



Full sized house cyclic racking test

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ABSTRACT: Earthquake and wind loads for timber framed house designs in New Zealand are specified in NZS 3604. Various lining and cladding manufacturers publish bracing strengths for their wall systems based on the BRANZ P21 racking test. The P21 tests are carried out on a short length of wall with contrived end restraints to simulate continuity of actual construction.

To verify that this design approach is realistic, an existing house was relined and cyclically racked to failure. This paper compares the actual house strength with the strength determined using the NZS 3604 design provisions.

1 INTRODUCTION

Houses in New Zealand are generally constructed with light timber framed (LTF) walls each with a variety of wall lengths, sheathing and fastening systems. The result is many different bracing systems, each of which achieves peak bracing resistance at different deflections. Thurston and Park (2002) discuss this incompatibility problem and also the basis for changing the current test and evaluation procedure used to establish bracing ratings. This is known as the BRANZ P21 test method (Cooney et al 1979) and is used to obtain the bracing ratings of timber framed wall systems for houses, and other low-rise structures, to meet the wind and seismic demand stipulated in the light timber framing standard, NZS 3604 (SNZ 1999).

Timber framed houses generally exhibit good racking resistance in large earthquake and wind events. However, complacency is unwise if consideration is given to the \$20 billion damage to wood-frame construction in the 1994 Northridge earthquake (Fischer et al 2000). New Zealand has not experienced a large earthquake in an urban area since the 1931 Napier earthquake, with the possible exception of the 1987 Edgecombe earthquake. Most bracing resistance of New Zealand homes is provided by plasterboard wall systems whereas, overseas, similar buildings use plywood and OSB lined walls in the belief that plasterboard is too brittle.

Fischer et al (2000) summarises 15 full size house racking and shake table tests. Most of these tests were on prescriptively designed houses and the researchers found that there was adequate strength to meet code level lateral forces. Only one of these tests measured house racking strength and compared this with the sum of the predicted individual house wall strengths which is the approach of this paper.

Without contrived end restraints to simulate continuity of actual construction, bracing walls without end straps tested as separate elements would fail at a low load due to rocking of the wall about the bottom compression end. In the testing reported herein and by Thurston (1994) it was observed that the behaviour of house walls is more consistent with the fastener slip model shown in Figure 1. The restraint used in the current P21 test method is effectively 3 nails in shear as shown in Figure 1. Thurston and Park (2002) advocate increasing the restraint from a "3-nail" to a "6-nail" restraint in recognition of the inability of fixed wall panels in houses to rotate in practice.

The full scale racking test described in this paper was a pilot investigation into the degree of conservatism implicit in the bracing procedures described in NZS 3604 (SNZ 1999). This is reported in detail by Thurston (2003).

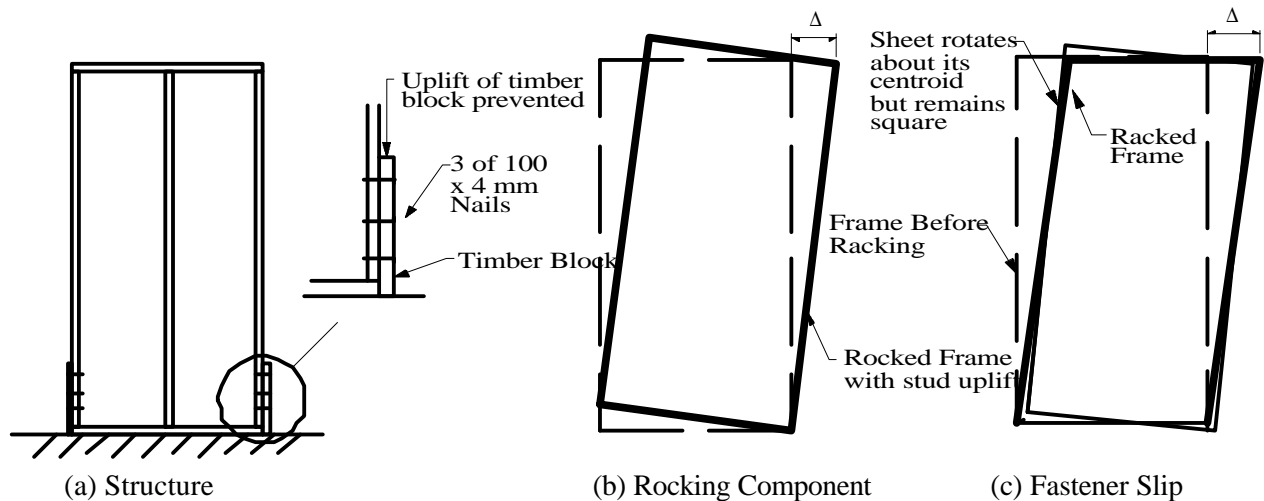


Figure 1. P21 end restraints and components of deflection.

