Assessment of Plasterboard Properties and Relationship to Lateral Capacity of Residential Structures

Y.L. Liew, E.F. Gad and C.F. Duffield
Department of Civil and Environmental Engineering
The University of Melbourne
Victoria 3010
AUSTRALIA
E-mail: y.liew@civag.unimelb.edu.au

Abstract

The most common residential form of construction in Australia consists of lightly framed structures made of timber or steel, with plasterboard interior lining, brick-veneer as exterior cladding and roof tiles or steel for roofing.

This paper presents part of an investigation into quantification of the bracing performance of plasterboard currently being conducted jointly by The University of Melbourne, BHP Steel, Boral Australian Gypsum, CSR Building Materials, CSIRO (Division of Building, Construction and Engineering) and Cyclone Testing Station (James Cook University).

Typical lateral load transfer mechanisms for such residential structures are summarised in this paper. The paper also presents a detailed literature review of current tests available to relate the properties of plasterboard to the lateral performance of clad wall frames. In addition, the paper reports the results from an on going experimental programme to establish the relationship between various plasterboard material properties (e.g. density and hardness) and its bracing capacity. Details of a large number of tests including connection shear tests, bending and nail withdrawal tests are also presented.

1. Introduction

The most common form of residential construction in Australia consists of a light framed structure made of timber or steel, with plasterboard as interior lining, brick-veneer as exterior cladding and roof tiles or steel roof claddings. Construction of such houses contributes significantly to the Australian economy. In 1998, the number of new houses accounts for 70% of the total new residential construction and 23% in value of the total construction industry in Australia (Australian Bureau of Statistics, 2000). Thus, optimisation of these structures can lead to large potential saving to the nation’s residential housing industry.

Researchers such as (Reardon, 1988), Barton et al. (1994) and Gad et al. (1995) in Australia; (Wolfe, 1982), (Tarpy, 1984) and (McCutcheon, 1985) in United States have demonstrated that plasterboard may provide significant racking capacity. However, current practice in Australia generally treats plasterboard as a non-structural component. One of the reasons for this is that there is no standard method accepted by industry, for testing and quantifying the structural contribution of linings. Indeed, various testing procedures are available worldwide with substantially different hold-down details and loading regimes. While plasterboard manufacturers conduct several tests as part of their quality control, none of these tests are directly related to the racking capacity of the board. Hence, designers and manufacturers have not fully exploited the structural contribution of the plasterboard.

Collaborative research involving the University of Melbourne, BHP Steel, Boral Australian Gypsum, CSR Building Materials, CSIRO (Division of Building, Construction and Engineering) and Cyclone Testing Station (James Cook University) has been investigating the bracing performance of plasterboard with the objective to establish appropriate test procedures.

As a subset of this investigation, results from the first series of tests to establish the relationship between the various plasterboard material
properties (e.g. density and hardness) and the lateral performance are presented in this paper.

2. Plasterboard Manufacturing

The production of gypsum plasterboard begins with the mining of gypsum from gypsum quarries. Gypsum in the form of rock is then washed, screened and transported to the plaster mill. In the mill, the gypsum is ground in a continuous flow of hot air to eliminate free moisture. The product of this process is then conveyed to calcination plant where it is converted to uniform setting plaster.

To produce continuous length plasterboard, a slurry paste from a mixture of plaster, additive and water is fed between two sheets of paper linerboard. (refer to Figure 1). Plasterboard is then cut to specified size by the guillotine. The individual boards are turned to have the face up before passing through a multi-deck drier to remove excess moisture. As boards leave the drier they are quality checked and tested prior to storage.

Figure 1. Major steps in the production of plasterboard (Diagram courtesy of CSR Plasterboard)

Plaster Linerboard  Guillotine  Loading Conveyor  Unloading Conveyor

Continuous flow of Plaster, additive and water mixture  Transfer Table  Drier  Palletising  Warehouse

Standard plasterboard dimensions are 1200mm × 2400mm with 10mm thickness, special longer, wider and thicker boards are also produced.

The definition for machine direction is the direction along which continuous sheet of plasterboard undergoes various fabrication stages, such as rollings, before it is cut into sheets of specific length and proceed to the drier.

The recessed edges, sometimes called the bounded edges or tapered edges, are found along the longer length of the board (along the machine direction) and their purpose is to accommodate joint reinforcement.

