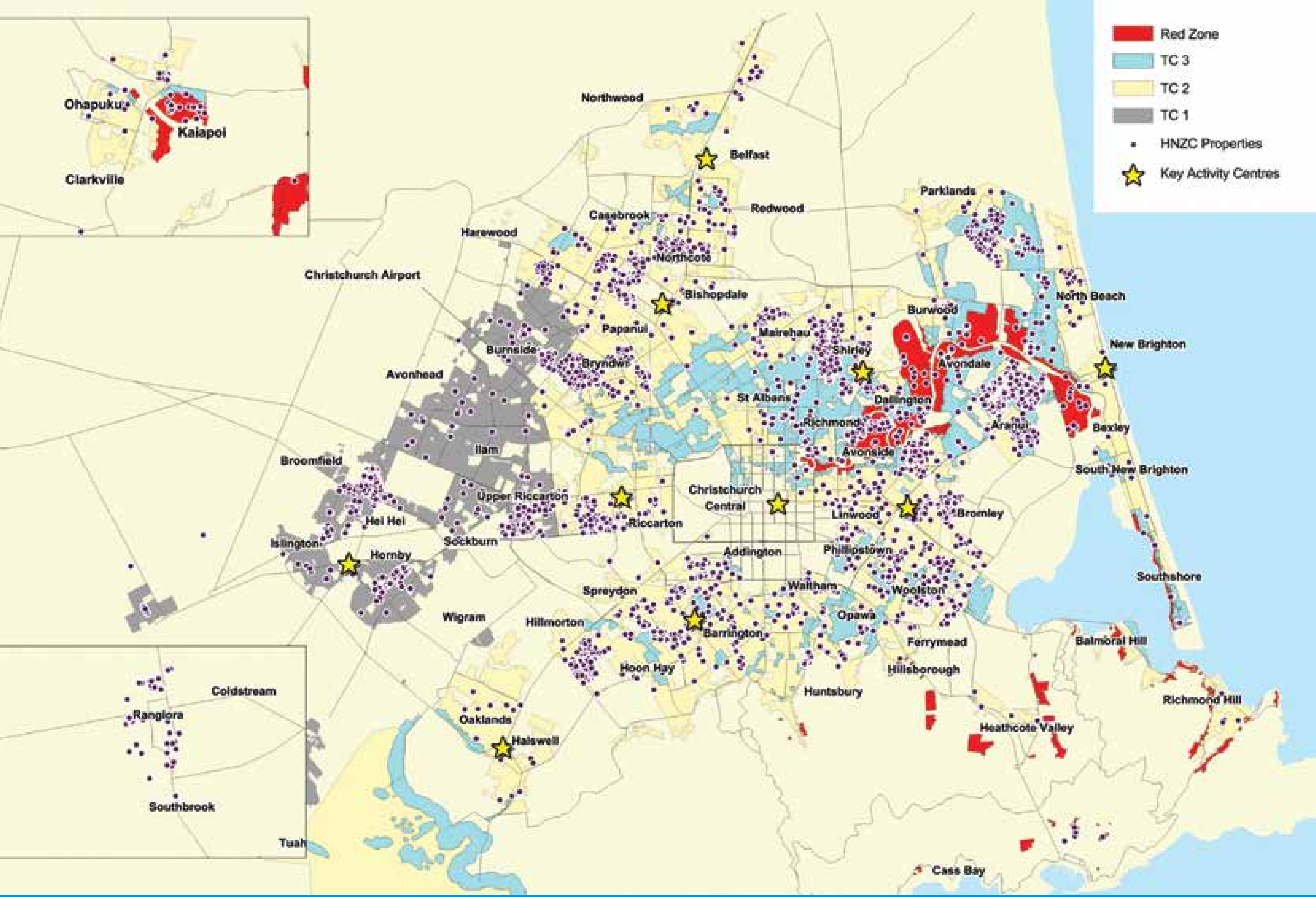





Housing New Zealand

Technical Report on the Results of Foundation Repair Trials
Conducted following the Canterbury Earthquakes



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Technical Report on the Results of Foundation Repair Trials Conducted following the Canterbury Earthquakes

Compiled by Housing New Zealand in partnership with
Southern Response Earthquake Services Ltd and Arrow International Ltd

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Publication disclaimer

The information contained within this publication is related specifically to the methodologies developed as a result of foundation repair trials conducted by Housing New Zealand and Southern Response following the Canterbury earthquakes 2010-2011.

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Contents

Foreword

The devastating earthquakes that struck Canterbury beginning on 4 September 2010 provided a unique opportunity for New Zealand engineers to develop new and innovative methods to repair damaged house foundations.

This technical report explains the process, the methods and the results that were trialled at 19 different houses in Christchurch owned by Housing New Zealand. The emphasis was on finding economic and viable solutions for either concrete perimeter foundations with timber floors or concrete floor slab foundations.

Geotechnical and structural engineers were engaged to conduct the trials and to identify the different house types required as well as the different land categories. Housing New Zealand worked with the Ministry of Business, Innovation and Employment's Engineering Advisory Group, the Building Research Association of New Zealand (BRANZ), Southern Response, Arrow International, Canterbury local authorities and different relevelling companies to produce a detailed and exact set of results based on specific site trials.

This work is an essential component of the ongoing earthquake recovery programme. Insurers and home owners now have detailed options to consider when assessing individual properties. Importantly, the results have added value to the wider community not only in New Zealand but in other countries where damaged house foundations can be assessed as to whether they are able to be repaired for an equitable cost or replaced.

The report has been peer reviewed by BRANZ giving it the technical endorsement it requires to be used as part of MBIE's building and construction guidelines.

I congratulate Housing New Zealand, its partners and its team of experts that have worked solidly to produce a resource that will have value in the construction, engineering, insurance and tertiary education sectors as well as providing insights for the home owner into the potential for individual properties.

Hon Dr Nick Smith
Minister of Housing

Introduction

This technical report documents in detail the development, implementation and results of house foundation repair trials on TC2 and TC3 land that were initiated by Housing New Zealand in Christchurch during 2013 as part of the government's earthquake recovery programme.

On 4 September 2010, a magnitude 7.1 earthquake struck the region of Canterbury, New Zealand. It was a violent shake that pre-empted a series of disastrous earthquakes in December 2010, February, April, June and December 2011. By far the worst was the 22 February earthquake that resulted in 186 lives lost and the collapse of many buildings in the city's central business district as well as damage to individual properties throughout the city and the region.

Liquefaction became a major problem for thousands of home owners particularly in the September and February earthquakes and especially in the eastern suburbs and in Kaiapoi.

A national civil defence emergency was announced immediately after the 22 February 2011 earthquake which wasn't lifted until April that year with the establishment of the Canterbury Earthquake Recovery Authority (CERA). The CER Act (2011) created extraordinary powers to the Minister for Earthquake Recovery in order to guide, support and coordinate Canterbury's recovery.

In May 2012, CERA published the Government's Recovery Strategy (He aha te Mahere Haumanutanga). It comprised six components of recovery:

- Leadership and integration
- Economic recovery
- Social recovery
- Cultural recovery
- Built environment
- Natural environment

In developing Housing New Zealand's recovery strategy, the organisation aligned its own principles with the components that were especially relevant to its mission and vision – to ensure that those in greatest need have access to a state house for the duration of that need.

Defining that need in the wake of the earthquakes' devastation resulting in damage to 95 per cent of Housing New Zealand's 6127 properties in Canterbury was a major challenge. More than 600 tenanted families were moved into safer accommodation at the time. More than 27,000 urgent health and safety emergency repairs were carried out on Housing New Zealand's properties. Critically, in June 2011, with the announcement of the new land zones, 215 of the organisation's properties were red-zoned, 27 of which were in Kaiapoi, the balance in Christchurch. A further 350 houses were damaged beyond repair.

Together with Southern Response, a Government-owned company established to resolve outstanding earthquake claims from residents who were insured with AMI, and Arrow International, Housing New Zealand determined to explore the feasibility of repairing house foundations that had earthquake damage.

There was no single 'off the shelf' manual available to demonstrate how any of the technical and building challenges could be tackled. The Ministry for Business, Innovation and Employment (MBIE)'s Department of Building and Housing published the first version of

[1] Liquefaction is a phenomenon whereby a saturated or partly saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking, causing it to behave like a liquid. The phenomenon is most often observed in saturated loose sandy soils, hence the volume of liquefaction in the eastern suburbs of the city.

[2] Housing New Zealand Annual Report 2011-2012 Impact Statement 1 pg 13.

[3] Southern Response Earthquake Services Ltd is the government-owned company responsible for settling claims by AMI policyholders for Canterbury earthquake damage which occurred before 5 April 2012 (the date AMI's day to day insurance business was sold to IAG). (source: SR website).

the Earthquake Repairs Guidance Document in December 2010. While this was an excellent engineering reference it did not cover the difficult land zones known later as Technical Category 3 (TC3) until the publication of Appendix C in November 2011. This new combined manual became the founding engineering guidance document to assist engineers, property owners and contractors to determine repair and rebuild methodologies.

The biggest challenge for most parties was the lack of practical knowledge to apply to the theoretical engineering principles as described in the new manual.

A partnership was established between Housing New Zealand and Southern Response in collaboration with the MBIE's Engineering Advisory Group, and the Building Research Association of New Zealand (BRANZ), working with identified geotechnical and structural engineers to develop a plan. The project management and research was funded jointly between Housing New Zealand and Southern Response Earthquake Services (SRES). The construction work and engineering design was funded by Housing New Zealand in addition to the provision of the identified properties for undertaking the trials. Christchurch, Waimakariri and Selwyn local authorities agreed to act as observers.

The basis of the plan was to determine the options for damaged homes on TC2 and TC3 land with an emphasis on finding economic and viable solutions for houses that had concrete perimeter foundations with timber floor (Type B) and concrete floor slab foundations (Type C). Different house types needed to be identified as well as the different land categories and as much as possible, the houses needed to be in different suburbs although it was obvious that most of the trials would be conducted in the east of the city.

In November 2012, Housing New Zealand identified 32 properties for the first site selection in Aranui, Avondale, Bishopdale, Bryndwr, Parklands, South New Brighton, New Brighton, North New Brighton, Burwood, Mairehau, Dallington and Lyttelton. The initial assessment criteria was based on:

- Geographical location
- Liquefaction on site
- Varying floor and foundation levels from 42mm to 208mm differential
- Floor slope over 1/200 or 0.5%
- Amount of damage to the foundation as well as the exterior cladding

From the initial assessment, 20 sites were eventually selected for further analysis of which five dwellings were on four TC2 sites and 15 dwellings were on 11 TC3 sites.

Detailed engineering analysis followed with 19 sites eventually being confirmed.

The trials themselves were conducted over seven months finishing in November 2013. From the trials, five specific repair methodologies have evolved which are documented in detail in this Technical Report.

The selection of contractors was from an approved list based on their recognised skill sets and experience for the different methodologies selected for them. The contractors' commitment to the trial programme was to provide an 'open book' policy on costs and individual intellectual property.

Each of the sites provided new challenges dealing with issues such as varying ground conditions, different construction methods and collateral challenges as a result of the applied methodology used.

The experience and support offered from the two principal structural engineering companies – Lewis Bradford and Powell Fenwick, and the advising geotechnical engineering company – Tonkin & Taylor, have been invaluable to this programme.

This Technical Report defines and explains the methodologies developed at each of the specific sites eventually identified as having the best potential outcomes. It is a reference document designed for use by the construction and engineering sectors, by students engaged in higher level learning about the technical impact of the earthquakes, for insurers to help in their understanding of what happened to houses and properties and for individual home and property owners to help them come to grips with the nuances of new and innovative engineering techniques. Ultimately, it is a report in its time which not only makes a substantial contribution to overall understanding of the options available, but which can act as a useful tool in the study of earthquake impacts and outcomes on homes and on land.

Methodology Colouring - Refer to pages 178 - 191 for details.

- Methodology 1
- Methodology 1a
- Methodology 2
- Methodology 3
- Methodology 3a
- Methodology 4
- Methodology 5
- No Methodology

1/41 A & B Reginald Street, Burwood

Property Details

Land Zone	TC3
Year	1989
Floor Area	100 sqm
Land Area	835 sqm
Foundation Type	C
Roofing Type	Concrete Tile
Cladding Type	Summerhill Stone
Floor Level Difference	88mm

Summary

This property sits on TC3 zoned land and was constructed in 1989 as a double unit with attached single garages between both units. The construction was a Type C foundation, timber framed walls with a Summerhill Stone masonry veneer and heavy weight concrete tile roof.

As a result of the earthquakes, the dwelling suffered vertical differential settlement up to 88mm with significant liquefaction ejecta over the front and rear yards.

The foundation performed well during the earthquakes with no visual cracks to the slab or foundation perimeter beam. Some minor staggered cracking occurred on the masonry veneer.

The methodology chosen for the repair of this dwelling was an Engineered Resin Lift.

The engineered resin was injected below the slab perimeter beam at 1m intervals and 1.5m centres around the perimeter of the building. The foundation beam could then be lifted by injecting more resin below the footing.

The concrete slab was lifted by injecting a weaker resin than had been used under the footing. This provided for a more controlled lift. During the lifting process care was taken to monitor the rate of resin injection to the rate of foundation lift required.

The construction of Type C foundations prior to the 1990s was such that there was no mandatory requirement to tie the perimeter beam to the concrete floor slab with reinforcing steel. This factor was not considered relevant until the engineered resin lift methodology was used for this dwelling.

The resulting implications were that when the resin was injected simultaneously around the perimeter and under the concrete floor slab, the slab lifted away from the perimeter beam. The concrete floor slab was supporting the timber framing and roof loads, whilst the perimeter beam was supporting the exterior masonry veneer cladding. It was discovered that the cavity had been infiltrated in the end wall as the result of the resin passing between the bottom of the slab and the top of the foundation perimeter beam. The foundation separation caused the brick ties to loosen significantly which rendered the end wall brick veneer unsafe and requiring replacement. This incident provided a better understanding of changes to the methodology when any form of Type C foundation lifting is contemplated.

When considering relevelling a Type C foundation, it is important to be aware that buildings constructed before 1990 were not required to have structural ties between the perimeter beam and the concrete slab. As a consequence care should be taken to minimise the risk of separation between the two. The slab could be tied to the beam by drilling and epoxing steel pins between the two, prior to any attempt to lift if this method was used.

The foundation lift for this dwelling was successful.

Construction

- Two, two bedroom units, each with attached single garage and concrete block inter-tenancy wall between the garages
- Type C2 foundation with heavy weight Summerhill Stone masonry veneer and concrete roof tiles.

Damage

- Significant signs of liquefaction ejection on site
- General condition of concrete floor slab good with no visible cracking
- Differential floor settlement of 88mm over entire length of both units
- Minor staggered cracking of mortar on masonry veneer in localised areas.

Image 1: Liquefaction ejecta potentially entered weep holes in veneer around perimeter

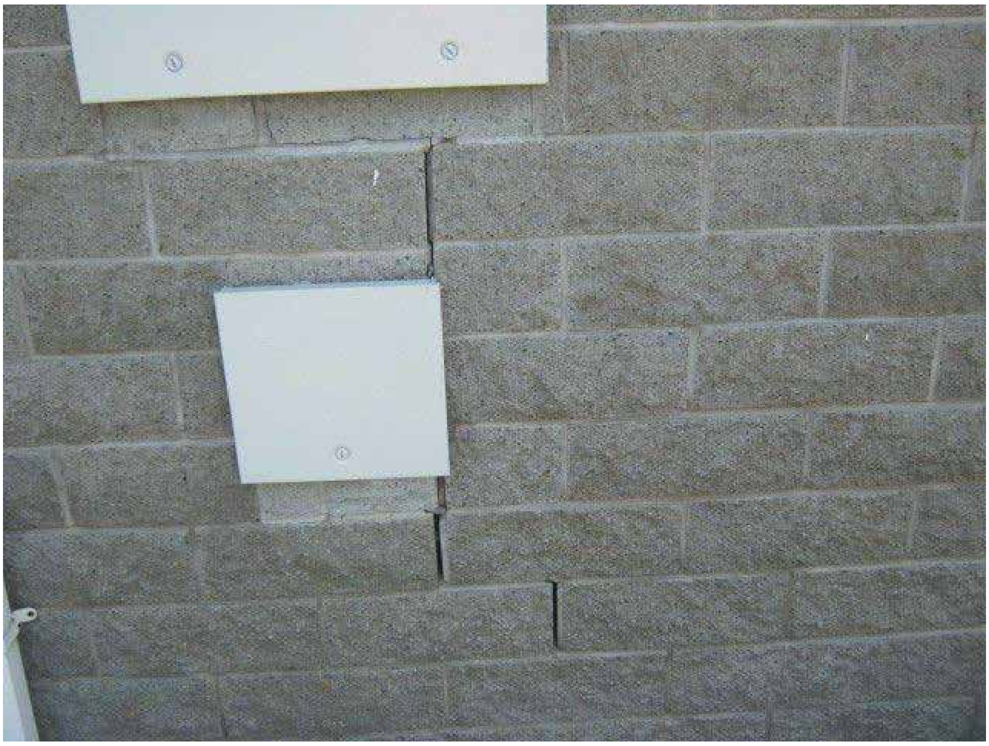


Image 2: Lateral spread of Summerhill Stone veneer cladding

Image 3: Step cracks in mortar

Image 4: Lateral spread of hard surfaces

Image 5: Significant liquefaction ejection over half the site

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Golder Associates referenced report for detailed information.

1: Summary of post-liquefaction vertical settlement

Design Event		Depth Range	Vertical Settlement
SLS	M7.5 PGA 0.13g	0 to 10 m	30 mm
		0 to 20.0 m	60 mm
ULS	M7.5 PGA 0.35g	0 to 10 m	140 mm
		0 to 20.0 m	210 mm

Notes: This assessment is based on the Golder CPT investigation only. A groundwater level of 1.5m below ground level has been used for this assessment.

2: Geotechnical Assessment Summary

The assessment indicates that the site falls within the following index categories defined by December 2012 MBIE Guidance, Part C:

• Vertical land settlement is Minor to Moderate (see Table 12.5)
• Global lateral displacement is Major (see Table 12.1)
• Lateral stretch is Minor to Moderate (see Table 12.4).

3: Summary of Soil Stratigraphy

Soil Stratigraphy	Density / Consistency	Location						
		CPT1	CPT2	CPT3	HA1	HA3	HA6	HA8
		Depth to base of stratum (m bgl)						
Silty SAND / Sandy SILT	Medium Dense	0.9	0.5	0.5	0.5	0.3	3.0 (EOH)	0.5
SAND / Silty SAND	Medium Dense – Dense	1.5	1.7	0.8	2.0	1.2	-	3.0*
Silty SAND / Sandy SILT/CLAY	Very Loose / Soft	4.3	3.7	4.2	3.0*	3.0*	-	-
SAND/Silty SAND	Loose – Medium Dense	6.7	11.0	7.0	-	-	-	-
CLAY / Clayey SILT/Silty CLAY	Soft	6.9	11.5	7.7	-	-	-	-
SAND / Silty SAND	Medium Dense – Very Dense	12.5	12.6	13.0	-	-	-	-
CLAY / Clayey SILT / Silty CLAY	Soft	13	13	13.1	-	-	-	-
SAND / Silty SAND	Medium Dense – Very Dense	19.7*	19.6*	20*	-	-	-	-

Notes: *Depth of termination.

Reference: Golder Associates Report No. 1178102318-001-R-Rev0-005-41Reginald

Repair Options

- Engineered Resin Lift. Roofing and cladding to remain (see Methodology 4)
- Mechanical Lift - Screw Pile and void filling under slab. Roofing and cladding to remain (see Methodology 2).

Chosen Repair Option

From a geotechnical point of view both foundation levelling options could be applied. The following factor led to the decision to use the Engineered Resin Lift methodology:

- Since an identical double unit property on adjacent land was also in the repair trial programme a decision was made to trial both methodologies. The adjacent property would use the Screw Pile methodology.

Summary of Engineered Resin Lift Process

- Established existing floor levels and external datum points for reference
- Prepared site and inserted injection rods around perimeter of foundation for resin lift of perimeter foundation beam
- Drilled 16mm holes in concrete slab in a grid pattern to accommodate injection rods for resin lift of concrete slab
- Incrementally injected resin around the perimeter of the foundation and monitored the change of levels to the perimeter beam
- Injected the internal floor slab in a grid pattern to allow even dispersment of the resin in the void under the slab. Closely monitored the change of floor levels
- Repointed cracks in masonry veneer and rebuilt end wall veneer.

Points of Interest

- Speed of repair process
- Additional injection material used due to underlying silty sands and the heavy weight roof and wall cladding
- Identification that there was no tie between the foundation perimeter beam and the concrete slab. The consequence was the slab lifted off the perimeter beam which meant a gap opened between the top course of the masonry veneer and the soffit line. This occurred at one end of the units
- The removal of the masonry veneer was required to remove the resin that had infiltrated the cavity
- Slab relevelled to final variation of 22mm over floor plan.

Time Frame

Four weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$5,325
Foundation		$96,690
Cladding	$1,488	
TOTAL	$1,488	$102,015

Foundation lineal metres	69.4Lm	
Foundation repair costs	$102,015	$1,470/Lm
Floor area / Foundation repair costs	196m²	$520/m²
New Build market price / m² (see Appendix 1 Cost Calculator)	Type C2 construction with Surface Structure Relevellable slab	$1,738/m²
Foundation repair costs / New build costs	$520 / $1,738	29.92%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

Image 6: Resin injection tubes inserted at specified centres

Image 7: Resin injected to return dwelling to level

Image 8: Resin injection lifted and filled voids under internal floor slab

Image 9: Injection points sealed to retain damp proof slab

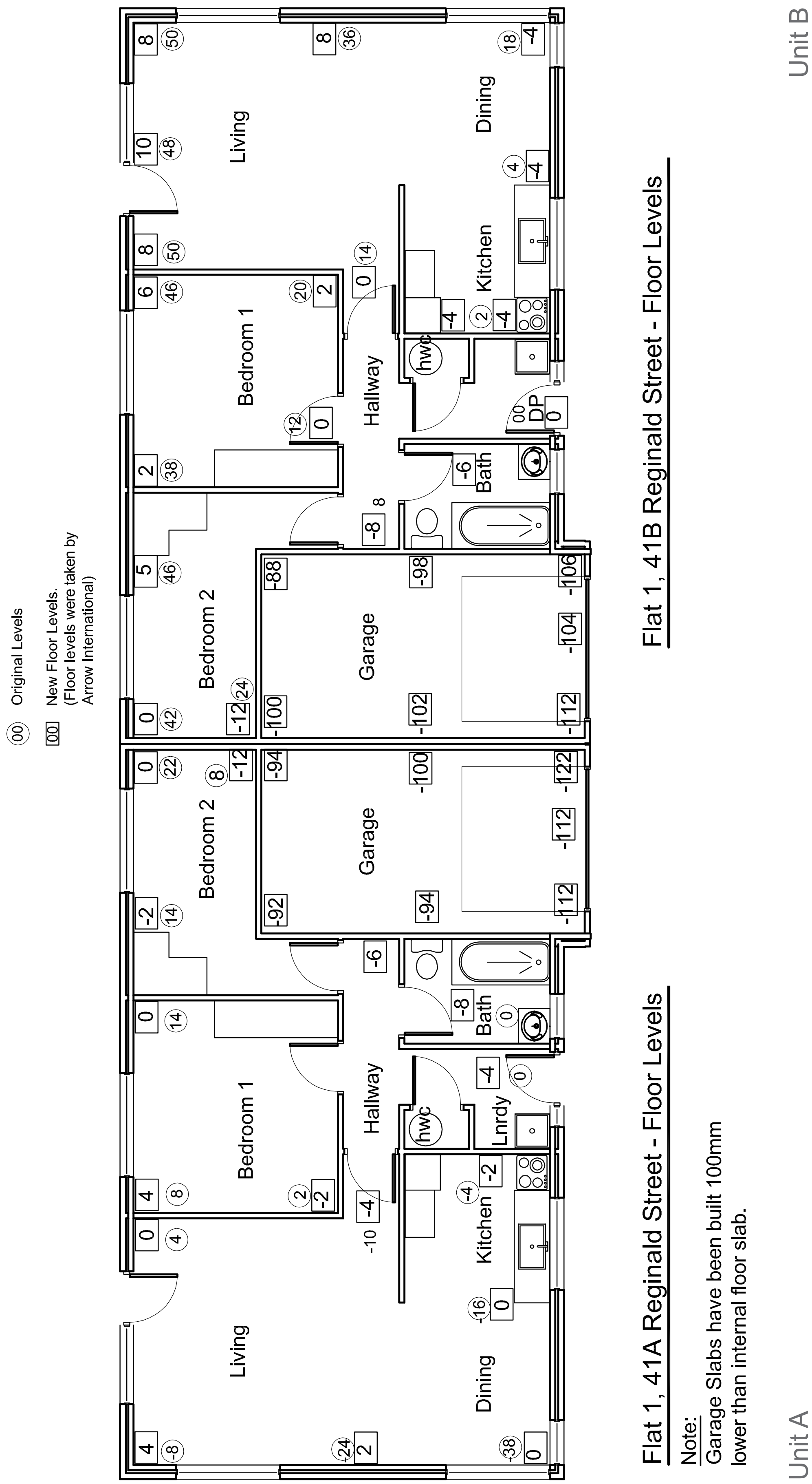
Image 10: Tapered gap between top of masonry veneer and soffit due to no structural connection between floor slab and foundation perimeter beam

Image 11: Gap between sill block and window frame indicates separation between floor slab and foundation perimeter beam

Image 12: Resin intrusion into cavity

Image 13: Affected area reclad

Floor Plan Showing Floor Levels



2/41 A & B Reginald Street, Burwood

Property Details

Land Zone	TC3
Year	1989
Floor Area	100 sqm
Land Area	835 sqm
Foundation Type	C
Roofing Type	Concrete Tile
Cladding Type	Summerhill Stone
Floor Level Difference	144mm

Summary

Built in 1989, the property sits on TC3 zoned land. This dwelling consists of a double unit with attached single garages between both units. The units had a Type C concrete floor slab foundation, timber framed walls with a Summerhill Stone masonry veneer and heavy weight concrete tile roof.

