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EXPERIMENTAL STUDY ON CARRYING SHEAR FORCE RATIO OF 12 - STOREY COUPLED SHEAR WALL

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SUMMARY

The Hybrid Wall System (HWS) building composed of center core reinforced concrete walls and exterior steel flame has the open space around the center core walls, and it is architecturally desirable. The center core wall is divided into several walls that are linked together by coupling beams and forms coupled shear walls. The coupled shear walls are the primary lateral load-resisting element in the HWS building.

In order to investigate the seismic performance of the coupled shear walls especially carrying shear force ratio of each wall, the seismic test on 1/3-scale 12-story T-shaped coupled shear walls has been conducted under the U.S.-Japan coopertive research project. Load transducers were inserted at the center of each coupling beam in order to measure the shear force carried by each wall connected by coupling beams. Most remarkable findings from the seismic test are that the carrying shear force ratio is different between the tension and the compression side wall, especially the shear force at the lower story is concentrated on the compression side wall from the relative small displacement level.

The factors affecting on the mechanisms of shear force carrying ratio in coupled shear walls are appointed as follows; 1) difference of the wall stiffness in tension and compression side walls, 2) slip effect of the wall, 3) wedge action of the coupling beams, and 4) residual compressive axial force of the coupling beams.

Among these factors, (1) slip of the wall, wedge action of the coupling beams and residual compressive axial force of the coupling beams are main factors to explain this mechanisms. But (2) difference of the wall stiffness is not a effective factor in this test.

INTRODUCTION

The U.S.- Japan cooperative structural research project on composite and hybrid structures have conducted from 1994 for 5-years. A building with center core reinforced concrete walls and exterior steel flame was selected as a target building for Hybrid Wall System (HWS,) that is one of four composite and hybrid structure systems, i.e.; Concrete Filled Tube Column System (CFT), Reinforced Concrete Column and Steel Beam System (RCS), Research for Innovation (RFI) [Yamanouchi et al, 1994]. The HWS building has the open space around the center core wall that is architecturally desirable. The center core wall is divided into several walls that are linked together by coupling beams and forms coupled shear walls. The coupled shear walls are the primary lateral load-resisting element in the HWS building. Flange part of each wall in the coupled shear walls can reduce seismic compressive stresses, and hence improve the overall seismic performance of the coupled shear wall. In seismic test on 1/3 scale 12-story coupled shear wall with flange walls [Teshigawara et al, 1997], it was confirmed that

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the HWS building had an excellent seismic performance. Its hysteresis characteristics was stable until building drift of 1/67, i.e. deflection angle at the 12th floor. The coupling beams and the wall foots absorbed the most of the seismic energy. Its deformation capacity was at 1/25 angle.

At present, the design methodologies of the buildings that have shear walls are prepared sufficiently in Japan, and the HWS building isn't designed rationally. Therefore, it is necessary to develop design methodologies that suitably evaluated seismic performance of the HWS building.

The coupling beams can be designed to absorb the most of the seismic energy as well as the wall foots, and the coupled shear walls are the primary lateral load resisting element in the HWS building. To evaluate the carrying shear force of walls is very important to design the HWS building. The fluctuation of shear force in the coupled shear wall are observed in the 12-story coupled shear walls test [Teshigawara et al, 1997] (Figure 1). The mechanism of fluctuating shear force in the coupled wall was checked, comparing the axial force measured by the load transducer with the value estimated from simplified model.

TEST SPECIMEN

Figure 1 shows the test building consisting of two flanged wall coupled by coupling beams, and 12-stories with 1.2m story height. Total height of test building is 14.4m. This specimen was designed as no tensile force was developed at walls when the fracture mechanism was developed, and the carrying load ratio of overturning moment was 6:4 by walls vs. by coupling beams. The model scale was 1/3.