3. Basic Terminology For Plasterboard

In Australia, the most common type of plasterboard used in residential construction has two important physical features, namely recessed edges and centre portion, referred to as field in this paper. Refer to Figure 2.

The field is the middle section of the plasterboard. According to Australian Standards (AS/NZS 2588:1998) the section which is 100mm away from all edges can be considered as field section. Usually the field sections have less connections to the supporting frame in house construction compared to the edges.

Other common terminologies which are used to determine the front and back faces of plasterboards are known as “face” and “back”, respectively. The
6. Research Aim

The flowchart presented on Figure 3 summarises the various aspects of current research, and the specific aim of this project.

Figure 3 Flowchart showing the research aims and generally acknowledged relationships.

Plasterboard Properties

Connection Performance

Wall Performance

House Performance

The earliest known extensive research involving isolated wall test was conducted by Blume et al in mid-sixties (Tarpy, 1981). Subsequent research has principally been conducted on isolated wall with extrapolation used to predict the actual house performance. This is because isolated wall tests are more economical and the behaviour as well as failure modes are simpler to analyse than whole house tests.

Although there are limited experimental results confirming the relationship between house and wall performance, this concept is widely accepted among the residential construction research community. In fact, the Australian Residential Timber-Framed Construction Code (AS 1684:1999) acknowledge this relationship by assuming the house bracing capacity is the sum of bracing capacity of each bracing wall.

(McCutcheon, 1985) successfully developed mathematical models to predict the racking performance of isolated walls by incorporating the relationship between isolated wall and connection performance into his equations. Similarly, based on this relationship, (Kasal and Leichti, 1992) and Gad et al. (1997) developed three dimensional finite element models to predict the racking performance of lined framed walls.

With the relationships between connection, wall
and house performance "established", it is evident that a gap of knowledge exists between the structural performance of the wall to the physical properties of plasterboard. The proposed research program focuses on this gap of knowledge with the objective to establish the relationship between the bracing performance of plasterboard and its properties (e.g. density and hardness).

This objective can be achieved by first relating the shear performance of the screw or nail connections between the plasterboard and the frame and the plasterboard properties. The next step is to verify this relationship by relating the plasterboard properties to the lateral performance of whole walls.

This research program contains 3 major aims:

- To determine the main properties which will affect the structural performance of plasterboard.
- To develop a control regime which will facilitate the quality control of the plasterboard production for bracing.
- To be able to provide guidance on the relative performance of lined walls given certain properties of plasterboard.

7. Experimental Program

The experimental program is designed to determine the main properties which contributes to bracing capacity of plasterboard as well as to develop a test method which can be used as a quality control in the production of plasterboard for bracing purposes.

It is intended to initially use the test procedures outlined in the AS/NZS 2588 (1998) and establish any correlation between these tests and bracing capacity of the plasterboard. If adequate correlation is not achieved, a new test procedure will be considered.

Tests included in the experimental program consist of plasterboard density test, bending strength test (AS/NZS 2588), nail pull resistance test (AS/NZS 2588), timber density test (AS/NZS 1080), timber moisture content test (AS/NZS 1080) and monotonic shear test. All the specimens tested were obtained from the field section of the plasterboard to produce more consistent results because it has relatively uniform density.

Although plasterboard density test is not outlined in Australian Standard, it is commonly conducted by the manufacturers on the production line as one of the quality control tests.

Of the tests suggested in AS/NZS 2588, the bending strength test and nail pull resistance test are identified as most relevant to this research. Bending strength tests provide relative results more specific to the paper quality, whereas nail pull resistance test can be used to determine relative hardness, bonding and density of the plasterboard. The results from these two types of tests are compared with those from tests such as plasterboard density test and monotonic shear test.

The monotonic shear test is based on a single screw model. According to (McCutcheon, 1985) and (Pellicane, 1991) the failure of full wall can be modelled by multiple shear failure of single screw connection. Thus, by testing a single screw/nail connection, it is sufficient to model the shear failure of a full wall. The testing procedure and equipment set up for these particular tests are based on the design developed by (Gad, 1997) with minor modifications for the purpose this research, refer Figure 4.

With the above tests in mind, the experimental program is divided into 2 phases:

Phase 1 is a pilot program to confirm and review the experimental set up. In this phase, a batch of plasterboard has been tested and the results obtained used to identify critical and significant parameters for later testing.

