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Repair and Reinstatement of Earthquake Damaged Houses – Phase III

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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 third 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, and the formulation of repair procedures to restore the house to a state equivalent to its pre-earthquake condition.

Acknowledgments

This work was jointly funded by the Building Research Levy and the Earthquake Commission.

BRANZ is grateful for the assistance provided by the following companies and people:

- Plaster Coat Ltd (Mr Jim Henderson) for advice on the construction and repair of the stucco wall system and the lath and plaster system
- R & R Building Ltd (Robbie Verschoor) for enabling access to a typical property with lath and plaster walls while being renovated
- Ian Bowman, Conservation Architect, for advice on lath and plaster construction
- Charlie Gibbs of Joyce Group Ltd for advice on typical size and fixing of lath strips.

REPAIR AND REINSTATEMENT OF EARTHQUAKE DAMAGED HOUSES – PHASE III

BRANZ Study Report SR 158 **GJ Beattie**

ABSTRACT

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

- stucco wall claddings
- softboard ceiling linings
- hardboard ceiling linings, and
- lath and plaster walls.

An investigation of a process of re-levelling structures using a ground injection technique has been undertaken. Surveys have also been carried out on a selection of houses with settled foundations and/or foundation slabs that have been re-levelled using this process to ascertain the permanence of the solution.

With reference to the claims files held by the Earthquake Commission following the 2003 Te Anau earthquake, an attempt was made to identify commonly used processes for the repair of very minor damage to the interior of properties.

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, stucco, softboard, hardboard, lath, plaster.

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1. INTRODUCTION

This report describes Stage III 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 (EQC) 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.

Stage II of the investigation is reported in BRANZ *Study Report 123* (Beattie 2003). In that study, four constructions were tested. These included:

- dynamic testing of a brick veneer exterior cladding
- cyclic testing of exterior walls that rely on the interior lining to provide the bracing resistance
- cyclic testing of exterior walls with an exterior insulation and finishing system (EIFS), weatherboard and fibre-cement sheet cladding, and
- realignment of a complete house that had been laterally distorted.

The current study has concentrated on the investigation of the performance of lining and cladding systems that, while not often used on new houses, have been commonly used in house construction in the past and are therefore still in existence in a significant proportion of the current housing stock. As well, an investigation has been made into the effectiveness of proprietary systems used for levelling house foundations that have settled during an earthquake.

2. EXPERIMENTAL STUDIES

In the current phase, six areas were studied. The first four of these involved the construction and testing of systems in the BRANZ Structures Laboratory and included:

1) a traditional stucco clad exterior wall

2) ceilings constructed using softboard sheet lining material

3) ceilings constructed using hardboard sheet lining material

4) a lath and plaster lined interior wall.

The other two areas involved the investigation of the suitability of a proprietary injection system for levelling settled foundations and floors, and the procedures for the treatment of minor damage in house structures.

2.1 Stucco clad exterior wall

Stucco (solid plaster) exterior wall claddings have varied in construction over the years. Currently, NZS 3604 (SNZ 1999) provides construction details for stucco on a rigid backing and stucco on a non-rigid backing. In both cases, the stucco is separated from the foundation by a ‘drainage gap’ so that moisture that finds its way to the back of the plaster can drain from the system. However, the inclusion of a drainage gap was not always included in earlier stucco wall designs and the plaster often continued down over the concrete foundation with no gap being formed. The aim of this investigation was to determine the levels of damage expected in the stucco under in-plane earthquake attack and to devise appropriate repair techniques.

A test specimen was constructed that was 2.4 m long x 2.87 m overall height, with a 550 mm wide x 900 mm high window opening (Figure 1). The stucco plaster system in the investigation used a non-rigid backing of black tar-impregnated building paper. The reinforcement for the plaster was chicken wire with an approximate 25 mm diameter hole. The mesh was spaced off the timber framing with plastic washers at 300 mm centres to simulate the bottle caps normally used in earlier times (Figure 1). It was fixed to the framing with 50 mm long flat head galvanised nails that were bent over to capture the wire mesh.

The plaster was applied in two separate coats, first a scratch coat (Figure 2) followed by a top coat. These were followed by a 'rough cast' splatter coat. The scratch coat was mixed in the proportions of 1:3 cement/sand and the top coat 1:4 cement/sand.

The plaster thickness was specified to be 25 mm, but the flexibility of the building paper meant that the thickness varied between 18 and 24 mm in the vicinity of the timber frame and 30 to 45 mm between frame members. The plastering contractor formed vertical slots in the top coat of plaster in line with the edges of the window (as would be expected in modern construction), but because this was not usual in old style construction, the slots were filled with an epoxy filler.

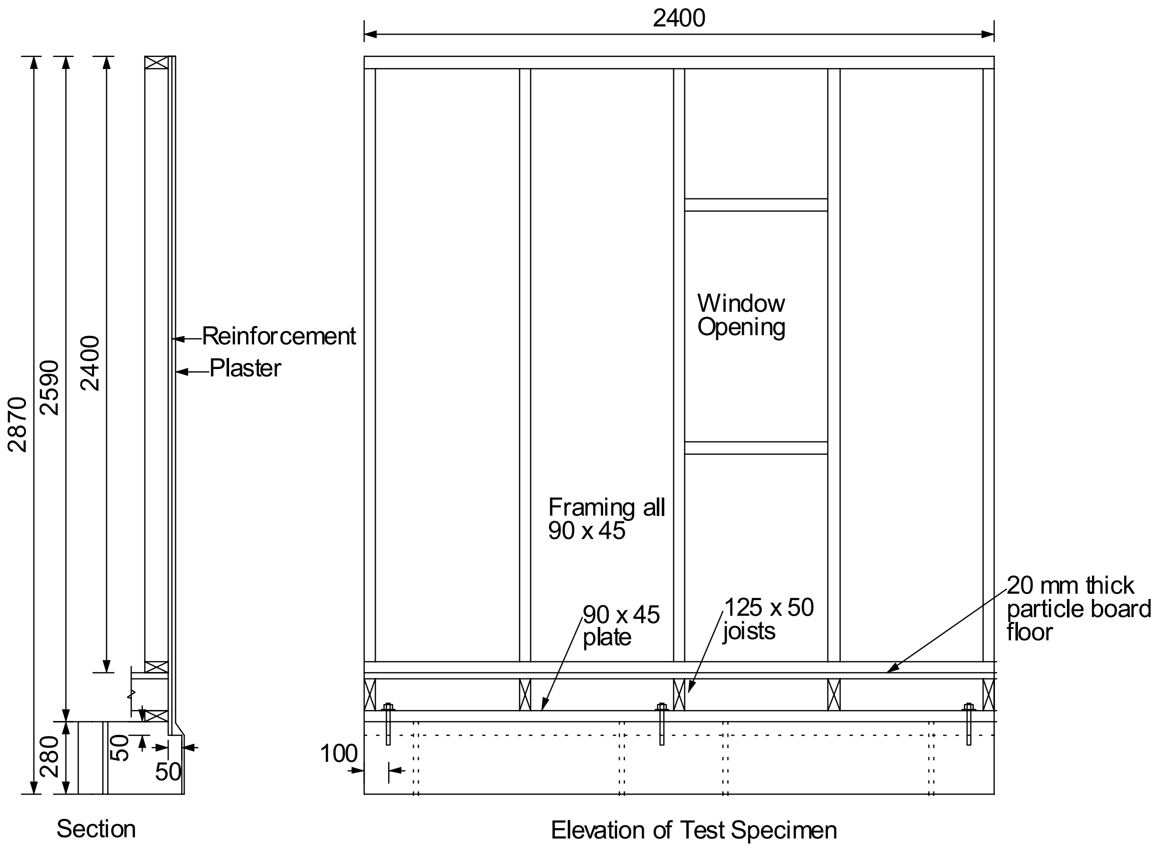

Figure 1: Construction details for the stucco wall

Figure 1: Building paper in place and chicken wire being added

Figure 2: Scratch coat being applied

2.1.1 Test regime

The specimen, complete with foundation, was positioned on the structures laboratory strongfloor so that horizontal load could be applied to it along its length (Figure 3). A steel channel section was coach screwed to the top plate of the specimen and the channel was attached to a servo-controlled hydraulic actuator. The top plate was restrained from movement out of the plane of the wall by lateral support rollers. A plywood 'window' was fitted in the opening, spaced off the framing members in a typical fashion for windows.

Figure 3: Stucco specimen ready for loading

The loading sequence was applied under displacement control. The wall was racked three times to the following top plate displacement levels:

±2.5 mm, ±5 mm, ±10 mm.

During the first cycle to +2.5 mm, a fine crack opened in the stucco at the bottom corner of the specimen and at the junction with the foundation (Figure 4). Similar cracks opened at the opposite end of the wall during the cycle to -2.5 mm. However, when the load was removed the cracks closed and could not be distinguished.

During the cycles to ±5 mm, the crack at the foundation junction extended along the full length of the wall (Figure 5). Fine cracks also began to form at the lower corners of the window and at one top corner. Horizontal cracks also formed on both sides of the window at about three-quarters of the way up the side of the window.

Further cracks appeared at approximately the timber floor level during the cycles to ±10 mm. It appeared that the stucco was rotating as a solid object as the joists and floor lifted off the timber plate on top of the concrete foundation.

Figure 4: Fine crack at the bottom of the wall and at the junction with the concrete foundation

Figure 5: Cracks extending along the foundation junction during cycles to ±5 mm

Light gauge metal straps were added to tie the end studs to the foundation and the wall was cycled again to ±2.5 mm, ±5 mm and ±10 mm. This was followed by a further three cycles to ±20 mm. After these three cycles some of the cracks were still visible, particularly along the line of the foundation junction (Figure 6).

