PULL-OUT STRENGTH OF STRAND LIFTING EYES IN PRECAST BEAMS AND SLABS


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Abstract: Strands bent into loops (known as lifting eyes) are often used to lift precast concrete slabs or beams. However, limited research on the pullout capacity of these anchors has been performed. In this research, a number of pullout tests were conducted on lifting eyes cast into a precast concrete Unispam slab, and lifting eyes cast into a precast concrete beam. The results obtained contributed to determining the pullout capacity and safe working load for these lifting eyes and provided a valuable insight for application to the precast concrete industry.

Keywords: Pull out test, Lifting eye, Unstressed strand, Lifting capacity.

1. Introduction

The concrete-strand bond in various applications has been investigated by many researchers. A literature review has revealed, however, the pullout strength and development length of unstressed strands has had limited study. One of the main applications of unstressed strands in the precast concrete industry has been as lifting eyes. These consist of strands that have been bent into loops and cast within slabs or beams. It is economical to use strands because short, off-cut lengths have little or no value in production, and are normally wasted. Currently, limited guidelines and standards for the design, fabrication and placement of these lifting eyes exist.

Therefore, in this research an experimental plan was developed with a focus on the pullout capacity of unstressed strands including straight strands and lifting eyes. This paper presents the results from the first part of this experiment (Tests 1 and 2) which was focused on the capacity of lifting eyes. In Test 1, seven samples of unstressed strand lifting eye embedded in a 75mm thick precast concrete slab (Unispam product) were loaded to failure. In the second Test, four types of lifting eyes (with different sizes and pin diameters) embedded in a concrete beam were investigated.

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2. Background and Literature Review

Various studies on concrete-strand bond in different applications have been reported in the literature; for example, Lim et al. (2013), studied the bond behaviour and transfer length of prestressing strands using experimental and finite element analyses. Dang et al. (2014) investigated the correlation of strand surface quality and bond strength. Askarinejad, et al. (2018) reported a series of pullout tests undertaken on specimens with 85 MPa concrete (nominal strength) and 7-wire prestressing strands. Dang, et al. 2013 analysed and compared the influence of various concrete characteristics and strand properties on strand bond.

However, the above studies are not necessarily applicable to the pullout strength and behaviour of un-stressed strands such as lifting eyes. Lifting eyes are one of the main applications of unstressed strand in the precast concrete industry. For example, these anchors are currently installed in a commercial precast product (known as Unispän). An example of lifting eyes embedded in Unispän is shown in Figure 1.

![Figure 1: Lifting eyes embedded in a Unispän precast prestressed concrete slab](image)

Here, Unispän refers to a floor system that incorporates a precast pre-stressed solid concrete slab with an in-situ concrete topping. Unispän is manufactured with a roughened top surface, so with the in-situ concrete topping it forms a composite slab. These units are required to be lifted usually the next day after manufacture and stored in a precast yard before being delivered to site. Usually a set of four lifting eyes are located in the corners of the Unispän slab. Figure 2 shows the angle of lift on a typical shallow precast units (Kuchma and Hart, 2009); an angle of lift more than 60 degrees is recommended.
The PCI Design Handbook (2017) addresses lifting eyes made from prestressing strands. According to the PCI Design Handbook, prestressing strand, both new and used, may be used for lifting eyes. The capacity of a lifting eye embedded in concrete is dependent upon the strength of the strand, length of embedment, the condition of the strand, the diameter of the eye, and the strength of concrete.

One of the most significant studies on the pull out capacity lifting eyes is reported by Moustafa (1974) supported by the Concrete Technology Associates (CTA). He conducted various tests on both straight strands and lifting eyes. They reported the breaking strength of lifting eyes cast into concrete beams for different strand size and pin diameters. Additionally, an experimental research program was conducted at the University of Illinois (Kuchma and Hart, 2009) to investigate the performance and capacity of lifting eyes cast in deck beams. They looked into different designs and embedment depths of lifting eyes cast in deck beams.

However, the above studies on lifting eyes were conducted on specific precast prestressed systems and the results are not necessarily applicable to other precast products. Additionally, the pullout tests in the above experiments were mainly conducted on lifting eyes cast into concrete beams with relatively large embedment depth which is quite different to a scenario such as a Unispan product with a relatively thin thickness where the lifting eyes are installed with less embedment depth compared to those in precast beams. The other limitation of above studies is their experimental setup where the pullout tests were carried out with the jack bearing on the specimen and therefore, providing a downward pressure confinement to the pullout cone. In this research, this issue is addressed by using steel posts on both sides of the specimen to support the jack, therefore, avoiding a confinement pressure on the concrete which better represents real life lifting conditions.
3. Fabrication Process and Tests Setup

The samples were fabricated and tested between July and September 2019. The following sections discuss the fabrication process and test setups for Tests 1 and 2.

