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Development and Testing of Cored Moment Resisting Stub Column Dampers

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ABSTRACT

Moment resisting stub columns (MRSCs) have increasingly adopted in special moment-resisting frame (SMF) systems in steel building structures, especially in Asian countries. Typical MRSCs usually give a lower deformation capacity compared with shear-panel stub columns, a limited post-yield stiffness, and severe strength degradation as using slender webs. A design of the cored MRSC, consisting of one core-segment and two side-segments using different steel grades, has been proposed in the study to reduce the mentioned demerits above. Several full-scale specimens of the proposed cored MRSC members has first been tested focusing on the hysteretic performance of the end plastic hinges. The effects of the member sizes of the core segment and the reduced column section details on the hysteretic behavior of the members were experimentally examined. The hysteretic performance of the cored MRSC is verified to achieve early yielding, great energy dissipation, enhanced post-yield stiffness and mitigated strength degradation caused by local buckling of flanges. A numerical model of the cored MRSCs was established and validated by the test responses prior to be adopted for a parametric study. Finally, an equation-based estimation method of the force-to-displacement relationship of the cored MRSCs in high accuracy has been established.

1. INTRODUCTION

Special moment-resisting frame (SMF) have been commonly used in building structures as a seismic load resisting system all around the world. The SMF provides a relatively flexible behavior compared to braced frames and shear-wall frame systems, and therefore it has usually been combined with various types of damper devices to improve its seismic performance by increasing either overall stiffness, strength or energy dissipation of the system. Installing stub columns (SCs) in the SMF gives an alternative solution with many benefits such as to increase overall stiffness and strength for resisting seismic loads and to give low impact on architectural versatility in the building.

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Various design details of SCs have been developed to achieve energy dissipation, and they can be categorized into two groups, including shear panel and moment-resisting types (Fig. 2). The MRSC with medium-to-large strength capacity usually requires large web slenderness ratio which potentially leads to severe strength degradation beyond the formation of plastic hinge and reduced ductility as illustrated in Fig. 3.

Furthermore, both of SPSC with shear plastic hinges and MRSC with moment plastic hinges provide very limited post-yield stiffness except the strain hardening effect. Greater post-yield stiffness of structural systems or stub columns was found to benefit the reduction of seismic responses of structural systems beyond the formation of plastic hinges (Ye et al. 2008).

To improve the drawbacks mentioned above, this study proposes an alternative design of MRSC with a cored configuration which is referred to as cored MRSC hereinafter, as illustrate in Fig. 4. The design consists of (a) a combination of core and side segments using different steel grades, and (b) detailing of RCSs (Fig. 4) to achieve a hysteretic behavior having (1) earlier energy dissipation, (2) enhanced post-yielding stiffness, (3) improved ductility and (4) postponed and mitigated the strength degradation beyond plastic hinge formation compared to the typical MRSCs, as illustrated in Fig. 3.

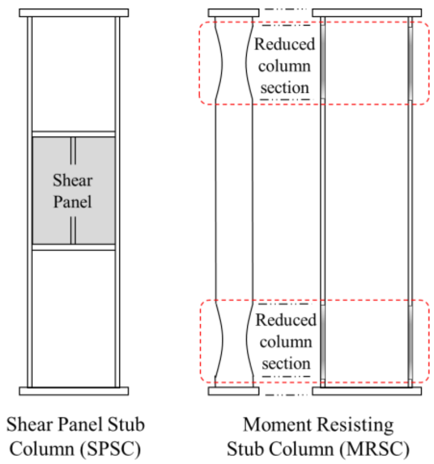

Fig. 2 Two types of stub columns.

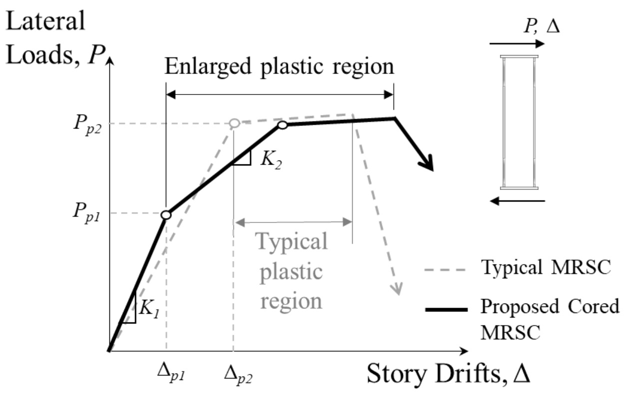

Fig. 3 Strength backbone curves of hysteretic behaviors of typical and proposed cored MRSCs.