The units performed relatively well in the earthquakes considering the amount of vertical settlement, showing little interior damage and minor exterior veneer damage.

The methodology chosen for the repair of this dwelling was Mechanical Lift Screw Pile.

The site offered good clearance around the perimeter of the dwelling to allow for machinery to manoeuvre and clear out any paths, trees and fences that would be in the way of screw pile installation. A bobcat was required to install the screw piles so good access was paramount.

Engineering specifications indicated that the screw piles needed to be installed to a depth of 4m to achieve minimum bearing capacity for lifting the foundation, veneer and roof. Due to the nature of the foundation trial, it was accepted that screw piles would be drilled until a torque resistance was achieved that the engineer felt would be adequate for lifting the foundation. This torque resistance was achieved at a depth of 1.2m.

The screw piles were positioned at 2.0m spacings around the perimeter of the foundation and at locations along the concrete block masonry inter-tenancy wall between the garages. Once the screw piles were in place they provided a temporary bearing point from which to jack the foundation. Custom-made brackets were bolted to the side of the foundation to provide the lifting points.

Core holes of 35mm in diameter were drilled through the slab in a grid pattern for injection ports for void filling under the slab.

As the perimeter foundation was lifted off the screw piles in increments of 5mm at a time, the void that was created beneath the internal slab was filled with cementitious grout.

During the relevelling process, it became evident that the slab was not lifting at the same rate as the foundation. This caused a dish in the slab and separation between the slab and the bottom plates of internal walls. Extra internal jacking points were required to bring the slab back into contact with the bottom plates. Core holes of 100mm in diameter were drilled through the slab to provide access for internal lifting points. The dish in the slab was relevelled by lifting it at these internal jacking points. These internal lifting points had a steel plate fixed to the concrete slab with a threaded rod protruding to a pre-poured concrete jacking pad directly under the 100mm access hole. Jacking was achieved by using the threaded rod action fixed to the concrete slab. The wall bottom plates had originally been fixed only with concrete nails. Some refixing of the bottom plate was required.

Bedrooms 1 and 2 and hallway of Unit A would not lift to the desired level despite the additional jacking points. Although the reason for this is not conclusive, it is likely that this was due to this area possibly being connected to the ground by an underpinning pad, or slab thickening with piles. It was decided that the variations in level were unnoticeable to the eye and no further works were needed.

Final levels were taken and approved and with jacks still in place. The perimeter foundation was ready for void filling. A 20MPa concrete mix was pumped into the space below the footing around the perimeter and under the party wall. The void fill was given three days curing time before the jacks, brackets and screw piles were removed. Once the jacks were removed it became evident that part of the foundation needed repairing at a location where a lifting point was too close to the corner.

The methodology used to repair these major cracks was to pour an extended footing under and out from the existing footing in the void space left once the slab had been lifted. D12 bars were epoxyed into the existing footing and tied to the extended footing reinforcing.

This property demonstrated challenges because of the unknown foundation and slab construction methods used. Despite this the dwellings were successfully relevelled to within the MBIE Guidance parameters.

Construction

- Two, two bedroom units, each with attached single garage and concrete block inter-tenancy wall between the garages
- Type C foundation with heavy weight Summerhill Stone masonry veneer and concrete roof tiles.

Damage

- Foundation had settled 144mm. The worst area was across the centre rear of the combined units
- Lateral spread of veneer claddings
- No cracks to concrete slab
- Minor cracks in concrete foundation
- Liquefaction ejecta in garages and around perimeter.

Image 1: Spreading of weatherboard cladding in the garage where foundation pulled in opposite directions

Image 2: Lateral spread of Summerhill Stone cladding caused by slippage on the foundation

Image 3: Vertical cracks in veneer

Image 4: Step cracking in mortar

Geotechnical Summary

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Notes: *Depth of termination.

Reference: Golder Associates Report No. 1178102318-001-R-Rev0-005-41Reginald

Repair Options

- Relevel using Engineered Resin Lift (see Methodology 4)
- Mechanical Lift and void fill under footing and slab (see Methodology 3).

Chosen Repair Option

Mechanical Lift was chosen. From a geotechnical point of view both foundation levelling options could be applied. The option to use the mechanical lift methodology was chosen considering an identical double unit property on the adjacent property was also in the repair trial programme and the Engineered Resin Lift methodology was used for that property.

Summary of Mechanical Lift - Screw Pile

- Excavated jacking points around perimeter of foundation
- Installed screw piles, lifting brackets and jacks
- Drilled internal core holes in concrete slab for lifting points and void fill injection ports
- Lifted perimeter foundation beam and concrete floor slab simultaneously
- Void filled under foundation and slab once desired height was achieved
- Removed jacks and brackets
- Back filled excavations.

Points of Interest

- The foundation perimeter beam of Unit B contained existing concrete underpins that were positioned at approximately 2m centres. These needed to be disconnected from the perimeter beam to allow the lift to proceed
- Localised areas of the slab were not able to be lifted. The reasoning could have been previous underpinning, slab thickening and/or mechanically connected piles under slab thickening
- Garage slab was independent and not connected to house slab. Thickness was inconsistent, ranging from 100mm to 30mm across the full depth of the garage
- Foundation needed moderate repairs due to damage caused at a lifting point which was located too close to the corner
- Completed floor level variation 144mm (not including garage floors).

Time Frame

Eight weeks from start on site to completion and handover. Included in this time was an additional two weeks of work required to disconnect the existing and unexpected underpinning pads under Unit B.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$6,269
Foundation		$60,481
TOTAL		$66,750

Foundation lineal metres	64Lm	
Foundation repair costs	$66,750	$1,042/Lm
Floor area / Foundation repair costs	175m²	$381/m²
New Build market price / m² (see Appendix 1 Cost Calculator)	Type C2 construction with Surface Structure Relevellable slab	$1,738/m²
Foundation repair costs / New build costs	$381 / $1,738	21.92%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Image 5: Jacking points excavated at centres determined by structural engineer

Image 6: Screw piles installed at depths determined by geotechnical ground conditions

Image 7: Lifting brackets and jacks installed for foundation lift

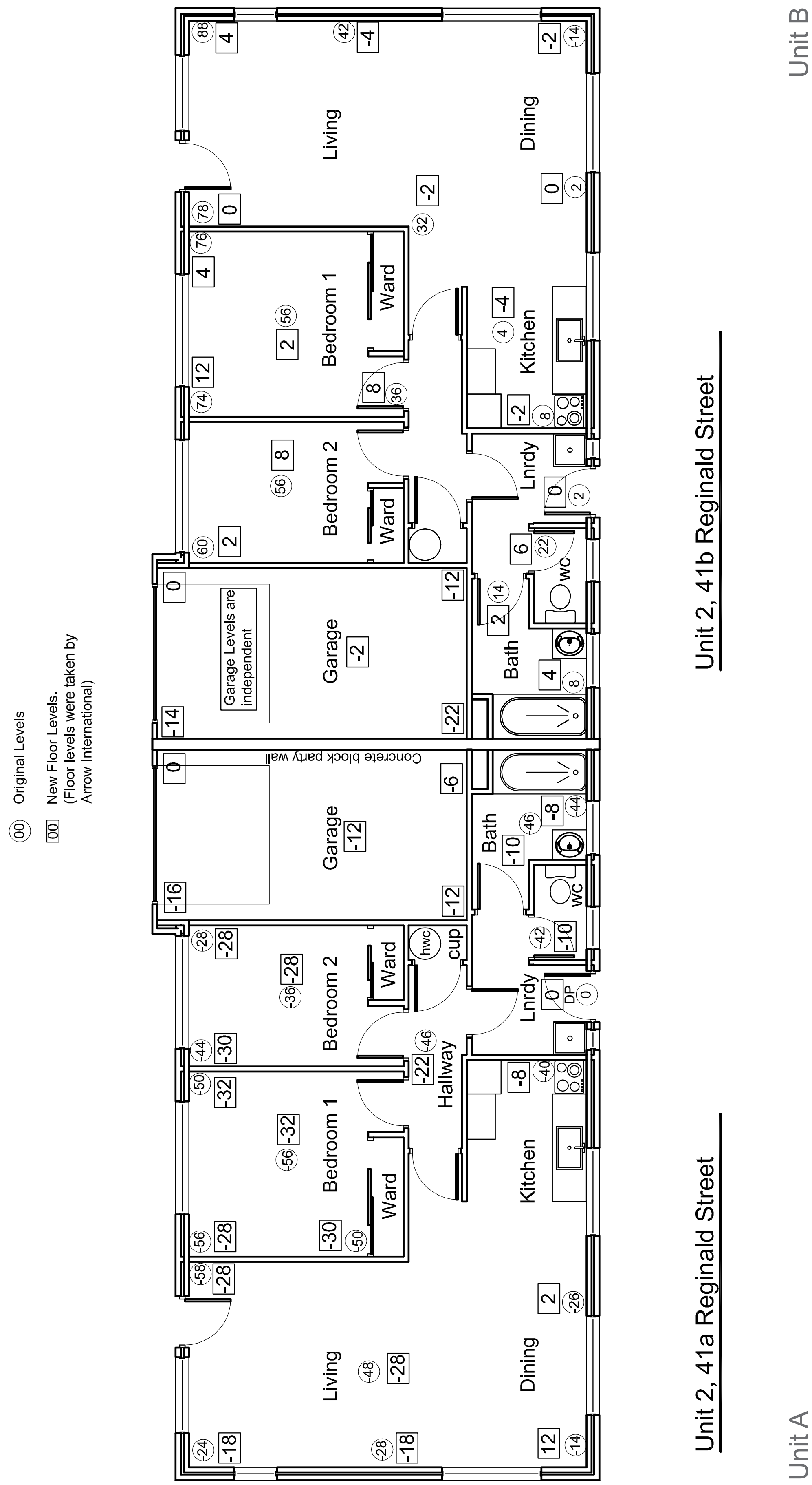
Image 8: Internal core holes drilled in slab for void fill injection points and internal mechanical lifting points

Image 9: Void fill under perimeter foundation beam and beneath concrete slab. New and existing cracks in foundation repaired with epoxy compound injection

Image 10: Separation between slab and bottom plate was rectified by mechanically lifting centre of slab at several points. The slab then had the void filled

Image 11: Damage to foundation beam caused by bracket being installed too close to the corner. Foundation repairs were necessary to remedy

Floor Plan Showing Floor Levels



1/126 Avondale Road, Avondale

Property Details

Land Zone	TC3
Year	1975
Floor Area	80 sqm
Land Area	655 sqm
Foundation Type	C
Roofing Type	Light weight pressed metal tiles
Cladding Type	Summerhill Stone
Floor Level Difference	168mm

Summary

This 80sqm property built in 1975, sits on TC3 zoned land. It was built using a Summerhill Stone veneer and light weight pressed metal roofing tiles.

After the earthquakes the concrete slab was out of level by up to 168mm over the length of the house from the bedrooms to the living room. While this amount of differential settlement was greater than that recommended in the December 2012 MBIE Guidance for relevelling, the slab was in good enough condition for it to be considered relevellable.

The original scope was to relevel the building then replace the brick veneer. The Mechanical Lift methodology was chosen for the relevel due to the good condition of the foundation, the poor ground conditions and the potential for the veneer to be left in place.

The front patio and rear steps were removed to allow access to the foundation.

Jacking points were excavated at each corner of the dwelling and at 2m maximum centres in between the corners of the building. Specific engineering designed (SED) jacking pads (1.2 x 1.2 x 0.5m) were constructed immediately below the base of the footing. Each of the jacking pads had pockets created to accommodate the hydraulic bottle jacks.

Core holes of 100mm diameter were drilled through the internal slab for void fill access and 350mm diameter holes were also drilled at internal jacking point locations. Care was taken not to compromise the damp proof membrane (DPM) by taping it to the sides of the holes. This would allow it to be re-established after relevelling (see Image 10,1/126 Avondale Road). The footing and slab were lifted simultaneously using bottle jacks under the footing and an internal lifting system to support and raise the slab. All this was carried out with the existing veneer in place.

The void filling used beneath the footing was standard 20MPa concrete that was poured 100mm wider and 100mm higher than the base of the foundation. This provided greater bearing for the existing footing.

Minor cracks in the foundation that appeared during the lifting process were repaired using epoxy resin.

Once the house was relevelled it became evident that the brick veneer had retained its structural integrity with all gaps closing up, therefore a reclad was not necessary. Cracks in the mortar were ground out and repointed. The repaired brick veneer was completely repainted and the foundation was replastered to cover the epoxy repaired cracks.

The floor level variation was 12mm at the completion of the job.

Property Construction and Damage

Construction

• Type C foundation. Concrete slab on grade
• Summerhill Stone veneer cladding
• Light weight pressed metal roofing tiles.

Damage

• Minor to moderate brick veneer damage. Vertical and step cracking
• Minor foundation damage. Cracks <3mm
• Bottom plate had disconnected from concrete slab between kitchen and lounge
• No cracks in concrete slab
• No damage to roof.

Image 1: Moderate brick veneer damage

Image 2: Bond failure of the mortar allowing separation of brick courses under differential settlement of the foundation beneath

Image 3: Step cracking from openings caused by differential settlement of the foundation

Image 4: Cracks at joints between plasterboard sheets from the corner of the opening

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Golder Associates referenced report for detailed information.

1: Summary of post-liquefaction vertical settlement

Design Event		Depth Range	Vertical Settlement
SLS	M7.5 PGA 0.13g	0 to 10 m	100 mm
		0 to 20 m	130 mm
ULS	M7.5 PGA 0.35g	0 to 10 m	210 mm
		0 to 20 m	330 mm

Notes: This assessment is based on the EQC CPT investigation only. A groundwater level of 1.0 m below ground level has been used for this assessment.

2: Geotechnical Assessment Summary

The assessment indicates that the site falls within the following index categories defined the December 2012 MBIE Guidance, Part C:

- Vertical land settlement is Potentially Significant (see Table 12.5)
- Global lateral displacement is Major (see Table 12.1)
- Lateral stretch is Minor to Moderate (see Table 12.4).

3: Summary of Soil Stratigraphy

Soil Stratigraphy	Density / Consistency	Location							
		CPT-6276	CPT-5189	CPT-4397	CPT-69	HA1	HA2	HA3	BH-8649
		Depth to base of stratum (m bgl)							
FILL	-	NE**	NE	NE	NE	NE	NE	NE	0.3
TOPSOIL	Stiff	NE	NE	NE	NE	0.20	0.20	0.40	NE
SILT	Firm	NE	NE	NE	NE	1.10	0.8	1.20	NE
Silty fine SAND	Loose to medium dense	NE	NE	NE	NE	1.30	2.10	2.80*	NE
Fine SAND	Medium dense	NE	NE	NE	NE	2.00	2.60	NE	NE
Fine to medium SAND with layers of sandy silt	Loose to medium dense	NE	NE	3.0	6.5	3.00*	NE	NE	9.0
Fine sandy SILT	Soft	3.0	9.0	7.0	10.0	-	2.90*	-	10.0
Fine to medium SAND	Very loose to dense	NE	20.0*	20.0*	NE	-	-	-	20.0*
SAND with interlayers of sandy SILT	Medium dense	17.0*	-	-	31.5*	-	-	-	-

Notes: *Depth of termination **NE – Not Encountered

Reference: Golder Associates Report No. 1178102318-001-R-Rev0-005-126 Avondale.

Chosen Repair Option

The lateral stretch and global lateral displacements were not determined to be a problem for this foundation. The predicted SLS settlement was on the border between either conducting a relevel and repair or a complete foundation rebuild. It was decided to follow the relevel and repair approach.

In this instance there was only one viable option for the repair of the foundation. The following factors led to the decision to use a Mechanical Lift Off Jacking Pads methodology (see Methodology 3):

- 168mm differential vertical floor settlement
- Foundation in good condition with minor cracks
- Ground conditions were poor. Mechanical lift offered opportunity to underpin footings to increase bearing of foundation.

Summary of Mechanical Lift Process

- Removed patio, concrete paths and steps for access to ring foundation
- Excavated and poured jacking pads under the foundation as per engineer's specifications
- Core drilled internal lifting points and void fill injection ports
- Relevelled foundation and slab simultaneously
- Void filled footings and under the slab once desired height was achieved
- Back filled excavations and sealed off internal core holes
- Reinstalled patio.

Points of Interest

- Once the building was relevelled, it was decided that the veneer did not need replacing as any gaps and cracks had closed up. A simple repair and repaint of the veneer was required
- External and internal lifting points are able to be reused quickly and efficiently if needed after another event
- Void fill product is a low MPa (1-3MPa) light weight, high flowing concrete that contains polystyrene for insulation.

Time Frame

Six weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		Included in cost
Foundation		$44,750
Cladding	$24,675	
TOTAL	$24,675	$44,750

Foundation lineal metres	37Lm	
Foundation repair costs	$44,750	$1,209/Lm
Floor area / Foundation repair costs	$80m^2$	$559/m^2$
New Build market price / m^2 (see Appendix 1 Cost Calculator)	Type C2 construction with Surface Structure Type 2B	$1,955/m^2$
Foundation repair costs / New build costs	$559 / $1,955	28.59%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

Image 5: Excavated jacking points as per engineer's specifications

Image 6: Concrete jacking pads poured and polystyrene inserted for reusable jacking voids

Image 7: Jacked and supported foundation

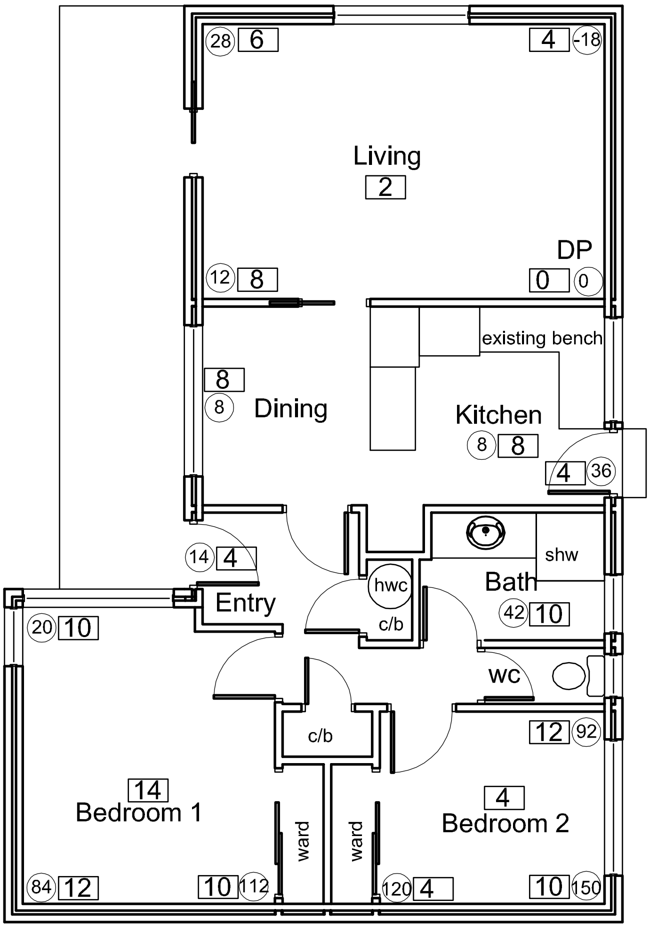
Image 8: Concrete slab lifted at same time as foundation. Void fill poured


Image 9: Vertical cracks in plasterboard closed up after foundation relevel


Image 10: DPM reinstated and concrete slab core holes sealed

Image 11: Mortar repointed and patios being reinstated

Floor Plan Showing Floor Levels



(00) Original Levels

[00] New Floor Levels.
(Floor levels were taken by Arrow International)

125 Aldershot Street, Aranui

Property Details

Land Zone	TC2
Year	1961
Floor Area	100 sqm
Land Area	685 sqm
Foundation Type	B
Roofing Type	Concrete Tile
Cladding Type	Brick
Floor Level Difference	74mm

Summary

This property built in 1961 sits within the TC2 land category. Construction is concrete perimeter beam with a suspended timber floor (Type B), timber frame walls and roof with masonry veneer and heavy weight tile roofing. Considering the weight of the cladding, the house performed well during the earthquakes, sustaining minimal damage to the perimeter foundation beam. This building displayed the consistent performance expected of the design and building practice applied in a house of this era.

Due to this performance, it was not deemed necessary to reduce the weight of the cladding and roof. However, one third of the brick veneer had vertical cracks and horizontal displacement so replacement of the cladding was required and a 70mm series brick was chosen as a lighter solution. The advantage of using this brick was that the existing timber windows did not require adjusting to suit the cavity. It did, however, mean the face of the new brickwork sat inside the existing foundation line.

The Jack and Pack methodology was chosen for the levelling of the floor as this was a simple process of disconnecting the bearers from the piles and systematically jacking and packing between the piles and bearers to lift the floor plane, with some bearers notched to lower the floor plane. All pile packing was less than the MBIE guideline maximum of 100mm. All piles were precast concrete with a wire looped through a hole in the pile and fixed to the bearers. New wire connections were made to the adjusted piles.

As this house had no insulation, once the original cladding had been removed, it was an opportune time to insulate the perimeter walls and fit building wrap, with flashing tape around the windows.

Once the insulation was completed, the perimeter foundation beam was scabbled on the top face and boxed to suit the new brick height. This level was determined from the soffit down in modules of the brick height.