3.1. Unispan with embedded lifting eyes (TEST 1)

Figure 3 shows a view of the sample 75mm thick precast concrete Unispan slab which was fabricated for this study. The sample was manufactured with the same dimensions as the commercial Unispan product (1.98m wide, 4.0m long, 75mm thick).

As shown in Figure 3, in the transverse direction, eight strands (9.6mm diameter) with a length of 1.9m and six strands (9.6mm diameter) with a length of 1.0m were installed. Eleven unstressed strand lifting eyes were also installed at the locations shown in Figure 3. Only seven lifting eyes out of 11 were tested to failure as four lifting eyes were used for lifting the sample.

Figure 4 shows the detailed dimensions of the lifting eye embedded in the Unispan.

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**Figure 3: Plan View of fabricated Unispan (all dimensions are in millimetres)**

**Figure 4: Lifting eye installed within the Unispan sample (dimensions in millimetres)**
The fabrication process of Unispan with embedded lifting eyes is shown in Figure 5. After installing the reinforcement and lifting eyes, concrete was poured and compacted using an immersion vibrator. On the next day, the sample slab was lifted out and transported to the area where the test was carried out.

Before the start of TEST 1, the concrete strength was recorded as 21MPa which was in the lower range of ideal concrete strength. A slightly lower concrete strength was intentionally desired to provide a worst case scenario.
A view of the test set up is shown in Figure 6. As shown in this figure, a portable hydraulic jack with a calibrated pressure gauge was used to apply the pullout force on the lifting eyes. Seven lifting eyes were tested to failure using this arrangement. The jack was setup using timber packers and steel plates and was positioned in such a way that the pullout cone was not confined.

![Figure 6. The experiment setup for Test 1](Image)

3.2. Concrete beam with embedded lifting eyes (TEST 2)

Figure 7 shows the detailed drawings of the sample concrete beam with embedded lifting eyes which was fabricated for this study. The beam is 700 mm deep and 3.7m long with four embedded lifting eyes (12.7mm strand and 9.6mm strand with either 25mm or 50mm diameter pin).

![Figure 7: Longitudinal and section views of beam with embedded lifting eyes (all dimensions are in millimetres)](Image)
The concrete beam and reinforcement details were designed to ensure the beam could resist bending under the pullout forces. After the concrete pour, the concrete beams were cured for one week and then transported to the area where testing was conducted. The strength of sample beam was recorded as 23 MPa at the time of testing which was in the lower range of ideal concrete beam strength. A lower strength was intentionally targeted to provide a worst case scenario.

A view of the test set up is shown in Figure 8. For TEST 2, four lifting eyes were tested using the setup shown in this Figure.

![Figure 8: The experiment setup for Test 2](image)

The concrete beam was anchored to the ground to prevent uplift of the beam while testing. The support posts and lifting beam (0.5m span) were designed to support the hydraulic jack. Two steel plates were used on each side to help reach the required height suitable to position the RLP-502 hydraulic jack. Using this arrangement, no downward confinement pressure was applied to the concrete during the pullout test.

4. Results and Discussion

4.1. Pullout capacity of lifting eyes in Unispan (TEST 1)

In Test 1, the pullout force was applied until failure. Considering the shallow depth of lifting eyes embedded in the UniSpan, the failure scenario included the rupture of concrete and dislodge of lifting eye. This was expected. Out of 11 lifting eyes, only seven lifting eyes (number 3 to 9) were tested to ultimate failure. Four lifting eyes located at the corners were required for lifting of the sample after the test. Figure 9 shows the typical failure observed in this Test.
Figure 9. Typical ultimate failure and dislodge of lifting eyes observed in Test 1 (Unispan)

Figure 10 shows the pullout force versus load increment measured for the seven lifting eyes embedded in Unispan.