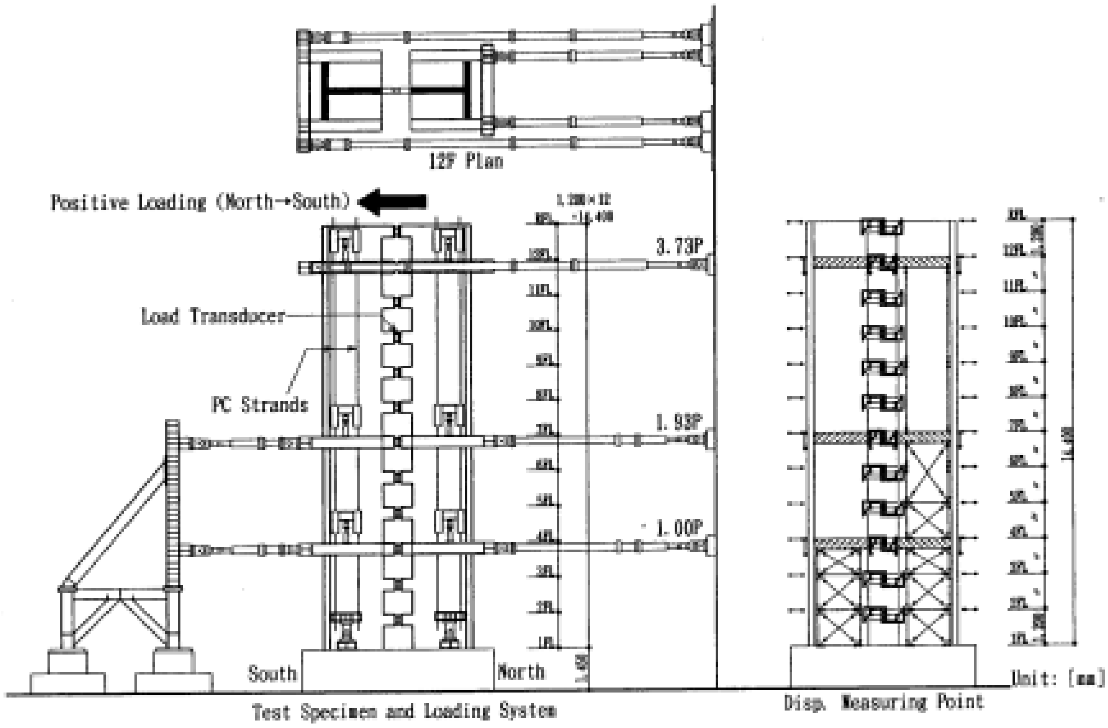

Figure 1 : Test specimen, Loading system, and Disp. measuring

Rebars arrangement is detailed in Figure 2. Rebars were arranged based on the consideration of flexural yield both at walls foos and at the end of coupling beams. Compressive zone was set as the area which bears compressive force due to overturning moment, with specified concrete strength. X-shaped rebar arrangement was applied to coupling beams. Wall shear reinforcement ratio Ps in the walls was 0.64%, while confinement reinforcement ratio Pw was double 1.2% at compressive zone.