2 DESCRIPTION OF TEST HOUSE

The test house is a single storey, plasterboard lined, fibre-cement weatherboard clad, standard Fletcher Homes house typical of those in the low cost end of the market about 1990. It was purchased unmodified from their catalogue. A plan of the house is shown in Figure 2 and photographs are given in Figure 3.

As the house was initially purchased by BRANZ with the intention of only being used for fire testing purposes, the house was simply placed on timber blocking nailed to a concrete foundation. By the time the structural testing project had started most of the plasterboard in the house was fire-damaged although the framing had not charred. All the house ceiling and wall plasterboard was therefore stripped and relined except for the bathroom, toilet, wardrobes and one bedroom which were undamaged by fire. The new lining was placed vertically with standard plasterboard screwed at either 150 mm or 300 mm nominal centres and bracing grade plasterboard fixed as a nailed bracing wall. Thurston (2003) provides full details of all linings and fasteners used.

Wall frames (2.4 m high) were prefabricated using gun-nails from kiln dried Radiata pine of size 90 x 45 mm for exterior walls and 65 x 45 mm for interior frames. Horizontal nogging was at 800 mm centres. Studs were at 600 mm centres. No supplementary stud hold-down straps or devices were used throughout the entire building.

The walls and ceiling were lined with 10 mm plasterboard as discussed above. All plasterboard joints were fully plastered and reinforced with paper tape. No skirting was used at the base of the walls and no ceiling coves at the top of the walls. Timber ceiling battens of size 68 x 32 mm ran perpendicular to trusses at 400 mm centres. Ceilings were screwed to these battens at 200 mm centres using standard gypsum plasterboard fixing details. At exterior walls the ceilings were fixed to double top plates. At interior walls the ceilings were not directly fixed to the wall plates.

The corrugated steel roof (without sarking) sloped 20° to a centre ridge and had gable ends. The roof trusses were at 1 m centres and spanned the 6 m width of the house.

The exterior of the house was clad with planks of fibre cement of cross section 300 mm x 6 mm. These were placed in the overlapping weatherboard style and were fixed to the adjacent stud near the bottom of the planks with a single 90 mm x 4 mm jolt head nail at 600 mm centres. The top of the plank was retained behind the plank above but was not fastened to it. Thus, the lateral resistance provided to the house by the exterior cladding is expected to be small.

This house has some weaker than usual racking resistance features. In particular, the bottom plates were gun nailed to the floor using only a single 90 mm long x 3.28 mm diameter gun nail at 600 mm centres. At exterior walls, and at interior Wall4, (Figure 2) these gun-nails penetrated into floor joists.

The remaining interior walls were not located above floor joists and hence the bottom plate nails were only fixed to the particleboard floor. There was lack of coving and skirting and wall hold-down straps. On the other hand, the west exterior wall is expected to be particularly strong as it has no openings.

3 TEST SET-UP AND INSTRUMENTATION

Figure 4 shows a general view of the test arrangement. The house was cyclically racked using two hydraulic jacks (see Figures 3a-d) each fixed to separate reaction frame. Each jack loaded a steel strut, which in turn loaded a steel beam (see Figure 2). Each end of each steel beam was connected to timber beam (Figure 2), which spread the applied force along the top plate of the adjacent house wall by use of strips of timber plywood located in the ceiling cavity. (See Figure 3(c).) An oil manifold ensured that the same force was applied to both jacks and the arrangement ensured that equal load was applied to the four timber beams.

Measurements included force applied by each jack, in-plane deflection of walls relative to the floor (as shown in Figure 2), house twist, plasterboard crack width and wall uplift movement.

4 PREDICTING HOUSE STRENGTH

It was desired to compare the measured house racking strength in the north-south (N-S) direction with that which would be obtained from summing the racking strength from the NZS 3604 (1999) bracing procedures assuming every transverse wall contributes according to its P21 (Cooney et al 1979) bracing rating.

