EXPERIMENTAL STUDY OF TIMBER-TO-CONCRETE DOWEL TYPE CONNECTIONS USED IN TIMBER PLATFORM FRAME

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Summary
Market forces in the U.K are dictating that timber frame houses are built with narrow frontages which contain a large percentage of openings. As a result of this, the number of full height panels which can be classified as offering resistance to racking forces is reduced and the performance requirements of the remaining panels are increased. As part of a wider project aimed at addressing this problem through the development of a “hybrid” racking panel, this paper considers the importance of a robust soleplate connection and its ability to offer secure anchorage. Specifically, it quantifies the degree of lateral (sliding) resistance offered by a range of commercially available fasteners. The results from an experimental test program show the lateral load-carrying capacity of each of these fasteners when used to connect a C16 or Laminated Strand Lumber (LSL) soleplate to a concrete foundation substrate. It is shown that the currently preferred method is inefficient in terms of both structural and economic performance when compared to other fasteners tested.
1. Introduction

Modern Methods of Construction (MMC) are gaining increased popularity in the U.K due to improved quality control, speed of construction and efficient use of materials. One of the most common examples of MMC is timber platform frame which at present accounts for approximately 20% [1] of new homes built in the U.K. Timber platform frame often competes in the low cost, high volume estate market where the cost of land and client desire for detached accommodation leads to narrow properties with openings often concentrated in the shorter walls [2]. This is problematic when designing for overall structural stability as reduced width shear wall panels do not have the ability to provide sufficient resistance to sliding and overturning (racking) forces caused by the applied wind load. In order to offer a solution to this problem, research is currently being carried out into the development of a Hybrid Racking Panel (HRP) which is optimised in terms of performance, cost and installation.

When considering the racking performance of a wall panel it is important to understand how the in-plane forces acting upon it are resisted and transferred to the foundation (Fig. 1). In order to resist in plane loading a shear wall relies on framing members, sheathing and nail connectors all interacting closely with one another [3]. Improvements in the racking performance can be achieved if each of these variables is optimised for the required conditions and this is central to the development of an HRP. However, the successful implementation of these improvements is dependent on secure anchorage specification which must ensure applied lateral (shear) and overturning forces are transferred safely to the foundations.

At present neither BS 5268 [4] nor the soon to be introduced Eurocode 5 (EC5) [5] offer a method specifically for the calculation of a timber-to-concrete connection’s lateral load-carrying capacity. Research by Aicher et al [6] has proved the calculated characteristic shear load capacity of a timber-to-concrete joint to be approximately the same as that obtained by using a timber design code for nailed timber-to-thick steel plate connection [7]. However, methods such as this only consider standard smooth or threaded types of fasteners.

Detailed in this paper is the experimental investigation of standard and non-standard fixings when used in conditions replicating that of timber sole plate to substrate connection. The purpose of the test program was to determine the feasibility of specifying the connections detailed and these findings are reported on. Further to this, the research program was conducted in a manner which would facilitate further investigation of the fixing types and connection detailing.

Research by Blass [8] identified that the three parameters influential to a joints load carrying behaviour are; (i) the bending capacity of the dowel (ii) the embedding capacity of the timber or wood based material (iii) the withdrawal capacity of the dowel. With respect to these, a supplementary test program was carried out and these results are also reported and discussed.

1.1 Site practice and detailing

The structural performance as well as the accuracy of a timber platform frame build is reliant on the initial positioning and fixing of the soleplate. Table 1 shows typical soleplate material specification whilst Fig. 2 shows the soleplate in relation to a typical wall footing detail.
A desktop study into practices adopted throughout North America (where timber frame accounts for 90% of low rise builds) showed that Laminated Strand Lumber (LSL) is often used in areas where high performance is required. Examples of this include shear walls designed to resist hurricane and seismic activity. As well as structural benefits, LSL is also well suited to use as a soleplate material. It is more resistant to moisture and the resultant warping and twisting it causes than sawn timber. Furthermore, it also offers uniform strength properties in each axis and this gives it improved resistance to compressive forces imposed by the vertical stud ends.

