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DEVELOPMENT OF DAMAGE REPAIR PROCEDURES FOR EARTHQUAKE DAMAGED BUILDINGS

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SUMMARY

This paper briefly outlines the preparation by BRANZ Ltd of an Earthquake Damage Assessment Catalogue for the New Zealand Earthquake Commission (EQC) to assist with the efficient assessment of house damage and repair strategies following a major earthquake. The paper describes a series of experimental investigations to simulate earthquake damage and develop repair strategies for elements of construction where a lack of recent earthquake activity has meant that there is no available documented description of damage and engineering judgment has been used to formulate the repair strategy in the Earthquake Damage Assessment Catalogue (EDAC).

The investigations have shown that often the damage is not obvious to the casual observer and careful interpretation of the evidence is required to develop a satisfactory repair strategy.

INTRODUCTION

New Zealand is a seismically active country, but a major earthquake has not been experienced in a large metropolitan area for many decades. Despite this, the EQC is preparing to be ready to respond to such an event when it does occur. The EQC primary objective is to settle claims fairly and quickly so that repairs can be undertaken promptly, thus minimising community disruption. A principal component of the response strategy is the EDAC, which contains written and photographic descriptions of the various expected damage states in residential houses, and appropriate repair strategies.

Because of the lack of any recent seismic events causing significant damage, experience of performance is lacking and much of the information contained in the EDAC is based on experience from the 1987 Edgecumbe earthquake and engineering judgment. This paper describes a series of experimental investigations undertaken by BRANZ Ltd in which simulations of house construction have been created and intentionally damaged, and repair strategies developed.

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EQC AND THE EARTHQUAKE DAMAGE ASSESSMENT CATALOGUE

The EQC is a New Zealand government agency established in 1993 to provide disaster insurance cover for residential property. When a residential property is insured for fire damage with a commercial insurance provider, it is automatically covered for earthquake damage by the EQC. As a result, over 90% of residential property in New Zealand is insured against earthquake damage.

The EQC has, since its inception, been developing a comprehensive programme to manage its role in the recovery phase following a natural disaster event, particularly earthquakes. It is known that there will be a very heavy demand placed on the EQC following a significant earthquake and it is therefore important that the recovery process is managed efficiently, with claims being settled in the shortest possible time so that life can return to normal. To aid this process, the EQC has developed a strategy for identification and assessment of damage incurred, the development of repair strategies and the estimation of the quantum of work required to undertake such repairs.

The EDAC has been developed by BRANZ Ltd [1] for the use of the building damage estimators who will be engaged by insurance loss adjusters to make an assessment of the damage sustained in an earthquake and formulate an appropriate repair strategy in keeping with the observed damage. Most estimators are expected to be builders. The catalogue contains written explanations of observable damage, supplemented with photographs taken following actual earthquakes, if available, or sketches. The pictorial descriptors are critical in that they assist the estimator to recognise the specific characteristic being observed as being consistent with the written description of damage. The EDAC has been sectioned into key areas of house construction (eg foundation, floors, walls, etc) to allow rapid retrieval of damage descriptors. An electronic version of the EDAC contains a purpose-made search facility centered on key areas of the house construction so that the search may be narrowed quickly. A typical record in the EDAC is presented in Figure 1.

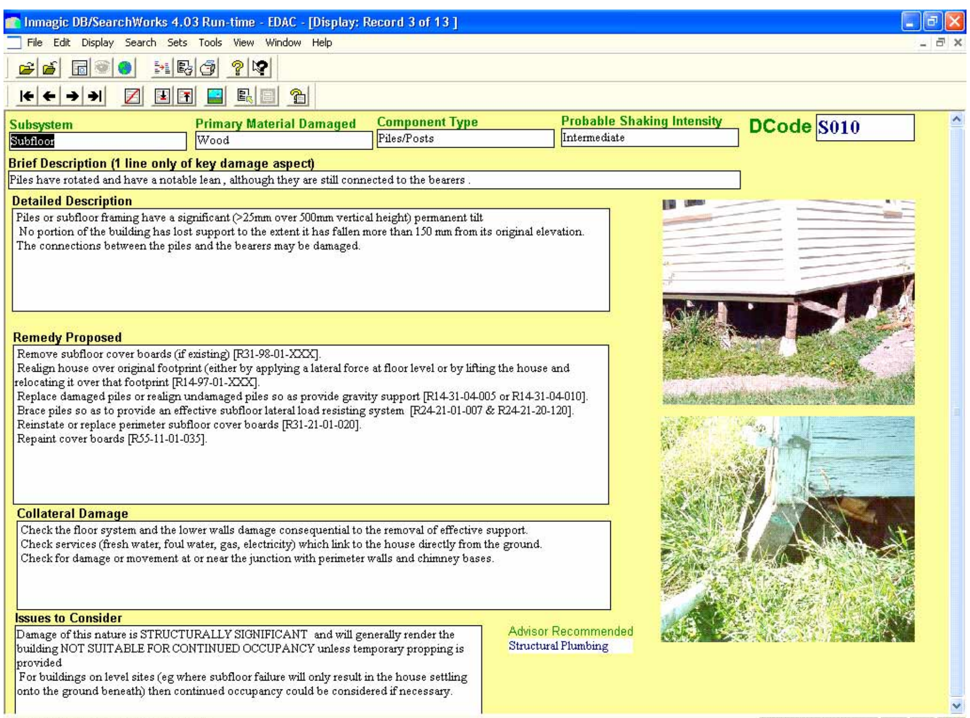

Figure 1 EDAC database record

It can be seen in Figure 1 that as well as the detailed damage description and the proposed remedy, there are further boxes containing information on expected collateral damage, issues to consider and whether or not the assistance of an advisor is recommended. Within the proposed remedy box, there are references inside square brackets. These refer to the appropriate associated entries within a separate costing database.

