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A PROPOSAL OF SEISMIC SHEAR STRENGTHENING METHOD FOR R/C SHORT COLUMNS IN EXISTING BUILDING STRUCTURES

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SUMMARY

In order to develop the effective method for strengthening (or repair and rehabilitation) of existing reinforced concrete short columns which are expected to fail (or damaged) in brittle shear mode during severe earthquakes, experimental studies are conducted by using 1/3-scale beam-column subassemblage specimens. Test results demonstrate that, if the short column is strengthened by a welded steel square tube, then brittle shear failure does not occur and the column can develop its ultimate flexural moment capacity. In addition, proposed strengthening method is applicable for repair and rehabilitation of damaged short columns failed in shear mode during severe earthquakes.

INTRODUCTION

Numerous examples of shear failures in reinforced concrete (R/C) short columns have been reported during the recent earthquakes in Japan and other earthquake countries. In Japan a new design method for R/C columns was proposed in 1970 in order to prevent the columns from brittle shear failures. On the contrary, a large number of R/C building structures having short columns which were designed in accordance with the old design provisions are still in use throughout the country. Preliminary analysis by authors indicates that most of those old short columns and some of the new short columns, especially in school buildings, are expected to fail in brittle shear failure modes during strong earthquakes. As the result, it is one of the most important engineering problems to be solved to develop the effective method for strengthening, repair and rehabilitation of those existing structural members at minimum cost. In the present paper, seismic shear strengthening, repair and rehabilitation methods by using steel plates and/or steel square tube are proposed to improve the seismic behavior of R/C short columns in the existing building structures practically, easily and inexpensively. The experimental study presented herein is one of the test series in Ref.1.

SPECIMENS

Test specimens adopted in the present study are 1/3-scale models of a 1.5-story beam-column subassemblage belonging to the lower levels of 4-story R/C school buildings. Overall dimensions of a typical subassemblage (Specimen NB) are shown in Fig.1 together with the cross-sectional details of the first-story short column and the spandrel beam of test specimens of Group E in Table 1. Each of the

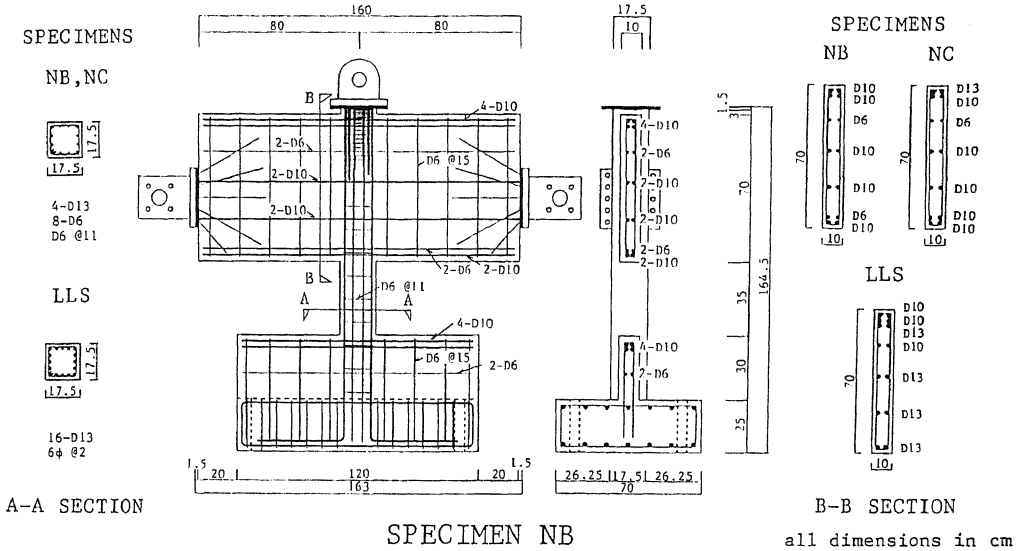
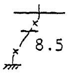
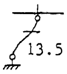
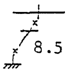
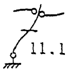
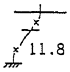


