Modelling of plasterboard lined domestic steel frames when subjected to lateral loads

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ABSTRACT: This paper presents the development of a detailed Finite Element (FE) model for plasterboard lined cold-formed-steel wall frames for residential construction. The model utilizes non-linear element properties and three-dimensional geometrical configurations. It is capable of simulating the influence of corner return walls as well as the contributions from the ceiling cornices. The analysis and results from the model correlate very well with experimental racking results. A sensitivity analysis was conducted on the model to study the influence of return walls and ceiling cornices. It is concluded that a wall with corner return walls, ceiling cornices and skirting boards has more than three times the lateral load capacity of an identical isolated wall panel.

1 INTRODUCTION

In Australia, typical domestic construction comprises a framed structure with plasterboard interior lining and brick-veneer exterior cladding, with terracotta or concrete roof tiles. Residential framed structures represent a large percentage of the total building construction. In fact, houses make up almost 60% of the country’s net wealth compared with business capital, the second most important form of private wealth, of only 28%.

There is a continual and increasing pressure to effectively utilise existing building resources through material development and efficient structural design. Current design procedures for residential framed structures are mostly based on the strength of the bare frame. Little attention is given to the interaction between the various substructures and the so-called non-structural components. Plasterboard is considered a non-structural component and its contribution to the lateral strength and stiffness of domestic structures is largely ignored.

Plasterboard manufacturers allow strength contributions of 0.3 kN/m and 0.5 kN/m for timber walls lined on one side and both sides, respectively (Boral, 1992). In the domestic timber framing industry minimal allowance is commonly adopted for the bracing provided by the plasterboard wall lining. The capacity of diagonal bracing is increased by a factor of 1.4 to accommodate the bracing strength provided by the plasterboard (Groves, 1993). Although this approach is simple, it does not reflect the role of the plasterboard as its contribution should be independent of the performance of the diagonal bracing. These design recommendations are based on tests conducted on single isolated frames. No guidelines are present for walls with return corners and ceiling connection through cornices.

This paper presents a detailed Finite Element (FE) model for plasterboard lined cold-formed-steel domestic wall frames. The model is based on the commercially available general purpose finite element package (ANSYS, 1994). The model is not only for isolated wall panels but also
for those walls with extra boundary conditions. Typical boundary conditions are return walls with set corner joints, skirt-boarding and ceiling cornices. These extra boundary conditions dramatically affect the performance of these wall panels and change the failure mode from that of isolated panels. The FE model has been used to predict racking load-deflection behaviour as well as ultimate load carrying capacities for wall panels. It can accommodate any fixing pattern for the plasterboard and any wall geometrical configurations. Static, cyclic and dynamic loading can be applied. The FE model is part of a project to assess the performance of brick veneer cold-formed steel-framed domestic structures when subjected to lateral loads and in particular to earthquake induced loads. A major part of the project was an experimental program on a 2.4m x 2.3m x 2.4m high one-room-house (Gad et al., 1995). Part of the experimental results is used to validate the analytical model presented in this paper.

2 BACKGROUND

Currently, there are three different methods for predicting the racking performance of lintel framed walls. The first is based on empirical relations obtained from experimental data. These relations are limited to the material and configurations used for the test specimens. The second method uses simplified mathematical derivations. These mainly relate the performance of the connection between the frame and the lining material to the performance of the whole wall. Collins (1980) and McCutcheon (1985) developed these methods with some success. Assumptions are made in these derivations to make the mathematics manageable which limit the analysis to simple wall configurations. The third method is based on finite element modelling. This method was successfully used by Foschi (1977), Itani and Cheung (1984), Dolan and Foschi (1988) and others. These models were mostly for isolated wall panels. More recently, Kusal et al. (1994) developed and verified a non-linear finite element model of a whole house using ANSYS. The researcher included the effects of openings and the non-linear properties of the connections. However, the corner connections were greatly simplified. Hence, this model would not be suitable for investigating the influence of the set corner joints. All the models were developed and verified for timber framed walls and mostly for plywood cladding. None of the models developed included other means of bracing (such as strap braces) in addition to the cladding material.

