Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.IV)

6-7-7

EXPERIMENTAL STUDY ON R/C SUBASSEMBLAGES TO PREVENT A SHORT COLUMN FROM SHEAR FAILURE BY USING A STEEL SQUARE TUBE

Koji YOSHIMURA[1], Masahide TOMII[2], Kenji SAKINO[2] and Akihiro TANAKA[1]

[1]Department of Architectural Engineering, Oita University, Dan-no-haru, Oita, Japan
[2]Department of Architecture, Kyushu University, Higashi-ku, Fukuoka, Japan

SUMMARY

According to the experimental results obtained by using the reinforced concrete (R/C) short column specimens, the short column confined by a steel square tube does not fail in brittle shear mode but can develop its ultimate flexural strength (Ref.1). To examine the validity of this reinforcing method, experiments were conducted by using four different R/C beam-column subassemblage specimens. Experimental results obtained demonstrate that the transversely reinforcing method by a steel square tube is quite effective to improve the seismic behavior of R/C short columns which are expected to fail in brittle shear mode during severe strong motion earthquakes.

INTRODUCTION

It is widely accepted that the ultimate shear strength carried by a reinforced concrete (R/C) short column having conventional rectangular hoops or spirals does not increase remarkably even if considerable amount of transverse reinforcements are provided into the short column. On the contrary, another experimental study by authors using short column specimens has demonstrated that, if the R/C short columns are confined not by the hoop reinforcement bars but by a steel tube, then brittle shear failure does not occur and the column can develop its ultimate flexural capacity (Ref.1). One of the special features of this reinforcing method is that the steel tube does not need to carry the longitudinal stresses but carries only the transverse hoop stresses. In order to examine whether this reinforcing method can be applied practically into actual building structures, both of analysis and experiment were carried out. Herein, by using the four different beam-column subassemblages which were subjected to a constant gravity load and alternately repeated lateral forces, the experimental phase of this study is briefly outlined. Full details are available in Ref.2.

DESIGN OF SPECIMENS

Model subassemblages adopted are approximately 1/3-scale models of a 1.5-story beam-column subassemblage belonging to the lower levels of a 3-story prototype school building as shown in the elevation in Fig.1. And four different subassemblages (specimens) were designed and constructed for this experimental study. Overall dimensions of a typical model subassemblage (Specimen ST-6) are shown in Fig.2, and details of the spandrel beams and first-story columns of all the specimens are listed in Fig.3 together with the theoretically expected failure modes. The shear-span-to-depth ratio of the first-story short column is approximately 1.0 for all the specimens. Each of the model subassemblages consists of two (left and right) second-floor spandrel beams, a lower half (bottom) of the second-story column and a first-story short column framing into a fixed foundation located in the ground floor.

Specimen **RH-10** has a short column whose shear reinforcement is provided by the conventional rectangular spiral hoops (shear reinforcement ratio: pw=1.64 %), and its deep spandrel beam is rectangular in shape, which is so-called a "wallgirder" having wall-thickness (width) of 10 cm. On the other hand, first-story short columns of other three specimens (Specimens **ST-6**, **ST-8** and **ST-10**) are confined by a steel square tube with tube-thickness of 6.0 mm, and there are no hoop reinforcement bars provided into the confined concrete by the steel tube. At the top and bottom of the steel tube, there are small gaps provided between the cover concrete of the column and the steel tube as shown in Fig.2. This is one of the special features of this reinforcing method by a steel tube, and is the fundamental difference from the ordinary steel tubular composite columns. Due to the presence of these gaps, the steel tube does not need to carry the longitudinal stresses but carries only the transverse stresses.

Specimen **ST-6** is a model of the prototype structure in Fig.1, and thus the spandrel beam of