Fig. 1 Subassemblage Test Specimen and Cross-sectional Details

model subassemblage consists of a second-floor spandrel beam, a lower half (bottom) of a second-story short column and a first-story short column framing into a fixed foundation located in the ground floor. The shear-span-to-depth ratio of the first-story short column is 1.0 for all of the specimens. Eight different specimens tested are listed in Table 1, where expected failure modes determined by rough analysis are also schematically illustrated. Each of the test specimen is classified into three groups; Group E (Existing), Group S (Strengthening) and Group R (Repair and Rehabilitation) as shown in Table 1.

Table 1 List of Test Specimens and Expected Failure Modes

	Test Group					
	E(Existing)		S(Strengthening)		R(Repair and Rehabilitation)	
Specimen Number	NC	 8.5 SF	NC-S	 13.5 FF	NC-R	?
	NB	 8.5 SF	NB-S	 11.1 FF	NB-R	?
	LLS	 11.8 SF	----		LLS-R	?

SF : Shear Failure in First-story Short Column
FF : Flexural Failure
○ : Location of Plastic Flexural Hinge

all dimensions in 10^4 N

Group E Specimens NC and NB in this group are the model subassemblages of two existing R/C school buildings which were designed and constructed in accordance with the new aseismic design provisions after 1970. Both of the specimens have the same cross-sectional details in their short columns, where area of the longitudinal reinforcement is pg=2.50 percent of the gross area of column section and the shear reinforcement ratio is pw=0.33 percent. The only difference in details between two specimens is the amount of longitudinal reinforcement in the spandrel beam. In addition to these two specimens, Specimen LLS was constructed to investigate the validity of the repair and rehabilitation method proposed in this paper. In Specimen LLS, quite large amount of longitudinal and shear reinforcements are provided in the short column, that is, pg=6.64 percent and pw=1.64 percent respectively.

Group S According to the preliminary analysis against severe earthquakes, both of the first-story columns of Specimens NC and NB had been expected to fail in brittle shear mode. In order to prevent these short-columns from shear failure during strong motion earthquakes, same specimens with the test Specimens NC and NB in Group E were constructed and their first-story short columns were strengthened by a welded steel square tube, which are designated as Specimens NC-S and NB-S respectively.

Group R Since all of the short columns of the three specimens in Group E had failed in brittle shear modes and had not been able to develop their ultimate flexural moment capacities, damaged first-story short columns were repaired and rehabilitated also by using a welded steel square tube in order to recover the lost seismic capacity. The name of these specimens repaired has a letter "R" after the specimen number in Group E, such as NC-R and NB-R as shown in Table 1.

STRENGTHENING METHOD (TEST GROUP S)

Strengthening method and procedure provided into the first-story short column in the test Group S is in the following:

(1) Machine a flat steel plate into L-shape plate by using a press-machine. Steel plates used are 6 mm in thickness.

(2) Weld each corner of faced two L-shape plates to make a square tubular section as shown in Fig.2. Clearance between steel tube and short column surface is approximately 5 mm.

(3) After fixing the steel tube by spacers, seal the top and bottom of the welded steel tube by an inorganic sealer allowing no liquid leakage, and at the same time, bury aluminium pipes with 10 mm diameter in the top and bottom sealing materials.

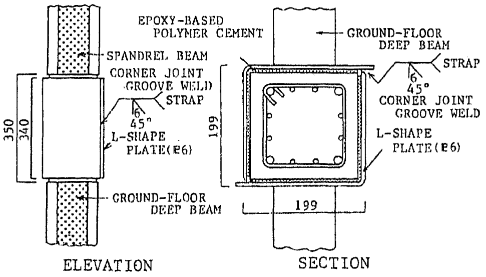


Fig. 2 Details of Strengthened Short Column

(4) By using the bottom aluminium pipes, inject an epoxy-based polymer cement under pressure into the clearance between steel tube and R/C column surfaces. Role of the top aluminium pipes is to exhaust the air from the clearance during the injection of the polymer cement.

