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Repair and Reinstatement of Earthquake Damaged Houses – Derivation of Repair Techniques – Phase II

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The work reported here was jointly funded by the Building Research Levy and the Earthquake Commission.

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Preface

This is the second of a series of reports prepared during research into establishing the likely damage that will be sustained by elements of houses when subjected to earthquake attack. The research also investigates the formulation of repair procedures to restore the house to a state equivalent to its condition before the earthquake.

Acknowledgements

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- Fosroc for assistance with the supply and application of coating systems
- Westview Aluminium for the loan of an aluminium window
- Texturite for advice on repair techniques for monolithic cladding systems and the application of repairs.

REPAIR AND REINSTATEMENT OF EARTHQUAKE DAMAGED HOUSES – DERIVATION OF REPAIR TECHNIQUES – PHASE II

BRANZ Study Report No. SR 123 (2006) **GJ Beattie**

REFERENCE

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ABSTRACT

Experimental investigations have been carried out to replicate the damage sustained in earthquakes and to derive cost-effective and practical repair procedures for:

- walls reliant only on the internal linings for providing lateral restraint to the structure
- brick veneer wall junctions, and
- Exterior Insulation and Finishing Systems (EIFS), weatherboard and monolithic exterior claddings.

Methods of straightening a house that has been left with a residual racking displacement were also investigated. The damage and repairs have been summarised, along with suggested other considerations, so that they may be incorporated into the Earthquake Commission's *Earthquake Damage Assessment Catalogue*.

KEYWORDS

Houses, earthquake damage, repair techniques, experimental investigations, wall linings, wall claddings, brick veneer.

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1. INTRODUCTION

This report describes Stage II of the investigation of repair strategies for elements of houses damaged in earthquakes. The project involved introducing levels of simulated earthquake-induced damage to a selection of house elements, developing suitable repair strategies, implementing those strategies and evaluating the effectiveness of the repairs. The outputs from this study were provided for upgrading of the relevant sections of the *Earthquake Damage Assessment Catalogue* (EDAC) (EQC 2001) which has been prepared by the Earthquake Commission for use by insurance assessors following an earthquake.

Stage I of this investigation is reported in BRANZ *Study Report 100* (Beattie 2001). That study included a review of the source references used for establishment of the first issue of the EDAC, and an earthquake damage and repair matrix which covered many more damage scenarios than were able to be experimentally investigated within the scope of the project.

Similarly, the current study has not been aimed to derive solutions for all possible damage scenarios, but rather it has picked a number of more commonly expected damage cases and investigated the repair solutions for these.

2. EXPERIMENTAL STUDIES

As discussed in the Stage I report, it became clear from interviews with loss adjusters and others that there were many instances where the level of damage was not clearly obvious from a cursory inspection. It also became clear that guidance would need to be provided to the assessor on what indicators might be present to be able to specify the likely necessary repair.

For the current study four areas were investigated. These included:

1) Further consideration of a brick veneer exterior cladding.

2) Exterior walls with interior linings expected to provide the total bracing resistance in the wall (e.g. a wall with an exterior brick veneer or weatherboards).

3) Realignment of a complete house which had been distorted laterally.

4) An exterior wall with variable non-bracing exterior cladding elements containing window penetrations and an interior lining containing a designated bracing element.

2.1 Brick veneer cladding (Specimen 1)

The brick veneer specimen was the same one that was investigated and reported on in the Stage I report. The static testing of the brick veneer specimen yielded no apparent damage on the outside face of the veneer, except for a couple of small material losses due to punching through of ties. It was also known that the mortar joint between the foundation and the veneer had lost its bond to the foundation during the static tests. No attempt was made to remedy this situation because it was thought that the majority of these mortar joints would be like this in practice, due to suction of the water from the mortar by the foundation when the first course was laid.

Before commencing the dynamic testing in Stage II, a Borascope was used to attempt to ascertain the condition of the tie connections. A Borascope is like a periscope with a light source directed through the tube and the user views the surroundings at the end of the same tube. This had very limited success, because the black building paper made the cavity very dark and it was not possible to determine the condition of any ties other than the ones immediately adjacent to the Borascope hole. Practically, after an earthquake the process of checking with a

Borascope would be very time-consuming and the outer face of the veneer would be peppered with holes.

The top two rows of veneer ties were known to be damaged from the static testing, and proprietary stainless steel spiral ties were added adjacent to them to strengthen the damaged connections before the start of the dynamic tests. These ties are like spiral stainless steel nails which are able to thread the brick veneer and drill into the stud members (Figure 1). A pilot hole is drilled through the veneer, and then an electric drill with a special fitting in the chuck is used to screw the tie into place. It self-bores into the stud. The proprietary ties were drilled through the brick, and in some instances penetrated the cavities within the individual bricks. The subsequent performance of these indicated that it is essential for the ties to penetrate solid brick (see comments later in this section).

Figure 1: View of a proprietary tie (note that the ties used for tying the veneer were longer than shown)

The brick veneer specimen was mounted on the laboratory shake table (Figure 2) and the base block was securely fastened to the shake table. To simulate the weight of a heavy roof and roof framing, 1000 kg of steel weights were fixed to the top plate of the specimen.

Figure 2: Veneer test specimen mounted on shake table

Accelerometers were used to record the accelerations of the veneer, the timber framing and the shake table. Displacement transducers recorded the displacement of the top of the face-loaded veneer and the framing at each end of the face-loaded veneer with respect to the shake table. A displacement transducer was used to record horizontal slip between the veneer loaded in-plane and the foundation block and another was used to record the uplift of the free end of the in-plane loaded veneer.

Before the simulated roof mass was added, the specimen was subjected to a sharp pulse to record the natural frequency of the elements.

Frequencies recorded were:

Table 7.5 Hz
Veneer 7.56 Hz
Timber frame 7.46 Hz

The roof mass simulation was then added and the specimen subjected to another pulse load.

Frequencies recorded were:

Table 5.0 Hz
Veneer 5.04 Hz
Timber frame 5.04 Hz

In an effort to create an initial shock load on the test specimen, the shake table was rapidly displaced 30 mm followed by two cycles at low frequency (0.2 Hz and ±10 mm). The peak acceleration recorded for the timber top plate was 1 g and for the top of the veneer it was 2 g.

Damage occurred along the fixings of the plasterboard to the bottom plate of the framed wall. While the nail heads were in their original positions at the completion of the test, there was clear evidence that they had pushed the plaster core out of the bottom of the sheets (Figure 3). With skirting boards present in a real situation, the only possible evidence of this damage may have been some observable displacement of the plasterboard with respect to the skirting board. This would not be so obvious if the wall was wallpapered. The recorded uplift of the veneer at the door end of the specimen (where there was no return wall) was 14 mm. The bottom plate remained firmly attached to the foundation and the studs lifted from it, confirming the observed damage in the plasterboard.

Figure 3: Evidence of nails pulling through the edge of the plasterboard sheets

There was also minor evidence of damage to the mortar on the face-loaded panel. In two places the ties appeared to ‘pop’ some of the mortar out of the joint near the top of the specimen. There was no collapse of any of the veneer.

Further cycling of the shake table showed that there was considerable differential horizontal movement between the face-loaded veneer and the timber framing. The proprietary ties in the top two courses had reamed out the installation holes in the veneer and it was possible to see the end of the ties moving in and out of the veneer as the shake table oscillated. Further below the proprietary ties, the original flat ties were also moving in and out of the mortar to which they had originally been bound. From the outside, there was no evidence of any de-bonding of the flat ties from the mortar, and in a real house it would be difficult to ascertain the extent of de-coupling if there was no external evidence of damage. Attempts to determine any change in sound caused by the de-coupling when the veneer was struck on the outside face yielded no discernable differences.

The interior linings had detached from the framing over most of the wall area by this stage and replacement of these would likely be necessary in a real house. This would provide the opportunity to inspect the condition of the veneer ties as long as there was no building paper present. (Building paper did not appear to be used with veneer construction and indeed was specifically stated as not required before the introduction of NZS 3604 in 1978 (SANZ 1978).) Gentle levering of veneer from the studs would show whether or not there is still an adequate connection.

A recording of the north-south direction displacement record from the El Centro earthquake was introduced to the shake table. The controller for the shake table was set to 40% of the full El Centro signal. Inspection of the veneer after shaking revealed that a section of the veneer at the bottom corner of the wall intersection had permanently displaced outwards. This was coupled with a horizontal crack in the face-loaded veneer in a mortar joint one course of bricks above the bottom row of ties. On the in-plane loaded face, the crack extended up at an angle from the bottom corner to about mid-height of the veneer where it stopped. This crack followed the line of the mortar joints in a stepped fashion, with one exception where the brick fractured.

A bricklayer was asked to inspect the damage and advise on the sort of repair he would carry out in this situation. His advice was to remove the lower courses of bricks in the corner where the major damage had occurred and replace these. He commented that it would never be as strong as the original wall because there would not be the gravity load on the last mortar joint beneath the existing veneer. A repair was commissioned. Fine cracks in the mortar (< 0.5 mm) were left on the basis that free water would not penetrate these and any seepage would be drained as usual behind the veneer. Attempting to repair the cracks would have been more obvious than leaving them as they were. A sequence of photographs showing the repair process is given in Figure 4 to Figure 6.