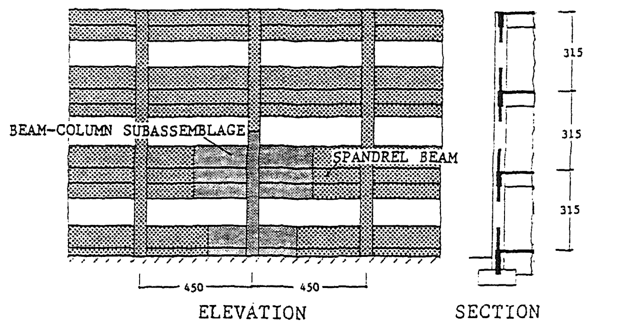

Figure 1. Prototype Structure

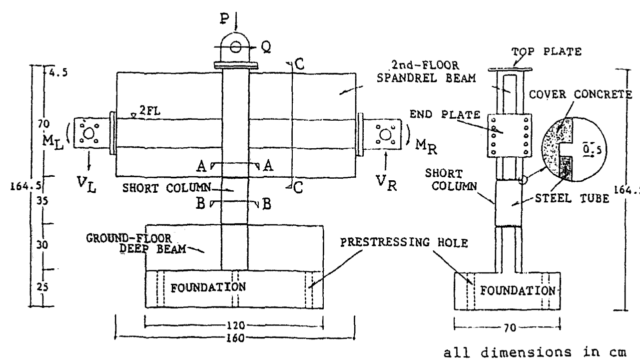

Figure 2. Subassemblage Test Specimen

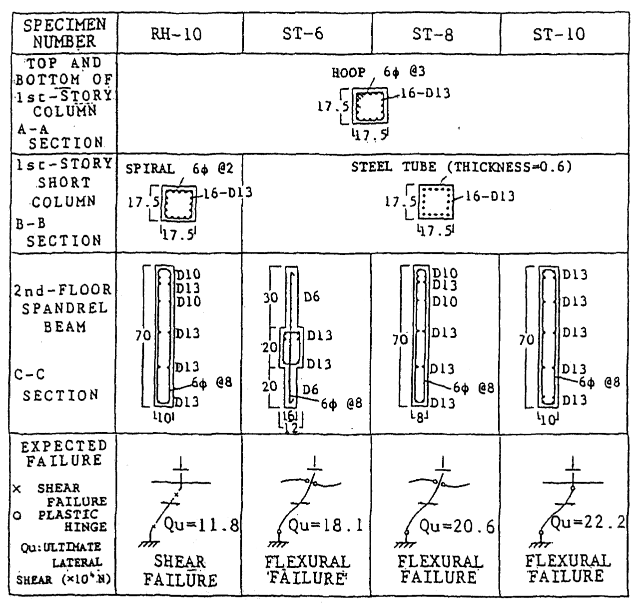

Figure 3. Detailing of Members and Expected Failure Modes of Subassemblages

this specimen has the upper and lower wall-elements with 6 cm wall-thickness along its rectangular floor beam. Spandrel beams of the specimens ST-8 and ST-10 are wallgirders with wall-thickness of 8 cm and 10 cm, respectively. All the columns of those four specimens have the same longitudinal reinforcements, the area of which is 6.64 % of the gross area of column section.

EXPERIMENTAL TEST SETUP AND TEST PROCEDURE

In designing the test setup, all of the boundary conditions required in testing such types of cruciform beam-column subassemblage specimens as shown in Fig.2 were taken into consideration, the details of which are discussed in Ref.2. Fig.4 shows the new test setup for the present test of R/C beam-column subassemblages. The foundation of the test specimen was fixed to the test floor by prestressing bars. The constant gravity load and the alternately repeated lateral forces were applied at the mid height of the second-story column by using the hydraulic loading jacks 1 and 2, respectively. Since the vertical reactions and deflections at the left and right beam supports should be always kept equal respectively, the "VERTICAL REACTION AND DISPLACEMENT EQUALIZER" is installed, and by using the "MOMENT AND ROTATION EQUALIZER" in Fig.4, both of the bending moments and rotation angles at the left and right beam supports can be equalized respectively. In addition, the elongation of the beams caused by cracking is not restricted according to this test setup.