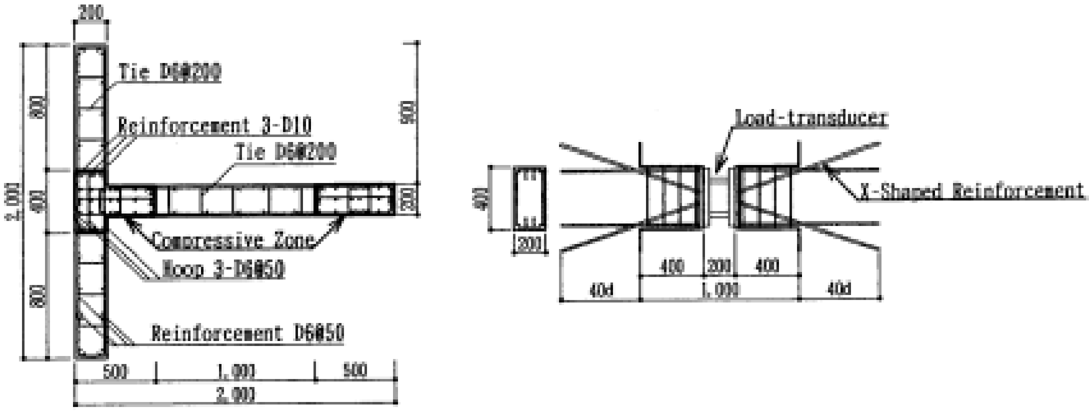

Figure 2 : Rebars arrangement

BASE SHEAR FORCE AND DISPLACEMENT OF WALL

Relation of base shear force and overall building drift (displacement at the 12th. floor) are shown in Figure 3. Overall building drift of loading step (hereafter L.S.) of 1/6000, the bending crack was developed at the coupling beams, and at L.S. of 1/1000, cracks were observed first at the compression wall web and then at tension wall flange. After that the yielding started at the main rebar of coupling beams. Up to L.S. of 1/600, the main rebar yielded at coupling beams of roof to 5th floors. At L.S. of 1/200, the yielding was observed at the main rebar of coupling beams. Then the yielding of the main rebar started at the tension ends of the compression wall. Up to L.S. of 1/100, buckling of the main rebar occurred at coupling beams of roof to 8th floors. Up to L.S. of 1/67, buckling of the main rebar occurred at roof to 3rd. floors. The yielding of the main rebar was observed both at compression and tension walls. The maximum loading capacity was 1440 kN in positive direction and 1370 kN in negative direction. UP to L.S. of 1/30, buckling of the main rebar occurred at the coupling beams of 2nd floor, fracture of the main rebar occurred at roof to 5th floors, and crushing of concrete occurred at the foot of the wall.

The maximum base shear was 1440 kN at L.S. of 1/67. Under this shear, the coupling beams developed their maximum displacements. At L.S. of 1/25, the compression toe of the tension wall crushed. At L.S. of 1/67, the maximum total base shear was nearly resisted by the compression wall. Beyond this point, excessive shear deterioration made the two wall piers behave as individual walls with nearly identical shear resistance.