The overall wall deflection in a racking test has two major components (see Figure 1); namely (1) that due to fastener slip, and (2) that due to total body rocking motion of the entire wall. The latter movement is a function of the end restraint and “3-nail”, “6-nail” and total end uplift restraint have been considered in this paper. The racking strength of bracing walls with “3-nail” end restraint is the strength derived from the current BRANZ P21 test method and that with the “6-nail” end restraint is the strength for a proposed revision of this test method. The sum of all wall strengths based on either “3-nail” or “6-nail” uplift restraint can be taken to be the NZS 3604 predictions based on the old and proposed revised P21 method respectively.

The predicted curve joining the cyclic load versus deflection plot peaks (hereafter called “backbone curve”) of each house N-S wall was obtained as follows:

(a) Laboratory testing was used to determine the load versus deflection curve for each type of fastener used to fix the linings. The wall load versus deflection relationship due to fastener slip was calculated using theory developed by McCutcheon (1985) and also using the Cashew software (Foltz et al 2000). Thurston (2003) gives information on this step in detail and found good agreement between both theoretical models and full P21 (Cooney et al 1979) test results. The relatively small deflection due to shear distortion of the sheathing was included in these calculations.

(b) The rocking component of deflection (see Figure 1) was obtained by examination of vertical movement at ends of bracing panels from historic P21 racking tests. Again Thurston (2003) gives information on this step.

The backbone curve for each wall was obtained by summing (a) and (b) above.

The house backbone curve was obtained by summing the N-S wall backbone curves as discussed in Section 5. The peak load on the backbone curve can be taken as the NZS 3604 strength prediction.

5 COMPARISON OF MEASURED AND PREDICTED HOUSE STRENGTH

Test hysteresis loops are shown in Figure 5. After three cycles to ± 60 kN (maximum wall deflection being 7 mm) a close inspection of the house found no plasterboard cracking. The first damage was observed when the total applied load reached 71 kN when bracing plasterboard cracking was observed

emanating from the east wall window openings. Cracks from each corner of both of these windows had extended to the ceiling or floor after the three cycles to ± 78 kN. As these had isolated the panel fasteners, (see Figure 6) the residual bracing panel strengths are expected to be severely diminished. During subsequent cycling these cracks widened, and the fasteners along this plasterboard bottom plate pulled through the adjacent plasterboard edge. The east wall windows and the sliding door on the east end of the north face jammed.

Slippage of the bottom plate of internal Wall2 on the particleboard floor (see Figure 2) was observed at cycling to ± 78 kN and this increased at subsequent cycles eventually reaching ± 15 mm. Slippage of the bottom plate of Wall7 reaching ± 6 mm was also monitored.