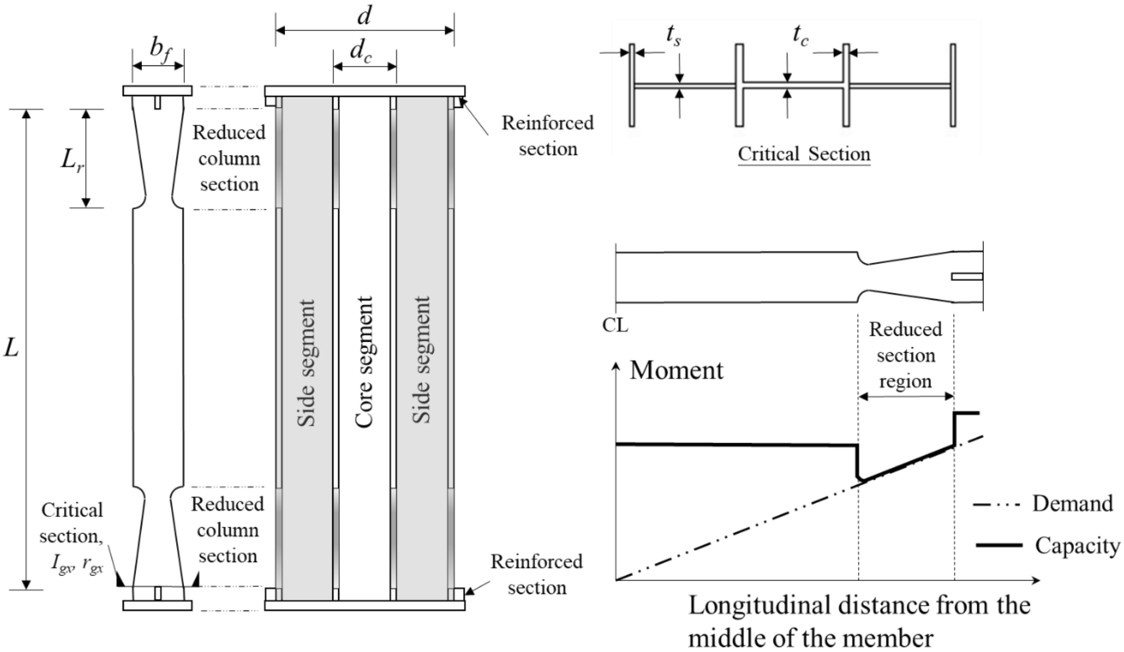

Fig. 4 Illustration of the proposed cored MRSC with the detailing of RCSs.

2. Design and Basic Mechanism of the Cored MRSCs

The cored MRSC provides a hysteretic behavior with two plastic strength capacities, i.e. two-phase plastic moment capacities at the critical section as shown in Fig. 4, and forms a tri-linear strength backbone curve, as illustrated in Fig. 3 comparing with that of the typical MRSCs. The first plastic moment capacity, M_{p1}, can be estimated by Eq. 1 below based on the stress distribution of the cross section as the side segments are fully yielded, and the flange surface of the core segment just reaches the yield strength of steel used for the side segment, $F_{y,s}$, as depicted in Fig. 5.

$$M_{p1} = F_{y,s}(Z_{x,s} + S_{x,c}) \tag{1}$$

The second plastic moment capacity, M_{p2}, can be estimated by Eq. 2 below based on the stress distribution of the cross section as the side segments are fully yielded and have developed its strain hardening ($C_h F_{y,s}$), the flanges of the core segment are fully yielded, and the web of the core segment just reaches its yield strength ($F_{y,c}$), as depicted in Fig. 5.

$$M_{p2} = C_h F_{y,s} Z_{x,s} + F_{y,c}(Z_{x,cf} + S_{x,cw}) \tag{2}$$

Two plastic moment capacities of the critical cross sections, which locate at intersections of the RCS and the reinforced section regions as shown in Fig. 4, can be further transferred to the corresponding lateral plastic load capacities of the member, P_{p1} and P_{p2}, the member length (L) by Eqs. 3 and 4, respectively.

$$P_{p1} = \frac{2M_{p1}}{L} \tag{3}$$

$$P_{p2} = \frac{2M_{p2}}{L} \tag{4}$$

3. Experimental Program

A pilot experimental program has been conducted to examine the proposed cored MRSCs focusing on the mechanism and hysteretic performance of the end plastic hinges. Full-scale specimens of the cored MRSC in half, including the end connection and the RCS details, were tested assuming the strength-to-deformation behavior of the stub column is symmetric about the inflection point locating right in the middle of the stub column. Figure 6 shows the adopted test setup in the study with a photo of an installed specimen.