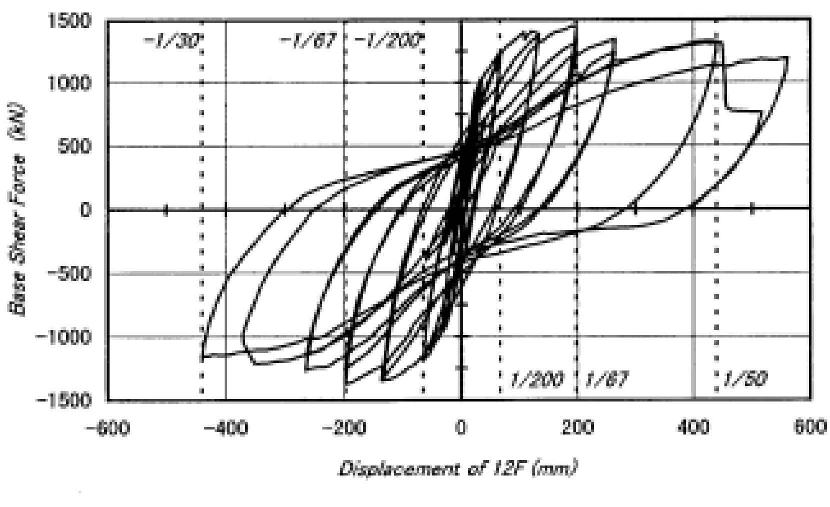

Figure 3 : Base shear force and displacement of walls

FLUCTUATION OF SHEAR FORCE

Story Distribution of Carrying Shear Force Ratio:
Figure 4 shows carrying shear force ratio along the height. The solid line shows carrying shear force of north and south walls which is distributed at the ratio of 1:1.Carrying shear force ratio is allocated equally to each story at L.S. of 1/6000 which is in the elastic region. According to the progress of deformation, the shear force ratio of compression wall is enlarging at the 1st and 2nd stories. It reached to the maximum ratio of 9:1 at L.S. of 1/67. In the progress of further deformation, carrying shear force ratio of compression wall was decreasing to 7:3 at 1st story distribution L.S. of 1/25. The difference of carrying shear force ratio between the compression and tension walls is conspicuous at lower stories, while that is not so much at upper stories. This means the beam axial force is smaller at upper stories than at lower stories as carrying shear force ratio between the walls (C. and T. walls) is changing shear force transfer by the axial force of coupling beams. The total sum of beam axial force of 2nd to roof stories mostly owes to compression force of lower stories. The total sum of beam axial force of 2nd to roof stories was experimentally 622kN [Sugaya et al, 1996].

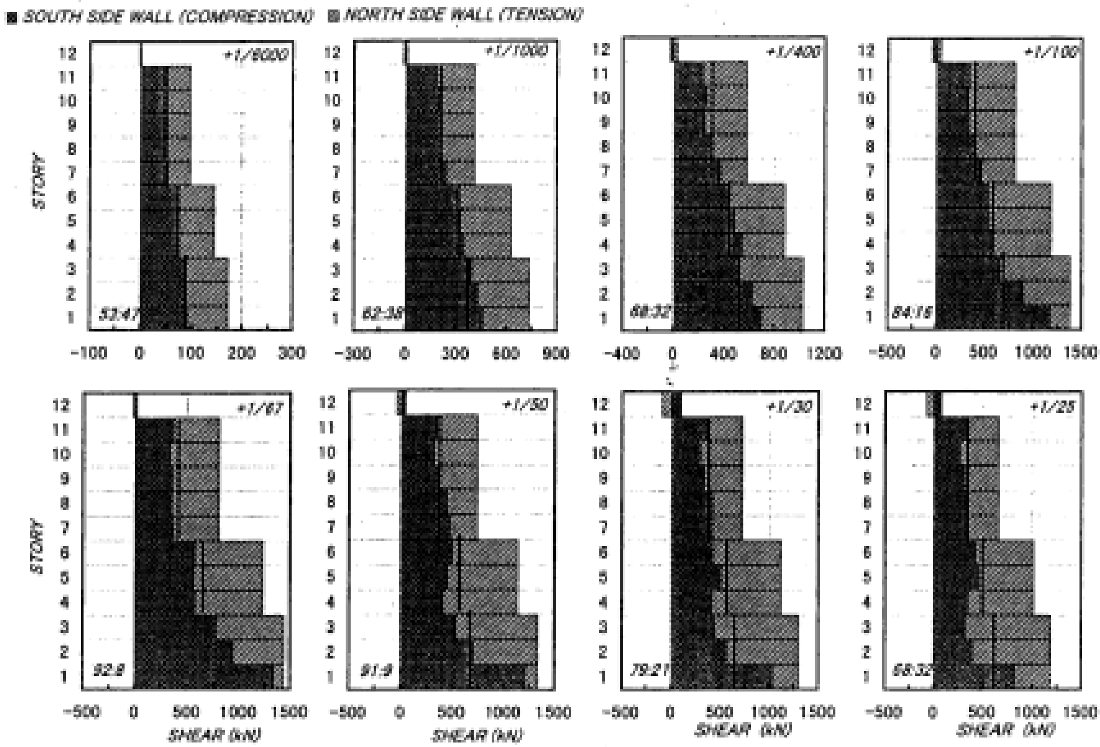

Figure 4 : Carrying shear force of each story

Fluctuating Factors for Carrying Shear Force:

Following factors are considered for fluctuation of carrying shear force of coupled walls.
1) Influence by Wall Behavior
1-1) change of stiffness of the walls which are suffered varied axial force
1-2) slip manner of the walls which are suffered varied axial force
2) Influence by Behavior of the Coupling Beams Confined by Walls
2-1) axial deformation accompanied with neutral axis movement of the coupling beams confined by walls (wedge action)
2-2) residual axial force near zero of the repeated total deformation of the coupling beams confined by walls

Fluctuation of carrying shear force was examined as follows based on each factor.