Figure 4: Damaged corner removed and propped

Figure 5: Replacement bricks being installed

Figure 6: Veneer repair completed (note mortar is darker because it is still fresh)

A decision was also made to replace the ties with proprietary spiral ties over the entire face of the walls at the same spacings as the original flat ties. The proprietary spiral ties were installed by GK Shaw Ltd, a company skilled in the installation of the ties. Because the bricks were made with holes in them, the ties were positioned such that they passed through the solid portion of the brick in each case. The expectation was that the tie would hold better in the solid brick than in the face shells.

The interior lining was also replaced and re-stopped before commencing further testing.

The specimen was subjected to further dynamic loading. Initially, the table was excited at 1 Hz and at a very low displacement amplitude (approximately ±2 mm). Further El Centro displacement records were fed into the table, starting at a low span setting (2%) and gradually increasing the span to 100%. The acceleration levels reached several times the gravitational acceleration (g) during these tests, but the associated frequency levels were high and were thought to be due to table resonances.

However, both the face-loaded section of veneer above the repaired area and the in-plane loaded veneer showed signs of permanent horizontal movement (Figure 7) to the extent that removal and re-building would be necessary. The spiral ties appeared to work well, but eventually began reaming out the installation holes in the bricks. None of the veneer collapsed, indicating that while the ties had lost some of their holding ability, they were still able to provide some resistance. The repaired area of the veneer was virtually undamaged, except for local cracking at the return in the wall (Figure 8).

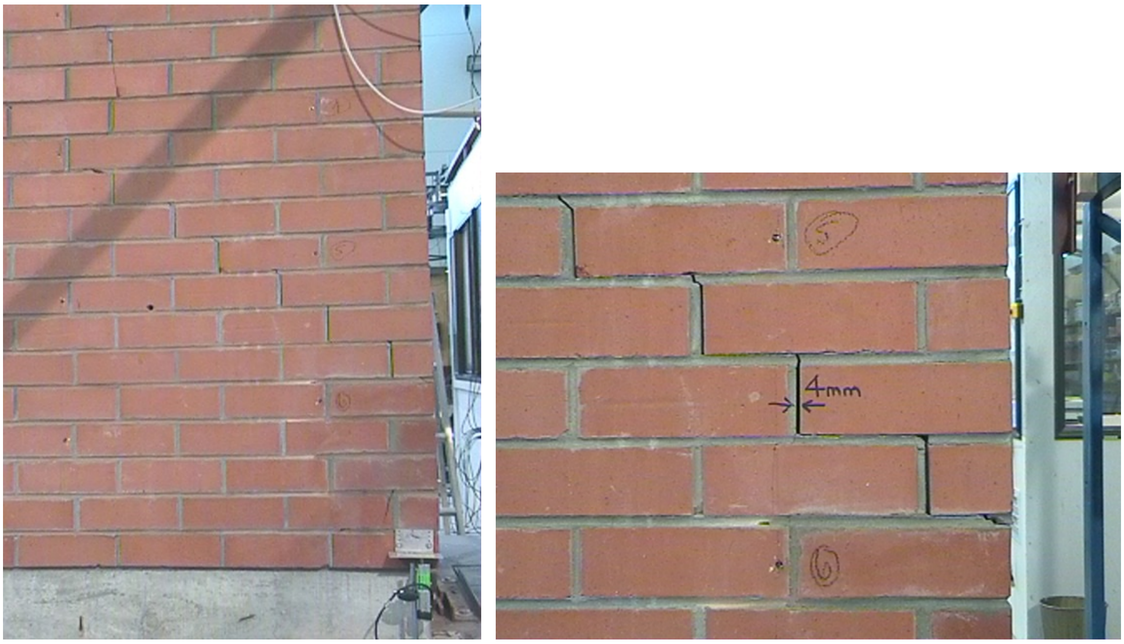

Figure 7: Views showing loss of alignment of the veneer face

Figure 8: View of damage to repaired veneer in the return corner

2.2 Exterior walls with only interior linings providing bracing resistance (Specimen 2)

Often with New Zealand house construction the exterior cladding is expected to play no part in the racking resistance of the structure. Instead, the interior linings are designed to provide the lateral load resistance. The types of exterior claddings that are not expected to provide bracing resistance include brick and concrete masonry veneer, exterior insulation and finishing systems (EIFS) and weatherboards.

A wall specimen was constructed on the strong-floor of the BRANZ Structures Laboratory that permitted an investigation of the development of damage to such systems and to determine the required repairs. The wall was 6.1 m long overall and had a 0.9 m return wall at each end. Parallel to the test wall, a support frame with no lateral load-resisting capacity was constructed to support a ceiling structure. Details of the wall framing are presented in Figure 9. The studs were at nominally 600 mm centres and the wall height from the bottom of the bottom plate to the top of the 90 x 45 top plate was 2415 mm. A double top plate arrangement with a 140 x 35 top member, typical of modern construction, was used to support the ceiling lining. Truss simulations were set over the test wall and the ceiling support wall and 100 kg weights were suspended at each end of the wall to model the roof weight. The walls were lined with 10 mm thick plasterboard and the assembly included a plasterboard ceiling. The bottom plate was nailed to the foundation beam with pairs of 100 x 4 mm flat head nails at 600 mm centres, as detailed in NZS 3604 (SNZ 1999). A single sheet of bracing grade plasterboard with a fibre-glass reinforced core was fixed to the wall at its mid-length. The sheet was nailed around its perimeter with 30 x 2.5 mm clouts and washers at 150 mm centres. Daubs of wallboard adhesive were used to glue the sheet to the intermediate stud at 300 mm centres. The remaining sheets were 10 mm standard plasterboard. To one side of the fibre-glass reinforced sheet, the plasterboard sheets were fixed to the framing with 30 x 2.5 mm clouts at 300 mm centres, commencing 12 mm from the corners. Pairs of clouts 50 mm apart were used to fix the sheets to the intermediate studs at 300 mm centres. In the other direction, the sheets were fixed with 25 mm x 6 g drywall screws. These screws were at 300 mm centres around the perimeter of the sheets, commencing 12 mm from the corners. Daubs of adhesive were used to glue the sheet at 300 mm centres to the intermediate stud.

One half of the wall was wallpapered (where the sheets were nailed in place) and the other half was painted. Timber skirtings and scotias were fixed with panel pins.

A 10 tonne hydraulic actuator was connected to the top plate of the test wall so that in-plane displacements could be applied to create the damage.

