Moment Capacity of L-Connections in PCSP Construction – An Experimental Study

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Abstract

The paper reports the results of an experimental study undertaken to develop a suitable cast-in-situ moment resisting vertical connection between two intersecting precast concrete sandwich panels (PCSP). Four types of cast-in-situ L-connections have been studied. The reinforcement in the connection is the 5.7mm diameter steel bar extended from the reinforcing wire mesh in the two panels. Eight specimens have been cast in total; there being two identical specimens for each type of the connection. The suitability of each connection has been examined as regarded its cracking moment, ultimate moment capacity and ductility measured in terms of the surface strain or change in the included angle between the intersecting panels under gradually increasingly moment. The paper describes the experimental investigation in detail and establishes the superiority of the looped-shape extended bar connection.

Article ready to publish. 2/12/2004.

INTRODUCTION

As early as 1970s, ACI committee 408 pointed out the need for research on joints in conventional concrete construction, as it was found that even when sufficient anchorage length for the reinforcing steel bar was provided, the reinforcing steel bar did not develop anticipated tensile stress [1]. Further, the tension cracks at the corner could not be prevented, even though a complicated reinforcement detail was adopted. As a result, Mayfield carried out extensive investigation to study the joint opening and closing moment capacities [2,3]. Jackson [4] and Abdul Wahab [5, 6] investigated the strength characteristics of joints obtained by intersecting U-bars. However, very little guidance is available on moment or shear capacities of cast-in-situ connections between precast concrete panels. Construction using PCSP leads to its own complexities as regards design of connections.

A PCSP consists of an insulation layer sandwiched between two reinforced concrete wythes interconnected by suitable shear connectors (see Fig. 1). The structural behaviour of the panels depends upon the strength and stiffness of the reinforced concrete wythes and the shear connector while the thermal resistance of the insulation layer governs the insulative value of the panel. Due to their superior insulation and structural efficiency, PCSP is increasingly being used as a load-bearing wall element.

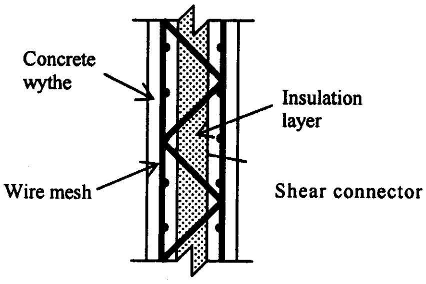

Fig. 1. Cross section of a PCSP

In a typical building, three types of vertical connections are encountered; there are L, T, or X-connections, as shown in Fig. 2. The present study relates to L-connections only. External load-bearing walls are subjected to wind induced lateral forces in addition to axial forces. The present paper presents only part of the results of the ongoing research on the study of connections in PSCP construction as related to cast-in-situ connections subjected to moment only.

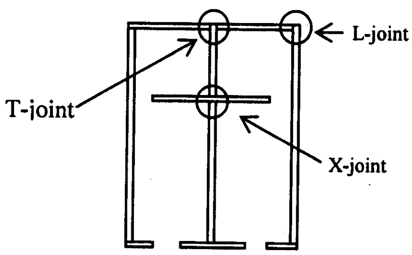

Fig. 2. A typical building plan

TEST SPECIMENS AND MATERIALS

A total of eight specimens representing four types of cast-in-situ L-connections have been cast. For each type of connection, two identical specimens have been tested under pure moment to get average values. A test specimen is made of panels 1 and 2 (Fig. 3); panels 1 being a PCSP while panel 2 is a solid precast concrete panel. The length of panels 1 and 2 is 1000mm and 800mm respectively, while the width for the two panels is 300mm. The overall thickness of wythes with one 40mm thick polystyrene layer in the middle. The reinforcement concrete wythes are connected by continuous steel truss shear connectors spaced 200mm apart and made of 5.7mm diameter mild steel bars. The shear connectors are so designed that the panel would not fail due to the failure of the shear connectors before the failure of the cast-in-situ connection. The reinforcement for the reinforced concrete wythes consists of a wire mesh with 100mm x 100mm openings and 5.7mm bar diameter. The concrete cover to the reinforcing wire mesh is 15mm. Each reinforcing steel bar has been extended from the reinforcing wire mesh to form the connection so that the spacing of the reinforcing steel bars in the connection is 100mm.

