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Behavior of Precast Wall Connections for Strengthening Reinforced Concrete Frames

Comportement d'assemblages de panneaux préfabriqués pour renforcer des cadres en béton armé

Verhalten vorgefertigter Wandverbindungen zur Verstärkung von Stahlbetonrahmen

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SUMMARY

A novel technique using precast concrete panels to strengthen or repair non-ductile reinforced concrete frames is presented. Tests of panel-to-panel and panel-to-frame connections are discussed. In particular, shear key geometry and arrangement, closure strip height and reinforcement, and panel and closure strip concrete strengths are examined for the panel-to-panel connections. Embedment depth of shear lugs in the frame segment and closure strip is studied for the panel-to-frame connections. The impact of the test variables on specimen ultimate strength and residual shear strength is examined.

RÉSUMÉ

L'article traite d'un nouveau procédé pour renforcer ou réparer des cadres en béton armé peu ductiles, au moyen de panneaux en béton préfabriqués. Les auteurs examinent les assemblages des panneaux entre eux et ceux des panneaux aux cadres. Dans le cas du premier type de liaison, ils soulignent l'importance de la forme géométrique et de la disposition des clavettes de cisaillement, l'épaisseur et l'armature des bandes de béton coulé sur place, ainsi que le rapport de la résistance du béton coulé sur place à celle du panneau préfabriqué. Pour le deuxième type de liaison, il y est question de la profondeur d'encastrement des raccords de cisaillement dans les cadres et dans les bandes de béton coulé sur place. Les auteurs soulignent l'influence des paramètres d'essais sur la résistance ultime et la résistance résiduelle au cisaillement des échantillons.

ZUSAMMENFASSUNG

Es wird ein neuartiges Verfahren zur Verstärkung oder Reparatur wenig duktiler Stahlbetonrahmen mittels Fertigteilscheiben vorgestellt. Dabei werden die Verbindungen der Scheiben untereinander und zum Rahmen angesprochen. Für erstere werden die Formgebung und Anordnung von Schubnocken, die Dicke und die Bewehrung des Ortbetonstreifens und das Verhältnis der Ortbetonfestigkeit zur Fertigteilfestigkeit erörtert; bei der Verbindung zwischen Scheibe und Rahmen werden die Einbindetiefe von Schubanschlüssen im Rahmen und im Ortsbetonstreifen untersucht. Der Einfluss der Testparameter auf die Traglast und die Restschubtragfähigkeit der Prüfkörper wird gezeigt.

1. INTRODUCTION

The use of precast concrete infill walls and post tensioned boundary members to strengthen and repair nonductile reinforcement concrete frame structures is a technique that takes advantage of the shear capacity of infill walls and moment capacity afforded by post-tensioning tendons adjacent to the boundary columns. The objective of this study is to develop a viable repair and strengthening technique that will greatly reduce construction time and cost.

The infill wall consists of several precast concrete panels united by closure strips. The panels will be connected to the existing frame elements using special shear dowels or lugs located in the boundary closure strips [Fig. 1]. Post-tensioned tendons adjacent to the existing columns will supplement the tensile capacity of the existing columns and delay opening of the horizontal closure strips.

To investigate the behavior of panel-to-panel and panel-to-frame connections, fifteen specimens were constructed and tested. The specimens were subjected to reversed cyclic loads which were initially applied in a load-control mode. When the specimen had softened considerably, displacement control was used. All joint specimens were tested using the setup shown in Fig. 2. The remainder of this paper focuses on the connection test program and resulsts.