An ‘off the shelf’ cementitious grout was used as the topping compound. The maximum depth of the compound needed was 65mm. The front edge of the packing compound was angled from the face of the brick line to the old foundation line.

The new 70 series brick veneer was then built on top of the now levelled perimeter foundation beam.

The foundation was replastered to cover the new topping. This camouflaged the difference between the foundation line and the new brick line.

The soffit and foundations were repainted. By painting the soffit the difference in the new brick line was camouflaged (40mm less than the original brick line).

A new finished floor level variation was 10mm across the floor area.

This methodology was a successful, simple and easy repair solution for this property.

Construction

• Heavyweight brick veneer cladding with concrete tile roof.

Damage

• Foundation in good condition with no visible cracking
• Vertical settlement of 74mm
• Brick veneer damaged on three elevations with minor to major cracking and separation
• No damage to roof.

Image 1: 65mm vertical settlement at this corner

Image 2: Existing brick veneer. Horizontal displacement

Image 3: Veneer damage and movement on foundation

Image 4: Veneer damage

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Geoscience referenced report for detailed information.

1: Summary of Liquefaction Analyses

Design Case	Calculated Vertical Settlement*	
	Total	Upper 10 m
ULS	160 mm to 210 mm	80 mm to 140 mm
SLS	10 mm to 15 mm	< 10 mm

*For an undeveloped site. Settlements beneath buildings are likely to be greater.

2: Summary of Ground Performance Expectations*

Performance Category	Land Damage Type	Land Damage Category
SLS	Vertical Settlement (in upper 10 m)	TC3 Minor to Moderate
ULS	Lateral Stretch	TC3 Minor to Moderate
	Global Lateral Movement	TC3 Minor to Moderate

*As per Tables 12.1, 12.4 and 12.5 of the December 2012 MBIE Guidance, Part C.

3: Summary of Subsurface Conditions Encountered in Ground Investigations

Depth (m)	Soil / Behaviour Type*	Density / Consistency
0.0 TO 0.2	TOPSOIL	N/A
0.2 to 4.75	SAND and Silty SAND	Loose to Medium Dense
4.75 up to 11.75		Medium Dense to Dense
11.75 to 18.3		Medium Dense to Very Dense

*A thin (0.2 m thick) lense of Peat was encountered in hand auger borehole HA03 between 0.8 m to 1.0 m.

Geoscience ref: 9653.000.001 Ph 002 18 January 2013.

Repair Options

Two options were considered:

- Jack and Pack (see Methodology 1)
- Mechanical Lift of foundation with engineered resin (see Methodology 4).

Chosen Repair Option

From a geotechnical point of view the ground was TC2 so either of the above repair methods could be used.

The following factors led to the decision to use the Jack and Pack repair methodology:

- 74mm overall vertical floor settlement
- Foundation was in good condition with no structural damage or cracks
- A third of the brick veneer had vertical cracks and horizontal displacement
- The existing brick could not be matched. The veneer needed to be replaced
- Removing the veneer allowed the superstructure to be relevelled and a topping laid on the perimeter foundation beam allowed for a new lighter weight brick to align with the relevelled superstructure.

Summary of Jack and Pack Process

- Removed exterior brick veneer
- Disconnected bearers from piles
- Relevelled floor by jacking and packing, or notching piles
- Packed perimeter foundation beam with cementitious grout
- Laid new brick veneer cladding
- Replastered foundation and repainted.

Points of Interest

- Rerouted electrical cable from cavity into framing
- Existing veneer cavity varied in width. New cavity set at a consistent 40mm width
- Insulated exterior walls and fitted new wrap
- Subfloor ventilation was in the perimeter beam. To prevent moisture movement from the subfloor into the cavity and the roof space the new building wrap was sealed onto the top of the perimeter foundation beam.

Time Frame

Six weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$9,717
Foundation		$15,508
Cladding	$21,353	
Insulation and Wrap	$2,835	
Gutter and Downpipes	$4,329	
TOTAL	$28,517	$25,225

Foundation lineal metres	45Lm	
Foundation repair costs	$25,225	$561/Lm
Floor area / Foundation repair costs	100m²	$252/m²
New Build market price / m² (see Appendix 1 Cost Calculator)	Type B2 construction with Surface Structure Type 2A	$1,896/m²
Foundation repair costs / New build costs	$252 / $1,896	13.29%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Image 5: New bearer packed for superstructure relevelling (still to be wired down)

Image 6: Foundation formwork ready for topping. Insulation being installed

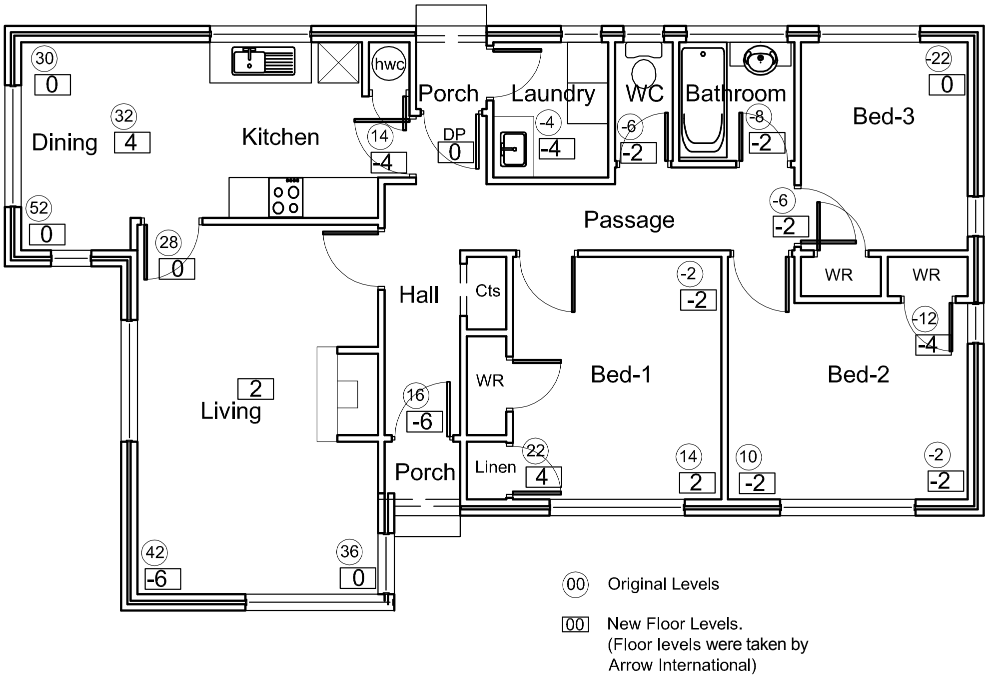
Image 7: Foundation scabbled and formwork ready for topping

Image 8: Insulation and wrap in place

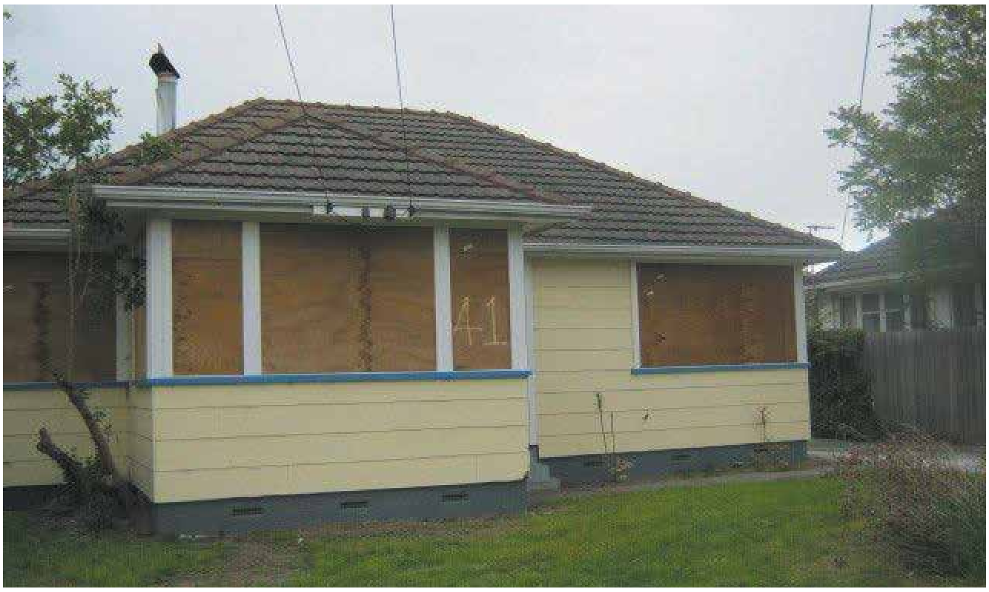
Image 9: Topping poured, flashing tape placed to seal cavity

Image 10: Repairs complete. New veneer cladding with replastered foundation

Floor Plan Showing Floor Levels



41 Aldershot Street, Aranui



Property Details

Land Zone	TC3
Year	1961
Floor Area	90 sqm
Land Area	650 sqm
Foundation Type	B
Roofing Type	Concrete Tile
Cladding Type	Asbestos Fibre Cement (aka Durock sidings)
Floor Level Difference	84mm

Summary

This dwelling sits on TC3 zoned land and was built in 1961. The construction is timber floor with asbestos fibre cement weatherside cladding (also known as Durock sidings), timber windows and heavy weight concrete tile roofing. After the earthquakes the foundation settlement was approximately 84mm in total. The floor levels in the living and sunroom areas were consistent, with minor variation of levels. Bedroom 2 was the one single room that showed the most vertical settlement.

The foundation was in good structural condition with no visible cracks and did not warrant a mechanical lift. The repair methodology for this dwelling would be a minor Jack and Pack given the minimal amount of damage.

Although the vertical settlement of the floor was 84mm across the width of the building, it was considered more economically viable to minimise the floor variation by both lifting and lowering the floor as appropriate. This approach reduced the need to replace all external cladding. As a result the finished floor levels came within 28mm.

The external cladding is an asbestos cement weathersiding (known as Durock siding) which required a specialist contractor to remove the bottom row of sidings. The removal of this bottom row allowed access to the bearers and floor joists that required either packing or notching. Bearers over piles were either notched or packed.

Fibre cement sheet cladding was cut to suit the required size and was used to replace the bottom row of asbestos fibre cement weathersiding.

New aluminium corner cover flashings were used to improve the weather tightness of the existing weathersiding.

Construction

• Type B1 foundation, timber floor, light weight asbestos fibre cement cladding
• Heavy concrete tile roof.

Damage

• Foundation in good condition with no visible cracking around the perimeter beam
• Maximum vertical settlement of floor of 84mm
• Damage to some bottom sheets of asbestos fibre cement weatherboard cladding and corners
• No roof damage.

Image 1: No earthquake damage to exterior cladding

Image 2: No earthquake damage to exterior cladding

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Geoscience referenced report for detailed information.

1: Summary of Liquefaction Analyses

Design Case	Calculated Vertical Settlement*	
	Total	Upper 10 m
ULS	140 mm to 200 mm	90 mm to 120 mm
SLS	7 mm to 25 mm	2 to 20 mm

*For an undeveloped site. Settlements beneath buildings are likely to be greater.

2: Summary of Ground Performance Expectations*

Performance Category	Land Damage Type	Land Damage Category
SLS	Vertical Settlement (in upper 10 m)	TC3 Minor to Moderate
ULS	Lateral Stretch	TC3 Minor to Moderate
	Global Lateral Movement	TC3 Minor to Moderate

*As per Tables 12.1, 12.4 and 12.5 of the December 2012 MBIE Guidance, Part C.

3: Summary of Subsurface Conditions Encountered in Ground Investigations

Depth (m)	Soil / Behaviour Type	Density / Consistency
0.0 TO 0.9	TOPSOIL / FILL	N/A
0.3 to 4.0	SAND	Very Loose to Dense
3.0 to 5.0	Sandy SILT	Stiff to Very Stiff
4.0 to 13.0	SAND	Dense to Very Dense
13.0 to 15.5	Sandy SILT	Stiff to Hard
15.5 to 17.3	SAND	Very Dense

Geoscience ref: 9653.000.001 Ph 002 18 January 2013

Repair Options

Two options were considered:

- Partial relevel of foundation ring beam using Engineered Resin
- No foundation lift. Remove bottom sheet of asbestos cement cladding, lift and lower super structure on foundation beam and piles (see Methodology 1a).

Chosen Repair Option

The methodology chosen for relevelling this building was Jack and Pack (see Methodology 1a).

- Due to the sound condition of the ring beam foundation a decision was made not to lift the foundation.

Summary of Jack and Pack Process

- Engaged approved asbestos removal contractors to remove bottom row of asbestos fibre cement plank cladding
- Laser levels were used to establish the areas of the floor structure to be lowered by checking out the bearers over the piles and what areas to be packed on the piles and ring beam
- Part of the ring beam had a full length bearer attached directly to it with floor joists attached along the top of it
- Lowering the floor structure meant checking out the bottom edge of the floor joists. The maximum check out of these 125 x 50mm joists was 25mm
- Bearers could be notched over the piles up to a maximum of 35mm for a 100x75mm bearer (see Appendix 2, MBIE 2013, Bearer Notching).

Points of Interest

• Working with asbestos cement cladding.

Time Frame

Three weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$7,821
Foundation		$13,440
Cladding	$5,582	
TOTAL	$5,582	$21,261

Foundation lineal metres	41Lm	
Foundation repair costs	$21,261	$519/Lm
Floor area / Foundation repair costs	$90m^2$	$236/m^2$
New Build market price / m^2 (see Appendix 1 Cost Calculator)	Type B1 construction with Surface Structure Type 1	$1,600/m^2$
Foundation repair costs / New build costs	$236 / $1,600	14.75%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

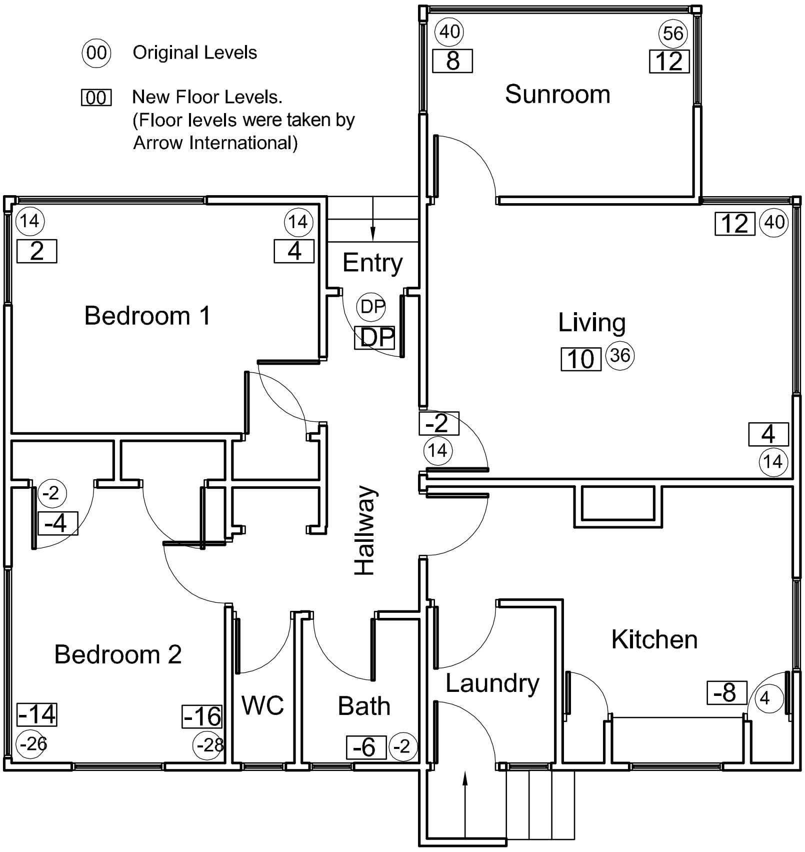
Image 4: Bottom row of weatherboards removed. Existing building wrap kept intact where possible

Image 5: Packed joists

Image 6: Joists notched over bearer. Bearer remains fixed to beam

Image 7: Fibre cement sheet replaced bottom row of asbestos weathersiding

Floor Plan Showing Floor Levels



6 Aldershot Street, Aranui

Property Details

Land Zone	TC3
Year	2004
Floor Area	98 sqm
Land Area	321 sqm
Foundation Type	C
Roofing Type	Pre-painted steel
Cladding Type	Brick
Floor Level Difference	50mm

Summary

This property sits on TC3 zoned land and was constructed as a double unit, built in 2004. The adjoining attached unit did not suffer any significant damage as a result of the earthquakes.

The unit at 6 Aldershot Street has two bedrooms and an attached single garage. Construction is concrete floor slab foundation (Type C), timber framed walls and roof, with masonry veneer and light weight roof cladding.

The most significant earthquake damage to this building was a structural crack which was less than 15mm running across the width of the building from bedroom 2 into the bathroom. There was mesh reinforcing visible in the slab albeit located within 25mm of the bottom of the slab.

The north-west corner of the living area had vertical settlement of 46mm tapering back to the central bathroom. This area of the building was identified for partial relevelling.

The relevelling of this floor area impacts on an attached wing wall which is an extension of the front elevation. Both the floor and the wing wall needed to be lifted in conjunction with each other.

The majority of the exterior damage caused to the masonry veneer was a result of the wing wall. This wing wall was constructed with two wythes of brick interwoven into the veneer on the front and side elevations. It had suffered a vertical settlement of 44mm and as a consequence the wall veneer pulled away from the kitchen window and loosened the brick ties on the north facing wall. There was minor hairline staggered cracking down the mortar line under the kitchen window.

Although the vertical settlement is close to the 50mm threshold suggested in the MBIE Guidance document, the principal reason for relevelling the floor slab was to lift the attached wing wall. This would bring the masonry veneer back into line and seal up against the kitchen window jamb. This meant there was no need to remove and relay the masonry veneer.

The north-west corner of the living area of this house and the wing wall were mechanically lifted by hydraulic jacks sitting on underpinned concrete pads.

The lifted floor area of the living room and kitchen had void filler injected beneath the slab to fill the void space created once the exterior foundation beam was relevelled.

The less than 15mm structural crack running across the width of the slab was ‘stitched’ together by cutting chases at 90 degrees to the crack at 300mm intervals. Steel rods were placed into the chase, and the crack and chase were both filled with a low viscosity epoxy resin levelling compound (see Methodology 5).

Once the relevelling of the slab was completed, the masonry veneer was secured back to the timber framing by drilling fastening points from the inside wall face through to the brick veneer. Special engineered fasteners were screw fixed through the timber studs and into the back face of the brick veneer. Once the fasteners were in place the holes in the interior wall surface were stopped ready for a paint finish.

Construction

• Type C foundation (slab on grade) with 70 series brick veneer cladding
• Light weight pre-painted steel roof.

Damage

• Structural crack (<15mm) through slab from internal corners on either side of building
• A number of minor slab cracks (<2mm) in close proximity to structural crack
• The north-east corner of the lounge through to the west side of the bathroom floor slab had settled 48mm. At the front east corner of the building there is a double wythe brick wall that is an integral part of the external brick veneer cladding. This wall had settled 44mm and as a result had 'pulled' the brick veneer away from the front kitchen window jambs (approx. 10mm). As a result of this settlement and pulling of the veneer from the timber framing, the north facing wall had demonstrated a 'loosening' of the masonry brick ties causing an unstable veneer cladding
• The brick veneer below the kitchen window suffered minor hairline staggered cracking down the mortar lines
• The north facing 3.5m high masonry veneer enclosing the patio also suffered loosening from the timber framing.

Image 1: Minor veneer damage, step cracking

Image 2: Loose bricks, lost connection with brick ties

Image 3: Moderate slab crack of 8-15mm through width of floor

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Golder Associates referenced report for detailed information.

1: Summary of post-liquefaction vertical settlement

Design Event	Depth Range	Vertical Settlement
M7.5 SLS PGA 0.13g	0 to 10 m	20 mm
	0 to 18 m	20 mm
M7.5 ULS PGA 0.35g	0 to 10 m	90 mm
	0 to 18 m	150 mm

Notes: This assessment is based on the Golder CPT investigation only. A groundwater level of 0.5 m below ground level has been used for this assessment.

2: Geotechnical Assessment Summary

The assessment indicates that the site falls within the following index categories defined by the December 2012 MBIE Guidance, Part C:

- Vertical land settlement is Minor to Moderate (see Table C12.5)
- Global lateral displacement is Minor to Moderate (see Table C12.1)
- Lateral stretch is Minor to Moderate (see Table C12.4).

3: Summary of Soil Stratigraphy

Soil Stratigraphy	Density / Consistency	Location		
		CPT1	HA1	HA2
		Depth to base stratum (m bgl)		
TOPSOIL	-	-	0.2	0.2*
SAND/silty SAND	Loose to Dense	18.0*	1.6*	-

Notes: * Depth of termination.

Reference: Golder Associates Report No. 1178102318-001-R-Rev0-005-6Aldershot.

Repair Options

Foundation - two options were considered:

- Partial relevelling using an Engineered Resin Llift (see Methodology 4)
- Mechanical Lift and void filling under slab and footing (see Methodology 3).

Slab Crack Repair Options

- Cut out a 600mm strip either side of the structural crack and replace with new attached reinforcing and concrete strip. This method would require some internal walls to be removed to gain access for this work
- Cut 600mm long chase grooves at 90 degrees to the structural crack at 300mm spacings. These grooves to be approximately 25x25mm. At the end of these grooves drill a 20mm diameter hole to a depth of 80mm. Place in each of the grooves a D10 reinforcing rod shaped like a staple. Fill grooves and structural crack with epoxy resin. This method is known as slab stitching.

Chosen Repair Option

The method used to repair the structural crack running through the width of the house was the slab stitching method. There appeared to be no yielding of the mesh reinforcement.

From a geotechnical point of view both foundation levelling options could be applied. The following factors led to the decision to use the mechanical lift and void filling repair methodology:

- To use the engineered resin lift methodology was not deemed an economic option considering the small portion of floor area to be lifted
- The mechanical lift and void filling method was considered a more economic option for the minimal lift required. It would also provide more control when lifting the attached wing wall foundation that had settled and caused the masonry veneer to pull away from the kitchen window jamb and 'pull' the veneer loose on its brick ties.

Summary of Mechanical Lift Process

- Removed patio concrete slab for access to ring foundation
- Excavated and poured concrete for foundation underpinning pads for mechanical lift
- Attached lifting brackets
- Drilled core holes in internal slab to release suction to earth
- Relevelled foundation by jacking between pads and brackets
- Filled void under perimeter beam, wing wall and slab with grout
- Stitched crack together with epoxy resin and reinforcing
- Refixed brick veneer to timber framing
- Reinstated ground around foundations
- Repoured concrete patio and connected patio post.

Points of Interest

- Methodology developed for stitching slab together with reinforcing bars and epoxy resin
- The ground water table had risen from the estimated Geotechnical depth of 1.2m to 700mm Below Ground Level (BGL). As a consequence, the intended depth of the jacking pads was reduced so the bottoms of the pads were above the water table. As a result, the lifting points on the foundation were created by attaching steel angle brackets to the face of the perimeter beam rather than lifting from the underside of the beam
- Same methodology was applied to the wing wall foundation when lifting the beam. Lifting the beam closed the veneer gaps at window jamb and tightened the loose veneer fixing points but still required additional mechanical fixing back to framing
- Internal slab crack repaired using stitching method (see Figure 1)
- Compromised brick ties were repaired using mechanical fastening installation.

