File No. DOIA 1819-0178

31 August 2018

Mr Jake Preston
fyi-request-8346-68955316@requests.fyi.org.nz

Dear Mr Preston

I refer to your email of 17 July 2018 to the Earthquake Commission (EQC) requesting the following information under the Official Information Act 1982 (the Act):

- *I request that all drafts research paper 0380 be provided, as clearly the response from Renee Walker was, at best, in error.*
- *I request all papers and minutes and any communications between EQC, its employees, contractors and agents, the EAG, and any staff or contractors associated with the support of the EAG, that relate to the briefings provided to parties outside EQC or EAG, on work related to research papers 0380.*

Your request was transferred by EQC to the Ministry of Business, Innovation and Employment (MBIE) on 3 August 2018 under section 14(b)(ii) of the Act, as EQC believed the information requested relates more closely connected with the functions of MBIE.

In response to the first part of your request MBIE did a search of its information system and found the following documents. These are released to you in full:

- *Guidance on house repairs and reconstruction following the Canterbury Earthquakes – 10 November 2010*

- *Preview of the update to: Guidance on house repairs and reconstruction following the Canterbury Earthquakes – October 2011*

On the second part I am refusing this under section 18(e) of the Act as the document alleged to contain the information requested does not exist or cannot be found.

You have the right under section 28(3) of the Act to request a review by the Ombudsman.
The relevant details can be found here:

www.ombudsman.parliament.nz

Yours sincerely

Dave Robson
Manager, Building Performance and Engineering

Department of
Building and Housing
Te Tari Kaupapa Whare

Preview of the update to:

Guidance on house repairs and reconstruction following the Canterbury Earthquakes

October 2011

Contents

1.0 Introduction

1.1 Scope

This preview document:

- supports the announcement of Canterbury Green Zone repair and reconstruction options following the 2010/11 Canterbury earthquake sequence
- provides a summary of updated technical guidance to engineering solutions for repairing and rebuilding houses, following the series of earthquakes, that will shortly be provided by the Department of Building and Housing
- outlines the technical categorisation system that will determine the appropriate methodologies for house repairs in the Green Zone on the flat in the Canterbury region
- provides options to enable repairs and reconstruction to proceed in the interim until the updated guidance is released.

The Department will shortly publish a full update to the document *Guidance on house repairs and reconstruction following the Canterbury earthquake*, which was issued in December 2010. This is a preview of the updated document and provides sufficient information to allow work to proceed in the interim until the new document is published. The new document will provide assessment criteria and detailed engineering solutions for the repairing and rebuilding of houses in Canterbury that have been damaged by the earthquakes.

The updated guidance document will primarily focus on solutions for Green Zone[1] land on the flat. The 22 February 2011 aftershock brought a greater understanding of damage to houses from liquefaction, particularly the extent of ground likely to settle appreciably in future earthquakes. This has led to land on the flat being assigned into three technical land categories that are determined by the expected future liquefaction performance. The guidance will concentrate on providing foundation solutions for the first two Technical Categories; these are areas where the overall settlement in a future earthquake is not expected to be excessive. Houses in the third Technical Category, where overall house settlement may be significant in a future earthquake, will require deep geotechnical investigation and specific engineering design. It is likely that deep piles founded to a good bearing layer will be required, but other innovative foundation system solutions, including ground treatment, are being trialled. Future guidance on solutions in this third Technical Category may be available by the end of 2011.

The guidance will also provide additional information on assessment approaches for properties in Port Hills areas affected by rock fall, landslip and shaking damage, as well as additional information on repair and assessment processes.

The guidance document is intended for use by the engineering design, construction and insurance sectors, local authorities, and their professional advisers and contractors. Publication of this document forms part of the Government's co-ordinated response during the transition to long-term recovery in Canterbury.

[1] Green Zone was announced by CERA, initially on 23 June 2011 as being land where repairs or reconstruction can proceed. This is progressively being updated. Refer www.cera.govt.nz.

1.2 Background

The Darfield, Canterbury earthquake of 4 September 2010 was an internationally significant event that focused attention on damage to residential properties from liquefaction and lateral spreading. The 22 February 2011 Christchurch earthquake caused further liquefaction that affected houses across a far wider area of Christchurch; it also caused extensive rock fall and some landsliding in the Port Hills. Significant shaking damage was observed in the hill suburbs. Other significant aftershocks, most notably on 13 June 2011, also caused liquefaction in the low-lying areas that were worst affected in the main earthquakes, and further shaking damage to hillside properties.

As at the end of August 2011, approximately 385,000 insurance claims relating to 120,000 properties had been submitted to the Earthquake Commission (EQC). Of these, approximately 65,000 are likely to have experienced land damage as a result of the Canterbury series of earthquakes; this ranges from very minor to very severe damage. The majority of the dwelling damage claims not affected by land damage relate to minor damage such as damaged chimneys and superficial cracking to cladding/linings. In many cases, the subsequent major aftershocks will have made the damage worse.

The volume of repair and reconstruction activity is placing considerable pressure on the insurance assessment, engineering design, construction, and consenting capacity available. Insurers and reinsurers need confidence that the rebuilding work is robust, without unnecessary costs. The guidance that will be provided aims for a consistent approach that minimises the individual investigation and design effort required for each property. It will take a prudent approach that is mindful of both costs and risks, providing solutions and construction methods that aim to meet the requirements of the Building Act and Building Code.

1.3 Acknowledgement

In preparing the updated guidance on house repairs and reconstruction following the Canterbury earthquakes, the Department acknowledges the contribution from:

- The Department's Engineering Advisory Group comprising engineers and remediation specialists with representation from the following organisations:
  - BRANZ (including a member of the NZS3604 Committee)
  - GNS Science
  - Structural Engineering Society (SESOC)
  - New Zealand Society for Earthquake Engineering
  - New Zealand Geotechnical Society
- The Earthquake Commission
- Tonkin & Taylor

2.0 The Technical Guidance document

2.1 Scope of updated guidance document

A large proportion of the significant damage to residential dwellings in the Canterbury earthquakes was caused by ground deformation resulting from the effects of liquefaction, rock fall, and some landslip.

Liquefaction gave rise to differential and overall vertical settlement effects and lateral spreading. The latter was the most damaging to buildings and infrastructure.

The Department's updated guidance document will provide standard methods and solutions for the assessment, repair and rebuilding of foundation and floor elements for areas on the flat.

Advice on assessing the effects of land movement on houses and retaining walls will also be provided. Along with limited general information on repairs, as in most cases specific advice will be required.

Recognised repair methods can be used for damage resulting from strong ground shaking, but some guidance, particularly for chimneys and superstructure elements, will be included in the document.

Canterbury focus

The options and recommendations in the guidance document will be specific to residential properties directly affected by the Canterbury series of earthquakes. National best-practice guidance on designing residential dwellings to take account of potential liquefaction will be prepared in due course, and will draw upon information in this document.

Types of dwelling covered in document

The document will focus principally on one-storey and two-storey light timber framed dwellings, which are the dominant form of construction in the affected area. Accordingly, the document will refer to the timber-framed buildings Standard, NZS 3604.

There are, however, other forms of construction and materials for which other design approaches and documentation apply (for example, non-specific design Standards such as NZS 4229 for reinforced concrete masonry). Assessment and repair specifications for these types of buildings will require case-by-case consideration, although the guidance provided on repair and reconstruction of foundations and floors could well apply.

Regulatory Context

The methods and solutions proposed in the updated document will not be mandatory. It will be issued as guidance under section 175 of the Building Act 2004.

The document aims to provide guidance to Building Control Authorities to assist them to comply with the Building Act, using the 'reasonable grounds' test under section 49 of the Act.

2.2 Objectives

The principal objectives of the guidance document will be to provide repair and reconstruction solutions and options that:

- are appropriate to the level of land and building damage experienced
- take account of the likely future performance of the ground
- meet Building Act and Building Code requirements
- are acceptable to insurers.

The approaches and options outlined in the guidance document will focus on meeting current regulatory requirements, with a view to also satisfying relevant insurance requirements without giving rise to betterment concerns. Owners may choose to specify additional measures to achieve greater levels of resilience, noting that this would be likely to be outside the scope of insurance contracts and would also require specialist geotechnical engineering advice.

2.3 Structure of the guidance document

The document will be structured in two parts, A and B.

- Part A provides technical guidance, including specific information on assessment and repairs or rebuilding options.
- Part B contains background technical information that gives the context for the information in Part A, including comments on relevant building regulatory provisions.

3.0 Technical Categories for liquefaction

3.1 Technical Categories

To clarify and simplify repair and reconstruction options and to enable resources to be focused on areas of greatest risk, the CERA Green Zone on-the-flat has been divided into three Technical Categories that reflect both the liquefaction experienced to date and future performance expectations. The Categories and corresponding criteria are summarised as follows:

- **Technical Category 1 (TC1):**
  - Future land damage from liquefaction is unlikely, and ground settlements are expected to be within normally accepted tolerances.
- **Technical Category 2 (TC2):**
  - Minor to moderate land damage from liquefaction is possible in future large earthquakes.
- **Technical Category 3 (TC3):**
  - Moderate to significant land damage from liquefaction is possible in future large earthquakes.

Observations of damage in the Canterbury series of earthquakes have been used to determine Technical Category 1. Technical Category 2 includes locations where underlying soil types are potentially susceptible and those areas where liquefaction was actually observed, as well as observations of damage.

Technical Category 1 is generally regarded as complying with the 'good ground' definition of NZS 3604[2]; this means it is suitable for standard residential construction (subject to confirmation from the standard NZS 3604 tests – ie scala penetrometer, hand auger). Technical Categories 2 and 3 are outside the definition of 'good ground' for standard residential construction, and are therefore not included within the scope of NZS 3604.

The different Technical Categories are outlined on Christchurch City, Selwyn and Waimakariri Residential Foundation Technical Category Maps:

- TC1 grey
- TC2 yellow
- TC3 blue

Technical Category (TC) and other land information can be obtained from a CERA website: **www.landcheck.org.nz**. The website will advise residential property owners and their insurers of the foundation Technical Category appropriate to their specific site.

Insurers, their Project Management Organisations (PMO's), Building Consent Authorities, designers and builders will have access to the Canterbury Recovery Orbit website, as necessary. This will enable access to Technical Category and existing geotechnical information specific to the site, provide a means to enter geotechnical data collected and facilitate building consent applications.

3.2 Other land considerations

Other land aspects are still being worked through with government and local authorities. These include the risk of flood to finished floor levels in some areas, and any land remediation.

[2]The definition of 'good ground' in NZS 3604 was modified when it was referenced in Acceptable Solution B1/AS1. Ground in Canterbury with the potential for liquefaction and lateral spread was excluded, refer to: http://www.dbh.govt.nz/liquefaction-construction-on-ground-guidance.

4.0 Overview of foundation repair and rebuild approaches

4.1 Interim repair and reconstruction options

Until the updated guidelines are published the following table provides options to enable repairs and reconstruction to proceed, using the December 2010 *Guidance on house repair and reconstruction following the Canterbury earthquake* as a basis.

Foundation Technical Categories	**Where new foundation (including floor slab) are required**[3]	**Where foundations (including floor slab) are to be repaired only** i.e. within criteria provided in Table 4.1 of December 2010 Guidance[4]	**Superstructure Repairs Only** No foundation damage
TC1	For foundations, follow NZS 3604:2011 Timber Framed Buildings, as modified by its referencing in Building Code Acceptable Solution B1/AS1 requiring ductile reinforcing in slabs: refer information sheet **www.dbh.govt.nz/canterbury-earthquake-seismicity**	Refer to December 2010 Guidance	Normal repair methods used Also refer to December 2010 Guidance
TC2	New houses with lightweight cladding and roofing, with suspended timber floors and foundations in accord with NZS 3604:2011 Or Use enhanced slab options 1 to 4 as provided in December 2010 Guidance with the exception that the depth of compacted gravel fill under Option 1 should be increased to 800mm minimum and the geotextile reinforcement replaced with Geogrid reinforcement		
TC3	Specific geotechnical investigations and specific engineering design required Deep piles if suitable bearing layer < 10 m Further guidance being developed following testing of other foundation system options	Specific geotechnical investigations and specific engineering design required	

[3]Solutions provided are minimum recommendations. Homeowners can always choose more robust options, noting the need to discuss this with the insurer.

[4]Note that the criteria to leave as is, relevel or replace foundations provided in Table 4.1 of the December 2010 document is being slightly relaxed in the updated guidance document, based on further research.

4.2 Repairs for liquefaction settlement

The extent and method of repairs requires careful consideration, including an understanding of what is practically achievable. In many cases where minor or moderate settlement has occurred, it is considered that foundations and floors can be re-levelled. In some cases the foundations have sustained significant damage and require replacement, but there is only minor damage to the house superstructure above (wall and roof framing, linings and cladding). In these cases, to reduce the period of displacement for the occupants, it may be appropriate to lift the house and construct new foundations and floors.

