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AN EXPERIMENTAL STUDY ON ANCHORAGE OF TENSILE REINFORCEMENT OF WALL-COLUMNS AT THE TOP STORY OF RC WALL-FRAME STRUCTURES WITH FLAT-BEAMS

KUMAZAWA Fumitoshi[1], AKIYAMA Hiroki[2],
TANUMA Takehiko[3], WATANABE Kazuhiro[4],
TAKAMITSU Hiroaki[5] and TESHIGAWARA Masaomi[6]

SUMMARY

It is a distinctive feature of a reinforced concrete wall-frame structure with flat-beams that wall-columns are connected to wide and thin beams, i.e. flat-beams. Because of this feature, it is difficult to ensure the anchorage length of tensile reinforcing bars of wall-columns at the top story. New details of anchorage for the tensile reinforcing bars were proposed to solve the problem, and seismic loading tests on joint specimens of a wall-column and flat- beams were carried out to verify the effectiveness.

INTRODUCTION

A reinforced concrete building structure system without any projection forms of columns and beams in dwelling spaces have been developed to conform to diversified housing needs. One of the answers is the wall-frame structure with flat-beams in which the wall-columns are connected to thin beams with the depth of 350-400mm approximately. There is, however, a case in which the thin beam causes a problem in ensuring anchorage length of tensile reinforcement of wall-columns at the top story. It is not difficult to ensure the anchorage length at the middle stories, because bending moment carried by the flat-beams can be shared in two wall-columns at the upper and lower stories. On the other hand, it is not easy at the top story, because the bending moment must be borne by a wall-column at the concerned story. As one of the countermeasures, a construction method in which the wall-column is made to project on the roof is proposed. However, it is required that the upper end of the wall-column is leveled with the upper surface

[1] Associate Professor, Shibaura Institute of Technology, Tokyo, Japan.
E-mail: kumazawa@sic.shibaura-it.ac.jp
[2] Structural Engineer, Urban Development Corporation, Yokohama, Japan. E-mail: h-aki@udc.go.jp
[3] Structural Engineer, Urban Development Corporation, Tokyo, Japan. E-mail: t-tanuma@udc.go.jp
[4] Structural Engineer, Urban Development Corporation, Yokohama, Japan.
E-mail: k-watanabe07@udc.go.jp
[5] Structural Engineer, Structure & High Design Engineering Co., Ltd., Osaka, Japan.
E-mail: shkozo@ss.iij4u.or.jp
[6] Chief Researcher, Building Research Institute, Tsukuba, Japan. E-mail: teshi@kenken.go.jp

of the roof slab from the point of view of design demand, construction problems and so on. An anchorage method of tensile reinforcing bars of wall-columns at the top story was newly devised in order to satisfy the demands above mentioned. Seismic loading tests on wall column-flat beam joint specimens were carried out to verify the effectiveness.

ANCHORAGE METHOD OF TENSILE REINFORCEMENT OF WALL-COLUMNS

An anchorage method of tensile reinforcing bars of wall-columns within joint regions of a wall-column and flat-beams without any projections on the roof slab is shown in Figure 1. A U-shaped anchorage of the tensile reinforcing bars can simplify the bar arrangement around the joint, because it is unnecessary to arrange the anchorage into the beams. And supporting reinforcing bars for the U-shaped anchorage can contribute to prevent slippage of the tensile reinforcement from the joint regions. Supplemental stirrups also play an important role in order to prevent bond failure of longitudinal reinforcing bars of flat-beams.

