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A new test setup for cruciform beam-column subassemblages subjected to earthquake loading

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ABSTRACT: In investigating the structural behavior of cruciform (or + shape) beam-column subassemblage test specimens which are subjected to gravity load and alternately repeated lateral forces, all the equilibrium and compatibility conditions required at the beam supports should be always satisfied during elastic through inelastic range of specimen's earthquake behavior. In most of the test setups used for this type of experiment, however, some of the required conditions at the beam supports are not satisfied because beam ends of the subassemblage are usually simply supported. Herein, a new test setup for testing a cruciform subassemblage is proposed and the effect of difference in the test setup on inelastic structural behavior of the subassemblage is investigated. Typical test results indicated that, due to the difference in the adopted test setup, inelastic behavior of the specimen including load-deflection relation, ultimate strength, failure mode and mechanism and cracking pattern are largely affected.

1 INTRODUCTION

In investigating the inelastic earthquake behavior of moment resisting frames experimentally, a cruciform beam-column subassemblage as shown in Fig.1 is frequently used as a test specimen. And in most cases when the test is conducted using these cruciform subassemblages, a test setup as shown in Fig.1 has been popularly adopted. This type of popular test setup, however, is insufficient for testing some cruciform specimens such as those having ordinary reinforced concrete (R/C) beams whose ultimate positive and negative flexural moment capacities are different at the beam-end, because hinge supports (or inflection points of the flexural deformation) of the left and right beams are always located at mid-span of the beam, and thus all the compatibility and equilibrium conditions required at the right and left beam-supports are not satisfied especially during the inelastic loading reversals of the subassemblage (refer to Figs.2 and 3).

Main objective of the present study is to develop a new test setup which is able to investigate the inelastic behavior of model subassemblages as closely as possible to the actual behavior of prototype moment resisting frame structures, which are subjected to gravity load and alternately repeated lateral forces.

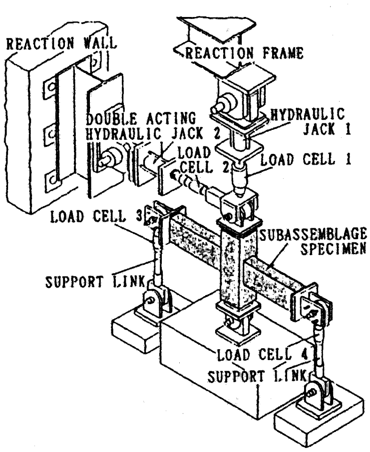

Figure 1. Popular test setup.

2 REQUIRED CONDITIONS FOR TEST SETUP

Fig.2 shows a schematic illustration of member forces and flexural deformation when a weak-beam-strong-column subassemblage is just before its ultimate state. At this stage, inflection point of the beam is no longer located at the mid-span of the beam but moves toward left due to the difference in the ultimate positive and negative flexural moment capacities of the beam-end. Compatibility and equilibrium conditions required at the mid-span of the beam are also presented in Fig.2.

While in Fig.3, member forces and flexural deformation occurred in the subassemblage are presented when the popular test setup shown in Fig.1 is used in the experiment. As is understood from this figure, all the conditions required at the beam supports are not satisfied in case of using the popular test setup shown in Fig.1.

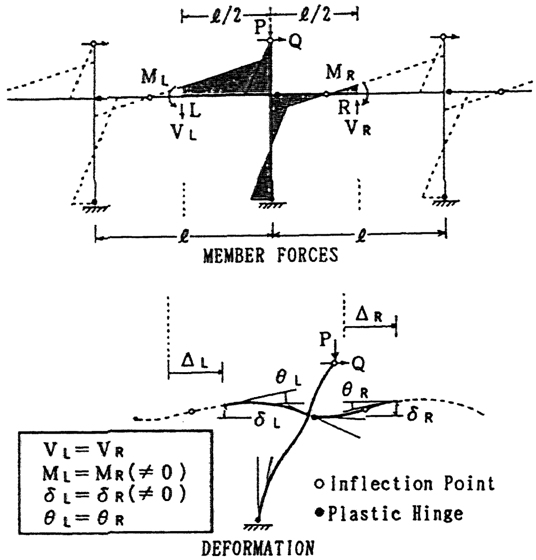

Figure 2. Actual member forces and deformation of subassemblage.

