QUALITY CONTROL TESTING OF PLASTERBOARD
FOR BRACING APPLICATIONS

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ABSTRACT

It is well recognized around the world that plasterboard clad walls can provide significant bracing to light framed residential structures. In Australia, local codes of practice allow up to 50% of lateral bracing to be provided by such walls. While plasterboard contributes to the structural performance, associated quality control tests do not explicitly cover the bracing quality of plasterboard. The majority of existing quality control tests are related to other performance criteria such as damage during handling and punching of nail or screw heads through the plasterboard in ceiling applications. This paper reports the findings of a study into the adequacy of existing plasterboard quality tests as a measure of its bracing capacity. The paper also reports the development of a new test method, described herein as fastener bearing test, as an alternate quality control method for bracing capacity of plasterboard. This fastener bearing test is subsequently validated through an extensive experimental program. The paper concludes that the proposed test is a simple and reliable method to assess the bracing capacity of plasterboard.

Key words: Light-framed Structures, Plasterboard, Gypsum, Testing, Bracing.
Introduction

Historically, the Australian residential housing industry treated plasterboard as a non-structural material when designing houses. However, the growing body of research demonstrating that plasterboard provides significant bracing capacity, even with nominal fixing, has led to the 1999 version of the Australian Standard for Residential Timber-Frame Construction (AS1684, 1999) incorporating a contribution up to 50% of the lateral bracing from plasterboard where nominally fixed plasterboard clad walls are adopted. The inclusion of the bracing strength of plasterboard into AS 1684-1999 was done without any associated changes or controls being put in place to ensure that the assumed structural properties of plasterboard are available. As a result, plasterboard manufacturers may modify the properties of plasterboard without any requirement to ensure the bracing performance of the plasterboard. It is understood that modifications are frequently made to plasterboard by way of the paper lining and plaster mix constituents of the board. Further, the majority of existing quality control tests are related to other performance criteria such as damage during handling and punching of nail or screw heads through the plasterboard in ceiling applications.

Plasterboard manufacturers would require additional tools and knowledge on the structural behaviour of plasterboard if they are required to meet the expectation of designers of residential structures and to guarantee the structural strength of their product. This paper reports the findings of a study into the adequacy of existing plasterboard quality tests as a measure of its bracing capacity. The paper reports the development of a new test method, described herein as fastener bearing test, as a specific quality control method for bracing capacity of plasterboard. This fastener bearing test is subsequently validated through an extensive experimental program and analytical modelling.

Approach

This study has conducted a detailed literature review along with field work at a number of plasterboard manufacturing plants. In addition, an extensive experimental program and analytical assessment have been undertaken.

From the literature review and the interviews with the plasterboard manufacturers, it has been found that:

- National and international standard test methods for plasterboard, such as AS/NZS 2588-1998, ISO 6308-1980 and ASTM C473-2000, do not provide any provisions related to the bracing quality of plasterboard.
- To safely utilise plasterboard as a bracing material, a representative test for quality control must be developed. Current quality control tests for plasterboard have primarily been developed for transportation and handling issues, with no intention to ensure the bracing performance of plasterboard.
Detailed analysis of load transfer mechanisms in typical light-framed structures indicates that all walls (both structural and non-structural) parallel to the applied lateral load contribute to the lateral capacity of the structure (Gad et al. 1999 and Liew et al. 2002). The specific strength and stiffness contribution of each wall vary significantly depending on wall length, bracing material and building system.

The lateral bracing performance of houses is directly related to the performance of in-plane (racking) walls. It is well established that the performance of an individual racking wall is directly related to the load-slip characteristics of sheathing-to-framing connections (shear connections) on the wall, which are highly influenced by the material properties of the sheathing. To understand the relative performance and contribution of plasterboard to the overall house response, full-scale racking tests of isolated walls combined with shear connection tests are concluded to be an appropriate methodology.

Based on the knowledge gained from a detailed literature review (Liew, 2004), information gleaned from the field works conducted in plasterboard manufacturing plants and correlation of data on the existing quality control test methods with the density of plasterboard, led to the development of a new test method, (described here as fastener bearing test) (Liew et al. 2004). Figure 1 illustrates the apparatus for the developed fastener bearing test.

**Figure 1:** Schematic details of the full test setup of the proposed fastener bearing test apparatus (dimensions are in mm).
Experimental Program and Results

The experimental program of this study, as summarized in Figure 2, was developed to evaluate and verify the proposed fastener bearing test. It comprised two phases with the first phase involving the conduct of a large number of density tests, fastener bearing tests and shear connection tests on plasterboard. This phase sought to correlate and verify the proposed fastener bearing test against the current shear connection test. In phase two of the testing program, full-scale, isolated wall racking tests and some supplementary shear connection tests were performed. This phase was aimed to further verify the fastener bearing test against a full-scale isolated wall racking test as well as to determine the load-slip curves for typical shear connections on plasterboard clad walls. Such curves were also used to facilitate the development of analytical models. It should be noted that this study is concerned with light-framed structures built in low seismicity and non-cyclonic areas that include the majority of Australian cities and many other parts of the world. A monotonic loading regime, which is typically adopted by industry testing facilities and manufacturers (e.g. Experimental Building Station TR440, 1978 and ASTM-E72, 1998) was thus employed in this study.