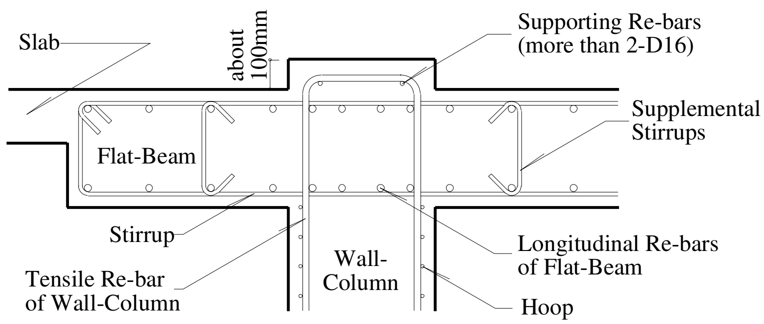


Figure 1: U-Shaped Anchorage of Tensile Reinforcement of Wall-Columns

LOADING TESTS

Test Specimens

Test specimens are three T-shaped joints of a wall-column and flat-beams on a scale of half size. All test specimens are planned to fail in shear at the joint regions of the wall-column and the flat-beams without any yielding of longitudinal reinforcing bars of the flat-beams in order to verify the anchorage strength of tensile reinforcement of wall-columns. The test parameter is anchorage method of the tensile reinforcing bars as shown in Figure 2. The test specimen with straight anchorage projected on the roof slab is named as FBI, and the specimen with the U-shaped anchorage in the joint regions is named as FBU. And a test specimen FBU2 has additional reinforcement to the specimen FBU, those are adding supporting reinforcing bars for the U-shaped tensile reinforcement of the wall-column and supplemental stirrups around the joint regions as shown in Figure 1. This specimen FBU2 is the repaired and strengthened the specimen FBU that has been tested once. In the repairing and the strengthening, concrete around the joint regions was removed and re-cast after newly arranging supplemental stirrups and U-shaped tensile reinforcement with supporting reinforcing bars. And the flat-beams of the specimen FBU are restrained by using PC steel rods in the thickness direction in order to regenerate and improve adhesion of longitudinal reinforcement of the beams, since the adhesion was damaged during loading tests on the specimen. Test results of concrete and reinforcing bars used for the specimens are listed in Table 1.

The ultimate resisting moment of joint regions of wall-columns and flat-beams is shown as a following equation [Ref. 1];