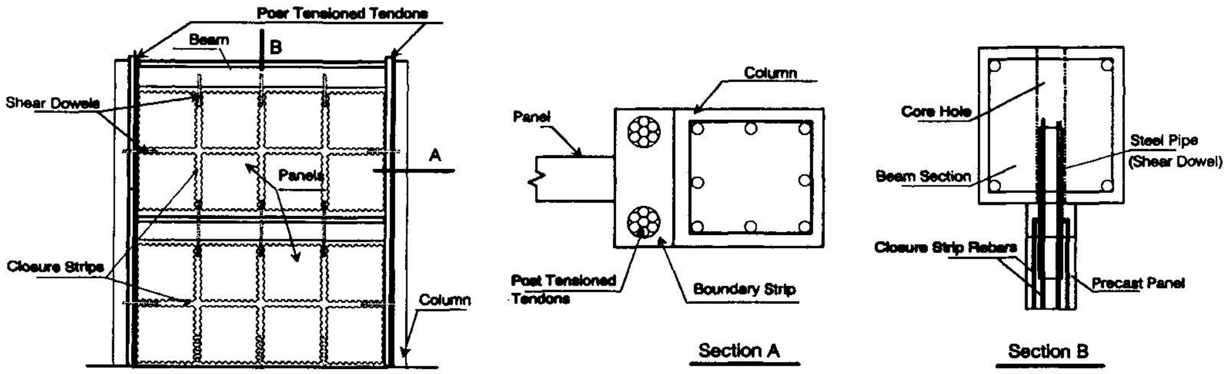

Fig.1 Precast Infill Wall System

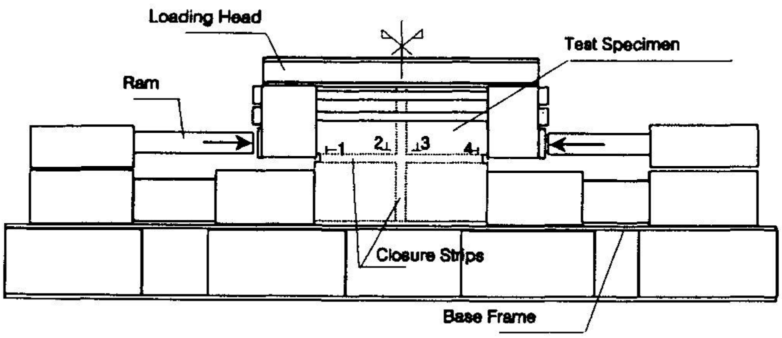

Fig. 2 Connection Specimen Test Set-Up

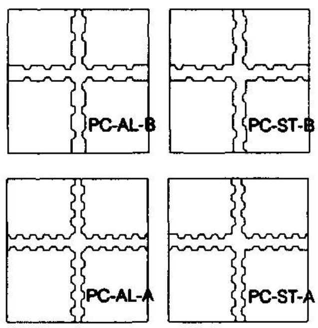

Fig. 3 Panel Connection - Key Patterns

2. PANEL TO PANEL CONNECTIONS

The weight and dimensions of precast panels will be limited to allow transport of the precast panels inside the building using a compact forklift during construction. The panel dimensions will be a function of the limiting weight, dimensions of the frame to be retrofited and wall thickness. For exampnle, a panel weighting approximately 8000 to 9000 KN with thickness of 15 cm would be as large as 150x150 cm. Twelve panel to panel connection specimens with thickness oo 15 cm and dimension of 125x90 cm were tested in the studies. Key patterns, closure strip dimensions and reinforcement and comparable strength of the panels and grout material in the closure atrips were variables in the studies.

2.1 Key Patterns

In order to allow shear transfer between panels, panel edges were cast with shear keys. Four specimens were cast initially with different key patterns as illustrated in Fig. 3. The specimens were full-scale representations of the connections located at the intersection of four panels. The panels were constructed with 35 MPa concrete and the closure strips were grouted with 50 MPa concrete containing 1.0 cm aggregate. Casting of joints was conducted with the panels in the vertical position to simulate the casting process that would be used in the field. The shear keys were 2.5 cm high and were positioned so the length of the crests and troughs were the same. For the less dense pattern, the length of the trough was increased by 50%. Keys on opposite sides of the closure strip were positioned to be aligned or staggered. The clear height of the closure strip was 5 cm and two #3 (0.95 cmdiameter) rebars were placed in both the horizontal and vertical closure strips.