Table 1 summarises the results obtained in Phase 1 of the testing program. To reduce the variability of the plasterboard specimens, four batches of 10 mm thick plasterboard sheets, named here as Types A to D plasterboard, with different plaster
mix but identical linerboard supplied by a single manufacturer, were used for testing throughout Phase 1. Details of the setup for the tests conducted in this phase can be found in Liew et al. 2004. Analyses of the results of these tests led to the following conclusions:

- The failure modes and load-displacement curves from the fastener bearing tests showed similar characteristics to those observed in shear tests of connections as well as typical failure of connections in racking tests of full walls. Typical load-displacement curves from the fastener bearing tests are shown in Figure 3.

- A very strong correlation exists between fastener bearing test and shear connection test has been found. This is illustrated by the relationship between the mean ultimate loads from the fastener bearing tests (MULFB) and the mean ultimate loads from the shear connection tests (MULSC) which are plotted in Figure 4. The results show the trend of increasing mean ultimate load from the fastener bearing tests with increasing mean ultimate load from the shear connection tests.

- For MULFB and MULSC the line of best fit using a linear least squares regression analysis was calculated from the test data as follows:

\[
MULFB = 0.75 \times MULSC + 44.67
\]  \hspace{1cm} (1)

For this relationship, the correlation coefficient, R, of 0.9996 was obtained, indicating that approximately 99.96% of the variation of the mean ultimate load from the shear connection tests can be explained by the mean ultimate load from the fastener bearing tests.

- The error bars in Figure 4 represent the maximum and minimum results of each test. These error bars show that the simplicity of the fastener bearing test presented in this study achieved higher consistency of experimental results compared with that of the shear connection test results.

![Figure 3: Typical load-slip curves from the fastener bearing tests.](image-url)
Table 1: Summary of results from Phase 1 which comprised density tests, fastener bearing tests and shear connection tests

<table>
<thead>
<tr>
<th>Plasterboard</th>
<th>Sample Size per Test</th>
<th>Mean Density (kg/m³)</th>
<th>Mean Ultimate Load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fastener Bearing</td>
</tr>
<tr>
<td>Type A</td>
<td>36</td>
<td>640 (0.65)</td>
<td>315 (3.7)</td>
</tr>
<tr>
<td>Type B</td>
<td>36</td>
<td>674 (0.84)</td>
<td>407 (5.7)</td>
</tr>
<tr>
<td>Type C</td>
<td>36</td>
<td>824 (0.70)</td>
<td>561 (4.1)</td>
</tr>
<tr>
<td>Type D</td>
<td>36</td>
<td>872 (0.79)</td>
<td>644 (4.1)</td>
</tr>
</tbody>
</table>

Note: Values in parentheses represent Coefficient of Variation in percentage.

Figure 4: Mean ultimate loads from shear connection tests versus mean ultimate loads from fastener bearing tests

- For all the plasterboard specimens, their ultimate failure modes in both the fastener bearing tests and shear connection tests were very similar, in which the maximum load was associated with excessive tearing of the face linerboard.
- Both the plaster mix and linerboard play a significant role in providing the bracing capacity of plasterboard. While gypsum provides the medium to transfer the applied load, the linerboard confines the gypsum from expanding and breaking outwards.
To effectively utilize the proposed fastener bearing test, plasterboard manufacturers need to set their acceptance criteria in order to suit the different products and their designated performance.

Tables 2 and 3 summarize the results of the full-scale isolated wall racking tests conducted in Phase 2 of the experimental program. A total of four walls were tested, named here as Walls 1 to 4. Walls 1 and 2 were clad with normal density (Type A) plasterboard, while Walls 3 and 4 with high density (Type D) plasterboard. These plasterboard sheets were nailed to frames using 2.8 mm × 30 mm plasterboard nails with various spacing as listed in Table 2. Adhesive was not applied to these wall specimens as its durability, over the actual design life of the structure, may be questionable. The purpose of employing various nail spacing for the same type of plasterboard was to cover a range of typical nailing patterns and to examine the effect of the number of nails used on the ultimate racking capacity of a plasterboard clad wall.

**Table 2:** Summary of Phase 2 results: Full-scale isolated wall racking tests.

<table>
<thead>
<tr>
<th>Plasterboard Type</th>
<th>Nail Spacing (mm)</th>
<th>Displacement at Ultimate Load (mm)</th>
<th>Ultimate Load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Perimeter Studs and Plates</td>
<td>Intermediate Studs</td>
<td></td>
</tr>
<tr>
<td>Wall 1: Type A</td>
<td>150 300</td>
<td>19.2</td>
<td>5414</td>
</tr>
<tr>
<td>Wall 2: Type A</td>
<td>300 300</td>
<td>26.2</td>
<td>3011</td>
</tr>
<tr>
<td>Wall 3: Type D</td>
<td>150 300</td>
<td>12.7</td>
<td>9491</td>
</tr>
<tr>
<td>Wall 4: Type D</td>
<td>300 300</td>
<td>20.9</td>
<td>5644</td>
</tr>
</tbody>
</table>