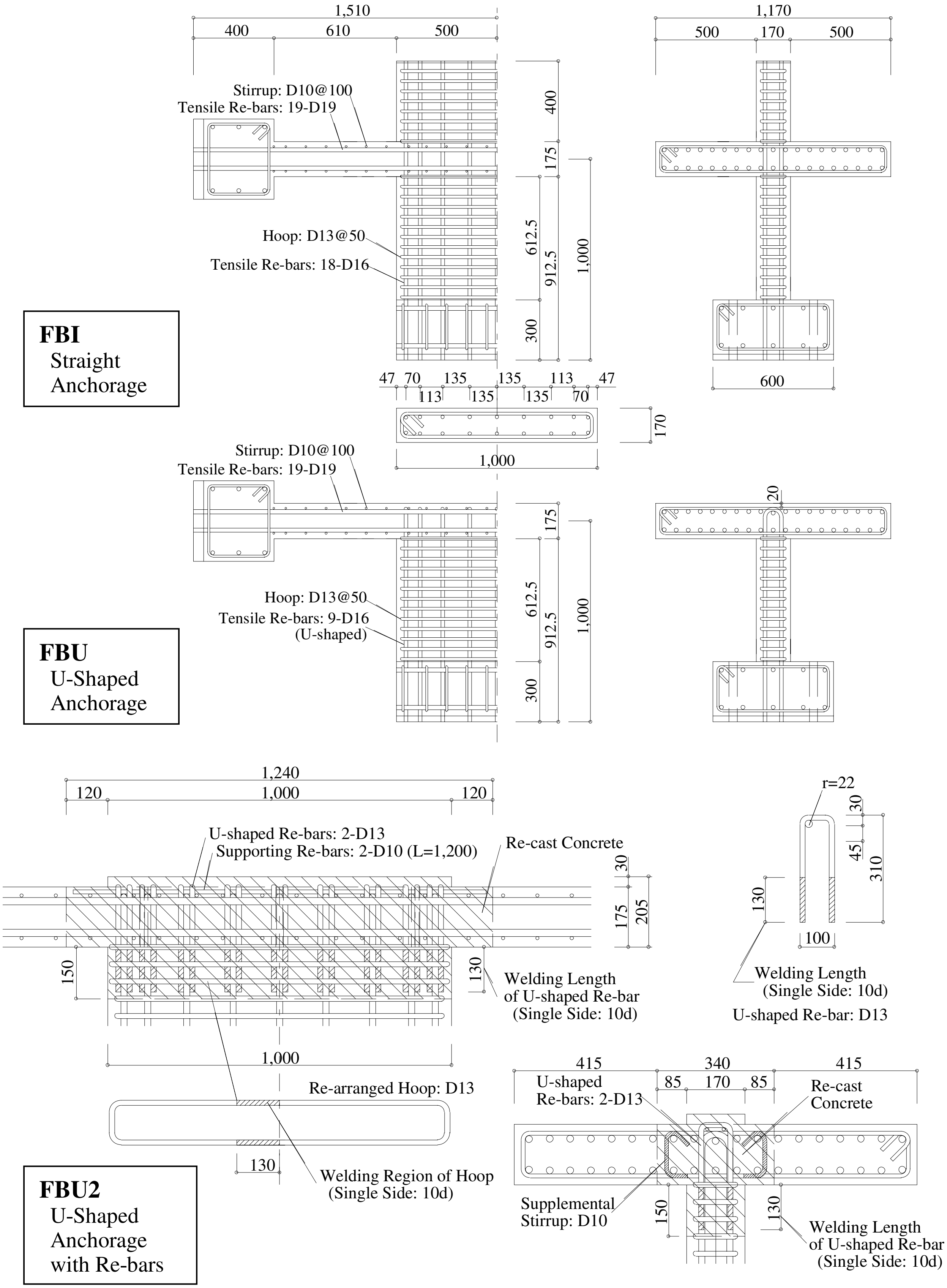


Figure 2: Shape of Specimens and Bar Arrangement (Unit: mm)

Table 1: Properties of Materials

Reinforcing Bars	Yield Strength (N/mm^2)	Tensile Strength (N/mm^2)	Yield Strain ($*10^{-6}$)
Shear Reinforcement			
D10 (Stirrup)	338.0	475.5	2,359
D13 (Hoop)	347.7	479.0	2,254
Tensile Reinforcement			
D16 (Wall-Column)	397.4	534.4	2,307
D19 (Beam)	387.2	568.9	2,158

Concrete	Compressive Strength (N/mm^2)		
	Wall-Column and Flat-Beam	Projected Part for Straight Anchorage	Repaired Regions
FBI	28.18 (26.06)	25.43 (22.86)	---
FBU		---	---
FBU2		---	28.60

Notes: Strengths at the time of loading tests are listed.
Values in parentheses show strengths after four weeks since casting of concrete.

$M_0 = M_f + M_s + M_t$

M_f : Resisting Moment transmitted by Longitudinal Reinforcing Bars within the Assumed Failure Section of Flat-Beam

$M_f = 0.9 \cdot \sum a_0 \cdot \sigma_y \cdot d$

where, $\sum a_0$: Area of Longitudinal Reinforcing Bars within the Section of Flat-Beam for Strength Calculation (mm^2)

σ_y : Yield Strength of Longitudinal Reinforcing Bars of Flat-Beam (N/mm^2)

d : Effective Depth of Flat-Beam (mm)

M_s : Resisting Moment by Shear Stress of Concrete at the Assumed Failure Sections of Flat-Beam