The tests were conducted under direct shear along the horizontal closure strip. No other loads were applied to the specimens. The observed responses for the four specimens were quite similar. An example of measured load-interface slip response for specimen PC-1 (PC-AL-A) is illustrated in Fig. 4. It was noted that:

(1) The failure was typically the result of a direct shear failure through the base of the panel keys. In this test, the panel concrete strength was much lower than the closure strip concrete strength.
(2) The residual strength or shear friction strength of the specimens was substantially lower than the peak strength of the uncracked specimens. In fact, the rebars in the vertical strip yielded [Fig. 5] completely and the residual strength was primarily dependent on the ultimate strength of the vertical closure strip rebars.
(3) Both aligned and staggered key patterns gave approximately the same shear capacity for the same key geometry.
(4) Some air was trapped between the precast panels and the top of the closure strip concrete. There was lack of adhesion at the interface.

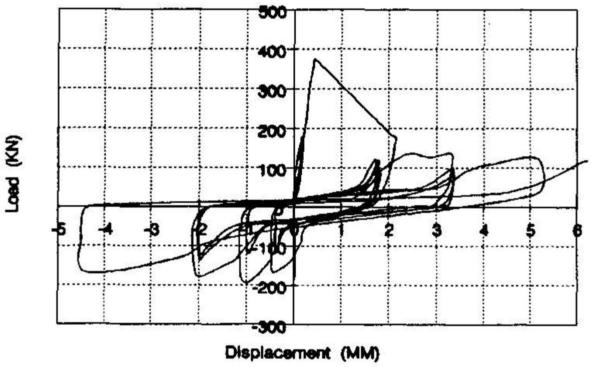

Fig. 4 Load-Interface Slip of PC-1

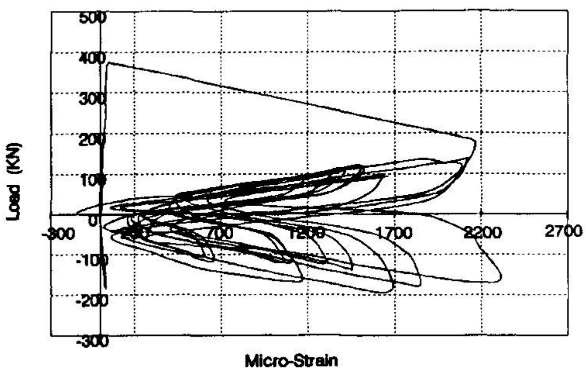

Fig. 5 Load-Rebar Micro Strain of PC-1

2.2 Strip Height

Although smaller closure strip heights result in placement of a small volume of concrete grout needed to construct the infill wall, the also make grouting of the closure strip difficult. It was not possible to grout the horizontal closure strip by placing grout from the vertical strip when the horizontal strip had a clear height of 5 cm. Furthermore, placing more rebars in the vertical closure strip to increase shear friction or placing shear lugs (described later) between the infill wall and existing frame requires a larger closure strip.

Several specimens were built with a clear closure strip height of 10 cm. The panel concrete strength was 30 MPa and the grout strength was 48 MPa. Specimen PC-5 was reinforced with 2-#3 rebars. Its ultimate strength was 310 KN and residual strength was 120 KN. Compared with the results of specimen PC-1 [Table 1], which had an ultimate strength of 374 KN, the lower strength of PC-5 was apparently the result of lower panel concrete strength. This suggets the ultimate direct shear strength is proportional to the panel concrete strength when the grout strength is higher than the panel concrete strength.

Although the closure strip height did not apparently affect the ultimate strength of the specimens, a 10 cm strip provided batter conditions for grouting. By adding superplasticizers to increase the grout slump to 20 cm or more, it was possible to cast the horizontal closure strips by placing grout through the vertical closure strip if some small openings were left in horizontal closure strip. The small openings provided in the horizontal closure strip focus to release entrapped air. The closure strip casting quality was much better than that of the 5 cm strip. In addition, the 10 cm strip was suitable for four or more rebars and the shear lugs that will be placed later.

2.3 Reinforcement

As mentioned previously, the reinforcement in the vertical closure strips played an important role in the shear friction strength. Within a certain range, more vertical strip reinforcement result in higher shear friction strength. Fig.6 illustrates the load-interface slip response of specimen PC-8. Comparing specimens PC-5 and PC-8, the vertical closure strip rebars increased from 2-#3 to 4-#4 (1.27 cm diameter bars) while the shear friction strength increased from 120 KN to 267 KN.