Figure 6: Crack patterns after cycling to ±10 mm (note cracks have been marked with a felt-tip pen)

Repairs were undertaken on the stucco joint at the foundation and at the ends and top corners of the wall. At the junction with the foundation, the loose plaster was chipped and raked out (Figure 7) and new plaster was applied (Figure 8). At the corners, new mesh was added where the old mesh had been damaged. No other repairs were undertaken on the finer cracks in the body of the wall. A good match was achieved between the old rough cast pattern and the new pattern (Figure 9). Some staining is visible in Figure 9 at the interface of the old and new plaster, but this would be easily covered by new paint.

Figure 7: Removal of loose plaster at the foundation junction

Figure 8: Repaired stucco wall at foundation junction and at the wall ends

Figure 9: Good match of cured repair plaster with old plaster

Rigid hold-down straps were added between the end studs and the foundation to prevent a concentration of damage at the foundation junction and force the stucco to be damaged elsewhere. Once the new plaster had cured sufficiently further cycling was carried out to ±10 mm, ±20 mm, ±30 mm, ±40 mm and ±60 mm. Before the cycles to ±60 mm, the plywood ‘window’ was also removed from its supporting frame to cause greater flexibility in the body of the panel.

This cycling caused considerable damage to the top corners of the stucco and for approximately 1 m down the edge where the stucco wrapped around the corner (Figure 10). This became more evident as the lateral deflection increased from ±10 mm to ±60 mm. The studs, especially the end ones, bent considerably about their weak axis during this cycling, as the nails first eroded holes in the stucco and then detached from the stiff stucco panel. This movement caused wear holes in the building paper. The top plate progressively detached from the studs, especially at the end remote from the actuator. While the appearance of the panel from the outside was of a solidly fixed cladding, inspection from the back (inside) clearly showed that there was little connection of the upper part of the panel to the wall framing and that demolition or re-connection would be necessary. It would be important for the inspection teams following an earthquake to push against any stucco walls where damage at corners was significant, to ascertain whether the connection to the framing was still intact. Any discernable movement would indicate that the link was suspect.

Some small cracks appeared in the repaired sections at the base of the stucco panel during this series of cycling. However, these were not sufficiently wide to require major removal and replacement of the plaster.

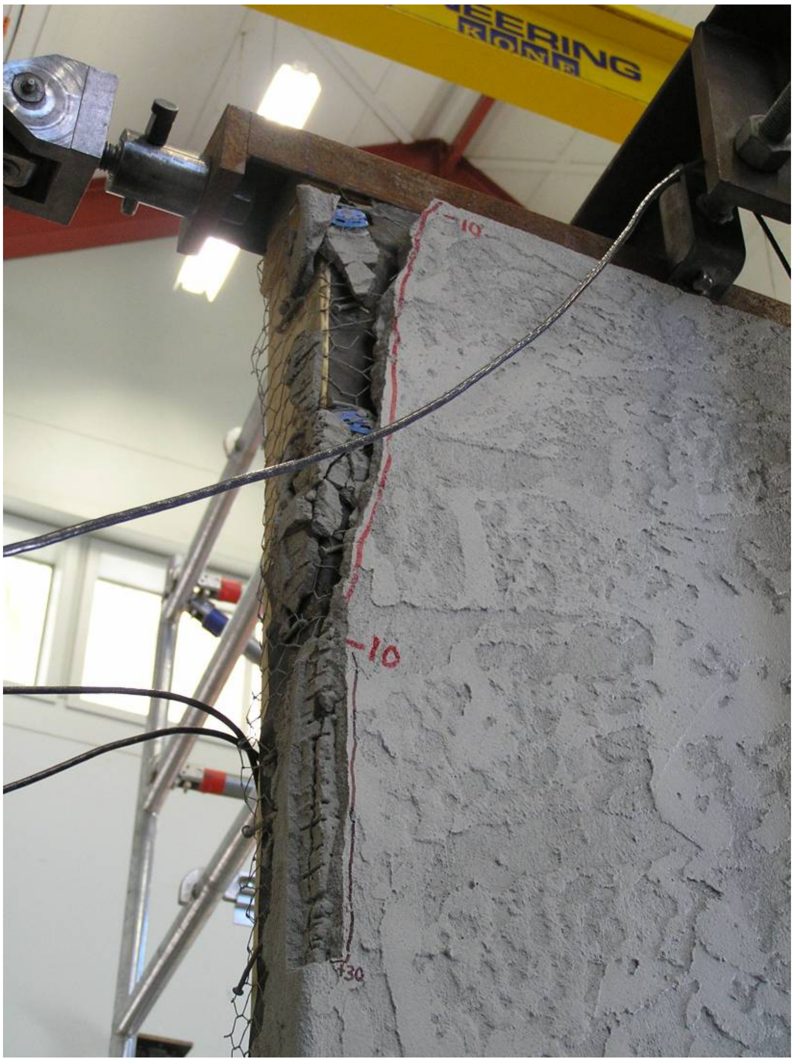

Figure 10: Damage at the top corners of the panel

A further round of repairs was undertaken at this point. The repairs involved re-building the top end sections of the stucco panel, re-fixing the panel to the framing with new nails, and repairing cracks near the base of the panel that had opened to approximately 1 mm. Fine cracks were also painted over to determine the effectiveness of this repair.

Re-building the top end sections followed a similar process to the earlier described repair of the wall foundation junction (Figure 11).

New nails were added along the top edge of the panel (Figure 12) and then these were plastered over.

Loose material was removed from cracks that were approximately 1 mm wide and these were scraped out using a pointed steel probe. The resulting slot was wetted, and then as the surface dried to a damp state, it was then ‘bagged’ over (Figure 13). This process involves smearing some new plaster over the crack and working it into the crack with a cloth. The resulting repair fills the crack and also spreads a thin layer over the adjacent surface.

Figure 11: Top corners of the stucco wall after repair

Figure 12: New nail added to re-attach the stucco panel to the framing (to be plastered)

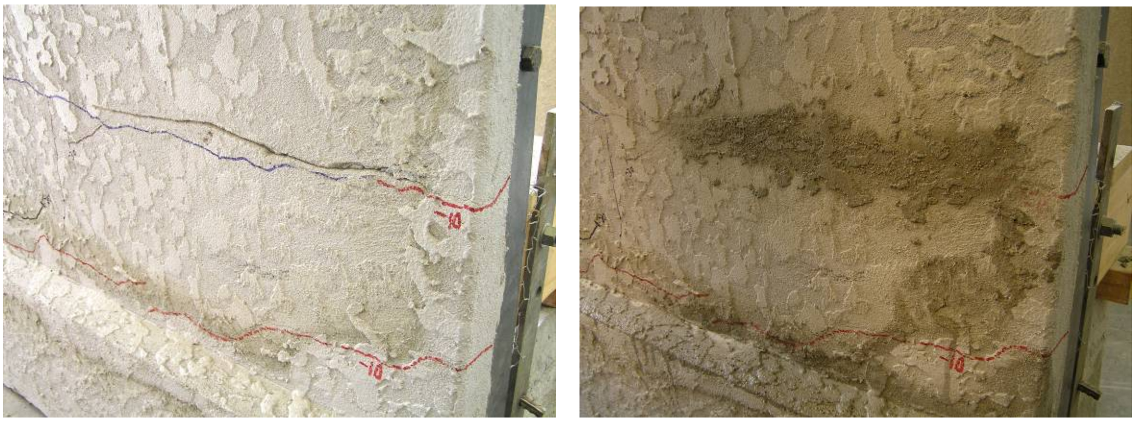

Figure 13: 1 mm wide crack prepared and then 'bagged' over

Fine cracks, less than 0.5 mm wide, may be adequately repaired by painting over with a flexible acrylic paint. The sequence of photographs in Figure 14 show an example crack before the application of paint, after the application of an acrylic primer undercoat (white), and after the application of a top coat of acrylic paint (grey).

Advice on usual paint repairs was obtained from the plasterers employed to build the stucco wall. They advised that they would paint over such cracks with Dulux Weathershield X10 (because it has a tough flexible finish) or Resene X-200 (because it has excellent crack-filling properties).

As an alternative, a cement paste may be worked into the dampened crack using a gloved finger, and the excess may be lightly brushed off with a wire brush before painting.