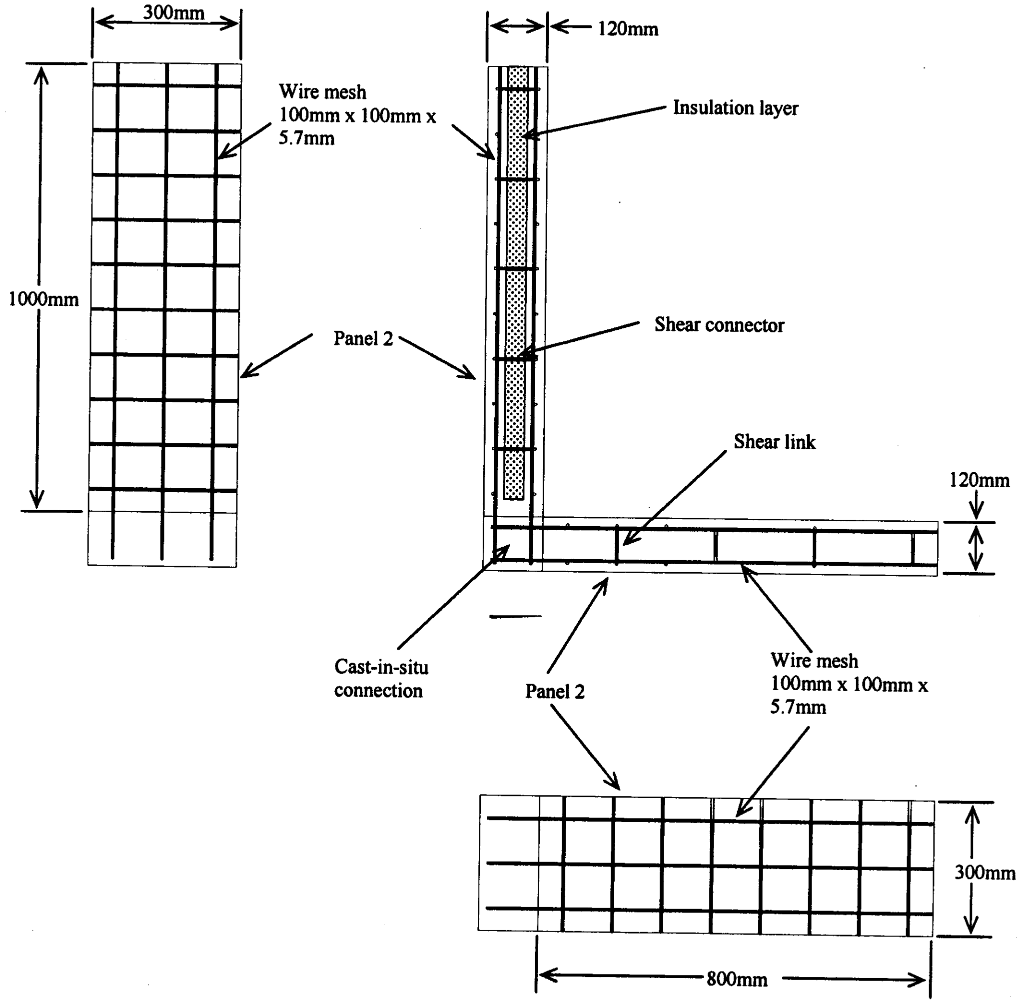

Fig. 3. Reinforcement details of the specimens

Fig. 4 shows the reinforcement details for the four types of the cast-in-situ connections, obtained basically by overlapping of the extended reinforcing steel bars from the precast panels in the connection zone. Due to the inherent nature of the precast panels, the reinforcing steel bars cannot extend continuously from panel into panel 2. Therefore, the actual anchorage length of the extended reinforcing steel bars is restricted by the limited cast-in-situ connection area.