Time Frame

Eight weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$12,648
Foundation		$25,311
Cladding	$6,571	
TOTAL	$6,571	$37,959

Foundation lineal metres	45Lm	
Foundation repair costs	$37,959	$791/Lm
Floor area / Foundation repair costs	$98m^2$	$387/m^2$
New Build market price / m^2 (see Appendix 1 Cost Calculator)	Type C2 construction with Surface Structure Relevellable slab	$1,738/m^2$
Repair costs / New build costs	$387 / $1,738	13.29%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Image 4: Jacking points excavated as per engineer's design

Image 5: Jacking pads poured and brackets installed ready for lifting

Image 6: Internal core holes drilled for void fill injection points and to release possible slab suction

Image 7: Exterior foundation jacked to required level

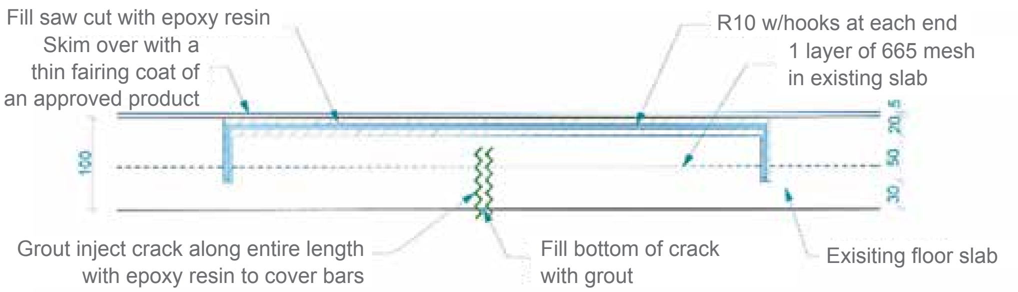
Image 8: Void filled under footing

Image 9: Void filled under internal slab making sure DPM of slab maintained

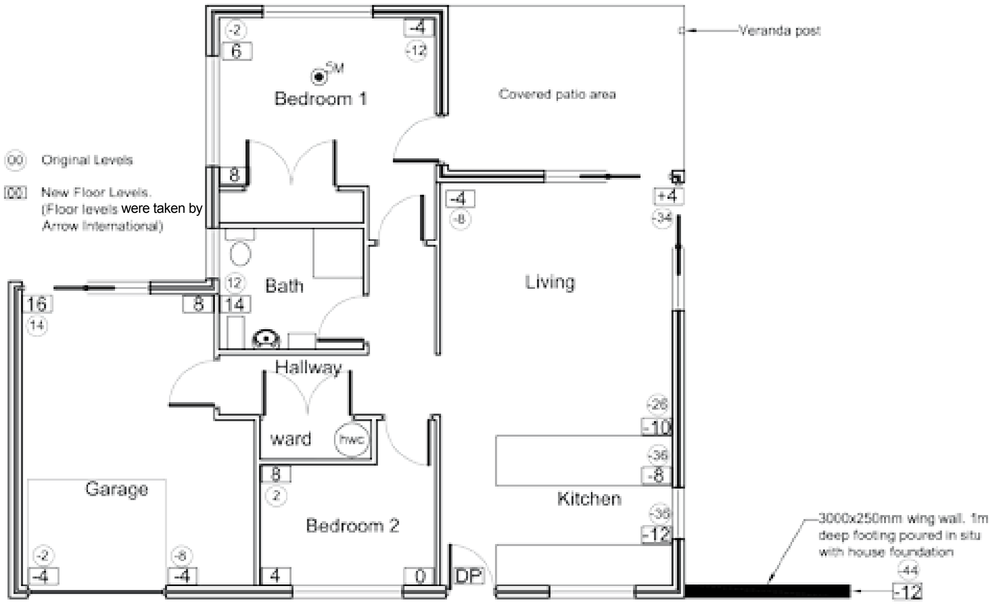
Image 10: Channels cut into slab perpendicular to crack

Image 11: Reinforcing bars inserted and epoxy compound put in place (see Figure 1)

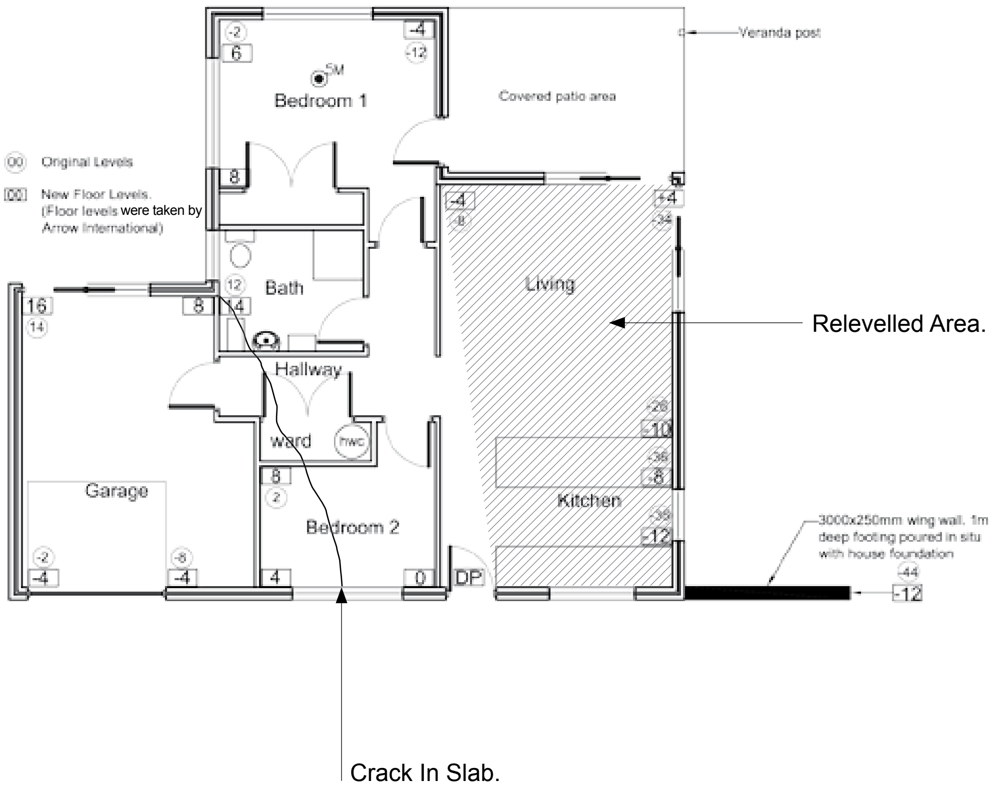
Figure 1 - Crack repair plan. Not to scale.



Floor Plan Showing Floor Levels



Crack In Slab and Relevelled Area



53 Eureka Street, Aranui

Property Details

Land Zone	TC2
Year	1967
Floor Area	110 sqm
Land Area	703 sqm
Foundation Type	B
Roofing Type	Concrete Tile
Cladding Type	Summerhill Stone
Floor Level Difference	104mm

Summary

This property, built in 1967, sits within the TC2 land category. Considering the weight of the cladding, the property performed well during the earthquakes with minimal damage to the perimeter foundation beam.

As the ground displayed a performance consistent with the technical category, it was not deemed necessary to reduce the cladding and roof weight. However, the Summerhill Stone needed to be replaced because it had undergone significant damage. The house had no insulation therefore it was an opportune time to insulate the perimeter walls and fit building wrap with flashing tape around the windows.

The cladding was replaced with a light weight 70mm series brick. By maintaining the same cavity size the existing timber windows did not need to be adjusted. However, the face of the new brickwork sat inside the existing foundation line.

The levelling of the floor superstructure was a simple process of disconnecting the bearers from the piles and systematically jacking and packing the piles. All pile packing was less than the MBIE guideline maximum of 100mm. All piles were precast concrete with a wire looped through a hole in the pile and fixed to the bearers. New wire connections were attached to the adjusted piles. A number of subpiles connected to the perimeter beam and supporting the bearer required replacement due to the poor quality concrete and there was evidence that these were not poured as part of the foundation beam. These subpiles were replaced with timber piles attached to the foundation beam.

The top of the foundation perimeter beam was scabbled and boxed to the new adjusted floor level height. This level was determined from the soffit down in modules of the brick height.

The topping compound used was an 'off the shelf' high flowing construction grout. The maximum depth of the compound needed was approximately 90mm. The top of the levelling compound was angled from the face of the brick line to the foundation line. This camouflaged the difference between the foundation line and the new brick line.

Some of the bearers were notched over the piles to lower the level of the floor structure (see Appendix 2, MBIE 2013, Bearer Notching).

The foundation was replastered with a splash coat of plaster (similar to existing) to cover the new additional packing compound.

The soffit and foundations were repainted. The soffit was painted to cover the reduced measurement of the new veneer cladding.

This methodology was a successful, simple and easy repair solution for this property.

Property Construction and Damage

Construction

• Timber floor Type B foundation
• Heavy weight Summerhill Stone veneer cladding and concrete tile roof.

Damage

• Foundation in good condition. There were two minor cracks which appear to have been repaired and painted before the last major earthquake event (February 2011)
• Vertical settlement of 104mm
• On three elevations the veneer had separated from the structure with panels that had collapsed. There was also masonry damage in separate locations, at the soffit, the edges of windows and ranch slider doors
• Sill blocks to several windows had been displaced with staggered crack lines evident in the veneer
• Several tiles near the roof edge were missing or broken and needed replacement. Otherwise no apparent roof damage.

Image 1: Damage to brick veneer at soffit

Image 2: Damage to brick veneer at windows

Image 3: Masonry veneer separated from structure

Image 4: Pre-existing foundation crack that appeared to have been repaired before the earthquakes

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Geoscience referenced report for detailed information.

1: Summary of Liquefaction Analyses

Design Case	Calculated Vertical Settlement*	
	Total	Upper 10 m
ULS	140 mm to 180 mm	70 mm
SLS	‹ 10 mm	‹ 10 mm

*For an undeveloped site. Settlements beneath buildings are likely to be greater.

2: Summary of Ground Performance Expectations*

Performance Category	Land Damage Type	Land Damage Category
SLS	Vertical Settlement (in the upper 10 m)	TC3 Minor to Moderate
ULS	Lateral Stretch	TC3 Minor to Moderate
	Global Lateral Movement	TC3 Minor to Moderate

*As per Tables 12.1, 12.4 and 12.5 of the December 2012 MBIE Guidance, Part C

3: Summary of Subsurface Conditions Encountered in Ground Investigations

Depth (m)	Soil/Behaviour Type	Density/Consistency
0.0 TO 0.3	TOPSOIL	N/A
0.3 up to 4.0	CLAY, SILT and SAND mixtures	Very Loose to Medium Dense / Very Soft to Stiff
3.8 to 15.0	SAND and Silty SAND	Medium Dense to Dense
15 up to 21.9		Dense

Groundwater as encountered between 1.8 and 2.0m depth in the hand auger bore holes.
Standing groundwater level was not recorded in the CPT.

Geoscience ref: 9653.000.001 Ph 002 18 January 2013

Repair Options

Two options were considered:

- Jack and Pack (see Methodology 1)
- Mechanical Lift Off Concrete Jacking Pads (see Methodology 3).

Chosen Repair Option

From a geotechnical point of view the ground fitted within TC2 so either of the above methods could be used.

The following factors led to the decision to use the Jack and Pack repair methodology:

- 104mm overall vertical floor settlement
- Foundation in good condition with no structural damage or major cracks
- Significant damage to the masonry veneer required full replacement which resulted in reducing the cladding load by 50%
- Removing the veneer allowed the superstructure to be relevelled with a cementitious grout laid on the foundation beam to accommodate a new 70mm series lighter weight brick veneer.

Summary of Jack and Pack Process

- Removed exterior masonry veneer
- Disconnected bearers from piles
- Replaced some subpiles attached to perimeter beam
- Relevelled floor by jacking and packing piles
- Packed foundation perimeter beam with cementitious grout
- Relayed new 70mm series brick veneer cladding
- Replastered and repainted foundation.

Points of Interest

- Subfloor ventilation was in the masonry veneer cavity. New subfloor ventilation was vented from the new masonry cavity but with attention given to closing the air flow to the cavity and duct the air flow to the subfloor space. Building wrap sealed against the top of the foundation to stop air flow into the wall cavity
- Replaced several existing subpiles that had disconnected from the perimeter foundation beam. Replaced with timber piles bolted to the perimeter foundation beam to support the perimeter bearer
- Existing veneer cavity varied in width. New cavity set at 40mm width
- Insulated exterior walls and fitted new wrap
- Floor level to within 24mm at completion.

Time Frame

Six weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$12,375
Foundation		$21,748
Cladding	$24,279	
TOTAL	$24,279	$34,123

Foundation lineal metres	45Lm	
Foundation repair costs	$34,123	$758/Lm
Floor area / Foundation repair costs	100m²	$341/m²
New Build market price / m² **(see Appendix 1 Cost Calculator)**	Type B2 construction with Surface Structure Type 2A	$1,896/m²
Foundation repair costs / New build costs	$341 / $1,896	17.98%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Image 5: Cladding removed, new insulation and wrap installed. Bearers packed

Image 6: Bearers notched where required to avoid maximum packing at other support positions

Image 7: Existing fireplace concrete pad topped up

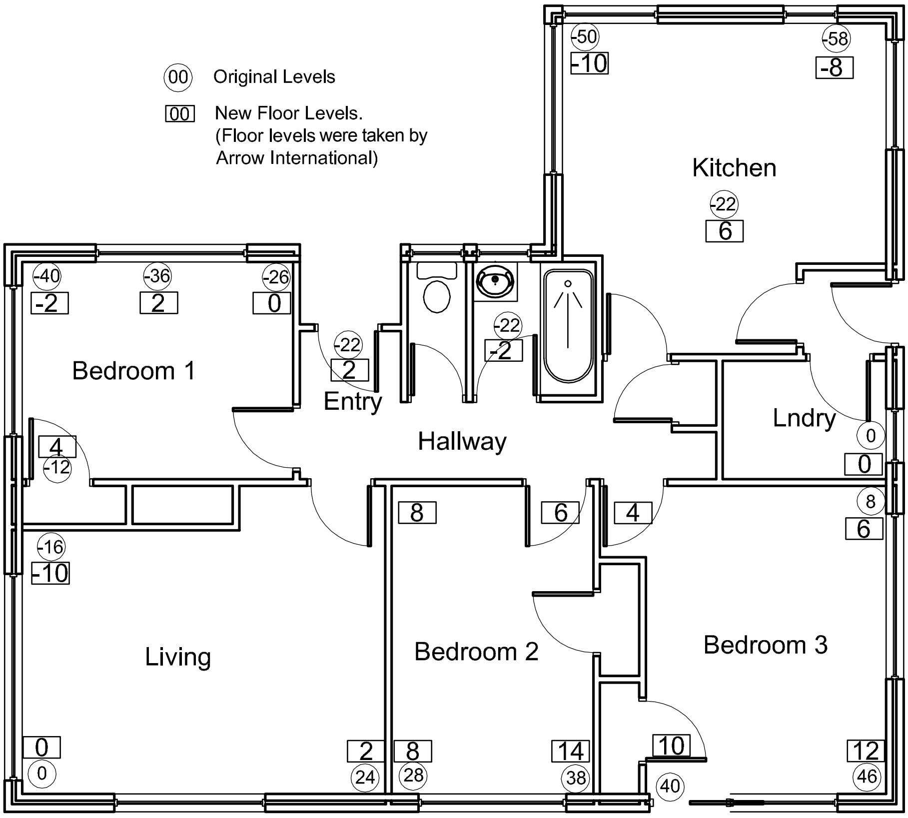
Image 8: Foundation formwork in place

Image 9: Cementitious grout poured into formwork that was preset to correct level

Image 10: Chamfer ground on top of foundation

Image 11: Reclad with lighter weight brick veneer

Floor Plan Showing Floor Levels



62 St Heliers Crescent, Aranui

Property Details

Land Zone	TC3
Year	1976
Floor Area	92 sqm
Land Area	640 sqm
Foundation Type	B
Roofing Type	Light weight pressed metal tiles
Cladding Type	Summerhill Stone
Floor Level Difference	104mm

Summary

This dwelling sits on TC3 zoned land and was built in the mid 1970s. Its construction was timber floor with heavy weight Summerhill Stone veneer cladding, aluminium windows and light weight pressed metal roof tiles. The earthquakes caused foundation differential settlements of approximately 104mm over the plan of the building.

The Summerhill Stone veneer cladding also suffered damage and partial collapse on all elevations. The Summerhill Stone required replacement and 70mm series brick was chosen for this purpose.

When the original veneer was removed it became evident that the north facing elevation had no cavity between the wall framing and the masonry veneer. This may have been due to the superstructure having moved on the foundation during the earthquakes or a minimal width cavity existing before the earthquakes. A compliant, uniform cavity was created around the entire house that resulted in a 40mm addition cast onto the outside face of the original foundation.

The perimeter foundation beam had a large number of minor cracks (<2mm). When excavating for the foundation underpinning lifting points, it become evident there were piles cast in situ under the foundation beam. These were located around the perimeter at approximately 1.5m centres and varied in depth from 300mm to 1.0m.

The methodology employed for this repair was Mechanical Lift Off Concrete Jacking Pads.

Underpinning concrete pads were located under all foundation beam cracks. These pads supported the lifting jacks to raise the perimeter foundation. All pile to bearer connections were disconnected to allow for the superstructure lift.

The perimeter foundation beam was lifted in conjunction with the internal bearer lines to ensure minimal damage. The entire perimeter foundation beam was lifted in unison with an arrangement of hydraulic bottle jacks connected together by a manifold to a hydraulic pump.

Once lifted, the bearer lines were packed and retied to the piles. All foundation beam cracks were injected with epoxy compound. The foundation extension added to accommodate the new brick veneer was poured in situ and bonded with a proprietary bonding agent to the existing foundation face. New wall blanket insulation and wall wrap was fitted to all external walls and a new 70mm series brick veneer was attached.

Plastering of the foundation extension was required to match the existing foundation.

The original subfloor ventilation was achieved through the Summerhill Stone veneer cladding. This method used in the 1970s vented both the subfloor, the wall cavity and roof space. With the new 70 series brick veneer cladding, venting of the subfloor was achieved again with vents in the veneer but with care, the air flow was directed through the wrap to the subfloor. The new wrap was sealed onto the top of the foundation and onto the soffit thus creating no air movement into the roof space.

Property Construction and Damage

Construction

• Type B Foundation with heavy weight Summerhill Stone veneer cladding
• Light weight, pressed metal tile roofing.

Damage

• Significant damage to and collapse of masonry veneer cladding in several places
• A large number of minor cracks to perimeter foundation beam.

Image 1: Major veneer damage

Image 2: Cracked foundation

Image 3: Bricks dislodged, failed connection to framing

Image 4: Failed brick ties

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Golder Associates referenced report for detailed information.

1: Summary of post-liquefaction vertical settlement

Design Event		**Depth Range**	**Vertical Settlement**
SLS	M7.5 PGA 0.13g	0 to 10 m	10 mm
		0 to 20 m	20 mm
ULS	M7.5 PGA 0.35g	0 to 10 m	210 mm
		0 to 20 m	200 mm

Notes: This assessment is based on the Golder CPT investigation only. A groundwater level of 1.0 m below ground level has been used for this assessment.

2: Geotechnical Assessment Summary

The assessment indicates that the site falls within the following index categories defined by the December 2012 MBIE Guidance, Part C:

- Vertical land settlement is Minor to Moderate (see Table 12.5)
- Global lateral displacement is Major (see Table 12.1)
- Lateral stretch is Minor to Moderate (see Table 12.4).

3: Summary of Soil Stratigraphy

Soil Stratigraphy	**Density / Consistency**	**Location**				
		CPT1	**CPT2**	**HA1**	**HA2**	**HA3**
		Depth to base of stratum (m bgl)				
TOPSOIL	N/A	NE**	0.25	0.1	0.1	0.1
SAND (FILL)	Very Loose	NE	NE	0.3	0.7	0.5
SAND	Very loose to Medium Dense	2.9	2.9	1.9*	2.5*	2.2*
Silty SAND / Sandy SILT	Firm	3.0	3.0	-	-	-
SAND	Medium Dense	19.7*	13	-	-	-
Silty SAND / Sandy SILT	Firm	-	13.1	-	-	-
SAND	Medium Dense	-	18.6*	-	-	-

Notes: * Depth of termination. **NE – Not Encountered

Reference: Golder Associates Report No. 1178102318-001-R-Rev0-005-62StHeliers.

Repair Options

- Mechanical lift off concrete jacking pads, epoxy compound cracks and replace heavy weight veneer cladding with a lighter weight cladding (see Methodology 3)
- Foundation rebuild – specific engineering design (SED) and replace heavy weight veneer with lighter weight cladding.

Chosen Repair

The following factors led to the decision to use the Mechanical Lift Off Concrete Jacking Pads methodology (see Methodology 3):

- If a new foundation was built it would influence the new finished floor height requirement for flood management area which, in turn, would impact on the repair cost of the building
- Due to cracking in the perimeter foundation beam it was deemed necessary to x-ray it to locate the position of any reinforcing steel and its size. This information would be used to assess whether the lifting method could be used without further damaging the beam. The scan indicated sufficient reinforcing steel to withstand mechanical lift.

Summary of Mechanical Lift Off Concrete Jacking Pads Process

- Removed all masonry veneer
- Identified foundation cracks and obtained ground penetrating radar evidence of foundation beam reinforcing
- Excavated for underpinning lifting pads and poured concrete as supporting lifting pads for the hydraulic jacks
- Disconnected all pile to bearer connections
- Insulated exterior wall and wrapped with building wrap
- Lifted superstructure and perimeter foundation beam simultaneously
- Bearers on the perimeter were supported on cast in situ half piles (part of perimeter foundation beam). Concrete void fill was placed under the full width of the perimeter foundation beam and the half piles
- Packed between bearers and piles and retied to piles
- Boxed and poured addition to face of foundation
- Laid 70mm series brick veneer
- Replastered foundation addition.

Points of Interest

- One elevation of the building had no cavity between the framing and the Summerhill Stone veneer
- Original foundation lines were not straight
- Some sections of foundation beam had piles under the foundation footing. These varied in depth from 300mm to approximately 1.0m. The spacing of these piles was approximately 1.5m
- Foundation had more reinforcing steel than was usual in 1970s construction.

