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EXPERIMENTAL STUDY ON SEISMIC PERFORMANCE OF FRICTIONAL HYBRID COUPLED WALL SYSTEMS WITH FRICTIONAL STEEL TRUSS COUPLING BEAMS

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1 INTRODUCTION

Coupled walls are widely used in mid- to high- rise buildings. The coupling beams couple two or more RC walls in series, and transfer vertical forces between adjacent walls to resist a portion of total overturning moments. The coupling action reduces the moment demands of individual wall piers, dissipates energy through inelastic deformations of coupling beams over the building height and provides larger lateral stiffness than the sum of its component wall piers[1]. However, the very deep RC beams may suffer brittle shear failure in earthquakes, which poses a risk to the life safety. In addition, the damaged RC coupling beams are difficult to repair and may render the whole building irreparable.

To mitigate these problems, we proposed an alternative frictional truss coupling beams (FTCBs)[2-3] to RC coupling beams. The FTCBs have several benefits, such as full and stable hysteretic behavior, damage control and rapid repair. The force and deformation mechanisms and formulae of strength and stiffness of FTCBs have been validated by component-level quasi-static tests. As shown in Fig. 1, the FTCBs can rotate about the top flange plates and thus adapt to slab deformation, while concentrate inelastic deformations in the replaceable friction dampers placed at the ends of bottom chords. The damper belongs to Asymmetric Friction Connections (AFCs), which slide sequentially between the bottom flange plate and the bottom chord flange, and then between the bottom flange plate and the cap plate. In addition, the limiting shear strength and initial stiffness of FTCBs can be separated designed by stable sliding strength of friction dampers and cross-sectional area of truss members.

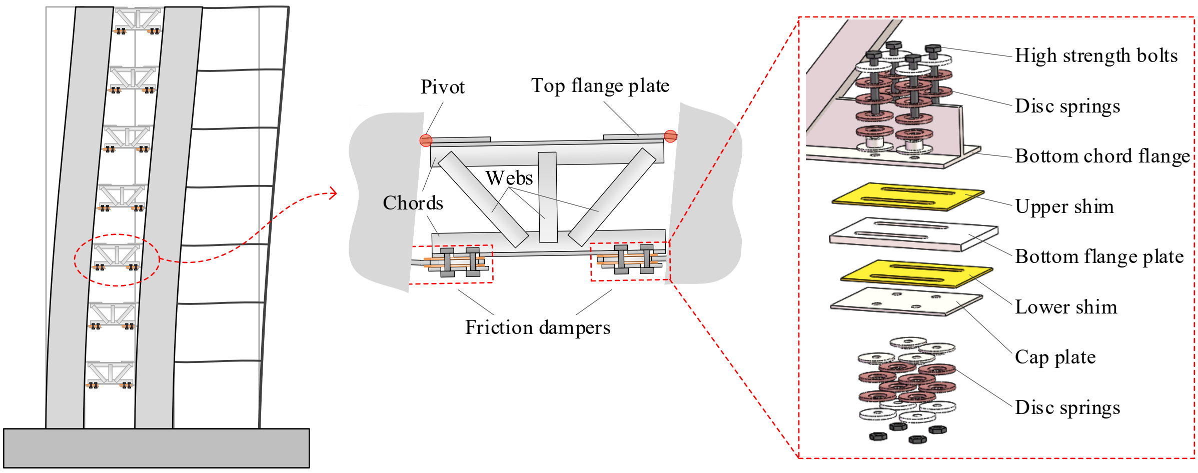


Figure 1: Frictional truss coupling beams (FTCBs)

The FTCBs and concrete wall piers form a hybrid coupled wall system. To validate the seismic performance of the hybrid system, a large-scale substructure quasi-static test was conducted. Fig. 2 shows the performance objectives of the hybrid coupled walls. The system remains elastic at design basis earthquakes with a probability of exceedance of 10% in 50 years. The first and second slides are activated at maximum considered earthquake (MCE) and very rare earthquake (VRE), respectively. Beyond the VRE, the wall piers shall yield at the bottom and finally suffer bending failure.