The lack of any significant damaging earthquakes in New Zealand over the past 10 years has meant that first-hand photographic information and documented observations on damage to New Zealand-style house construction has been limited. Hence, in the preparation of the first version of the EDAC, a combination of experience, judgment and a limited laboratory-based experimental programme was used to provide a description of likely total damage from observation of the surface damage. The expectation is that the EDAC will be a "living document", able to be easily modified as new information comes to hand, either from continuing experimental investigations or from the experience of future earthquakes.

EXPERIMENTAL STUDIES

A series of experimental investigations has been undertaken at BRANZ Ltd to replicate expected damage in various critical elements of a residential structure and to develop repair strategies. The outcomes of these investigations have been included in the EDAC as they have become available.

The investigations have included:

1. A wood-framed wall with a sheet bracing cladding and gypsum plasterboard lining, complete with return walls and a window opening representing a common modern exterior wall form.
2. A piled subfloor system with lateral cross braces.
3. An exterior wall containing window penetrations and with variable non-bracing exterior cladding elements and an interior lining with a designated bracing element.
4. One unit of a complete two storey 1960s wood-framed duplex housing unit. The other unit had been badly fire damaged.
5. A corner section of a brick veneer cladding complete with gypsum plasterboard lined timber-framed supporting walls.

Details of these investigations are reported in the following sections of this paper.

Test protocol

In the first four investigations the specimen was connected to a horizontal double-acting hydraulic ram and subjected to sets of full reversed cyclic displacements (three cycles per set) of increasing amplitude. The procedure required that both the load and displacement be recorded and that a full set of observations be made to identify the onset of varying degrees of damage. At appropriate milestone points, the test was suspended and repairs were undertaken. Once curing of the repair compounds had occurred, the specimen was again exercised, initially to half the maximum displacement magnitude before the repair but increasing to another damage state and repaired until eventually the recorded resistance diminished or the capacity of the hydraulic rams was exceeded.

In the fifth investigation the specimen was mounted on a uni-directional shaking table and subjected to simulated earthquake shaking. Once damage had occurred, repair procedures were trialled and the specimen was subjected once again to further shaking.

Wood framed wall with external sheet bracing cladding (Specimen 1)

Systems of wood framed walls with external sheet bracing cladding were common before the Code of Practice for Light Timber Framed Buildings not requiring specific design [2] was first introduced in 1978. They rely on bracing being provided by the exterior fibre cement sheet sheathing and the function of the plasterboard lining is purely to provide a surface for interior decoration. Because of this, the plasterboard sheets have often been nailed at large centres and sometimes not at all behind skirting boards. Both conditions were replicated in the test specimen. Details of the test specimen are presented in Figure 2.