4.3 Reconstruction in liquefaction affected areas

As a guiding principle to mitigate the effects of liquefaction, it is preferable to build using light materials rather than heavy materials. Light construction (roof, walls and floors) significantly reduces the imposed load on the subsoils, thereby reducing the settlement potential. For example, a lightweight structure will exert as low as 30% of the imposed weight around the perimeter compared to a heavy roof, masonry cladding and concrete slab dwelling.

The guidance document will, however, provide foundation solutions for Technical Categories 1 and 2 that enable other forms and weights of cladding material to be used.

For dwellings on Technical Category 1 sites, timber piles and timber floors, or concrete foundations (with B1/AS1 modifications[5]) that comply with the timber framed buildings standard, NZS 3604, are considered appropriate.

For dwellings on Technical Category 2 sites, further enhanced foundation systems (e.g. a stiffer and more effectively tied concrete slab placed on well compacted gravels) are recommended as appropriate solutions. The additional cost of constructing a more robust foundation and floor system than the minimum requirements of NZS 3604 is considered minor in the context of the overall repair or rebuilding cost. It is estimated at less than 5% of the total house cost, depending on option selected. Furthermore, following the proposed solutions are likely to cost less than the geotechnical and structural engineering investigation and design that would be necessary to provide an alternative solution on a house-by-house basis.

For dwellings on Technical Category 3 sites, initially only general information will be provided on specifically designed options such as deep piled foundations. It is also noted that, while the performance of shallow piled and timber sub-floor framed dwellings in future liquefaction events in these areas is difficult to quantify, this type of construction is more readily repairable than other forms of construction.

Specific information on foundation repair and reconstruction options will not be provided in this version of the updated guidance document for dwellings on Technical Category 3 sites. Field trials are being undertaken during October to evaluate site land remediation options. Further information to assist with foundations in Technical Category 3 will be provided in coming months.

[5]Modifications in Acceptable Solution B1/AS1 include additional requirements for slab reinforcement and ties between the slab and footings - see www.dbh.govt.nz/liquefaction-construction-on-ground-guidance

Individual house owners in any of the Technical Categories may wish to go above and beyond the solutions that will be suggested in the document. They may specify a higher level of foundation performance. The document will provide information on the relevant engineering principles and parameters to be adopted for an enhanced foundation and floor system. It should assist engineers undertaking specific structural and geotechnical engineering design, and inform discussions with insurers as to whether the system falls within the scope of the insurance policy.

4.4 Landslip and rock fall

Foundations subject to landslip and rock fall will require specific engineering design. Broad guidance on landslip and the assessment of retaining walls will also be provided in the guidance document.

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New Zealand Government

Guidance on House Repairs and Reconstruction Following the Canterbury Earthquake

A Summary of Geotechnical and Structural Engineering Recommendations to Guide House Repairs and Reconstruction

Prepared by the Engineering Advisory Group
to establish the feasibility and indicative content of a Guidance Document
to be produced by the Department of Building and Housing

Draft for Discussion at Workshop
Wednesday 10 November 2010

This draft is confidential and is provided to you for discussion purposes only, and is NOT to be copied or distributed. The contents do not represent government policy

Contents

Overview

Context

This draft document was prepared as part of a project to establish the feasibility and indicative content of a Guidance Document to be produced by the Department of Building and Housing.

This draft was prepared during October 2010, with the objective of providing a basis for rapid guidance to organisations involved in the repair and reconstruction of houses affected by this earthquake. The principal focus is the construction and insurance sectors and local authorities, and their professional advisers and contractors. The earthquake and its effects are complex, and it is acknowledged that the full picture about how residential structures responded to liquefaction effects has yet to be established, with research being ongoing. It may well be that some aspects of the recommendations in document are added to or changed over time.

The options and recommendations in this draft document are specific to houses directly affected by the Darfield, Canterbury earthquake. While information on mitigating the effects of liquefaction on residential dwellings is provided, this document does not represent a best practice guide for addressing liquefaction in other parts of Canterbury or New Zealand.

Purpose and Scope

The purpose of this draft document is to provide guidance on the engineering performance objectives and requirements for the repair and reconstruction of houses damaged in the Darfield, Canterbury Earthquake.

The focus of the document is on foundation and floor elements, and standard methodologies are provided for both structural repairs and new construction. Guidance is also provided for common areas of superstructure concern such as chimneys.

The document summarises the different requirements of insurance contracts and building regulatory provisions as they apply to both repairs and the construction of new elements and whole dwellings. The land damage zones and categories from the Tonkin and Taylor Stage 2 reports are summarised, and observations made regarding the future likelihood of liquefaction. Repair criteria and assessment approaches are outlined, along with re-levelling techniques and options for replacement foundation elements.

Future Performance

The effect of the widespread liquefaction in certain areas of Canterbury has been to cause differential settlement, tilting and in some cases spreading of foundations. The land remediation approaches being adopted by Government will have the effect of significantly reducing the future risk of lateral spreading, which was the most damaging liquefaction effect in this earthquake.

Liquefaction may well occur in future earthquakes in the affected areas, and may again result in differential settlement. The suggested options for new foundation elements provide a measure of additional protection should liquefaction occur in future earthquakes, taking the opportunity to mitigate the risks of future damage at relatively minor cost. The recommendations reflect the basic engineering principle that wide, stiff and appropriately tied foundation systems will perform better than other foundation and floor forms.

Individual house owners may wish to go above and beyond the solutions suggested in this document, and specify a higher level of foundation performance than required by either building regulations or insurance. This document provides information on the relevant engineering principles and parameters to be adopted for an enhanced foundation and floor system, for which specific structural and possibly geotechnical engineering input will be necessary, in addition to discussions with insurers.

Application

Table 1 below summarises the principal building outcome objectives corresponding to the land zones defined in the Tonkin and Taylor Stage 2 report.

The outcome objectives listed in the table are regarded as meeting the fundamental requirements of both building regulations and insurance, as outlined in Section 2.

Table 2 on the following page extends this to summarise the recommended design process elements for the foundations and other parts of the building corresponding to these outcome objectives.

Table 1: Land and Building Outcome Objectives

Land Zone	Land Damage	Overall Outcome Objectives Depending on Levels of Building Damage
A	No Apparent Land Damage	Repaired building
		New building with foundations to resist liquefaction where the land is subject to liquefaction as shown on published hazard maps
B	Minor or Moderate Land Damage	Repaired building
		Repaired building with new foundations to minimise superstructure damage from future liquefaction
		New building with foundations to minimise superstructure damage from liquefaction
C	Moderate, Major or Very Severe Land Damage	Repaired building
		Repaired building with new foundations to minimise superstructure damage from future liquefaction
		New building (most likely) with foundation designs to minimise superstructure damage from liquefaction
Not Zoned	No Apparent Land Damage	For buildings in areas that have not been the subject of specific land assessment (eg. building damage only or isolated areas of land damage), the above combinations apply depending on the specific circumstances
	Minor Land Damage	
	Moderate Land Damage	
	Major Land Damage	
Restriction Zone	Very Severe Land Damage	New building with foundations specifically designed to resist liquefaction (including lateral spreading)

Table 2: Summary of Design Process Elements Corresponding to Overall Outcome Objectives

Overall Outcome Objective	Design Process	
	Walls, Suspended Floors and Roof	**Foundation and Floor**
Repaired building	Existing house repaired; plus addition of smoke detectors	Repairs where necessary
Re-levelled and repaired building	Existing house repaired; plus addition of smoke detectors	Reinstatement only, via re-levelling (Section 5.1)
New foundations and floors to minimise superstructure damage from future liquefaction	Existing house repaired; plus addition of smoke detectors	Guidance Document solutions (Section 5.2)
New building with foundations to minimise superstructure damage from future liquefaction	To NZS 3604 requirements	Guidance Document solutions (Section 6)
New building with foundations specifically designed to resist liquefaction (including lateral spreading)	To NZS 3604 requirements	Specific Engineering Design (Section 6)

Repair and Reconstruction Options and Criteria

The criteria and options for repair and reconstruction outlined in this draft document apply where land remediation has addressed the future risk of significant lateral spreading (ie. Land Zones B and C).

The extent and method of repairs requires careful consideration, including an understanding of what is practically achievable. In many cases where minor or moderate settlement has occurred, it is considered that foundations and floors can be re-levelled. In some cases where the foundations have sustained significant damage and require replacement, the house superstructure above (wall and roof framing, linings and cladding) have sustained only minor damage. In these cases it may be appropriate to lift the house up and construct new foundations and floors, with the objective of reducing the overall period of displacement of occupants.

Where new foundation elements are considered necessary, enhanced foundation systems (eg. a stiffer and better tied concrete slab placed on well compacted gravels) are recommended as the solution to be provided under insurance provisions. Six foundation and floor options are outlined for both foundation replacement and full reconstruction options. The additional cost of constructing a more robust foundation and floor system than the minimum requirements of the light timber framed structures code (NZS 3604) by providing effective tie reinforcement in thicker concrete slab floors is considered minor in the context of the overall repair or rebuilding cost, and should give a significant improvement in performance in future earthquake events in the affected areas.

Site Verification

The suburb geotechnical reports being prepared for EQC will investigate the deeper soil profiles and the liquefaction hazards for a number of suburbs affected by liquefaction in Christchurch. They will address the geotechnical seismic risk/issues for the suburb as a whole, and provide sufficient information for the design of structures for this hazard.

Field investigations for individual sites may therefore be limited to Scala Penetrometer Testing and hand augers to confirm that the upper 2m of land meets NZS 3604 requirements for static bearing. It is expected that these reports need not be more than a one page letter or template detailing the observed damage, and providing confirmation that the upper 2m provides sufficient bearing capacity.

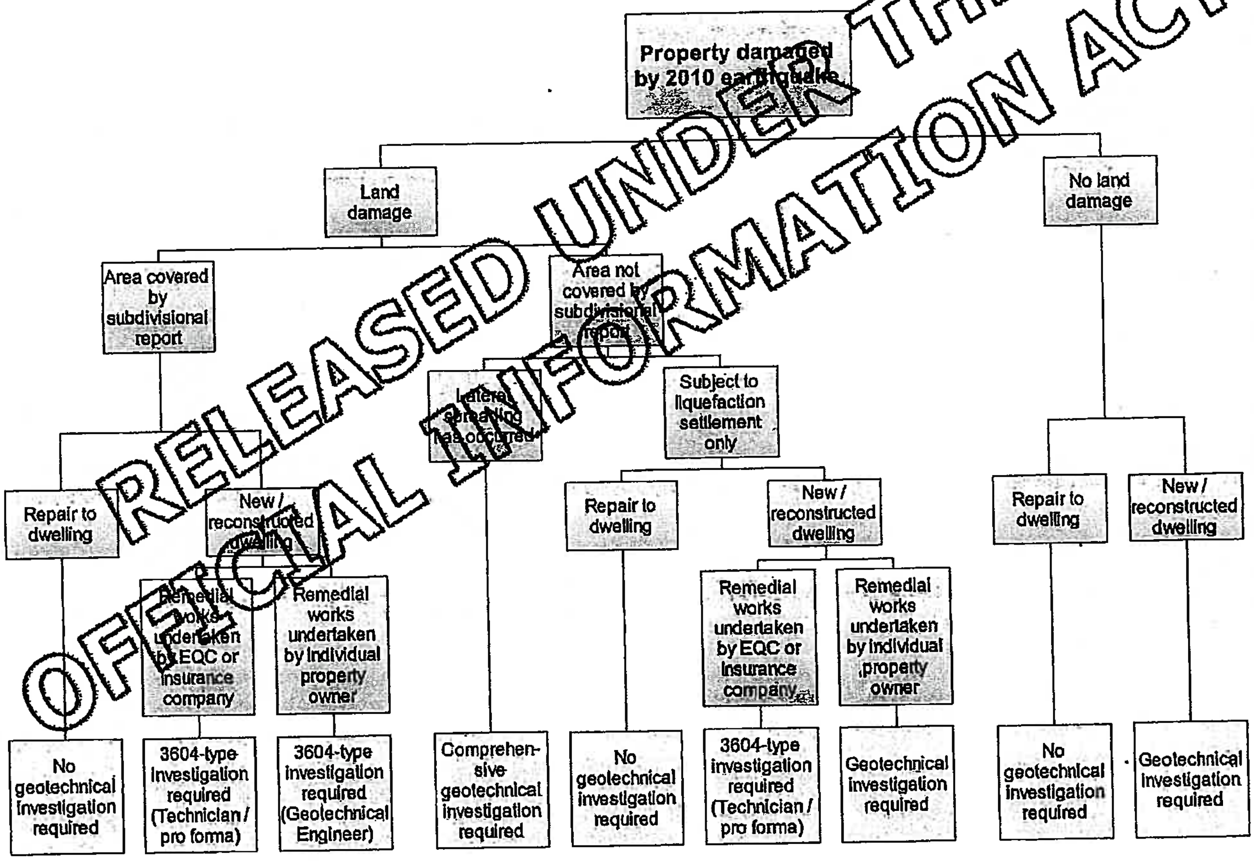

Figure 1: Summary of relationship between individual site investigation and land damage

1. Introduction and Scope

1.1 Background

The Canterbury Earthquake of 4 September 2010 had generated approximately 105,000 claims to the Earthquake Commission (EQC) by the end of October 2010. Of these, approximately 10,000 are likely to have a land component of damage. The majority of dwellings damaged will have minor damage including damaged chimneys and superficial cracking to cladding/linings. Approximately 50,000 claims have estimated dwelling damage between $10,000 and $100,000 (excl GST).