![Graph showing pullout force vs load increment for seven lifting eyes](image)

**Figure 10. Pullout force vs load increment for seven lifting eyes embedded in Unispan**

It can be seen in Figure 10 that the ultimate pullout capacity ranged between 27.3kN and 37.2kN. Considering that all lifting eyes used in this test have the same design, the observed variation in the ultimate capacity could be due to the construction tolerances for positioning the lifting eye. Considering that the thickness of UniSpan is relatively small (75 mm), the construction variation in position of the lifting eye (in particular the vertical embedment of the lifting eye) could have contributed to the variation in the pullout capacity.
The maximum pullout capacity recorded for each lifting eye tested to failure (dislodgement of lifting eye) is presented in Figure 11.

![Figure 11. Ultimate pullout capacities of tested lifting eyes embedded in Unispan](image)

To determine the safe working load, the lower fifth percentile value is calculated and then divided by a factor of safety (FOS = 3). The lower fifth percentile can be calculated using the equation:

\[
\bar{X} - t \frac{s}{\sqrt{n}} \tag{1}
\]

Where \( \bar{X} \) is the mean value (pullout capacity), \( s \) is the standard deviation, \( n \) is the number of samples (here \( n=7 \)) and \( t \) is the statistical distribution value derived from a statistics \( t \) table. Here, the mean (average) value and standard deviation are calculated as 30.9 kN and 3.1 kN respectively. Based on 7 test samples, the \( t \) value is 2.447, so the lower fifth percentile value is calculated as 28 kN. Dividing this value by FOS = 3, the safe working load per lifting eye in a Unispan slab is calculated as 9.3kN.

Typically there are four lifting eyes embedded at one fifth of the length from each end of a Unispan unit; however, it is also common for Unispan units to be lifted by angled chains from a single hook, referred to as a “standard lift” by the Worksafe NZ Guideline (2018) for lifting precast concrete, so the weight of the unit is divided by 2 to determine the demand on each lifting eye. Unispan units 2.4m wide do flex to equalise the load on each lifting eye, so it is safely conservative to assume in the worst case scenario that the load is split between two lifting eyes. Therefore, the total safe working load for lifting a Unispan unit is calculated as \( 2 \times 9.3 \text{kN} = 18.6 \text{kN} \).
Unispan product is manufactured in various shapes and dimensions. Standard widths are generally 1.2m, 1.225m or 2.4m wide. The approximate total weight of a Unispan unit, maximum 8.0m long x 1.2m wide is 1800kg (17.6 kN). It means, the calculated safe working load (lifting force) is only about 5% higher than the total weight of such Unispan unit. An 8.0m long x 2.4m wide Unispan unit will obviously weigh double this weight (3600kg or 35.2kN) which is considerably higher than the 18.6kN safe working load.

4.2. Pullout capacity of lifting eyes in Concrete Beam (TEST 2)

The typical failure scenario for the lifting eyes embedded in the concrete beam included either snapping of the lifting eye strand or development of significant cracks through the depth of the concrete beam. Table 1 shows the size and pin diameter used for each lifting eye in this Test.

<table>
<thead>
<tr>
<th>Lifting eye No</th>
<th>Strand size (mm)</th>
<th>Pin diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.6</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>9.6</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>12.7</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>12.7</td>
<td>50</td>
</tr>
</tbody>
</table>

Figure 12 shows the typical failure observed in Test 2 and Figure 13 shows the pullout force versus load increment measured for the four lifting eyes embedded in the beam.

Figure 12. Typical failures observed in Test 2 (Concrete beam).
The maximum force (pullout capacity) measured for each lifting eye to failure are presented in Figure 14. It can be seen that the pullout capacity ranges between 154.2 kN for lifting eye 1 (size 9.6mm and pin diameter of 25mm) to 255.2 kN for lifting eye 4 (size 12.7 mm and pin diameter of 50mm).

Currently, the common method used in industry for determining the safe working load for lifting eyes embedded in concrete beams is based on the equation proposed by Moustafa (1974), as follows:

\[
SWL = \frac{2 \times k \times T \times \sin \alpha}{FOS}
\]  
(Eq 2)
Where, SWL is the Safe Working Load, $k$ is a constant depending on the pin diameter, $\alpha$ is the angle of lifting eye legs, FOS is the Factor of Safety and $T$ is the strand failure load (based on strand tensile strength).

To compare the measured capacities with the capacities currently used in industry, the SWL values and the corresponding theoretical pullout capacity ($\text{SWL} \times \text{FOS}$) are calculated for each lifting eye and then compared with the measured pullout capacities obtained in this experiment. The results including the percentage difference between the measured and theoretical pullout capacities are shown in Table 2.