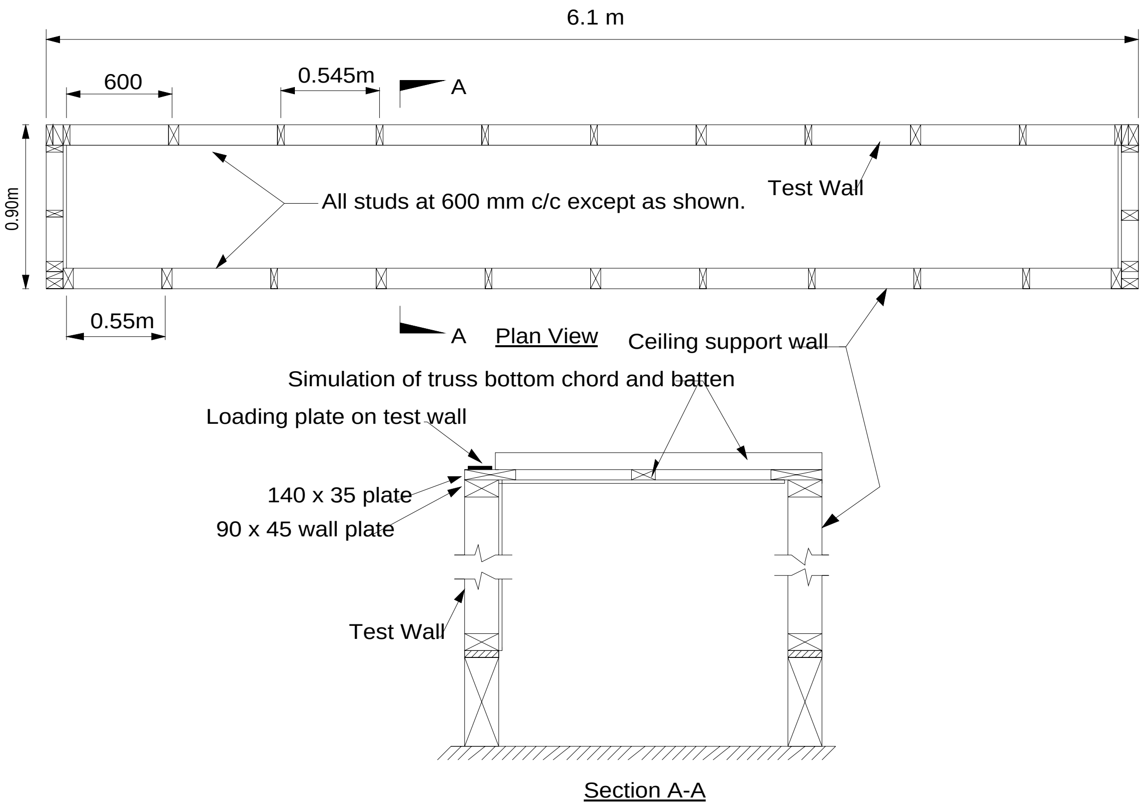

Figure 9: Details of the Specimen 2 wall framing

Testing began by displacing the top plate of the test wall for three cycles to ± 4 mm and inspecting for damage. There was no discernable damage. This was followed by three displacement cycles to ± 8 mm. During these cycles, the scotia at the nailed sheet end lifted slightly with respect to the wall lining and the wall lining slipped horizontally about ± 4 mm with respect to the skirting board. At the completion of the cycling there was no discernable damage. Three further sets of cycles to ± 8 mm were made, and during these the peak load dropped off gradually. This suggested that the linings were slipping on the fastenings until they reached the ends of the slots formed in the previous cycles, at which point they began to take up load. Having sustained this amount of damage, the structure would be more flexible than when first built and subsequent earthquakes would cause the structure to deflect slightly more before taking up the load resistance. However, there would be no more danger of collapse. Therefore it is not likely that repairs would be needed after an earthquake that caused wall displacements of ± 8 mm.

After cycling to ± 14 mm popping at nail heads was seen at six nails in the painted zones, but none in the wallpapered zones (Figure 10). Any similar damage that may have been present under the vinyl wallpaper was hidden and therefore would not be detectable by an assessor. There were faint cracks in the paint along the junctions between the timber scotia and the wall which would likely be covered by a new coat of paint. There was a small amount of crumbling and wrinkling of the plasterboard corner at the painted end near the bottom of the joint (Figure 11). A repair in this area would require cutting out of the taped joint and re-stopping with new tape. This could possibly only extend to just above the region of wrinkling, but it may be difficult to match a paint repair. Re-stopping and painting of the popped nail heads would be necessary and extra fixings should be added adjacent to the popped nails.

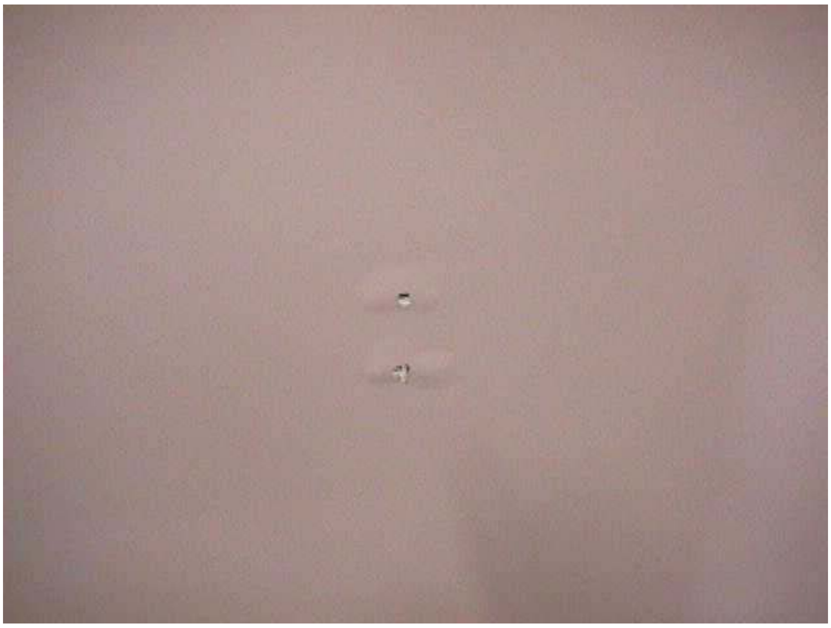

Figure 10: Popped nail damage on painted plasterboard

Figure 11: Wrinkling and crumbling of the plasterboard at the painted corner

After cycling to ± 21 mm popping at nail heads was seen at 70% of nails in the painted zones, but none in the wallpapered zones. Any damage under the vinyl wallpaper, scotia and skirting was hidden. There were cracks along the ceiling/scotia and scotia/wall junctions which would likely need a plaster skim coat and sanding before being covered by a new coat of paint. The skirting had pulled away from the wall by approximately 1 mm, probably due to some sheet lining nail rotation. The skirting was removed at this point and revealed significant damage in the plasterboard at both lining and skirting nail locations. The large slip of the plasterboard relative to the bottom plate had resulted in plasterboard fastener heads embedding into the plaster, and the shanks of the fasteners had gouged holes in the plaster, severely weakening the wall's in-plane strength.

In positions where the lining was not a designated bracing element, it would be acceptable to re-nail the skirting board and re-paint it. If the wall contained bracing elements it would be desirable to remove the skirting and the scotia to inspect the fixings through the bracing elements. Re-nailing of these adjacent to original positions, but in undamaged board, would be a satisfactory solution to re-instatement of the lateral load-resisting capability. However, the dilemma facing the inspector will be knowing which panels are the designated bracing elements. Because of this, it should be expected that the skirting and scotias will need to be removed and all the linings re-fixed before replacing the skirtings and scotias.

The wall junctions in both the painted and the wallpapered sections were crumbling and wrinkling near the bottom corner. A similar repair, as specified above, of cutting out the stopped joint and installing new paper tape and stopping would be necessary. The daubs of glue fixing the plasterboard sheets to the intermediate studs had failed in the top and bottom thirds of the wall on many studs. The plasterboard rattled against the studs when tapped. A simple solution in this instance would be to nail or screw the board to the intermediate studs. These would require stopping and re-painting or re-papering.

Re-fixing of the sheets beneath the skirtings and the scotias was undertaken and the specimen was cycled to ± 32 mm. During the first cycle to 32 mm, as the displacement reached 21 mm the resistance climbed to the same level that it was during the third cycle to this displacement before the repair, indicating that the repair had improved the strength (Figure 12). However, the ‘pinched’ nature of the loops (i.e. large displacements before load increases) meant that the wall was still quite flexible, despite the repair having been undertaken.

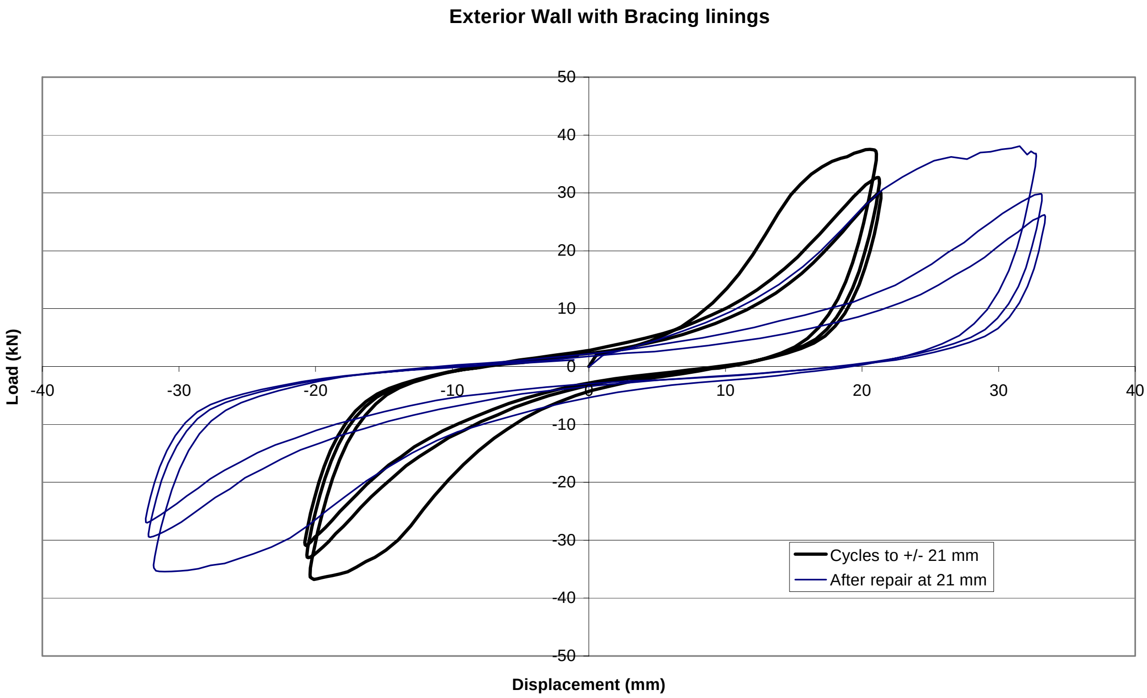

Figure 12: Load – displacement plot before and after repair at 21 mm

It is therefore recommended that if internal wall linings are showing fresh signs of damage (e.g. new cracks at the junctions with skirting boards and scotias, nail popping and cracking on joints between sheets), the skirting boards and scotias be removed and the sheets be re-fixed at 150 mm centres along both the top and bottom edges.