(5) After curing, cut off the inorganic sealer from the top and bottom of the strengthened short column. This is to make the steel tube not to carry the longitudinal stresses but to carry the only transverse stresses during earthquakes.

Compressive strength of the polymer cement injected was 291 kgf/cm^2 (28.5 MPa) at the time of the experiment. Provided that the shear failure does not occur in those two strengthened short columns during the lateral loading reversals, failure mechanism at their ultimate state of the test Specimens NC-S and NB-S become ductile flexure modes, that is column mechanism in Specimen NC-R and beam mechanism in Specimen NB-S, respectively as shown in Table 1.

REPAIR AND REHABILITATION METHOD (TEST GROUP R)

Repair and rehabilitation technique provided into the damaged short columns in the test Group E is as follows (see Fig.3):

(1) Remove the residual interstory displacement occurred in the first-story short column in the test specimens of Group E.

(2) Cut off the cracked cover concrete around the core of each short column.

(3) Surround the naked short column by a welded steel square tube as mentioned

in the strengthening method in the test Group S.

(4) After sealing the bottom of the steel tube by an inorganic sealer and burying aluminium pipes in the sealer, put round coarse aggregate into the clearance between steel tube and concrete core of the short column. Maximum size of the coarse aggregate is 10 mm in diameter.

(5) Seal the top of the steel tube and also bury the aluminium exhaust pipes.

(6) Inject the epoxy-based polymer cement under pressure from the bottom pipes.

(7) After curing the polymer cement more than two-weeks, cut off the top and bottom sealer. Compressive strength of the polymer concrete was 258 kgf/cm^2 (25.3 MPa) at the time of the subassemblage test.

(8) By using an epoxy resin adhesive (epoxy-based putty adhesive), repair and recover the cracked and lost sections in the cover concrete near the top and bottom of the short column (see Fig.3).

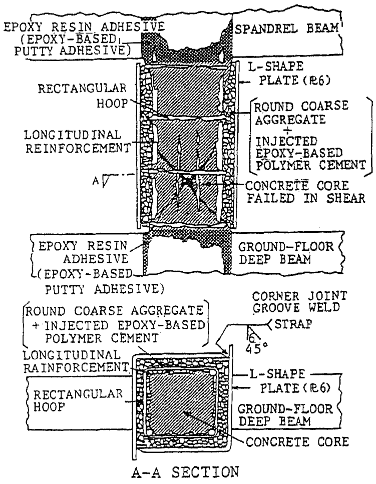


Fig. 3 Details of Repaired Short Column

EXPERIMENTAL TEST SETUP AND PROCEDURE

All of the specimens except for Specimens LLS and LLS-R were tested by using the test setup shown in Fig.4, in which all of the boundary conditions required in testing such types of the cruciform beam-column subassemblages as shown in Fig.1 are taken into consideration. Details of this test setup are discussed in Ref.1. Axial load to the column and alternately repeated lateral forces were applied at the mid height of the second-story short column by using the hydraulic jacks 1 and 2 in Fig.4. Since vertical reactions and displacements at the left and right supports of the spandrel beam should be always kept equal respectively, the "VERTICAL REACTION AND DISPLACEMENT EQUALIZER" is installed, and by using the "MOMENT AND ROTATION EQUALIZER" bending moments and rotation angles at the left and right beam supports can be equalized, respectively. All of the tests were intended to conduct under a constant gravity load: P/AcFc = 0.1, where P, Ac and Fc are axial load, gross-area of the column and compressive strength of the concrete in each specimen, respectively. The value of this gravity load is the corresponding value of the axial load to which first-story columns of 3- to 4-story school buildings are subjected. Displacement-controlled procedure was adopted for the loading program and the lateral displacement amplitude of each loading cycle was gradually increased.

