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EXPERIMENTAL ANALYSIS OF THE STRENGTH AT THE PANEL POINT OF R/C PANEL STRUCTURE

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ABSTRACT

This paper presented the strength at the panel zone of the reinforced concrete (R/C) Thick Wall Frame System (TWFS) experimentally. TWFS structures have been used for R/C residential building because of their wide spaces, flat walls and their noise protection behaviour. Thick walls and floor slabs were connected to form the TWFS structure. TWFS was prone to represent the failure at panel zone under flexural load. The panel zone failure induces the wall failure like the column failure of a frame system. Therefore, to prevent the panel zone failure, several additional reinforcements, such as Kanzashi (hairpin) bars and Shin (lead) bars, have been proposed and arranged. However, the utilities of them have not been investigated precisely. In this analysis, R/C TWFS models were tested under the combination of Kanzashi and Shin bars. The models were tested under monotonic loading and the displacement and the strains were measured. From the experimental results, the failure mechanisms of TWFS were clarified. Kanzashi and Shin bars prevented the formation of the plastic hinge at the panel zone of TWFS intesection and moved the occurence of the plastic hinge to the floor slabs. Shin bars improved the ductility of the panel zone together with Kanzashi bars.

KEYWORDS

Thick wall frame structure, TWFS, kanzashi-bar, shin-bar, panel zone, hinge relocation.

INTRODUCTION

Thick Wall Frame Structure (TWFS) have been applied to the condominium to obtain the large vacant space without columns and beams (Figure 1). The system is composed of the frame system in ridge direction and has rigidities of the frame compared with conventional beam column frame systems. In addition, the stresses are concentrated at the panel zone which is the intersection of walls and floors. Therefore, the strengthening at panel zone is expected (Genji 1995).


Figure 1. Sample of TWFS

The panel zone represents the plastic hinge and causes the reduction of the load bearing capacity of the frame up to failure. To prevent such a failure, the relocation system, that moves the location of plastic hinge from the panel zone to the floor panel or the wall, has been studied (Genji 1995). To obtain these improvements, Kanzashi bars and Shin bars are allocated (Figure 2). Kanzashi bars are allocated parallel to the main rebar of the floor panels to prevent the pullout of the main rebar. Also, Shin bars are allocated at the intersection of the floor slab rebar and the wall rebar. However, the effect of both Kanzashi bar and Shin bar against the deformation and the stress distribution has not been studied in detail.

In this paper, the stiffening behaviour at panel zone was investigated depending on the experimental work.

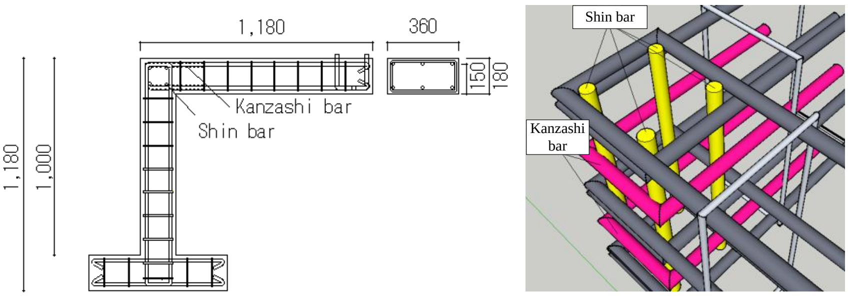


Figure 2. Cross section of TWFS (unit : mm)

EXPERIMENTAL WORK

Experimental Model

Figure 3 shows the panel zone in detail. Main rebar of a wall is crossing perpendicular to the main rebar of a slab. Kanzashi bars are inserted parallel to a slab rebar. Shin bars are arranged at the intersection of main rebar. The specifications of the model are shown in Table 1. Specimens A, B and C are provided under combination of such reinforcements. Material properties of rebar and concrete are obtained from material tests and are shown in Tables 2 and 3, respectively. Specimens were made under the consideration of the joint at TWFS. In addition, Kanzashi bars and Shin bars are arranged to study the effectiveness of such rebars.

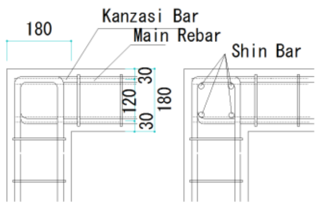


Figure 3. Panel Zone

Table 1. Specifications of the model

Specimen	Thickness x Width（mm）	Main rebar	Hoop	Kanzashi bar	Shin bar
A					None
B	180x360	6-D16	D6@200	4-D16	D16
C					D10

Table 2. Material properties of rebar

Rebar	Young's modulus (GPa)	Yield strength (MPa)	Yield strain (%)	Tensile strength (MPa)	Elongation (%)
D16(SD295)	186	310	0.17	489	26

Table 3. Material properties of concrete

concrete	Young's modulus (MPa)	Compressive strength (MPa)
Normal concrete	21	31

The length of the Kanzashi bars is 360mm. Concrete is poured into the wall and the slab simultaneously. Concrete thickness of the wall and the slab is 180mm and the width of them is 360mm.