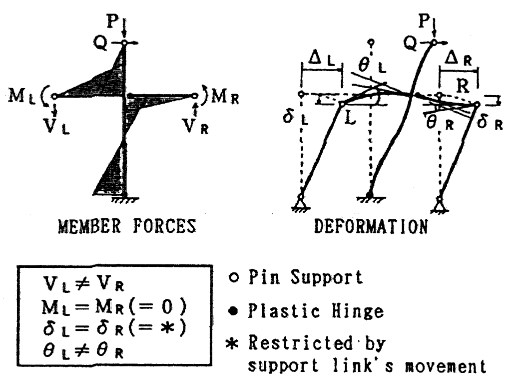

Figure 3. Member forces and flexural deformation in popular test setup.

In order to design a test setup whose beam-supports are intended to locate at the mid-span of each beam, all the compatibility and equilibrium conditions shown in Fig.2 must be always satisfied. By taking into account of these required conditions, the new test setup shown in Fig.4 was designed and constructed. One of the most characteristic features of this test setup is that "vertical reaction and displacement equalizer" and "moment and rotation equalizer" are installed between left and right beam supports. According to these equipments, shear forces, V_L and V_R, in left and right beams are always kept equal. In addition, bending moments (M_L and M_R), vertical displacements (δ_L and δ_R) and rotation angles (θ_L and θ_R) at the left and right beam-supports are also kept equal, respectively all thorough the experiment.

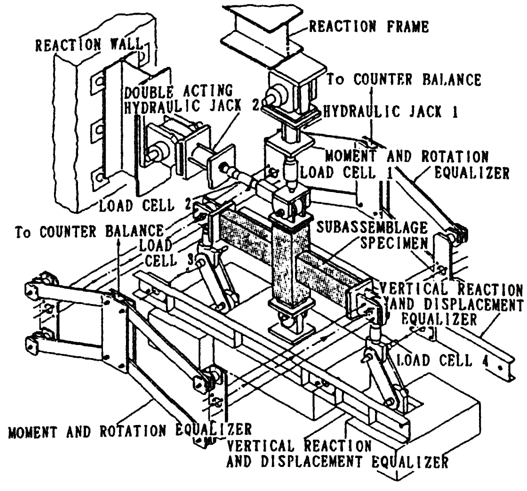

Figure 4. Proposed new test setup.

3 SUBASSEMBLAGE TEST SPECIMENS

In order to examine the effect of difference in test setup on inelastic structural behavior of the test specimen, two same cruciform subassemblage specimens shown in Fig.5 were designed and tested by using the popular and new test setups shown in Figs.1 and 4, respectively.

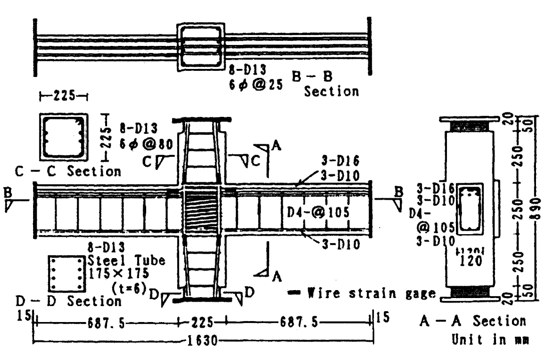

Figure 5. Subassemblage test specimen.

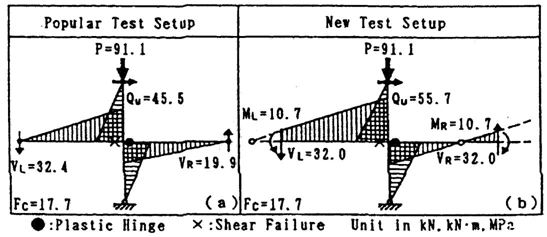

Figure 6. Predicted ultimate state.