2.3 Vertically realigning a house that has been left out-of-plumb by an earthquake (Specimen 3)

2.3.1 Description of the house

An opportunity arose to attempt to straighten a house at the BRANZ site that had been pushed out-of-plumb in an earlier research project. The structure was a single storey dwelling with a corrugated galvanised steel roof and fibre-cement weatherboards and was supported on a pile foundation (Figure 13).

The interior of the house was lined with plasterboard, with certain sections of wall designated as bracing elements. The ceiling was also plasterboard and not detailed for diaphragm action. The flooring was 20 mm particleboard. The framing was 90 x 45 radiata pine with studs at 600 mm centres. At the top plate level two plates were used – a 90 x 45 plate overlain by a 140 x 40 plate. The ceiling battens, which spanned across the underside of the bottom chord of the roof trusses, butted into the 140 x 40 top plate.

A floor plan of the house is given in Figure 14.

The house had been displaced in the transverse (short) direction at the eaves level in a previous research investigation and was left with a permanent offset at eaves level. The aim of the testing in this study was to investigate methods of returning the house to an acceptable vertically aligned state using tools that were likely to be readily available to a builder after an earthquake.

Figure 13: House to be plumbed (aligned vertically)

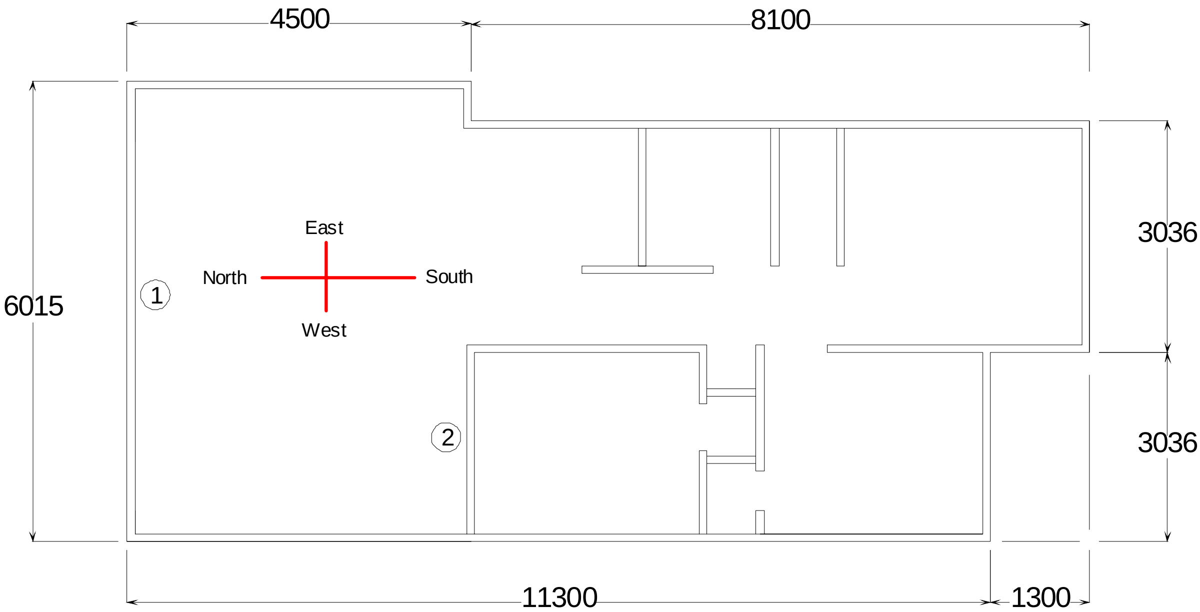

Figure 14: Floor plan of the house

In the view given in Figure 14, the house was displaced at eaves level in an east direction. Wall 1 contained two large windows, and in the previous testing it was found to deflect the most easily of any of the transverse (east-west) walls. Wall 2 distorted within its plane and it also slipped at the bottom plate to flooring connection. There was very little observable damage at the connections between the walls and the ceiling, indicating that the force transfer mechanism at this level was effective. There was also only minor cracking of the paint over the ceiling panel joints.

First, an attempt was made to realign Wall 1 using a light wire rope and ratchet winch (commonly available from a builder's merchant) fitted across the long diagonal of the wall while the internal linings were still in place (Figure 15). A light gauge (3 mm thick) steel plate at each end of the rope was attached to the top and bottom plates of the wall with a 12 mm diameter coach screw. The rating of the ratchet winch was 2 tonne, but it was found that no more than a 700 kg force was able to be applied before the winch began to distort within itself.

Figure 15: Light wire rope tensioning device and remote end connection

At a load of 700 kg, it was possible to pull Wall 1 towards a vertical orientation (but not all the way), and on release of the load the displacement increased again.

The wall linings were removed in an effort to remove some of the resistance to the applied load, but this provided little improvement. It was suggested that the fibre-cement weatherboards may have been providing some bracing resistance, but these are only singly nailed and therefore there are no nail couples. It was more likely that the ceiling was transferring the load to the remaining walls in the house, and these and the ceiling were deflecting elastically and then returning the wall to its original position after the load was released.

The same ratchet winch was used to attempt to pull Wall 2 back to a vertical state, but the results were very similar to Wall 1. In this case, the wall linings were not removed.

Wall 1 was then loaded on the same diagonal with a wire fence strainer (Figure 16), but the loading mechanism was too coarse and did not allow easy increase of the load. A 700 kg force was again the maximum that could be achieved.

It took a 3 tonne capacity 'cum-along' rigger's hoist loaded to its capacity attached to the exterior of the house in the region of Walls 1 and 2 to pull the walls 11 mm past vertical. Once that stage had been reached, a light gauge steel strap brace was fixed to Wall 1 with 35 x 2.87 mm diameter nails (Figure 17) before the externally applied load was removed. The house relaxed, but remained in a close to vertical orientation. The problem with employing this procedure after an earthquake is that there is not likely to be a suitable reaction point remote from the house, and also significant damage would be caused connecting to the house.

From the observed response, it would seem that the plasterboard ceiling, and possibly the roofing to a lesser extent, were providing an effective load transfer mechanism between walls. To realign a whole house in a simple manner it will be necessary to load all parallel walls at the same time so that any elastic resistance can be overcome. If this does not work, it may be necessary to remove the wall linings before loading and installing metal strap braces to hold the frame in position to maintain alignment before adding new linings.

Figure 16: Wire fence strainer used to try to re-align the wall

Figure 17: Light steel strap brace (was fixed to Wall 1 while pulled to a position beyond vertical)

The only requirement for fixing the bottom plates of internal walls of a house that are not bracing walls and are not load bearing walls is two 100 x 4 mm nails at 600 mm centres along the plate. It is likely that such walls will move longitudinally with respect to the flooring during an earthquake because these nail pairs will not be able to resist the earthquake forces. In this house, Wall 2 was one such wall and it translated approximately 20 mm along the floor as a rigid body. To restore this wall to its original position, two methods were attempted. The first of these involved nailing a block to the floor nearby to the end of the wall in question and using a crow bar to lever the bottom plate back into place (Figure 18). This method was only mildly successful. The wall could not be moved far before the block began to prise off the floor.

Figure 18: Re-aligning Wall 2 with a crow bar

A 2 tonne capacity car bottle jack was introduced to provide the necessary push to return the wall to its original position. The reaction to the jack load was provided once again with the timber block nailed to the floor, but this was also propped against a wall on the opposite side of the hallway and another block was nailed to the floor on the other side of that to provide the necessary reaction strength. As Wall 2 was moved to its original position the bottom plate of the wall (which was a 70 x 45 member) buckled quite significantly out of the wall plane and the bottom plate of the adjacent orthogonal wall also showed signs of misalignment (Figure 20). Further jacking would have been required further along this wall to straighten the plate. Wall 2 would have required temporary lateral guides to prevent out-of-plane buckling during the house realignment process.

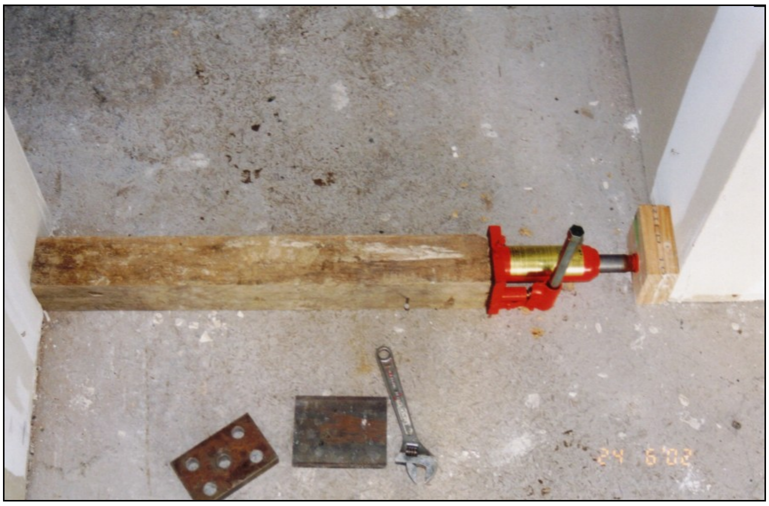

Figure 19: Car bottle jack used to translate the wall

Figure 20: View showing misalignment of the plate in the orthogonal wall

The testing experience has shown that it is likely that more than one rigger's hoist will be required to realign all parallel walls at the same time so that individual walls are not 'fighting' against other parallel walls as was the case in this investigation. It must be considered that it may not be possible to obtain sufficient hoists to realign those houses needing realignment after an earthquake.