Time Frame

Eight weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$9,572
Foundation		$52,984
Cladding	$20,698	
TOTAL	$20,698	$62,556

Foundation lineal metres	59Lm	
Foundation repair costs	$62,556	$1,060/Lm
Floor area / Foundation repair costs	92m²	$680/m²
New Build market price /m² **(see Appendix 1 Cost Calculator)**	Type B2 construction with Surface Structure Type 2A	$1,896/m²
Foundation repair costs / New build costs	$680 / $1,896	35.86%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

Image 5: Opportunity taken to insulate and wrap

Image 6: Jacking points excavated under foundation cracks as specified by engineer

Image 7: Jacks in place. All points of foundation lifted simultaneously

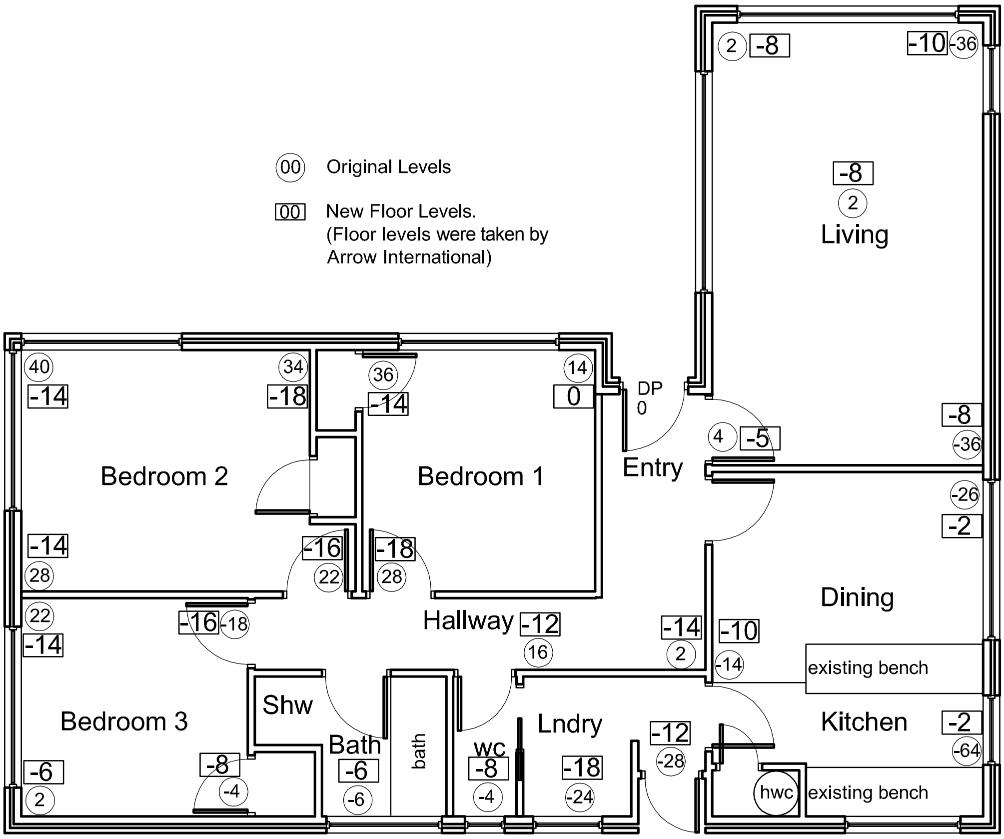
Image 8: H5 timber packers installed before jacks removed

Image 9: Void fill under footing

Image 10: H5 timber packers installed, prior to jacks being removed

Image 11: Foundaton repaired and house reclad

Floor Plan Showing Floor Levels



1 Seafield Place, South New Brighton

Property Details

Land Zone	TC3
Year	1976
Floor Area	100 sqm
Land Area	615 sqm
Foundation Type	B
Roofing Type	Concrete Tile
Cladding Type	Summerhill Stone
Floor Level Difference	104mm

Summary

This property, built in 1976, sits on TC3 zoned land, and was built using a Summerhill Stone veneer with concrete roof tiles. As a result of the earthquakes the heavy structure had settled 190mm, yet levels showed the house was out of level by only 104mm. The geotechnical and structural engineers recommended replacing the heavy weight roof cladding with light weight pre-painted steel and the Summerhill Stone with a modern 70 series brick veneer. The foundation would be lifted back to level, plus an additional 100mm to bring it up to its original height above ground.

Once the cladding was removed, the opportunity was taken to insulate and wrap the external walls. The new building wrap provided waterproofing while the superstructure was exposed during lifting. Front and back steps were disconnected from the foundation and removed.

The original engineer's design required concrete pads to be poured to a depth of 500mm below the base of the foundation at a maximum of 2m centres. Upon excavation it was evident the water table level was higher than expected and therefore it was not possible to proceed with excavations below the foundation. A 1m wide trench was dug around the perimeter to the depth of the foundation to expose the full face of the foundation (see Image 5, 1 Seafield Place). The lifting methodology was changed to metal brackets bolted to the side of the foundation with jacks supported on temporary dunnage of 200x100mm sleepers (see Image 6, 1 Seafield Place). Due to the high water table, the geotechnical engineer did not want to see the bearing ground between the bottom of the foundation footing and the water table reduced. For this reason permanent concrete jacking pads were not used.

Internal piles were disconnected from the bearers to allow the foundation to be lifted. The foundation was lifted slowly to the required height using a hydraulic jacking manifold system (see Image 7, 1 Seafield Place).

With the bearers being 100 x 75mm and some requiring packing exceeding 100mm in height, a continuous sized bearer (100 x 75mm) was run directly under and supporting the existing bearer. This was attached to the existing bearer with nail-on plates either side of the bearer at the pile location (see Image 10, 1 Seafield Place).

Concrete of 20MPa was placed in the void under the perimeter foundation beam. Cracks in the foundation beam were injected with epoxy resin. Void fill under the perimeter beam was extended in width between the lifting jacks, reinforced and connected to the existing beam by epoxying D12 starter rods. This was subject to specific engineering design (SED) (see Images 8 and 9, 1 Seafield Place). These extra width pads provided additional bearing support to the perimeter beam.

During lifting, two weak points in the foundation caused the foundation to crack and rotate about its longitudinal axis. These were where there were waste pipes over a gulley trap and where the rear entry steps were rebated through the foundation. The repair of these two cracks followed the same methodology as above.

The brick cladding was replaced and right-angled window jamb flashings were fitted to close off the cavity. New entry steps were built and the land contoured to slope away from the foundation.

Construction

- Type B foundation, concrete piles with concrete perimeter beam
- Summerhill Stone
- Heavy weight concrete tile roof.

Damage

- Minor to moderate brick veneer damage. Vertical and step cracking.
- Minor foundation damage. Cracks <3mm
- Significant floor hogging in lounge area
- Foundation had settled 190mm uniformly but was only 104mm out of level
- Earthquake damage to the roof tiles caused a leak which in turn caused partial collapse of ceilings in the lounge and bedroom.

Image 1: Minor step cracking in veneer

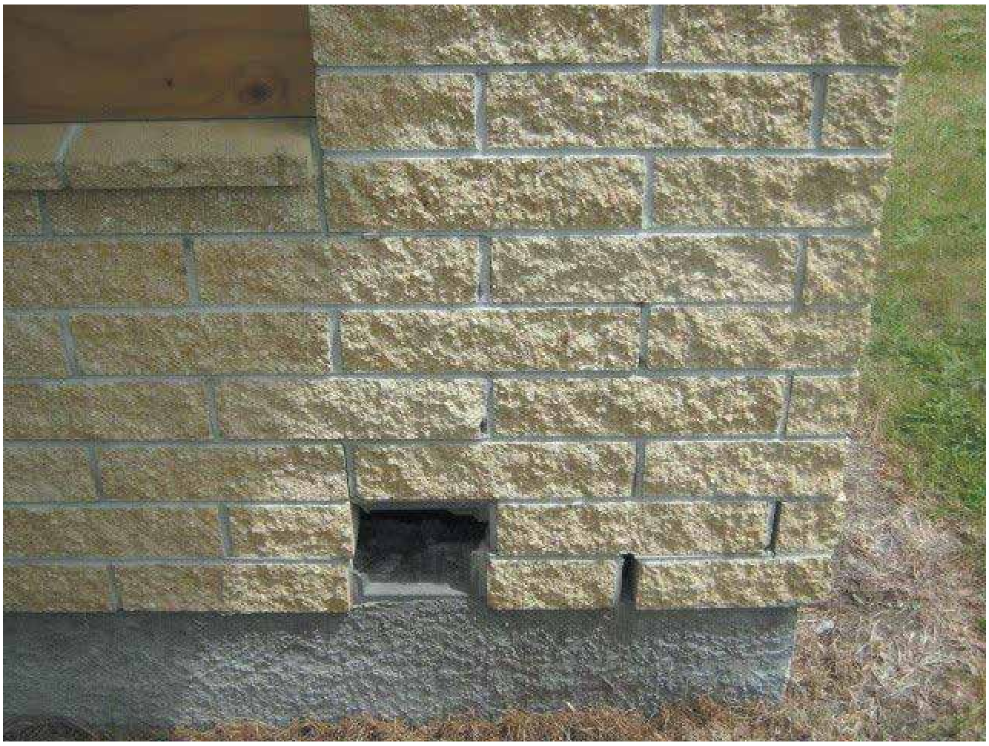


Image 2: Minor damage to brick veneer

Image 3: Minor damage to foundation

Image 4: Uneven floor settlement

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Geoscience referenced report for detailed information.

1: Summary of Liquefaction Analyses

Design Case	Calculated Vertical Settlement*	
	Total	Upper 10 m
ULS	150 mm to 210 mm	25 mm to 60 mm
SLS	Not Expected	Not Expected

*For an undeveloped site. Settlements beneath buildings are likely to be greater.

2: Summary of Ground Performance Expectations*

Performance Category	Land Damage Type	Land Damage Category
SLS	Vertical Settlement (in the upper 10 m)	TC3 Minor to Moderate
ULS	Lateral Stretch	TC3 Minor to Moderate
	Global Lateral Movement	TC3 Major

*As per Part C, Tables 12.1, 12.4 and 12.5 of the December 2012 MBIE Guidance.

3: Summary of Subsurface Conditions Encountered in Ground Investigations

Depth (m)	Soil/Behaviour Type	Density/Consistency
0.0 up to 0.4	TOPSOIL	N/A
0.2 to 4.0	SAND and Silty SAND / Sandy SILT	Loose to Medium Dense / Soft to Stiff
3.0 up to 6.0	SAND and Silty SAND	Medium Dense to Dense
5.0 to 22.8		Dense

Groundwater was encountered between 1.1m and 1.3m depth in the hand auger boreholes.
Standing groundwater level was not recorded in the CPTs.

Geoscience ref: 9653.000.001 Ph 002 18 January 2013.

Chosen Repair Option

In this instance there was only one viable option for the repair of the foundation. The following factors led to the decision to use the Mechanical Lift methodology:

- 190mm overall vertical floor settlement
- Foundation was in good condition with only minor cracks
- Ground conditions were poor. Mechanical lift offered opportunity to underpin footings to increase bearing area of foundation.

Summary of Mechanical Lift Process

- Removed entry steps for access to perimeter foundation beam
- Removed heavy weight roof and replaced with lighter weight pre-painted steel roofing
- Removed existing veneer cladding. Insulated walls and installed new building wrap
- Excavated trench around perimeter of foundation for access to face of foundation.
- Installed temporary dunnage, lifting brackets and jacking system
- Relevelled house in small increments using laser level to gauge progress
- Void filled and underpinned foundation at required height with poured concrete. Back filled trench
- Reclad exterior walls with 70 series veneer and constructed new steps.

Points of Interest

- Earthquake damage to roof initiating a reclad. Opportunity to reduce weight of roof and exterior cladding
- Water table level was higher than expected requiring change from initial methodology to lifting from the side of the foundation off temporary dunnage to keep above the water table
- Lack of support at weak points in foundation caused foundation to crack and rotate during lift
- The new veneer was constructed with a compliant cavity which exposed the cavity at the window jambs. A right angle flashing was used at the window jamb to close off the cavity
- Final floor level variation 20mm.

Time Frame

Ten weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$14,973
Foundation		$55,750
Cladding	$20,599	
Roofing	$17,990	
TOTAL	$38,589	$70,723

Foundation lineal metres	45Lm	
Foundation repair costs	$70,723	$1,572/Lm
Floor area / Foundation repair costs	100m^2	$707/m^2
New Build market price / m^2 (see Appendix 1 Cost Calculator)	Type B2 construction with Surface Structure Type 2A	$1,896/m^2
Foundation repair costs / New build costs	$707 / $1,896	37.28%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

Image 5: With cladding removed, opportunity taken to insulate and wrap. Trench excavated around foundation perimeter for access to footing

Image 6: Foundations mechanically jacked to required height

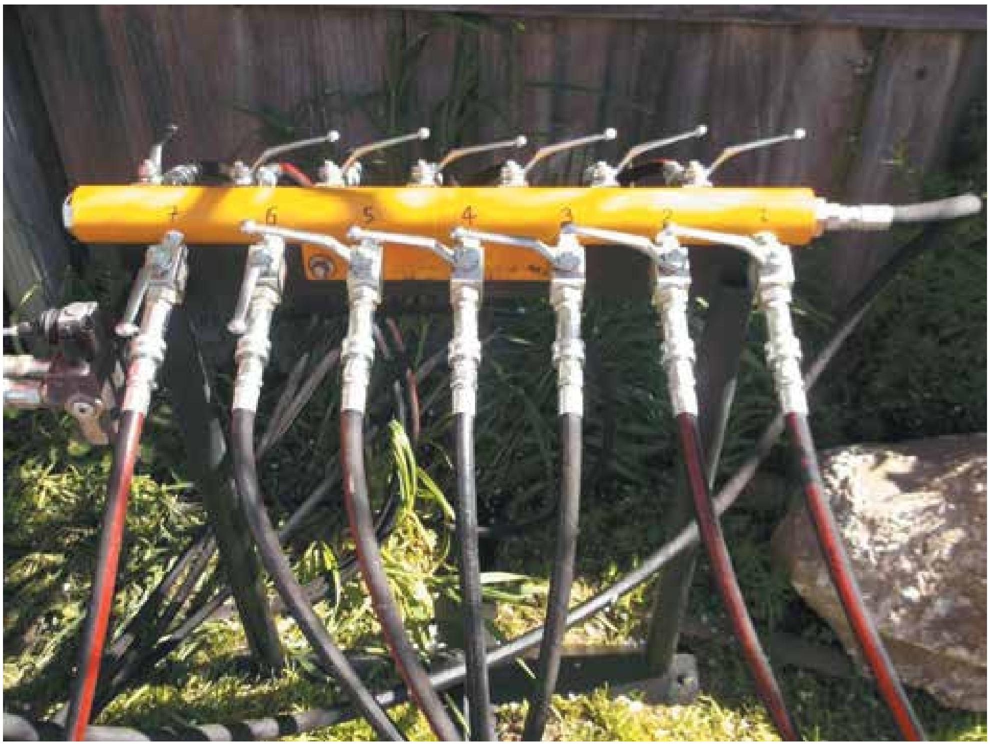


Image 7: Mechanical jacking manifold system

Image 8: Reinforcing installed under foundation cracks as per engineer's specification

Image 9: Voids under relevelled footing filled with poured concrete

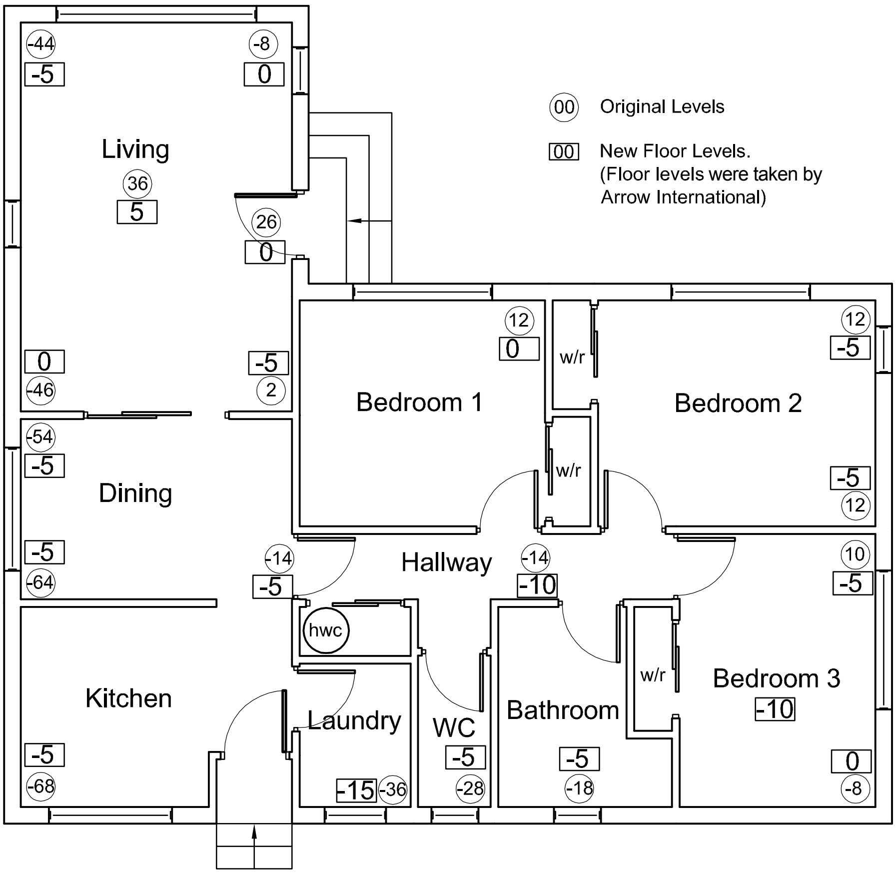
Image 10: Areas requiring over 100mm packing were jacked, packed and strapped using double bearers

Image 11: Floor reinstated to level

Image 12: Aluminium window flashings installed to provide cover for window at brick junction

Image 13: Relevelled, reclad and reroofed

Floor Plan Showing Floor Levels



43 Ashwood Street, Parklands

Property Details

Land Zone	TC3
Year	1977
Floor Area	110 sqm
Land Area	563 sqm
Foundation Type	B
Roofing Type	Light weight pressed metal tile
Cladding Type	Brick
Floor Level Difference	78mm

Summary

This dwelling sits on TC3 zoned land and was built in 1977. The construction is timber floor with heavy weight masonry veneer cladding, aluminium windows and light weight pressed metal tile roofing. After the earthquakes, the foundation settlement was minor (approximately 78mm in total) although liquefaction was evident in the subfloor space. The 78mm is a combination of vertical settlement and joist hogging.

The foundation was in good structural condition with one minor hairline crack. The veneer was also in very good condition with a minor hairline staggered crack under one window. A previous repair had been made to a staggered crack in the veneer following the September 2010 earthquake.

A minor Jack and Pack was required to repair this dwelling given the minimal amount of damage.

As the condition of the foundation and masonry veneer cladding was sound, it was not considered necessary to undertake foundation relevelling or removal of the existing veneer to pack the foundation beam for new masonry veneer. However, an attempt was made to lift and lower the perimeter superstructure with the veneer cladding still in place. To accommodate this, it was planned to remove the top course of the veneer and the window sill blocks. Only minor lifting and lowering of the superstructure was achieved around the affected perimeter beam due to a large resistance from the brick ties. In the end the veneer and sill blocks were not required to be removed.

Sections of the floor were removed for ease of access but more so for planing the top edge of joists that had hogged. Some joists needed to be packed. As a result of this work and the minor jacking, the finished floor plane was evened out to be within the MBIE Guidance of 1:200 slope over 2m and the maximum differential settlement was reduced to 54mm.

To further improve the differential settlement between the new and existing floor levels would have meant the removal of the masonry veneer to apply a jack and pack methodology. The decision was made by Housing New Zealand to accept the achieved finished floor level since it was within the MBIE Guidance document.

Construction

- Type B Foundation
- Summerhill Stone cladding
- Light weight pressed metal tile roofing.

Damage

- Foundation in good condition with one minor hairline crack
- Vertical settlement 78mm across the entire floor
- Minor staggered hairline crack under one window
- No roof damage
- Minor hogging of timber floor spans.

Image 1: Minor step cracking in veneer

Image 2: Hairline crack in foundation

Image 3: Minor step cracking from window corners

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Geoscience referenced report for detailed information.

1: Summary of Liquefaction Analyses

Design Case	Calculated Vertical Settlement*	
	Total	Upper 10 m
ULS	210 mm to 240 mm	120 mm to 140 mm
SLS	20 mm to 35 mm	15 mm to 35 mm

*For an undeveloped site. Settlements beneath buildings are likely to be greater.

2: Summary of Ground Performance Expectations*

Performance Category	Land Damage Type	Land Damage Category
SLS	Vertical Settlement (in the upper 10 m)	TC3 Minor to Moderate
ULS	Lateral Stretch	TC3 Minor to Moderate
	Global Lateral Movement	TC3 Minor to Moderate

*As per tables 12.1, 12.4 and 12.5 of the December 2012 MBIE Guidance, Part C.

3: Summary of Subsurface Conditions Encountered in Ground Investigations

Depth (m)	Soil/Behaviour Type	Density/Consistency
0.0 up to 0.4	TOPSOIL	N/A
0.2 up to 5.7	SAND and SAND-SILT mixtures	Very Loose to Medium Dense / Very Soft to Stiff
5.5 up to 10.0	SAND and Silty SAND	Medium Dense to Dense
10.0 up to to 10.7	Sitly SAND and Sandy SILT	Medium Dense / Stiff
10.7 up to 18.9	SAND and Silty SAND	Dense

Geoscience ref: 9653.000.001 Ph 002 18 January 2013

Repair Options

Two options were considered:

- Partial relevelling using Engineered Resin Lift (see Methodology 4)
- No ring foundation lift necessary but attempt to rectify hogging of floor by packing and notching bearers over piles.

Chosen Repair Option

The following factors led to the decision to use the Jack and Pack repair methodology:

- Due to the good structural condition of the foundation and masonry veneer and as the floor levels were not excessively out of level, it was considered prudent to leave both intact
- There was some minor hogging of some floor areas. This was due to some pile movement and joists between bearers were bowed in opposite directions. This was remedied by packing and notching of bearers over piles.

Summary of Jack and Pack Process

- Set up laser levels to determine floor plane variations
- Lifted portions of room floor sections identified for straightening, packing or notching of bearers
- Part removal of some masonry sill blocks and top row of masonry veneer that loosened during the jacking and packing process
- Planed or packed affected floor joists
- Packed or notched out bearers over piles to improve floor plane levels.

Points of Interest

- This property required adjusting and improving floor plane without major structural implications to the foundations or masonry veneer
- The final variation in floor level was 54 mm (reduced from 78 mm) but slopes were evened out to less than 1 in 200.

Time Frame

Three weeks for start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$6,815
Foundation		$6,058
Cladding	$525	
TOTAL	$525	$12,873

Foundation lineal metres	45Lm	
Foundation repair costs	$12,873	$286/Lm
Floor area / Foundation repair costs	110m^2	$117/m^2
New Build market price / m^2 (see Appendix 1 Cost Calculator)	Type B2 construction with Surface Structure Type 1	$1,640/m^2
Foundation repair costs / New build costs	$117 / $1,640	7.13%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

Image 4: Flooring removed to access subfloor

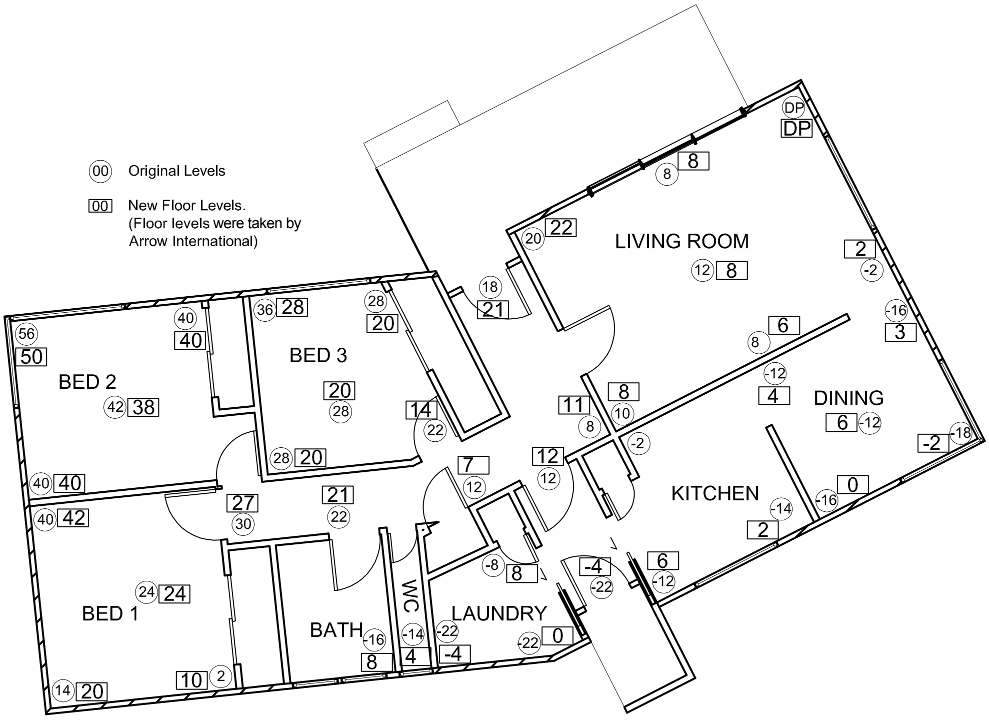
Image 5: Piles packed or notched where necessary to create required level

Image 6: Individual joists packed if required to level localised areas

Image 7: Internal flooring replaced with original materials if available and fixed down using glue and screws

Image 8: Sills and bricks that loosened during jacking and packing reinstated

Floor Plan Showing Floor Levels



18 Four Elms Place, Parklands

Property Details

Land Zone	TC3
Year	1975
Floor Area	110 sqm
Land Area	530 sqm
Foundation Type	B
Roofing Type	Metal tiles
Cladding Type	Light weight, pressed metal tiles
Floor Level Difference	138mm

Summary

This home was built in 1975 and sits on TC3 land. It was constructed using a Type B foundation with heavy weight Summerhill Stone cladding and light weight pressed metal roofing tiles. As a result of the earthquakes the foundation had settled 138mm causing moderate damage to the brick veneer and minor cracks to the perimeter foundation beam.