### Table 2. Measured and theoretical pullout capacities of tested lifting eyes

<table>
<thead>
<tr>
<th>Lifting eye No</th>
<th>Strand size, mm</th>
<th>Pin diameter, mm</th>
<th>Strand failure load (kN)</th>
<th>$k$</th>
<th>SWL (kN)</th>
<th>Theoretical pullout capacity (kN)</th>
<th>Measured pullout capacity (kN)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.6</td>
<td>25</td>
<td>103.3</td>
<td>0.65</td>
<td>44.7</td>
<td>134.1</td>
<td>154.2</td>
<td>+15%</td>
</tr>
<tr>
<td>2</td>
<td>9.6</td>
<td>50</td>
<td>103.3</td>
<td>0.8</td>
<td>55.1</td>
<td>165.3</td>
<td>215.8</td>
<td>+30%</td>
</tr>
<tr>
<td>3</td>
<td>12.7</td>
<td>25</td>
<td>181.4</td>
<td>0.65</td>
<td>78.6</td>
<td>235.8</td>
<td>215.8</td>
<td>-8%</td>
</tr>
<tr>
<td>4</td>
<td>12.7</td>
<td>50</td>
<td>181.4</td>
<td>0.8</td>
<td>96.7</td>
<td>290.1</td>
<td>255.2</td>
<td>-12%</td>
</tr>
</tbody>
</table>

**Note:**
- Strand failure load (kN) is based on the strand yield strength as per the strand certificate
- Theoretical pullout capacity is calculated as “$\text{SWL} \times \text{FOS}$”
- Percentage difference is calculated as (measured capacity - theoretical capacity) / theoretical capacity

### 5. Conclusions and Recommendations

The pullout capacities and safe working loads for a number of lifting eyes embedded in two precast concrete systems were investigated through an experimental study. Two test regimes were reported in this paper. In Test 1, seven lifting eyes embedded in a precast concrete Unispan slab were loaded to failure to obtain the lower fifth percentile safe working load. In Test 2, four lifting eyes (with different size and pin diameter) embedded in a concrete beam were investigated. It should be noted that in both Tests, the safe working loads for lifting the Unispan unit and the concrete beam were calculated using a safety factor of 3. The following conclusions can be drawn from this research:

1. The total safe working load for lifting the Unispan unit was calculated as 18.6 kN. The calculated safe working load (lifting force) is only about 5% higher than the total weight of Unispan unit (8.0m long x 1.2m wide unit). For larger units such as standard 8.0m
long x 1.2m wide Unispan unit, the calculated safe working load will be considerably lower than the unit total weight.

2- The measured pullout capacities for the two 9.6mm size lifting eyes embedded in a concrete beam were higher than the theoretical (expected) pullout capacities by 15% and 30% respectively.

3- The measured pullout capacities for the two 12.7mm size lifting eyes embedded in a concrete beam were lower than the theoretical (expected) pullout capacities by 8% and 12% respectively.

Based on the results obtained in this study, the following suggestions are made for future research:

1. The calculated safe working load for lifting the Unispan unit would be lower than the total weight of any Unispan unit larger than 8.0m long x 1.2m wide. To address this shortfall, modifications in the design of lifting eyes plus possible changes in the placement of lifting eyes should be explored. Additionally, the lifting arrangement will need to be equalised analysing the torsional flexibility. More testing of units at higher concrete strength as well as lifting eyes with alternative anchorage configuration is recommended.

2. The effect of lateral loading on the lifting eye could be investigated. When a precast concrete slab is lifted by a crane, there are four cables connecting lifting eyes to the crane. The cables generate a certain angle with the horizontal axis; this means the lifting eyes are subject to a combination of vertical and lateral loading.

3. It is recommended the effect of handling practices and lifting methodology are investigated. The type of rigging equipment and lifting process can affect the distribution of the load between four lifting eyes. Better distribution of the load, will reduce the demand per lifting eye.

4. The measured pullout capacities for the two 12.7mm lifting eyes embedded in concrete beam were lower than the theoretical (expected) pullout capacities. Therefore, additional tests on 12.7mm lifting eyes are recommended.
Acknowledgments

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References


Hadi, M. N., Bond of High Strength Concrete with High Strength Reinforcing Steel, The Open Civil Engineering Journal, 2, 143-147, 2008.