Influence of Change of Stiffness of the Walls :

Based on the test, which was a pilot test for lower 2 stories of 12-story building, for T-shaped wall which are suffered varied axial force, it is inferred that the stiffness of a single wall is almost equal in both compression and tension walls, and the influence by stiffness difference of the walls is a little [Arisono et al, 1995]. Figure 5 shows relation between shear force and drift angle in this test.

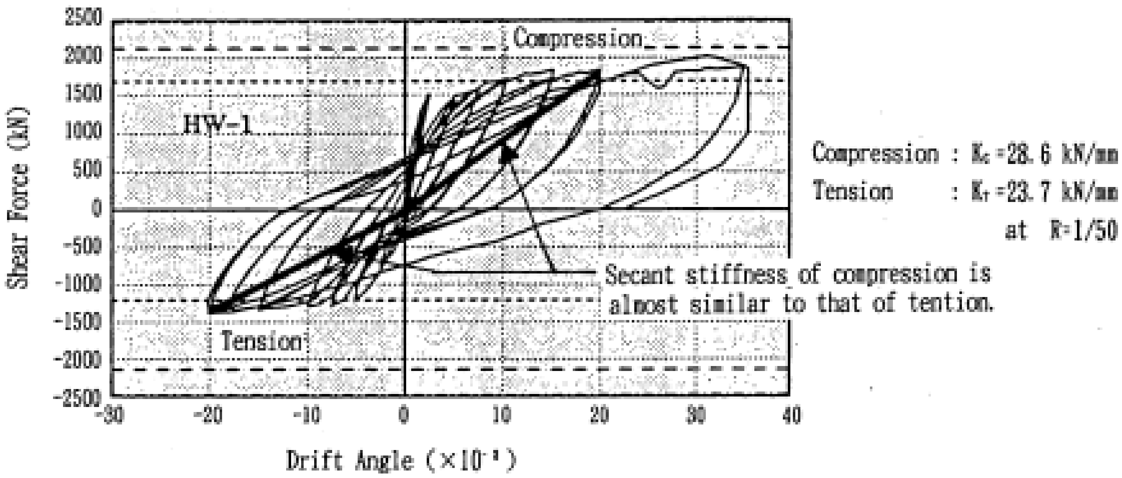

Figure 5 : Shear force and drift angle (T-shaped Wall Test)

Influence of the Slip of Walls :

Figure 6 shows the model model fluctuating mechanism of shear force by wall slip manner. When the flange of T-shaped wall becomes the compression wall, a bending crack develops at the web end. Then the web-end becomes compression and the crack is closed. The rebar cannot carry the force, and then the wall shear force moves to the other one in the slip manner.