2.4 Investigation of the performance of walls with installed windows and various claddings (Specimen 4)

The in-plane loading performance of walls with and without penetrations such as windows and doors is known to be different due to the introduction of stress-raising points in the penetrated case. Furthermore, racking damage to the framing could possibly lead to leakage problems around windows and doors subsequent to the earthquake. This study considered a length of wall with three different types of exterior cladding, all including a window and in two cases a corner construction was also included. At both ends of the wall, the construction returned 900 mm and a ceiling was installed between the long wall section and a parallel frame in the line of the free ends of the return walls. The layout of the wall system is presented in Figure 21 and Figure 22 and an overall photograph is given in Figure 23.

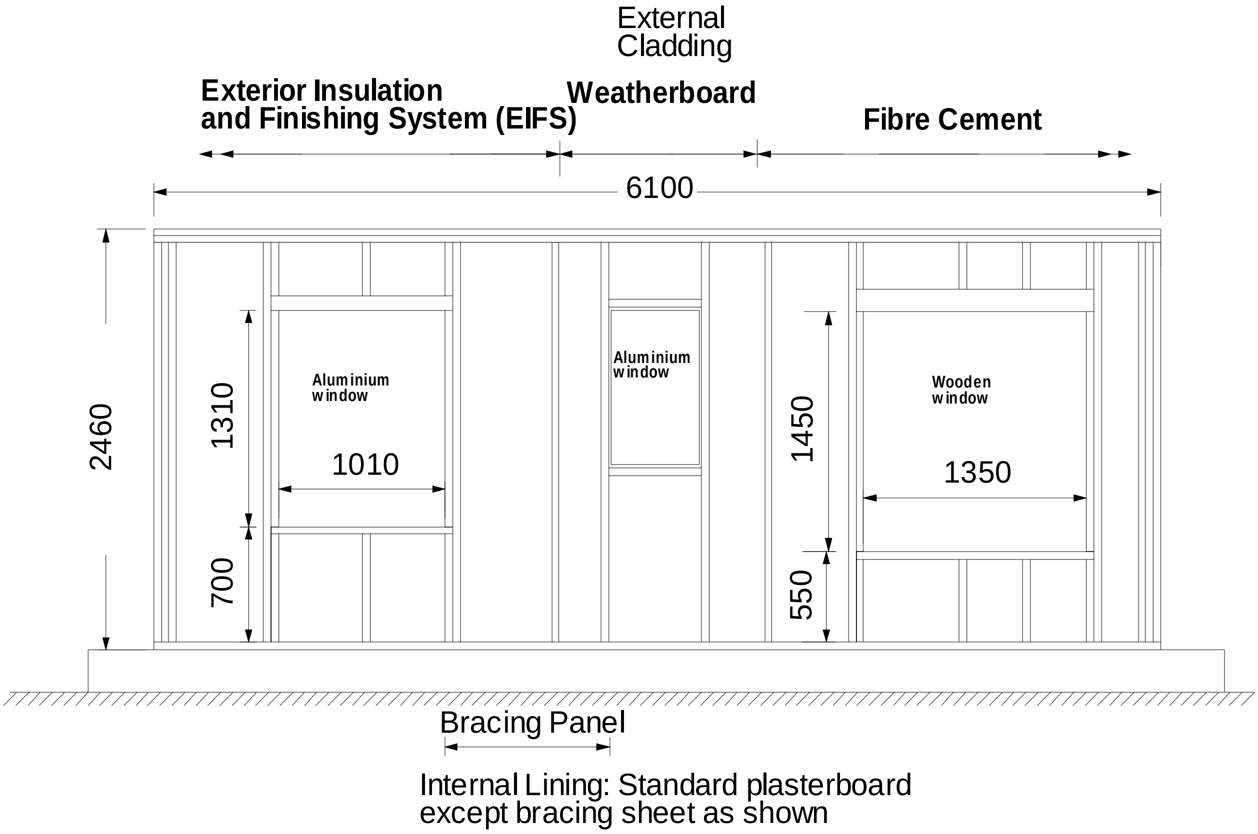

Figure 21: Arrangement of the penetrated wall (Specimen 4) viewed from the inside

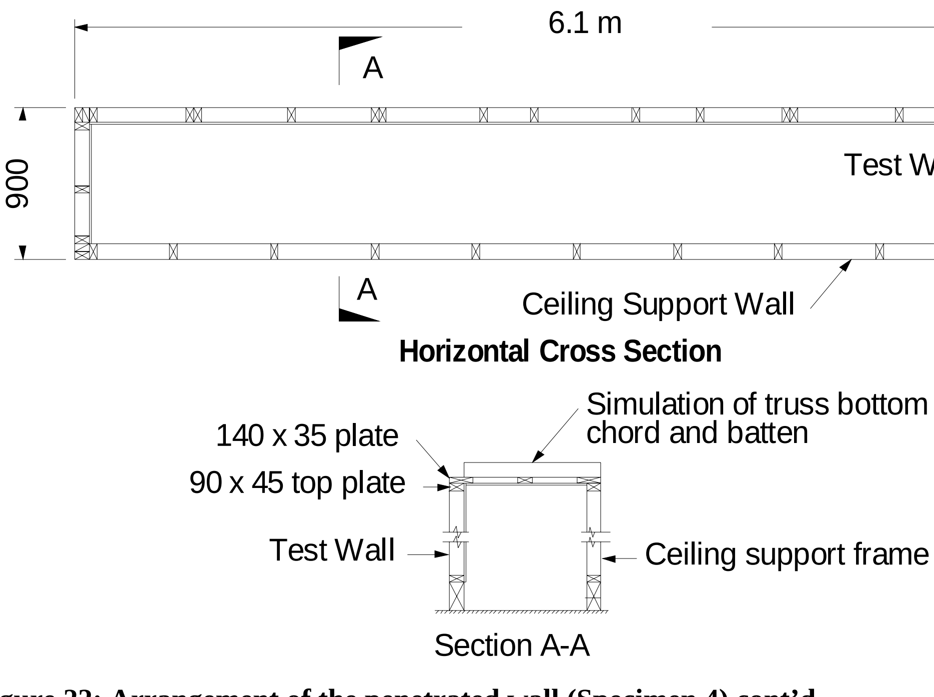

Figure 22: Arrangement of the penetrated wall (Specimen 4) cont'd

Figure 23: Overall view of the test specimen

The fibre-cement section was described by the manufacturer as a monolithic textured cladding solution for light-weight construction. Installation was in strict accordance with the manufacturer's *Technical Information* brochure. This section was coated with a single size aggregate textured coating and painted with a high-build acrylic by a recognised applicator. An old timber window, typical of construction used before 1980, was installed in the traditional manner of this era except that a sill flashing was only placed under half the length of the window sill to enable the influence of this flashing to be determined during rain water penetration tests. The weatherboard clad section was installed in accordance with the manufacturer's *Technical Information* brochure and contained a non-opening aluminium window. The right-hand end of the specimen (as viewed in Figure 23) was clad with an Exterior Insulation and Finishing System (EIFS) which comprised 40 mm thick expanded polystyrene foam over-coated with a polymer-modified cement texture plaster with irregular grain size which was trowelled over the wall. This was painted with a high-build acrylic by a recognised applicator. The aluminium window in this section contained a fixed pane and a sliding pane and was installed in a manner typical for this type of cladding.

2.4.1 Testing sequence

The aim of the testing was to determine whether the racking deformation of the wall would cause damage to the wall claddings and the flashings around the openings to the extent that the weather penetration resistance would be reduced. It was also to determine appropriate repair techniques for any damage incurred.

The construction was conducted in stages so that various factors could be investigated. Initially, the exterior claddings were applied. Building wrap was first fixed to the framing in accordance with the manufacturer's recommendations, including cutting and mitring the wrap into the window framing (Figure 24). Other proprietary products specified by the manufacturers of the three systems were also installed in preparation for the installation of the windows (Figure 25). A view of the window head and side flashings installed in the weatherboard section is given in Figure 26. The thickness of the EIFS foam was 40 mm and the sheets were fixed to the framing with 75 x 3.15 mm flat head galvanised nails and 40 mm diameter plastic washers at approximately 150 mm centres (Figure 27). The fibre-cement cladding and the EIFS were over-coated with an acrylic paint system.

To determine whether or not the weather penetration resistance was affected, a catch tray was constructed in front of the specimen so that water could be sprayed, when required, on the outside face of the wall using a spray rig matching the requirements of NZS 4211 (SNZ 1985). Essentially, this consisted of six water jets spraying at a 100° fan angle at the face of the wall. Each jet had an output of approximately 5.4 litres per minute.

