Limit States Behaviour of the Connections
Typically Used for Precast Load-Bearing Shear Wall Panels

by

Sami H. Rizkalla, Ph.D., F.ASCE*

and

R. Serrette**

Use of precast load-bearing shear wall panels has become popular for highrise construction due to the high quality that can be achieved at the manufacturing plant and the ease of panel assembly at the erection site.

A total of six connection configurations, typically used for precast concrete load-bearing shear wall panels were tested to study the connections' behaviour at various limit states. Prototype precast concrete panels were used to subject the connection to monotonic shear load up to failure. Two levels of preload, applied normal to the joint, were used to study the dead load effect on the behaviour of such panels.

The different configurations include two types of dry-packed multiple shear keys, dry-packed plain surface, dry-packed plain surface with continuity reinforcement, and dry-packed with two types of mechanical shear connections in addition to the continuity bars. Applied load, average concrete strains, steel strains and deformation were measured to determine the mechanism and the contribution of each component of the connection, at the various limit states.

Test results were used to develop and calibrate mathematical models introduced to predict the capacity of such connections.

* Associate Professor and Head of Structures Division, Civil Engineering Department, University of Manitoba, Winnipeg, Canada, R3T 2N2.

** Graduate Student, Civil Engineering Department, University of Manitoba.
INTRODUCTION

Behaviour of the connections typically used for precast concrete load-bearing shear wall panels greatly influences the structural integrity of the entire structure. The current design sources (1, 2, 3) provide very limited information to describe the behaviour and design of such connections. The information available in the literature (4, 5, 6, 7, 8), which is mainly applicable to describe the shear friction concept and the dowel action mechanism of initially cracked concrete, is not directly applicable to the behaviour of such connections.

This paper discusses the results of two phases of experimental work undertaken to examine the behaviour of six connection configurations. The first phase included four types of connections: a dry-packed plain surface connection, a dry-packed connection with continuity reinforcement, and dry-packed connections with two types of mechanical shear connectors, in addition to the continuity bars. The second phase included two different types of dry-packed multiple shear key configurations. All the connections were subjected to monotonic shear load up to failure.

OBJECTIVE AND SCOPE

The primary objective of this paper is to investigate the limit states behaviour of six connection configurations typically used for precast concrete load-bearing shear wall panels. Thirteen prototype precast concrete shear wall panel specimens were used to test six different connections currently used by the construction industry. The study attempted to identify the contribution of each component used for
these types of connections. The results of the experimental program were used to refine and calibrate proposed rational mathematical models introduced to predict the strength of such connections before and after cracking.

**EXPERIMENTAL PROGRAM**

**Test Specimens**

A total of thirteen specimens were tested. Dimensions of all the precast panels were identical, with a thickness of 200 mm. Overall dimensions of the precast panels used and location of the mechanical strain gauges locations are shown in Figure 1. The dimensions correspond to a prototype scale of the precast panels typically used for highrise construction. The six connection configurations tested in this study are as follows:

- **Type I:** Dry pack grout only.
- **Type II:** Dry pack grout and 25M continuity bars.
- **Type III:** Dry pack grout, 25M continuity bars, and shear connectors Type A.
- **Type IV:** Dry pack grout, 25M continuity bars, and shear connectors Type B.
- **Type V:** Large-size dry-packed multiple shear keys.
- **Type VI:** Small-size dry-packed multiple shear keys.

Details of the above connections are shown in Figure 2.
Figure (1). Overall dimensions and average strain gauge locations of typical test specimen.
Figure (2). Details of the six connections considered in this study.
The average compressive strength of the normal weight concrete and the dry pack grout used for each specimen were determined using standard 150 x 300 mm concrete cylinders and 75 mm cubes, respectively. The concrete was supplied by a local ready-mix concrete company with a maximum aggregate size of 14 mm and an average slump of 75 mm. The reinforcement bars were Grade 400 W and the shear connection plates were 300 W steel, according to CSA CAN3-S16.1-M84 (9).

Each specimen consisted of two precast panels, as shown in Figure 1. All parameters, such as steel details and concrete material, were kept constant. Prior to testing, specially-designed temporary steel brackets were used for specimens with dry pack grout only. The dry pack grout mix consists of 2 parts concrete sand, 1 part normal portland cement, and approximately 0.5 parts water. The mix was placed and compacted into the 20 mm wide joint space between the two panels and the multiple shear keys. The mixture was of a dry consistency, which allows the tamping and compaction of the material.

Electric resistance strain gauges were used to measure the strains of the continuity bars and the shear connector plates. The average strains of the concrete and the dry pack were measured using mechanical strain gauges at various locations, as shown in Figure 1 for a typical specimen. LVDT's were also used to monitor the deformation parallel and perpendicular to the joint.
Testing Apparatus and Procedure

Each specimen was positioned vertically into the testing machine, as shown in Figure 3. The joint centerline of the specimen was aligned with the vertical centerline of the top and bottom heads of the testing machine. To study the dead load effect, two levels of preload applied normal to the joint equivalent to 2 MPa and 4 MPa were used. A post-tensioning scheme consisting of four hydraulic jacks, Dywidag bars and a series of plates designed to allow deformation of the joint were used to measure the preload, applied normal to the joint, as clearly shown in Figure 3. An additional post-tensioning scheme was used at the outer edges of each panel to prevent premature failure of the panel at the loading zones.