To truly quantify the contributions of plasterboard to racking performance of wall panels a model is required to accurately accommodate the effects of the set corner joints as well as the wall-ceiling connection via the cornice. Such a model would yield the modes of load transfer between the plasterboard and the framing members and the ultimate failure mode. The model could also be used for sensitivity analysis to identify critical parameters and provide design guidelines.

3 CONSTRUCTION OF THE FE MODEL

3.1 Typical load transfer between the frame and plasterboard

In single isolated lintel frames, racking loads are primarily resisted by the shear strength of the cladding to frame connections (screws or nails). The failure mode of these walls is by tearing of plasterboard around the screws or nails. This generally occurs along the bottom connections or top and bottom connections. These mechanisms of load transfer and failure mode were recognised by many researchers including McCutcheon (1983) and Dowrick and Smith (1986). A section of a typical wall with two return walls is shown in Figure 1. When this wall is initially racked, the load is transferred from the frame to the plasterboard through the screws or nails in a similar fashion to a single frame. When the frame starts to move relative to the plasterboard, the gap closes between the plasterboard and the flange of the end stud of the return wall. This leads to a direct bearing of the plasterboard on the flange and hence another mode of load transfer between the frame and the plasterboard. When the racking displacement increases further, the bearing plasterboard edges start to crush. The crushing of the plasterboard edges propagate as the racking displacement increases. This becomes another failure mode.

3.2 Elements used for the models

At the early stage of modelling an isolated lintel steel wall frame was modelled. The frame had tab-in-slot connections and was lined with standard 10mm plasterboard. The plasterboard was screwed to the frame according to the recommendations from the plasterboard industry. The developed model was verified against experimental results from a number of walls of identical construction details. The FE model accurately predicted the load-deflection curve and the ultimate failure load. The failure modes from the FE model and the experimental walls were quite similar.

Studs, top and bottom plates were modelled as beam elements while spar elements were used for the noggings. The connections between the studs and the top and bottom plates were modelled as pinned connections to represent the tab-in-slot connections.

Plasterboard was modelled as shell elements with a thickness. The screws connecting the plasterboard with the frame were modelled as non-linear spring elements. Each screw was actually modelled by four springs, two in the horizontal direction (one for the positive direction and one for the negative) and similarly two in the vertical direction. These spring elements had different load-deflection characteristics depending on the location of the screw being modelled. For example, the screws tearing through the plasterboard edges would be different to those in the middle of the board and yet different to those in the recessed part of the board. Hence, a number of shear tests were conducted on the plasterboard-stud screw connections to get the appropriate load-deflection curves. It should be noted that the performance of plasterboard screw connections are sensitive to construction quality. For example, over-driven screws or those driven not at a right angle to the plasterboard would have substantially lower shear resistance. Therefore, many of these connections had to be tested to eliminate unrepresentative results.

In modelling the return walls, the gap between the plasterboard and the flange was included as shown in Figure 1. To include the crushing of the plasterboard along the edges, the crushing capacity of the plasterboard had to be determined. Hence, a number of compression tests were conducted on plasterboard to determine its capacity when loaded along its edge. Based on these tests the load-deflection of a small segment in compression was obtained and then modelled as

Figure 1. Typical wall with return corners and plasterboard layout at the corner.
a non-linear spring. Hence, a series of spring elements with gaps were attached to the plasterboard edges and the flanges of end studs of the return walls.

The cornice performs these functions when combined with return walls. First, it prevents the out-of-plane buckling of the plasterboard when it is bearing against the return walls. Secondly, it assists in preventing the rotation of the plasterboard relative to the frame because it ties the wall plasterboard to that of the ceiling. Thirdly, it transfers a proportion of the racking load from the ceiling lining directly into the wall plasterboard (i.e. not through the frame). These effects were considered in the model. The effect of the skirting-boards is to prevent out-of-plane buckling at the bottom. Hence, out-of-plane buckling was not considered.

3.3 Capabilities and limitations

The features of the model are:

- three dimensional effects can be included and any geometrical configurations can be accepted;
- although it was only used for plasterboard and steel frames it can accommodate any material properties, and non-linearities of connections;
- static, cyclic and dynamic loading can be performed.