According to the test results and analysis, the shear friction is related to specimen ultimate strength, specimen cross section and vertical closure strip reinforcement. The ultimate strength also appears to be related to the amount of vertical closure strip reinforcement. Comparing PC-5 with PC-9 and PC-10 [Table 1], the ultimate strength for the latter two was 50% higher than the strength of the former because of the increase in the vertical closure strip steel.

When the vertical steel exceeded a certain level, the specimen experienced a concrete failed demonstrated by specimen PC-12. There were 6-#5 (1.59 cm diameter bars) rebars in the vertical strip and the ultimate load applied was 900 KN.

2.4 Grout Strength

All specimens except PC-7 were grouted with concrete having a strength of between 40 MPa and 50 MPa while the panel concrete strengths were between 30 and 35 Mpa. Because the grout strength was between 1.4 and 1.6 times the panel concrete strength, the failure of the specimens was typically along the base surface of the panel keys. In order to investigate the affect of grout having a lower compressive strength than the panle concrete, specimen PC-7 was grouted with concrete having 22 MPa concrete strength. Failure of this specimen was along the base surface of the closure strip keys.

2.5 Influence of Loading

All the specimens discussed to this point were tested under direct shear. This type of direct shear load between panels will obviously not exist in actual precast infill walls. Nonetheless, it was used to indentify the best details for joining together precast infill panels. In order to simulate a more realistic loading mode on theis connections, a compressive load was applied vertically on the specimen by tightening the loading head down to the base. Ulike the connections tested in direct shear which failed along the base of the panel or closure strip keys, connections subjected to combined load of direct shear and normal load experienced seversl diagonal cracks in the horizontal closure strip region. This type of cracking may be more representative of the behavior that will be experienced by actual panel-to-panel connections. Furthermore, the addition of vertical load also enhanced the ultimate strength.

It should be noted that this failure mode is based not only on the vertical load applied but also depends on the presence of asufficient number of rebars in the vertical closure strip to prohibit premature failure of panel keys.

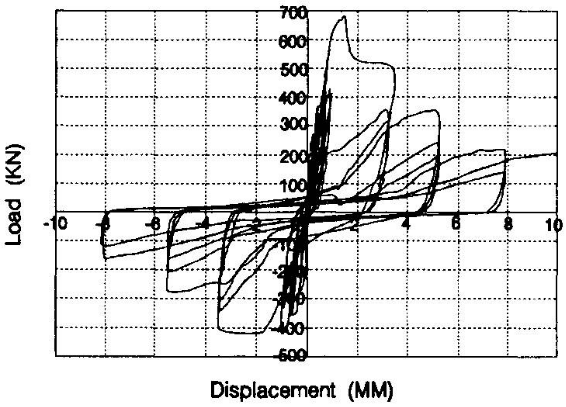

Fig. 6 Load-Interface Slip of PC-8

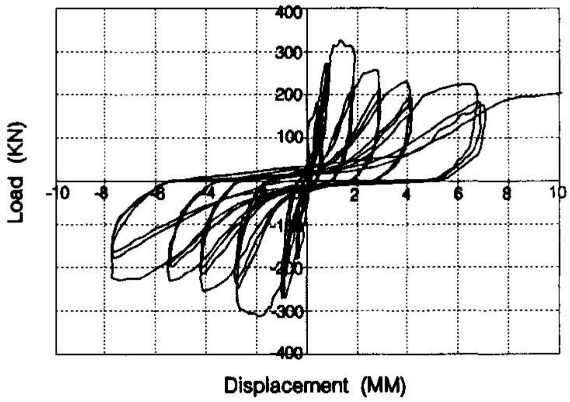

Fig. 7 Load-Interface Slip of FC-3

3. PANEL TO FRAME CONNECTIONS

In order to facilitate shear transfer along the interface between the precast infill wall and existing frame, a special shear dowel or lug made of a steel pipe will be embedded in the interface [Fig.1]. In the infill wall, the closure strips provide space for the embedment of the shear dowels. For the existing frame, cored holes in beams and columns are used to embed the shear dowels.