The brick veneer appeared to need full replacement, because the cracking damage was widespread, however, once relevelled only a partial replacement was necessary. The foundation was relevelled using a Mechanical Lift Off Concrete Jacking Pads.

Patios, steps, fences and paths were removed so jacking points could be excavated under the foundation as per engineer's specifications. To avoid removing too much support from beneath the foundation at once, every second jacking point was excavated. Concrete jacking pads and jacks were placed to provide support. Then the remaining jacking points were able to be excavated and pads placed. The jacking pads were 1.2 x 1.2 x .05m deep and were reinforced with D16 reinforcing steel. Polystyrene blocks were placed in each concrete pad to form a void for the jack to be positioned.

The bearers were disconnected from the piles allowing the perimeter foundation to be lifted off the concrete jacking pads without being restrained by the piles. As the foundation was lifted, concrete pavers were used as permanent packers beneath the footing. Once the desired height was achieved, final jacking and packing of internal piles took place.

As this lift was over 100mm in some places, new 100x75mm bearers were required to be placed under the existing bearers to allow for packing over 100mm (see Image 10, 18 Four Elms Place). A custom-made mechanical internal jacking system was developed by the contractor to relevel from above the floor without removing large sections of the floor.

The contractor also developed a system with tension bars along both sides of the foundation beam that was able to squeeze up the cracks (see Image 11, 18 Four Elms Place). Final levels were taken, determined to be satisfactory, and the perimeter foundation beam was ready for void filling. Jacks were removed and sand was placed in the cavity. This would allow the jacking pads to be easily exposed and used again to relevel the house in the event of further settlement. Formwork was placed around the perimeter of the footing and void fill concrete was poured 100mm wider and 100mm higher than the bottom of the existing footing.

Once the house was returned to its original floor level it became evident that the gaps and cracks in the brick veneer had closed up, meaning only a partial replacement of a 6m² area and a general grind out and repoint of the now minor mortar cracks was required.

Construction

- Type B2 foundation with Summerhill Stone veneer cladding and light weight pressed metal roofing tiles.

Damage

- Minor cracks in foundation
- Moderate damage to brick veneer with step cracking
- No damage to roof.

Image 1: Moderate damage to Summerhill Stone cladding


Image 2: Step cracking in mortar


Image 3: Lateral spreading of hard surfaces

Image 4: Minor cracking to concrete perimeter foundation

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Golder Associates referenced report for detailed information.

1: Summary of post-liquefaction vertical settlement

Design Event	Depth Range	Vertical Settlement
M7.5 PGA 0.13g	0 to 10 m	30 mm
	0 to 20 m	35 mm
M7.5 PGA 0.35g	0 to 10 m	120 mm
	0 to 20 m	215 mm

Notes: This assessment is based on the Golder CPT investigation only. A groundwater level of 1.0 m below ground level has been used for this assessment.

2. Geotechnical Assessment Summary

The assessment indicates that the site falls within the following index categories defined by the December 2012 MBIE Guidance, Part C:

- Vertical land settlement is Minor to Moderate (see Table 12.5)
- Global lateral displacement is Minor to Moderate (see Table 12.1)
- Lateral stretch is Minor to Moderate (see Table 12.4).

3: Summary of Soil Stratigraphy

Soil Stratigraphy	Density / Consistency	Location				
		CPT1	CPT2	HA1	HA2	HA3
		Depth to base of stratum (m bgl)				
SAND or Silty SAND	Medium Dense to Dense	2.7	2.5	1.5*	1.9*	1.8*
Interbedded SAND, silty SAND and clayey SILT	Very loose to loose and very soft to soft	5.2	5	NE**	NE	NE
SAND or silty SAND	Medium Dense	20*	20*	NE	NE	NE

Notes: * Depth of termination. **NE – Not Encountered.
January 2013
Reference: Golder Associates Report No. 1178102318-001-R-Rev0-005-18FourElms

Repair Options

- Partial replacement of perimeter foundation beam – front third of house
- Relevel perimeter foundation beam by Mechanical Lift Off Concrete Jacking Pads and jacking and packing piles (see Methodology 3).

Chosen Repair Option

The following factors led to the decision to use the Mechanical Lift methodology:

- 138mm vertical settlement
- Foundation was in good condition with only minor cracks
- Ground conditions were poor. Mechanical lift offered opportunity to underpin footings to increase bearing capacity of foundation.

Summary of Mechanical Lift Off Jacking Pads Process

- Excavated 1.2 x 1.2 x 0.5 deep jacking points beneath perimeter foundation beam
- Poured concrete jacking pads
- Disconnected bearers from piles
- Mechanically jacked perimeter foundation to desired height
- Packed perimeter foundation with permanent packers
- Jacked and packed internal piles
- Pulled perimeter ring foundation together to close up cracks
- Void filled under footing
- Back filled excavations.

Points of Interest

- Existing stormwater and waste pipes ran along the side of the foundation. Pipes were removed to allow excavations to occur
- Internal mechanical floor relevelling system was able to be operated from above floor
- House initially appeared to require a reclad but after relevelling damage was minimal with only a partial replacement and repaint required
- Floor level differential of 14mm at completion.

Time Frame

Three weeks from start on site to handover (for relevelling and brick repairs).

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		Included in cost
Foundation		$49,500
Cladding	$37,787	
TOTAL	$37,787	$49,500

Foundation lineal metres	67Lm	
Foundation repair costs	$49,500	$739/Lm
Floor area / Foundation repair costs	110m^2	$450/m^2
New Build market price / m^2 (see Appendix 1 Cost Calculator)	Type B2 construction with Surface Structure Type 2A	$1,896/m^2
Foundation repair costs / New build costs	$450 / $1,896	23.73%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

Image 5: Jacking points excavated and reinforcing installed

Image 6: Concrete jacking pads poured up to bottom of footing

Image 7: Perimeter ring foundation jacked and packed

Image 8: Bearers jacked and packed

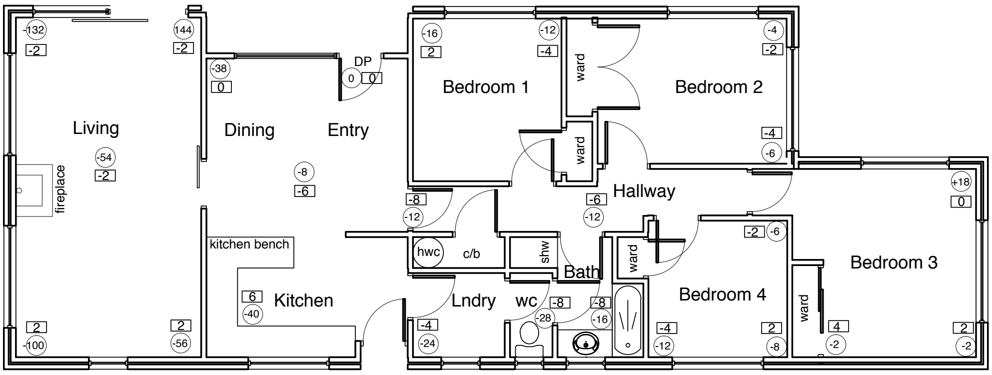
Repair Images

Image 9: Entire foundation packed and jacks removed ready for void fill

Image 10: Where lift was over 100 mm, piles were packed with an extra bearer spanning at least two piles

Image 11: Tension bars pulled foundation together closing up cracks

Floor Plan Showing Floor Levels



(00) Original Levels

[00] New Floor Levels.
(Floor levels were taken by Arrow International)

37 Charnwood Crescent, Bishopdale

Property Details

Land Zone	TC2
Year	1975
Floor Area	120 sqm
Land Area	635 sqm
Foundation Type	B
Roofing Type	Concrete Tiles
Cladding Type	Brick
Floor Level Difference	118mm

Summary

This property sits within TC2 zoned land and was built in 1975. This dwelling has three bedrooms and is constructed with a concrete perimeter foundation beam (Type B) with suspended timber floor on precast concrete piles. It has timber framed walls and roof, with masonry veneer and heavy weight concrete tile roofing.

The perimeter foundation beam was constructed independently of the perimeter piles and settled independently of the piles after the earthquakes. Despite the vertical settlement of the perimeter foundation beam, there was only minor structural damage to the foundation itself, so Jack and Pack was chosen as the repair methodology. Roof tiles had also dislodged, particularly at hip junctions and on the ridge line, and repairs were required to some of the roof framing.

The brick veneer suffered moderate structural horizontal and staggered cracking which necessitated the replacement of the cladding.

The concrete tile roof suffered damage to the hip capping and some tiles were broken. The timber roof framing had suffered damage as a result of struts supporting the under purlins breaking and causing tiles to break therefore allowing water to penetrate.

The tiles were removed allowing for the damaged framing to be repaired. Rafters were packed and new purlins were installed to accommodate the change in roofing material. Removal of the roof provided an opportunity to install insulation in otherwise unreachable areas of the roof space.

The perimeter foundation beam had a thick first mortar course that had been displaced by the earthquakes. This was removed and the foundation was cleaned and scabbled back to a flat, workable surface. Formwork was installed to a maximum height of 120mm (width of the foundation) and a new epoxy levelling compound topping was placed (see Appendix 3, MBIE 2013, Foundation Topping).

Right angle aluminium flashings were fitted against the existing aluminium windows to compensate for the less than 40mm cavity between the old brick veneer and the timber framing. The new brick veneer (with 40mm cavity) was laid up to the sides of the windows to provide a weatherproof junction against the bricks (see Image 11, 37 Charnwood Crescent).

Due to the house being lifted back to an acceptable level variation, the concrete patios and step heights became non-compliant. These were built up with a concrete topping and replastered.

The entire perimeter foundation was plastered to cover up the new concrete topping and brick packing.

Construction

- Heavy weight brick veneer and concrete tile roof
- Perimeter foundation beam was a maximum of 120mm wide and supported only the brick veneer. Floor and superstructure supported on independent concrete piles.

Damage

- Foundation in good condition. Few minor cracks in the perimeter foundation beam
- Vertical differential settlement of 118mm
- Moderate brick veneer damage
- Significant damage to concrete roof tiles.

Image 1: Moderate damage to heavy weight roof

Image 2: Minor damage to perimeter foundation

Image 3: Vertical split bricks and mortar

Image 4: Foundation has settled at corners causing damage to veneer

Image 5: Minor foundation damage

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Geoscience referenced report for detailed information.

1: Summary of Liquefaction Analyses

Design Case	Calculated Vertical Settlement*	
	Total	Upper 10 m
ULS	40 mm	10 mm
SLS	‹10 mm	‹10 mm

*For an undeveloped site. Settlements beneath buildings are likely to be greater.

2. Summary of Ground Performance Expectations*

Performance Category	Land Damage Type	Land Damage Category
SLS	Vertical Settlement (in the upper 10 m)	TC3 Minor to Moderate
ULS	Lateral Stretch	TC3 Minor to Moderate
	Global Lateral Movement	TC3 Minor to Moderate

*As per Tables 12.1, 12.4 and 12.5 of MBIE Guidance 2012, Part C.

3: Summary of Subsurface Conditions Encountered in Ground Investigations

Depth (m)	Soil/Behaviour Type	Density/Consistency
0.0 up to 1.3	TOPSOIL / FILL / BURIED TOPSOIL	N/A
1.0 to 1.4	PEAT*	
1.4 to 5.6	Well-graded GRAVEL	Medium Dense to Dense
5.6 to 7	Sandy SILT	Stiff to Hard
7.0 to 11.0	Sandy GRAVEL	Medium Dense to Dense
11.0 to 11.6	SILT	Firm
11.6 to 16.45	Well-graded GRAVEL	Dense

*Peat was encountered in the machine borehole from approximately 1.0 m to 1.4 m depth.

Geoscience ref: 9653.000.001 Ph 002 18 January 2013.

Repair Options

- Mechanical Lift around ring foundation - jack and pack internal piles (see Methodology 3)
- Jack and Pack internal piles and foundation topping (see Methodology 1).

Chosen Repair Option

The following factors led to the decision to use the jack and pack repair methodology:

- 118mm overall vertical floor settlement
- Horizontal cracks in foundation where existing topping had been displaced
- Over 30% of brick veneer needed replacing. Existing brick could not be matched so full replacement needed
- Removing veneer allowed the super structure to be relevelled more easily
- Topping laid on the perimeter foundation beam provided a level surface for the new 70mm series lighter weight bricks to be laid.

Summary of Jack and Pack Process

- Removed brick veneer and installed new building wrap
- Disconnected piles and relevelled floor by jacking and packing, or notching bearers
- Removed concrete roof tiles and replaced with lighter weight pre-painted steel roofing iron
- Packed perimeter foundation beam with epoxy levelling compound
- Laid new 70-series brick veneer cladding
- Topping concrete to patios and steps to match raised floor and comply with building code step heights
- Replastered foundation.

Points of Interest

- Internal concrete piles and superstructure were independent of perimeter foundation beam
- Foundation perimeter beam had existing concrete topping under the brick veneer. This was displaced during the earthquakes
- Electrical cable that was running through brick cavity was rerouted through the framing
- While the roof was removed opportunity taken to insulate ceiling in areas not accessible from within roof space
- Simple repair of damaged roof framing while roofing was being replaced
- Final floor level variation 24mm.

Time Frame

Ten weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		$13,086
Foundation		$24,573
Cladding	$20,007	
Roofing	$18,507	
TOTAL	$38,589	$37,659

Foundation lineal metres	52Lm	
Foundation repair costs	$37,659	$724/Lm
Floor area / Foundation repair costs	120m²	$314/m²
New Build market price / m² **(see Appendix 1 Cost Calculator)**	Type B2 construction with Surface Structure Type 2A	$1,896/m²
Foundation repair costs / New build costs	$314/$1,896	16.56%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

Image 6: Cladding removed. Opportunity taken to replace any worn insulation and new wrap installed

Image 7: Subfloor jacked and packed

Image 8: Foundation cleaned and scabbled. Formwork installed for pouring of foundation topping

Image 9: Roofing removed. Opportunity taken to insulate areas not accessible from roof space

Image 10: Foundation topping poured and formwork removed

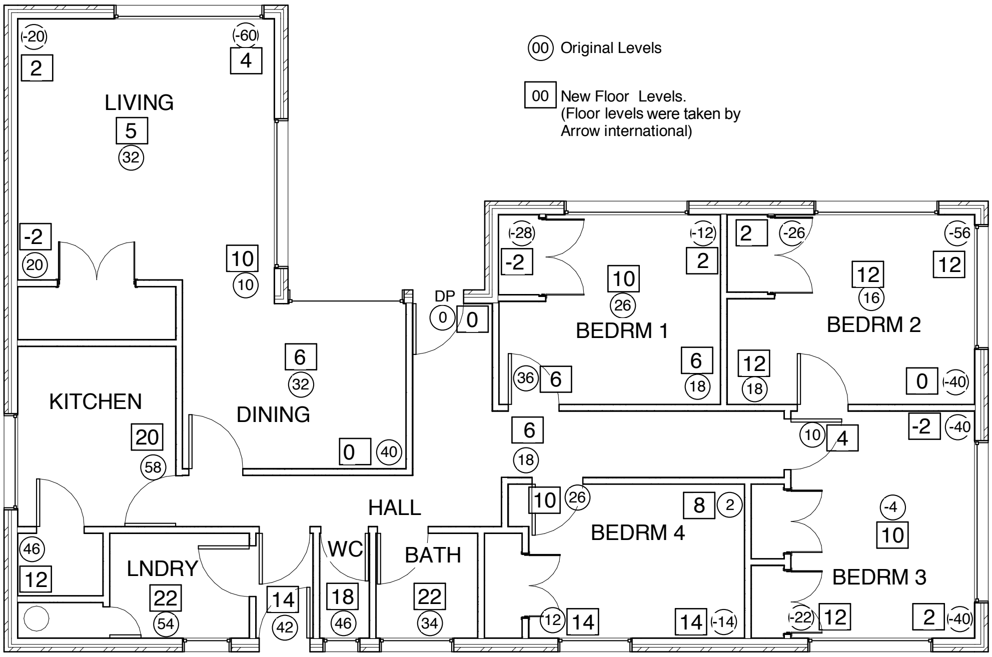
Image 11: New building wrap installed. 50x50mm flashings to windows to provide cover at window brick junction

Image 12: Brick slithers laid to bring foundation level where a topping of more than 1:1 ratio required

Image 13: Offset new cladding to allow foundation to be plastered in line with brick veneer

Image 14: Works complete

Floor Plan Showing Floor Levels



21 & 21A Riselaw Street, Mairehau

Property Details

Land Zone	TC3
Year	1988
Floor Area	239 sqm
Land Area	779 sqm
Foundation Type	C
Roofing Type	Concrete Tile
Cladding Type	Summerhill Stone
Floor Level Difference	138mm

Summary

Built in 1988, the property sits on TC3 zoned land. This dwelling consists of a double unit with attached single garages between both units. The units have a Type C concrete floor slab foundation, timber framed walls with a Summerhill Stone masonry veneer and heavy weight concrete tile roof.

Although this dwelling had experienced vertical differential settlement across the full length of the building, most of the settlement occurred around the garage inter-tenancy wall resulting in large amounts of ejecta liquefaction pushing up the drive asphalt.

The methodology chosen for the repair of this dwelling was Mechanical Lift – Screw Pile.

The site offered good clearance around the perimeter of the dwelling to allow for machinery to manoeuvre and clear out any paths, trees and fences that would be in the way of screw pile installation. A bobcat was required to install the screw piles so good access was paramount.

Engineering specifications indicated that the screw piles needed to be installed to a depth of 3m to achieve minimum bearing capacity for lifting this foundation, veneer and roof. The engineer required a specific torque resistance. To some areas screw piles were 4.2m deep. The rear of the garages where the ground was wet the screw piles were 5.0m deep.

The screw piles were positioned at 1.8m spacings around the perimeter of the foundation and at locations along the concrete block masonry inter-tenancy wall between the garages. Once the screw piles were in place they provided a temporary bearing point from which to jack the foundation. Custom-made brackets were bolted to the side of the foundation to provide the lifting points.

Core holes of 25mm in diameter were drilled through the slab in a grid pattern for injection ports for void filling under the slab.

As the perimeter foundation was lifted off the screw piles in increments of 5mm at a time, the void that was created beneath the internal slab was filled with cementitious grout.

During the relevelling process, it became evident that the slab was not lifting at the same rate as the foundation. This caused a dish in the slab and separation between the slab and the bottom plates of internal walls. Extra internal jacking points were required to bring the slab back into contact with the bottom plates. Core holes of 300mm in diameter were drilled through the slab to provide access for internal lifting points. The dish in the slab was relevelled by lifting it at these internal jacking points. These internal lifting points had a steel rod and a RH5 bar under the slab to lift the slab. The wall bottom plate had originally been fixed only with concrete nails. Some refixing of the bottom plate was required.

Despite the challenge of the floor slabs, and the foundation and slab construction methods used, the dwellings were successfully relevelled to within the MBIE Guidance parameters.

Construction

- Two, two bedroom units, each with attached single garage and concrete block inter-tenancy wall between the garages
- Type C2 foundation with heavy weight Summerhill Stone masonry veneer and concrete roof tiles.

Damage

- Significant signs of liquefaction ejection on site
- General condition of concrete floor slab good with no visible cracking
- Differential floor settlement of 138mm over entire length of each unit
- Minor staggered cracking of mortar on masonry veneer in localised areas.

Image 1: Unit settled below ground level

Image 2: Attached garages settled below driveway raised by liquefaction ejecta

Image 3: Garage drive hump and sand boil

Image 4: Minor masonry veneer cracking

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Golder Associates referenced report for detailed information.

1: Summary of post-liquefaction vertical settlement

Design Event	Depth Range	Vertical Settlement
M7.5 SLS PGA 0.13g	0 to 10 m	80 mm
	0 to 20 m	90 mm
M7.5 ULS PGA 0.35g	0 to 10 m	140 mm
	0 to 20 m	240 mm

Notes: This assessment is based on the Golder CPT investigation only. A groundwater level of 1.5m below ground level has been used for this assessment.

2. Geotechnical Assessment Summary

The assessment indicates that the site falls within the following index categories defined by the December 2012 MBIE Guidance, Part C:

- Vertical land settlement is Minor to Moderate (see Table 12.5)
- Global lateral displacement is Severe (see Table 12.1)
- Lateral stretch is Minor to Moderate (see Table 12.4).

3: Summary of Soil Stratigraphy

Soil Stratigraphy	Density / Consistency	Location						
		CPT1	CPT2	HA1	HA2	HA3	HA4	HA5
		Depth to base of stratum (m bgl)						
TOPSOIL	-	-	-	0.2	0.4	0.3	0.4	0.3
Silty SAND / Sandy SILT	Loose to Medium Dense / soft to firm	1.8	1.5	1.5	1.8	NE**	1.8	1.9
SILT	Soft to firm	2.0	1.9	1.8	2.0	2.1	NE	NE
Organic SILT	Soft	2.1	2.0	1.9	2.1	NE	NE	NE
Clayey SILT	Soft to very stiff	3.0	2.3	3.0*	3.0*	3.0*	3.0*	3.0*
Silty SAND / sandy SILT	Very loose	4.0	4.0	-	-	-	-	-
Clayey SILT / Silty CLAY	Very soft to soft	5.7	5.5	-	-	-	-	-
Silty SAND / sandy SILT	Very loose	6.2	7.5	-	-	-	-	-
SAND / Silty SAND	Loose to Dense	20.0*	20.0*	-	-	-	-	-

Notes: * Depth of termination. ** NE – Not encountered.

Reference: Golder Associates Report No. 1178102318-001-R-Rev0-005-21_21aRiselaw.

Repair Options

- Mechanical Lift – Screw Pile and void fill under footing and slab
- Mechanical Lift Off Concrete Jacking Pads and void fill under footing and slab.

Chosen Repair Option

- Mechanical Lift Screw Pile was chosen. From a Geotechnical point of view both foundation levelling options could be applied. The option to use the Mechanical Lift Screw Pile methodology was chosen to compare against a similar property where the same methodology was to be used.

Summary of Mechanical Lift – Screw Pile Process

- Excavated jacking points around perimeter of foundation
- Installed screw piles, lifting brackets and jacks
- Drilled internal core holes in concrete slab for lifting points and void fill injection ports
- Lifted perimeter foundation beam and concrete slab simultaneously
- Void filled under foundation and slab once desired height was achieved
- Removed jacks and brackets
- Back filled excavations.

Points of Interest

- The average concrete slab thickness throughout both units averaged out at 160mm. Mesh reinforcing was apparent in the bottom 50mm of the slab
- Dishing across the width of the slab was rectified by additional mechanical lifting points at mid point spans
- Garage slab was independent and not connected to house slab. Thickness was consistently 100mm across the full depth of the garage
- Foundation needed moderate repairs due to damage caused at a lifting point which was located too close to the corner.

Time Frame

Eight weeks from start on site to completion and handover.