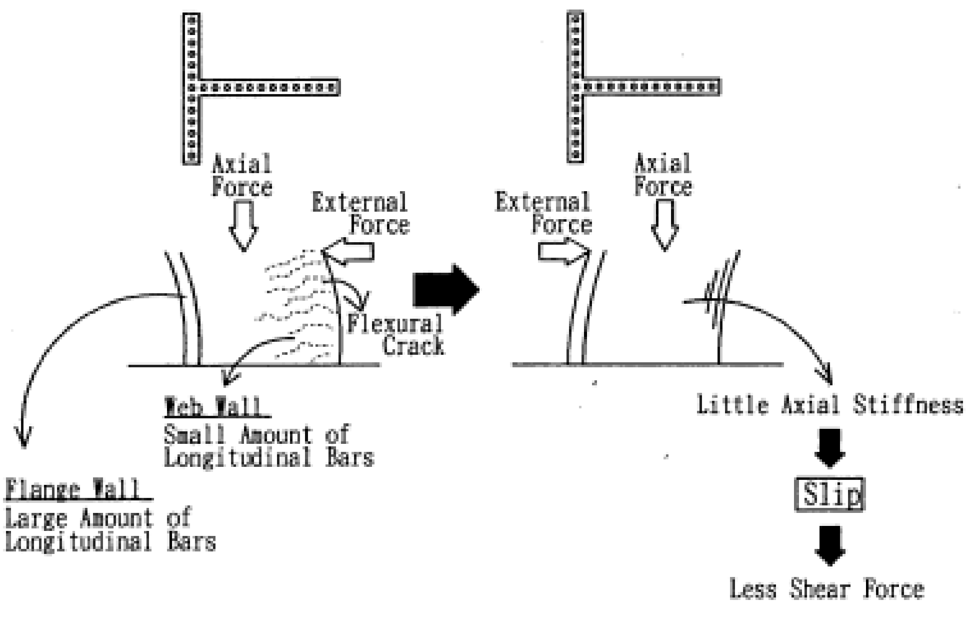

Figure 6 : Slip Manner Model of Multistory Wall

Figure 7 shows the results from a fiber-model analysis (a broken line) and a test (a solid line) on the curvature of the 1st floor wall. Contraflexural point of moment is assumed to be 6.84m based on the test result, then shear force transfer due to slip manner can be estimated as 127kN. In this case the effect on fluctuation of carrying shear force by the coupling beams was omitted.

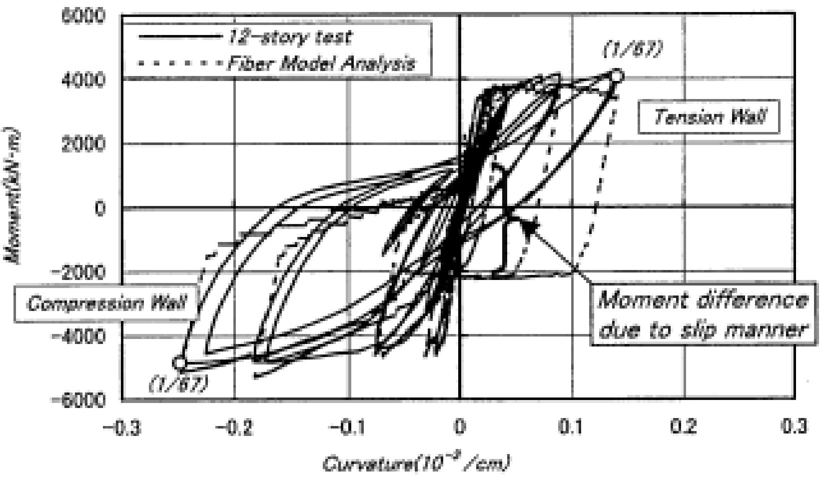

Figure 7 : Moment and curvature by the test and analysis

Influence of Wedge Action of Coupling Beams :

Figure 8 shows the model of wedge action of coupling beams. When coupled walls are laterally deformed, coupling beams act as wedges. Then compression axial force occurs, by the combination the lateral stiffness of walls and axial stiffness of coupling beams.