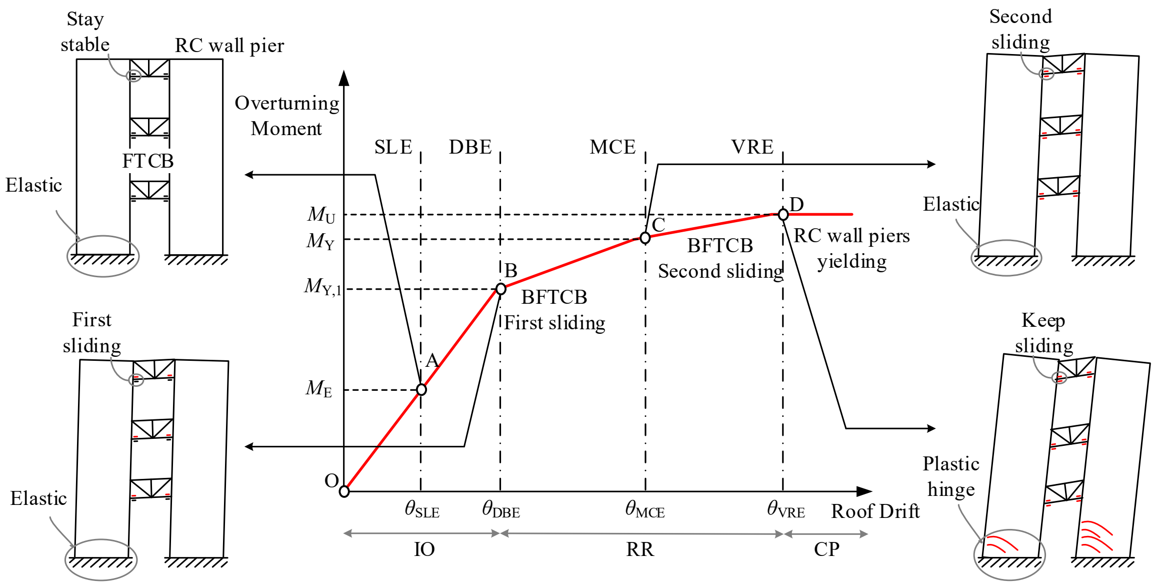


Figure 2: Performance objectives

2 EXPERIMENTAL PROGRAM

2.1 Test Specimen

The specimen was designed based on a practical project of 24-story frame-shear wall dual system. As shown in Fig.3, the RC coupling beams in the Type C frames were to replaced FTCBs to form the prototype. The replacing principles are keeping the same strength as RC beams and controlling the stiffness (or drift) to meet the performance objectives in Fig. 2. Then the first three stories of the hybrid coupled wall system was taken as a substructure. Due to the setup limit, the substructure was 2/3 scaled to form the test specimen. The total height of specimen is 7.8 m. The width of wall piers is 2 m. And the span of FTCBs is 1.2 m with a span-to-height ratio of 1.8. Table 1 shows the design strength information.