In the U.K the preferred method for securing the soleplate and providing lateral resistance is the shot fired dowel. This is a smooth type dowel installed via a powder actuated tool (Fig. 3). This method has found favour due to its ease and speed of installation. However, the performance of this fastener must be validated in relation to the increased shear forces which will require to be transferred by the proposed HRP. Therefore, an experimental program to evaluate the lateral resistance offered by it and other fasteners, along with the effect of using LSL as a soleplate material was developed.

2. Experimental program

To evaluate the performance of the shot fired dowel and provide comparative data from other fastener types an experimental investigation was carried out. Eleven commercially available dowel-type fasteners (supplied by ETA Fixings UK Ltd) which were suitable for fixing the soleplate and providing shear resistance were selected. These were divided into 4 sub categories; Masonry Screws (MSC), All purpose masonry screws (KF), Shot fired dowels (KMN) and a non standard fastener type known as an Express nail (EXPN) (Figure 4 & Tables 2-5).

![Fig. 3 KMN45LV tool](image)

![Fig. 4 Illustration of tested fastener range](image)
Table 2 Average dimensions of tested Masonry screws

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Thread</td>
</tr>
<tr>
<td>MSC36070</td>
<td>69.13</td>
</tr>
<tr>
<td>MSC36082</td>
<td>80.74</td>
</tr>
<tr>
<td>BTB4C70</td>
<td>69.60</td>
</tr>
<tr>
<td>BTB4C82</td>
<td>81.79</td>
</tr>
</tbody>
</table>

Table 3 Average dimensions of tested All purpose masonry screws

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Thread</td>
</tr>
<tr>
<td>KF7.5×80</td>
<td>80.64</td>
</tr>
<tr>
<td>KF7.5×100</td>
<td>100.66</td>
</tr>
</tbody>
</table>

Table 4 Dimensions of tested Express Nails

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>X section area (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Point</td>
<td>Shank</td>
</tr>
<tr>
<td>EXPN6×60</td>
<td>60.23</td>
<td>6.04</td>
</tr>
<tr>
<td>EXPN6×100</td>
<td>99.89</td>
<td>6.12</td>
</tr>
<tr>
<td>EXPN8×70</td>
<td>70.04</td>
<td>7.86</td>
</tr>
<tr>
<td>EXPN8×90</td>
<td>89.82</td>
<td>7.86</td>
</tr>
</tbody>
</table>

Table 5 Dimensions of tested Shot fired dowel

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>Diameter (mm)</th>
<th>Washer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>Root</td>
<td>Head</td>
</tr>
<tr>
<td>KMN72</td>
<td>74.46</td>
<td>3.8</td>
</tr>
</tbody>
</table>

The experimental investigation conducted replicated UK in-situ sole plate connection detailing, Dense Aggregate Block (DAB) with a characteristic strength of 7N/mm² was used and Damp Proof Coursing (DPC) was placed at the timber/block interface (Fig. 5), and lateral load tests were carried out in accordance with BS EN 1380 [10].

![Fig. 5 Details of lateral load-carrying capacity set up and specimen under test](image-url)
Installation methods for each fastener (Table 6) were carried out as per manufactures recommendations. Details of the test methods used for the supplementary program can be found in the standards given (Table 7).

**Table 6 Installation methods for tested fasteners**

<table>
<thead>
<tr>
<th>Fastener type</th>
<th>Installation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masonry Screw</td>
<td>Pre-drill timber and substrate as per Manufacturer’s specification. Brush and blow debris from hole. Screw into place with cross head drill bit.</td>
</tr>
<tr>
<td>All purpose masonry screw</td>
<td>Pre-drill timber and substrate as per Manufacturer’s specification. Brush and blow debris form hole. Screw into place with Torque bit.</td>
</tr>
<tr>
<td>Express nail</td>
<td>Pre-drill timber and substrate as per Manufacturer’s specification. Brush and blow debris from hole. Drive fastener home with hammer.</td>
</tr>
<tr>
<td>Shot fired dowel</td>
<td>Install with KM45LV cartridge tool and charges</td>
</tr>
</tbody>
</table>