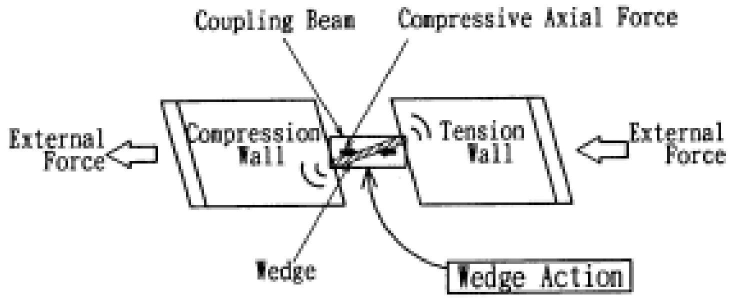

Figure 8 : Wedge action occurrence model of coupling beam

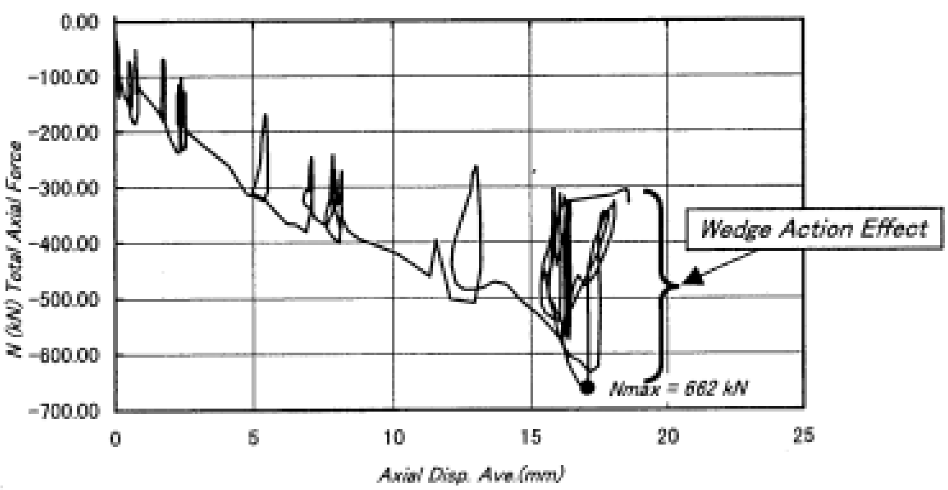

Figure 9 : Axial Displacement Ave. and Total Axial Force In Coupling Beams

Figure 9 shows the relation between axial displacement (average of 12) of coupling beams in 12-story test, and the total axial force of 12 coupling beams. When axial displacement of beams extends, compressive axial force of beams increases. Fluctuation of axial force at the same axial displacement represent wedge action effect, and expansion of coupling beams increases axial force gradually (residual axial force mentioned later).

In order to check this wedge action effect, simple brace model analysis based on the test results is done [Sugaya et al, 1998], it was found that fluctuation ratio of carrying shear force was 7:3 due to "Wedge Action", and the sum of compressive axial force of coupling beams was 245kN.

Influence of Residual Axial Force :

The axial extension displacement in coupling beams is getting larger, according to the progress of deformation. At the total deformation of zero of coupled walls, residual axial extension displacement exists and residual axial force occurs by confine of walls. Coupling beam in member tests [Sugaya et al, 1995] extend two times longer than that in 12-story test in Figure 10. In case of 12-story test, coupling beams are confined by walls, from which, it is assumed that the wall extension is almost equal to the shrinkage that the difference of axial disp. of beams between coupling beam test and 12-story test. Residual axial force is accumulated at coupling beams of lower stories which are highly confined by the loading foundation mat.

