daejeon . Various parameters were considered like the displacement amplitude, the frequency of the excitation, the bolt clamping force and the number of the loading cycles. In the cycle test the effectiveness of several frictional material were also investigated. The best material capable of sustaining up to 400cycles without any property degradation was chosen for the further extensive investigations where the damper device were installed in a 1/3 scale portal frame model . The hysteresis curves in figure 5 indicate that within the considered frequency range between 2 Hz to 6Hz the amount of dissipated energy per cycle was almost frequency independent. The damping energy per cycle was proportional to the excitation amplitude.

*Figure 4 Laboratory test*

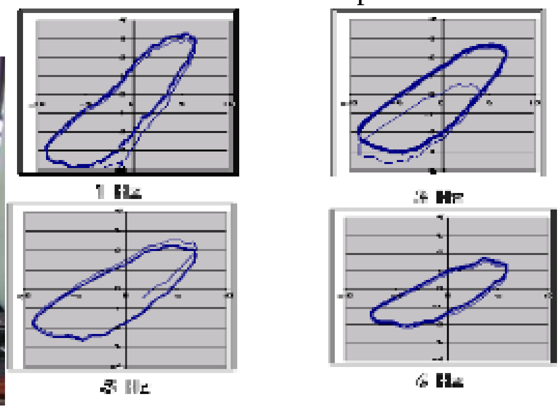

*Figure 5 Hysteresis curves of the damper*

## FULL SCALE SHAKING TABLE TESTS

In order to verify the effectiveness of the damper devices in a full scale structure shaking table tests were performed during 3 months of 2004 in KIMM in DAEJEON, KOREA. The test model has a steel moment-resisting frame structure with 2.0m story height and 4.5m bay in the direction of shaking. Figure 6 displays the set up the full scale investigation. Two damper devices in each storey were installed in plane of the shaking direction. The brace members consists of 20mm diameter round steel bars pin connected to the damper plates and frame joints. The column and girder cross sections are I $150\times150\times8\times12$ and $150\times100\times6\times9$, respectively. The columns are fixed at their bases and the beam –to-column joints are welded . Due to the fact that the columns resist bending about the minor axis of their cross sections , the structure is relatively flexible in the direction of testing, and the frequency of the natural vibration and the damping in the shaking direction is 1.418Hz, 1.15%, respectively. Heavy concrete blocks are used to simulate the floor weights. The total mass of the frame structure including the auxiliary base parameter frame was 32ton. Displacement and acceleration were measured by displacement transducers and accelerometers attached

to base and each floor level. Strain gages were also mounted at base level locations in the columns. The size of the shaking table is 4m×4m. The facility can simulate a ground excitation up to 3g. Altogether 4 cases of ground excitation with maximum ground acceleration ranged from 0.05g to 0.14g were considered.
The consecutive tests with an increasing peak ground acceleration of 0.01g, 0.05g, 0.125g, and 0.14g were performed without readjusting the bold clamping forces. Table 1 shows the maximum responses displacement at each storey without and with damper devices. The considered peak ground excitation was 0.14g. The shaking table tests showed that a reduction of structural vibration up about 80% could be achieved. Figure 6 shows the time histories of the roof displacement in case of a shaking intensity of 0.14g

*Figure 6 Evaluation of the shaking table test*

*Table 1 Effectiveness of the friction damper, 0.14g*

| Story no. | 1 | 2 | 3 | Strain |
|---|---|---|---|---|
| Displacement[mm] Without damper | 14.4 | 27.6 | 38.0 | 205 |
| Displacement[mm] With damper | 2.85 | 5.9 | 7.58 | 34.4 |
| Reduction(%) | 80 | 79 | 80 | 83 |

The results of the large-scale experiment are used for a verification of the finite element model. The braces are modelled by tension-only links with initial pre-stressing force. The modal damping ratios for the first and second vibration modes are set to 8.26%, 3.53%, respectively. Figure 7 shows that with the current numerical model the experiment response can be predicted.