Repair Cost Analysis

Description	Consequential Earthquake Repairs	Foundation Repair Cost
Preliminary and General		Included in cost
Foundation		$101,697
Cladding	$6,550	
Roofing		
TOTAL	$6,550	$101,697

Foundation lineal metres	81Lm	
Foundation repair costs	$101,697	$1255/Lm
Floor area / Foundation repair costs	239m^2	$425/m^2
New Build market price / m^2 (see Appendix 1 Cost Calculator)	Type C2 construction with Surface Structure Type 2B	$1,955/m^2
Foundation repair costs / New build costs	$425 / $1,955	21.74%

All figures shown are excluding GST. The superstructure rates are guideline market rates taken from various publications (Rawlinsons Residential Housing). The TC3-Foundation option rates have been taken from the MBIE survey of benchmark foundation costs (v0.75 Draft. 15.10.2013). The cost for the relevellable slab is an estimated market rate.

Repair Images

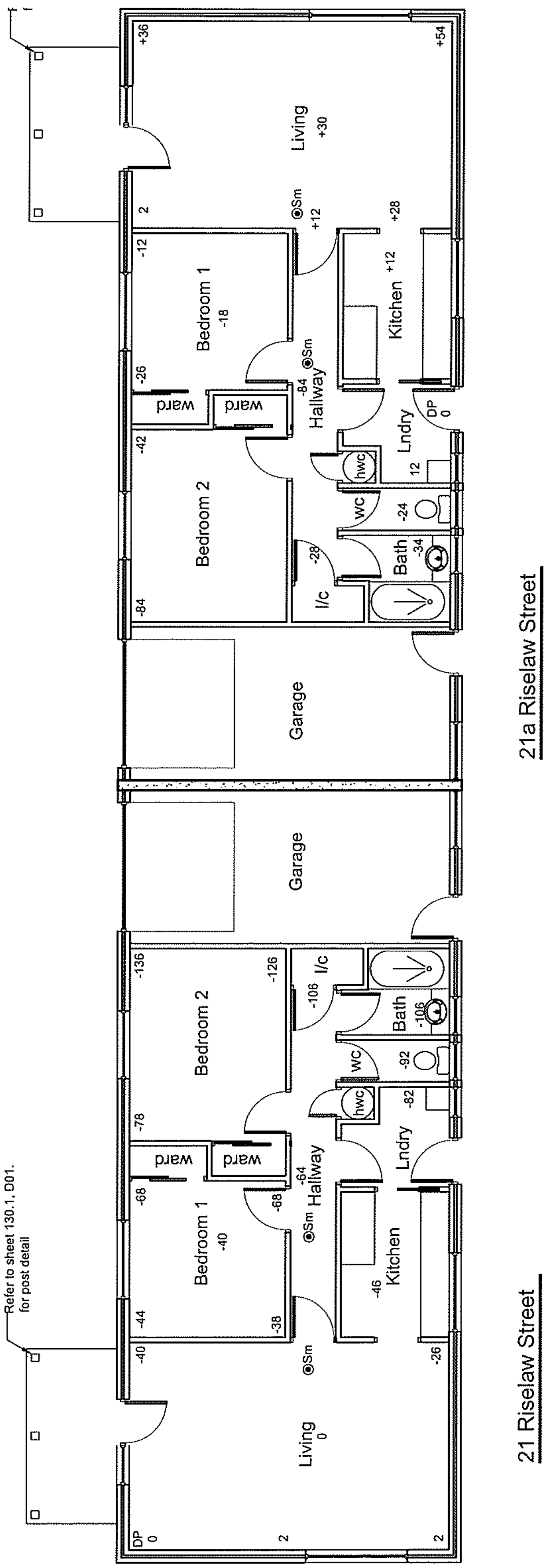
Image 5: Screw piles in place with brackets attached to foundation perimeter beam

Image 6: Lifting brackets attached to foundation and screw piles

Image 7: Jacks fitted to brackets

Image 8: Void filling epoxy levelling compound injection points

Floor Plan Showing Floor Levels



Note: The finished floor levels could not be confirmed at the time this document was going to print.

5 St Heliers Crescent, Aranui

Property Details

Land Zone	TC3
Year	1976
Floor Area	130 sqm
Land Area	561 sqm
Foundation Type	B
Roofing Type	Light weight pressed metal roof tiles
Cladding Type	Summerhill Stone
Floor Level Difference	32mm

This property suffered only minor damage during the earthquakes. Differences in the floor levels were under the 50mm threshold and unnoticeable as these differences were not in the path of hallways or access. The decision was made for this property to be deferred from the Foundation Repair Trial as it would require only minimal repair work and therefore was not an appropriate candidate for the Foundation Trial.

11 & 13 Ashby Place, Bryndwr

Property Details

Land Zone	TC2
Year	1948
Floor Area	240 sqm
Land Area	1154 sqm
Foundation Type	B
Roofing Type	Concrete Tiles
Cladding Type	2/3 Brick, 1/3 Weatherboard
Floor Level Difference	116mm

Summary

These two, two-storey units built in 1948 sit within the TC2 land category. The foundation perimeter beam was independent of the internal concrete piles and therefore had settled independently of the subfloor and piles. Construction is concrete perimeter beam, timber floor, heavy weight brick veneer for two thirds height with a midfloor concrete lintel beam, and weatherboard cladding for one third height.

The independent perimeter foundation had major cracks to all sides. The roof had opened up adjacent to the inter-tenancy wall, due to broken collar ties and diagonal braces. The inter-tenancy wall in the roof space had dislodged and lost structural integrity. Major damage occurred to the brick veneer.

The interior suffered major damage to all lathe and plaster linings to both levels.

The engineers recommended that the foundation perimeter concrete beam should be replaced with a wider beam and at least 600mm into the existing ground. To achieve this the two-storey house would have to be lifted and moved. The engineer also recommended the inter-tenancy wall, exterior cladding and roof all be replaced with light weight materials. Also, all the interior ceiling and wall linings were to be replaced.

A costing exercise was completed on the above repair methodology and found the aged asset was over capitalised and uneconomic to repair.

Image 1: Roof lost structural integrity

Image 2: Vertical and step cracking of bricks and mortar

Image 3: Vertical and step cracking of bricks and mortar

Image 4: Foundation settled at corners causing damage to veneer

Geotechnical Summary

Tables 1 through 3 provide a summary of site conditions, liquefaction analysis and ground performance expectations. Refer to Geoscience referenced report for detailed information.

1: Summary of Predicted Settlements

Design Case	Calculated Vertical Settlement*	
	Total	Upper 10 m
ULS	20 mm up to 120 mm	20 mm up to120 mm
SLS	20 mm up to 120 mm	20 mm up to 120 mm

*For an undeveloped site. Settlements beneath buildings are likely to be greater.

2: Summary of Ground Performance Expectations

Performance Category	Land Damage Type	Land Damage Category
SLS	Vertical Settlement	Consistent with TC2
ULS	Lateral Stretch	Consistent with TC2
	Global Lateral Movement	Consistent with TC2

3: Summary of Subsurface Conditions Encountered in Ground Investigations

Depth (m)	Soil Type	Density/Consistency
0.0 up to 0.4	TOPSOIL/FILL	N/A
0.3 up to 0.8	Sandy SILT	Soft to Firm
0.7 up to 1.5	SILT	Very Soft to Hard
1.2 up to 2.0	Gravelly SAND and SAND	Medium Dense to Dense
1.4 up to 10.0		Medium Dense to Dense
10.0 to 14.0	Sandy GRAVEL	Dense
14.0 to 15.45		Very Dense

Geoscience Ref: 9653.000.001 Ph 002 30 January 2013

REPAIR METHODOLOGY 1

Jack and Pack

Leaving perimeter foundation in its settled state
Masonry veneer and Type B foundation
(Concrete perimeter foundation with piles)

Definition: The Jack and Pack method requires jacking up the superstructure (floor framing, wall and roof framing with internal linings and roof claddings) and packing (using plastic shims or solid treated timber) onto the existing piles to support the subfloor structure. This relevelling may also include notching of bearers to achieve acceptable levels for the floor. In some cases this includes packing the existing concrete perimeter foundation beam with a cementitious grout to provide a level supporting surface for the masonry veneer cladding.

STEP	ACTIVITY
1.	Carry out a visual inspection of the concrete foundation perimeter. If foundation has differential vertical settlement less than 100mm and there is no visual structural damage to the concrete perimeter beam, consideration can be given to using Jack and Pack as a method of repair. Note: With a foundation in good condition you could possibly go to 150mm. However, this would require a topping depth that might exceed the width of the perimeter foundation beam and therefore would need some mechanical connection to the beam. Refer to note 17 for piles that require packing greater than 100mm.
2.	Check Table 2.2 of MBIE Guidance document for non-structural crack repairs. If foundation perimeter beam has minor cracking as described in Table 2.2, or less, Jack and Pack could be considered as a repair method.
3.	If available, use a robotic camera for a subfloor photographic survey to determine damage to subfloor structure and piles.
4.	Check floor levels for vertical settlement and prepare plan and strategy for relevelling bearers over piles.
5.	A reference point needs to be established to check the floor level changes.
6.	Check for gaps around window and door openings. Take photographs and use these for ‘before and after’ references.
7.	Remove all damaged masonry veneer.
8.	Establish reference datum at independent location away from the house.
9.	Remove all mortar and loose concrete from top of foundation. Scabble the top surface of the perimeter foundation beam ready to take grout.
10.	Check if subfloor ventilation is in the perimeter beam or masonry veneer cavity. If vent is at the top of the foundation this is an indication there is no continuous steel reinforcing bar in the top of the foundation beam.
11.	When the veneer has been removed, consideration should be given to insulate the external wall. If vents were in the veneer cladding, care needs to be taken when installing new building wrap so the new wrap does not compromise subfloor ventilation when vents are replaced.

12. When wrapping the framing with new building wrap, locate where the veneer ventilation will be and 'black out' the wrap. Coloured wrap can spoil the elevation when visible through the vents.

Note: When the veneer is completely replaced the new construction must comply with the Building Code. This will require that the veneer cavity is not connected to the roof space. By running the wrap down the wall and out on to the perimeter foundation, moisture will be directed to either vertical perpend slots or vents and will prevent moisture behind the veneer from entering the subfloor space. However, it will also prevent the subfloor space from being ventilated so new vents would be required in the foundation or first row of bricks.

13. Apply appropriate Health & Safety procedures when contemplating working under the timber floor structure.

14. Disconnect pile connections to timber bearers. Consider how the new connections are going to work.

15. If the floor is to be lowered by notching bearers see Appendix 2 for guidelines on maximum notching of bearers.

16. Pack on top of pile with H3.2 timber packer or approved plastic shim packer.

17. If existing bearers are 100 x 75mm and the packing of these bearers exceeds 100mm in height, run a continuous sized bearer (100 x 75mm) directly under and supporting the existing bearer. Attach this to the existing bearer with nail-on plates either side of the bearer at the pile location.

Note: In the MBIE Guidance document the maximum packing of piles is 100mm.

18. Reconnect bearers and packers to piles by similar method as original method eg. wire tie through the pile stapled to both sides of the bearer or original bearer if an under-bearer has been added.

19. If piles need to be replaced (refer to MBIE Guidance Appendix A, 1.1) substitute options such as 125x125 H5 treated timber piles bedded in a concrete footing can be used (see Table 6.1 of NZS 3604 for footing size).

20. If masonry veneer has been removed, box up both sides of the foundation to form a parallel line with the soffit. The new foundation line should be set out to suit new brick module sizes to alleviate the cutting of the top row of bricks.

21. Use an 'off the shelf' high flow cementitious grout. The maximum height of the topping levelling compound can not exceed the width of the foundation eg. if the foundation width is 150mm, the maximum height can be 150mm (see Appendix 2). Use of this principle means no reinforcing is necessary.

22. The new brick veneer can have a variable cavity between a minimum of 40mm to a maximum of 70mm to accommodate existing window frames. Since the new 70 series brick veneer is narrower than the old masonry veneer, there will most likely be a ledge at the foundation line. This can be camouflaged by tapering the edge of the grout topping from the brick face to the foundation line.

23. Since the foundation has been packed it will need to be plastered and repainted to cover the junction. A splash coat of plaster may be used to replicate the original finish.

Points to consider:

- When adjusting the top of the foundation with grout topping and the subfloor ventilation is in the perimeter foundation beam, consider the visual impact when the vents are not parallel to the new foundation height. This variation may not be noticeable over a large span.

REPAIR METHODOLOGY – 1a

Jack and Pack

Leaving perimeter foundation in its settled state
Weatherboard cladding and Type B foundation
(Concrete perimeter foundation with piles)

Definition: The Jack and Pack method requires jacking up the superstructure (floor framing, wall and roof framing with internal linings and roof claddings) and packing (using plastic shims or solid treated timber) onto the existing piles to support the floor framing. This relevelling may also include notching of bearers to achieve acceptable levels for the floor.

STEP	ACTIVITY
1.	Carry out a visual inspection of the concrete foundation perimeter. If foundation has vertical settlement less than 100mm and there is no visual structural damage to the concrete perimeter beam, consideration can be given to using Jack and Pack as a method of repair.
2.	Check Table 2.2 of MBIE Guidance document for non-structural crack repairs. If perimeter foundation beam has minor cracking as described in Table 2.2 of the Guidance document or less, Jack and Pack could be considered as a repair method.
3.	If available, use a robotic camera for a subfloor photographic survey to determine damage to structure and piles.
4.	Check floor levels for vertical settlement and prepare plan and strategy for relevelling or notching of bearers over piles.
5.	A reference point needs to be established to check the floor level changes.
6.	Check for gaps around window and door openings. Take photographs and use these for 'before and after' references.
7.	The bottom row of weatherboards may need to be removed to accommodate and camouflage the angle and slope on the foundation or the amount to be relevelled. With weatherboard cladding it may be simplest to form a metal flashing to accommodate and camouflage the slope difference of the foundation to the level line of the weatherboards.
8.	Establish reference datum at independent location away from the house.
9.	If cladding is other than weatherboard, eg. sheet cladding, it is possible to camouflage the foundation slope by extending the sheet length.
10.	With non-masonry veneer houses, all subfloor ventilation is in the perimeter foundation beam. If vents are in the top of the foundation, this is an indication there is no continuous steel reinforcing bar in the top of the foundation beam.
11.	If the cladding has been removed, consideration should be given to insulate the external timber wall framing.
12.	Apply appropriate Health & Safety procedures when contemplating working under the timber floor structure.
13.	Disconnect the pile connections to timber bearers. Consider how the new connections are going to work.

14. If the floor is to be lowered by notching bearers see Appendix 2 for guideline on maximum notching of bearers.

15. Generally, weatherboard and sheet cladding will overhang the foundation perimeter beam. In most cases the perimeter foundation beam will have a plate or bearer fixed directly to it with a R10 dowel or bolt. These bearer plates are either 100x50 or 100x75mm.

16. In most cases the simplest method of relevelling the floor structure will be to leave the bearer plate fixed to the perimeter foundation beam and either pack or notch the individual joists. When notching the joists, refer to Appendix 2 for allowable notch depths. When packing joists, fit full width and length of existing bearer plate with H3 timber packer for joists to sit on. Refit joists to bearer plate with an approved joist connector.

17. Pack on top of pile with H3.2 timber packer or approved plastic shim packer.

18. If existing bearers which span the piles are 100 x 75mm and the packing of these bearers exceeds 100mm in height, run a continuous sized bearer (100 x 75mm) directly under and supporting the existing bearer. Attach to the existing bearer with nail-on plates either side of the bearer at the pile location.

19. Reconnect bearers and packers to piles by a similar method as original method eg. wire tie through the pile stapled to both sides of the bearer or original bearer if an under-bearer has been added.

20. If piles need to be replaced (refer to MBIE Guidance Appendix A, 1.1) substitute options such as 125x125 H5 treated timber piles bedded in a concrete footing can be used (refer Table 6.1 of NZS 3604 for footing size).

21. Care needs to be taken to ensure the cover of the cladding over the perimeter foundation beam is weathertight. The minimum cover of the cladding is 50mm below the lowest timber member.

22. In some situations the face of the foundation perimeter beam could protrude past the line of the weatherboard cladding. When relevelling and packing of the perimeter foundation beam occurs, special design attention needs to be given to camouflage the slope variation between the foundation top and the level line of the weatherboards. This detail could be achieved by manufacturing a metal flashing.

Points to consider:

- When adjusting the levels of the dwelling, consider the visual impact when the subfloor vents are not parallel to the bottom of the cladding. This variation may not be noticeable over a large span.

REPAIR METHODOLOGY 2

Screw Pile

Masonry veneer and Type C foundation (Concrete slab)

Definition: Screw piling involves installing screw piles around the perimeter foundation beam at spacings and depths determined by an engineer. The screw piles act as the solid bearing point for the jacks lifting the foundation. Brackets are bolted to the foundation above each screw pile to provide a jacking point. The foundation is lifted and the internal slab is void filled simultaneously with a high flowing grout.

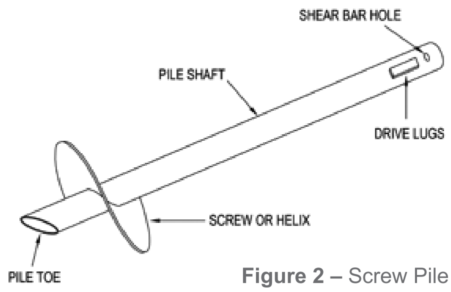


Figure 2 – Screw Pile

STEP	ACTIVITY
1.	Carry out visual inspection of perimeter foundation, any inter-tenancy walls (fire walls) and concrete slab. Screw piling can be used on any foundation or inter-tenancy wall with minor to moderate structural damage. Screw piles can vary in lifting height but are dependent on a Specific Engineering Design (SED) being undertaken.
2.	Obtain a geotechnical report to establish site profile and ground bearing conditions.
3.	Check floor levels in reference to foundation levels and establish site datum point.
4.	SED is required to determine screw pile location points, depth of bearing (each of which is dependant on position of foundation cracks), and geotechnical information. An engineer will also determine internal jacking points and void filling specifications.
5.	Install screw piles to required depth to achieve suitable bearing for temporary lift (generally less than 2.0m in depth).
6.	Install lifting brackets to the head of each screw pile and to the side of the perimeter foundation beam. Note that these are usually proprietary components developed by the lifting company.
7.	Drill core holes in internal floor slab as per SED for both mechanical jacking points (if required) and void filling points. Consideration is needed around the water proofing qualities of the internal void fill. Care is to be taken not to compromise the existing damp proof membrane (DPM) - usually a polythene film. Install internal lifting points if required.
8.	Where possible, only drill through floor coverings (eg: Vinyl floor coverings) in hidden areas such as underneath ovens, fridge spaces and in wardrobes. These small areas can then be repaired rather than replacing the entire floor covering.
9.	Slowly commence jacking (5mm increments) the perimeter ring foundation. The internal slab needs to be void filled and lifted simultaneously to avoid sagging of the concrete slab and disconnection of frame bottom plates.

10. Before underslab void filling is commenced, identify and check out plumbing and drainage services under slab or perimeter foundation beam. Arrange to secure or replace services that could otherwise be compromised during relevelling and void filling.

11. Consistently check internal floor levels and footing levels with reference to site datum and final required level during the jacking operation.

12. Once final height is achieved, lock off jacking points and complete void filling process.

    Note: By filling the void quickly will redistribute the load over the whole beam rather than leaving it on the point load screw piles.

13. Once final levels of floor and foundation are satisfactory, the external void fill can take place. Box out to the full width of the void fill required under the perimeter footing. Pump fill into voids by beginning at one jacking point and allowing it to flow to the next jacking point, ensuring void is filled consistently between the two points. Block off each jacking point so as not to encapsulate the jacks while pouring the void fill. Continue this step around entire perimeter.

14. Allow enough time (minimum of three days) to ensure void fill under the perimeter beam is cured enough for jacks to be removed.

15. Seal off internal jacking points and void filling holes with consideration to waterproofing requirements.

16. If void fill is placed between existing slab and existing DPM, consider internal void fill product drying specifications before replacing any floor coverings. This is to avoid moisture seeping through existing slab and becoming trapped in floor coverings such as carpets or vinyl.

Points to consider:

- Screw pile lengths will depend on the shallow bearing capability of the ground. Generally, sufficient bearing will be attained for jacking within the top 2.0 metres.
- The number of piles around the perimeter will depend on the strength of the foundation and the number of cracks in the perimeter beam. This is an engineering determination at design stage.
- Care needs to be taken to achieve or maintain a continuous moisture barrier under the slab. The existing underslab DPM must not be damaged. If the existing underslab DPM is damaged while drilling, jacking and void filling, a method of applying a ‘patch’ polythene film and sealing should be applied.
- Houses built with a concrete floor slab can have the bottom timber plate of internal walls fixed to the slab with shot fired fasteners. When lifting the slab it is important the slab is raised on a straight plane so as to minimise the ‘sag’ of the slab as this may pull the fasteners from the concrete and create a separation between the slab and the bottom plate. If separation does occur, consideration will need to be given to removing the linings of the affected wall and refastening with appropriate proprietary fasteners.

REPAIR METHODOLOGY 3

Mechanical Lift Off Concrete Jacking Pads

Mechanical jacking concrete perimeter ring foundation and jacking and packing of piles Type B foundation (Heavy weight brick veneer cladding)

Definition: Mechanical jacking of the perimeter ring foundation by pouring a series of concrete jacking pads at spaced locations beneath the existing foundation and using jacks under or beside the footing to lift the foundation back to level, filling the space beneath the lifted foundation with concrete void fill and packing the existing piles to support the floor framing.

STEP	ACTIVITY
1.	Carry out a visual inspection of the concrete perimeter foundation. If foundation has vertical settlement less than 100mm and there is no visual structural damage to the concrete foundation perimeter beam, consideration can be given to mechanical jacking as a method of repair.
2.	Check Table 2.2 MBIE Guidance document for non-structural crack repairs. If the foundation perimeter beam has minor cracking as described in Table 2.2 of the Guidance document or less, mechanical jacking could be considered as a repair method.
3.	If available, use a robotic camera for a subfloor photographic survey to determine damage to structure and piles.
4.	The ground water table level needs to be considered to determine how deep the excavations can go. Geotechnical survey data should be used as a reference but an on site physical investigation is needed as the geothechnical report will be specific to the time of year it was undertaken and water levels will vary depending on the season. If high ground water table levels do not allow excavation below the footing, consider Methodology 3a – Mechanical Lift Off Temporary Dunnage. Alternatively, brackets can be bolted to the side of the foundation to provide a lifting point as opposed to lifting from beneath the footing. This will, in turn, reduce the depth of excavations.
5.	Check for gaps around window and door openings. Take photographs and use these for ‘before and after’ references.
6.	Excavate for jacking pads around perimeter foundation beam as per engineer specifications. To avoid compromising bearing below footing, excavate for every second jacking pad and pour the pad. Time is needed for pads to cure before proceeding to excavate and pour the remaining jacking pads.
7.	Disconnect bearers from piles to allow subfloor to freely lift simultaneously with the perimeter foundation beam. Consideration needs to be given to any major internal load-bearing walls that will need to be lifted at the same time as the perimeter foundation is being lifted.
8.	Apply appropriate Health & Safety procedure for working under floors. To avoid damaging expensive flooring when cutting access holes to the subfloor, consider removing flooring in inconspicuous places such as in wardrobes, under fridges or ovens.

9. Install jacks on each jacking pad and lift in increments of up to 5mm at a time around the entire foundation using a laser level to monitor floor levels until desired lift height is achieved.

10. Pack perimeter foundation with H5 100x100 blocks or concrete pavers and packers so jacks can be removed. Packers will become part of the void fill.

11. Apart from major internal load-bearing walls, the rest of the subfloor will generally effectively float above the piles.