Figure 14: Fine crack to be repaired by painting

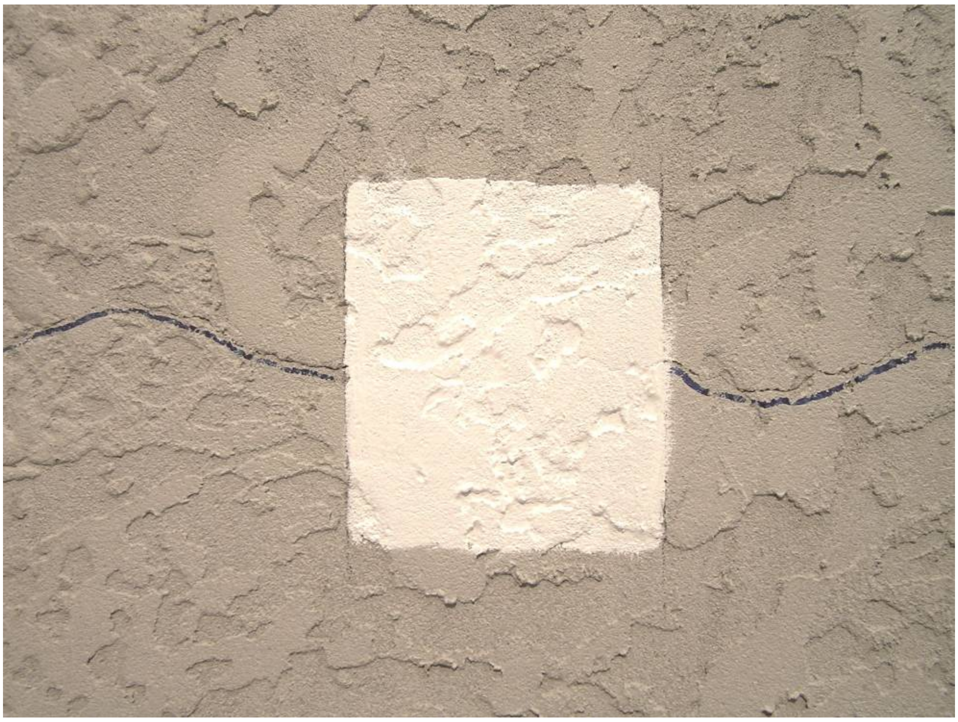

Figure 15: Crack after the application of the undercoat

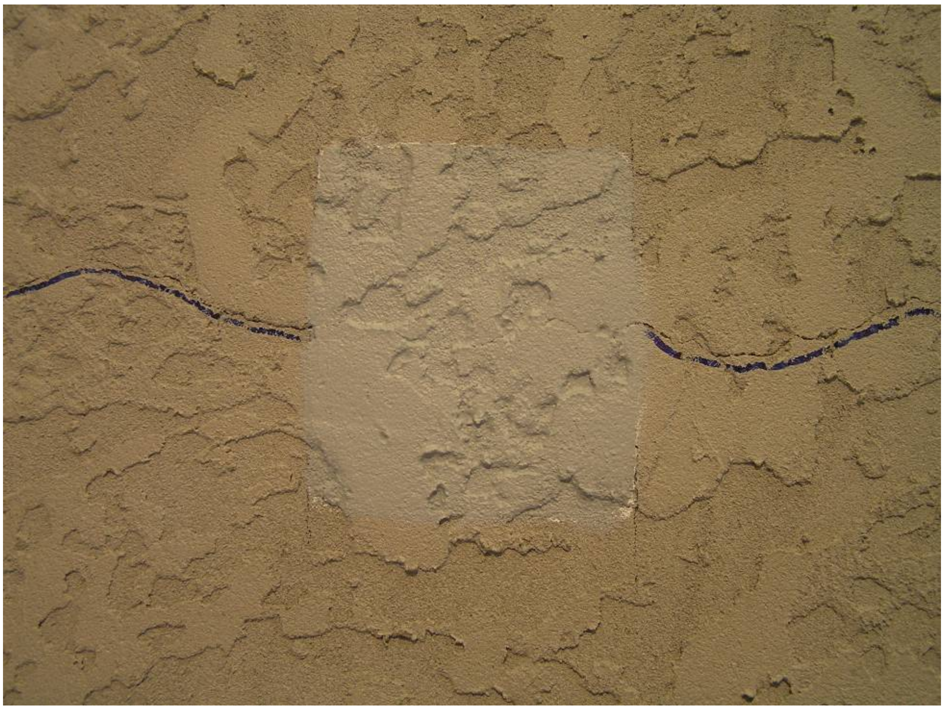

Figure 16: Crack after application of the top coat

2.2 Softboard ceiling linings

Softboard ceiling linings were a commonly used lining for bedrooms and living areas of older houses. The sheets were often referred to as ‘pinex’ sheets (a trade name of the Laminex Group). The product is manufactured from high grade wood fibre pulp, mixed with sizing agents and binders. It is de-watered to form a continuous sheet.

2.2.1 Test regime

A test specimen was constructed to simulate a typically constructed ceiling, except that it was constructed upside down for easier monitoring. This consisted of a ceiling 2.4 m x 2.4 m lined with two sheets of softboard. The test specimen modelled one half of a 4.8 m x 2.4 m ceiling that would be loaded in practice by the inertial forces from attached side walls in an earthquake. A diagram of the specimen is presented in Figure 17. The line along which the load was applied represented the end of the room and the reaction frame on the right hand side of the figure represented the centreline of the room.

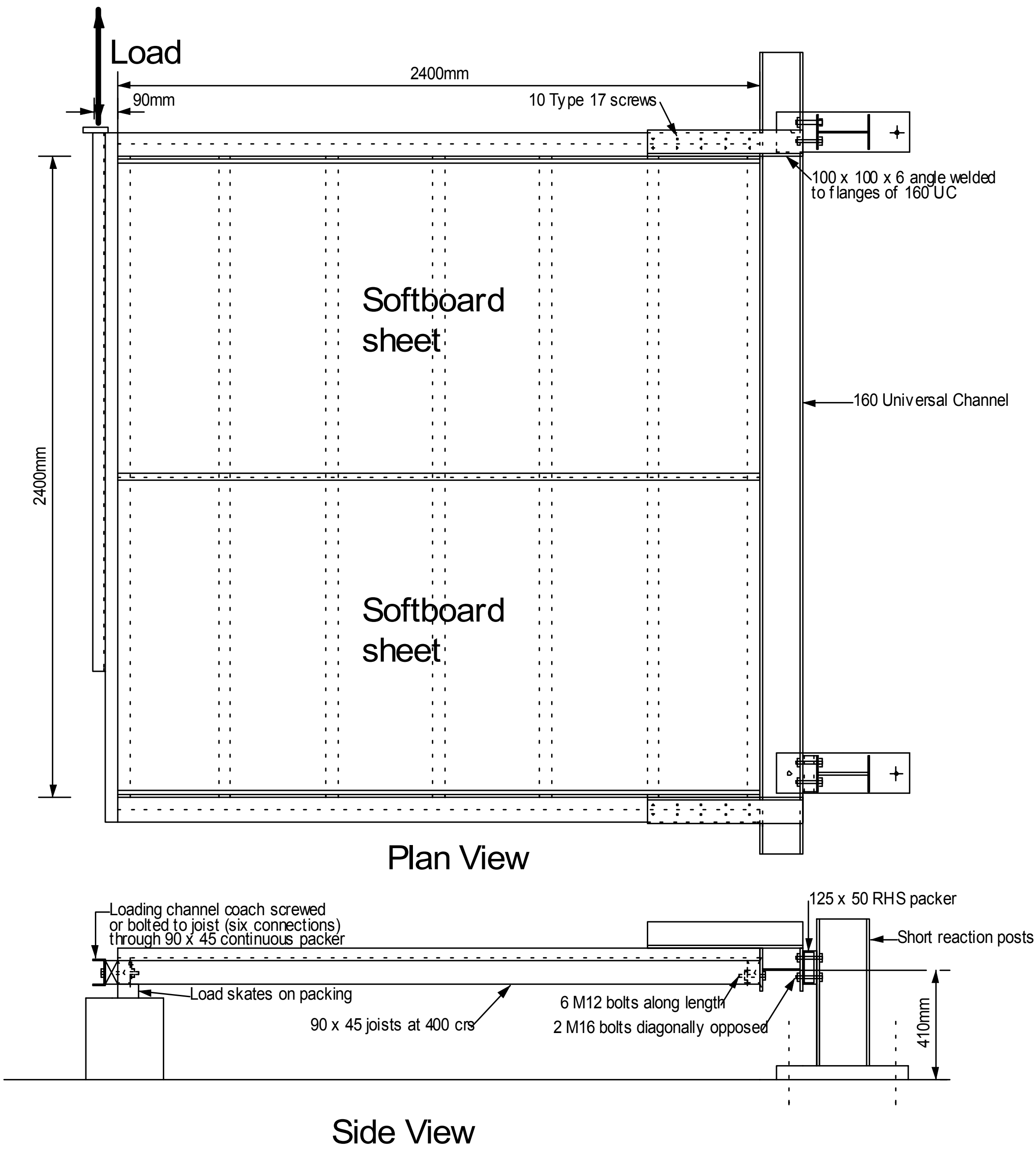

Figure 17: Diagram of the set-up for the softboard ceiling test

Small sections of softboard were installed vertically along the side edges of the specimen to model softboard wall linings (Figure 18), and quad sections (quarter rounds) were installed over the joint. A section of half round beading was also installed over the joint between the two sheets of softboard to replicate usual construction practice. The softboard was fixed to the ceiling framing with 30 mm galvanised clouts at 400 mm centres, and the quads and half round were fixed with 40 mm panel pins. The heads of the clouts were driven just below the surface of the softboard and then covered with a spot of gypsum plaster, if exposed in the body of the sheet. A coat of acrylic ceiling paint was applied to the finished specimen (Figure 19) so that movements could easily be identified.

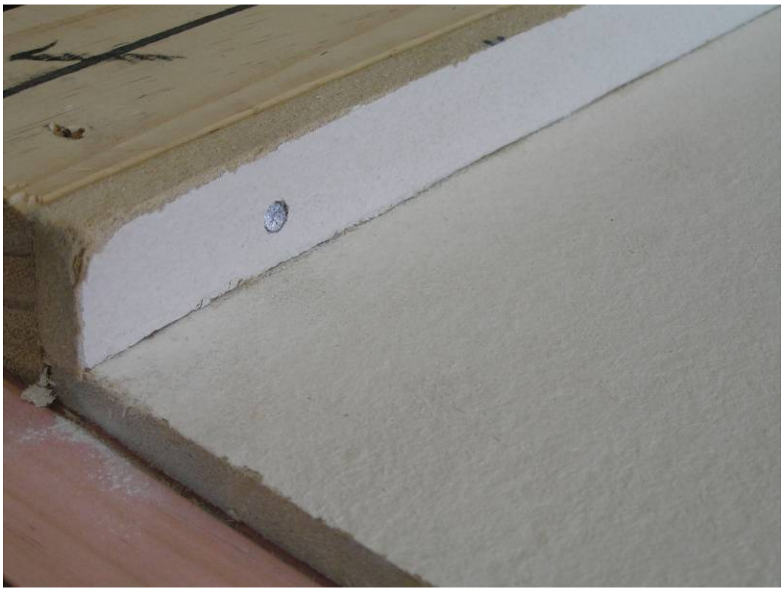

Figure 18: View of short section of softboard at ceiling perimeter

Figure 19: Softboard ceiling ready for testing

Load was applied in the direction shown in Figure 17 to move the specimen to increasing levels of displacement while the damage development was observed. During the testing, the load resistance was monitored against displacement, but the ceiling was not expected to provide any diaphragm action.

During cycling to ±5 mm, movement between the beading and the softboard was noted at the half round beading between the sheets. The movement was approximately 2 mm and was sufficient to break the paint (Figure 20). There was also sufficient movement of the softboard to cause the nail heads to 'pop' at the fixed end of the specimen (Figure 21) and under the half round bead (Figure 20).