Experimental Setup

In experiment, the specimen was put on the reaction base and was fixed by two bolts like a cantilevered frame (see Figure 4). At the end of the frame, the concentrate load was applied via hydraulic jack. The loading jack was connected to the hinged joints to remove the moment load caused by the deformation of the specimen. The deformations and the strains were measured by the displacement transducers and the strain gauges at each loading step. The load was applied monotonically in upward as shown in Figure 4. The loading step was every 5kN. The displacement and the strains were measured in each loading step. The cantilever arm, that is the distance between the wall centre and the loading point, is 945mm.

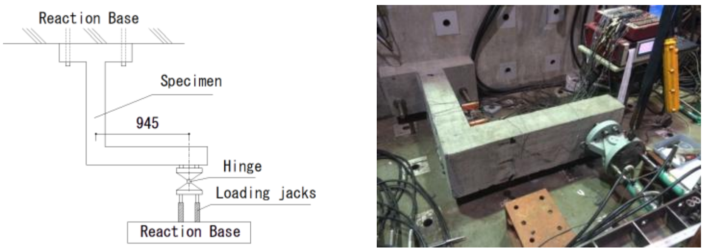


Figure 4. Experimental setup

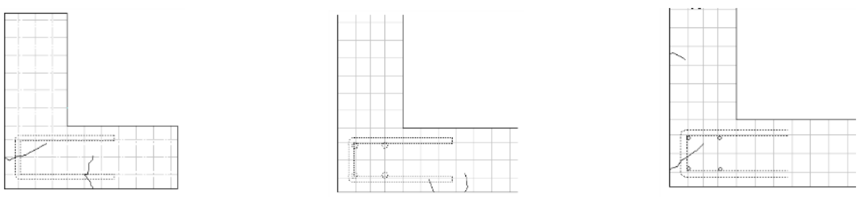
EXPERIMENTAL RESULTS

Crack Propagation

Focusing on the crack propagation, the stress distribution and the role of Kanzashi as well as Shin bars are investigated. The specimen A has only Kanzashi bar. Specimens B and C have Kanzashi bar and Shin bar. The size of Shin bar in specimens B and C is D16 and D10, respectively.

Figure 5 shows the cracks with loading stages. When the applied load is 22kN (Figure 5 a)), the specimen A shows the concentrate cracks around the panel zone.

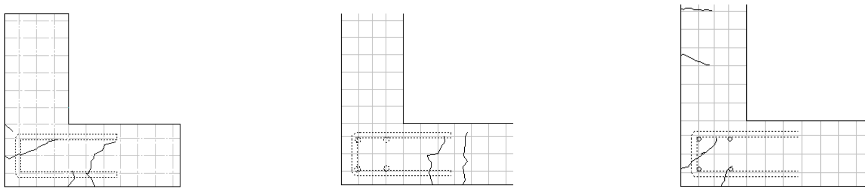
However, the specimen B does not show the crack around the panel zone at this loading stage. Therefore, Shin bar contributes the strength of panel zone. In case of C, the spacimen shows the concentrate cracks like the specimen A because the size of Shin bar is smaller than that of the specimen B. In case of the specimens A and C, the concrete at the panel zone fails.



A (Kanzashi bar) B (Kanzashi &D16 Shin Bars) C (Kanzashi &D10 Shin Bars)

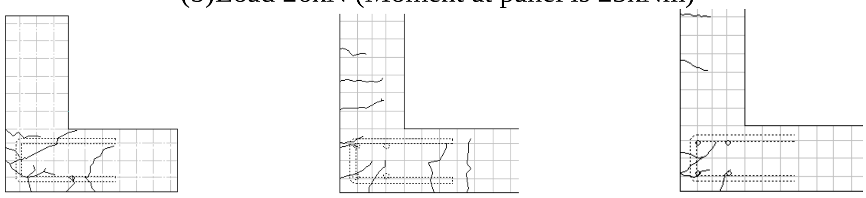
(a) Load 22kN (Moment at panel is 20kNm)

Figure 5. Crack propagation at panel zone



A (Kanzashi bar)　B (Kanzashi &D16 Shin Bars)　C (Kanzashi &D10 Shin Bars)

(b)Load 26kN (Moment at panel is 25kNm)



A (Kanzashi bar)　B (Kanzashi &D16 Shin Bars)　C (Kanzashi &D10 Shin Bars)

(c)Load 32kN (Moment at panel is 30kNm)

Figure 5. Crack propagation at panel zone (cont'd)

The specimen A does not improve the panel zone failure by the stiffening with only Kanzashi bar. Also, the specimen C does not improve the panel zone failure.