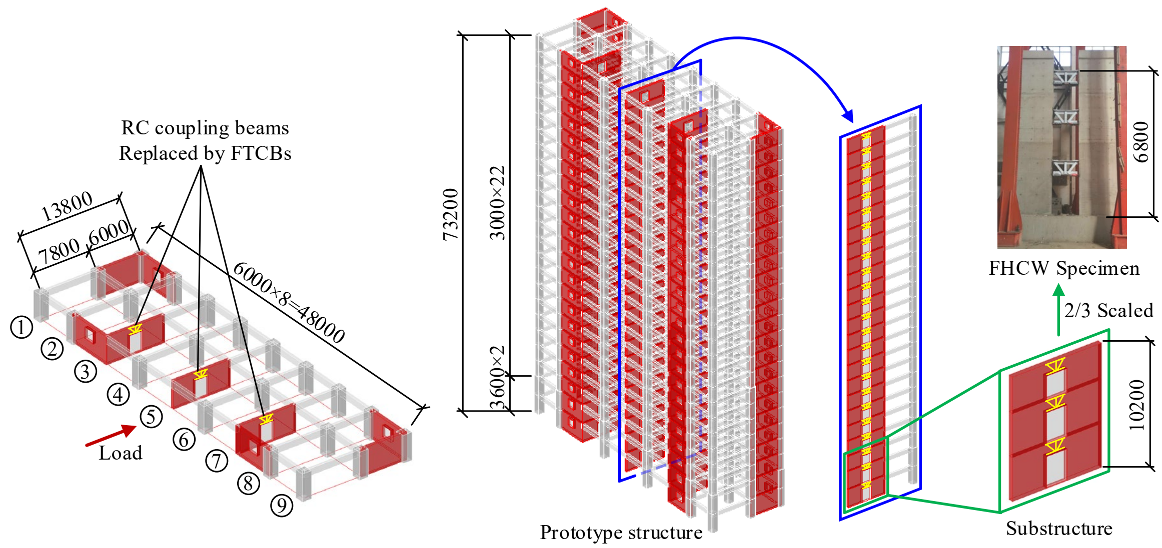


Figure 3: Specimen design procedure

Table 1: Design Strength of Specimen

		Full scale	2/3 scaled
Bending resistance of a single wall pier (kN·m)		12417.3	3679.2
Limiting shear strength of FTCB (kN)	Story 1	562.5	250.0
	Story 2-3	607.5	270.0
Shear resistance of the hybrid coupled walls (kN)		3688.9	1093.0

2.1 Test Setup, Loading Protocol, and Instruments

Fig.4 shows the test setup. For the horizontal loading, two actuators were symmetrically placed about the centerline of walls in the thickness direction to avoid torsion. To apply the varying axial forces and moments from the upper stories, four vertical actuators were used. In addition, two lateral restrainers were added on both sides to avoid the out-of-plane deformation.

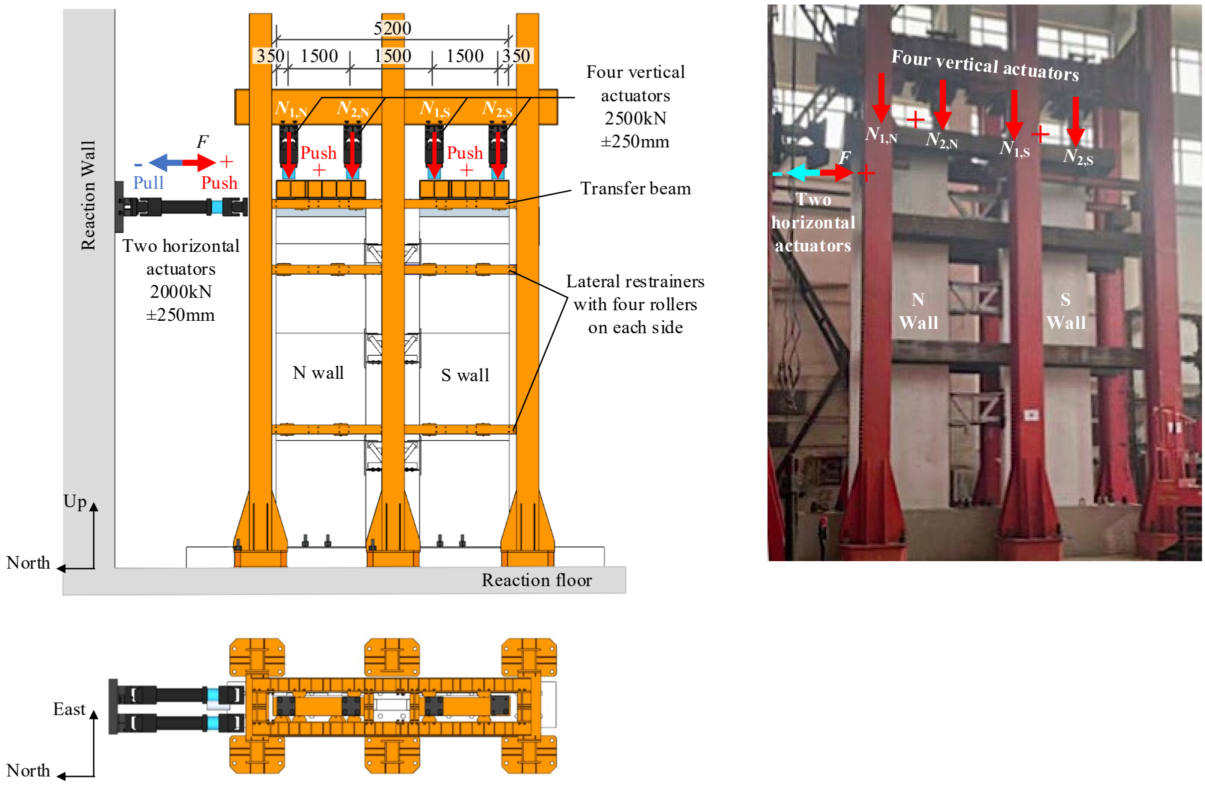
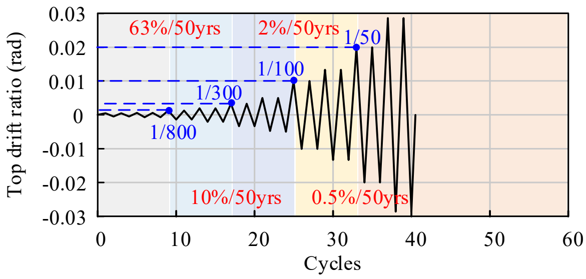
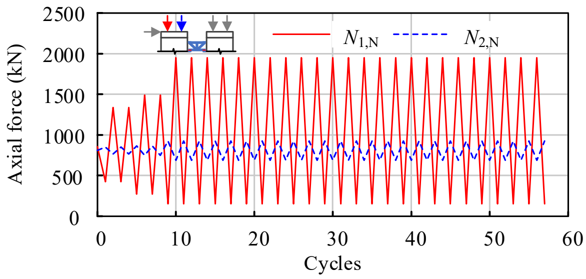