The testing procedure was started by applying the normal preload to the designed level followed by initial reading of all the instrumentation. The testing machine was used to apply the vertical shear load in increments of 100 kN. At each increment, all readings of all instrumentation were recorded followed by marking of the cracks. The experiment was terminated after extensive deformation and a significant drop in the load-carrying capacity was observed. Description of the tested specimens of the two phases, including the material properties of the concrete and dry pack grout, are given in Table 1.
Table 1. Overall Test Parameters

<table>
<thead>
<tr>
<th>Dry Pack Configuration</th>
<th>Load normal to connection MPa</th>
<th>Type of connection</th>
<th>Specimen mark</th>
<th>$f'_c$ MPa</th>
<th>$f'_{cg}$ MPa</th>
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<tr>
<td><strong>Phase I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Plain surface</td>
<td>2</td>
<td>I</td>
<td>SP11</td>
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<td></td>
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<td>II</td>
<td>SP12</td>
<td>32.3</td>
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<td>III</td>
<td>SP13</td>
<td>43.5</td>
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<td>IV</td>
<td>SP14</td>
<td>46.5</td>
<td>66.5</td>
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<tr>
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<td><strong>Phase II</strong></td>
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<tr>
<td>Multiple shear key</td>
<td>2</td>
<td>V</td>
<td>ILK2</td>
<td>47.5</td>
<td>37.0</td>
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<td>ISK2</td>
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<td>44.1</td>
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<td>2SK4</td>
<td>37.2</td>
<td>38.7</td>
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<tr>
<td>Plain surface</td>
<td>2</td>
<td>I</td>
<td>INK4</td>
<td>49.5</td>
<td>38.5</td>
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</tbody>
</table>

**Note:** $f'_{cg}$ is the cube compressive strength of the dry pack grout.
Figure (3). Test set-up.
TEST RESULTS AND DISCUSSION

Typical failure patterns of the various connections tested in this study are shown in Figures 4(a), 4(b), and 4(c). Typical load-slip behaviour of the connections tested in Phase I under a preload level of 2 MPa and 4 MPa are shown in Figures 5 and 6, respectively. The behaviour of the specimens tested in Phase II under the same preload levels are shown in Figures 7 and 8.

The test results of Phase I indicate that regardless of the mechanical connectors used, the cracking strength of the connections depends mainly on the bond strength at the dry pack-concrete interface. The residual shear, which represents the ultimate capacity of the connection is related to the level of the load normal to the joint, the dowel action of the continuity bars, and the resistance of the mechanical connectors. Thus, the ultimate shear resistance, \( V_u \), of these connections can be predicted using the following proposed model:

\[
V_u = \mu \sigma_n A_c + A_b f_y / \sqrt{3} + V_w
\]

where \( \mu \) = friction coefficient factor, 0.7 is proposed
\( \sigma_n \) = compressive stresses normal to the connection
\( A_c \) = cross-sectional area of the connection
\( f_y \) = yield strength of the continuity bars
\( A_b \) = area of the continuity bars
\( V_w \) = shear strength of the weld

The predicted ultimate shear resistance based on the proposed model was found to be in good agreement with the measured values, as shown in Figure 9.
Figure (4a)  Typical failure of connections I & II.
Figure (4b). Typical failure of connections III and IV.
Figure (4c). Typical failure of connections V and VI.
Figure (5). Load-displacement of the connections tested in phase I under preload of 2 MPa.
Figure (6). Load-displacement of the connections tested in Phase I under preload of 4 MPa.
Figure (7). Load-displacement of the connections tested in phase II under preload of 2 MPa.

Figure (8). Load-displacement of the connections tested in phase II under preload of 4 MPa.
Figure (9). Predicted and measured ultimate load.
The test results of Phase II indicate that using multiple shear keys will enhance the maximum shear capacity by as much as 60 percent in comparison to the plain surface connections at the same level of pre-load. The behaviour of these connections suggests that the shear capacity depends mainly on the strength of the weaker material within the vicinity of the connection and the level of the load normal to the connection. The difference in multiple shear key configurations used in this study had no measurable effect on the ultimate shear load capacity of the connection. It should be noted that the strength of the dry pack grout used in Phase II is considerably lower than the grout strength used in Phase I.

**CONCLUSION**

The behaviour of the various connections typically used for precast concrete shear wall panels is determined. Based on the test results, it was found that the behaviour is mainly dependent on the following basic parameters:

1) The tensile strength of the weaker material within the connection.
2) The bond strength of the dry pack grout.
3) The load level normal to the connection.
4) Dowel action of the continuity bars and the shear strength of the mechanical shear connectors.
5) The presence of the multiple shear keys.

The proposal mathematical model introduced for the plain surface dry-pack connections was found to be in good agreement with the measured values.
ACKNOWLEDGMENTS

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