When the applied load is 26kN (Figure 5 (b)), the cracks occur on the slab of the specimen B. Crack position moves from panel zone to the slab zone. Then the specimen shows the ductile behaviour even the external load exceeds 32kN (Figure 5 (c)). Therefore, the hinge relocation is established.

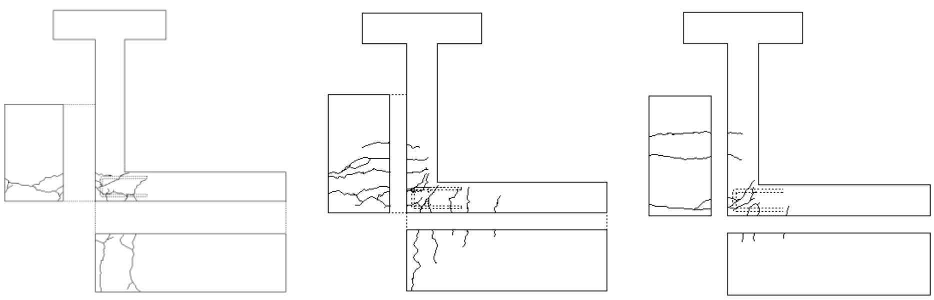
Ultimate States of Specimens

Table 4 shows the yielding of a main rebar and the ultimate moments of each specimen. The frame with both Kanzashi and Shin bars (Specimen B) represents the highest ultimate load. The specimen with Kanzashi bars and D10 Shin bar (Specimen C) shows higher ultimate strength than that with only Kanzashi bar (Specimen A).

Fig. 6 shows the crack patterns of the specimens at the ultimate strength. In specimens A and C, the cracks concentrate at the panel zone. The failure pattern is the shear failure at panel zone of the intersection of wall and floor. On the otherhand, specimen B shows the beam failure because the plastic hinge relocates from panel zone to the end of the Kanzashi bar (Figure 6).

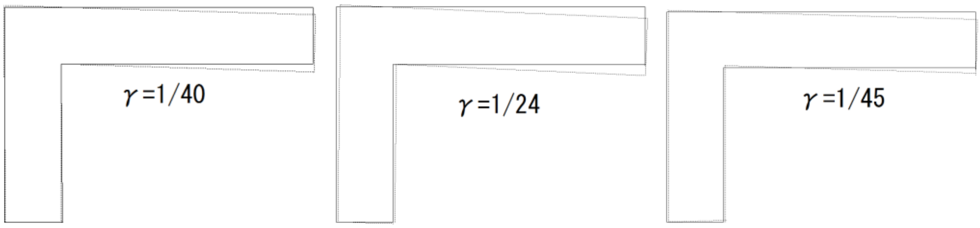
Table 4. Strength of Specimens

Specimen	Yield of main rebar(kNm)	Ultimate strength(kNm)
A	31.91	32.88
B	33.02	42.71
C	28.16	35.72



A（M=32.9kNm）　B（M=42.7kNm）　C（M=35.7kNm）

Figure 6. Crack patterns at the ultimate states



Specimen A Specimen B Specimen C

Figure 7. Deformation of the specimens

From the results of the material tests and the measurement of the strain gauges, the rebar yields under bending moment 32kNm. In this moment level, the strength of specimen B exceeds only 1% to that of cpecimen A. Also, the specimen shows smaller yield moment. Shin bars do not work as the reduction of yield moment of Kanzshi bars. The specimen A without Shin bar fails with additional moment 0.9kNm after yielding of the main rebars. On the other hand, the specimens B and C fails with additional moment 9kNm and 8kNm, respectively. Therefore, the specimens B and C show 30% redundancies from the yielding of main rebar to the failure.

Figure 7 shows the deformation of the specimens. The dotted line denotes the ultimate status. The maximum rotation angles for each specimen show in the figure. There are few differences among deformations but the maximum rotation angle of specimen B shows 1/25 and is larger than 1/40 of the specimen A and 1/45 of the specimen C, respectively.

From the experimental results, the toughness of the specimens A and B is 1.57 and 2.62, respectively.

Load Carrying Behavior of Frame

Figure 8. shows the relation between the applied moment and the strains for each specimen. The strain of the rebar located on outside columns is presented (N in Figure 8) . In specimens A and C, the panel zone fails under an applied moment 30kNm. Therefore, the strain in rebars grows rapidly. However, in specimen B, the stress at the position N transfers to other rebars and the sudden failure does not occur.