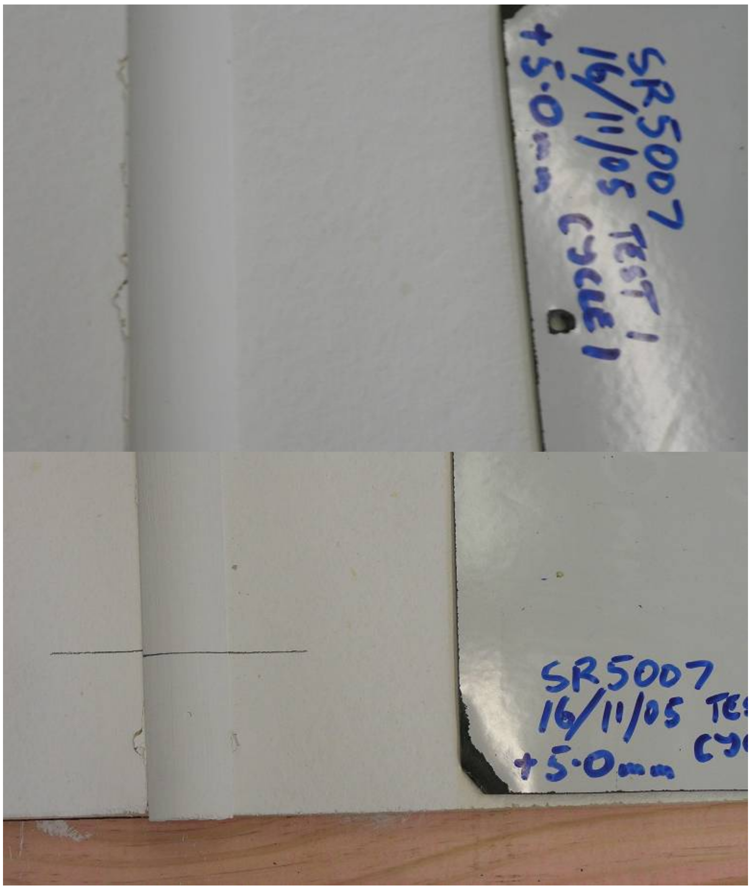

Figure 20: Movement of softboard sheet with respect to the beading

Figure 21: Nail head beginning to show through gypsum plaster

After cycling to ±10 mm, some looseness of the softboard was evident at the loaded end of the specimen, caused by the nails scoring small slots in the softboard. The individual sheets had begun to rotate in-plane and movement between the sheets and the quads was obvious (Figure 22).

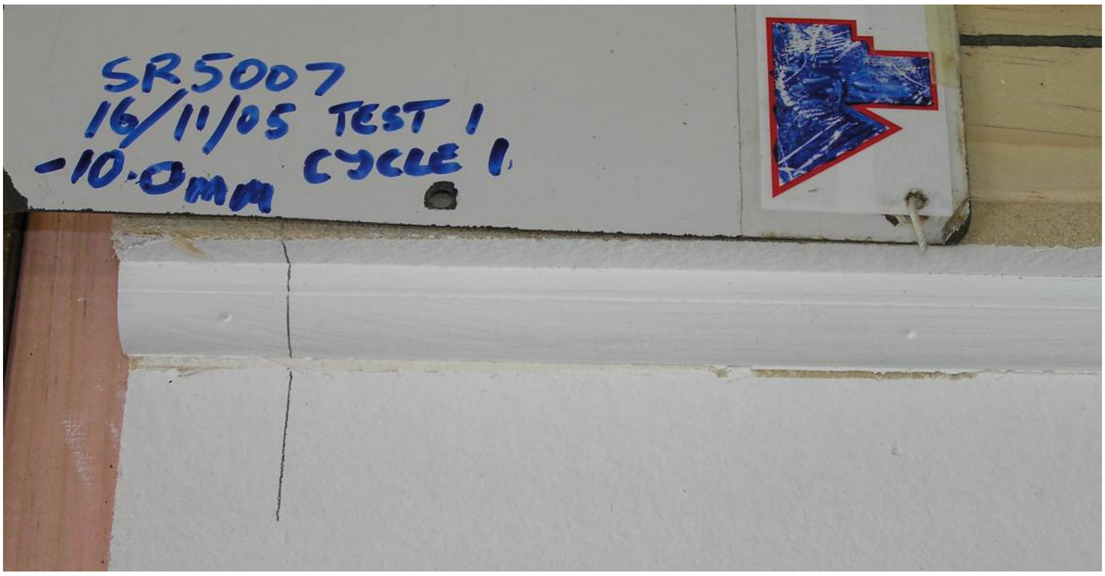

Figure 22: Withdrawal of the softboard sheet from under the quad section

After three cycles to ±20 mm, the racking was sufficient for the clouts securing the sheets to have worked large slots in the sheets (which would be expected to partially fall from the ceiling if not retained by the beading). It is expected that after such damage, the sheets would need to be re-fixed to the ceiling framing. Cycling to ±40 mm caused the sheets to buckle along the loaded edge (Figure 23), and when the specimen was returned to zero displacement the half round beading had been lifted by approximately 10 mm. The clouts had pulled through the edges of the sheets and the corner nails had broken off sections of the sheets (Figure 24).

Figure 23: Buckling of the sheet edges at 40 mm displacement

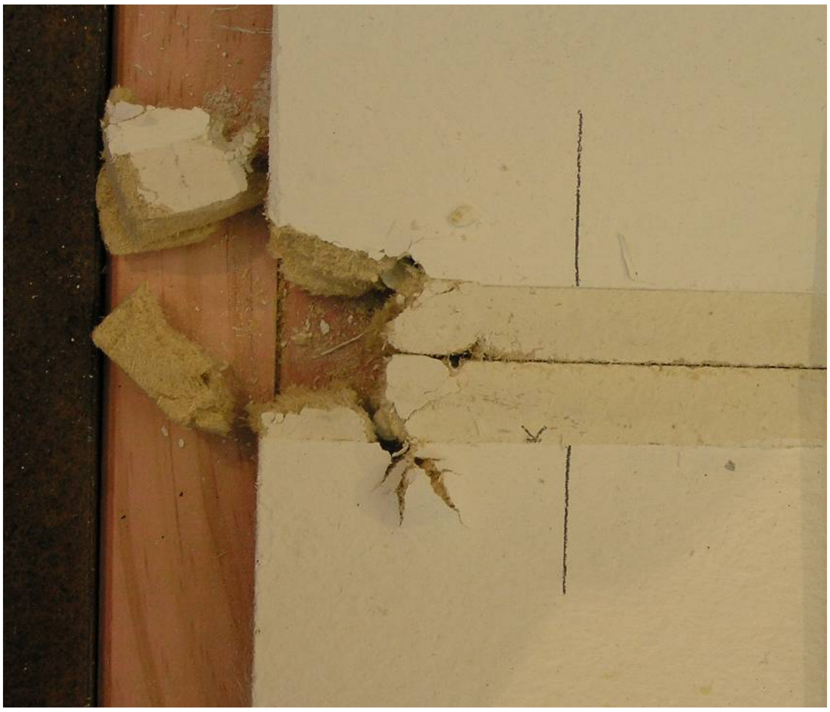

Figure 24: Breakout of the sheet corners

2.2.2 Repair process

The half round beading was able to be removed intact. Most panel pins pulled through the timber beading and were hammered below the surface of the softboard. The bulges in the softboard caused by the working of the nails (Figure 25) were pushed back in place by hand and new clouts were driven approximately 25 mm from the original ones. A gap of up to 2 mm between the softboard and the ceiling joist remained after nailing due to displaced material left around the old nail hole when the nail pulled through. Displaced material around the nail holes above the surface of the softboard was either pushed or lightly hammered below the surface. The damaged areas and the heads of the new nails were then plastered in two operations: first to fill the larger holes; and then with a finishing coat to complete the repair. The plaster was then lightly sanded, where necessary, and two coats of primer undercoat were applied by brush. The surface looked presentable, but the plastered areas felt smoother than the softboard surface. If the paint had been applied by roller the surface texture would probably have been more uniform.

The quads along the two edges were tapped down to make firm contact with the softboard, and in the places where light damage was visible the surface was plastered. Two coats of primer undercoat were then brushed on.

After re-nailing the softboard sheets to the joists, the centre join between the two sheets of softboard was plastered to cover the damage around the nails. The plaster was sanded and then the half round was re-applied using new panel pins. Two coats of primer undercoat were then brushed on. The repair looked acceptable, except for the end of the join between the two sheets where the missing corners of softboard were filled with plaster. Care would be required to achieve a similar texture on the surface of the plaster fill as the softboard.

It should be noted that since the investigation was undertaken, BRANZ has been advised that new softboard may no longer be available. Repairs would therefore have to involve patching of the damaged boards or complete removal and replacement with some other lining material.

Figure 25: Damage to underside of softboard caused by movement with respect to nails

2.3 Hardboard ceiling linings

2.3.1 Test regime

The investigation of the behaviour of hardboard ceiling linings followed the softboard lining investigation and the same test rig was used. However, to obtain a better representation of the performance, the specimen was constructed in an orientation matching the service condition. Figure 26 shows the lay-up of the sheets before installation in the test rig. The hardboard sheets were fixed to the framing with 40 x 1.6 mm panel pins at approximately 150 mm centres. The ceiling joists were spaced at 400 mm centres and two rows of nogs were installed at 800 mm centres between the joists.

Figure 26: View of the hardboard test specimen before installation in the test rig

A quarter round bead was installed along three edges of the specimen and a half round bead was fixed over one half of the joint between the sheets. A champher was formed on the edges of the two sheets at their junction, and a gap of 2 mm was left between the sheets. These are typical construction techniques for hardboard linings. All joint areas were painted over with two coats of acrylic paint before the test started.