Figure 24: Building wrap mitred and fixed into the window frame

Figure 25: Proprietary flashings installed before the windows and EIFS cladding

Figure 26: Window head flashing and side flashings in weatherboard section

Figure 27: EIFS section with foam sheets fixed in place and window installed

(a) Initial water resistance test

The interior lining was not installed initially, but the ceiling support wall was temporarily clad and a negative pressure of 300 Pa was introduced to the space between the two walls in accordance with NZS 4211. Water spray was directed at the exterior cladding and the spray from all nozzles exceeded 5.4 litres per minute.

The water penetration around the windows was significant, entering from both the window head and window sill levels. The weathertightness experts group at BRANZ advised that this would be expected to reduce significantly when the internal lining was installed, as it would provide a seal and the driving force for water penetration of a differential pressure across sheathing with openings would therefore not be present.

A significant observation was that the section of the timber window with a sill flashing leaked very little compared to the end with no sill flashing.

(b) Second water resistance test

The 10 mm thick plasterboard wall linings were then screwed into place using drywall screws. The screws were 25 mm x 6 g and had a 12 mm edge distance, with a single screw placed at each corner and screws at 300 mm centres around the sheet perimeter and along the intermediate studs. A sheet bracing panel was incorporated in the wall between the two aluminium windows. The fixings for this panel were 25 mm x 6 g drywall screws, but with washers included. These were placed 50 mm in from each corner and at 150 mm centres around the sheet perimeter and at 300 mm centres down the internal stud.

The joints between sheets were taped and stopped. A plaster cornice was installed at the timber window end of the specimen. A taped square corner joint at the wall/ceiling junction was used at the other end. The end with the square corner joint was painted and the end with the plaster cornice was wallpapered with wallpaper representative of that used before the introduction of vinyl wallpapers. Perspex viewing windows (approximately 150 mm by 150 mm) were fitted below the windows at one corner of each window and the cavity space was artificially lit. Power points were fitted under each window to provide realistic holes in the wall lining; in case this affected the differential pressure distribution.

A spray test was conducted and there were no visible leaks around the wooden window. The fixed window showed minor signs of leakage through the frame itself, although some water appeared to be entering through the mitre joints at the interior sill ends and then must have found its way past the flashings into the wall cavity. The aluminium window in the EIFS section only showed signs of leakage up through the drain holes in the interior sill channel. These appeared to have a captive ball beneath each which was expected to rise under suction and block the hole. However, one of these had malfunctioned.

(c) First racking test

The wall was then subjected to a series of in-plane racking cycles to the following displacement levels:

1) three sets of 3 cycles to ± 4 mm
2) three sets of 3 cycles to ± 9 mm
3) one set of 3 cycles to ± 14 mm
4) one set of 3 cycles to ± 24 mm

At each displacement increment a record of the observed damage was made.

1) ± 4 mm displacement cycles

The wall creaked during cycling. The interior vertical lining joint below the left-hand side (painted side) corner of the middle window developed minor rippling in the paper tape and faint cracking. Otherwise there were no detectable cracks on either the interior or exterior faces. No movement between wall and skirting/covings/base beam etc was observed using the marked vertical lines across these intersections.

2) ± 9 mm displacement cycles

The vertical joint in the interior lining above and below the left-hand side (painted side) corners of the middle window cracked approximately half-way up to the scotia and down to the skirting respectively. The vertical lining interior joint above the right-hand side (wallpapered side) corner of the middle window had rippled and ripped.

In both of these instances, a satisfactory repair would involve gouging out the joint between the two sheets and re-taping and stopping the joints. Painted walls would require new paint and wallpapered walls would require new wallpaper.

The paper tape had pulled away from the vertical wall joint for 50 mm from the top and bottom of the right-hand side corner of the EIFS window and for 150 mm from the left-hand side corner. There was also minor cracking at these joint locations.

The vertical joint in the fibre-cement cladding centred directly below the timber window had bulged (Figure 28) and would require repair. While the joint appeared to remain watertight, it was very noticeable in the monolithic finish. A procedure suggested by the plaster coating applicator involved vee-ing out the joint and filling with a flexible sealant before refinishing the wall with a new plaster coating and paint. Attempts to refinish the area locally only would very likely be impossible to complete without the region being obviously different, mainly because of difficulty matching the paint colour. The bulge was left without repair so that the joint's performance under larger deflections could be observed.

Figure 28: Bulge in fibre-cement cladding joint after ± 9 mm racking

A 150 mm long diagonal crack had formed in the fibre-cement cladding from the top corner of the timber window, reaching 1 mm width at 9 mm wall deflection (Figure 29). This was obviously a failure of the substrate board. However, when the wall was returned to its zero deflection point this crack closed and was not visible to the eye alone. Assessors would need to carefully check for this damage. If the structure remained vertically aligned after the earthquake the crack may not show, but it could form a path for moisture entry in the future. A new coat of paint over the area would serve to re-seal the crack.

Figure 29: 1 mm wide crack in fibre-cement cladding above window head

A diagonal crack had formed over the width of the sill only at each end of the window in the EIFS section (Figure 30), reaching 1 mm width at 9 mm wall deflection. However, when the wall was returned to zero deflection these cracks closed and were only just visible to the eye alone.

Figure 30: Crack in the corner of the EIFS cladding at the corner of the window

3) ± 14 mm displacement cycles

During these cycles greater damage had occurred at the vertical joints at the middle window (Figure 31). Cracks emanating from the left-hand side corner now extended to the skirting and scotia respectively, with adjacent sides of the cracks sitting proud by approximately 2 mm. The wallpaper had ripped further at the right-hand side corner of the window.

Figure 31: Damage to the interior surfaces at the joints between sheets

Wrinkling of the ceiling/wall joint was occurring where the square joint had been created above the EIFS window, but no damage was observed along the plaster cornice above the timber window. In the body of the interior lining the joint cracks now extended full height to the scotia and skirting on both corners of the EIFS window. Some horizontal slip (± 1.5mm) was occurring between the skirting and the bottom plate.

The appropriate repair procedure would be to gouge out the joints and re-tape and re-stop them, followed by refinishing the wall with wallpaper or paint, as appropriate.

On the exterior wall face the cracks emanating from the bottom of the EIFS window now extended 50 mm approximately diagonally down the wall and were 0.2 mm wide when the racking load was removed. There was also faint cracking diagonally upwards from the top corners of this window. These cracks could be sealed with a new coat of paint.

The bulge under the timber window in the fibre-cement clad section was no more pronounced. Cracking had been observed from both top corners of this window, but these could not be detected by eye once the wall had returned to zero deflection. A repair procedure, as noted in the previous section, would be satisfactory.

There was no sign of any damage in the section of wall clad with weatherboards.

4) ± 24 mm displacement cycles

The damage had increased in the interior linings at the vertical joints at the corners of the windows installed in the EIFS and weatherboard sections. These cracks were vertical and generally up to 2 mm wide.

Wrinkling of the ceiling/wall square joint above the large aluminium window had increased. No further damage to this joint was observable.

Slight but full height wrinkling of the wall paper had occurred at three of the four corners of the timber window. Later inspection (by removing the wallpaper) showed that a full height vertical crack had occurred at the left-hand side bottom corner of the window. Note that the plasterboard was cut around this window in accordance with the manufacturer's recommendations.

The slip of the skirting relative to the bottom plate was measured at ± 1.5 mm.

In this situation the assessor of a damaged building will need to consider carefully the lateral load-resisting system. Because the wall claddings are not of the type expected to offer any in-plane racking resistance, the resistance should be expected to be provided by at least part of the interior lining or perhaps let-in timber braces. There is no easy non-destructive method of determining which part of the wall lining will be the bracing element. It is suggested that the skirting board needs to be removed so that the virgin faces of the sheets beneath it can be exposed. Bracing grade plasterboard sheets are often coloured differently from standard grade sheets and are fixed with either nails and washers or screws with large diameter heads. Significant damage to these indicates that the sheet should be replaced and re-fixed in accordance with the manufacturer's recommendations.

Long lengths of wall linings with no colour differences could be standard plasterboard in combination with a diagonal light metal brace or a let-in timber brace. In this instance, it should be possible to identify the position of the brace by checking along the edge of the bottom plate between the lining and the floor for the end of the brace. The brace end connection will require checking to ensure that it is still attached to the bottom plate. If not, it will be necessary to remove the linings to repair or replace the brace. Joints between sheets in modern construction will be paper taped and the likelihood of any damage along these joints is small. Any damage will be evidenced on the surface by nail popping. On older construction, there is not likely to be any tape on the joint and cracking will be present in the painted surface or in the wallpaper. If a large shear displacement is present between two sheets and the adjacent joints show no (or little) signs of movement, then there is likely to be a let-in timber brace in a section of the wall on one or the other side of the joint showing the large shear displacement. The joints will require modern paper taped stopping and the bottom edge of the sheets needs to be re-nailed at 150 mm centres before the skirting board is re-installed.