Following the earthquake, an Engineering Advisory Group was established by EQC to consider a range of technical issues affecting parties involved in the repair and reconstruction of residential dwellings.

The principal focus of the Group was to establish the feasibility and indicative content of a Guidance Document to be subsequently produced by the Department of Building and Housing.

Most of the damage to residential dwellings in the Darfield Earthquake was caused by the effects of liquefaction. With the notable exception of chimneys and unrestrained masonry walls, generally only minor damage was generated by strong ground shaking. Liquefaction gave rise to both differential settlement (vertical) effects and lateral spreading, with the latter being most damaging to buildings and infrastructure.

A standard explanation for the occurrence of liquefaction is included in Appendix 1.

1.2 Purpose and Scope of this Document

The purpose of this draft document is to provide guidance on the engineering performance objectives and requirements for the repair and reconstruction of houses damaged in the Darfield Earthquake.

The focus of the document is on foundation and floor elements, and standard methodologies are provided for both structural repairs and new construction. Guidance is also provided for common areas of superstructure concern such as chimneys.

This draft was prepared during October 2010, with the objective of providing a basis for rapid guidance to organisations involved in the repair and reconstruction of houses affected by this earthquake. The principal focus is the construction and insurance sectors and local authorities, and their professional advisers and contractors. The earthquake and its effects are complex, and it is acknowledged that the full picture about how residential structures responded to liquefaction effects has yet to be established, with research being ongoing. It may well be that some aspects of the recommendations in document are added to or changed over time.

The options and recommendations in this draft document are specific to houses directly affected by the Darfield, Canterbury earthquake. While they contain information on mitigating the effects of liquefaction on residential dwellings, this document <u>does not</u> represent a best practice guide for addressing liquefaction in other parts of Canterbury or New Zealand.

The document summarises the different requirements of insurance contracts and building regulatory provisions as they apply to both repairs and the construction of new elements and whole dwellings. The land damage zones and categories from the Tonkin and Taylor Stage 2 reports are summarised, and observations made regarding the future likelihood of liquefaction. Repair criteria and assessment approaches are outlined, along with re-levelling techniques and options for replacement foundation elements.

1.3 Organisations Involved

The organisations directly involved in the preparation of this document are:

- Department of Building and Housing
- EQC
- NZ Structural Engineering Society
- Tonkin & Taylor Ltd

Other organisations that have been consulted with during the preparation of this document include:

- Insurance Council of New Zealand
- Private insurers
- Christchurch City, Waimakariri District and Selwyn District Councils
- Institution of Professional Engineers New Zealand

2. Summary of Insurance and Regulatory Requirements

2.1 Insurance Requirements

This section provides a synopsis of insurance principles and requirements of the Earthquake Commission Act 1993 in relation to dwelling claims arising from the 2010 Darfield, Canterbury Earthquake. The land component of the claims will be dealt with by others, which includes aspects of compliance with current codes.

The Claimants' insurance policies are essentially a legal contract between the insured and the insurer. EQC covers the insured's dwelling and any structures appurtenant to the dwelling for the first $100,000 + GST. The relevant insurance company will address the dwelling portion of the claim up beyond this level in accordance with the individual terms and conditions of the contract. For the majority of claimants and insurance companies this will mean full replacement, which includes aspects of compliance to current code.

For dwelling claims that cost less than $100,000 (excl GST) where EQC is contracted to repair the dwelling because the claim is under the EQC cap, EQC must:

- Reinstate to a condition substantially the same as but not better or more extensive than, the building's condition when new – so far as circumstances permit and provided the costs are reasonably incurred.
- If circumstances do not permit, or the costs of an as new reinstatement are not reasonable, then EQC is not obliged to replace or reinstate exactly or completely but only as the circumstances do permit and in a reasonably sufficient manner.
- EQC's reinstatement obligation extends to the costs required to comply with any applicable laws and other fees payable in the course of reinstatement such as architects, surveyors and fees payable to local authorities.

For claims that cost less than $100,000, repairs to any damaged portion of a dwelling must be undertaken to a level that meets all current building legislative requirements (refer to Section 2.2 following).

The relevant provisions of the EQC Act generally mean that 'Like for Like' entitles the claimant to have their dwelling repaired fully to its pre-earthquake condition. To borrow the words in the EQC Act, repairs should restore the building to 'substantially the same' as its condition when new, unless circumstances do not permit full reinstatement or the cost of an as new replacement.

With regard to the obligations of private insurers, the following applies:

1. The reinstatement requirements of the private insurer will depend entirely on the terms of the contract between that insurer and the insured person.
2. These obligations vary to some extent between insurers and even between different policy wordings provided by the same insurer. For example, it is understood that one insurer provides two different policies which respectively require them to:
   - Repair the building to the state it was in before the damage or pay the cost of repairing, allowing for depreciation and wear and tear.
   - Repair or rebuild or to an "as new" condition.

The latter of these covers is very similar to the EQC insurance, but does not have the proviso that the repair may be limited to a "reasonably sufficient manner". On the other hand, the former insurance policy is more limited than the EQC cover and only provides for repair on an indemnity rather than replacement basis.

2.2 Regulatory Requirements

This section sets out some of the matters under the Building Act 2004 which will need to be considered when houses damaged by the Canterbury Earthquake are being repaired and reconstructed.

The requirements will vary depending on the particular circumstances of the repairs or rebuild. The below sections provide a general explanation of the key regulatory factors. However, when applied, the particular circumstances of each repair or reconstruction need to be considered.

2.2.1 Performance Objectives for the repair and reconstruction of damaged houses

The points below relate only to single detached dwellings.

A) Relevant Building Act 2004 requirements

1. All building work must comply with the building code (Building Act 2004 s 17)
2. Building work includes alterations and repairs and rebuilding of part of the building fall within the definition of 'alteration' (Building Act 2004 s 7).
3. Where a building is altered, section 112 of the Building Act requires that after the alteration the building must comply, as nearly as is reasonably practicable, with the provisions of the building code that relate to:
   i. means of escape from fire, and
   ii. access and facilities for persons with disabilities.

   and continue to comply with the other provisions of the building code to at least the same extent as before the earthquake.
4. The requirement to provide access and facilities for people with disabilities does not apply to private houses. Special requirements for houses relating to fire safety are essentially limited to the installation of smoke detectors (and if the house is not fully detached there may be other requirements).
5. Therefore, requirements of s 112 can generally be satisfied by ensuring that repaired houses have smoke alarms and by ensuring that the other elements of the house, such as structural, weathertightness, sanitary, etc, performance of the house, are no worse than before the earthquake.
6. In summary, this means that if a house is being repaired, any work undertaken to effect the repair needs to comply with the building code. However, with the exception of fire safety, the remainder of the house only needs to comply with the building code to the same extent as it did before the earthquake.

B) Houses written off and rebuilt on the same title

7. Rebuilt houses would be considered new houses and they would be required to comply with the current building code (refer Appendix 1).

Building Code requirements to prevent structural collapse (B1.3.1)

8. The building code clause B1 Structure requires new building work to have a low probability of rupture, becoming unstable or collapsing (clause B1.3.1).

9. Quantification of this requirement is well understood by structural engineers. AS/NZS 1170 is widely used by engineers as a guide to meet the requirements of building code clause B1 and is referenced in Verification Method B1/VM1, which if followed, is treated as complying with building code clause B1.

10. Buildings which are designed using AS/NZS1170 are required to satisfy following primary design cases:
    1. The Serviceability Limit State (SLS) design case and;
    2. The Ultimate Limit State (ULS) design case.

11. The ULS design case an extreme load, or extreme combination of loads that the building needs to stand up to. ULS seismic loads for residential properties are based on a 1 in 500 year earthquake (a 10% chance of occurring in 50 years, the nominal life of the building). A building is expected to suffer moderate to significant structural damage, but not collapse, when it is subjected to a ULS load.

12. Special note of the following points should also be made with regard to ULS loads:
    - It may be uneconomic and/or not feasible to repair a building or structure which has been subjected to an ULS load,
    - A building is likely to collapse if it is subjected to a load which is significantly greater than the ULS load for which it has been designed to sustain, and,
    - All buildings are at risk of being subjected to a level of seismic shaking which is greater than its design ULS seismic load. It should be noted, however, that this probability of exceedance is extremely low.

13. The SLS design case is a load, or combination of loads, which a building or structure is likely to be subjected to more frequently during its design life. If properly designed and constructed, a building should suffer no structural damage when it is subjected to an SLS load. SLS seismic loads for residential properties are based on a 1 in 25 year earthquake.

14. In land damaged areas where there was lateral spreading, a number of house foundations did rupture during the Canterbury earthquake and were consequently close to collapse. Rebuilding on land that continues to have the potential for lateral spread will require specific foundation design to resist failure.

Building Code requirements to prevent loss of amenity (B1.3.2)

15. Building Code clause B1 also requires new building work to have a low probability of causing loss of amenity through undue deformation, vibratory response, degradation or other physical characteristics throughout their lives (clause B1.3.2).

16. Amenity is defined as "an attribute of a building which contributes to the health, physical independence and well being of the building's user but which is not associated with disease or a specific illness".

17. Current acceptable solutions, verification methods and standards do not provide an explanation of what is meant by "loss of amenity". However, loss of amenity might include with loss of services including sewer and water connections, damage to sanitary fixtures (bathroom, kitchen, laundry), or the building envelope not being weathertight. Deformation limits that may cause cracks to the structure or cladding are addressed in Section 4.

18. Measures should be taken when designing and building foundations on land with the potential for liquefaction to minimise the possibility of loss of amenity should a similar event occur.

Ground damage in Christchurch

19. Liquefaction and lateral spread issues have not been specifically addressed in Standards, Verification Methods or Acceptable Solutions supporting the Building Code.

20. Houses which comply with Acceptable Solution B1/AS1 are treated as complying with building code clause B1. B1/AS1 references NZS 3604 which has a definition of 'good ground' (refer NZS 3604:1999, Section 3.1.3) aimed at ensuring there is adequate static bearing capacity for the standard foundation designs proposed. The definition of 'good ground' does not consider land with liquefaction ground damage potential.

21. Land remediation being undertaken in suburbs where there is a risk of lateral spread in a future earthquake event will limit the risk of foundation rupture, thereby satisfying Building Code clause B1.3.1. However, foundations for houses being rebuilt on land that may still be subject to liquefaction need to be stiffer and better tied together than those detailed in NZS 3604 for 'good ground' in order to limit the risk of loss of amenity through undue deformations and comply with building code clause B1. See Section 6 for further guidance on the type of foundations that may be appropriate.

22. It is recommended that services should enter the building at few well defined, well recorded locations, through connections that are as flexible as possible that will fail in well defined locations outside the slab system and are then easy and quick to re-connect.

Superstructure

23. Where a house is being entirely rebuilt, the superstructure, if built in accordance with NZS 3604, will comply with Code Clause B1.

24. All building elements must be built to current building code requirements (treated timber framing, drainage cavities for cladding where appropriate, insulation and double glazing, etc).

C) Repair of damaged houses and replacing the foundation

25. A house superstructure that is still reasonably intact may be able to be temporarily lifted off existing foundations so that new foundations can be built. The new foundation would be required to comply with the Building Code, refer paragraph 22 and 23 above, using generic solutions proposed in Section 6.

26. Replacing the existing house on the new foundations is similar to house removal operations that take place extensively around the country. The house only needs to perform to the same level as it did prior to the earthquake apart from fire safety[1].

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[1] Structural or energy efficiency upgrades may be required if houses are moved to new locations in different wind, seismic or climate zones. This will not be the case when they are restored in the same location.

However building work undertaken will need to meet Building Code requirements. Smoke detectors will need to be fitted if they are not already in place.

27. Part of the house may need complete replacement. Any new part of the house will need to meet all Building Code requirements (refer paragraphs 24 and 25 above).

D) Repair of damaged houses in-situ

28. Per A) above, the building work being carried out must comply with the current building code, but the rest of the house only need to perform to the same level as it did prior to the earthquake, apart from fire safety. Smoke detectors will need to be fitted if they are not already in place (and if the house is not fully detached there may be other requirements).