Figure 4: Test setup

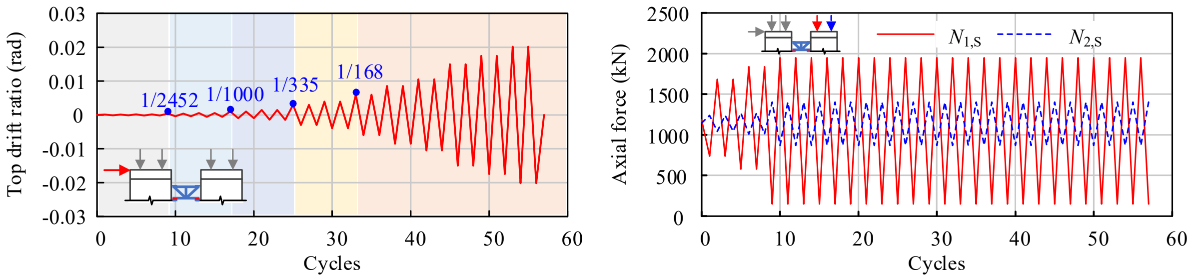
The loading protocols were derived from the following procedure. The numerical model of the prototype was cyclically loaded. The lateral force record at the horizontal actuator level was used as the horizontal protocol. The axial forces and moments at the cap beam were converted to the axial loads of vertical actuators. The principle is to keep the same resultant force and moment. The varying axial loading protocols were then obtained by scaling and adapting to setup limit. Fig.5 shows the displacement-controlled horizonal loading protocol and force-controlled vertical loading protocols.



(a) Full scale 24-story prototype



(c) Vertical loading protocols of N wall



(b) Horizontal loading protocol (d) Vertical loading protocols of S wall

Figure 5: Loading protocols

Both transducers and strain gages were used to monitoring the lateral deformations of the system, the shear deformation and internal forces at the bottom of walls, the shear deformation and force of FTCBs, and the sliding displacement of friction dampers.

3 TEST RESULTS

3.1 Test Observation

Fig. 6 showed the failure mode of the hybrid coupled walls. Bending failure of wall piers occurred beyond the very rare earthquake level. Within the very rare earthquake level, no major damage was observed in either wall piers or FTCB anchorage regions. Rapid repair could be achieved by retightening the loosen bolts or replacing the worn shims.