Phase 2 can be regarded as the major part of the experimental program. Optimised experimental procedure developed from Phase 1 will be used to test on multiple batches of plasterboard. These batches of plasterboard will be selected to represent each distinct property of plasterboard such as density, hardness and paper thickness.
8. Results and Observations

This paper reports the results obtained from Phase 1 of the experimental program which is based on standard 13 mm thick core plasterboard. All the tests specimens were obtained from one board to ensure consistency.

Table 1 shows the tests conducted, the number of specimens, average results and standard deviations for each type of tests.

It must be noted that Phase 1 results are only preliminary, however, they show some interesting trends between the across and along machine direction.

The results from the bending tests show that the average breaking force for across and along machine directions are 534 N and 219 N respectively. According to plasterboard manufacturers, the fibres of the linerboard along the machine directions are usually about two and a half times more than the across machine direction.

As a result, the board will have higher bending strength in the across machine direction. Similar bending behaviour can be observed in concrete slab with comparable ratio of steel reinforcement.

Monotonic shear tests show only 4% difference between the along and across machine directions. It seems that the shear strength of the connection between the plasterboard and studs is insensitive to the fiber alignment in the linerboard.

9. Work in Progress

Data is being acquired from plasterboard manufacturers regarding the tests outlined by the Australian Standards. Establishment of correlations between tests is being analysed in an attempt to reduce the number of tests in Phase 2. If there are no correlations, a new testing method will be developed to specifically test the bracing capacity on the production line.
Table 1 Results from Phase 1

<table>
<thead>
<tr>
<th>Experiment Descriptions</th>
<th>Number of Test</th>
<th>Average</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Plasterboard Density Test</td>
<td>8</td>
<td>8.3 kg/m²</td>
<td>0.067 kg/m²</td>
</tr>
<tr>
<td>2) Bending Strength Test</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Across Machine Direction</td>
<td>4</td>
<td>534 N</td>
<td>24.1 N</td>
</tr>
<tr>
<td>Along Machine Direction</td>
<td>2</td>
<td>219 N</td>
<td>0 N</td>
</tr>
<tr>
<td>3) Nail Pull Resistance Test</td>
<td>8</td>
<td>253 N</td>
<td>15.2 N</td>
</tr>
<tr>
<td>4) Timber Density Test</td>
<td>6</td>
<td>356 kg/m³</td>
<td>14.7 kg/m³</td>
</tr>
<tr>
<td>5) Timber Moisture Content Test</td>
<td>6</td>
<td>14.2 %</td>
<td>0.6 %</td>
</tr>
<tr>
<td>6) Monotonic Shear Test (Single Screw)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Across Machine Direction</td>
<td>6</td>
<td>511 N</td>
<td>8.5 N</td>
</tr>
<tr>
<td>Along Machine Direction</td>
<td>4</td>
<td>491 N</td>
<td>8.3 N</td>
</tr>
</tbody>
</table>

10. Discussion and Concluding Remarks

It has been established that there is a direct relationship between the lateral performance of plasterboard-clad light-framed walls and the shear performance of the connections between the plasterboard and the frame.

The performance of such connections is turn directly related to the connection elements, namely the plasterboard, screws or nails and the framing members. This research focuses on the plasterboard properties which affect its bracing capacity, particularly from quality control point of view.

The main structural properties of plasterboard are attributed to three important elements, namely, the linerboard (paper), plaster and bonding between them. The linerboard provides the initial strength to withstand the shear load applied on the connection due to the imposed lateral load. As the shear load increases, the fastener starts to tear the two layers of paper and consequently bearing and crushing the plaster. The bonding between the plaster and linerboard provide confinement to the plaster and integrity to the board.

While the plasterboard manufactures do control each of these three elements, testing the complete board may best assess the bracing strength of the plasterboard because of its complex behaviour under shear loading.

The indicative finding of Phase 1 results have shown that there is no significant difference between the shear strength of screw connections in the across and machine directions at the field section of the board. It is acknowledge that the sample size of Phase 1 is statistically small. However, we have reasonable confidence in the range of results based on the range of values obtained for each test.

Typical values for the critical parameters have been reported in the results from Phase 1, Table 1, in this paper.

Work is progressing on the review and analysis of existing database provided by manufacturers. Identified correlations between existing routine tests conducted by the manufacturers and board bracing strength will form the basis for additional testing in Phase 2.

11. ACKNOWLEDGMENTS

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12. REFERENCES

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Liew, YL; Gad, EFB; Duffield, C

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