Load was applied in a similar fashion to that shown in Figure 17 for the softboard ceiling, except that the hardboard was oriented the same as an actual ceiling (i.e. the hardboard was on the underside of the framing). The specimen was moved to increasing levels of displacement while the damage development was observed.

After cycling to ±5 mm, slight movement between the half round beading and the hardboard had caused the paint on the junction to crack. The movement between the sheets was approximately 0.5 mm and this also caused a fine crack in the paint at the bevelled joint. At the ends of the specimen, a fine crack was also visible in the paint between the quad and the hardboard. There did not appear to be any disconnection of the hardboard from the framing.

After three cycles to ±10.0 mm, the crack in the paint at the join between the two sheets of hardboard was more noticeable (Figure 27). Some vertical movement of the sheets with respect to the framing was evident because the surface of the hardboard could be pushed up. This indicated that the panel pins had pulled out of the framing slightly. The paint covering some panel pin heads near the join in the sheets appeared to have been slightly disturbed.

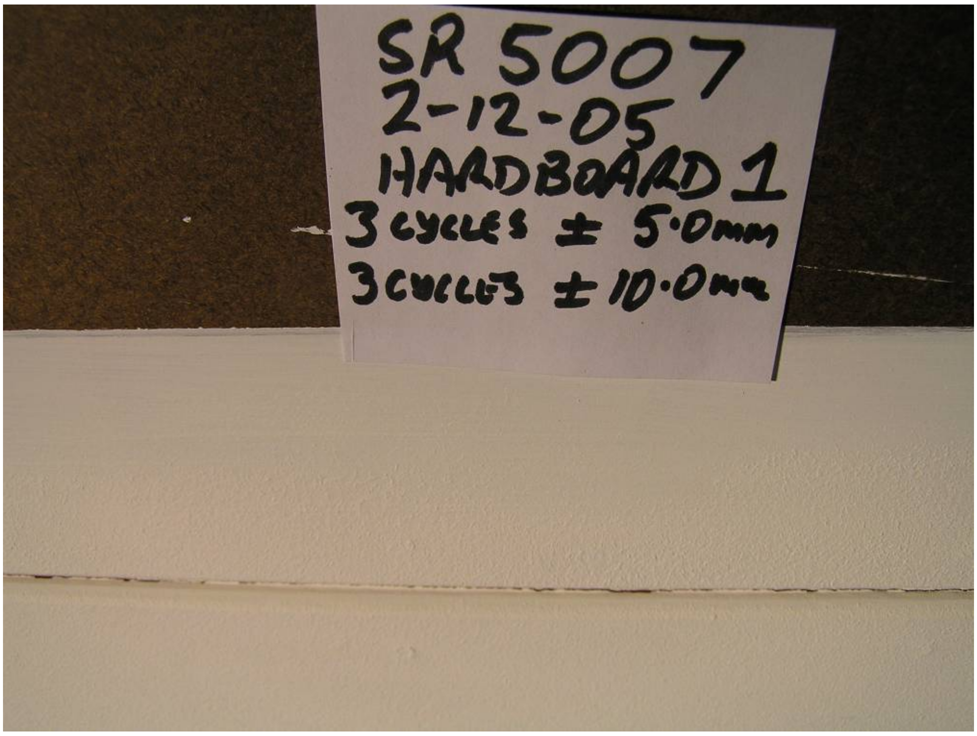

Figure 27: Crack observed in paint between sheets at champhered joint

During the three cycles to ±20 mm, the sheets began to pull out from beneath the quad sections at the specimen edges and the longitudinal misalignment at the joint between the sheets extended to 5 mm. The heads of the panel pins securing the sheets to the framing were clearly visible (Figure 28). At the junction between the sheets, the hardboard could be lifted approximately 0.5 mm to contact the framing because it had dropped away from the framing during the cycling. Nowhere was the hardboard fully detached from the framing.

Figure 28: Panel pin heads becoming clearly visible during cycling to ±20 mm

During the second half of the first cycle to ±40 mm, the hardboard fully detached from the framing along the eastern (loaded) edge of the specimen (Figure 29). When the displacement returned to 0 mm, both the quad sections had been pushed out by the buckling sheets. The heads of the panel pins at the joint between the sheets were approximately 2 mm proud of the surface, and the half round beading had lifted approximately 1 mm. Where it covered panel pin heads, some damage had been sustained by the half round (Figure 30). The panel pins away from the edges of the sheets showed little sign of disturbance, and the sheets were not damaged except immediately around panel pin heads.

2.3.2 Repair process

Repairs were undertaken which involved removal of the quad beads and the half round bead. Where the sheets needed to be re-attached to the framing, a block of 100 x 50 mm timber was used to 'hammer' the sheet back against the frame. This process prevented the sheet from local damage that would have been caused using a traditional hammer. Exposed panel pin heads were punched home and the hardboard was re-fixed with extra panel pins placed between the old pins. The surface was sanded where protrusions had been created by the moving panel pins and the holes were filled with gypsum plaster before repainting. A section of the repaired ceiling is shown in Figure 31. New sections of beading were installed.

Figure 29: Hardboard detached from the framing during the ±40 mm cycle

Figure 30: Damage to half round bead caused by panel pin head

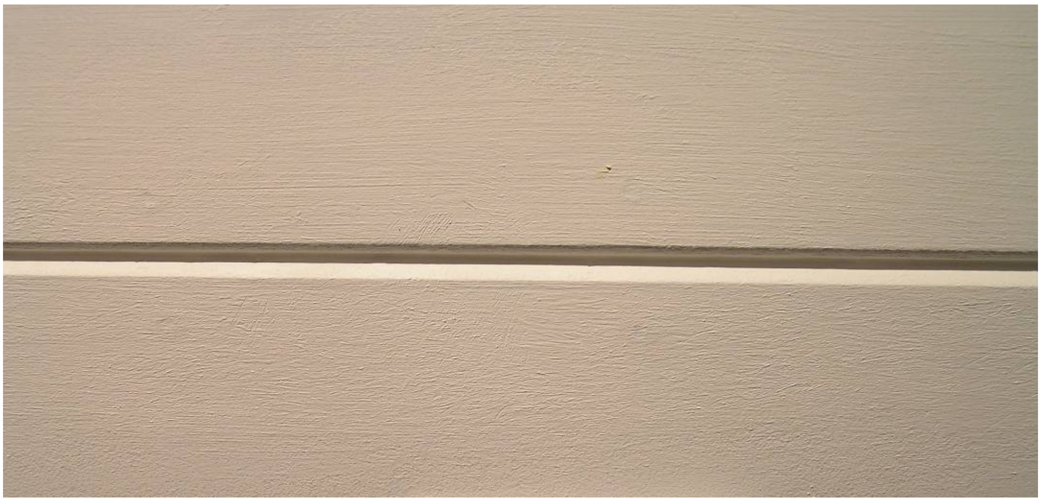

Figure 31: Repaired champhered joint

2.4 Lath and plaster wall

The lath and plaster wall is loosely based on what was found in old publications, the experience of the plasterer employed to construct the wall, plus what was learned from observations made during the refurbishment of Lady Ferguson House, 18 Moturoa Street, Thorndon, Wellington. Further research was undertaken to discover the materials used and the construction process for lath and plaster walls. Very often in the past, horse or ox hair was used to provide some tensile strength to the plaster. However, no hair was available for use in the construction of the laboratory specimen.

2.4.1 Wall construction

The lath and plaster wall was constructed on the same foundation that had been used for the earlier stucco wall investigation. A timber floor section was constructed on top of the foundation and a section of wall was constructed on top of the timber floor (Figure 32). The wall dimensions were 2400 mm wide x 2400 mm high. It was built using 90 mm x 45 mm radiata pine timber with studs at 400 mm centres. No nogs were installed.

Radiata pine laths, of 35 mm x 8 mm cross-section, were fitted horizontally, with 8 mm gaps between them to simulate old style construction. They were fixed with one 25 mm long flat head galvanised clout at each stud and two clouts where they were joined on the same stud.

There were approximately 25 butt joints spaced fairly evenly over the wall. A base board 160 wide and 25 mm thick was fitted to simulate normal practice where the skirting board was fixed in front of this base board. It was spaced off the studs with 15 mm packers so that it would protrude beyond the finished plaster coating by approximately 16 mm.

Figure 32: Timber framing for the lath and plaster wall

The first plaster coat consisted of 16:4 sand/hydrated lime and one part of cement by volume. Water was added to achieve the required consistency. The coat was applied to an approximate thickness of 7 mm from the outside face of the timber laths. The plaster was squeezed between the laths to form a key (Figure 33), with the wall structure and the surface of the plaster was roughened with a coarse toothed metal comb to form a key for the following coat (Figure 34). Compression test cylinders were made from a sample of the mix. These were tested at an age of 21 days and had a mean compressive strength of 2 MPa.

The second plaster coat consisted of 1:5 sand/lime by volume. Lime plaster takes several years to achieve its full strength, but this could not be easily replicated in the test. Water was added to obtain the required consistency. This coat was applied to make a total thickness of approximately 18 mm from the outside face of the timber laths. One half of the plaster was towelled to a fairly smooth finish, while the other half was roughened in a similar manner to the previous coat. Three test cylinders were made from a sample of the mix for compression testing. These were stripped on 16 February 2006. They tended to crumble and were very weak and slightly damp. They were left beside the wall to 'cure' and tested at an age of 22 days. The strength was very low at 0.2 MPa.

The third plaster coating (the finishing coat) was applied on Friday 10 February 2006 and consisted of 2:3 casting plaster/hydrated lime with water added to achieve the required consistency. The coating was applied to a thickness of approximately 2 to 3 mm. This coating was only applied to the left hand section of the wall. The previous coat was still damp below the surface and could be deformed by applying firm finger pressure.

The right hand half of the wall was sized with two coats of wallpaper size on 13 February 2006, and on the following day it was covered with imported English non-vinyl wallpaper using heavy duty wallpaper adhesive (Figure 35). The wall was left to dry and cure until 23 February 2006, when it was subjected to an in-plane racking displacement.