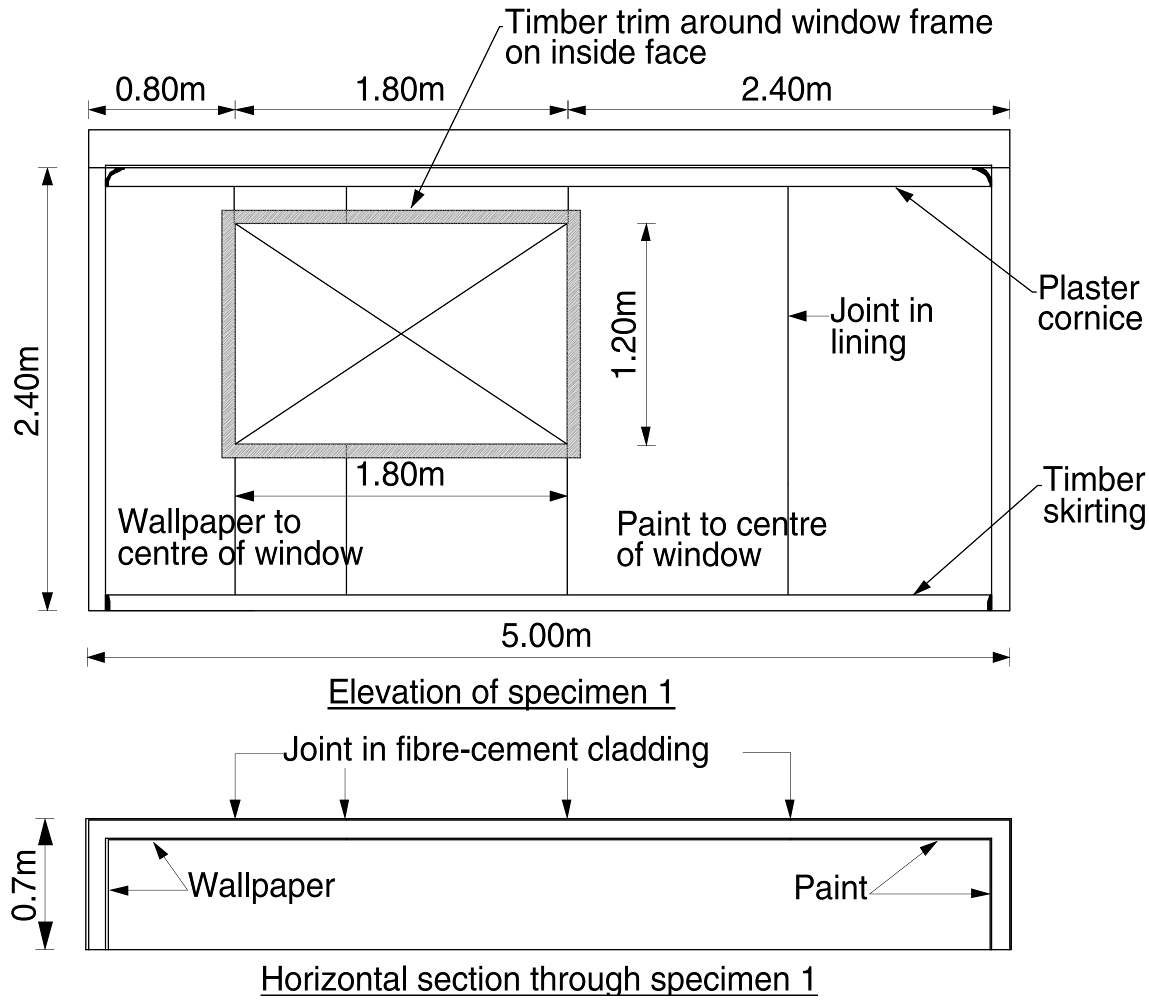

Figure 2 Details of specimen 1

The specimen bottom plates were coach-screwed to timber beams which were in turn fixed to the laboratory strongfloor to simulate a concrete foundation system, and a section of plasterboard ceiling, complete with cornice, was included to model the junction between the walls and the ceiling (Figure 3). One end of the interior face was painted while the other was wallpapered, to investigate the differences in observed damage formation. On the exterior face, the fibre-cement board was nailed in accordance with the manufacturer's literature. The tapered edge joints between the sheets were filled with a proprietary joint filler (Figure 3). No texture coating was applied to the surface of the fibre-cement board. Although it is not recommended by the manufacturers, the sheets of plasterboard and the fibre-cement sheets were joined at the edge of the window to represent what has been common practice by the construction industry.

Figure 3 Plaster cornice between wall and ceiling and filled tapered joint in exterior cladding

A horizontal cyclic displacement sequence of increasing amplitude was applied to the wall top plate to simulate earthquake action. During cycles to ±5 mm, fine cracks became evident in the stopping at sheet joints above and below the corners of the window opening. The corresponding joints in the exterior cladding also showed signs of fine cracking during these cycles. The cycling sequence was interrupted at displacement levels of 5 mm and 15 mm and various repair techniques were employed at each level to repair the cracks in the interior lining at the taped and stopped plaster joints and also the exterior cracking which occurred in the proprietary acrylic jointing compound used between the fibre-cement sheets. The lining repair involved removing the tape from the joint, gouging a “V” shaped groove in the stopping between the plasterboard sheets, and re-taping and re-stopping the joint.

The exterior cladding sheets remained in sound condition but the joints showed signs of increased cracking and the fixing nail heads began to damage the surface locally as the displacement increased. The joints were ground out and a “V” shaped groove was fashioned at the junction. After the 15 mm cycles, extra nails were added between the existing ones to resurrect the wall stiffness and strength. The cycling continued on to ±40 mm displacement and the feasibility of various repairs was evaluated at this point. Although the strength of the specimen up to 15 mm displacement was slightly less after the repairs, once the displacement cycles passed 15 mm, the resistance returned to its original strength and thereafter continued to increase until the peak resistance was achieved at 20 mm to 25 mm displacement, as expected from a virgin specimen (Figure 4). No damage was observed at the cornice up to 40 mm displacement.

The test results for this system indicated that it would not generally be necessary to remove the exterior sheet sheathing or the plasterboard lining after earthquakes causing in-plane deflections of the top plate of up to ±40 mm. In these combinations of wall claddings in older houses, the interior lining is not expected to perform any bracing function, and it is therefore not necessary to reinstate any bracing capacity. Re-nailing of the sheet material and re-stopping plasterboard joints and popped nails, depending on the level of damage, followed by redecoration, would be necessary on plasterboard linings. The exterior sheet cladding is likely to partially detach from the framing in a severe event but can be re-nailed and the joints refilled with appropriate filler materials. The re-nailing will need to be done carefully so that the bracing capacity of the cladding is re-established. Any nailing repairs to the sheet cladding will mean that the texture coating will require reinstatement.

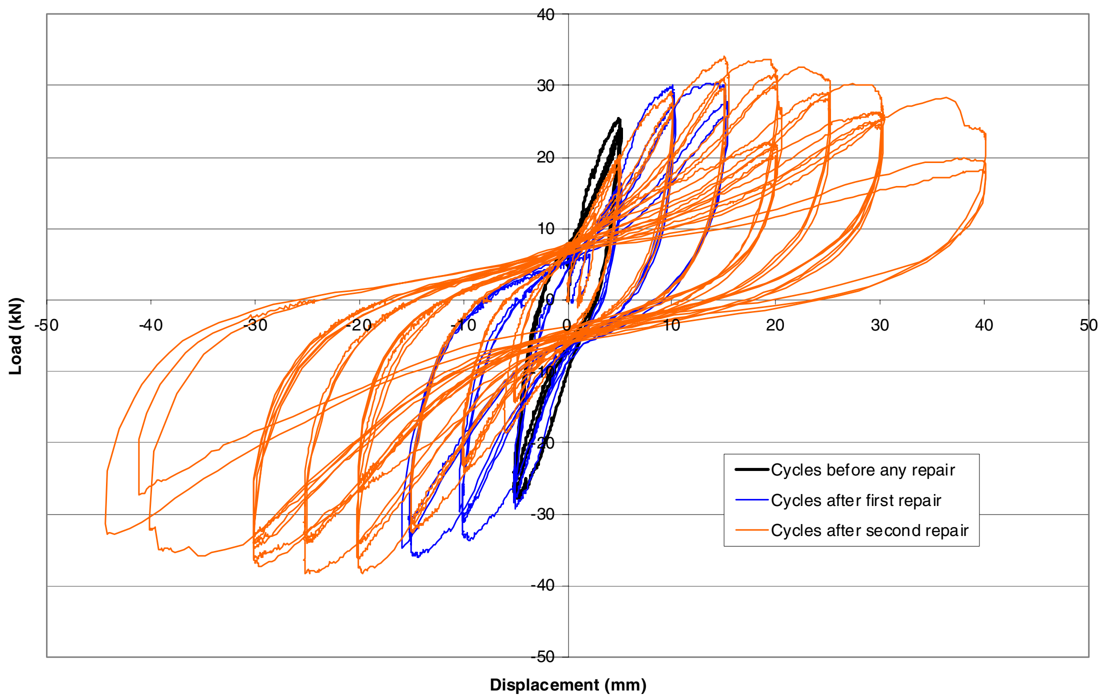

Figure 4 Load-deflection plot for Specimen 1 after repairs

A piled subfloor system with lateral cross braces (Specimen 2)