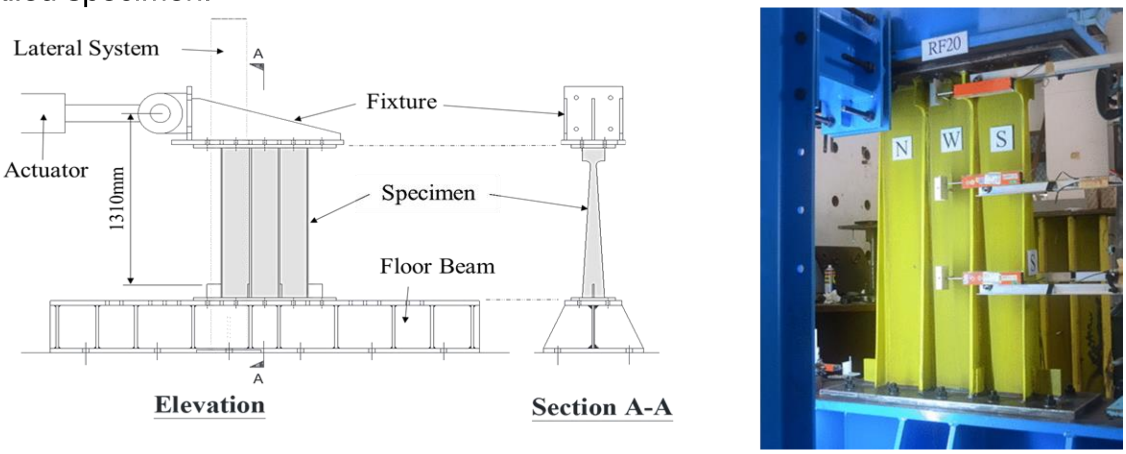

Fig. 6 Elevations and a photo of adopted test setup in the experimental program.

4. Numerical Simulations

A general discrete model was developed in OpenSees frameworks (Mazzoni et al. 2006) to simulate the cyclic behavior of the cored MRSCs. The developed model was first validated by the experimental results before adopted to perform a parametric study in the study.

5. Parametric Analytical Study

A parametric analytical study was performed using the developed numerical model mentioned above to establish the equations of estimating the initial and post-yield stiffness of the cored MRSCs which is difficult to estimate due to the complex geometries and mechanism. The analytical strengths ($P_{p1,ana}$ and $P_{p2,ana}$) and stiffness ($K_{1,ana}$ and $K_{2,ana}$) were then obtained based on the tri-linear curve formed by the tangents of the strength backbone as shown in Fig. 15.

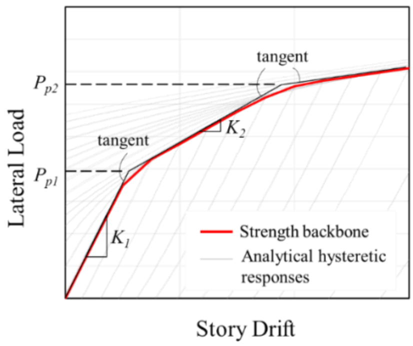

Fig. 15 Illustration of the method of obtaining stiffness and plastic strength capacities upon analytical results.

Regression analyses were performed to establish the empirical equations of estimating the initial stiffness (K_1) and the post-yield stiffness (K_2) individually based on the analytical responses in the parametric study. Equations 5 and 6 show the regression results for the initial stiffness (K_1) and the post-yield stiffness (K_2) in the SI unit of tonf/mm, respectively.

$$K_1 = 0.13\left(\frac{12EI_{gx}}{L^3}\right)\left(\frac{L}{r_{gx}}\right)^{0.83}\left(\frac{2L_r}{L}\right)^{-0.08}\left(\frac{d_c}{d}\right)^{0.39} \quad (5)$$

$$K_2 = 0.24\left(\frac{12EI_{gx}}{L^3}\right)\left(\frac{L}{r_{gx}}\right)^{0.39}\left(\frac{2L_r}{L}\right)^{-0.23}\left(\frac{d_c}{d}\right)^{1.33} \quad (6)$$

6. Summery and Conclusions

- The mechanics of the proposed cored MRSCs has been experimentally verified. It is shown that the side segments enable to provide early yielding and great energy dissipation, while the core segment mostly remains elastic without the occurrence of flange local buckling to thereby enhance the post-yield stiffness and mitigate strength degradation of the member due to local buckling of the flanges.
- The effect of the core-segment depth was clarified upon the experiments. Adopting deeper core-segment is verified to enhance overall stiffness and strengths of the member but reduce cumulative plastic deformations. In contrast, the member with shallower core-segment provides lower overall stiffness and strengths but significantly increases its cumulative plastic deformations.
- A discrete model was established and validated by the cyclic responses of the specimens in the study, which is a general model and therefore could be applied to predict the hysteretic performance of the cored MRSCs in various dimensions.
- A set of physical model equations of estimating the lateral plastic load capacities (P_{p1} and P_{p2}) was proposed and verified by the measured results of all specimens as well as the developed numerical model in the study.
- A set of regression equations was established to accurately estimate the initial and post-yield stiffness (K_1 and K_2) of the cored MRSCs upon the results of the parametric study using the developed discrete model considering a wide range of geometric parameters. An equation-based estimation method of lateral force-to-displacement relationship of the cored MRSCs has thereby been completed to form an essential basis for developing the cored-MRSCs design procedures as the future work.

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