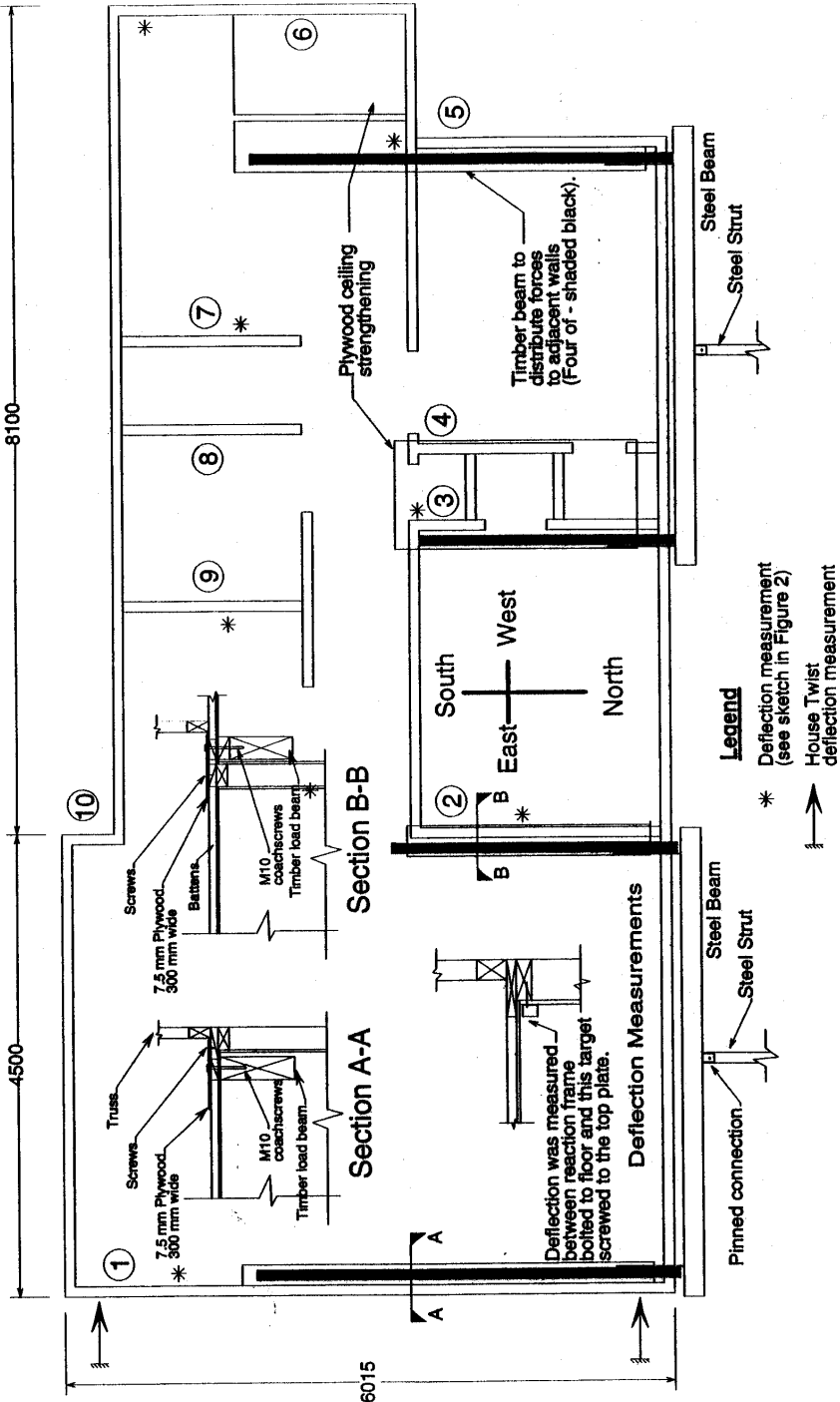


Figure 2 House Plan and Cross Sections



(a) General view of test in progress



(b) Connection to timber loading beams



(c) Plywood strip in roof space to connect timber loading beams to wall top plate



(d) Hydraulic jack, load cell and connection to reaction frame.

Figure 3. Test photographs

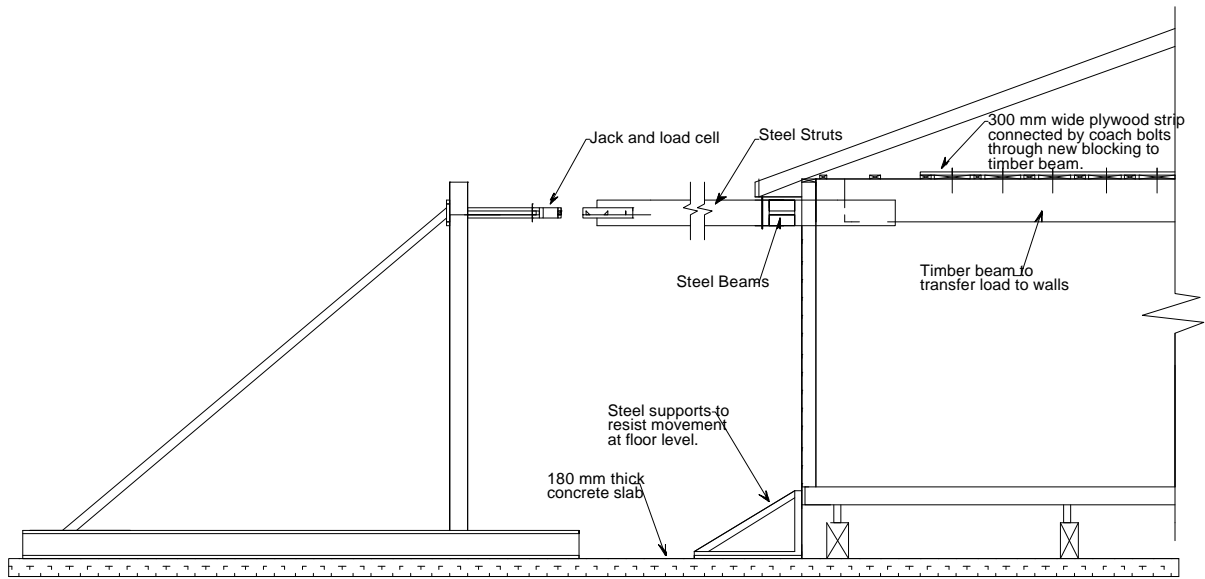


Figure 4. Test setup.