A specimen which included four piles and three diagonal braces was constructed to determine the repair procedure for various levels of damage that may occur in an earthquake. The pile members were 125 mm x 125 mm in cross section and the brace members were 100 mm x 75 mm. Dimensional details are presented in Figure 5. Construction of the braced piles replicated the requirements of NZS 3604 [3]. All bolted connections were M12 galvanised bolts through close-fitting holes in the timber. A 50 mm x 50 mm x 3 mm flat washer was installed beneath each bolt head and under each nut. The bolts were tightened firmly with an adjustable spanner, as would be expected to occur in practice. To simulate the "pinned" support from the ground, the bases of the piles were restrained against movement along the line of the piles 500 mm below the bottom brace connection, but were allowed to rotate to simulate expected ground deformation.

Load was applied at the floor level and the specimen was cycled to increasing increments of displacement of the bearer, up to ±100 mm. The backbone curve of the first cycle load peaks is presented in Figure 6. It was not possible to see any damage in the system at the completion of the cycling despite there being a significant permanent offset. A brace was removed to determine the damage at the bolted connections. The bolt had distorted significantly and the holes in the timber members at their adjacent faces were elongated. Two repair options were considered. The first involved filling the holes with all-purpose plastic putty, re-drilling and installing new M12 bolts. The specimen was cycled again after this repair and achieved approximately 70% of the initial strengths at corresponding displacements (Figure 6). In the second option, the M12 bolts were removed and the holes were drilled out to accommodate M16 bolts. These were installed and the specimen was cycled once again. It can be seen in Figure 6 that the stiffness of the M16 repair was less than the original M12 stiffness up to 20 mm displacement, but the strength of the repaired specimen matched the original strength beyond this level.