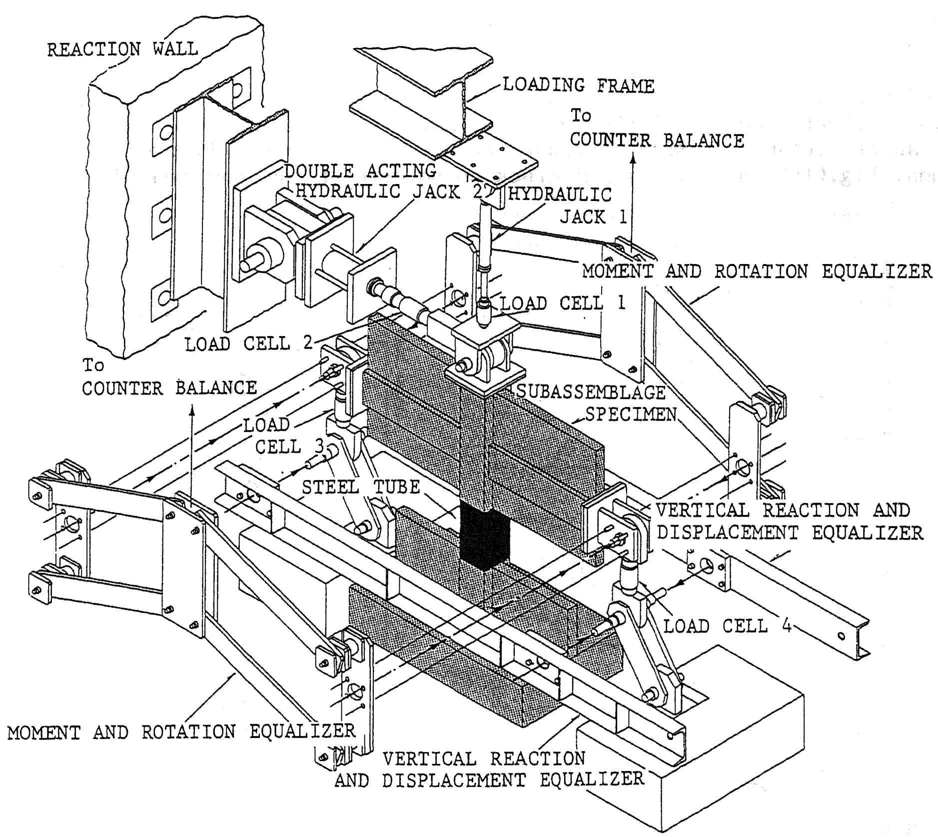

Figure 4. Experimental Test Setup

All of the tests were conducted under the constant axial load: P/AcFc = 0.1, where P, Ac and Fc are the constant axial compression, the gross area of column section and the compressive strength of the concrete in each of the test specimen, respectively. The value of this constant vertical load is the corresponding value of the axial force to which the first-story columns of the 3-story prototype structure in Fig.1 are subjected. The displacement-controlled procedure was adopted for the loading program and the lateral displacement amplitude of each loading cycle was gradually increased.

All of the applied loads, and the vertical reactions at the beam supports were measured by the load cells 1,2,3 and 4 in Fig.4. Important strains of the longitudinal and transverse reinforcement bars, and the surfaces on the concrete and the steel tube were measured by strain gages. Lateral displacements including story drift and the deflection angle of the short column were measured by the displacement transducers located at the measuring frame. All the informations measured during the loading cycles were sent to the personal computer and were processed simultaneously.

EXPERIMENTAL RESULTS

Applied lateral load versus story drift relations obtained for all the test specimens are shown in Fig.5(a) through (d). Test specimen RH-10, the transverse reinforcement of which is provided by the conventional rectangular spiral hoops, failed in the shear failure mode and was not able to develop its ultimate flexural moment capacity. The measured load-story-drift hysteresis loop of this specimen (Fig.5(a)) indicates the small level of strength and ductility, large load degradation, and considerable pinching after the ultimate strength. Peak values exceed the theoretical lateral load-carrying capacity which was determined by the ultimate shear strength of the short column. After yielding of the spiral hoops in the short column occurred, pronounced shear cracks were observed in the short column. Fig.6(a) shows the final cracking pattern of the specimen RH-10.