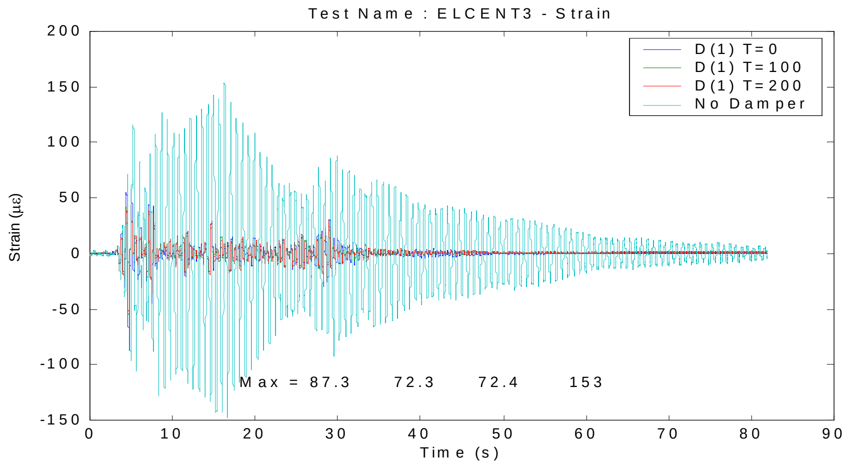


*Figure 7 Strain histories, 0.14g*

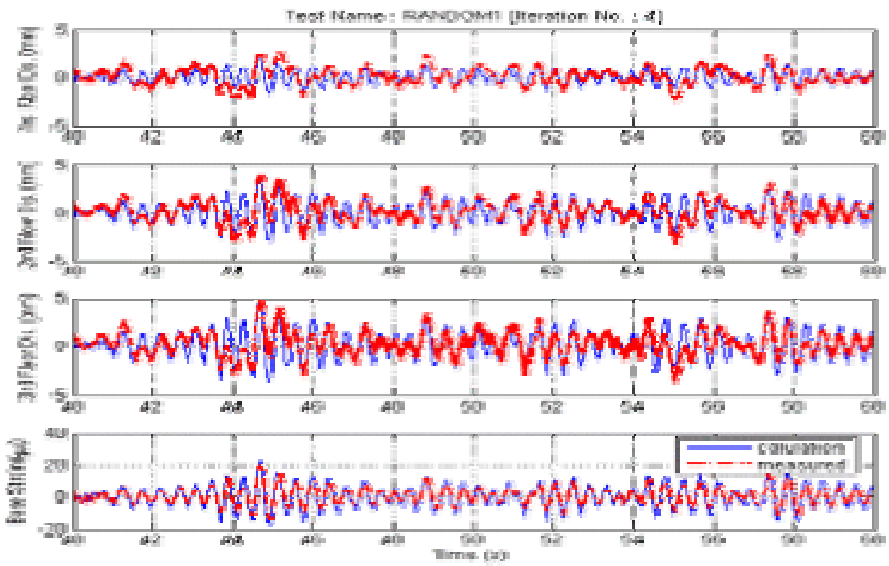

*Figure 8Roof displacement of friction damper frame, 0.14g*

## CONCLUSIONS

In this paper, results of full-scale shaking table experimental testing of a pulley friction damper device developed recently at the KIMM are presented. Previous cyclic tests on a scaled frame model have indicated that the new pulley friction is frequency independent in the 2-6Hz range and its energy dissipation capacity is proportional to the story drift amplitude and bolt-clamping force. The rigorous full-scale testing at the shaking table facility of KIMM proved the excellent capability of the proposed damping system to significantly reduce the earthquake-induced building vibrations. During the series of 10 shaking table tests, no damage occurred to the dampers , bracing bars, frame members and connections. The proposed friction damper devices is easy to manufacture and implement in structures. Its first full scale-application was promising in terms of speed of installation. The seismic protection based on passive energy dissipation eliminate the tight demand for structural ductility and allows for preventing structural and non-structural damage. Thus an alternative to the conventional ductility-based earthquake-resistant design is made possible both for new construction and for upgrading existing structures

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