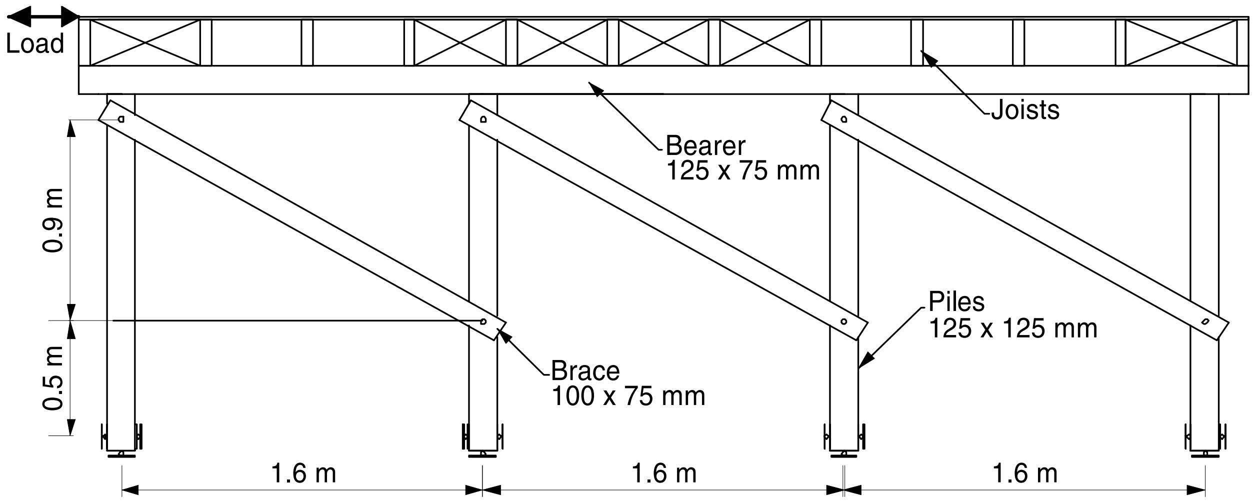

Figure 5 Braced pile test specimen

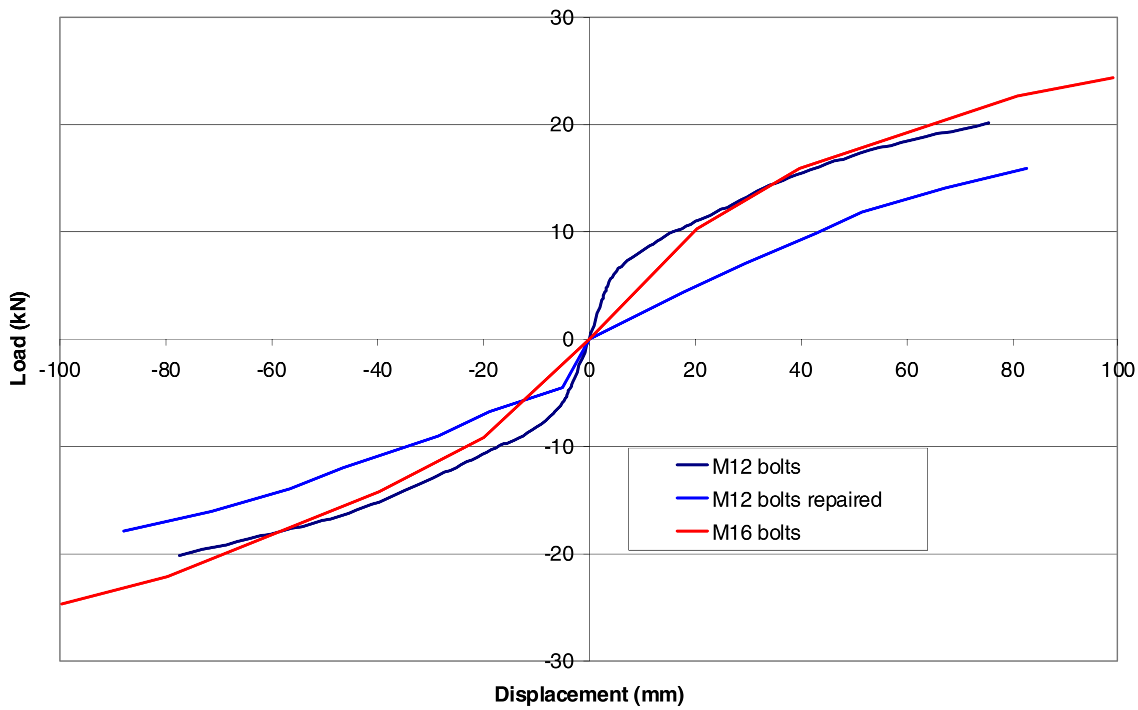

Figure 6 Load-displacement response of pile system

With braced piles, it appears that it will probably be necessary to remove at least one brace after a severe earthquake to check for unseen damage. A decision can be made at that point about whether it will be sufficient to retighten the existing bolts (thus mobilising greater friction between the two timber surfaces and stiffening the joint) or whether the holes should be drilled out and M16 bolts installed. The inclusion of split ring or toothed plate connectors may be another repair option but these are no longer readily available in New Zealand.

An exterior wall containing window penetrations and with variable non-bracing exterior cladding elements and an interior lining with a designated bracing element (Specimen 3)

Because window and door openings in exterior walls introduces points of high stress under racking loads a specimen was designed to investigate the development of damage and devise appropriate repairs. It was not certain whether the wall racking would damage flashing details around the openings to the extent that they would subsequently leak. This study considered a 6.1m 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 interior lining was standard plasterboard except that one designated bracing panel was lined with fiberglass reinforced plasterboard. An exterior view of the wall is presented in Figure 7. A plaster cornice was installed on the junction between the wall and ceiling at the left end in Figure 7 and at the right end the joint was taped and stopped as a square joint. The bottom plates were attached to the strongfloor in the same manner as Specimen 1.

Figure 7 View of the exterior face of the specimen 3 wall

The left end of the wall in Figure 7 was clad with fibre-cement sheet described by the manufacturer as a monolithic textured cladding solution for lightweight construction. The fibre-cement was coated with a single size aggregate textured coating and painted with a high build acrylic paint. The fibre-cement sheets were cut around the window opening with joints formed above and beneath the centre of the opening. The window included in this section was recycled from a pre-1980 dwelling and was flashed with metal flashings typical of the era. The central section was clad with a reduced density, fibre-cement, bevel back weatherboard system and the window was a fixed pane aluminium window flashed with proprietary flashings supplied by the weatherboard manufacturer. The right end was clad with an exterior insulation and finish system (EIFS) which comprised 40 mm thick expanded polystyrene foam overcoated with a polymer-modified cement texture plaster with irregular grain size which was troweled over the wall. This was painted with a high build acrylic paint. The aluminium window in this section contained a fixed light and a casement sash and was installed in a manner typical for this type of cladding, using typical uPVC flashings supplied by the coating manufacturer.

Initially, a water spray was applied to the exterior surface of the specimen in accordance with NZS 4211 [4]. Leakage was minimal at the two aluminium windows, primarily entering from where condensation was normally expected to drain. The wall was then subjected to three in-plane racking cycles to displacement levels of ±4 mm, ±9 mm, ±14 mm and ±24 mm. The damage description in this paper is limited only to the exterior claddings. Interior lining damage and treatment was similar to specimen 1.

After the 4 mm cycles there was no damage that would require any repair work. Up to the 14 mm displacement cycles the joint between the fibre-cement cladding sheets bulged so that the joint was visible through the textured coating. A diagonal crack was also visible at the top corner of the window at the peak displacement, which was obviously due to cracking in the fibre cement substrate. This crack closed as the load was released and would have been difficult to recognise without careful inspection. A new coat of paint over this area would serve to reseal the crack against moisture penetration but the bulged joint between sheets would require "V"ing out and filling with a flexible sealant before applying a new textured coating. The bottom corners of the window sill in the EIFS cladding also had signs of fine cracking which could be painted over and the weatherboard system had no discernable damage.

At 24 mm displacement, the cracks in the EIFS cladding extended some distance diagonally away from the corners of the window opening (Figure 8). The three smaller cracks were "V"ed out to a 5 mm width through the thickness of the coating and the cracks were filled with polymer modified cement plaster, trowelled on and feathered out with a sponge. The fourth (larger) crack was scraped out to a taper finish over an approximately 100 mm width, a length of fibreglass mesh was laid over the crack and polymer modified cement plaster was trowelled over the joint and "sponged". The surface was painted over after three days and though not obvious, the repaired areas were still visible.

Figure 8 Crack repairs in EIFS cladding

Beneath the timber window, the bulged joint between the fibre-cement sheets had become more pronounced (Figure 9). It was scraped out to a wide taper finish and trowel-filled with acrylic flexible jointing material. The typical repair procedure proposed by the plasterer for the diagonal cracks involved filling the crack with a flexible and paintable modified silicone sealant which was smoothed with a finger and then dabbed with a dry paper towel to give the same appearance as the surrounding plaster. This process was only partially successful and a new textured coating would be required if it was essential to remove all signs of the repair.