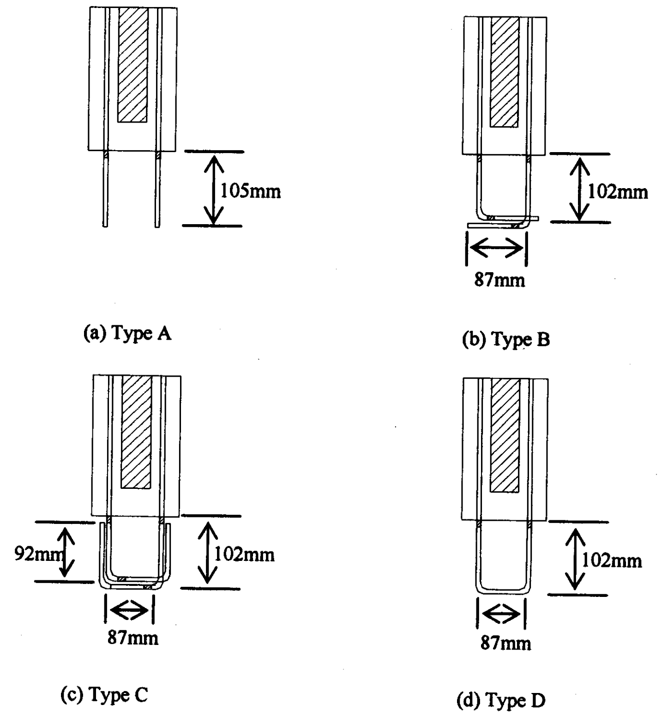

Fig. 4. Types of cast-in-situ connections investigated

It is seen that the anchorage length of the reinforcing steel bars for connection type A is 105mm. In order to increase the anchorage length of the reinforcing steel bars, the steel bars for joints type B and C were bent as shown in Fig. 4 thus permitting anchorage lengths of about 189mm and 281mm to be achieved. In case of connection D, a loop has been created through welding of a U clamp to the reinforcing bars of the wire mesh. The required anchorage length, according to BS 8110 is about 529mm.

Some pertinent material properties are given below:

Concrete:

compressive strength, $f_{cu} = 39N/mm^2$; elastic modulus $E_c = 26kN/mm^2$.

Plain steel mesh wire:

tensile strength $f_t = 650N/mm^2$; elastic modulus $E_s = 189kN/mm^2$.

TEST PROCEDURE

Two specimens of each type of the four connections have been tested under gradually increasing pure moment. The setup is shown in Figure 5. Panel 2 of the specimen is fixed to the reaction frame. In order to subject the connection to a pure moment, two equal and opposite forces, P are applied to Panel 1 of the specimen by jacks 1 and 2 operated by a centrally controlled unit. These two forces are separated by a distance of 0.55m, so that the connection is subjected to a moment of 0.55P kNm. The value of the force applied is determined from the load cell located between jack 1 and the reaction frame.

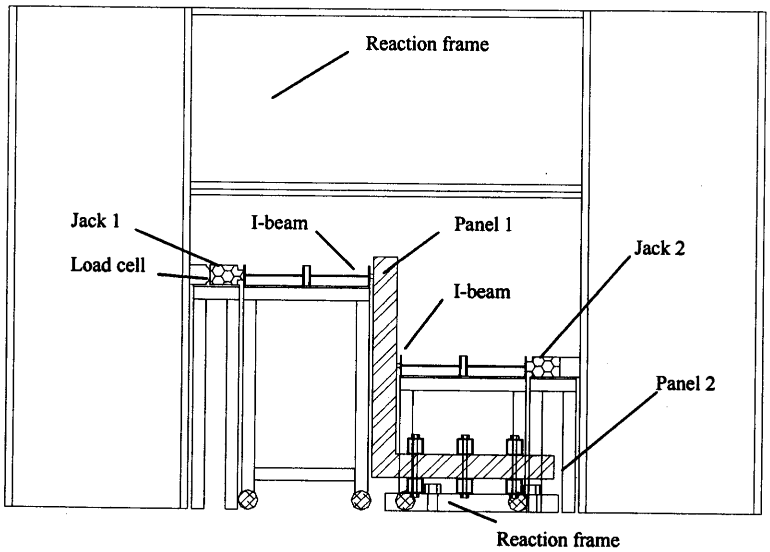

Fig. 5: Test set-up for pure moment test

Fig. 6 shows the location of the electric resistance strain gages (gage length = 30mm) used to measure surface concrete strains. Strain gages SS1 is located on the cast-in-situ concrete, strain gage SS2 is located on the construction joint between panel 1 and the cast-in-situ connection, and strain gage SS3 is located on panel 1. Demec gage studs have been provided to measure change in the included 90° angle between panels 1 and 2 with the help of a Demec gage.