12. Jack any bearers that require further lifting.

If existing bearers are 100 x 75mm and the packing of these bearers exceeds 100mm in height, run a continuous sized bearer (100 x 75mm) directly under and supporting the existing bearer. Attach this to the existing bearer by nail-on plates either side of the bearer at the pile locations.

Pack on top of pile with H3.2 timber packer or other suitable and approved packer as described in the MBIE Guidance document. Fix one-piece packer to bearer.

If floor is bowed in places and requires lowering, apply a localised weight (cement bags or similar) to the area before re-fixing the bearer to the pile.

13. If the floor is to be lowered by notching bearers refer to Appendix 4 for guideline on maximum notching of bearers.

14. Reconnect bearers and packers to piles by similar method as original method eg. wire tie through the pile stapled to both sides of the bearer or original bearer if an under-bearer has been added.

15. If piles need to be replaced (refer to MBIE Guidance Appendix A, section A1.1) 125x125 H5 treated timber piles bedded in a concrete footing can be used (see Table 6.1 of NZS 3604 for footing size).

16. Take final levels and ensure that these are within acceptable limits before replacing flooring that may have been removed for access.

17. Pour concrete beneath perimeter foundation to fill voids, ensuring it flows through unseen areas between jacking points. This provides an opportunity to create a larger footing to increase bearing capacity of the foundation.

Points to consider:

- Penetrations in the foundation can create weak points that could possibly break and rotate under the pressure of lifting. Potential weak points could be pipe penetrations, vent holes, recessed (stepped) areas that accommodate steps and patios, or changes in direction. Care should be taken to provide extra support in these areas.

REPAIR METHODOLOGY 3a

Mechanical Lift Off Temporary Dunnage

Mechanical jacking concrete perimeter ring foundation using temporary dunnage and jacking & packing of piles. Type B foundation (Heavy weight brick veneer cladding)

Definition: Mechanical jacking of the perimeter ring foundation by placing temporary dunnage beside the foundation as support for jacks to lift the foundation back to level and packing the existing piles to support the floor framing.

Mechanical jacking using temporary dunnage can be used when high water table levels do not allow excavations below the perimeter foundation.

STEP	ACTIVITY
1.	Visual inspection of concrete perimeter foundation. If foundation has vertical settlement less than 100mm and there is no visual structural damage to the concrete perimeter beam, consideration can be given to mechanical jacking as a method of repair.
2.	Check Table 2.2 of MBIE Guidance document for non-structural crack repairs. If foundation perimeter beam has minor cracking as described in Table 2.2 of the Guidance document or less, mechanical jacking could be considered as a repair method.
3.	If available, use a robotic camera for a subfloor photographic survey to determine damage to structure and piles.
5.	Check for gaps around window and door openings. Take photographs and use these for 'before and after' references.
6.	For access to the foundation, excavate a 1m wide trench around the perimeter to the depth of the foundation.
7.	Disconnect bearers from piles to allow subfloor to freely lift simultaneously with the foundation beam. Consideration needs to be given to any major internal load-bearing walls that will need to be lifted at the same time as the perimeter foundation is being lifted.
8.	Apply appropriate Health & Safety procedure for working under floors. To avoid damaging expensive flooring when cutting access holes to subfloor, consider removing flooring in inconspicuous places such as in wardrobes, under fridges or ovens.
9.	Bolt right angled brackets to foundation to provide lifting points at centres specified by the engineer. Take care to install extra lifting points next to cracks in the foundation and areas that could be considered weak points (see points of interest below). Place dunnage (200 x 100mm bearers) below brackets, parallel to the foundation as bearing points to lift off. Concrete pavers can be used under dunnage to provide extra bearing.
10.	Install jacks under each jacking bracket and lift in increments of up to 5mm at a time around entire foundation using a laser level to monitor floor levels until desired lift height is achieved.

11. Install formwork against the bottom of the footing to accommodate the concrete void fill. This provides an opportunity to create a larger footing to increase the foundation bearing capacity. Re-check levels of foundation prior to void filling to ensure no settlement has occurred. Jacks and brackets can be removed once void fill has cured.

12. Apart from major internal load-bearing walls, the remainder of the subfloor will generally effectively float above the piles.

13. Jack any bearers that require further lifting.

If existing bearers are 100 x 75mm and the packing of these bearers exceeds 100mm in height, run a continuous sized bearer (100 x 75mm) directly under and supporting the existing bearer. Attach to the existing bearer by nail-on plates either side of the bearer at the pile locations.

Pack on top of pile with H3.2 timber packer or other suitable and approved packer and as described in MBIE Guidance document. Fix one-piece packer to bearer.

If floor is hogged in places and requires lowering, apply a localised weight (cement bags or similar) to the area before re-fixing the bearer to the pile.

14. If the floor is to be lowered by notching bearers refer to Appendix 2 for guideline on maximum notching of bearers.

15. Reconnect bearers and packers to piles by a similar method as original method eg. wire tie through the pile stapled to both sides of the bearer or original bearer if an under-bearer has been added.

16. If piles need to be replaced (refer to MBIE Guidance Appendix A, section A1.1) 125x125 H5 treated timber piles bedded in a concrete footing can be used (see Table 6.1 of NZS 3604 for footing size).

17. Take final levels and ensure that these are within acceptable limits before replacing flooring that may have been removed for access.

Points to consider:

- Penetrations in the foundation can create weak points that could possibly break and rotate under the pressure of lifting. Potential weak points could be pipe penetrations, vent holes, recessed (stepped) areas that accommodate steps and patios, or changes in direction. Care should be taken to provide extra support in these areas.

REPAIR METHODOLOGY 4

Engineered Resin Lift

Type C foundation
(Also applicable to Type B foundations followed by jacking and packing of internal piles)

Definition: Engineered resins consist of a solid polymer network formed by the reaction between two components - a proprietary engineered resin and a hardener. Lifting is achieved through expansion of the resin, allowing fine control of localised areas, and levels are achievable with no excavations and minimal intrusion.

The spacing and number of injection locations, resin mix specification, resin propagation radius and resin injection pressures are determined by the weight, strength and area of the structure to be corrected, and the amount of lift required.

STEP	ACTIVITY
1.	Undertake ground testing with a Scala Penetrometer or similar device. This will indicate current ground bearing capacities. A minimum of 200kPa bearing capacity is required to be able to lift a structure. If 200kPa bearing is not present in current ground conditions, engineered resin can be injected at 1m vertical intervals to achieve ground strengthening and then the strengthened ground can be used as the reaction to the levelling injection.
2.	Drill and install resin injection tubes (holes ranging from 6 – 16mm) around the perimeter of the footing and through the concrete floor slab. The spacing of injection points is relative to the parameters mentioned above. However, usually an injection grid of between 1.8 and 2.1 metres is applied. In tiled areas, injection points can be carefully inserted in mortar lines or in inconspicuous areas such as in wardrobes, under fridges or ovens.
3.	Inject resin directly below the footing at a depth of 500mm around entire area to be relevelled. If ground improvement is required to reach 200kPa, the length of the injection tubes can be lengthened to deliver the resin to considerable depths. By injecting the resin at 1 metre vertical intervals below the footing ground improvement is achieved providing suitable bearing to lift against.
4.	By continuing the injection process, having filled all voids and achieved compaction, the upward pressure of the expanding resin begins to gently lift the slab or footing.
5.	Carefully monitor the rate and extent of the lift using a number of locally placed laser level targets and slab level gauges.
6.	Once desired levels are achieved, undergo further ground testing to confirm ground improvement.

Points to consider:

- Site specific factors such as ground conditions, current foundation conditions and site access need to be considered before applying the engineered resin injection method.
- Geotechnical information needs to be analysed to ensure ground conditions can accommodate engineered resin without the loss of excessive product into unsuitable soils.
- Some unique urethane technologies provide up to 500% increase in bearing capacity.
- Resin can compact a specific, isolated weak layer, at depth, without the need for excavation.

CAUTION:

When considering relevelling a Type C foundation, be aware that buildings constructed before 1990 were not required to have structural ties between the perimeter foundation beam and the concrete slab. As a consequence, care should be taken to minimise the risk of separation between the two. The slab could be tied to the beam by drilling and epoxying steel pins between the two prior to any attempt to lift.

REPAIR METHODOLOGY 5

Crack Repair – Stitching

Type C foundation
(Slab stitching - Repairing cracks over 20mm in Type C concrete floor slabs)

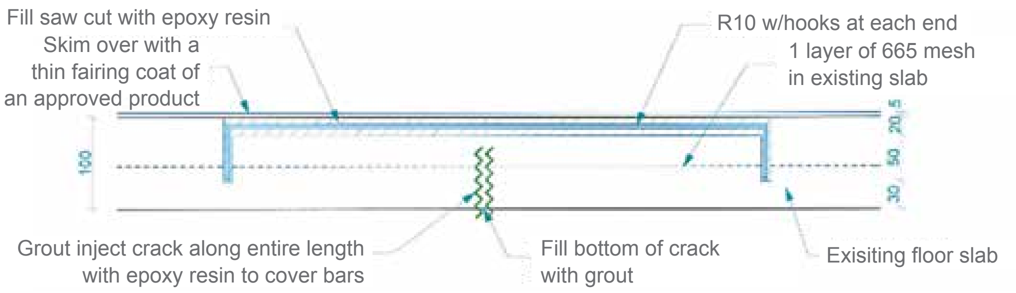
Definition: Slab stitching is used once concrete slabs have been relevelled. The process involves cutting chases at right angles to the crack and installing reinforcing bar staples set in an epoxy resin to prevent further spreading of the crack (see Figure 1).

STEP	ACTIVITY
1.	Cracks over 20mm require engineering input for repair specifications. All relevelling work must be completed before work begins on slab stitching.
2.	Inspect the crack to ensure there are no vertical misalignments greater than 2mm across the crack. Examine the crack closely to ensure reinforcing mesh has not been fractured or compromised. If there is an offset of more than 2mm or it is evident that reinforcing mesh has been fractured, refer to MBIE Guidance Document: Appendix A4.3 Relevelling floors.
3.	Grind chases in concrete every 300mm and at right angles to the slab crack. The chase is generally 20mm deep x 20mm wide x 600mm overall length. At each end of the chase, a 20mm hole is drilled to a depth of 70mm. The crack and chases need to be cleaned and dried to ensure a good bond with the poured in resin or grout.
4.	Fill bottom of crack with grout that will seal off the bottom and stop epoxy flowing out through tailings below the slab. Note: In theory there should be a damp proof membrane (DPM) under the slab and over the tailings so the loss of epoxy resin will be beneath the concrete and over the DPM.
5.	Use R10 rods as staples and insert these into the chases. Hooks of 50mm at each end of the staples sit in the pre-drilled holes at each end of the chase. Ensure staples are sitting at least 5mm below the surface of the slab.
6.	Pour epoxy resin to fill the crack and chases, covering reinforcing steel up to level of the concrete surface.
7.	Once epoxy resin is cured, a floor levelling compound can be used to smooth the surface if there is minor offset in levels either side of the crack.

Points to consider:

- As floor slab cracks only offer access to the top surface, preparation and process is vital. Care needs to be taken to ensure sufficient cleaning of the crack, successful injection of the correct grout and the crack is filled completely.
- Refer to MBIE Guidance Document, Appendix A4 for more information on assessment and repair options for concrete floor slabs.

Figure 1 - Crack repair plan. Not to scale.



Appendix 1

New Build Market Rates per m^2

Date 2/12/2013

	Superstructure (Timber framing) (excluding foundations below bottom plate)				
	Type **B1** Foundation	Type **B2** Foundation	Type **C1** Foundation	Type **C2** Foundation	
	Timber floor, Concrete perimeter foundation	Timber floor, Concrete perimeter foundation	Concrete slab (slab on grade)	Concrete slab (slab on grade)	
	Light weight cladding and roofing	Masonry veneer and heavy weight roofing	Light weight cladding and roofing	Masonry veneer and heavy weight roofing	
	$1,378	$1,418	$1,378	$1,418	
	PLUS (one of the following)				
	TC3 Foundation Options				
	NZS 3604	TC3 Guidance Document 2012	TC3 Guidance Document 2012	TC3 Guidance Document 2012	Relevellable Slab (Firth)
	Slab on Grade	Surface Structure Type 1	Surface Structure Type 2A	Surface Structure Type 2B	Surface Structure (not part of MBIE foundation survey costs)
	$152	$222	$478	$537	$320 estimated market costs
	TOTALS (add Superstructure and a Foundation option)				
B1	**$1,530**	**$1,600**	**$1,856**	**$1,915**	**$1,698**
B2	**$1,570**	**$1,640**	**$1,896**	**$1,955**	**$1,738**
C1	**$1,530**	**$1,600**	**$1,856**	**$1,915**	**$1,698**
C2	**$1,570**	**$1,640**	**$1,896**	**$1,955**	**$1,738**

Notes:
All figures shown are excluding GST
The Superstructure rates are guideline market rates taken from various publication. (Rawlinsons Residential Housing)
The TC3 Foundation option rates have been taken from the MBIE survey of benchmark foundation cost. (v0.75 Draft. 15.10.2013)
The cost for the relevellable slab is an estimated market rate

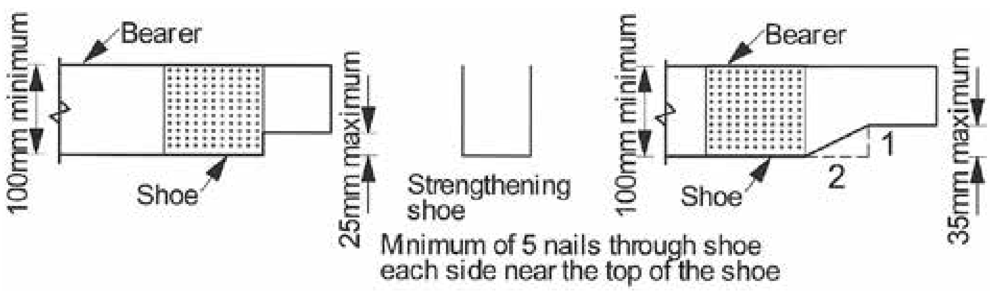
Appendix 2

MBIE 2013, Bearer Notching

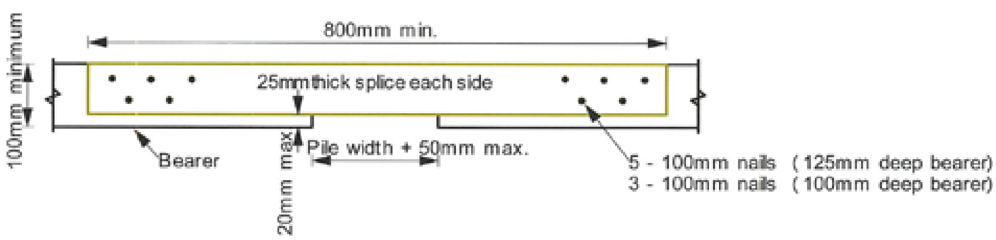
Proposed addition to Guidance

Notch Limits

End Notches



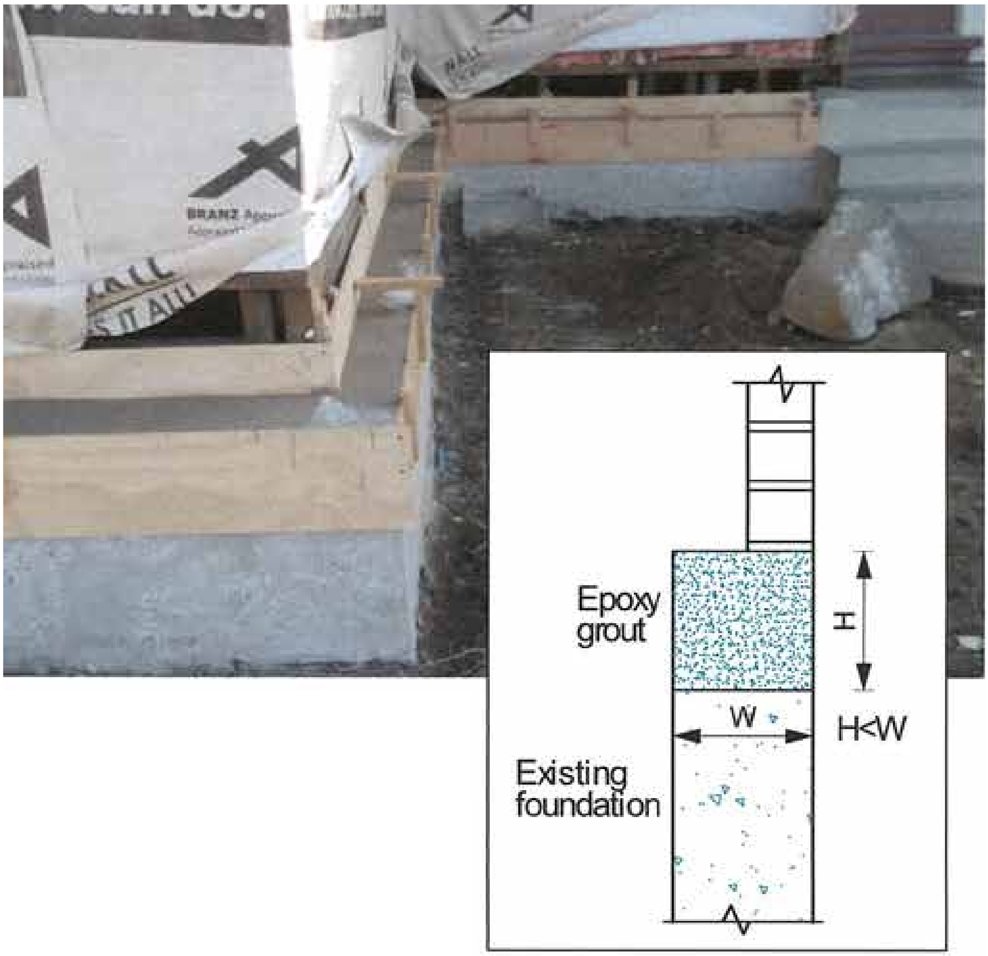
Mid-span notches



Appendix 3

MBIE 2013, Foundation Topping

Proposed addition to Guidance



- Veneer replacement provided opportunity to relevel perimeter foundation with epoxy grout to accept new veneer
- Existing roughened
- Maximum grout thickness H < W.

References

[1] Liquefaction is a phenomenon whereby a saturated or partly saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking, causing it to behave like a liquid. The phenomenon is most often observed in saturated loose sandy soils, hence the volume of liquefaction in the eastern suburbs of the city.

[2] Housing New Zealand Annual Report 2011-2012 Impact Statement 1 pg 13.

[3] Southern Response Earthquake Services Ltd is the government-owned company responsible for settling claims by AMI policyholders for Canterbury earthquake damage which occurred before 5 April 2012 (the date AMI's day to day insurance business was sold to IAG). (source: SR website).

HNZC – Canterbury Earthquake Recovery Videos

Methodologies:
http://www.hnzc.co.nz/canterbury-earthquake-recovery-programme/Videos
Video 1 – Re-levelling: A Unique Approach (6 Aldershot Street)
Video 2 – A different approach to re-levelling (62 St Heliers Crescent)
Video 3 – Foundation Repair Trials: Re-levelling a house in Aranui (53 Eureka Street)
Video 4 – The Impact of Severe Liquefaction (21 & 21A Riselaw Street)

Ministry Of Business Innovation & Employment Guidance
(MBIE Guidance, December 2012)

MBIE Survey Of Benchmark Foundation Costs
(V 0.75 Draft. 15.10.2013)

Rawlinsons Residential Housing

Figure 2 – Repair Methodology 2 - Screw Pile
http://en.wikipedia.org/wiki/File:Screwpilediagram.gif

Glossary of Terms

Ministry of Business Innovation & Employment Guidance (MBIE Guidance 2012)

Repairing and rebuilding houses affected by the Canterbury earthquakes

http://www.dbh.govt.nz/UserFiles/File/Publications/Building/Guidance-information/pdf/canterbury-technical-guidance-introduction.pdf

Part B:

Future liquefaction performance expectations for land and buildings

Table 10.1: Observed land performance and proposed technical categories
Foundation technical category
Observed land performance.

TC1

TC1 covers those areas of greater Christchurch where on an area-wide basis, no significant land deformation occurred as a result of liquefaction from either the 4 September 2010 earthquake or the 22 February 2011 aftershock and there is generally greater than 3m depth to groundwater.

TC2

TC2 covers those areas of greater Christchurch where on an area-wide basis or negligible land deformation occurred as a result of liquefaction from the 4 September 2010 earthquake and only relatively small amounts of land deformations occurred as a result of the 22 February 2011 aftershock. It also includes some areas in Selwyn District and northern Christchurch that did not suffer land damage but are considered at some risk of potential ground damage from liquefaction until proved otherwise.

TC3

TC3 covers those areas of greater Christchurch where on an area-wide basis, land deformation occurred as a result of liquefaction from the 4 September 2010 earthquake and moderate to severe land deformations occurred as a result of or the 22 February 2011 aftershock, together with the areas identified at high future probability of ground damage until proved otherwise.

Uncategorised

Uncategorised areas include: parks, commercial areas and properties greater that 4,000m^2, together with those areas that were not mapped for damage from the 4 September 2010 or the 22 February 2011 earthquakes.

(Date: December 2012. Version: 3)

Foundation Types
Part A: Technical guidance
Section 2.1 Typical dwelling foundation types

Table 2.1: House foundation and floor types on the flat

Type A: Timber-framed suspended timber floor structures supported only on piles. Stucco, weatherboard or light texture-clad house.

Type B1: Timber-framed suspended timber floor structures with perimeter concrete foundation. Stucco, weatherboard or light texture-clad house.

Type B2: Timber-framed suspended timber floor structures with perimeter concrete foundation. Brick or concrete masonry exterior cladding (veneer).

Type C1: Timber-framed dwelling on concrete floor (slab-on-grade). Stucco, weatherboard or light texture-clad house.

Type C2: Timber-framed dwelling on concrete floor (slab-on-grade). Brick or concrete masonry exterior cladding (veneer).

(Date: December 2012. Version: 3)

List of Acronyms and Definitions

Term	Definition
Bgl	Below Ground Level
BH	Borehole
CPT	Cone Penetrometer Test
DPM	Damp Proof Membrane
EOH	End of Hole
Foundation Type B1, B2, C1, C2	House foundation and floor types (see Glossary of Terms)
HA/DCP	Hand Auger and Dynamic Cone Penetration Test
PGA	Peak Ground Acceleration
SED	Specific Engineering Design
SLS	Serviceability Limit State
TC1, TC2, TC3	Land category – see Glossary of Terms
ULS	Ultimate Limit State

Conclusion

The 2010 and 2011 Christchurch earthquake events created an unprecedented amount of damage to homes and properties. One of the biggest challenges for most parties has been the lack of practical knowledge to repair damaged homes.

The underlying focus for this reference document is that it complements the MBIE Guidance and can be used by the engineering and contracting community as well as property owners, to help determine repair methodologies for homes in Christchurch and as a guide following large earthquakes or similar events in New Zealand.

From the trial, five repair methodologies have been developed that best suited the repair of the properties in the programme. These different methodologies were prescribed yet, until the completion of the trial, were not confirmed practical or viable in this situation.

The single most important factor is the need to understand the ground and the performance expectations for the land the house is situated on. This knowledge will enable a successful choice and application of an appropriate repair methodology.

All those involved in the trial fully embraced the programme by offering their knowledge and experience to ensure the methodology used by them on each of the properties would help benefit not only Housing New Zealand and Southern Response Earthquake Services, but also the wider community.

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Maiden Group

Martin Civil Construction

Slab Jacking NZ Ltd

Smartlift Systems

Stake Consulting Ltd

Uretek Ground Engineering (NZ) Ltd

Housing New Zealand
Housing New Zealand Corporation

Te Manapou i te Haumanutanga o Waitaha
Contributing to the earthquake recovery of Canterbury