29. There is a range of issues to consider for repaired houses, and some of these are covered as follows:

<u>Foundations and Floors</u>

- cracked slabs – damage to Damp Proof Membrane causing dampness though floor slab from original ground damage or through repairs and re-levelling of slab. Grouting solutions to lift the slab can be done so that the membrane is not broken. Large cracks may have already damaged the membrane, so the slab would need to be broken out and membrane repair made.
- tolerances required for floor level. A level platform is a fundamental assumption for all buildings. Construction tolerances for new construction are provided in a number of Standards referenced in Acceptable Solutions or Verification Methods as being code compliant (refer NZS 3109, 3114, 3604 and 3404). Refer to Table 4.1 for criteria to be used.

<u>Walls</u>

- repairs to wall bracing where plasterboard has popped. The repair should be done to current requirements for bracing but overall the house only needs to perform to the same level as before.
- cracks repaired, brick veneer tied to framing, weathertight to the same level as previous (noting that there may be additional issues where the house had weathertight issues prior to the earthquake).
- Insulation, including windows(double or single glazed) to the same level as previous. Where there is access to wall cavities, it would be clearly sensible for the owner to upgrade insulation, but this would be betterment. The EECA *Warm up NZ* programme may be able to be accessed.

<u>Roofs</u>

- Most roof damage is probably from chimney collapse. Matching imperial tiles may not always be possible and more extensive replacement may be required.
- It may be sensible in some cases to replace heavy roofs with lightweight materials.

Chimneys

- Refer Section 5.2 for repair options.

Services

- Ensure earthing straps are reconnected.
- Ensure that appropriate tradespeople are used to reconnect electricity, gas and oil fired central heating services and appropriate certificates are issued.

2.2.2 Building Consents

Not all building work requires a building consent (refer Building Act 2004 s 41 for specific exclusions). In particular, building work described in Schedule 1 of the Building Act does not require a building consent. Appendix 3 provides a list of typical work required to rebuild or repair houses following the Canterbury earthquake with recommendations on whether a building consent is necessary. It is recommended that checks are undertaken the appropriate Council to confirm whether a building consent is needed.

Whether or not a building consent is required, all building work must comply with the building code (BA04 s 17).

3. Future Performance Objectives and Expectations for Land and Buildings

This section outlines the current understanding of the performance of land and dwellings in the 2010 earthquake. Relevant future performance criteria for both repaired and reconstructed dwellings are established from an understanding of the performance of land and buildings in the recent earthquake and relevant design standards described in Section 2.

3.1 Land and Building Damage and Performance Assessment

Observed Land Damage

The Earthquake Commission (EQC) is required to undertake a geotechnical assessment of all claims that contain land damage. Immediately following the 4th September earthquake, a regional reconnaissance damage mapping exercise was undertaken by geotechnical engineers on behalf of EQC under the direction of Tonkin & Taylor. From this mapping study, areas of very severe land damage were identified and further more detailed local mapping was undertaken.

The land damage has been ranked according to the categories detailed in Table 3.1 following. The table also provides a comparison between the damage categories developed for the local mapping and the performance levels given in the New Zealand Geotechnical Society Earthquake Engineering Practice Guidelines (NZGS, 2010).

Local damage maps of the most affected 15 suburbs of greater Christchurch have been completed. The spatial distribution of the zones of land damage, as detailed in Table 3.1, is illustrated in a generic section shown in Figure 3.1 below.

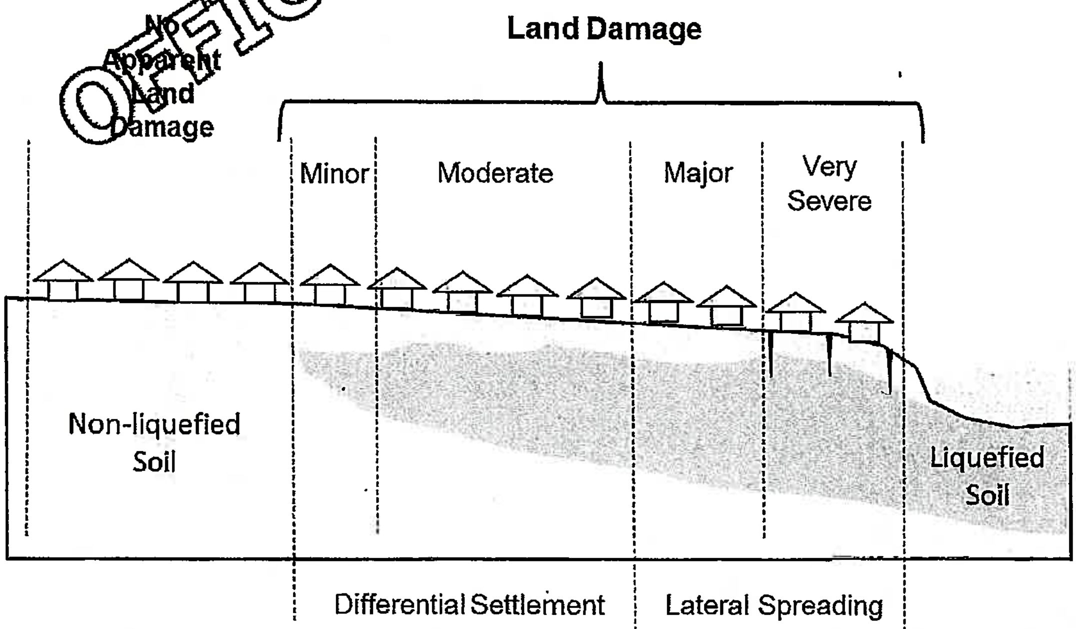


Figure 3.1. Schematic section of spatial distribution of zones of land damage

Table 3.1 – Local mapping categories

Descriptor Land Damage	Description	Performance Level*
Very Severe	• Extensive lateral spreading (>1 m) • Surface rupture, large open cracks, (>100 mm) • Extensive liquefaction (ejected sand) • Significant horizontal & vertical displacement >500 mm • Heavy structural damage to buildings • Dislocation of roads/services • Dwellings most likely to be uninhabitable and beyond economic repair	L5
Major	• Extensive liquefaction (ejected sand) • Large cracks from ground oscillations • Horizontal & vertical displacement >50 mm • Structural damage to buildings • Major differential settlement >1/100 • Damage to roads and failure of services • Dwellings generally uninhabitable and beyond economic repair	L4
Moderate	• Visible signs of liquefaction (ejected sand) • Small cracks from ground oscillations (<50 mm) • No vertical displacement of cracks • Some structural damage to buildings • Moderate differential settlement >1/100 • Moderate damage to roads/services • The majority of houses are likely to be habitable in the medium term with reduced serviceability but are variable with respect to cost to repair them.	L2 to L3
Minor	• Shaking-induced damage - cyclic deformation • Minor ground cracking (tension) and buckling (compression) • No liquefaction visible at the surface • No permanent horizontal or vertical displacements • Occasional minor structural damage and varying degrees of cosmetic damage • Minor Street, pavement and landscaping repairs required.	L0 to L3
Building	• No apparent land damage • No signs of liquefaction at the surface • Potential building damage due to earthquake shaking but not visible from the road frontage - Potential chimney damage - Potential internal and external wall damage	L0

* Performance Level based on general interpretation (NZGS, 2010). This table focuses on observed land damage as assessed in the field versus effects from liquefaction as discussed in the NZGS Guideline.

Land damage from the earthquake generally comprised lateral spreading close to water courses/streams/rivers (major to very severe) and liquefaction induced settlements (minor to very severe). The lateral spreading extended in some areas up to 400 m laterally from water courses with up to 4 m lateral ground movement. Settlements of up to 500 mm from liquefaction occurred over large areas, with significant differential settlements occurring over short distances.

Observed Building Damage

Building damage can be divided into two broad categories: damage that was caused solely from earthquake shaking (No apparent land damage to minor land damage zone), and damage that resulted from seismic induced ground deformation (minor to very severe land damage zone).

With respect to the current building damage, three broad categories (minor, moderate and severe) are applicable for insurance considerations, as summarised in Table 3.2 below.

Table 3.2 - Categories of building damage

Severity	Repair Cost (Excludes GST)	Description
Minor	<$10,000	Cracks in interior linings, non structural cracks in the exterior.
Moderate	$10,000 to $100,000	Chimney damage, roof damage, minor structural damage, cracks in exterior linings which affect weather tightness.
Severe	>$100,000	Buildings out of level, twisted, broken through hogging or dishing, differential settlement generally more than 50 mm, stretched more than 20 mm.

Building damage due to ground movement causes stretching, hogging, dishing, racking/ twisting, tilt, differential settlement, differential displacement or any combination of the above. The severity of the building damage is dependent on the damage type, the type of building, the building geometry and the amount of foundation movement which has occurred.

The following three broad groups of dwellings have been used in the subsequent sections of this document:

Type A	Timber framed suspended timber floor structures supported only on piles
Type B	Timber framed suspended timber floor structures with perimeter concrete foundation
Type C	Timber framed dwelling on concrete floor

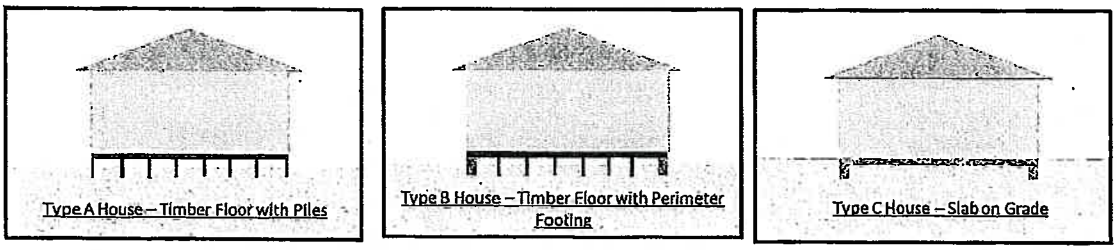


Figure 3.2: Type A, B and C Dwellings

The apparent damage to Type A buildings is generally easier and less costly to repair. Type C buildings are typical of the newer subdivisions of Kaiapoi, Bexley and Brooklands, with a significant number of buildings being less than 10 years old. These buildings are typically supported on a shallow reinforced concrete perimeter strip footing, with concrete cast-on-grade floors. The floors are, in many cases, unreinforced, and not tied in to the perimeter foundations. These foundation and flooring systems have been observed to perform poorly in those areas that have undergone land deformation. In addition, such buildings will be difficult and more costly to repair.

Linking Land and Building Performance Expectations

The relevant building code performance requirements are set out in the Earthquake Loadings Code NZS 1170.5: 2004. The performance requirements for residential buildings are:

- Ultimate Limit State - under a seismic event with an annual probability of exceedence of 1/500, people are not to be endangered and collapse of the structure is to be avoided.
- Serviceability Limit State - under a seismic event with an annual probability of exceedence of 1/25, damage to the building is to be avoided.

These performance requirements are however specific to the building structure only, and no reference is made to the land performance on which the building is founded.

With respect to natural hazards, the Building Act 2004 requires that a building be "not likely" to be subject to damage from erosion, subsidence, inundation or slippage. There is a similar provision in the Resource Management Act 1991 relating to subdivision consent. At these levels of shaking, however, damage is expected. The geotechnical issue is what is expected of the ground under such high levels of shaking, and how this compares with other natural hazard risk levels. An examination of the land and building performance under this earthquake, which approached that of a ULS level event, provides a guide.

A lesson from this event is that there are significant advantages in people being able to remain in their homes for as long as possible after the event. So this means employing building practices to limit the damage so that buildings remain habitable and ultimately gain a Green (Inspected) placard from Council. The performance target should therefore be one of habitability. A future policy of encouraging wide, stiff foundation systems such as stiff rafts (e.g. waffle slab) or stiff inter-connected footings is considered to be the best way of improving performance with respect to both amenity and collapse.

In the areas where liquefaction occurred (with the exception of the very severe land damage zone), the residential houses have been considered to have broadly met the ULS performance requirements (i.e. there were no observed collapsed houses or loss of life). In the very severe land damage zone, the houses were in varying states, but no collapses were observed. There was however greater potential for loss of life to occupants in the houses in these zones. In addition, in many areas the habitability of dwellings was compromised by excessive land movement. On this basis it could be assumed that the land in the very severe land damage areas did not perform to design requirements.

Where buildings can be repaired on their existing foundations, it is likely that the damage to the buildings is not so severe that they needed to be evacuated (i.e. no Red or Yellow placards issued by councils) and that the buildings have remained habitable. Accordingly, the land and buildings have performed adequately under close to the design (ULS) earthquake, and therefore can broadly considered to have complied with the relevant building code.

Where buildings require demolition because they cannot be repaired within the building value, but have remained habitable (i.e. a Green council placard), these buildings and the land beneath them can also be considered code compliant.

Where major land deformation has occurred due to flow sliding and lateral spreading, and significant differential settlement, and significant building damage has occurred (Red council placard), it is considered that additional measures need to be incorporated, through engineered designed building foundations and/or ground protection, to comply with the building code.