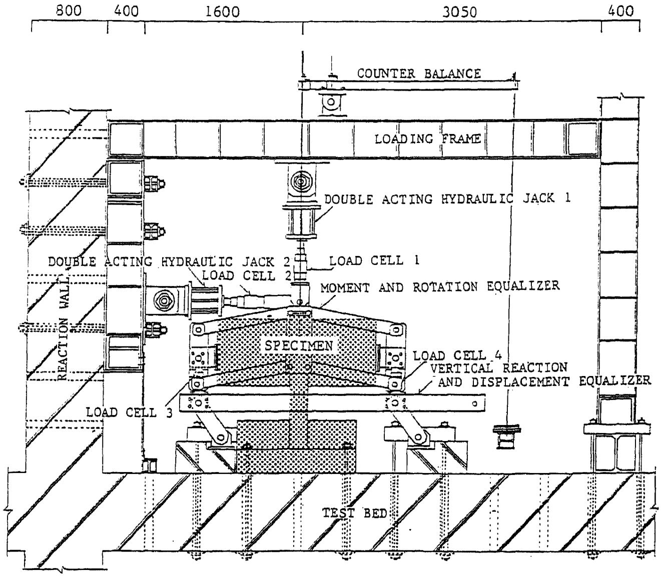


Fig. 4 Experimental Test Setup

EXPERIMENTAL RESULTS

Axial-Load versus Story-Drift Relations Fig.5 shows one of the typical examples of axial-load versus story-drift relations measured during the experiment. As can be seen from the figure, the axial load applied to the column was kept to be almost constant during the early stage of each test when the story-drift in the first-story is approximately within the value of 0.2 % rad., however, at larger lateral displacement amplitudes, the axial load increased gradually from the initial value of 0.1 to finally about 0.2 of the (P/AcFc)-value. This increase in axial load was mainly caused by the elongation of columns due to crackings and high axial rigidity of the new test setup. Such variation in axial load did not occur in Specimens LLS and LLS-R because of being conducted by the old test setup with poor axial rigidity.

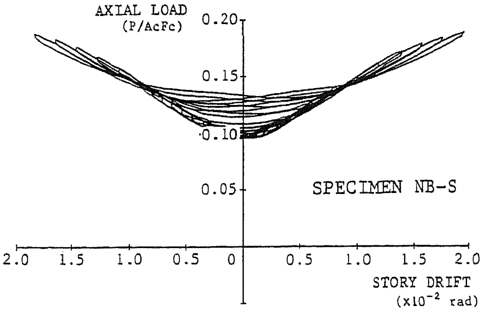
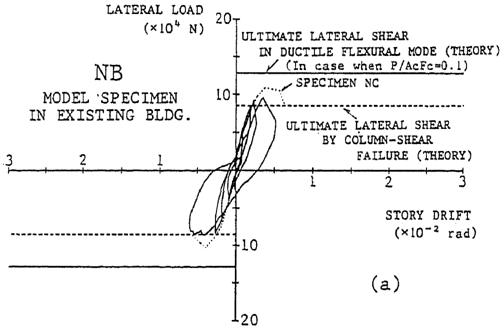


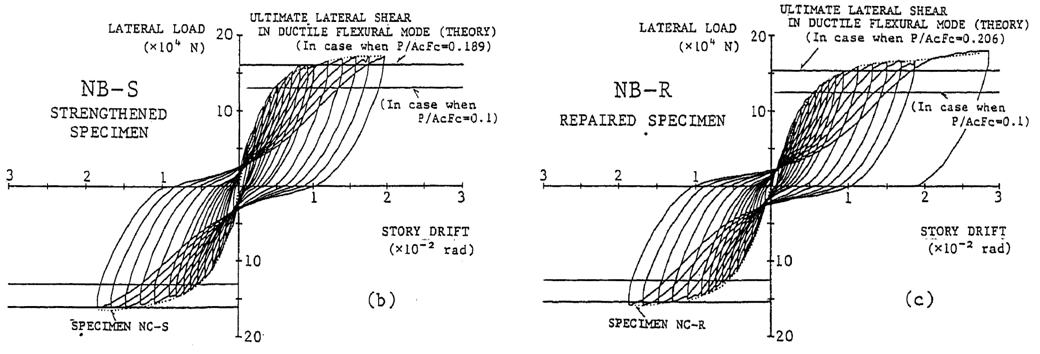
Fig. 5 Axial-Load versus Story-Drift Relation