On the exterior face of the wall the cracks emanating from the bottom corners of the window in the EIFS cladding now extended 210 and 350 mm down the wall (Figure 32). Cracks from the top corners were 100 mm and 130 mm long respectively.

Figure 32: Cracking damage in EIFS cladding after cycles to ± 24 mm

The plaster coating applicator was engaged to carry out a repair on these joints. The three smaller cracks were vee'd out for the full coating depth and about 5 mm wide (Figure 33). The larger crack was scraped out to a taper finish over about 100 mm width. The fibre-glass mesh had fractured (possibly during the scraping out process). A new strip of fibre-glass was used over this scraped out area and it was filled with polymer-modified cement plaster. The polymer-modified cement plaster was trowelled over the other cracks and a few minutes later was feathered out with a sponge (Figure 34) which gave the same texture as the original texture coating – which had irregular grain size. Spray painting of the surface was undertaken after three days. One coat of spray paint was applied around the crack and shortly afterwards the entire wall was re-sprayed. Once dry, while the wall looked almost as new, it was still possible to identify where the cracks had been repaired. On some occasions it may be necessary to apply a new coat of texture coating over the entire wall before re-painting.

No cracks had occurred on the face of the weatherboard section. However, it was noted that some boards were slipping horizontally with respect to each other by as much as ± 1 mm during the racking, which would likely have cracked any paintwork in an actual house. The repair procedure in this case would have required a re-paint of the cladding.

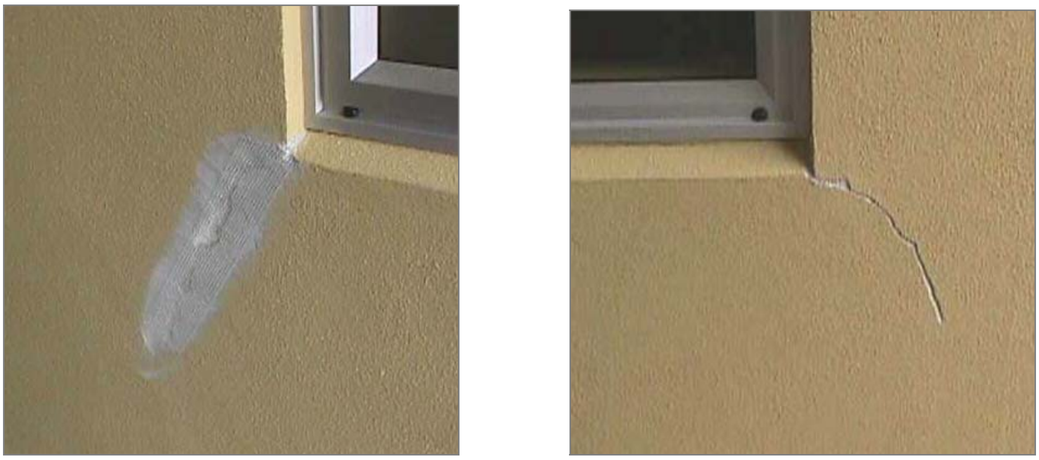

Figure 33: Crack in EIFS cladding prepared for filling

Figure 34: Feathering with a sponge to match the coating

The bulge under the timber window in the fibre-cement cladding was still more pronounced. The cracks emanating from the bottom corners of the timber window now extended well down the wall and were several millimetres wide (Figure 35). Cracks from the top were 250 mm long.

The typical repair procedure for the bulged joint involved scraping out the joint to a wide taper finish (Figure 36) and trowel filling with acrylic flexible jointing material (Figure 37). Three days later the entire fibre-cement wall plaster surface was re-trowelled with an aggregate filled sealant coating (rather than just locally at the joint). The wall was then re-painted with a high-build acrylic paint.

The typical repair procedure proposed by the plasterer for the diagonal cracks involved filling the crack with a flexible and paintable modified silicone sealant (Figure 38), which was smoothed with a finger and then dabbed with a dry paper towel to give the same appearance as the surrounding plaster. However, once painted, this repair was still visible and so these cracks were then covered by the new plaster coating and paint, both referred to above for the repaired bulging joint.

Figure 35: Diagonal cracks in the fibre-cement wall from the bottom corners of the window

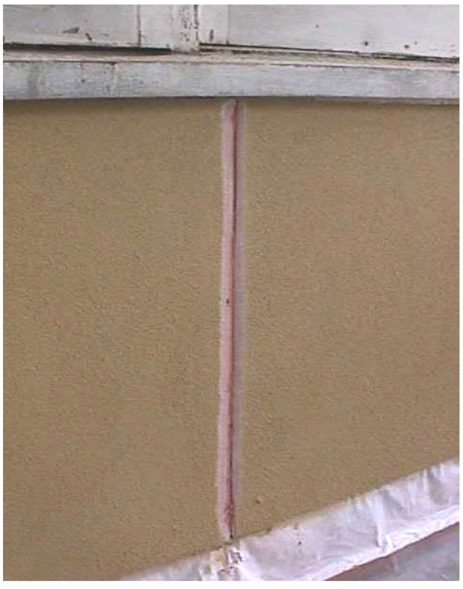

Figure 36: Fibre-cement sheet joint prepared ready for filling

Figure 37: Fibre-cement joint filled with flexible jointing material

Figure 38: Filling the diagonal crack in the fibre-cement cladding with sealant

With large diagonal cracks, normal practice is to replace the sheet rather than trying to repair a diagonal crack as it will likely crack again at serviceability level loadings.

Where there are only fine cracks in the wall, the recommended practice is to fill the cracks with a paintable modified silicone sealant as above and then paint all over with a high-build acrylic. There is no need to re-trowel with an aggregate filled sealant coating. If re-trowelling is done, it needs to be over the entire plane of the wall to ensure a consistency of finish.

Where cracks are wider than 1 mm, they should be filled with sealant (no feathering necessary) and then the entire plaster surface re-trowelled with an aggregate filled sealant coating as this surface finish is hard to match. The wall should then be painted all over with a high-build acrylic.

None of the racking action introduced to the wall in this series of tests caused any damage to the flashing systems around the windows. Because of this, it was decided that once the cracks in the cladding materials and the joints were repaired, there would be no more likelihood of water penetration than there had been before the racking began. A water spray test was undertaken after the exterior cladding was repaired which confirmed this view.

3. SUMMARY OF REPAIR TECHNIQUES DERIVED

The aim of the experimental work was to derive repair techniques for a selection of wall cladding and lining systems and to derive a method for realigning a house that has been left out-of-plumb after an earthquake. The derived repair procedures are presented in Table 1.

Table 1: Repair procedures for the investigated constructions

System	Damage sustained	Repair procedure	Other considerations
Brick veneer corners	No obvious damage to the veneer panel, but some small offset of the veneer with respect to the foundation	Nothing necessary, but attempt to establish whether the wall is still stable by striking and watching for any out-of-plane movement	Older brick veneer construction (pre-1990) where flat ties were used is likely to have very poor tie-mortar bond before the earthquake. While the veneer is still standing undamaged, it may be that the connection to the framing is non-existent and consideration should be given to whether remedial ties should be added. Checks should be made to determine whether or not the veneer has displaced outwards on the foundation slab/wall
Brick veneer corners	Minor cracks (<0.5 mm) following the mortar lines	No repair required	Any sort of repair to such a fine crack is expected to be more obvious than the crack itself. Checks should be made to determine whether or not the veneer has displaced outwards on the foundation slab/wall
Brick veneer corners	Cracks in veneer 0.5 mm to 2 mm	Fill cracks with low viscosity epoxy grout	Checks should be made to determine whether the veneer has displaced outwards on the

System	Damage sustained	Repair procedure	Other considerations
			foundation slab / wall. This will provide an indication of whether the ties have pulled out of the mortar, necessitating the addition of remedial spiral ties to re-fix the veneer to the framing (it is imperative that the ties do not pass through any cavities in the bricks)
Brick veneer corners	Cracks in veneer > 2 mm and generally following mortar lines	Carefully remove the affected section of bricks and temporarily prop sections of sound veneer above. Progressively rebuild the veneer up to the underside of the original panel, fixing to the studs with new veneer ties	Checks should be made to determine whether the veneer has displaced outwards on the foundation slab / wall. Inspection of the ties will be possible through the hole left by the removed section of veneer. If destroyed or damaged ties are visible, installation of additional spiral ties through solid portions of brick is recommended
Exterior walls relying on plasterboard linings to provide the designated bracing resistance	Cracking of the painted joint between the skirting and the wall lining (not likely to be visible with wallpapered walls)	Re-punch any popped nails on skirting boards and re-stop. Apply a new coat of paint to the affected wall and skirting board	Nothing specific
Exterior walls relying on plasterboard linings to provide the designated bracing resistance	Opening of the painted joint between the skirting and the wall lining (up to 2 mm), occasional nail popping in the body of the wall lining and some evidence of compression / shear failure of the lining at interior angle wall junctions	Check that the wall is still plumb (within 10 mm of vertical) before re-fixing the linings. The popped nail heads will require punching and re-stopping. Extra fixings should be added adjacent to the popped nails in case the wall linings are loose. Corner junctions will require re-stopping. Re-paint the junction between the wall lining and the skirting board	If movement has been sufficient to cause nail popping, it is likely that the nails along the top and bottom edges of the lining behind any wooden scotias and skirting boards have ripped through the edges of the sheets. The scotias / skirting board should be removed and the lining re-nailed adjacent to the original fixings before the board is replaced. Removal of the skirting