$M_s = \tau_u \cdot (C_2 + d) \cdot d \cdot (C_1 + d)$

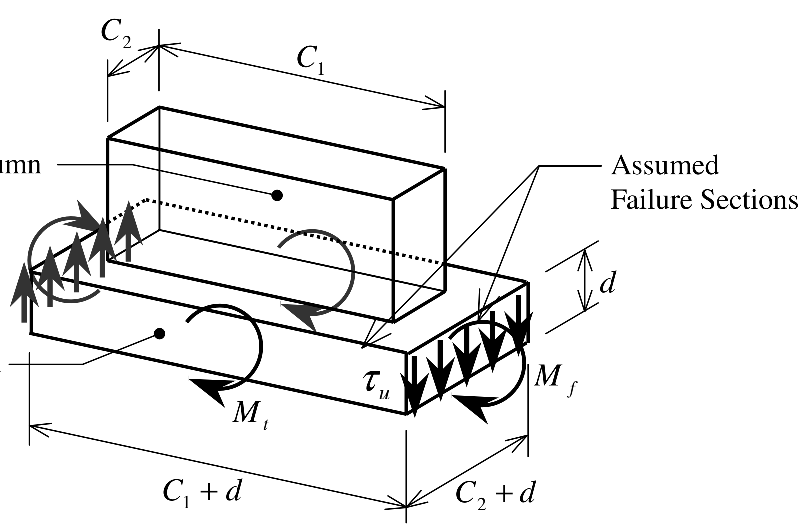


Figure 3: Assumed Failure Section and Resisting Mechanism of Joint Regions

where, τ_u : Shear Strength of Concrete ($=0.335\sqrt{\sigma_B}$) (N/mm^2)

σ_B : Compressive Strength of Concrete (N/mm^2)

C_1 : Depth of Wall-Column (mm)

C_2 : Width of Wall-Column (mm)

M_t : Resisting Moment by Torsional Stress of Concrete at the Assumed Failure Sections of Flat-Beam

$$M_t = \tau_{tu} \cdot d^2 \cdot \{(C_1 + d) - d/3\}$$

where, τ_{tu} : Torsional Shear Strength of Concrete ($=6\tau_u$) (N/mm^2)

Some variables included in the above-mentioned equations are indicated in Figure 3.

Loading Method

A cyclic loading was statically applied to the specimens using the actuator system controlled by displacement as shown in Figure 4. The test specimen was supported with pin device at the base stub and the loading stubs. Horizontal loading actuator connected to the loading stub supported with pin device was controlled by fixed displacement. Vertical forces were applied by two actuators supported with pin device according to the following schedule in principle; one cycle at the deflection angle of 1/2,000rad., and two2 cycles at the angles of 1/800rad., 1/400rad., 1/200rad., 1/100rad., 1/50rad. and 1/25rad.. Since the central line of the horizontal loading actuator deviated from the center of the joint regions of the wall-column and the flat-beams according to the vertical displacement of the loading stubs, the bending moment affected to the joint regions was defined adding the moment applied by the horizontal actuator to the moment applied by the vertical actuators. The harnesses were installed in order to prevent falling of the test specimen to out-plane directions.