Figure 9 Repair to bulged joint between fibre-cement panels

The weatherboard section of cladding showed no obvious damage but, if it had been painted, the paint would have torn at the sheet junctions. Although this may look unsightly, the weather penetration resistance was still intact. There was no obvious damage to any of the flashing details at the completion of the cycling and a water spray test conducted after the repairs had been undertaken confirmed that there was no leakage.

One unit of a complete two storey 1960s wood-framed duplex housing unit (Specimen 4)

The focus of this assessment was the performance of interior walls of an existing 1960s house. The test walls were located in a two storey duplex housing unit with a concrete block wall separating the two dwellings. The house was constructed in 1964 for the Housing Corporation of New Zealand (now Housing New Zealand). The plan dimensions of each unit were 7.9 m by 6.65 m. The roof was corrugated galvanised steel over 75 mm x 50 mm purlins supported by 100 mm x 50 mm rafters at 900 mm centres.

The exterior cladding was bevelback weatherboards over the upper storey and asbestos cement sheets over the bottom storey. Ceiling linings in both the upper and lower storeys were fibrous plaster, while the wall linings were gypsum plasterboard. Both the upper and lower storey floors had nominal 80 mm wide tongue and groove floor boards over 200 x 50 mm floor joists at 450 mm centres on the top floor and 125 mm x 50 mm joists at 450 mm centres on the lower floor. Wall framing was generally 100 mm x 50 mm at 450 mm centres on both storeys. The top and bottom plates of the lower storey were 100 mm x 75 mm. Floor plans are presented in Figure 10.

Testing began by applying load along the line of the top plate of the upper storey test wall (Figure 11) in both directions. Initially the ceiling was left intact and during loading it appeared to be rotating in a horizontal plane about points midway between the test wall and the outer walls as the loading approached 125 kN. There was some cracking damage on the joints between the plasterboard at the top corners of the doorway which would have required re-taping and re-stopping before redecoration (either paint or wallpaper). The section containing the let-in timber brace (see Figure 11) retained its shape and tended to rotate as a rigid body with the bottom plate lifting from the floor at the edge of the door opening. It was clear that significant load was being transferred to the outer walls via the ceiling lining so this was cut on two lines parallel to the test wall and about 1 m either side of the wall. The stiffness of the specimen reduced as a result but the nailing of the individual sections of the ceiling still appeared to be providing significant in-plane moment resistance.