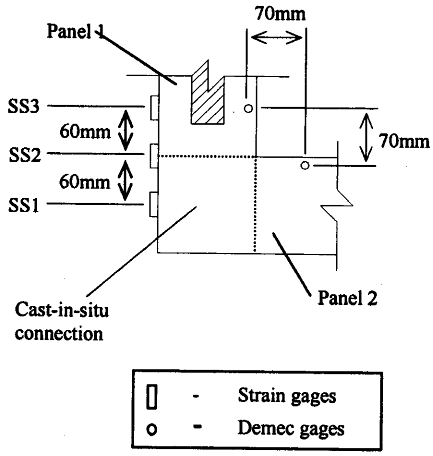

Fig. 6. Locations of the strain gages and Demec gages studs

RESULTS AND DISCUSSION

The performance of the four types of connections under a gradually increasing moment has been compared by measuring the change in the included angle, hence after called rotation for brevity, and the concrete surface strain. The average value of the observations on the two identical specimens of each connection type is presented.

Figure 7 shows the moment vs. rotation graph for connection types A, B, C and D. From the graph, it is clear that all the four types of connections behave in a similar manner initially, the behaviour being essentially elastic and linear. As the moment is increased, connection type A fails suddenly so that its behaviour is the least ductile as compares to the behaviour of the other three types of connections. Connection type D shows the highest ductility with a long well defined increasingly flatter curve near failure.

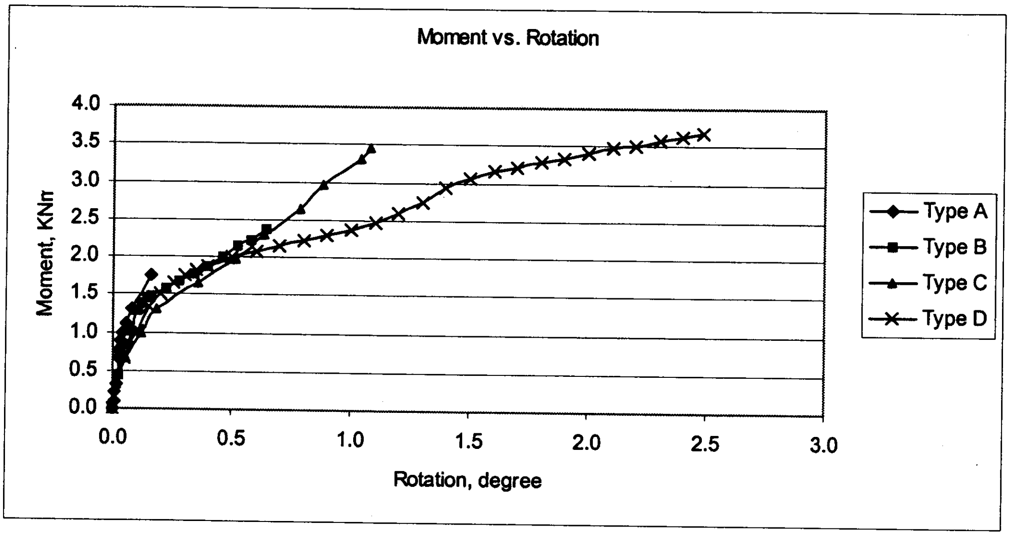

Fig. 7. Moment vs. rotation for connection types A, B, C and D

Table 1 gives the values of the first cracking moment and the ultimate moment capacities of the four types of connections. It is seen that although type D has almost similar first cracking moment as type B and C, its ultimate moment capacities is respectively 53.9%, 40.4% and 6.0% higher than of the connection type A, B and C.

Table 1 also gives the ratio of the ultimate moment to the first cracking moment for the four connection types, the ratio being indicative of the reserve strength. It is seen that connection type D has much superior performance compared to connection types A, B and C.

Table 1: Results of pure moment test

Specimen	Type A	Type B	Type C	Type D
First cracking moment, M_{cr} (kNm)	1.16	1.59	1.65	1.54
Ultimate momentt, M_u (kNm)	1.70	2.20	3.47	3.69
M_u / M_{cr}	1.47	1.38	2.10	2.40

Fig. 8 shows the moment vs. concrete surface strain graphs for connection types A, B, C and D. It is seen that the location SS2 is just at the interface between the in-situ concrete and panel 1 of the specimen and undergoes much greater strains than at the locations SS1 and SS3. Further, the strain at location SS2 shows a ductile behaviour. It may, however, be noted that strain gage SS2 became ineffective due to the appearance of the crack underneath before the ultimate moment could be reached. The strain SS1 is measured in a region of a complex stress state not liable to easy interpretation.