3.1 Connection Specimen

The holes to be cored in beams have three functions: to permit the shear dowel embedment, to anchor vertical closure strip reinforcement, and to facilitate placement of closure strip concrete placing. The size of the hole should be determined based on the width of the beam, the size of the dowel pipe and the number of reinforced vertical closure strip bars. A 10 cm diameter hole was cored in a 45 cm wide concrete beam segment and a steel pipe with 7.5 cm outside diameter was embedded in the hole. Before embeding the pipe in the interface of beam segment and precast panels, concrete was cast through the cored hole into the closure strips. Three specimens with various combination of pipe embedment in the closure strip and beam segment were cast and tested.

Table 1 Test Specimen Properties

member	f_c' of panel	panel thickn.	key height	key space	strip height	f_c' of strip	rebars	peak load	residual strength	Load condt.	remark
PC-1	35.5 MPa	15 cm	2.5 cm	6.25 cm	5 cm	50.1 Mpa	2-#3	374 KN	--		PC-ALA
PC-2	35.5	15	2.5	9.375	5	50	2-#3	276	--		PC-ALB
PC-3	35.5	15	2.5	6.25	5	50	2-#3	325	--		PC-STA
PC-4	35.5	15	2.5	9.375	5	50	2-#3	310	--		PC-STB
PC-5	29.7 MPa	15	2.5	6.25	10	47.7	2-#3	310	120 KN		Aligned
PC-6	29.7	15	2.5	6.25	10	47.7	4-#4	797	--	Vert. L	Aligned
PC-7	29.7	15	2.5	6.25	10	22.2	4-#4	455	262		aligned
PC-8	29.7	15	3.75 cm	9.375	10	47.7	4-#4	680	267		Aligned
PC-9	29.7	15	2.5	6.25	10	47.7	4-#3	460	178		Aligned
PC-10	29.7	15	2.5	6.25	10	47.7	2-#4	484	178		Aligned
PC-11	29.7	15	3.75 cm	9.375	10	47.7	4-#3	697	205	Vert. L.	Aligned
PC-12	29.7	15	2.5	6.25	10	47.7	6-#5	900	--	Vert. L.	Aligned
FC-1	29.7	15	2.5	6.25	10	47.7	23/10*	283	--		Aligned
FC-2	29.7	15	2.5	6.25	10	47.7	23/23	315	205		Aligned
FC-3	29.7	15	2.5	6.25	10	47.7	10/23	327	209		Aligned

* where 23/10 means the pipe embedded 23 cm and 10 cm in frame and panel respectively

3.2 Shear Dowel Performance

Because there were no shear keys in frame meber segment, the interface between the retrofit element and frame member segment cracked at lower load than the panel-to-panel connection specimens. As a result, the steel pipe began resisting shear at a relatively low load. Under cyclic load, the concrete developed a bearing failure on each side of the pipe and the pipe yielded. An conclution of the tests, the panels were split along their axes.

The different pipe embedments resulted in no significant differences in measured ultimate strengths. However, it is necessary to embed the pipe in closure strip with sufficient length to fully develop its yield. Specimen FC-1 with 10 cm pipe embedment in the closure strip developed slightly lower ultimate strength and could not develop significant residual shear strength before failing. Both FC-2 and FC-3 with a pipe embedment of 23 cm in the closure strip developed significant higher ultimate strength and significant residual strength [Fig, 7]. The residual strength of panel-frame connection is approximatly the shear yield strength of the steel pipe.

4. CONCLUSIONS

A novel technique utilizing precast infill wall panel to strengthening or repair non-ductile reinforced concrete frames was presented. Results of cyclic load tests on panel-topanel and panel-to-frame connections were discussed. The factors infuluence the performance of panel to panel connection were the height of the closure strips, the quantity of vertical closure strip reinforcement and the type of load mode. For a limited number of panel-to-frame connections, the size and embedment of the shear dowel were believed to have significant affect on the connection ultimate and residual strengths. To investigate the behavior of these connection details worked with post tension in a precast infill wall system under more complex loads, a large scale test frame is currently being constructed and will be tested.