This model has also been combined with another FE model for cross strap braces developed by Burton (1997). The combined models were used to confirm the load sharing between the plasterboard and the cross strap braces (Gad et al, 1995).

Plasterboard to frame nail or screw connections exhibit stiffness degradation and slip development under cyclic loading. ANSYS does not support elements with stiffness degradation; however, the developed models accommodated slip development. The models developed did not include door or window openings, but that can be accommodated in a similar fashion to that described by Kaasal et al (1994). Glue connections between plasterboard and the framing members were not considered because of the uncertainty of the performance of the glue over the life span of the structure.

4 VERIFICATION OF THE MODEL

To verify the model with return walls the analytical results were compared with those obtained experimentally. The experimental results are based on tests conducted on a 2.4m x 2.3m x 2.4m high one-room house. The details of the experiment and the configuration of the test house are described by Gad et al (1995). The lateral load resisting elements in this test house were two plasterboard-lined (on one side) walls with return wall. The test house was also fitted with ceiling plasterboard, ceiling cornice and skirting-boards. Because of the test house symmetry each wall assembly resisted half of the lateral loads. The out-of-plane return walls were minimal, therefore their contribution by bending was negligible.

A finite element model was constructed using the above mentioned elements to model half of the test house. Half of the test house is basically a 2.4m long by 2.4m height cold formed steel framed wall with 10mm thick plasterboard lining on one side. At each end of the wall there is a return wall with set corner joints and along the top and bottom of the wall there is a ceiling cornice and skirting-board, respectively. The modelled wall had the same plan as that presented in Figure 1 but only the end studs of the return walls were modelled. The plasterboard was attached to the frame with the screw fixing method as recommended by the Australian plasterboard literature, in which screws are fixed at 200mm centres along the end studs, 400mm centres along the intermediate studs and 600mm centres along the top and bottom plates. The framing connections were tab-in-slot.

The analytical and experimental load-deflection curves are shown in Figure 2. The analytical model predicted the ultimate load capacity with a very good degree of accuracy. The frame

![Experimental and Analytical Load-Deflection Curves](image)

Figure 2. Comparison between the experimental and analytical results.

![Deflected Shape of Frame Under Racking Load](image)

Figure 3. Deflected shape of frame under racking load.

deflected shape is shown in Figure 3 and matches what was observed in the experiment. It should be noted that in the experiment, the top of the frame was fixed while the bottom was racking. This produces the same net shear deformation as fixing the bottom and racking the top.

5 SENSITIVITY ANALYSIS

In order to illustrate and quantify the influence of boundary conditions on the performance of framed frames a sensitivity analysis was conducted on three wall configurations. These walls are identified as walls (a), (b) and (c) as illustrated in Figure 4. These three walls demonstrate the influence of ceiling to wall connection and return walls. The plasterboard was fixed in the same way for all the three walls as described previously. The framing members and connections were also identical.

In all these models the racking load was applied to the frame not the plasterboard. If the load is applied to the plaster directly then the load distribution may be different. For wall (b) the wall-plasterboard was prevented from moving vertically relative to the frame. This was the modelled contribution of the ceiling-wall connection through the cornice. The resulting load-deflection curves from the three walls are presented in Figure 5.
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REFERENCES


Barton, A. D. Performance of light gauge steel domestic frames when subjected to earthquake loads. A PhD thesis to be submitted to The university of Melbourne.


6 CONCLUDING REMARKS

A finite element model has been described to model plasterboard-lined domestic cold-formed-steel wall frames under racking loads. The model is three-dimensional and capable of accommodating boundary condition effects such as return walls, ceiling lining, ceiling cornices, and skirting-boards. The model was successfully verified against experimental results. The analytical and experimental load-deflection curves matched with a very good degree of accuracy as well as the deflected shapes and mode of failure. Based on a sensitivity analysis, contributions of return walls and ceiling cornices to lateral stability, were identified. It was found by including the return walls and ceiling cornice the load carrying capacity increases by more than three times. These boundary conditions enhance the racking resistance of plasterboard lined frames dramatically.