Figure 33: Plaster squeezed between the laths

Figure 34: Scratched surface to receive second coat

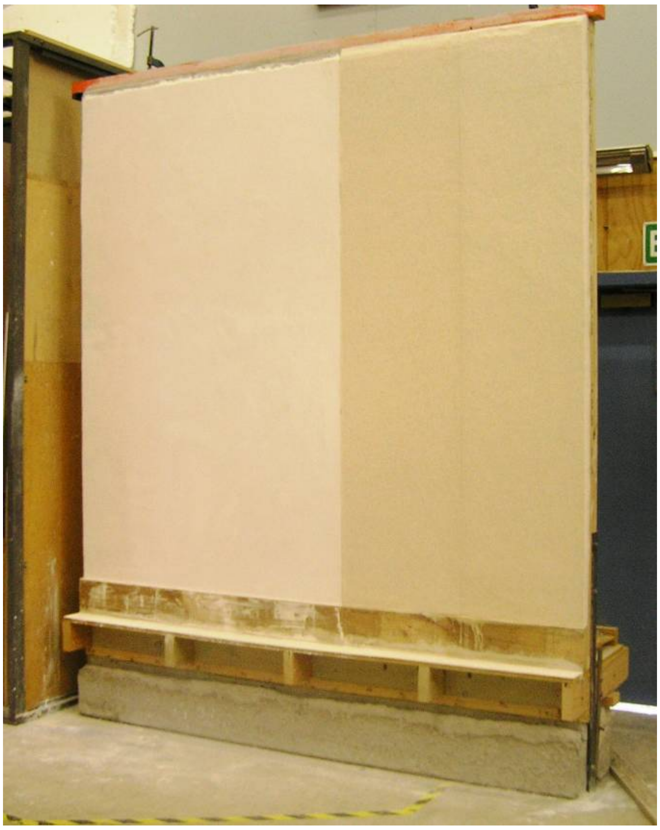

Figure 35: Completed lath and plaster wall with casting plaster top coat (left side) and wallpaper over second coat (right side)

2.4.2 Test regime

The test specimen was set-up in a similar manner to the stucco wall specimen. That is, it was anchored to the laboratory strongfloor and a horizontal in-plane load was applied to the top plate. The top of the wall was restrained from movement out-of-plane with roller supports. The top of the wall was displaced slowly to predefined displacement levels. The first level was ±5 mm. During the first half cycle to 5 mm, the top third of the plaster began to detach from the lath and was only held in position by the wallpaper, which was stapled to the ends of the laths. The wallpaper was cut to release the plaster. When the direction of displacement was reversed, little further damage was observed. However, during the next cycle to +5 mm large sections of the plaster fell from the wall (Figure 36). It appeared that the strength of the first coat was insufficient to prevent the plaster from shearing on a plane at the front face of the laths. When viewed from the back of the wall, the plaster that had been forced through the gaps during construction was still in place.

2.4.3 Repair technique

It could be argued that the plaster had not reached the strength that would be expected of it in normal service, and therefore the failure was premature. However, in subsequent discussions with the building contractor working at Lady Ferguson House in Thorndon, it was discovered that he had found it too difficult to work with the old lath and plaster walls and had elected to remove both the plaster and the lath and apply new gypsum plasterboard over 20 mm thick packing fixed on the face of the studs, thus matching the original thickness of the wall lining. This meant that door frames required no alteration to accommodate the new linings. To retain elaborate cornices, the plasterboard was butted up to the underside edge of the cornice. New skirting boards were fitted over the gypsum plasterboard.

Figure 36: Large sections of plaster lost from the upper third of the wall during cycling to ±5 mm

2.5 Soil injection procedures to level house foundations and floor slabs

In normal usage, houses may settle if they have been constructed on soft soils without appropriate consideration of the conditions. This settlement generally occurs early in the life of the house as the soft soil is compacted under the weight of the house, and it is difficult to reverse. Settlement may take place during an earthquake if liquefaction of layers of soil deep beneath the house foundation occurs. Timber pile foundations can be relatively easily re-levelled by jacking the house up at the bearer level and inserting appropriately sized packers between the piles and the bearers. However, the building weight and access difficulties with concrete floors and associated foundations mean that conventional jacking processes cannot be used.

Settlement can also occur if the backfill beneath the house is either not compacted sufficiently during placing or is inappropriate for the situation. Such inappropriate materials include singular sized cohesionless particles, which may appear to be compacted when the foundation slab is poured but a more efficient configuration of the particles is possible. Vibration assists in the compaction process, and if the particles are not properly compacted initially, the vibrations occurring during an earthquake may be sufficient to cause compaction to occur. BRANZ is aware of cases where foot traffic on the floor slab has also been sufficient to cause further compaction to occur.

A potential means of levelling concrete floors and foundations is by the injection of proprietary products beneath them. This process performs two functions: the first is to fill voids that may be present in soil beneath the building (effectively compacting the soil); and the second serves to add extra bearing material between the compacted layers and the foundation or slab (thereby lifting them to the desired level).

The process is a specialist operation that should be undertaken by experienced operators. Generally, a number of injection tubes are inserted in the ground along the outside face of the foundation or, in the case of concrete floor slabs, in a grid pattern through the slab. Disruption to the property is minimal. Carpets are required to be lifted when slabs must be raised, but vinyl floor covering may be left in place if careful removal and replacement of circular 'plugs' of the vinyl is carried out.

The products used are resins which combine to form thermoset polymers in a chemical reaction. The resulting product is infusible and insoluble. Up to a certain limit the compressibility of the resulting product is directly proportional to the applied load (elastic response), but above this limit the intercellular structure is permanently modified and will not recover its initial form. The elastic limit is dependent on the density of the material and the type of resin used will determine this. Common densities are in the range of 65 to 100 kg per cubic metre beneath floors and 300 kg per cubic metre in deep injection.

The polymers are chemically very stable and are not affected by most solvents. The polymers also do not pose any threat to the environment.

2.5.1 Site visits

Before making any recommendations on the injection system, BRANZ undertook two site visits to properties that had been subjected to the injection process.

Property 1

The first of these properties was a brick veneer house with concrete perimeter foundation walls and piled foundations between. A section of the perimeter foundation had sunk up to approximately 100 mm below the rest of the floor. In this process, a large crack had formed in the brick veneer (Figure 37). The crack was approximately 10 to 15 mm wide and the misalignment of the mortar joints suggested that some vertical differential movement had occurred at the break.

The injection process had been carried out early in 2004 and concentrated on two lengths of wall adjacent and at right angles to each other at the sunken corner.

The crack and misalignment were clearly visible at the time of the BRANZ visit. This indicated that the foundation had not been lifted to a level state. This requires some qualification, however. The intersection of an addition to the front of the property, constructed after the corner had settled, would have been damaged had the wall been fully lifted. The owner also advised that more product could have been injected than was, but he had authorised the injection crew to stop because of the extra cost that would be involved. A horizontal line had been drawn across the crack before the injection commenced and the owner advised that there had been a definite difference in level between the two halves when the injection was complete. At the time of the BRANZ visit, the two halves had aligned again (Figure 38), suggesting that possible settlement had occurred since the injection work.

This case suggested that further settlement may have occurred since the injection work, but this must be tempered by the statement by the owner that he had elected to stop the injection when it may have been possible to lift the foundation further.

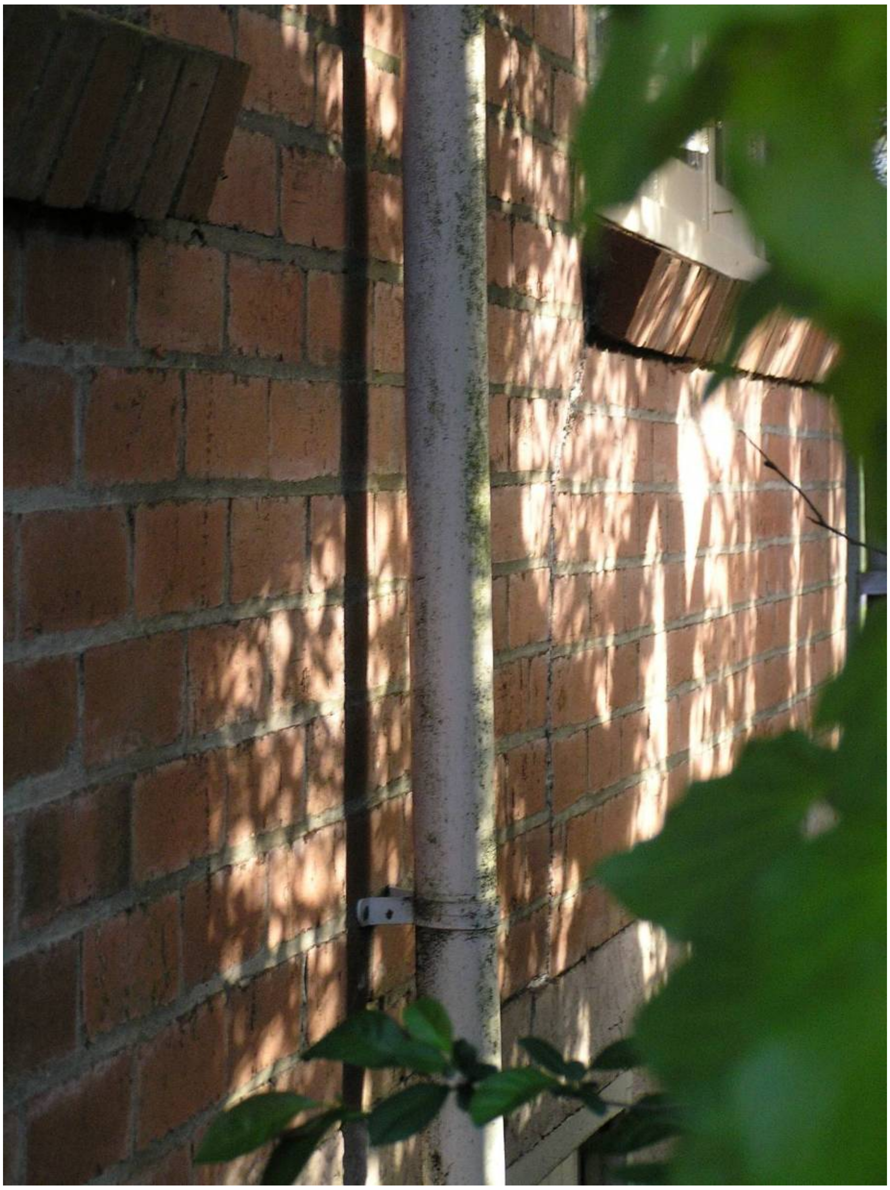
Figure 37: View of wall showing the misalignment of the mortar joints and the crack