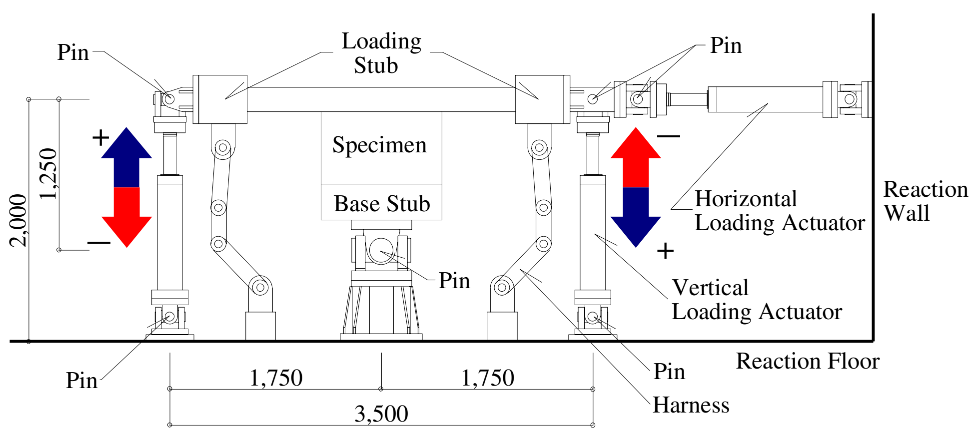
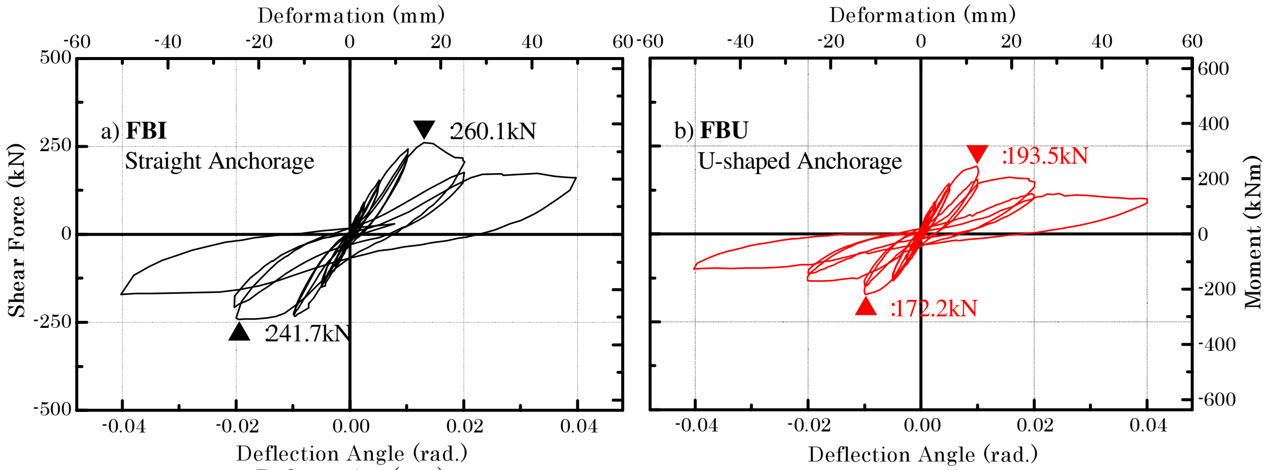


Figure 4: Loading Setup (Unit: mm)

TEST RESULTS

The bending moment affected to the joint regions of a wall-column and flat-beams is converted into shear force of the wall-column, and relationships between shear force and deflection angle are shown in Figure 5. The maximum strengths observed during loading tests are listed in Table 2 with the calculated strengths, and enveloped curves of the relationships in the positive loading direction are shown in Figure 6.



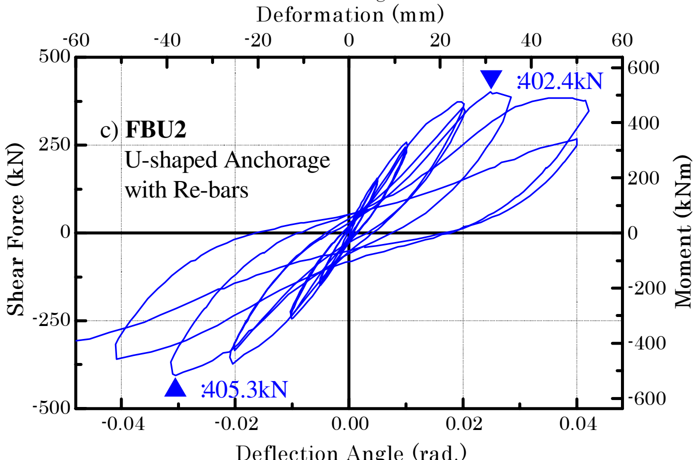


Figure 5: Hysteresis Loops

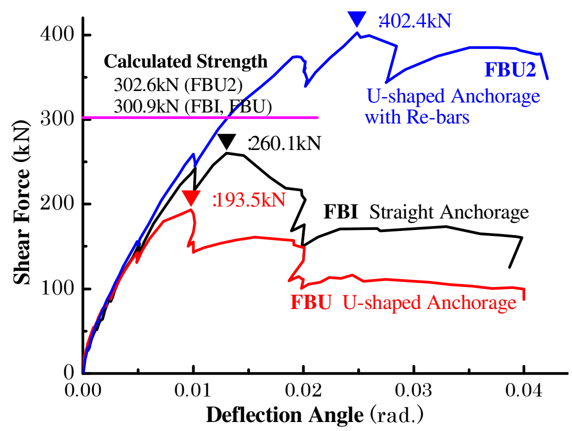


Figure 6: Enveloped Curves

Table 2: Strengths of Specimens Unit: Strength [kN], Deflection [rad.]