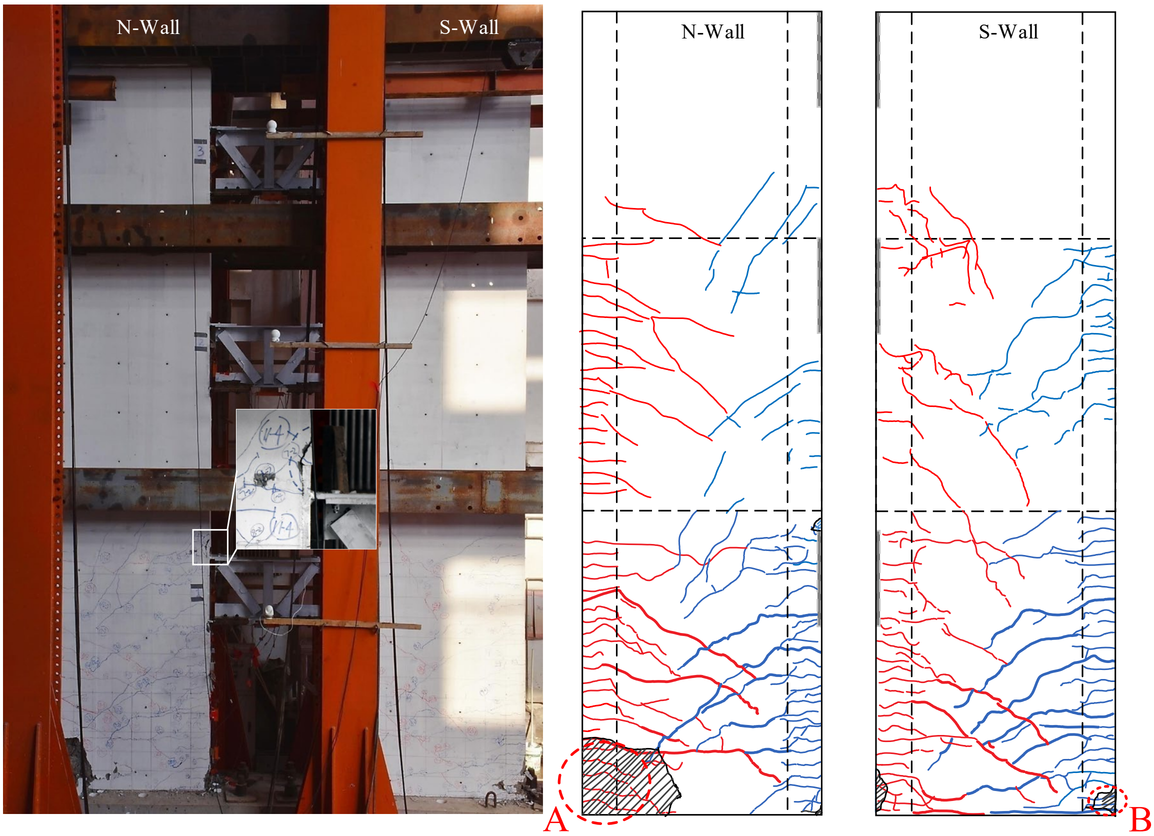
3.2 Hysteretic Behavior

As shown in Fig. 7(a), the specimen had different positive and negative responses. The reason was that the substructure was taken from a dual system. The internal forces distribution varied with the loading direction. Using the material test results and actual loading conditions, the calculated strength had errors within 10%.

Fig. 7(b) shows the hysteretic curve within the very rare earthquake level. The performance points met the expected performance objectives in Fig.2.