Dr David Hopkins (Department of Building and Housing) made the following summary of the views of experts who are involved in examining the impact of the earthquake and gathering data to better understand its implications:

> *Comparing the intensity of ground shaking in the 4 September earthquake with that used in the design of new buildings and infrastructure, the building performance and damage caused suggests that this was a moderate earthquake with much less impact than expected from a "design" earthquake.*
>
> *It is most unlikely that earthquake design standards for buildings and infrastructure in Christchurch / Canterbury need to be changed as a result of the earthquake. There is no reason evident so far to suggest they should be increased or decreased. The performance of buildings and infrastructure was generally as expected by experts. The earthquake is a reminder that good engineering design and good quality construction is important.*
>
> *It is also possible to reduce the damage to buildings caused by liquefaction and lateral spreading by using robust foundations, tying of floor slabs to buildings, using piled foundations, ground improvement or densification of the liquefiable layers. The choice of method will depend on cost-effectiveness.*

If houses are to be rebuilt in the very severe land damage zone, then specific engineering design would be required. It may be appropriate to incorporate structural measures in their design to allow for significant lateral spreading, or else to put in place some form of ground treatment works to limit the lateral spreading strains to more tolerable limits for the structures.

3.2 Future Building Performance Expectations

Land that has liquefied in this event is also likely to be vulnerable to future liquefaction in future strong shaking events.

Where houses are rebuilt, the option exists to construct a more robust foundation, to provide a greater level of performance in a future liquefaction event, particularly with respect to amenity. A stiff foundation system where all the elements are tied together will tolerate differential ground settlement better than the unreinforced slabs and non-connected strip footings present in many of the damaged dwellings. This is likely to allow more effective and economic repair following any future liquefaction event. Differential settlement of the structure would still be expected, but damage may be reduced, and re-levelling would be more feasible.

Housing stock that does get repaired without any foundation improvement is likely to perform in a similar manner as observed in this event.

With regard to the design of new dwellings, the buildings should be designed to be able to resist possible lateral spreading of the ground beneath the foundation of up to 50mm and to limit future tilting, sagging or hogging of the foundation to less than 1 in 400. The issue of acceptable levels of differential settlement is addressed in Section 4.2.

For the design of new and remediated buildings, foundation systems and the buildings themselves need to be designed to accommodate total settlements, differential settlements and lateral strains of the ground that may occur in a future event. The foundations and buildings need to be sufficiently stiff to ensure that expected ground movements do not result in severe distortion due to hogging, sagging or reverse flexure. Where possible, the foundation system should have sufficient stiffness to permit re-levelling by jacking at perimeter points. With regard to lateral spreading, the foundation system should also have sufficient tensile strength to permit sliding of the house in relation to the ground without breaking or distorting. The strength should be sufficient to withstand forces equal to frictional resistance to sliding over half the house footprint.

It is also recommended that extra grade tolerances be provided for services together with more flexibility at service connections.

4. Repair Criteria and Assessment Approaches

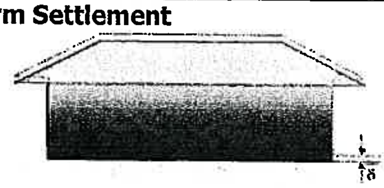
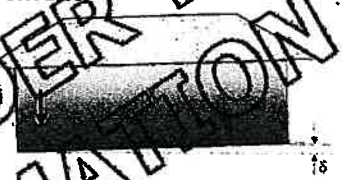
This section provides recommended criteria for the different levels of repair for houses with damage from the earthquake. Suggested assessment approaches are also outlined.

4.1 Definitions

Displacements

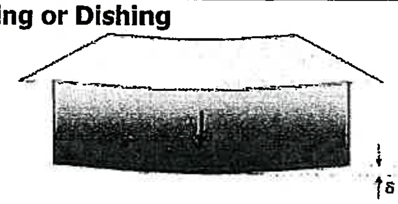
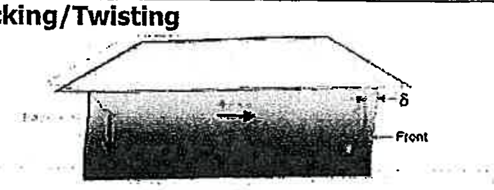
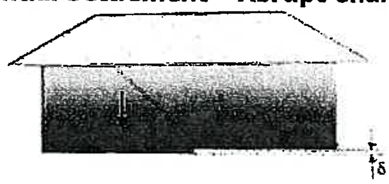
To assist with the understanding of the descriptions provided in this and subsequent sections, the following pictorial definitions for floor displacement are provided:

(i) Simple Settlement Cases

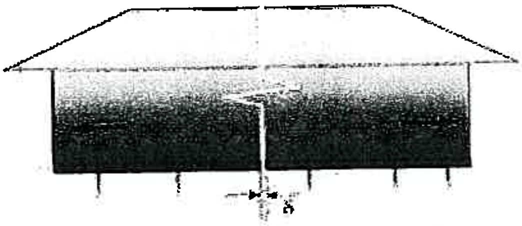
Uniform Settlement	**Tilt Settlement**
 For uniform settlement the complete foundation has settled by the same amount over the area of the foundation.	 With tilt settlement, the whole foundation tilts as a rigid body.

(ii) Differential Settlement Cases

Parts of the foundation settle by different amounts results in uneven slopes in the floor. Differential settlement is the most difficult behaviour on which to set acceptable limits.

Hogging	**Sagging or Dishing**
	
Racking/Twisting	**Differential Settlement – Abrupt Change**
 Twisting of the foundation can occur where all corners of the foundation have settled by different amounts.	

(iii) Lateral Stretching



Lateral stretching of a foundation may occur when the ground beneath it spreads laterally during the ground shaking. If the floor plate of the dwelling is not strong enough, then the lateral spreading will cause an extension of the floor plate (i.e. the concrete floor slab will crack or the timber floor will fracture generally at joints between framing members).

Combinations of any of the above settlement cases and also combinations of settlement and stretching are possible.

Piles

For the purposes of this document "piles" have the definition from NZS 3604:1999 that is "a block or column-like member used to transmit loads from the building and its contents to the ground".

4.2 Foundations and Floors

Repair/Rebuild Assessment Categories and Criteria

The categories and criteria contained in Table 4.1 on the following page are to be used to establish *firstly* whether or not houses need to be re-levelled, and then *secondly* if action is necessary with regard to either a **re-level,** a **foundation rebuild** or a **house rebuild** being required.

The recommended approaches for re-levelling the different foundation and floor systems are outlined in Section 5.1.

The recommended approaches for replacing existing foundation and floor systems whilst retaining the house superstructure are outlined in Section 5.2.

Table 4.1: Repair/Rebuild Categories and Criteria

Floor Type	Decision Parameters				Comments
	NO action necessary	**Foundation Re-level required**	**Foundation Re-build required**	**House Re-build required**	
Type A Timber framed suspended timber floor structures supported only on piles	The slope of the floor between any two points >2m apart is <0.25% [Note (a)]	The slope of the floor between any two points >2m apart is 0.25%-0.75%	The slope of the floor between any two points >2m apart is >0.75%, OR The variation in floor level is >50mm [Note (c)] over the floor plan, OR The floor has stretched >50mm [Note (d)]	The house has fully or partially collapsed off the piles	Any abrupt changes in floor level may require at least re-levelling, depending on the type of floor covering
Type B Timber framed suspended timber floor structures with perimeter concrete foundation	The slope of the floor between any two points >2m apart is <0.25% [Note (a)]	The slope of the floor between any two points >2m apart is 0.25%-0.50%, OR Individual cracks in the perimeter foundation are <5mm [Note (b)]	The slope of the floor between any two points >2m apart is >0.50%, OR The variation in floor level is >50mm over the floor slab, OR Individual cracks in the perimeter foundation are >5mm (see comment), OR The floor has stretched >20mm [Note (e)]	The house has fully or partially collapsed off the piles	Foundation rebuild may only need to be in the vicinity of the damage
Type C Timber framed dwelling on concrete floor	The slope of the floor between any two points >2m apart is <0.25% [Note (a)], AND There are no cracks in ceramic floor tiles, AND There is no distress in vinyl floor coverings or carpet	The slope of the floor between any two points >2m apart is 0.25%-0.50%, OR Cracks in the floor slab are <3mm and the accumulation of cracks over the major orthogonal dimensions are <20mm	The slope of the floor between any two points >2m apart is >0.50%, OR The variation in level over the floor plan is >100mm, OR There is irreparable damage to buried services within the house footprint	This will relate to the degree of superstructure damage [Note (f)]	Abrupt changes in floor level may require re-levelling depending on the floor coverings present

Explanatory Notes:

(a) Reasoning covers human perception and more applicable than overall slope
(b) Note that for veneer may need to rebuild veneer – <u>for inclusion in superstructure section</u>
(c) Pile packing unstable at greater than 50mm
(d) Stretch less than 50mm can be pulled together again
(e) No opportunity to pull the foundation together again and <u>superstructure implication for veneer</u>
(f) Economic decision for each property

Investigation Approaches

The degree of out-of-level of the damaged floor should be established using appropriate means, such as a dumpy or laser level and staff.

The degree of lateral extension of the ground floor plate of the house should be established. Note that this is different to the lateral movement of the ground beneath the house, and needs to be measured on the structure. This may be done by adding the crack widths in the floor slab along the length of the floor and across the width of the floor. For suspended timber floors supported only by piles, this will require a careful inspection of the exterior claddings at the bottoms of ground floor walls for signs of lateral extension. It is expected that lateral extension in this case will be concentrated at one or two discrete locations where connections in the framing have failed.

The degree of extension and/or flexural damage to the perimeter foundation (if present) should also be established. This can be done by careful inspection of the outside face of the foundation. Cracks should be measured and inspected for the presence of reinforcing steel (with a torch in large cracks or a cover meter). If the crack is wide (up to 5mm) but there is no vertical misalignment or out-of-plane misalignment it is likely that reinforcing steel is present.

4.3 Superstructure

4.3.1 Chimneys

Chimneys are likely to be constructed using clay bricks, concrete bricks, precast concrete elements or steel/stainless steel flues, and they will be situated either on the outside of the house or internal. Some houses may have both cases present.

Earthquake damage in chimneys will generally be obvious. Clay brick chimneys constructed with lime mortar are likely to have suffered significant damage (i.e. have either collapsed above the roof line or from a lower point in the case of external chimneys). External chimneys may also have tilted away from the face of the adjacent wall, if there has been settlement of the foundation under the earthquake action.

Repair options for brick chimneys are presented in section 5.2.1.

4.3.2 Wall Bracing

Superstructure deformations associated with significant levels of foundation deformation and repair may have caused sufficient damage to the wall bracing systems to reduce their ability to resist future earthquake and wind actions efficiently.

Where there is evidence of significant racking of walls (e.g. shear deformations on sheet junctions and associated nail/screw popping, lifting of sheets from behind skirting boards and/or diagonal cracking of sheets or residual structure deformation), the wall linings will need to be replaced, re-stopped and re-decorated. Trims (e.g. scotias, skirtings) will need to be removed and possibly replaced. Fine cracks at the junctions of sheets with no accompanying nail/screw popping indicate that there is little damage to the bracing system and replacement of sheets will not be required.

External sheet cladding connections and joints must also be checked and re-fixed. Houses built since 1978 are likely to rely on the bracing capacity of exterior sheet claddings (e.g. fibre-cement board).

4.3.3 Wall and Roof Frame Connections

Wall frame connections and, to a lesser extent, roof frame connections, may have been damaged if severe deformation of the structure has occurred due to ground settlement or lateral spreading. It is not possible to provide blanket criteria for assessment of the damage to framing and framing connections and each house must be considered individually.

Roof framing is generally triangulated, meaning that it is self bracing. The exception is a gable ended roof where roof plane or roof space bracing is relied on to provide bracing in the ridgeline direction. If the roof shows signs of major distortion (which could be as a result of ground disturbance or ground shaking), then a check of all roof bracing members and their connections will be necessary. Such damage is more likely with a heavy roof cladding, such as concrete or clay tiles.

Connections between roof framing and wall framing will be distressed if the wall linings or the ceiling linings have separated more than 20mm from the wall/ceiling junction.

4.3.4 Light Gauge Steel framing

It is likely that some modern light gauge steel framed houses will have been affected by liquefaction or lateral spreading in the Canterbury earthquake. These houses are obviously not covered by the provisions of NZS 3604.

The superstructure of light gauge steel framed houses is likely to behave differently to timber framing when subjected to excessive differential displacements. Where timber may fracture or nailed joints may pull apart if overloaded, the light gauge steel framing is likely to buckle and new framing sections will be required.

5. Repairing Houses

This section contains methodologies for the reinstatement or replacement of house structures that have been affected by ground settlement (liquefaction) or ground spreading, or both of these effects.

