OUT-OF-PLANE BEHAVIOUR OF CONNECTIONS BETWEEN PRECAST CONCRETE PANELS AND THEIR FOUNDATIONS

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SUMMARY

Precast concrete panels are commonly used throughout New Zealand in both low-rise industrial buildings and multi-storey buildings. The panel connection details vary depending on the building and connection type. Following the Canterbury earthquakes, concerns have been raised regarding the seismic behaviour of several different types of precast panel connections. One particular concern is the out-of-plane behaviour of shallow embedded anchors used in wall-to-foundation connections in low-rise industrial buildings. This type of connection is commonly used within the precast industry, and therefore it is essential to understand the expected seismic performance. A comprehensive experimental investigation is underway to assess the out-of-plane behaviour of different panel-to-foundation connection details using threaded inserts. A test setup was developed to simulate the expected shear and bending actions on the panel during an earthquake using a horizontal jack positioned at a certain height up the panel. A total of 12 panels were designed to represent commonly constructed connection details.

INTRODUCTION

Precast concrete elements are commonly used in New Zealand to construct structural members, such beams, columns, wall panels, and floor diaphragms. Some of the advantages of using precast concrete member include: (1) improved quality of members, (2) high speed of construction, (3) optimised use of materials and onsite labour, and (4) improved architectural finishes [1]. Less obvious advantages of precast concrete construction include reduced air pollution, noise pollution and traffic congestion [2]. The use of precast concrete buildings has come under extensive scrutiny following major earthquakes around the world [3-8]. In most cases, failure of precast concrete buildings during earthquakes is attributed to inadequate connections between the precast members and other structural elements [9].

In New Zealand, precast panels use a variety of grouted, bolted, welded, and in situ stitch type connections. In low-rise buildings, a type of proprietary threaded insert connection is widely used in precast concrete buildings for connecting precast concrete panels to floor diaphragms and to foundations, as shown in Figure 1. These inserts are installed inside the precast concrete elements, and starter bars are screwed into the inserts onsite to connect the wall panel to the foundation, as shown in Figure 2. Examples of manufactured precast panels using this particular type of proprietary threaded insert connections are shown in Figure 3.
The seismic behaviour of threaded inserts and their use in precast panel connections has been questioned by some engineers, particularly following the 2010/2011 Christchurch earthquake [10]. In terms of their design, dimensions and shapes, these threaded inserts are manufactured to provide enough resistance to prevent the bars from pulling out of them. However, concerns about the use of threaded inserts in concrete panel connections are related to potential concrete break-out prior to the panel achieving its full flexural capacity, and inadequate load paths in the connection region due to the shallow embedment. Despite New Zealand Concrete Structures Standard, 3101:2006 [11], containing provisions regarding the anchorage of various types of inserts in concrete, some engineers are still concerned about the cyclic behaviour of shallow embedded inserts.
A comprehensive experimental programme is underway to assess the seismic behaviour of typically precast concrete panel connection currently being used in New Zealand. One aspect of this project is investigating the out-of-plane response of wall-to-foundation connections that use threaded inserts. A summary of the planned out-of-plane panel tests is presented.

HISTORICAL REVIEW

Several investigations have been conducted to assess the load-deformation behaviour of shallow embedded inserts and a comprehensive literature review addressing anchor bolts and welded studs was carried out by Klingner and Mendonca [12]. Based on this review, it was concluded that previous assumptions for predicting the capacity of connection against break load were not conservative enough. The main reason for the observed difference between the experimental tests and predicted capacities was related to the quality of the concrete. In most cases, the quality of the concrete around the insert was lower than that indicated by the concrete test cylinders. This lower quality of concrete is a result of different casting, compacting and curing techniques. Klingner and Mendonca’s [12] investigation suggested that more accurate procedures are required to predict the ultimate capacity of these connections.

Both experimental and numerical analyses were conducted by Ballarini et al. [13] to examine the tensile capacity of embedded inserts. Ballarini et al. used linear elastic fracture mechanics to model the failure mechanism of shallow anchored inserts. Numerical analysis was also performed using a two dimensional model and the results were carried over to a three dimensional model by assuming a symmetric behaviour of the connection. The results of the experimental and numerical studies were compared with design code recommendations. For most design codes, the strength of the connection was calculated as the tensile strength of the cone-shaped concrete around the insert. Both numerical and experimental results confirmed that the cone-shaped break-out assumption used to calculate the tensile capacity of embedded inserts was not conservative enough. The reason for this overestimation is that an assumed tensile resistance equal to the maximum tensile strength of the concrete was not correct. Ballarini et al.’s [13] analysis indicated that the failure resulted from the fracture process and did not contribute to the tensile capacity of the concrete.

Both numerical and experimental studies were carried out by Vervuurt et al. [14] to analyse the pull-out behaviour of inserts embedded in concrete. T-shaped steel anchors cast in concrete beams were tested with a monotonic pull-out load. Concrete confinement was provided by two prestressed steel bars on each side of the beam, and a prestressing load was applied to each of the steel bars to prevent slipping. To minimise the effect of support friction, hinge tensile bars were used at the support of the beam. A numerical study was also conducted using a lattice model to simulate the crack patterns in the concrete. Only the area where cracks were expected to appear was modelled, using brittle beam elements, and the remainder of the specimen was assumed to behave elastically. The fracture of the concrete was modelled by removing the beams from the mesh when their stress reached fracture stress. A good agreement was observed on the failure mechanisms in both the experiments and the analytical model.