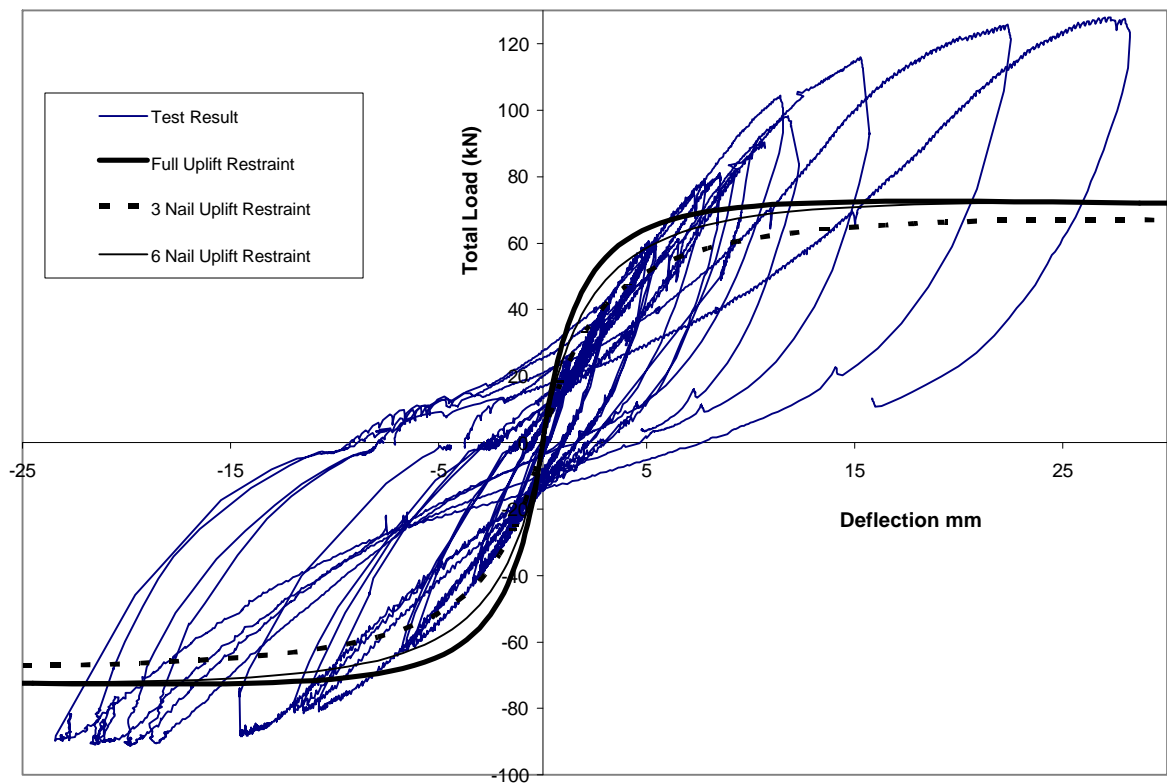


Figure 5. Forces resisted by house load versus deflection of Wall3

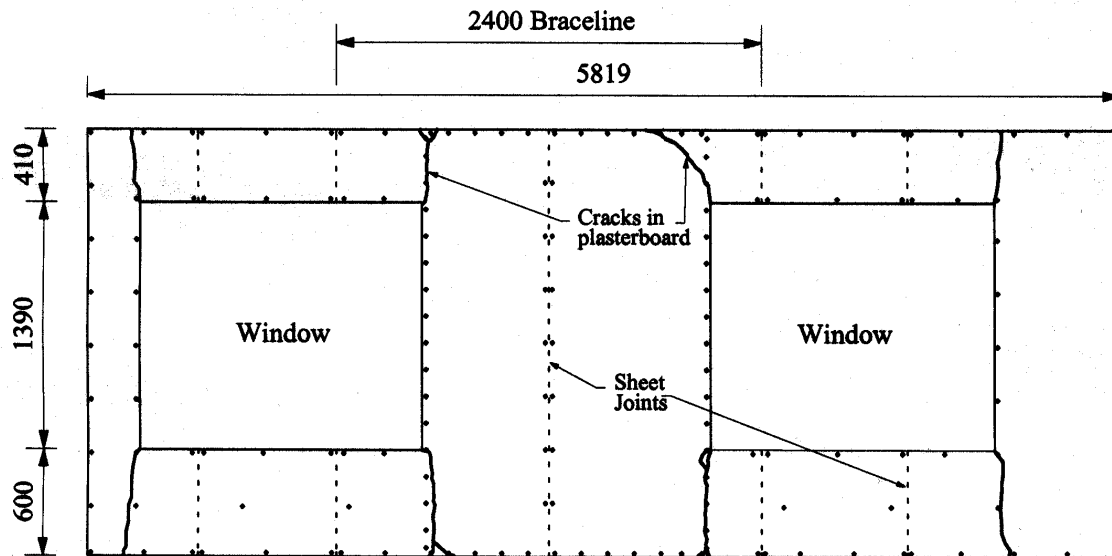


Figure 6. Plaster board cracks formed in the East Wall (Wall1)

Fine plasterboard cracks had formed from wardrobe door corners during cycling to +114, - 90 kN and the vertical plasterboard junction of Wall5 with the interior wall had cracked. During the final load cycle 2 mm uplift occurred at the now lightly cracked interior junction of Wall8 and the ceiling/wall junction of Wall8 had also lightly cracked. With the exception of Wall1 and Wall8, no cracks were observed in any plastered joints. Fastener heads fixing the plasterboard to the bottom plate had worked into the plasterboard in all N-S walls, except for the west exterior wall, which only experienced 4 mm deflection and showed little signs of stress. Despite the walls having no hold-down devices, apart from minimal bottom plate nailing, only Wall8 had uplifted.

House twist was found from east-west deflection measurements relative to the ground of the ends of the east wall. (See Figure 2.) The maximum monitored out-of-plane movement was 2.1 mm at the north end and 0.9 mm at the south end - indicating that house twist was small.

A plot of the measured total load resisted by the house versus the deflection of Wall3 (see Figure 2) is given in Figure 6. This is compared with the prediction of total house response which was obtained as follows: At each deflection of Wall3 the deflection of other N-S house walls was measured. The predicted force resisted by each wall at this deflection was obtained using the load/displacement relationships discussed in Section 4. These forces were then summed over all walls.

Figure 6 shows good agreement between “3-nail uplift restraint” theory and measurement for initial stiffness. However, compared to the uplift full-restraint prediction actual house strength was more than 75% greater for push loading and 25% greater for pull (average 50%). This is attributed to the plastered lining joints preventing the sheet from movement at the top of bracing walls and at corners and various “systems effects”, which is a term for the cumulative influence of moment and shear resisting “effects” which do not readily lend themselves to rational engineering analysis.