House foundation and floor types are categorised according to Table 5.1 below. The Type B and C house foundations have been sub-divided into those supporting light and medium weight claddings (B1 and C1) and those supporting heavy claddings such as brick veneer (B2 and C2).

Table 5.1: House Foundation and Floor Types

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).*

An overall summary of the process is provided in Table 5.2 following, with detailed method statements included in Appendices 4 and 5.

Recommendations for repairs for 'above the floor plate' damage to superstructure elements such as to chimneys, wall bracing, wall and roof frame connections are provided in Section 5.2.

Table 5.2: Summary of Foundation Re-levelling and Re-building Approaches

Foundation Type	Foundation Re-levelling			Foundation Re-build		
	Re-level Strategy	Occupancy During Re-level Operations		Re-build Strategy	Occupancy During Re-build Operations	
Type A Timber framed suspended timber floor structures supported only on piles. *Stucco, Weatherboard or light texture clad house*	Remove base skirt, disconnect services if adjacent to works, re-pile affected area, re-connect services and re-skirt perimeter.	Yes	Minor disruption to occupants during re-levelling.	Remove base skirt, disconnect services if adjacent to works, re-pile affected area, re-connect services and re-skirt perimeter.	No	Usually only minor disruption to occupants. Need to consider distress to framing, trusses and bracing at this level of foundation damage.
Type B1 Timber framed suspended timber floor structures with perimeter concrete foundation. *Stucco, Weatherboard or light texture clad house*	Disconnect services if adjacent to works, expose affected perimeter concrete foundation beam and re-level, re-pile affected area, inject relevant cracks in beam, re-connect services and reinstate ground to beam	Yes	As for Type A regarding piles. Re-levelling the beam using urethane grout may permit occupancy during the work. Beam jacking may require vacancy depending on which part of the beam is to be re-levelled.	Disconnect services, remove decks and paths, remove perimeter concrete foundation beam and replace, re-pile, re-connect services and reinstate ground to beam.	No	As for Type A regarding piles. Replacing the beam will require vacancy as the perimeter of the house will be disrupted.
Type B2 Timber framed suspended timber floor structures with perimeter concrete foundation. *Brick or concrete masonry exterior cladding (veneer)*	Disconnect services if adjacent to works, possibly partial removal of cladding, remove decking and paths to expose affected perimeter concrete foundation beam and re-level, re-pile affected area, inject relevant cracks in beam, re-connect services and reinstate ground to beam.	No	Perimeter will be disrupted to give access to beam and will disrupt services. Partial beam and cladding removal and reinstatement is included.	Disconnect services, remove exterior cladding, remove perimeter concrete foundation beam, decks and paths and replace, re-pile, re-connect services and reinstate ground to beam, replace cladding.	No	Perimeter will be disrupted to give access to beam and will disrupt services. Complete removal and replacement of the exterior cladding is included. Need to consider distress to the framing, trusses and bracing at this level of subsidence.

Table 5.2 (continued): Summary of Foundation Re-levelling and Re-building Approaches

Foundation Type	Foundation Re-levelling			Foundation Re-build		
	Re-level Strategy	Occupancy During Re-level Operations		Re-build Strategy	Occupancy During Re-build Operations	
Type C1 Timber framed dwelling on concrete floor (slab on grade). *Stucco, Weatherboard or light texture clad house*	Re-level using urethane foam. Disconnect and reinstate services, if necessary. OR Re-level using slab and beam jacking with screw piles or jacks. Disconnect and reinstate services, if necessary. OR Re-level using slab and beam jacking with screw piles or jacks. Disconnect and reinstate services.	Subject to individual situations	This procedure is limited to slabs with crack width <3mm. They will need to be sealed prior to re-levelling. The process requires stripping out of the interior floor coverings.	Disconnect services, remove decks and paths, jack and grout, re-connect services and reinstate ground. OR Disconnect services, temporarily raise house on beams, remove and replace slab, paths and decking, reinstate house and reconnect.	No	Severely cracked slab with differential settlement over 150mm may have caused severe damage to the timber framing, trusses and bracing.
Type C2 Timber framed dwelling on concrete floor (slab on grade). *Brick or concrete masonry exterior cladding (veneer)*	Disconnect services if adjacent to works, possibly partial removal of cladding, possibly remove decking and paths to expose affected perimeter concrete foundation beam and re-level, inject relevant cracks in slab, re-connect services and reinstate paths and deck. OR Disconnect services, partially remove cladding temporarily raise house and replace slab, reinstate and reconnect.	Yes -	This procedure is limited to slabs with crack with <3mm and only minor cracking to veneer mortar. The process requires stripping out of the interior floor coverings.	Disconnect services, remove exterior cladding, remove house and replace slab, reinstate house, paths, decks and services, replace cladding.	No	Severely cracked slab with differential settlement over 150mm may have caused severe damage to the timber framing, trusses and bracing.

5.1 Re-levelling or Replacing Foundations and Floors

5.1.1 Concrete or Timber Piles Throughout (Type A)

These foundation systems are likely to be present where the dwelling is clad with lightweight (e.g. timber or fibre cement weatherboards, sheet claddings, EIFS claddings) or medium-weight materials (e.g. stucco).

Re-levelling foundation

In these instances, it may be possible to re-level the existing foundation or lift the superstructure, including the timber floor, re-pile as necessary and remediate any damage caused to the claddings and linings of the structure. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 4.

Re-building foundation

In these instances, it will be possible to lift the superstructure, including the floor, re-build the pile system beneath the house and remediate any damage caused to the claddings and linings of the structure. The process will be very similar to that employed by a house removal company engaged to relocate or re-pile a house. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 5.

5.1.2 Perimeter Concrete Foundation Wall (Light or medium-weight claddings) (Type B1)

These foundation systems are often present where the dwelling is clad with lightweight claddings (e.g. timber or fibre cement weatherboards, sheet claddings, EIFS claddings) or medium-weight materials (e.g. stucco).

Re-levelling foundation

In these instances, it is possible to lift the superstructure, including the floor, and remediate any damage caused to the claddings and linings of the structure. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 4.

There are three lifting options, as follows:

- **Lifting Option 1: Perimeter Foundation Jacking Using Portable Jacks**
- **Lifting Option 2: Perimeter Foundation Jacking Using Piles (Screw or similar)**
- **Lifting Option 3: Perimeter Foundation Jacking Using Expanding Urethane Foam**

The third option is a proprietary lifting process where urethane foam is injected into the ground beneath the foundation at multiple points along the length of the foundation. The expanding foam lifts the foundation. This process also densifies the surrounding ground which serves as a reaction layer for the lifting operation. The process is specialised and must be undertaken by an experienced operator.

Re-building foundation

The degree of settlement that has occurred in this instance will be such that the perimeter foundation is expected to be heavily damaged and not easily reparable. The period of original construction of the house is likely to require the replacement of the perimeter concrete foundation with a new perimeter concrete foundation, to maintain the style. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 5.

5.1.3 Perimeter Concrete Foundation Wall (Heavyweight veneer cladding) (Type B2)

These continuous foundation walls are always present where the dwelling has a timber floor and is clad with heavy cladding materials (e.g. brick or concrete masonry veneer).

In these instances, it is likely to be very difficult to lift the foundation without causing significant damage to the veneer cladding. However, it is recommended that the levelling operation is undertaken with the veneer in place and a decision is made on the possibility of repairing the existing veneer rather than demolishing and rebuilding once the foundation is level.

If the veneer is removed, the owner may choose to have insulation installed in the exterior walls if this was not already in place, but this will be at the owner's expense.

Re-levelling foundation

All three lifting options in section 5.1.2 may be used. A summary of the process is given in the following table and a more detailed process description included in Appendix 4.

Re-building foundation

In these instances, it will be very difficult to lift the superstructure, including veneer cladding, without causing irreparable damage to the veneer cladding. It will be necessary to demolish and rebuild the veneer once the new foundation has been constructed and the house superstructure has been re-installed on the foundation.

If the veneer is removed, the owner may choose to have insulation installed in the exterior walls if this was not already in place, but this will be at the owner's expense.

Once the veneer has been removed, the remedial works will follow the steps outlined in section 5.1.2 and then the veneer will be re-built on the new foundation. A summary of the process is given in Table 5.2 and a more detailed process description included in Appendix 5.

5.1.4 Slab on grade floors (Light or medium weight claddings) (Type C1)

Re-levelling foundation

In instances of slab on grade floors where the dwelling is clad with lightweight claddings (e.g. timber or fibre cement weatherboards, sheet claddings, EIFS claddings) or medium-weight materials (e.g. stucco), it is possible to lift the superstructure, including the floor, and remediate any damage caused to the claddings and linings of the structure. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 4.

Re-building foundation

The degree of settlement that has occurred in this instance will be such that the floor slab and edge beam are expected to be heavily damaged and not easily reparable. The slab will be badly deformed and cracked. The repair process will involve lifting the superstructure (from the bottom plate) demolishing and re-building the slab and edge thickening. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 5.

5.1.5 Slab on grade floors (Heavyweight veneer cladding) (Type C2)

Concrete slab on grade floor systems are often used with heavy cladding materials (e.g. brick or concrete masonry veneer). In these instances, it is likely to be very difficult to lift the floor without causing significant damage to the veneer cladding. However, it is recommended that the levelling operation is undertaken with the veneer in place and a decision is made on the possibility of repairing the existing veneer rather than demolishing and rebuilding once the floor is level.

If the veneer must be removed the owner may choose to have insulation installed in the exterior walls, if this was not already in place, at his/her own expense.

Re-levelling foundation

All three lifting options in section 5.1.2 may be used. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 4.

Re-building foundation

In these instances, the veneer must be demolished to allow the superstructure to be lifted off the existing concrete slab, moved and then replaced.

If the veneer must be removed the owner may choose to have insulation installed in the exterior walls, if this was not already in place, at his/her own expense.

Once the veneer has been removed, the remedial works will follow the steps outlined in section 5.1.4 and then the veneer will be re-built on the new foundation. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 5.

5.2 Repairing Superstructure Elements

5.2.1 Chimneys

Repaired chimneys must meet the Building Code performance requirements for Structure and Fire Safety. Any repairs or re-builds must be done correctly to prevent the possibility of a potential house fire.

The top of the chimney must be a minimum of 600mm above the ridge line (AS/NZS 2918).

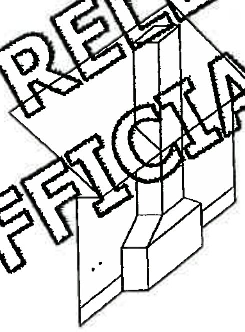
Environment Canterbury requirements:

Outside Christchurch, Kaiapoi, Rangiora and Ashburton Clean Air Zone 1 open fires are permissible.
In Christchurch Clean Air Zone 1 – use of an open fire or a greater than 15 year old solid fuel burner is permissible outside of the winter period (defined dates) but only with dry wood.

In Christchurch Clean Air Zone 2 – existing open fires and solid fuel burners are permissible but only with dry wood.

External chimney repair options

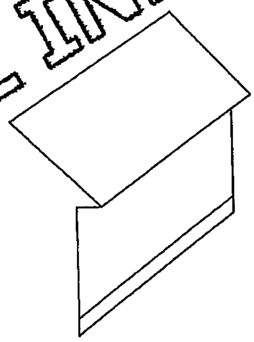
The following options are suggested for unreinforced masonry chimneys located on the outside of a dwelling:



Existing chimney prior to earthquake damage

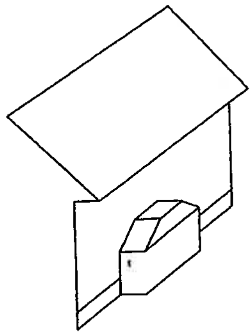
Unreinforced masonry or precast concrete blocks

Damage sustained: Stack above roof has toppled but bottom is still flush against the house



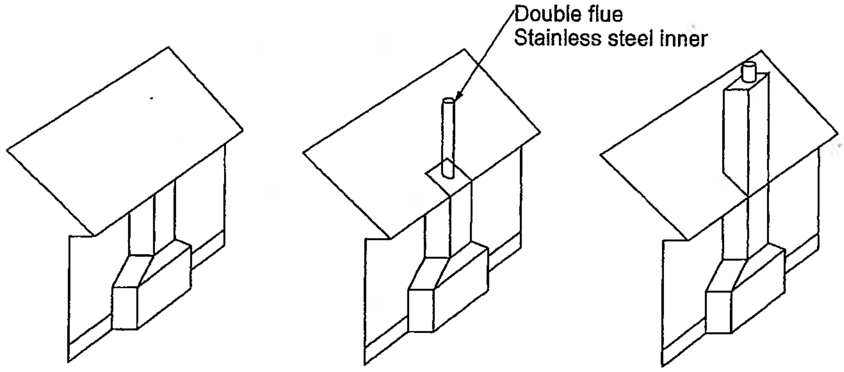
Repair Option 1:

Completely demolish the chimney and repair the outside wall of the dwelling. Note: if the chimney has separated from the wall at the soffit by more than 10mm then it must be demolished to the foundation. Rebuild if required to B1/AS3 or similar.