System	Damage sustained	Repair procedure	Other considerations
			will reveal which panels are designated bracing panels, as these will be fixed with nails and washers or screws at 150 mm centres and the sheet is likely to be a different colour
Exterior walls relying on plasterboard linings to provide the designated bracing resistance	Opening of the painted joint between the skirting and the wall lining (up to 2 mm), general nail popping in the body of the wall lining and major evidence of compression/shear failure of the lining at interior angle wall junctions, visible through the wallpaper	Check that the wall is still plumb (within 10 mm of vertical). Remove the scotias and skirting boards. Punch all popped nails and re-fix the lining panels with fixings adjacent to the original fixings. Nail-fix the sheets to the intermediate studs at 300 mm centres. (No popped nails in the body of the sheets are likely to be because glue daubs between the sheets and the studs have failed.) Re-stop and redecorate the walls	Any door and window frames within the wall length should be checked for misalignment, causing the door or window to jam. If the wall is within ± 5 mm of plumb, and the door or window still jams, then this may be related to foundation settlement
Exterior walls relying on plasterboard linings to provide the designated bracing resistance	Lining sheets have popped off the wall and are hanging loose	Remove the scotia, skirting boards and architraves, check and re-plumb the wall, and replace the lining sheets with appropriate types, ensuring that designated bracing sheets (identified by different sheet colour) are also replaced with bracing sheets	Any door and window frames within the wall length should be checked for misalignment, causing the door or window to jam. If the wall is within ± 5 mm of plumb, and the door or window still jams, then this may be related to foundation settlement
Whole house	House is distorted due to lateral racking so that vertical lines (e.g. edge of door frames) are now sloping at 1 in 480 (5 mm over 2.4 m wall height)	Check operation of doors and windows. If these are stuck, ease and re-paint fresh wood surface to match surrounding paintwork. If not stuck, no reinstatement is expected	Distortion of wall linings may be present at corners and openings

System	Damage sustained	Repair procedure	Other considerations
Whole house	House is distorted due to lateral racking so that vertical lines (e.g. edge of door frames) are now sloping at greater than 1 in 480 (5 mm over 2.4 m wall height), but less than 1 in 150 (15 mm over 2.4 m wall height). Doors and windows are jammed	Remove skirting boards and scotias. Attach brackets to the bottom plate and diagonally opposite top plate and fix a minimum capacity 3 tonne rigger's hoist between the two. Tension the hoist until the wall has passed the 'plumb' position and release the hoist. Check that the wall has returned to the 'plumb' position and re-nail the sheet linings. Re-install the skirting and scotia boards and redecorate	The elastic stiffness of modern plasterboard ceiling diaphragms may prevent a single wall from being re-plumbed in isolation. In this instance, more than one wall may need to be re-plumbed at the same time. Check damage to exterior cladding
Whole house	House is distorted due to lateral racking so that vertical lines (e.g. edge of door frames) are now sloping at greater than 1 in 150 (15 mm over 2.4 m wall height). Doors and windows are jammed	Remove skirting boards and scotias. Remove wall linings on affected walls. Attach brackets to the bottom plate and diagonally opposite top plate and fix a minimum capacity 3 tonne rigger's hoist between the two. Tension the hoist until the wall has passed the 'plumb' position by 10 mm. Fit diagonal light gauge metal braces parallel to the hoist and release the hoist. Fit new interior linings and redecorate	The elastic stiffness of modern plasterboard ceiling diaphragms may prevent a single wall from being re-plumbed in isolation. In this instance, more than one wall may need to be re-plumbed at the same time. **During the time that the linings are removed the stability of the structure may be in jeopardy, especially if it is the bottom storey of a two storey structure.** Ensure that temporary braces are installed. **The services of a structural engineer are required**. Also, check damage to exterior cladding
Internal wall	Wall bottom plate has translated in-plane along the floor	Temporarily fix a reaction block to the floor adjacent to the end of the affected wall and use a hydraulic 'bottle' jack to push the wall back into its original position. Remove the skirting boards on both sides of the wall and add	Movement is likely to have occurred because the bottom plate was nailed only to the flooring rather than the floor framing

System	Damage sustained	Repair procedure	Other considerations
		pairs (one each side of the plate) of skewed 75 x 3.15 mm nails at 600 mm centres along the plate. Re-fix the skirtings and redecorate	
EIFS cladding system	Hairline cracks at the ends of window sills	Paint over the area with the same colour paint as the wall	
EIFS cladding system	Diagonal cracks/bulges in the texture coating up to 2 mm wide extending from the corners of window and door openings	Vee out the crack for the full coating depth by 5 mm wide and fill with trowel applied polymer-modified cement plaster. Feather the finish with a damp sponge to replicate the texture. Re-paint the area to match	The appearance of the surface at the repaired crack may still be noticeably different after painting and a new texture coat over the entire surface may be required to alleviate this
EIFS cladding system	Diagonal cracks/bulges in the texture coating over 2 mm wide extending from the corners of window and door openings	Scrape the texture coated surface off on both sides of the crack for a distance of 50 mm each side, tapering inwards towards the crack. Fill the area with polymer-modified cement plaster, including a strip of fibre-glass mesh. Feather the finish with a damp sponge to replicate the texture. Re-paint the area to match	The appearance of the surface at the repaired crack may still be noticeably different after painting and a new texture coat over the entire surface may be required to alleviate this
Textured coatings on fibre-cement board backing	Bulging of filler at sheet junctions	Scrape out the joint beyond the gap between the sheets to created a tapered recess and fill with flexible acrylic jointing material. Apply a new texture coat to the entire wall. Re-paint the area to match	Careful inspection should be made to ensure that the problem has been caused by the earthquake and not normal temperature related expansion and contraction or timber framing shrinkage
Textured coatings on fibre-cement board backing	Hairline cracks extending from the corners of openings	Paint over the area with the same colour paint as the wall	
Textured coatings	Cracks between	Fill the crack with	

System	Damage sustained	Repair procedure	Other considerations
on fibre-cement board backing	0.5 mm and 2 mm wide ex-tending from the corners of openings	flexible paintable seal-ant. Over-coat the entire wall with a new texture coating.	
Textured coatings on fibre-cement board backing	Diagonal cracking greater than 2 mm wide extending from the corners of openings	Remove the cracked sheet and replace with new sheet. Re-apply textured coating in accordance with the manufacturer's instructions to match existing and re-paint	Large rectangular areas of coating of a different texture may be obvious and a complete wall re-coat may be necessary
Weatherboards	Cracking of paint lines between boards	Remove flaking paint at the joints and re-paint the wall	Care will be required to determine whether the cracking has resulted from the earthquake. If inspection of the interior lining on the same wall shows no damage, the cracking is likely to be normal wear
Window and door flashings	Tearing of flashing connections	Remove claddings in the area of the flashings and reattach or replace flashings. Replace clad-dings and redecorate exterior	Experimental testing has indicated that flashing damage should not be expected unless the structure is severely distorted in the earth-quake, in which case the claddings and linings are likely to require repair or replacement in any case

4. CONCLUSION

Experimental investigations have been carried out to determine the damage sustained and the preferred repair methods on walls reliant only on the internal linings for providing lateral restraint to the structure, on brick veneer wall junctions and on EIFS, weatherboard and monolithic exterior claddings. Methods of straightening a house that has been left with a residual racking displacement were also investigated. The damage and repairs have been summarised along with suggested other considerations.

5. DISCLAIMER

In the laboratory tests, while every effort has been made to model the expected construction details, and the observed behaviour is expected to be representative of an actual element in practice, BRANZ cannot be held liable for subsequent earthquake damage to elements repaired by the suggested procedures. The performance will be influenced by the strength of the subsequent event, the correct identification of the damage sustained and the quality of the repair carried out, over all of which BRANZ has no control. Repairs must be undertaken by recognised tradespeople.

6. REFERENCES

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7. APPENDIX: PROPRIETARY PRODUCTS USED IN TESTS

Proprietary products used for the experimental work reported here were as follows:

Flat ties: Lumberlok brick veneer ties

Proprietary ties: Helifix Retrotie HRT60 x 195

Fibre-cement cladding: James Hardie Ltd Monotek

Plasterboard: Winstone Wallboards Ltd GIB Board®

Bracing board: Winstone Wallboards Ltd GIB Braceline®

Flexible jointing material: Fosroc Flexipaste

Plaster: Fosroc Polyclad plaster

Weatherboards: James Hardie Ltd Linea® weatherboards

Flexible and paintable modified silicone sealant: Fosroc Silaflex MS