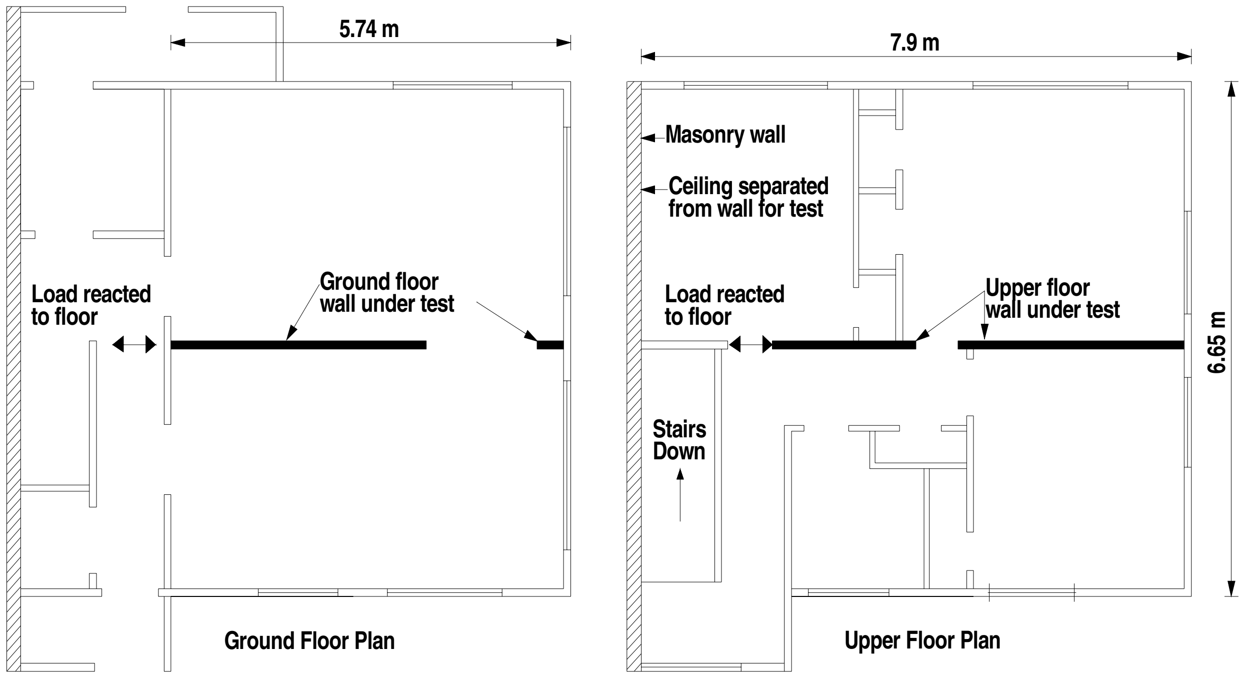

Figure 10   Two storey duplex unit floor plans

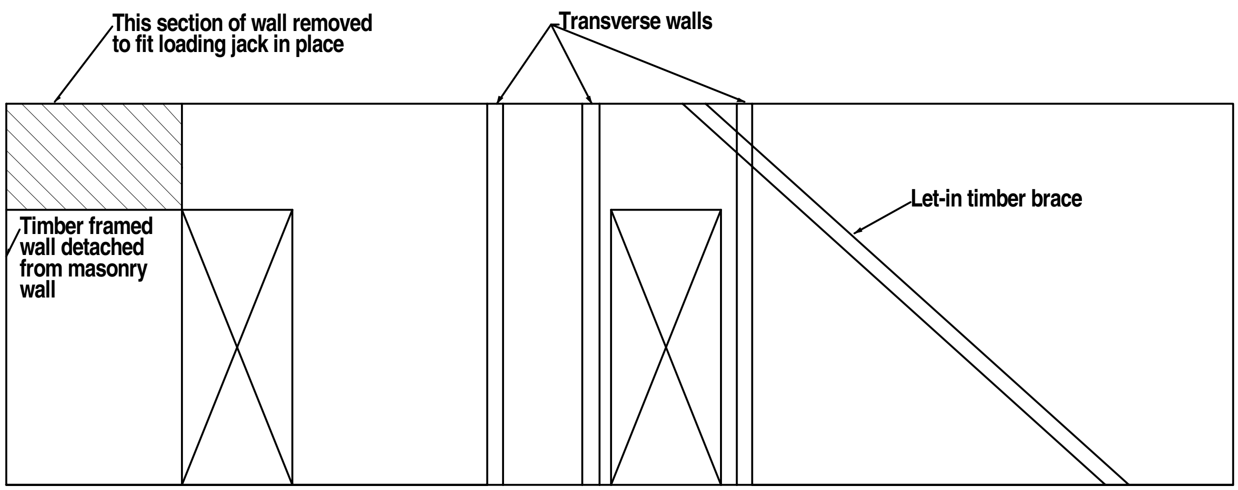

Figure 11   Elevation of upper storey test wall

The test rig was relocated to the ground floor and installed so that the racking load was introduced to the underside of the upper floor joists approximately 350 mm on either side of the top plate of the wall under test. The ground floor ceiling was cut in the same manner as the upper floor ceiling and then four floor boards were removed on either side of the wall in an attempt to prevent forces reaching the outer walls. Following this, the linings were all removed from the parallel wall in the hallway and the top plate of the orthogonal wall was cut on the lines of the ceiling cuts. Each alteration caused a small decrease in the stiffness of the test wall but the same peak loads were still able to be achieved. Finally, the 150 mm x 25 mm let-in timber brace contained within the test wall was cut. Backbone curves enveloping the hysteresis loops achieved for each condition are plotted in Figure 12.

The investigation determined that it is difficult to isolate individual bracing elements in a real house because of the complex interrelationships present. Although not normally allowed for in the design of force transferring systems, the in-plane strength of ceilings and plank floors that are not designed as diaphragm elements is significant. The structure of the house was cellular, thus providing a great deal of resistance to lateral load by the numerous walls, even though these were not designated bracing walls. The walls that included let-in timber diagonal braces provided large lateral load resistance and the section of the wall containing the brace tended to behave as a rigid body, rotating about its base. It is expected that such cellular style houses will behave well in severe earthquakes.

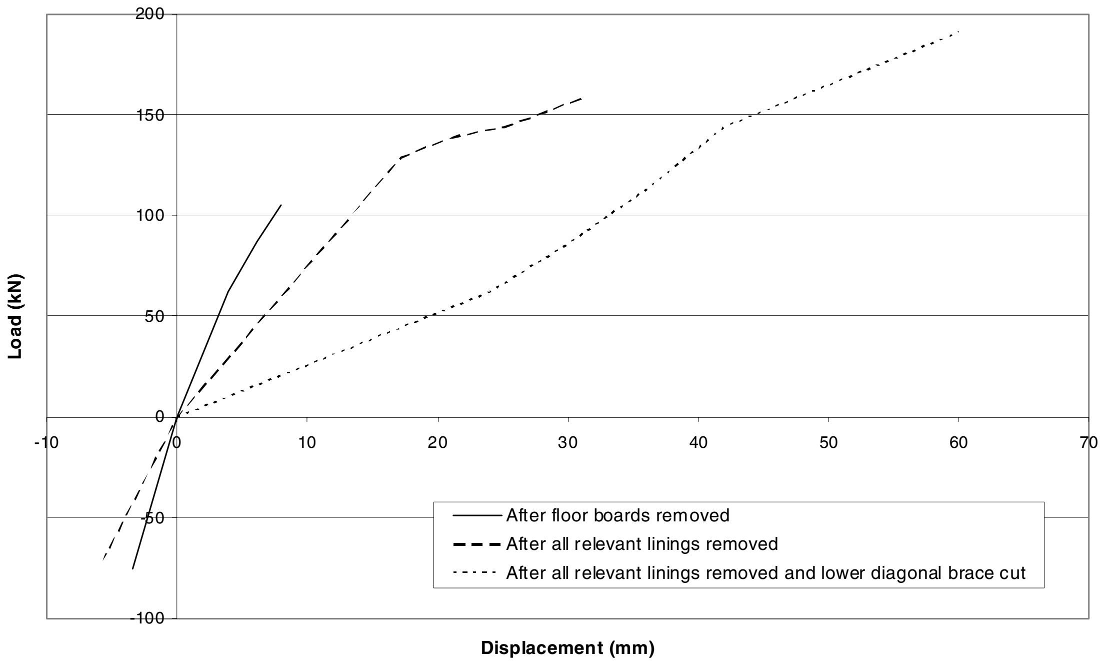

Figure 12 Comparison of the backbone curves before and after the diagonal brace was cut in the test wall

A corner section of a brick veneer cladding complete with gypsum plasterboard lined timber framed supporting walls (Specimen 5)

Damage to brick veneers has been widespread in historic earthquakes. A corner section of brick veneer cladding was constructed on a concrete foundation to simulate the corner of a house. The veneer length was 2.6 m and the return section was 1.4 m long. The veneer was connected to a 90 x 45 mm timber-framed wall with proprietary veneer ties on a grid of 300 mm x 600 mm (stud spacing), fitted so that the bottom flat face of the ties rested on the top of the brick to represent historic construction practices. The inside face of the framing and a section of ceiling framing was lined with standard gypsum plasterboard. To simulate the mass of a heavy concrete tile roof, 1000 kg of steel weights were supported on the framing at top plate level. The specimen was mounted on a shaking table (Figure 13) and accelerometers and displacement gauges were installed to monitor dynamic performance.