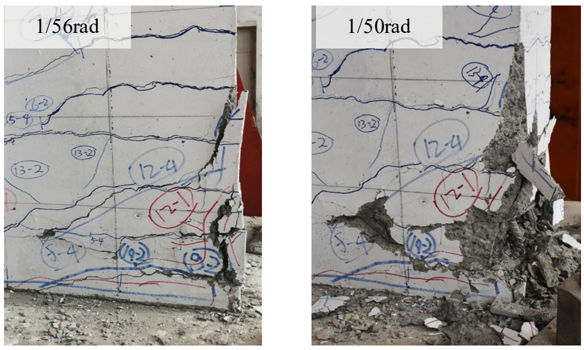
The coupling ratio measures the effects of coupling action. The theoretical coupling ratios of the prototype was 70.3% and 64.1% for elastic and plastic states, respectively, while the experimental values were greatly reduced after the 3rd cycles (Fig. 8). The reason was that the amplitudes of the applied axial loads (Fig. 5) in the test were limited by the setup capacity and safety concerns. The contributions of the upper FTCBs to the coupling action were ignored. This is one of the limitations of the test and the effects of coupling action need further studies.

The FTCBs exhibited full and stable hysteretic curves. The error of limiting shear strength was within 5% except the negative strength of 1st story FTCB. The error came from the misalignment in the pre-test for adjusting pretensions. After sliding, the dampers absorbed about 50% of total energy. The wall piers were generally elastic within the plastic drift limit of dual system in Chinese seismic design code.



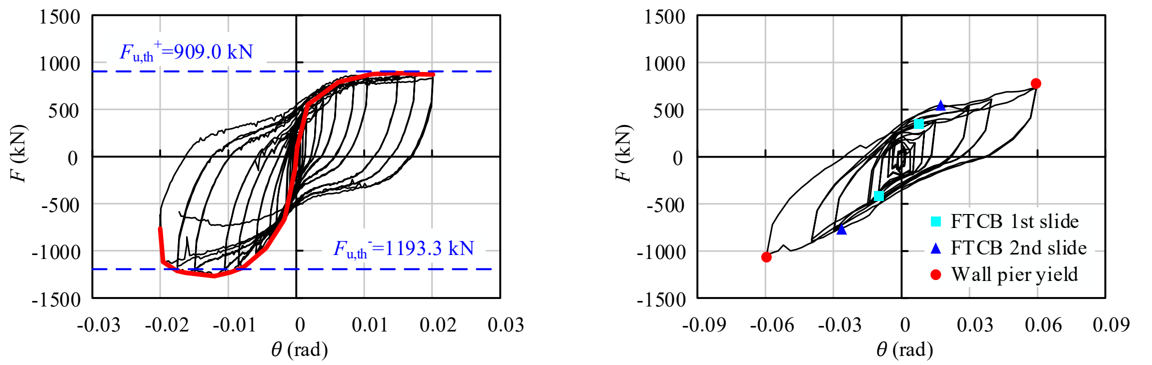
(a) Crack distribution

(b) Damage in position A



(c) Damage in position B

Figure 6: Test phenomena



(a) Hysteretic curve (b) Responses within the very rare earthquake level

Figure 7: Hysteretic curves of the hybrid coupled walls

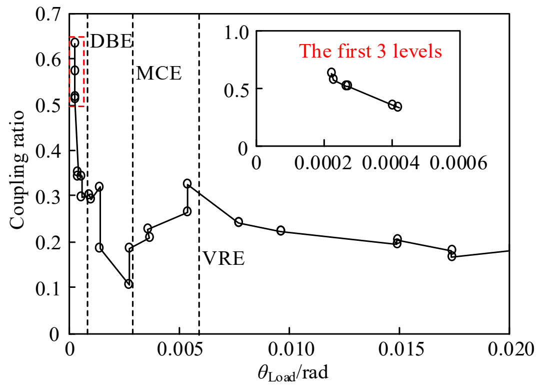


Figure 8: Coupling ratio

4 CONCLUSIONS

- The hybrid coupled wall system met the performance objectives and showed ductile bending failure. The damage of N Wall was server than that of S Wall due to the different axial loads.
- The varying axial loads reflected the influence of upper stories on the substructure. The calculated bending strength of the hybrid coupled walls had errors within 10%.
- The FTCBs slid before wall yielded to dissipate energy. The proportion of damper energy dissipation was about 50%.
- No major damage occurred in the wall piers or anchorage regions. Rapid recovery can be achieved after earthquakes.

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