Static Loading Tests of Column Mid-height Uplift Mechanism with Steel Dampers

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Summary

Observations from past earthquakes suggest that rocking motion can be beneficial for buildings to survive severe ground motions. Such observations motivated the development of rocking frames that are provided with a mechanism that allows column mid-height uplift (CMU). This paper describes an experimental study on the seismic performance of the CMU mechanism accompanied by dampers. The proposed CMU device behaved as expected, exhibiting sufficient stiffness and strength in shear while permitting free uplift motion. The dampers comprising honeycomb steel sheets exhibited excellent ductility and energy dissipation capacity.

Keywords: Seismic; Rocking frame, Column mid-height uplift, Steel damper, Static loading tests; Cyclic loading

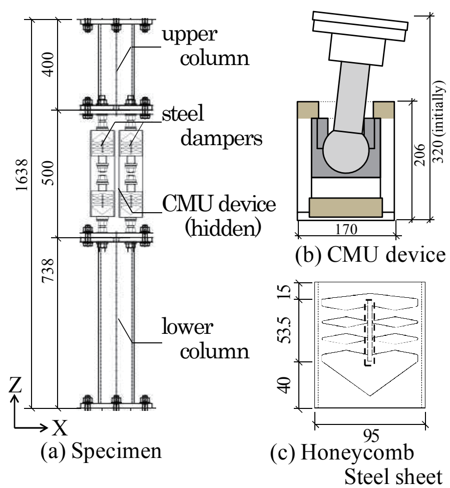
1. Introduction

Observations from past earthquakes suggest that some buildings survived severe ground motion because of accidental uplift at their foundation. Motivated by such notion, the writers developed rocking systems that are provided with a mechanism that permit column mid-height uplift (CMU). The CMU mechanism shall fully resist shear forces and generally be accompanied by steel dampers. Conceptually, the CMU rocking system can reduce story drift of the first story compared to the column-base uplift (CBU) system because the CMU system forces double-curvature bending of the first-story columns while the CBU system forces single-curvature bending. One-third scale specimens were subjected to static cyclic loading to examine the load transfer mechanism of a proposed CMU device and the hysteretic behaviour of steel specialized dampers.

2. Test Plan

The 1/3-scale specimen (Fig. 1a) comprised an upper and lower part of the column, a CMU device (Fig. 1b), and four steel dampers. The steel damper comprised a honeycomb steel sheet (Fig. 1c) screwed to a steel cage at the two sides and welded to an anchor bolt in the middle. A total of seven specimens were constructed and tested. Three specimens used a 3.2-mm, normal steel, SGH400, for the honeycomb sheets while the other four used a 2.6-mm, low-yield-point steel, SPCE.

The specimen was fixed to a strong beam and loading beam at the bottom and top, respectively. Three different loading protocols were used: (I)



(a) Specimen
(b) CMU device
(c) Honeycomb Steel sheet

Fig. 1 Specimen

monotonic vertical-only loading; (II) cyclic, vertical-only loading; and (III) cyclic, transverse-plus-vertical loading. The biaxial loading protocol (III) included cases where the transverse direction was taken in the X-direction or Y-direction. Vertical displacement in Z was introduced proportionally to the transverse displacement only when the transverse displacement (in X or Y) was positive.

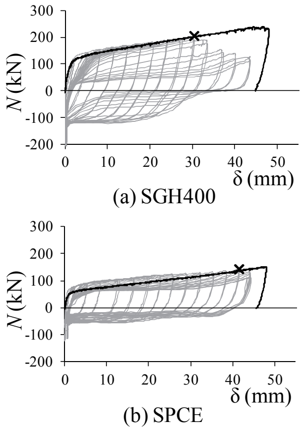
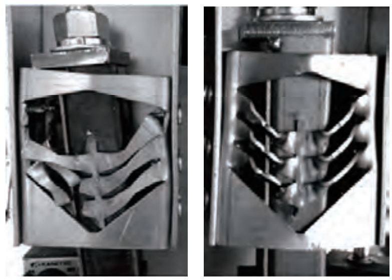


Fig. 2 Vertical Response

3. Test Results

Fig. 2 shows the relationship between axial load, N, and elongation of the CMU device, δ, obtained from four specimens. Each figure overlays a cyclic loading response over a monotonic loading response of the same steel material. The "X" mark indicates the stage when a crack was first noticed in the honeycomb sheet. The cyclic-loading curves were enveloped by the corresponding monotonic curve in the earlier stage of the test, but discrepancy increased as the hysteretic curve gradually narrowed in cyclic loading. The discrepancy was notably larger in the SGH400 dampers than in the SPCE dampers.

Fig. 3 shows photographs of the honeycomb sheet at the end of the test. Fig. 3a and b show the cyclically loaded SGH400 and SPCE sheets from the same specimens plotted in Fig. 2.The damper failed by fracture at the ends of the honeycombs or out-of-plane distortion of the honeycombs. Fracture was more prominent in the SGH400 sheets while out-of-plane transformation was more prominent in the SPCE sheets. Comparing the cyclically loaded specimens in Fig. 2, the SGH400 dampers developed larger strength than the SPCE dampers during early cycles. However, cracking in the honeycomb occurred earlier and developed more ralidly in the SGH400 dampers. As a result, the cumulative dissipated energy at the end of the test was nearly equal between the SPCE and SGH400 dampers.



(a) SGH400 (b) SPCE

Fig. 3 Steel dampers at end of test

Fig. 4 plots the maximum (positive and negative) transverse load, H, measured at each transverse displacement amplitude for the cyclically loaded specimens. Transverse displacement refers to the relative horizontal displacement measured between the top and bottom of the column, Δ, or the CMU device, Δ_d. The CMU device possessed sufficient stiffness and strength in shear when the piston and cylinder disengaged.

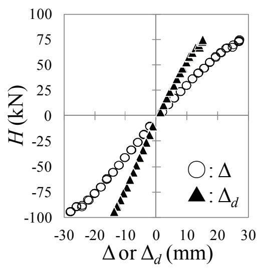


Fig. 4 Peak transverse force

4. Conclusions

A series of 1/3-scale tests were conducted on the proposed CMU device accompanied by steel dampers. The steel dampers used honeycomb steel sheets of either SGH400 or SPCE. Key observations are summarised in the following.

1. The CMU device can transmit shear forces while permitting smooth uplift motion. The steel dampers dissipated ample energy in proportion to the amount of uplift in the CMU device.
2. The SGH400 sheet dissipated larger energy than the SPCE sheet during the earlier stage of the loading, due to larger strength. However, cracking of the honeycomb sheet progressed more rapidly. The cumulative dissipated energy at the end of the test was similar between the two steel types.