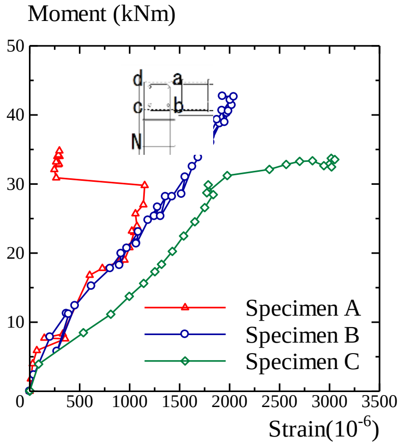
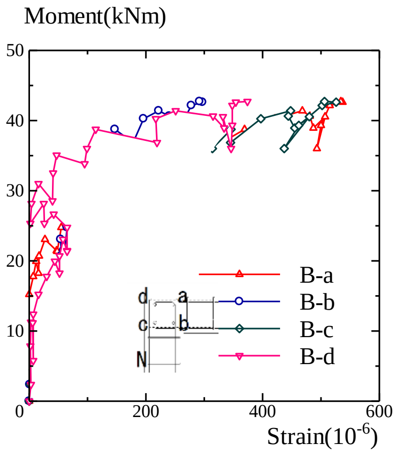
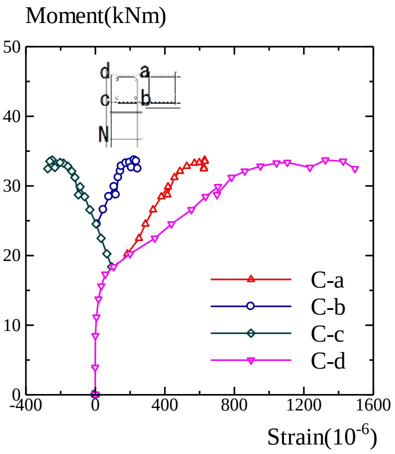


Figure 8. Strains in rebar

Figure 9 shows the strains in Shin bars a,b,c and d. The sizes of Shin bars are D16 and D10 for the specimens B and C, respectively. In specimen B, the strains in Shin bars grow modelately but the strains graw rapidly in specimen C. Also, the strains in specimen B are smaller than that in specimen C at the same moment level. From the results, Shin bars in specimen C deforms larger than than that in specimen B. Therefore, the appropriate Shin bar size is adopted in Specimen B because Shin bar prevents the movement of main rebars and Kanzashi bars and represents the smooth stress transform in



D16 Shin bar

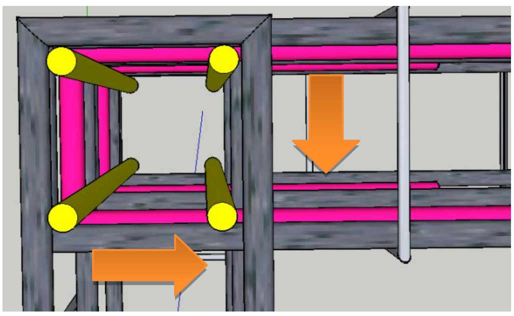


D10 Shin bar

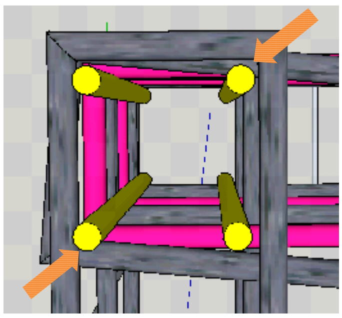
Figure 9. Stresses in Shin bars

specimen B. To form the relocation of hinge and to prevent the local failure of panel zone, the arrangement of both Kanzashi bar and Shin bar is requirerd.

Figure 10 shows the deformation mechanisms of the panel zone. When the moment is applied to the panel zone, the main rebar in the floor moves downward and the main rebar in the wall rotates clockwise. Then the rebars deform as shown in Figure 10 (b). From Figure 10 (b), Shin bars at right upper and left lower prevent the deformation and are bent in opposite direction (see Figure 9 C-a and C-c) if the thin bars are adopted. In case of appropriate bars are arranged, Shin bars show stable and represent the small strains. Therefor, the concrete in panel zone fails if the enough Shin bars are not arranged (see Figures 5 and 8).



(a) before deformation



(b) after deformation

Figure 10. Deformation mechanisms of panel zone

CONCLUSIONS

In this paper, the effects of the Kanzashi bar and Shin bar to prevent the panel zone failure of TWFS are investigated experimentally. Following conclusions are obtained in the experimental results.

1. Shin bar prevents the pull out of main rebars and Kanzashi bars.
2. To install Kanzashi bars and Shin bars introduces the ductile failure of the panel zone of TWFS
3. To expect the hinge relocation, both Kanzashi bars and Shin bars are required.

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