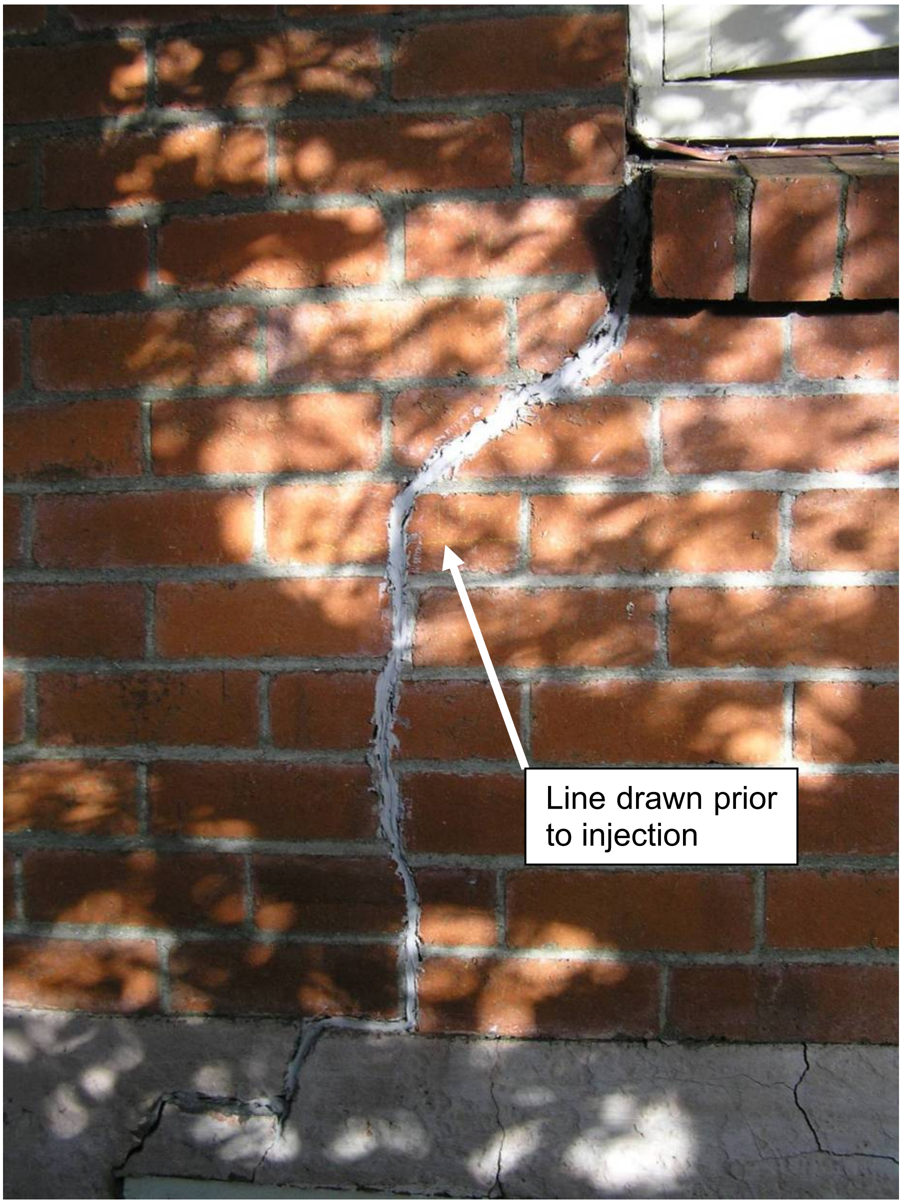

Figure 38: Line drawn at the time of injection

Property 2

The second property viewed was also a dwelling with a brick veneer cladding. This property had a slab-on-grade foundation with a perimeter footing and in one corner of the dwelling the foundation had sunk by approximately 50 mm due to poor subsoil conditions. This displacement had caused two significant cracks to form in the mortar joints of the concrete brick veneer wall (Figure 39). The crack locations are identified by the different mortar colour in Figure 39. The settlement had caused a difference in the level of the sill blocks of approximately 10 mm before the injection was carried out.

At the opposite end of the house a concrete slab in the yard adjacent to the house had also sunk at the edge adjacent to the house, causing rainwater to pond against the house.

Both areas were lifted using the injection technique in 2002. The process almost completely closed the cracks in the veneer and in the foundation, to the point where re-pointing of the mortar joints was all that was required to remedy the outside of the appearance. Unfortunately, in this case, the mortar was not properly matched with the original mortar. The resulting crack in the foundation was no more than a typical shrinkage crack (<0.5 mm) and could have been easily repaired by rubbing in a cement paste. At this property, the floor adjacent to the sunken footing was lifted off the underlying hardfill during the injection process beneath the footing. However, the suspended span that was created was considered to be sufficiently small for mesh reinforced concrete that further injection beneath the slab for support was unnecessary.

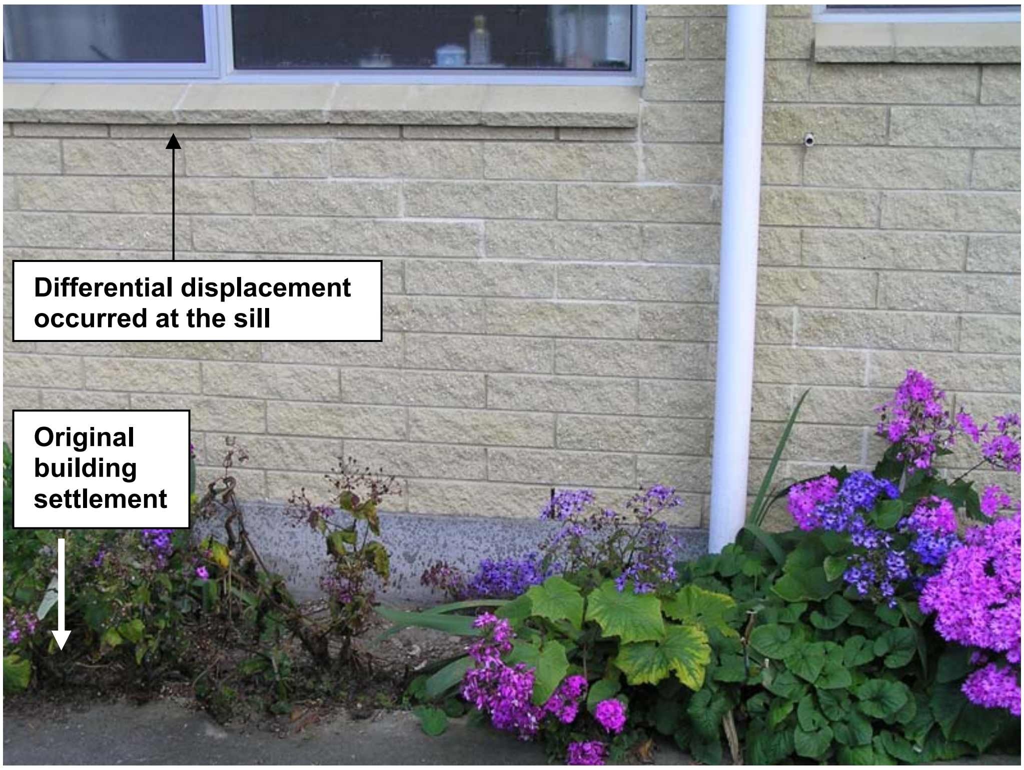

Figure 39: Overall view of the repaired veneer where the foundation had settled

The only evidence of any injection work beneath the yard slab was the small holes left after the injection process that had been grouted (Figure 40). The owner of the property indicated that there had been no more water ponding problems since the levelling work was undertaken.

Property 3

The author did not personally visit this property, but interviewed the owner on the telephone. Settlement of the slab had occurred between the foundation beams during an earthquake in 2003. Tiles on the floor had cracked as a result of the differential settlement. The injection system was used to re-level the floor slab and the tile floor was replaced. The owner confirmed that the slab has remained level since the job was done (a period of approximately three years) and the re-tiled floor is in perfect condition.

Recommendations

Two properties have been visited and the owner of another was interviewed to ascertain the initial and long-term effectiveness of the injection technique.

The first of the visited properties showed that the process may not always be successful if the area to be consolidated and then lifted is difficult to confine. It may have been possible to lift the sunken area to level with the injection of more material but the process would have been expensive, given that the unit cost of the product is high. Alternative methods such as the use of screw piles may have been more economic. A penetrometer investigation to ascertain the bearing strength of the soil, over a depth of at least 2 m below the foundation, would be necessary before any decision on the levelling technique to be used was made.

The second and third situations were slab-on-grade foundations which were successfully lifted back to their original level. The injection system has proven to be an efficient method on re-levelling slab-on-grade floors. Carrying out some subsurface checks with a penetrometer at points around the perimeter of the house is advised before any levelling process is instigated. When slab settlements occur between foundation beams, this is a sign that the earthquake has caused recompaction of the hardfill beneath the floor slab.