**Table 7 Supplementary test program details**

<table>
<thead>
<tr>
<th>Test</th>
<th>Carried out to</th>
<th>Carried out on</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point side withdrawal strength</td>
<td>Based upon BS EN 1383[11]</td>
<td>Fasteners tested in 7N block installed at minimum recommended depth</td>
</tr>
<tr>
<td>Head side pull through strength</td>
<td>BS EN 1382[12]</td>
<td>Fasteners tested in both C16 Solid timber and LSL</td>
</tr>
<tr>
<td>Embedment strength</td>
<td>BS 383[13]</td>
<td>Fasteners tested in both C16 Solid timber and LSL.</td>
</tr>
</tbody>
</table>

4. **Results**

Results from tests determining the lateral load carrying capacity (Fig. 7) of each fastener in both C16 timber and LSL show 2 particularly relevant results:

1. The current method of fixing the soleplate (KMN72) is proven to give the lowest lateral resistance of the fasteners on test.
2. By specifying LSL over C16 timber, lateral resistance can be increased.

These findings are directly applicable to currently employed practices. Moreover, the results provide a bank of information for the future specification of fasteners based upon requirements.

In all test cases the development of at least one plastic hinge in the fastener was observed. In the case of threaded fasteners, ultimate failure was found to occur through combined bending and shear forces. This lead to a sudden failure in the area where the hinge had formed. For smooth types of fastener the development of the hinge caused rotation and withdrawal of the fastener from the substrate. There was no sudden loss in connection strength but rather a predictable failure as the fastener was pulled from the substrate.
The angle to which this hinge developed was found to be dependent on the resistance to embedment offered by the timber member (Fig. 8). Results show the embedment resistance of LSL to be consistently higher than that of C16 timber.

In line with these findings, LSL was also found to offer improved resistance to head side pull through (Fig. 9). In this respect, Fastener KF75×80/100 was found to give the highest values from tested fasteners and this was attributed the fastener being threaded over its entire length with no smooth shank. Due to this, the additional threads in the timber offered increased resistance.

Since the overall withdrawal strength of the fastener is taken to be the of the lesser of the head side pull through and point side withdrawal the use of LSL and the resultant increase in head side pull through strength can, in cases, be shown to change the withdrawal parameter. In such cases the point side withdrawal strength becomes critical.

In determining the performance of each fastener, additional findings were made; namely the importance of the installation of fasteners as per manufacturers recommendations. The point side withdrawal capacity of each fastener was found to be highly dependent on the adherence to specified penetration depths. Furthermore, incorrectly drilled holes and those which had not been properly cleared of debris were found to be detrimental in this respect.

5. Discussion
In order to make these results relevant to the fastener’s specified on site, additional factors such as cost and method of installation must be taken into account. By using assumed values for the amount of lateral resistance required we can easily see the economic inefficiency of the current methods of fixing (Fig. 10). A direct result of this finding has been the trial specification of fastener KF7.5×80 on site. Data from the test program has indicated that the fastener gives improved performance in relation to both lateral resistance and holding down. However, its method of installation has been found to be both
labour intensive and time consuming. Therefore, whilst it offers improvements in performance it can not be considered a fully optimised solution.

Although the primary aim of this paper was to present the results of a laboratory based test program, through the study of site practices it is understood that increases gained from improved specification will be negated if the recommended installation practice is not adhered too (Fig. 11). Therefore, to ensure that the values obtained through test are replicated in live situations it is important to ensure that good practice is maintained throughout.

6. Conclusion

The primary purpose of this work was to provide test data on a range of fixings suitable for connecting the soleplate to the foundation substrate. In doing so each fixings performance would be evaluated in relation to the method currently employed. The aim was to improve current fastener specification and also provide data which can be used as part of a long term collaborative research project to develop a “hybrid racking panel”.

Although test data combined with cost analysis highlighted the potential for immediate improvements in specification, site trials of the revised specification demonstrated that it was not an optimal solution as the more onerous installation method impinged upon on-site efficiency. Additionally, the importance of observing the manufacturers specified methods and adhering to good practice throughout the installation procedure has also been highlighted.

The performance of each fastener when Laminated Strand Lumber is used in place of C16 timber has also been quantified. It has been shown that connection capacity can be directly increased by specifying LSL. Further investigation is needed to determine if the improved structural performance and construction benefits fully justify the increased costs associated with engineered wood products.

7. Acknowledgements

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8. References