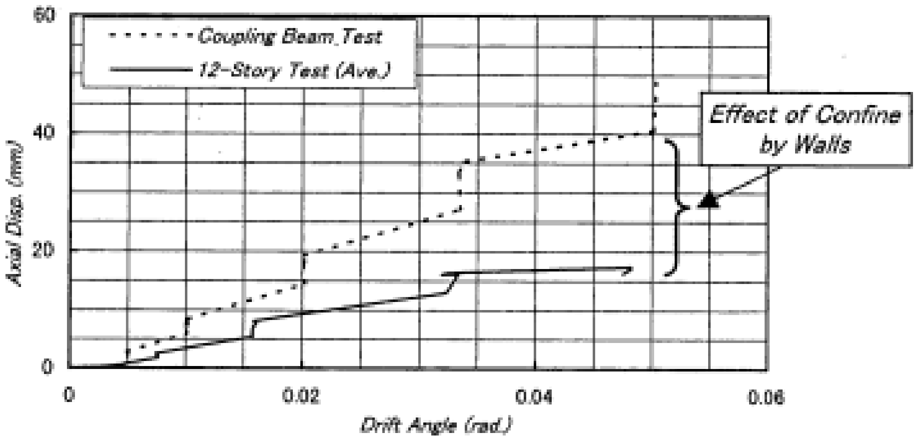

Figure 10 : Axial displacement and drift angle in coupling beam

Figure 11 shows residual axial force occurrence model of coupling beam. Coupling beams in assumed hinge zone can carry the axial force up to their yield strength of compression rebars. This value approximates to carrying axial force assumed for X-shaped rebar of coupling beam in hinge zone. Fluctuation of carrying shear force by residual axial force is assumed 263kN (from yield strength of X-shaped rebar in hinge zone).

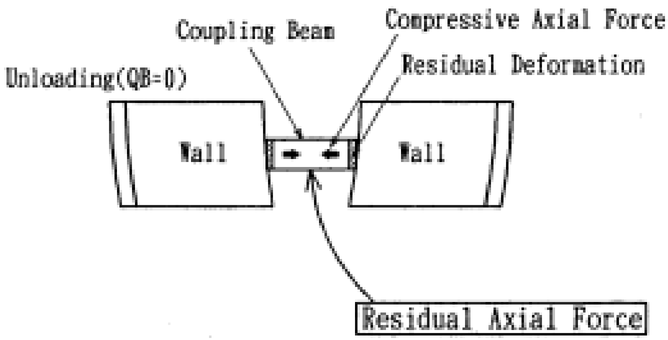

Figure 11 : Residual axial force occurrence model of coupling beam

Figure 12 shows the relation between rotational drift angle and total axial force in coupling beams. Residual axial force is about 420kN. This residual axial force includes the effect of slip manner (127 KN). The test result of axial force of coupling beams approximates the total value of wall slip manner and residual axial force effects (263KN + 127KN = 390KN).

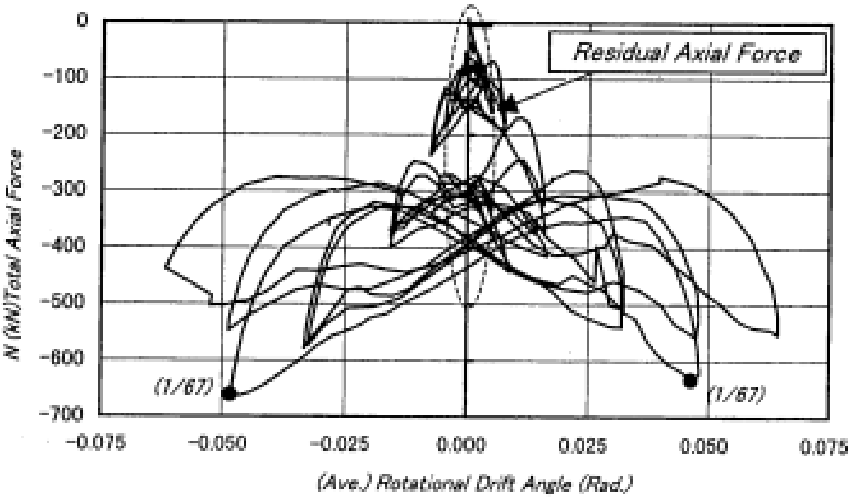

Figure 12 : Drift angle and total axial force in coupling beam

CONCLUSION

This paper discusses the mechanisms of the carrying shear force ratio between tension and compression side walls in coupled shear walls.The factors affecting on the mechanisms of shear force carrying ratio in coupled shear walls are appointed as follows; 1) difference of the wall stiffness in tension and compression side walls, 2) slip effect of the wall, 3) wedge action of the coupling beams, and 4) residual compressive axial force of the coupling beams.Among these factors, (1) slip of the wall, wedge action of the coupling beams and residual compressive axial force of the coupling beams are main factors to explain this mechanisms. But (2) difference of the wall stiffness is not a effective factor in this test.

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