If this building was located in a “very high” wind zone, NZS3604 stipulates a wind demand force of 28 kN. The predicted wind resistance of the house (peak load on “3-nail uplift restraint” curve in Figure 5), which is also the NZS3604 predicted house resistance if all house walls are considered, was 67 kN. The measured house strength (averaged over the “push” and “pull” directions) was 61% greater than this.

Large differences in house wall deflections occurred which implies that the ceiling diaphragm action was far from being perfectly rigid, as is often assumed.

House free vibration tests determined the house natural frequency to be 20.8 Hz and the ratio of critical damping, λ , was found to be 8.2%.

6 CONCLUSIONS

The average (push + pull) cyclic strength of a plasterboard lined house was 50% greater than that predicted based on summing all the component walls and assuming all the walls are restrained against uplift. This average measured strength was 61% greater than the strength predicted from NZS 3604. Although it is recognised this is but one example of a typical New Zealand house, it indicates that simple summing of all component bracing walls will give a conservative estimate of total house strength for single storey structures.

Despite the wall bottom plates being nailed with only a single nail at 600 mm centres, measured wall uplift was low. This raises the question whether additional stud uplift restraints are necessary – except perhaps at door openings (Thurston 1994).

The testing also indicated that diaphragm action may be inadequate to transfer face loads from near the ends of a building to internal walls. Thurston (2003) consequently makes recommendations for change to provisions of NZS 3604 on the distribution of bracing elements. However, at the house ultimate load no cracking occurred within the plasterboard ceiling and cracking along the wall/ceiling junction was light.

7 ACKNOWLEDGEMENTS

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