Repair Option 2:

Demolish the chimney to the top of the base and gather and weatherproof. Seal fireplace. Repair external cladding, roof and soffit



Repair Option 3:

Demolish the chimney to below the roof line, brace with timber frame at ceiling level and repair the roof. Seal fireplace.

Repair Option 4:

Demolish the chimney to below the roof line and flash a new steel flue and shield for old chimney stack venting.

Repair Option 5:

Demolish the chimney to below the roof line and build timber frame with brick slip cladding to match lower section. ONLY suitable for steel flue. Triple shield - requires minimum 450mm space inside framing.

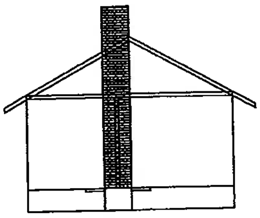
If the chimney has tilted away from the wall of the house by an amount greater than 10mm at the eaves, then this is indicative of a failure of the soil beneath the chimney, which may have been the case before the earthquake occurred. Check for obvious signs of aging of the crack such as the presence of moss and debris between the chimney and the wall of the dwelling.

If it is established that the movement is a result of the earthquake then demolish the chimney and rebuild if appropriate, reinforced as per Figure 2 or Figure 3 of B1/AS3, including the foundation of the chimney. A 300mm layer of compacted hardfill beneath the chimney foundation should be included and the chimney base tied to the house foundation.

Internal chimney repair options

Often internal fireplaces have been built back-to-back to provide heating for adjacent rooms. Their greater mass of the fireplace than adjacent timber floor systems may have caused greater settlement of the chimney in the earthquake, which tends to pull the adjacent floor down with it. If this settlement causes a slope in the adjacent floor of greater than 1% (10mm in 1m), the floor framing should be detached from the chimney foundation, raised to the correct level and re-fixed to the chimney foundation. A screed can be used to raise the hearth and firebox floor to the same level.

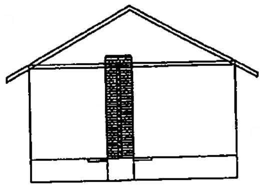
The following options are suggested for unreinforced masonry chimneys located within the dwelling:



Existing chimney prior to earthquake damage

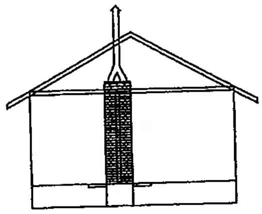
Unreinforced masonry or precast concrete blocks

Damage sustained: Stack above roof has toppled.



Condition of chimney breast and stack to roof is good.

Remediation Option 1: Demolish chimney to a point just above the ceiling framing and cap. Repair roof frame and roof cladding.
SEAL FIREPLACE TO PREVENT FUTURE USE

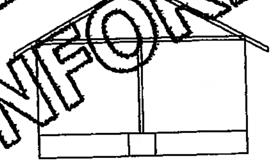


Condition of chimney breast and stack to roof is good.

Remediation Option 2: Demolish chimney to a point just above the ceiling framing and fit steel flue from burner and flash at roof line. Combine flues if back to back stacks present. Install metal heat shield to vent brick chimney stack to exterior

Condition of chimney breast and stack to roof is good.

Remediation Option 3: Demolish chimney to a point just above the ceiling framing and build timber framed chimney with steel flue and shielding to match AS/NZS 2918.



Condition of chimney breast and stack to roof is poor.

Remediation Option 4: Demolish chimney to ground floor level and repair roof, wall and ceiling framing. Remove hearths if required and repair floor and walls.

5.2.2 Wall Bracing

Where there is evidence of significant racking of walls (e.g. shear deformations on interior sheet lining junctions and associated nail/screw popping, lifting of sheets from behind skirting boards and/or diagonal cracking of sheets), the wall linings will need to be replaced, re-stopped and re-decorated. Trims (e.g. scotias, skirtings) will need to be removed and possibly replaced.

Any damage to the wall framing members will need to be repaired. Note that significant damage to the framing is unlikely unless there has been substantial spreading or substantial abrupt change differential settlement beneath the house.
External sheet cladding connections and joints must also be checked and re-fixed. If the cladding has a bracing function then the sheet fixings must be checked and if damaged appropriate fixings will need to be installed in the intervening gaps and the finish reinstated.

5.2.3 Wall and Roof Frame Connections

Fractured timber members must be replaced or spliced to ensure their continued function. Joints between members that have been pulled apart must be reinstated and re-fixed. Such damage in walls will generally only be expected if the wall linings are showing signs of severe distress (such as detached sheets).

Roof framing is generally triangulated, meaning that it is self bracing. The exception is a gable ended roof where roof plane or roof space bracing is relied on to provide bracing in the ridgeline direction. If the roof shows signs of major distortion (which could be as a result of ground disturbance or ground shaking), then a check of all roof space connections will be necessary, and repairs undertaken to reinstate the bracing function. Such damage is more likely with a heavy roof cladding, such as concrete or clay tiles.

If the wall linings or the ceiling linings have separated more than 20mm from the wall/ceiling junction, it may be necessary to remove the ceiling linings or soffit linings to gain access to the joints so that they may be re-connected.

5.2.4 Light Gauge Steel framing

Deformations of linings and claddings (particularly out of plane) will indicate that the support framing has likely buckled. Linings and claddings will need to be removed for inspection of the framing, and bent and buckled framing members must be replaced.

6. Rebuilding Houses

6.1 General

For the areas where most houses are to be rebuilt, the land remediation measure being undertaken by Government will largely eliminate the possibility of significant lateral spreading occurring. As outlined in Section 3, it is considered appropriate to allow for potential lateral spreading of up to 50mm horizontally for all areas other than in Building Restriction Zones. For Building Restriction zones, specific engineering design is required for any new dwellings in these areas, and this must take into account the potential for significant lateral spreading unless the subject of site land remediation.

Rebuilding houses on land which is still susceptible to liquefaction in the future but which is likely to only suffer nominal lateral spreading as above will require a foundation system that is capable of resisting some tension effects, also be capable of spanning over possible local settlements of the ground beneath the house.

Maintaining the house in a flat level plane cannot be guaranteed unless a system is employed that will provide support for the structure from a level below the liquefiable soil. Such a system will often be uneconomic because of the length and number of piles required. Alternatively, provision may be made in the design of the new foundation system to ensure that it has sufficient stiffness to remain in a near flat plane after a future earthquake and is capable of being re-levelled as a single body.

The concrete slab-on-grade floor system detailed in NZS 3604 is not suitable for achieving this outcome, as it is too flexible and it lacks the in-plane strength to resist significant lateral spreading without rupturing.

The use of NZS 3604 for the design of the superstructure (i.e. everything above the ground floor plate) is however acceptable for reconstruction of any house within the scope of NZS 3604 – that is, the dimensional limitations are adhered to, and the use is limited to Importance Level 2 (AS/NZS 1170.0).

The indicative foundation and floor options presented in sections 6.2.2 and 6.2.3 following will require design and detailing by structural engineers. They are expected to be able to withstand lateral spreading of the ground beneath the foundation of up to 50mm, and bridge a length of 5m of settled soil (or sudden lack of support) beneath the foundation and cantilever a distance of up to 3m over settled soil at the building footprint extremities.

These shaded parameters are subject to further discussion. Consideration is also being given to possible alignment with the simple housing foundation solutions (including with respect to issues such as regularity limits), and expansive soil class equivalence.

Site preparation should ensure that all grass and topsoil is removed prior to the placement of foundations or gravel fill. Historically, poorly graded river gravels (tailings or 20/40 river stone) have been used under slabs. These materials should have a separation geotextile (Bibum A19 or equivalent) placed between the stone and the subgrade and the tailings should be compacted in minimum 200 mm layers using a plate compactor. Alternatively, a well graded aggregate (AP 40 or similar) could be used, which should also be compacted in minimum 200 mm layers with a plate compactor, but no separation geotextile layer is required.

Site investigation requirements are outlined in Section 7.1.

6.2 Indicative New Foundation and Floor Options

This section provides details of alternative foundation and floor solutions for houses that are likely to be affected by liquefaction in future earthquakes with a return period of 150 years or greater.

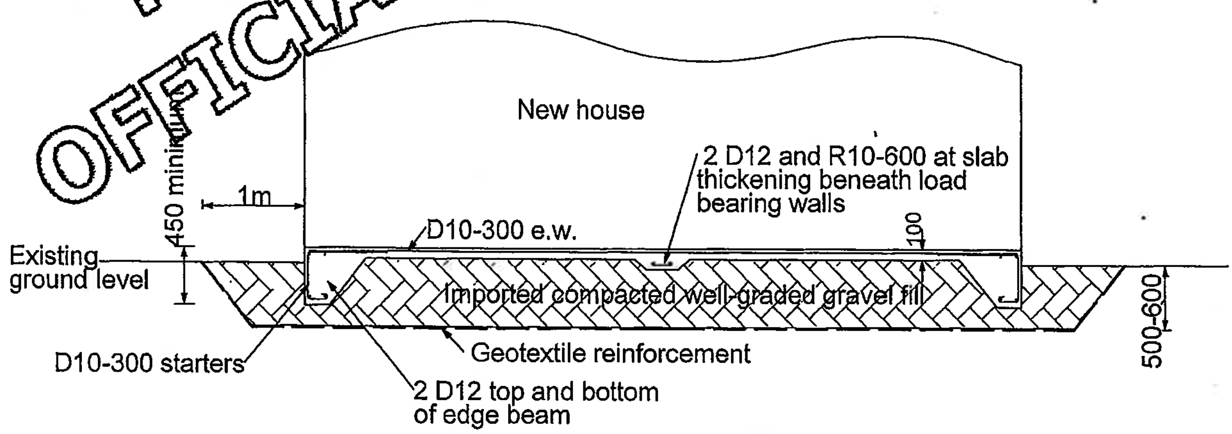
6.2.2 Floor Construction – Reinforced Concrete

Several options may be employed, but each has limitations which must be recognised.

The common options include:

Option 1 - Excavation and replacement of the upper layers of soil with compacted well graded gravels and construction of a reinforced NZS 3604 slab foundation (only suitable for thin layers of liquefiable soils)

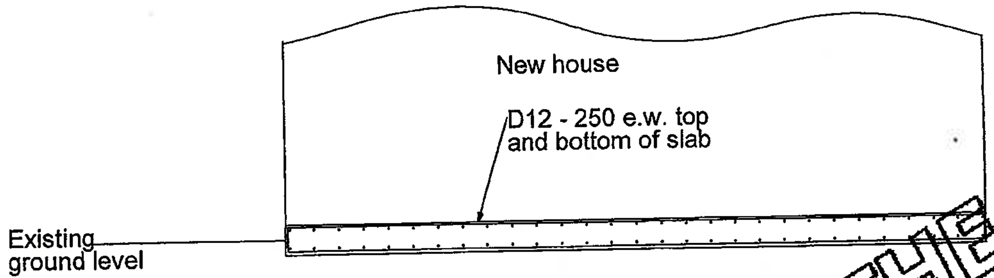
<u>New Foundation Option 1</u>



Note: NZS 3604 ground clearances adjacent to house foundation must be complied with

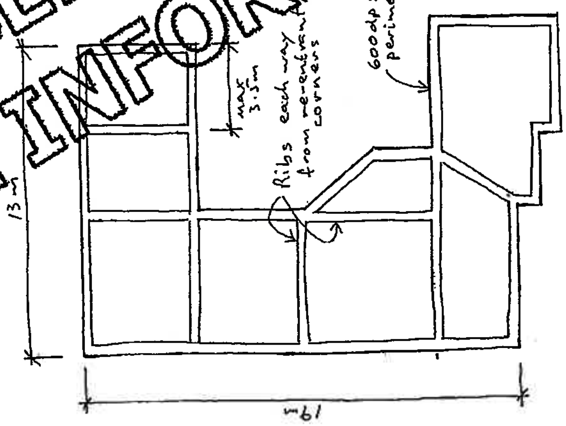
Option 2 - Construct a thick slab foundation over the existing soil (no special soil preparation)