**Table 3:** Loads measured at serviceability displacements.

<table>
<thead>
<tr>
<th></th>
<th>Load at +8mm deflection (N)</th>
<th>Load at -8mm deflection (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall 1: Type A</td>
<td>4343</td>
<td>-4814</td>
</tr>
<tr>
<td>Wall 2: Type A</td>
<td>2781</td>
<td>-2774</td>
</tr>
<tr>
<td>Wall 3: Type D</td>
<td>8467</td>
<td>-9187</td>
</tr>
<tr>
<td>Wall 4: Type D</td>
<td>5063</td>
<td>-4638</td>
</tr>
</tbody>
</table>

The test setup and loading protocol adopted in these full-scale isolated wall racking tests were based on the recommendations by TR440 (Experimental Building Station, 1978) for lateral wind loading, with the inclusion of uplift restraints to simulate the continuity of top plates, return walls and other boundary conditions which are often provided in actual houses. The uplift restraints were provided in the form of five steel rollers on the top of each stud. The steel rollers were pushed snug tight to the top
plate, thus, only a minimum amount of load was applied vertically. Each of these rollers was connected to a load cell to monitor the load imposed on the rollers. In addition, each wall specimen was prevented from out-of-plane movement by employing four rubber rollers which were fitted snug tight on each side of the wall. The specimen was pulled (North) and pushed (South) to complete a full cycle at serviceability displacement (typically equals Height/300 which is 8 mm for 2400 mm high walls) before pulling to failure. It was considered to have failed when the applied load decreased below 80% of the maximum load recorded or when a sudden rupture occurred leading to a significant loss of load, whichever happened first. Details of the test setup for these full-scale isolated wall racking tests are reported in Liew, 2004.

The findings obtained from the above described full-scale isolated wall racking tests are summarized as below:

- The ultimate load of Wall 4 (clad with highest-density plasterboard, i.e. Type D) was approximately 1.8 times of Wall 1’s (clad with lowest-density plasterboard, i.e. Type A) ultimate load. This compares with the results of the shear connection tests and the fastener bearing tests conducted in Phase 1, in which the ultimate load of Type D plasterboard was found to be approximately 2.1 times of Type A plasterboard. The limited number of full-scale isolated wall racking tests conducted in this study had an error of approximately 15% between the predictions from the fastener bearing tests and those from the full-scale isolated wall racking tests and, as a result, can be considered in good agreement. This not only demonstrates that the results from the fastener bearing tests are consistent with the shear connection test results but also with those obtained from the full-scale isolated wall racking tests.
- Adding twice the number of nails at the perimeter of the wall had an increase in the ultimate load of 80% and 68% for Type A (lowest density) and Type D (highest density) plasterboard, respectively.
- The ultimate loads for the four wall specimens were only about 10% to 25% higher than the loads measured at serviceability displacement (8 mm), suggesting that plasterboard clad walls may reach their ultimate loads close to their design serviceability deformation. This should be taken into account in the design of light-framed residential structures, in particular when different cladding materials with different load-deflection characteristics are used for the same wall or within the same house.
- The plasterboard sheathings of all the wall specimens experienced significant translation and rotation. These mechanisms are not commonly observed in a full-scale house test where plasterboard is typically restricted from vertical and horizontal movements by ceiling cornices and return walls.
- The distribution of lateral forces in the end studs is dependent on the nailing pattern (i.e. spacing of nails between the plasterboard and studs).
Limitations

The developed fastener bearing test is designed for quality control of plasterboard and does not attempt to replicate the full behavior of fasteners connecting plasterboard to framing members. For example, this test does not consider the influence of the fastener head on the connection behavior and the bending of fastener shank under bearing. In addition, this test has not been correlated with shear connection tests in which screw is used as an alternative fastener. However, it is expected that using screws as fasteners would produce similar results to that of using nails.

The fastener bearing test presented in this study is developed and verified for monotonic loading protocol only. However, it can be easily adapted for different loading protocols (e.g. cyclic) to align with the loading protocol that is used to assess the performance of racking walls.

Conclusion

This study has successfully proposed, developed and verified a new test method, described herein as fastener bearing test, through an extensive experimental program and subsequent analyses. The test enables plasterboard manufacturers to reliably control the bracing quality of plasterboard, hence, allowing engineers to safely design the overall bracing capacity of light-framed residential structures. The contributions of each component of plasterboard and its effects on the bracing performance of plasterboard have also been examined and discussed.

It should be noted that although this and other studies proves that plasterboard has the capability to provide significant bracing capacity, the deformation compatibility of plasterboard with other types of bracing material has to be studied further. That is, plasterboard clad walls may have higher initial stiffness than other bracing walls in the structure (e.g. those with diagonal cross strap bracing or plywood clad) and may also achieve their full strength at lower deformation. Hence, the direct addition of strengths from all individual walls without regard to the deformation compatibility may not reflect the true lateral performance of the overall structure.

References