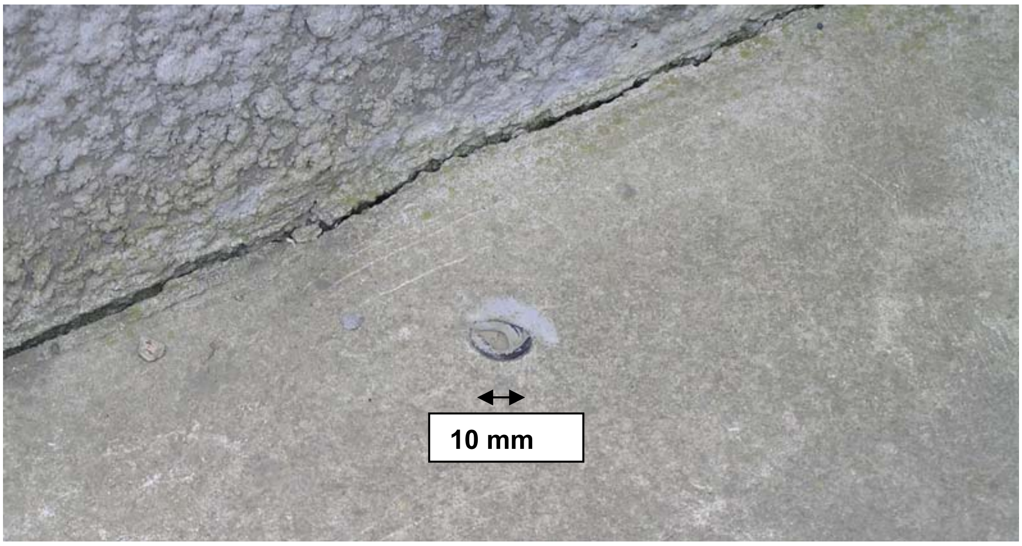

Figure 40: Evidence of the injection process beneath the yard slab

2.6 Processes for minor repairs to interior linings

In an effort to identify appropriate methods for carrying out repairs of minor damage of interior linings, EQC claims files were inspected for a range of properties affected by the Te Anau earthquake of 2003. Unfortunately, the detail contained in the claims files was rather limited and it was difficult to determine the levels of damage observed from the files and then align this with the repairs undertaken. This analysis was coupled with an inspection of photographs taken by Mainzeal Construction representatives who were charged with organising repair work on houses for which claims had been processed.

Despite the difficulties encountered in scanning the claims files, minor cracking of joints between interior lining sheets appeared to be the main issue that was dealt with by painting and decorating companies after the Te Anau earthquake. The sorts of phrases used in the files included:

“Pull back wallpaper, rake and re-stop joints and re-fix paper”.

“Re-paper after crack repair”.

“Ceiling repair – strip and re-coat”.

“Ceiling – repair popped nails and cracks and repaint”.

“Repair cracks inside and outside and two coats of ceiling flat paint or acrylic low sheen inside and X200 outside”.

“Re-paper walls”.

By far the most common photographed feature was apparent movement at joints between the lining sheets and between the cladding sheets. With regard to linings, these joints were particularly evident above and below window openings. It was debatable whether much of the observed cracking between sheets was actually caused by the earthquake or whether it was the result of normally expected seasonal movement of the houses. This is an issue that is not often easily able to be definitely resolved.

When the opening of cracks caused the covering wallpaper to rip, the repair process involved removal of the wallpaper, removal of any loose gypsum plaster, filling the crack with stopping compound and then re-papering the wall.

If the cracks were evident in painted walls, the process involved repainting over the crack (for fine cracks) with acrylic paint. Wider cracks (greater than 1 mm) were raked out and filled with a polymer modified plaster before repainting.

In discussion with Mainzeal personnel, it was made clear that small painting and decorating companies prefer to provide a quote for the complete redecoration without bothering to refer to the *Earthquake Damage Assessment Catalogue* and costing database. It is also necessary to allow for up to three visits to the property to reach agreement with the home-owner on acceptable colour schemes before commencing the repair work.

3. SUMMARY OF REPAIR TECHNIQUES DERIVED

The aim of the experimental work was to derive repair techniques for older style constructions that are likely to be found in houses constructed prior to 1980. The investigated constructions included stucco exterior cladding on a flexible backing, softboard ceiling linings, hardboard ceiling linings and lath and plaster wall linings. The derived repair procedures are presented in Table 1.

Table 1: Repair procedures for the investigated constructions

System	Damage sustained	Repair procedure	Other considerations
Stucco cladding	Fine cracks less than 0.5 mm wide	Repaint using two coats of flexible acrylic paint	
Stucco cladding	Cracks from 0.5 to 1.0 mm wide	Scrape out crack with pointed steel probe, dampen the area and smear new cement plaster over the crack, working the plaster into the crack with a cloth	Push on the wall with the palms of hands to determine whether the stucco is still tied to the framing. If it is, new nails must be fixed through the stucco into the framing and the heads plastered over
Stucco cladding	Loose or lost sections of stucco plaster	Chip out loose plaster. Fit new reinforcing mesh if old mesh is damaged. Mix and apply new stucco plaster and finish texture	With this level of damage present, it is possible that the stucco has detached from the timber framing. If it isn't, new nails must be fixed through the stucco into the framing and the heads plastered over
Softboard ceiling linings	Minor cracking of paint at sheet junctions (caused by racking in the plane of the ceiling)	Scrape out any loose flakes of paint and apply undercoat and top coat of acrylic paint to match. Note that it may be necessary to repaint the complete ceiling if a colour match is not possible	Cracks caused by shear along the joint tend to flake the paint, whereas normally expected shrinkage of the softboard and the paint creates a more even crack
Softboard ceiling linings	Softboard 'loose' in that it can be pushed up to contact the framing	Remove timber beading, if present, and re-nail the softboard to the framing. Use gypsum plaster to cover exposed nail heads. Install new timber beading and repaint. Note that it may be necessary to repaint the complete ceiling if a colour match is not possible	While it may be possible to carefully remove the timber beading and re-use it, allowance should be made for complete replacement
Softboard ceiling	Minor bulging of sheets at junctions	Remove timber beading, if present. Lightly	If the softboard is bulging or buckling

System	Damage sustained	Repair procedure	Other considerations
linings	and/or fixing nails pulled through the softboard	hammer high spots in the softboard caused by old nail heads. Re-nail the sheets to the framing. Use gypsum plaster to cover exposed nail heads and patch. Install new timber beading and repaint. Note that it may be necessary to repaint the complete ceiling if a colour match is not possible	excessively this is likely indicating that the framing in the area has been racked by the earthquake and has not returned to its original position. Further checking of the room for vertical and horizontal alignment should be carried out before deciding on the repair to the ceiling
Softboard ceiling linings	Sheets have fallen fully or partially from the framing	Remove remaining timber beading, if present. Replace the sheets with alternative ceiling lining – plasterboard recommended	The framing in the area may have been racked by the earthquake and has not returned to its original position. Further checking of the room for vertical and horizontal alignment should be carried out before repairing the ceiling
Hardboard ceiling linings	Minor cracking of paint at sheet junctions (caused by racking in the plane of the ceiling)	Scrape out any loose flakes of paint and apply undercoat and top coat of acrylic paint to match. Note that it may be necessary to repaint the complete ceiling if a colour match is not possible	Cracks caused by shear along the joint tend to flake the paint, whereas normally expected shrinkage of the hardboard and the paint creates a more even crack
Hardboard ceiling linings	Heads of panel pins securing the sheet to the framing exposed and sheets able to be pushed up 0-3 mm to contact the framing	Add new panel pin fixings adjacent to the existing pins. Punch down the heads of the old pins. Fill holes with gypsum plaster and sand off when set. Apply undercoat and top coat of acrylic paint to match. Note that it may be necessary to repaint the complete ceiling if a colour match is not possible	
Hardboard ceiling	Gaps between	Using a block of timber as	Note that significant

System	Damage sustained	Repair procedure	Other considerations
linings	timber beading (if present) and hardboard sheets and hardboard sheets partially detached from framing	a spreader, 'hammer' the sheets back against the framing. Add new panel pin fixings adjacent to the existing pins. Punch down the heads of the old pins. Fill holes with gypsum plaster and sand off when set. Apply undercoat and top coat of acrylic paint to match. Note that it may be necessary to repaint the complete ceiling if a colour match is not possible	misalignment of sheets at junctions may indicate that the framing in the area has been racked by the earthquake and has not returned to its original position. Further checking of the room for vertical and horizontal alignment should be carried out before repairing the ceiling
Lath and plaster wall	Loss of plaster patches and/or wide cracking	Carefully remove architraves and skirting boards and retain for re-use. Remove plaster and laths from the framing. Attach appropriate thickness packing strips to the framing and fix new gypsum plasterboard. Stop joints and fixings and finish with paint or wallpaper. Re-attach architraves and skirting boards and repaint	Significant racking of the building is likely to cause a failure of the plaster to lath connection which is not economically repairable. As the lath and plaster is removed, ensure that let-in timber braces are present in the wall framing. If this is not the case, add temporary diagonal braces and obtain engineering advice before re-lining
Concrete foundation walls	Wall has settled with associated cracking	Injection of proprietary product into the soil beneath the foundation while monitoring floor levels	Age of cracks in foundation wall should be relatively easily determined by freshness or presence of soil and/or moss. Fresh cracks would indicate that settlement has occurred in the earthquake. Structural and/or geotechnical engineering advice is required
Concrete floor slab	Floor slab has sunk either between foundations supporting walls or	Injection of proprietary product into the soil beneath the slab and/or foundation while	The age of slab settlement between foundations may be difficult to determine.

System	Damage sustained	Repair procedure	Other considerations
	inclusive with foundations	monitoring floor levels	When both have settled, this may have occurred well before the earthquake. Look for other indicators such as old cracks in veneers, stucco or evidence of movement at joints in exterior sheet claddings. Structural and/or geotechnical engineering advice is required

4. REFERENCES

Standards New Zealand 1999. *NZS 3604 Timber Framed Buildings*. SNZ, Wellington, New Zealand.

Personal communication with Robbie Vershoor, building contractor undertaking the Lady Ferguson House refurbishment project.