TEST PROGRAM

To evaluate the behaviour of wall-to-foundation connections using threaded inserts, precast concrete panels have been manufactured for testing in the out-of-plane direction. A total of 12 tests have been planned to investigate the capacity and failure mode of these panel connections. The panels were intended to replicate commonly used details in low-rise industrial buildings found from an extensive examination of drawings from recently
constructed precast panels. To simulate the seismic load on a panel, the lower potion on the panel was subjected to a single lateral load at a high equivalent to the point of contra-flexure. The jack will apply a horizontal load to the top of the panel resulting in a combination of bending shear at the wall-to-foundation connection equivalent to that of a 9 m high panel with a fixed connection at the foundation and pinned connection to the roof.

Test setup

The out-of-plane panel test setup that is being used to evaluate the threaded insert connections is shown in Figure 4. All 12 precast concrete panels are connected to a common strip foundation, and each panel will be loaded in the out-of-plane direction using a hydraulic actuator that is connected to the top of the panel. A steel frame is used as a reaction frame, so that the hydraulic actuator can be dismantled and re-used for the subsequent tests.

![Overall schematic of panel setup](image1)

(a) Overall schematic of panel setup

![Cross-section of single panel setup](image2)

(b) Cross-section of single panel setup

Figure 4. The specimen test setup

Panel details

To perform relevant tests on the threaded insert connections, test variables such as horizontal and vertical spacing between inserts, embedment depths, panel lengths, size of
inserts, slab thicknesses and load levels were considered. To determine the appropriate range of test variables, a survey on base connection details used in past precast concrete constructions was carried out. Construction drawings from a number of projects completed from 2005 to 2013 were studied, and the details of the precast concrete panels tested in this experimental programme were chosen to represent the most commonly used details observed. A summary of the test variables for each of the 12 tests included in Table 1 and sample drawings of the test walls are shown in Figure 5.

Table 1. The test table of out-of-plane experiment for threaded insert connections

<table>
<thead>
<tr>
<th>Panel</th>
<th>Length (mm)</th>
<th>Height (mm)</th>
<th>Slab thickness (mm)</th>
<th>Inserts</th>
<th>Horizontal spacing (mm)</th>
<th>Vertical spacing (mm)</th>
<th>Embedment depth (mm)</th>
<th>Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>900</td>
<td>2550</td>
<td>350</td>
<td>RB12Ti</td>
<td>300</td>
<td>200</td>
<td>108</td>
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<tr>
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<td>2550</td>
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<td>RB12Ti</td>
<td>300</td>
<td>200</td>
<td>108</td>
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<tr>
<td>3</td>
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<td>350</td>
<td>RB12Ti</td>
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<td>Cyclic</td>
</tr>
<tr>
<td>4</td>
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<td>710</td>
<td>RB12Ti</td>
<td>300</td>
<td>300</td>
<td>100</td>
<td>Monotonic</td>
</tr>
<tr>
<td>5</td>
<td>900</td>
<td>2550</td>
<td>710</td>
<td>RB12Ti</td>
<td>300</td>
<td>300</td>
<td>100</td>
<td>Cyclic</td>
</tr>
<tr>
<td>6</td>
<td>900</td>
<td>2550</td>
<td>710</td>
<td>RB16Ti</td>
<td>300</td>
<td>490</td>
<td>118</td>
<td>Monotonic</td>
</tr>
<tr>
<td>7</td>
<td>900</td>
<td>2550</td>
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<td>RB16Ti</td>
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<td>490</td>
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<tr>
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<td>RB16Ti</td>
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<td>RB16Ti</td>
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<td>118</td>
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<td>RB16Ti</td>
<td>354</td>
<td>354</td>
<td>118</td>
<td>Cyclic</td>
</tr>
</tbody>
</table>

* indicates test procedure including nail plate

The diameters of the connection bars connected to the threaded inserts were 12 mm and 16 mm, and the additional embedment depth when nail plates are used was 8 mm from the surface of the panel. The specified concrete compressive strength was 40 MPa for the
Precast concrete panels and 25 MPa for the foundation slab. For typically constructed panels, the two cone-shaped concrete breakout area of the threaded insert connections can overlap. Therefore, it is expected that the connection strength will be less than calculated breakout capacity of the threaded inserts and four additional tests were proposed to compare the strength differences between the single breakout and group breakout of the inserts.

**Loading**

Six tests will be conducted by applying monolithic loads, whilst the other six precast concrete panels will be subjected to reversed cyclic loads. This loading will allow for comparisons between the behaviour of these threaded insert connections under cyclic and monolithic loads to be established. If the panel behaves as intended, the failure should be controlled by flexural yielding of the panel prior to connection failure. In this case the test setup will be modified to allow the strength of the panel-to-foundation connection to be determined independently. The precast panel will be retrofitted using steel frames that are fixed onto its sides in order to strengthen the panel and place a higher demand on the connection, as shown in Figure 6. The horizontal load will be applied until failure of the connection occurs.

![Figure 6. The details of steel frame used to strengthen the panel](image)

**CONCLUSIONS**

Concerns have been raised regarding the seismic performance of precast concrete panel connections that use shallow embedded inserts. To address these concerns, an experimental test program is currently being conducted to investigate the out-of-plane behaviour of commonly used wall-to-foundation connections that use threaded inserts. A total of 12 tests will be conducted considering a number of different variables, including insert size and spacing, embedment depth, and loading type. The results of these tests will be used to evaluate the seismic behaviour and validate design procedures of such wall-to-foundation connections.
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REFERENCES