Specimen	Calculated Strength	Experimental Maximum Strength		Strength Ratio (Test/Cal.)
		Shear Capacity	Deflection	
FBI Straight Anchorage	300.9	+260.1 -241.7	+1/77 -1/51	0.86 0.80
FBU U-shaped Anchorage		+193.5 -172.2	+1/102 -1/102	0.64 0.57
FBU2 U-shaped Anchorage with Re-bars	302.6	+402.4 -405.3	+1/40 -1/33	1.33 1.34

Note: Upper values are observed during the positive loading and lower values are during the negative.

The specimen FBI with straight anchorage finally failed in shear at the joint regions without any slippage of tensile reinforcement from the regions. As was the case of this specimen FBI, the maximum strengths in each loading direction was observed during the loading cycle of 1/50rad.. The specimen FBU with U-shaped anchorage had strength deterioration with the slippage before shear failure. As was the case of this specimen FBU, the maximum strengths were observed at the peak of the loading cycle of 1/100rad. in both loading directions. They were approximately 70% of the values of the specimen FBI, and U-shaped anchorage of tensile reinforcing bars of the wall-column made the characteristics of the joint regions worse as a result. The maximum strengths in either case were less than the calculated values. It is one of the causes that adhesion of longitudinal reinforcing bars of the beams of the both specimens was lost during loading tests.

On the other hand, the slippage on the specimen FBU2 with U-shaped anchorage, supporting re-bars and supplemental stirrups was not observed during loading tests. And this specimen FBU2 was performed well and finally failed in shear at the joint regions. It is considered that adhesion of the longitudinal reinforcing bars of the beams was not lost during loading tests by conducting PC steel rods to regenerate and improve the adhesion properties. The maximum strengths in each loading direction of the specimen FBU2 exceeded the calculated values and also exceeded the maximum strengths of the specimen FBI which was failed in shear at the joint regions. The specimen FBU2 maintained on 80% of the maximum strengths until the drift of 1/25rad. in each loading direction.

CONCLUDING REMARKS

Static cyclic loading tests on the three T-shaped joint specimens consisted of a wall-column and flat-beams carried out with a test parameter of anchorage method of tensile reinforcing bars of the wall-column, i.e. straight anchorage projected on the roof slab, U-shaped anchorage in the joint region, U-shaped anchorage with supporting reinforcing bars and supplemental stirrups.

The test specimen with straight anchorage finally failed in shear at joint regions of a wall-column and flat-beams. However, the maximum strength was less than the calculated value, since adhesion of the longitudinal reinforcing bars and the concrete of the flat-beams was lost during loading tests.

Tensile reinforcement of a wall-column was slipped from the joint regions in a case of the test specimen using U-shaped anchorage system without any additional reinforcing bars. By adding supporting reinforcing bars to the U-shaped anchorage and supplemental stirrup to tie up the longitudinal reinforcing bars of beams, it was possible to restrain the slippage of the tensile reinforcement and make the joint strength higher.

Supporting reinforcing bars for the U-shaped anchorage and supplemental stirrup around the joint regions were essential to improve performance of the U-shaped anchorage system. This bar arrangement system for T-shaped joints of a wall-column and flat-beams at the top story is effective to keep good characteristics until large deformation region.

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REFERENCES

1. Architectural Institute of Japan Standard for Structural Calculation of Reinforced Concrete Structures, 1999.11 (in Japanese).