Lateral-Load versus Story-Drift Relations Applied lateral-load versus interstory displacement relations observed in Specimens NB, NB-S and NB-R are respectively shown in Fig.6(a),(b) and (c). A dotted curve in each figure shows the envelop of the lateral-load versus story-drift relations obtained from the corresponding test Specimens NC, NC-S and NC-R, respectively. Since each of the dotted curve is very close to all of the points of loading reversals, it can be understood that there is no considerable difference in the load-carrying capacity between two corresponding test specimens.

Fig.6(a) shows that the test Specimens NB and NC in Group E with ordinary rectangular hoop reinforcement failed in brittle shear mode when interstory displacements in the first-story was not larger than 0.5 % rad., and these specimens were not able to develop their ultimate flexural moment capacities, which are determined by a precise analysis and are shown by solid lines parallel to the horizontal axis in Fig.6. On the contrary, Specimens NB-S



(a)



(b)

(c)

Fig. 6 Lateral-Load versus Story-Drift Relations and NC-S in Group S whose short columns were strengthened by a steel square tube did not fail in shear mode but reached to the ductile flexure mechanism showing their ultimate moment capacities as shown in Fig.6(b).

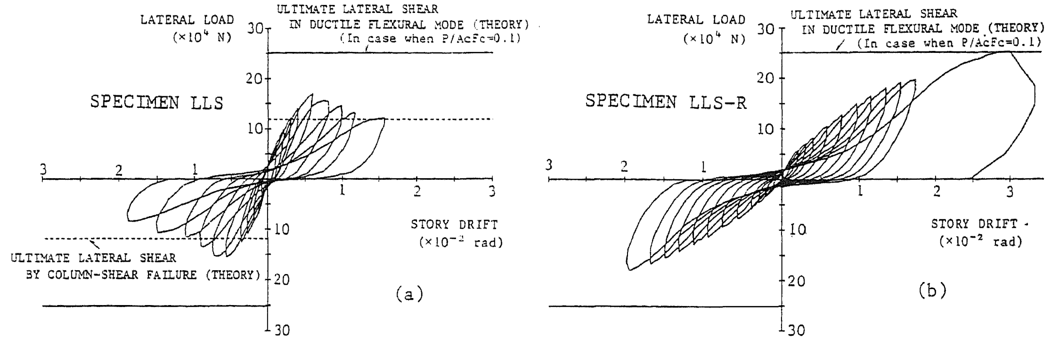


Fig. 7 Lateral-Load versus Story-Drift Relations

It is worthy of note that, by repairing and rehabilitating the damaged short columns in Specimens NB and NC by a welded steel square tube, repaired Specimens NB-R and NC-R in Group R did no longer fail in brittle shear mode as shown in Fig.6(c). In addition, these repaired specimens were able to develop their ultimate flexural moment capacities and, moreover it is very important to note that these repaired specimens showed very close load-carrying capacities to the strengthened Specimens NB-S and NC-S. Similar results was also obtained in the test Specimens LLS and LLS-R whose lateral load-displacement relations are respectively given in Fig.7(a) and 7(b). As the result, it may be concluded that the proposed strengthening (or repair and rehabilitation) method by a steel tube is quite effective to improve the seismic behavior of the R/C short columns which are expected to fail (or damaged) in brittle shear mode during severe earthquakes.

CONCLUSIONS

By using a welded steel square tube, strengthening method for R/C short columns which are expected to fail in brittle shear mode was proposed, and the validity of the proposed method to improve the seismic behavior of the R/C short columns in the existing building structures was verified by the experiment. In addition, this reinforcing method by using steel plates is also applicable to repair and rehabilitate the damaged short columns during strong motion earthquakes. This method proposed is quite practical because of being effective, inexpensive and very easy.

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REFERENCE

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