The table was excited several times with sharp pulses followed by two low-frequency sinusoidal cycles to ± 10 mm. The free end of the in-plane loaded veneer lifted more than 10 mm from the foundation during the pulses and differential movement was obvious between the veneer and the framing. Although no part of the veneer collapsed, an inspection revealed that the bond between the veneer ties and the mortar had been lost. In an in-service situation this would be particularly difficult to identify because the outside face of the veneer appeared to be unchanged.

Figure 13 Brick veneer corner specimen mounted on the shaking table

Several holes were drilled through the veneer and an optical probe (Borascope) was used to inspect the cavity for tie damage. This was unsuccessful because the dark building paper and bricks prevented any reflection of light from the Borascope, making it impossible to inspect anything but the immediately adjacent tie. The interior linings were removed from the specimen and replaced because they had detached from the framing and during this process it was determined that the tie connections had largely failed despite appearing sound. It is likely to be necessary to remove sections of the interior lining after damaging earthquakes and gently lever between the studs and veneer to check on the integrity of the joints.

A recording of the north-south direction displacement record for the 1940 El Centro earthquake was input to the shake table. 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.

An experienced bricklayer advised that the damaged section of the veneer could be carefully removed and replaced with new matching construction. This repair process was undertaken (Figure 14). 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. Having also determined that the ties were no longer supporting the veneer, it was decided to install proprietary spiral stainless steel ties in a grid pattern similar to the spacing of the original ties. To install these ties, a hole is drilled through the veneer and the helical tie is screwed through the hole into the stud behind. To ensure that the ties are correctly positioned to match the stud positions, it would be necessary to employ a "stud-finder" or a cover meter. The top of the tie hole is normally filled with coloured grout to match the veneer colour.

Propping and removal | Adding replacement bricks | Completed repair (mortar still wet)

Figure 14 Sequence of veneer repair

The repaired specimen was subjected to further dynamic loading. Both the face-loaded section of veneer above the repaired area and the in-plane loaded veneer showed signs of permanent horizontal movement to the extent that removal and rebuilding 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 though 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.

The testing successfully replicated the sort of veneer damage observed in real earthquakes (Figure 15). The major difficulty with brick veneers that are not obviously damaged in an earthquake is in determining the integrity of the tie connections without invasive investigations. Often there will be movement on the joint between the veneer and the foundation because the bottom course of mortar has failed and this may be an indicator of loss of tie integrity. Significant movement on this joint will mean that removal and rebuilding of the veneer will be necessary. Proprietary helical ties which can be installed through an existing veneer are an effective means of re-securing the veneer to the timber framing.

Figure 15 Corner veneer damage observed in a real earthquake

Full details of the experimental programme and its findings have been published by Beattie [5][6]. Details of specific damage and proposed remedial measures are tabulated within the reports and correlate to the repair strategies outlined in the EDAC.

PROPOSED FUTURE WORK

This series of investigations is part of an on-going programme of work to derive effective methods of carrying out repairs to earthquake damaged houses. Future studies are expected to include:

- Further investigation of the diaphragm load resisting/transferring capability of older style suspended floors (particularly tongue and groove floors) and ceiling linings
- Investigation of the damage development and repair procedures for older lining and cladding systems which, though no longer constructed or not popular, nevertheless may be found on significant numbers of the current housing stock. These will include:
  - lathe and plaster
  - board and scrim
  - traditional stucco

CONCLUSIONS

This paper has briefly outlined the preparation by BRANZ Ltd of an Earthquake Damage Assessment Catalogue for the Earthquake Commission to assist with the efficient assessment of house damage and repair strategies in the recovery phase following a major earthquake. A large part of the document has been put together based on experience and engineering judgment because of the lack of recent damaging earthquake activity in urban areas. The paper describes a series of experimental investigations to simulate earthquake damage and develop repair strategies, which have been fed back into updates of the EDAC.

The investigations have shown that often the damage is not obvious to the casual observer and careful interpretation of the evidence is required to develop a satisfactory repair strategy.

FUNDING ACKNOWLEDGEMENT

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REFERENCES

1. BRANZ. “Earthquake Damage Assessment Catalogue – Ver 1.3”. BRANZ, September 2003.
2. SANZ. “NZS 3604:1978 Code of practice for Light Timber Framed Buildings not requiring specific design”. Standards Association of New Zealand, Wellington, New Zealand.
3. SNZ. “NZS 3604:1999 Timber Framed Buildings”. Standards New Zealand, Wellington, New Zealand.
4. SANZ. “Specification for performance of windows”. Standards Association of New Zealand. Wellington, New Zealand.
5. Beattie, G.J. “Repair and Reinstatement of Earthquake Damaged Houses – Derivation of Repair Techniques”. Study Report No. 100(2001). BRANZ, Judgeford, Porirua City.
6. Beattie, G.J. “Repair and Reinstatement of Earthquake Damaged Houses – Derivation of Repair Techniques – Phase II”. Study Report No. 123(2003). BRANZ, Judgeford, Porirua City.