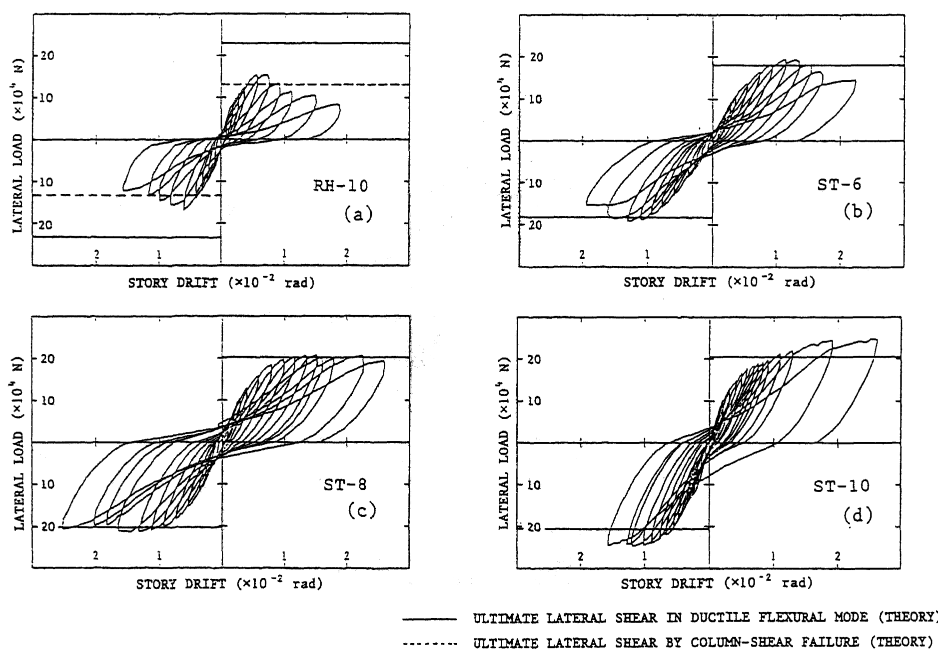

Figure 5. Lateral-Load versus Interstory Displacement Relations

The ultimate lateral load measured in the specimen ST-6 exceeds slightly the theoretically expected value in the beam-plastic hinge mechanism as shown in the bottom of Fig.3. The first plastic flexural hinge was formed at the bottom of the first-story column and then the second and third hinges were formed at the column faces of the right and left spandrel beams. Just after forming the final (third) hinge, crushing of the wall-element concrete initiated in the regions adjacent to the column faces, and then degradation of lateral load capacity started. The considerable deterioration in strength observed in the hysteresis loops in Fig.5(b) is caused by these crushing and spalling-off of the wall-element concrete. Cracking pattern after the test of this specimen is shown in Fig.6(b).

The hysteresis loops in Fig.5(c) indicate that the measured ultimate lateral load in the specimen ST-8 exceeds slightly the theoretically expected lateral strength. As can be seen in the expected failure mode shown in the bottom of Fig.3, the second and third plastic hinges of this specimen were expected to form at the right and left of the column faces of the spandrel beams. In the experiment, however, the third (final) hinge was not formed at the column face but formed at the top of the first-story short column. The main reason to this cause is that the intermediate longitudinal bars were not taken into consideration in evaluating the flexural strength of the spandrel beam with rectangular cross-section. In the test of the strong beam-weak column specimen, ST-10, hinges were formed at the top and bottom of the first-story short column.

Although the specimens ST-8 and ST-10 failed in the column-failure modes, considerable strength deterioration did not take place, and those two specimens showed very good ductility and energy dissipation potentials. In addition, there were no pronounced local fractures and/or shear deterioration in the beam-column joint occurred in those specimens.