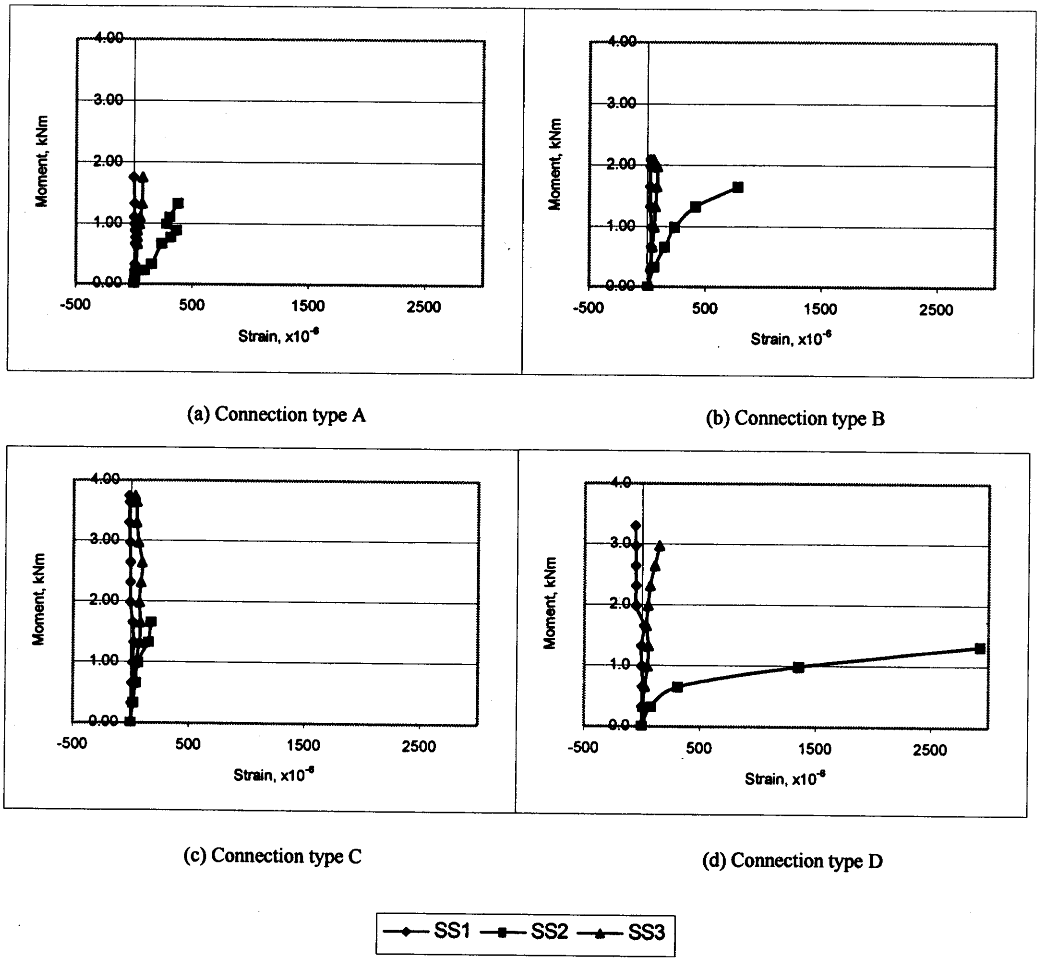

Fig. 8. Moment vs. concrete surface strains on the specified locations on the PCSP

CONCLUSION

PCSP construction leads to inadequate lengths at the cast-in-situ vertical connections due to relatively smaller connection area. The present study undertaken to develop a suitable connection indicates the superiority as well as the adequacy of a loop type connection type D. The connection type D also exhibits a ductile behaviour under increasing moment till failure. It is also seen that all the four types of connections studied in the present investigation have similar first cracking moment capacities thereby showing the inertness of the anchorage bars before the onset of cracking. The ultimate moment of resistance of the connection, however, depends on the anchorage length. The looped extended bars into the connection (Type D) increase the ultimate moment by about 120% over the open-ended extended bars (Type A).

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