Test specimens used are R/C beam-column subassemblages as shown in Fig.5, and the expected ultimate states of the specimen are presented in Figs.6(a) and 6(b) when each specimen is tested by the popular and new test setups. It can be noted that, the ultimate lateral shear of each column, and shear forces and bending moments induced in the beams are expected to be quite different due to the adopted test setups, although the expected failure modes for both specimens are similar. Mechanical properties of materials used in these specimens are given in Table 1.

Table 1. Material properties of specimens.

Concrete		Reinforcement			
Specimen	Compressive Strength $_c\sigma_B$ (MPa)	Bar Size	Yield Strength σ_y(MPa)	Tensile Strength σ_u(MPa)	Elongation ε_B (%)
Popular	17.4	D16	357	519	23
		D13	342	494	25
		D10	364	518	22
New	20.5	D4	264	332	39
		6φ	320	460	27

4 TEST SETUP AND MEASUREMENTS MADE

By using the test setups shown in Figs.1 and 4, two same subassemblage specimens with cross-sectional details in Fig.5 were respectively tested under a constant gravity load. Fig.7 shows the location of displacement transducers and electrical wire strain gages for both specimens. Applied lateral loads and reaction of the beam-supports were measured by the load-cells shown in Figs.1 and 4. In addition, bending moments occurred at the beam-supports were also measured in the new test setup.

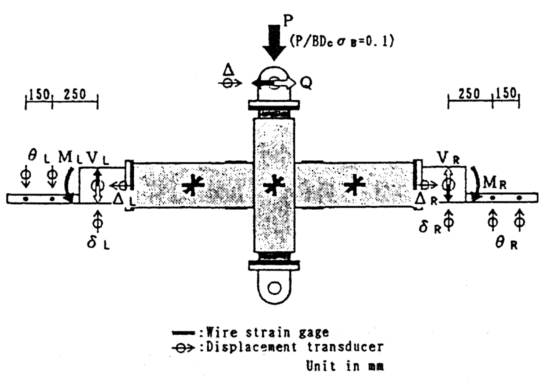

Figure 7. Location of displacement transducers and wire strain gages.

5 TEST RESULTS AND DISCUSSIONS

Typical test results obtained from using the popular and new test setups are shown in Figs.8 through 14. In each figure except for Fig.12, the left figure shows the test result due to the popular test setup in Fig.1 and the right figure is obtained by the new test setup in Fig.4.

Figs.8, 9 and 10 show lateral load versus story drift relations, member forces at ultimate state and final crack patterns obtained by using the popular and new test setups. Solid lines in Fig.8 represent the ultimate lateral strengths of the specimens determined by the theory in which P-Δ effect is taken into account. In Fig.9(b), partial weights of the loading equipment (3.5 kN) are also applied on the beam ends. In both specimens, one beam failed in flexure under positive bending moment while the other beam failed in shear failure mode as was predicted in Fig.6, however, test results in Figs.8, 9 and 10 indicate that the inelastic behavior of the test specimen including lateral load-displacement relation, ultimate lateral strength, failure mode and mechanism, and crack pattern was largely affected due to the difference in the adopted test setup.

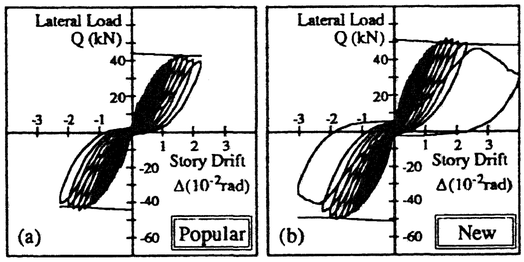

Figure 8. Story shear-drift relations.

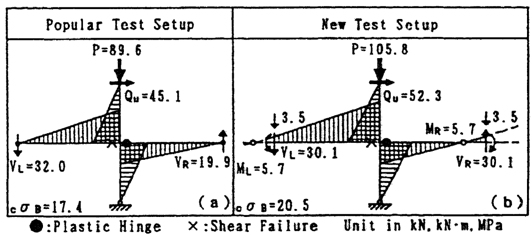

Figure 9. Member forces at ultimate state.

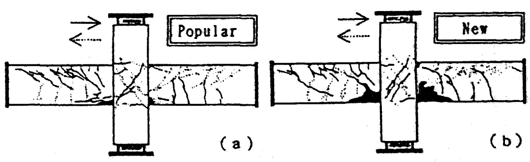

Figure 10. Crack patterns after test.