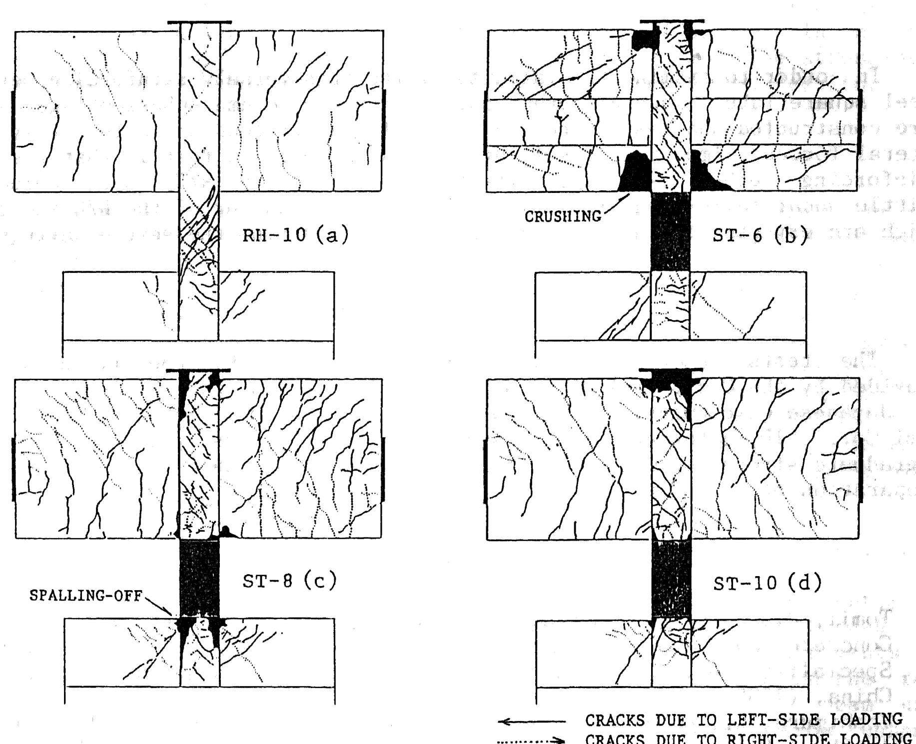

Figure 6. Cracking Patterns of Test Specimens after Test

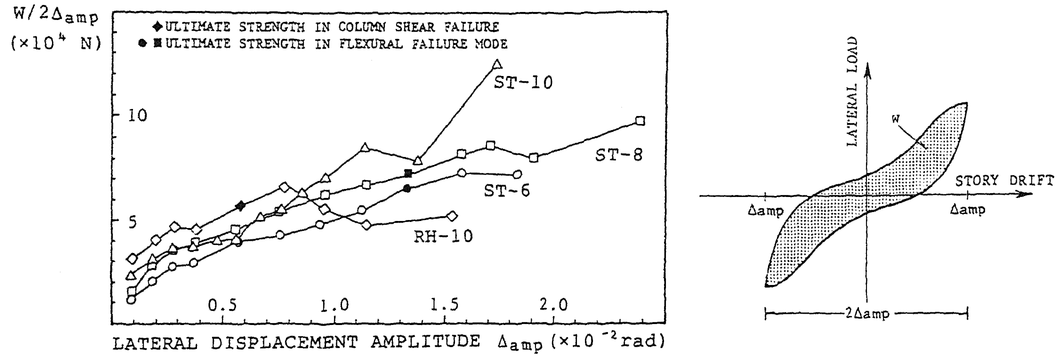

Figure 7. Energy Absorption Capacity

Fig.7 shows the comparison of the energy absorption capacity in all the specimens. The area within the hysteresis loop for each cycle of loading shown in Fig.5(a) through (d) was divided by a sum of the corresponding plus and minus interstory displacements. Results are plotted in Fig.7 against the corresponding displacement amplitudes. Gradual increase in the energy dissipation per unit story drift can be observed from the figure. It is worthy of note, however, that the rapid deterioration in energy absorption capacity occurs when the short column of the specimen RH-10 reached at its ultimate shear strength.

CONCLUSIONS

In order to examine the validity of the transversely reinforcing method by a steel square tube, four different curuciform beam-column subassemblage specimens were constructed and tested under a constant gravity load and alternately repeated lateral forces. Important result drawn from the present test is that the proposed reinforcing method is quite effective to prevent the R/C short columns from brittle shear failure and to improve the seismic behavior of the R/C short columns which are expected to fail in brittle shear mode during the severe earthquakes.

ACKNOWLEDGEMENTS

The tests reported herein were made possible by the financial support provided by the Grant in Aid for Scientific Research of the Ministry of Education of Japanese Government. The authors wish to thank Mr. Takehiko KAN of Kumagai Gumi Co., LTD, a former graduate student of Oita University and Mr. Kazuo IGUCHI, a graduate student of Oita University, for their assistances in the experiment and preparation of this paper.

REFERENCES

1. Tomii, M., et al., "Earthquake-resisting Hysteretic Behavior of Reinforced Concrete Short Columns Confined by Steel Tube", Proc. of the International Speciality Conference on Concrete Filled Steel Tubular Structures, Harbin, China, (1985)
2. Yoshimura, K., et al., "Experimental Study on R/C Subassemblages to Prevent A Short Column from Shear Failure by using A Steel Square Tube", Proc. of Pacific Conference on Earthquake Engineering, Wairakei, New Zealand, Vol.1, (1987)