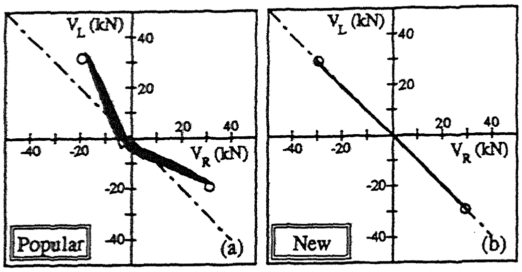

Figure 11. Shear forces in left and right beams caused by lateral load application.

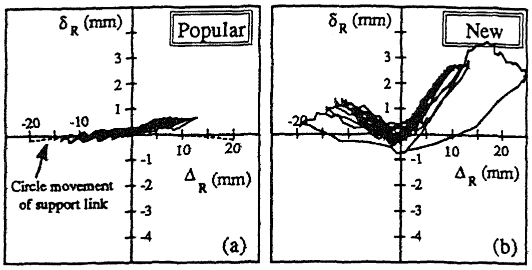

Figure 13. Vertical displacements occurred at right beam support.

Fig.11 shows relationship between shear forces occurred in the left and right beams during the application of all lateral loads. Open circles in the figure represent the corresponding theoretical values at the ultimate state of each subassemblage. Fig.11(a) shows that, when the subassemblage specimen is tested by the popular test setup, shear forces in the left and right beams are always different and do not become equal. By using the new test setup, however, those of the left and right beams become equal as can be observed in Fig.11(b).

Fig.12 represents the comparison of bending moments occurred at the left and right beam supports in case of using the new test setup. Again, the required condition that those two moments should be equal but should not be always kept to zero is satisfied by using the new test setup. Of course, those two moments are always kept to zero in case of using the popular test setup because both of the left and right beams are simply supported by the frictionless bearing seats.

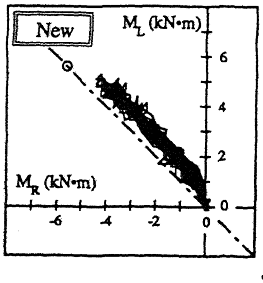

Figure 12. Bending moments at left and right beam supports of the new test setup.

Fig.13 shows the relation between vertical and horizontal displacements of the right beam support observed in both test setups. From this figure, vertical displacements occurred in the popular test setup are smaller than the new test setup because of being restricted partially by the movement of the support link. On the contrary, vertical movement of the beam support is not restricted in the case of the new test setup as can be observed in Fig.13(b).

In Fig.14 vertical displacements observed at the left beam support are plotted against those at the right beam support. In case of using the popular test setup, vertical displacement in one beam-end is nearly equal to the other beam-end except that each other has the opposite sign. This means that, when upward displacement occurs at one support, then nearly the same amount of opposite (or downward) displacement takes place at the other support. Difference of these values observed between two supports are seemed to be caused by the elastic deformation of the support link and small clearance existing in the loading and/or supporting equipments, although those displacements are very small. By considering those deformations, it may be concluded that the vertical displacements in the new test setup are almost equal.

Clear difference in rotation angles could not be observed between two test setups because the amounts of these deformations were quite small.

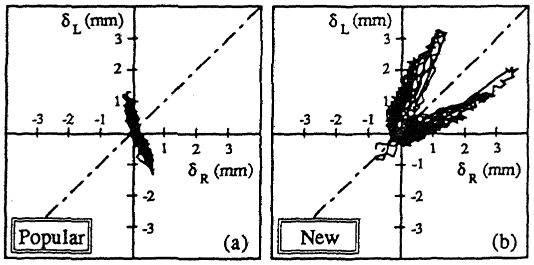

Figure 14. Vertical displacements at left and right beam supports.

6 CONCLUSIONS

Since popular test setups used for testing cruciform beam-column subassemblages have many defects, a new test setup was proposed and the same specimens were tested by using the two different test setups. Test results indicated that, in some cases, considerable different test results from actual behavior of the prototype structures are expected to occur when the popular test setup is used for this type of experiment.