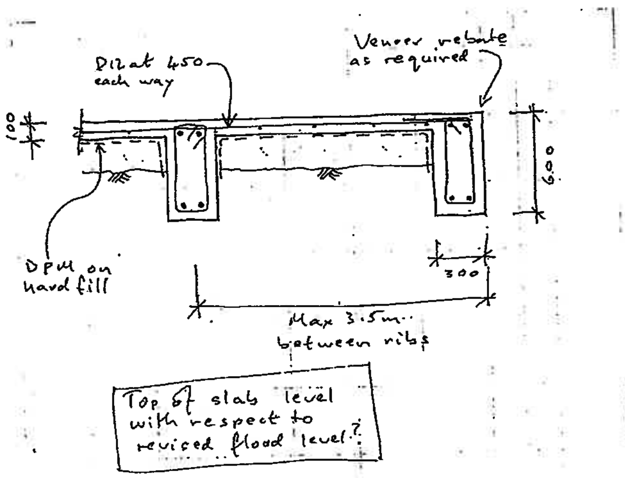
<u>**New Foundation Option 2**</u>



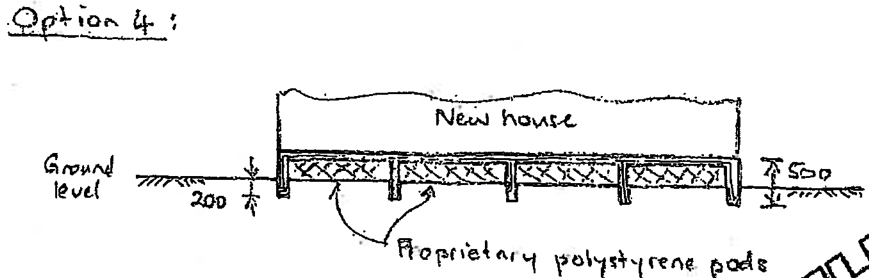
Note: NZS 3604 ground clearances adjacent to house foundation must be complied with

Option 3 - Construct a generic beam grid and slab foundation (no special soil preparation)





Option 4 - Construct a stiffened waffle slab over the existing soil (no special soil preparation)

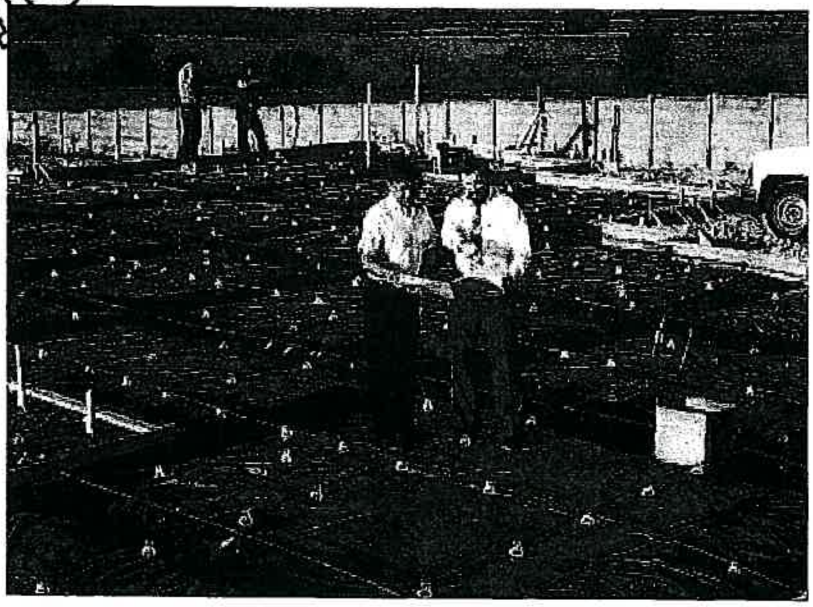


Option 5 - Construct a post-tensioned waffle slab over the existing soil (no special soil preparation)

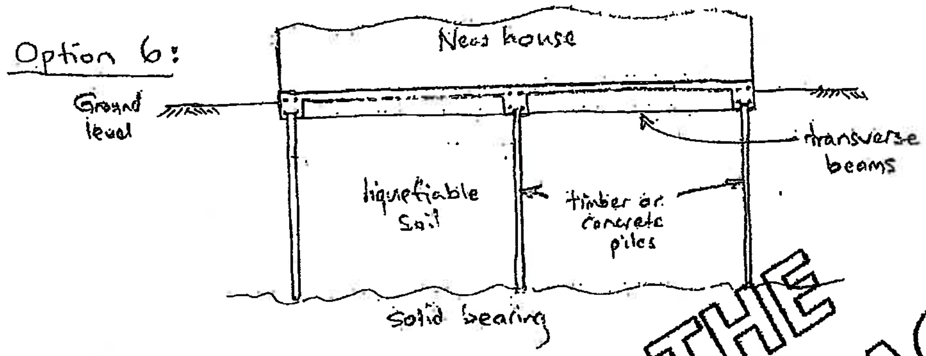
The generic post-tensioning option for use in houses usually involves single 12.9 or 15.2mm strand tendons in an un-bonded format. The factory applied greased and sheathed strands are supported in the slab on bar chairs and tensioned through mono strand anchorages fixed at both ends through the perimeter formwork. Tensioning is carried out using calibrated centre-hole hydraulic jacks.

After tensioning the excess strand is cropped and a cover cap (anticorrosive grease filled) is fitted to the end and the formed recess is mortared over.

Post-tensioned slabs are tensioned to about 1MPa (in time) to overcome drying shrinkage and give some bridging, through settlement, capacity. Spacing of the tendons is nominally 1.0m centres each way.



Option 6 - Drive piles to solid bearing beneath a liquefiable layer and construct a floor slab with reinforced thickening on pile rows in both directions to tie the tops of the piles together (no special soil preparation).



6.2.3 Floor Construction – Timber

A timber framed floor on timber or concrete piles constructed in accordance with NZS 3604 is not seen as an acceptable means of achieving a sufficiently stiff floor plate under a new house structure to resist the potential differential settlements associated with liquefiable soil and that would be expected in a future major earthquake event. However, with sufficient knowledge of the subsoil conditions beneath the site, it may be economic to drive timber piles to dense gravels and use a timber floor system in accordance with NZS 3604.

This approach will require a specialist engineering soil investigation to establish pile lengths.

6.3 Guidance for Specific Engineering Design

Other options may be developed as specific designs in more complicated land and/ or building situations than will be applicable for the above options, or to achieve increased levels of performance in future earthquakes.

For these specifically designed cases, the following criteria should be satisfied:

- A full geotechnical investigation of the site should be carried out before designing the foundation
- Design for the potential for lateral ground spreading of up to 50mm, as a minimum, or other values as indicated from the geotechnical investigation
- Design for the potential for differential settlement of the supporting ground that may create a length of no support for the ground floor of 5m beneath sections of the floor and 3m at the extremes of the floor (ie ends and outer corners)
- Design to ensure that the floor does not hog or sag more than 1 in 400 (i.e. 25mm hog or sag at the centre of a 10m length)
- Appropriate provision should be made for "flexible" services entry to the dwelling to accommodate the potential differential settlement of the foundation as indicated in the geotechnical report.

7. Recommended Arrangements for Engineering Input

7.1 During the Assessment and Repair Specification Phase

A number of building consents have already been applied for by property owners to repair or reconstruct dwellings following the 2010 earthquake. In most of these cases, local Councils have requiring as part of the consent application a site specific geotechnical report that assesses the future risk of liquefaction. To adequately assess the future liquefaction hazard at a specific site, a full geotechnical investigation would be required including either drilled boreholes or Cone Penetrometer Tests together with groundwater monitoring and laboratory testing. While Scala Penetrometer Testing is not capable of extending to sufficient depth to determine the full liquefaction risk, it can adequately determine the depth of any stiff overlying raft if present.

Assuming the recent earthquake was approaching an Ultimate Limit State (ULS) event, the recent behaviour of the ground at individual sites is considered to be a useful guide to the likely performance of the site in a future ULS event. Any requirement for a full geotechnical report with field investigations (Boreholes or Cone Penetrometer Tests) for all sites that have suffered land damage from the recent earthquake would have major impacts on reconstruction time frames and also cost implications. A pragmatic approach is therefore considered necessary to ensure timely reconstruction in accordance with broader community recovery programme objectives.

On this basis, it is recommended that the level of investigations required be in proportion to the severity of land damage, as well as the amount of investigations which have been undertaken by EQC for the land remediation work. The Tonkin and Taylor Ltd Darfield Earthquake Stage 2 Report contains maps which identify three land zonation categories. These maps mainly cover the worst affected suburban areas, but do not extend into the residential rural areas or into the less damaged suburban areas which are outside the areas identified on the land damage maps.

Areas covered by Suburb Geotechnical Reports

Three zonation categories have been used on the maps (see example in Figure 7.1):

- Zone A – No land damage
- Zone B – Land damage in areas where the ground surface may be disturbed and require minor surface levelling and possible filling or compaction may be required.
- Zone C – Land damage in the areas where substantial land remediation will be undertaken.

Land damage refers to places where liquefaction has resulted in settlement and or lateral spreading.

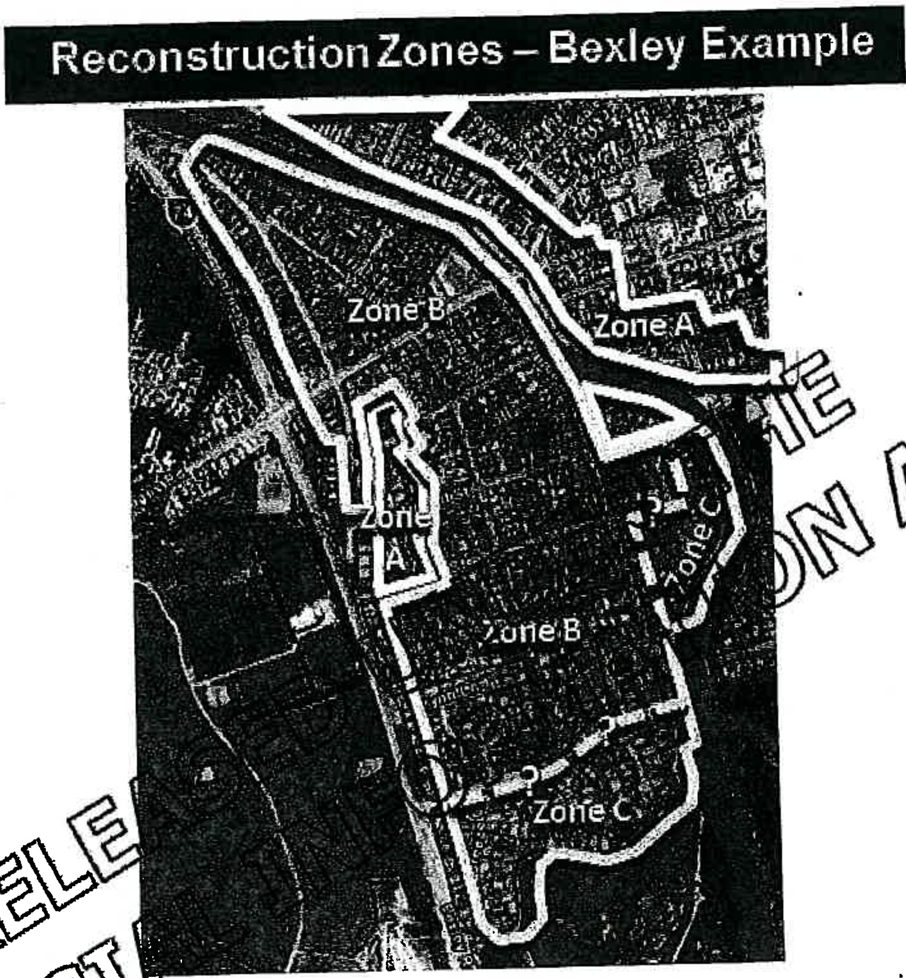


Figure 7.1 Example of Bexley Zone map

Suburb geotechnical investigations and reports will be undertaken by EQC for a number of the mapped suburbs. These are being prepared for two purposes:

1. For the design of the perimeter land treatment work if required
2. To address the overall liquefaction hazard

The suburb geotechnical reports will investigate the deeper soil profiles and the liquefaction hazards. They will address the geotechnical seismic risk/issues for the suburb as a whole, and provide sufficient information for the design of structures for this hazard.

In the areas covered by the suburb geotechnical reports, deep subsoil investigations (i.e. Boreholes or Cone Penetrometer Tests (CPTs)) will not be required on individual sites. In these areas, for <u>reconstructed</u> houses only, an NZS 3604-type geotechnical investigation will be required (unless one already exists for the specific site).

In this context, an *NZS 3604-type investigation* is an investigation that meets the requirements of NZS3604 <u>for the normal static conditions</u>, excluding the effects of liquefaction.

Field investigations may therefore be limited to Scala Penetrometer Testing (DCP) and hand augers to confirm that the upper 2m of land meets NZS 3604 requirements for static bearing (ie. ultimate bearing capacity of 300kPa or other capacity as indicated from the suburb geotechnical reports). It is expected that these field investigation reports need not be more than a one page letter or template detailing the observed damage, and providing confirmation that the upper 2m provides sufficient bearing capacity. An example template for such an investigation report is included in Appendix 6 (to be prepared).

In the case where the rebuilding work is to be managed by EQC or the relevant Insurance Company, it is envisaged that the NZS 3604-type investigations may be carried out by a technician under the employment of the managing organisation or a company under the direct control of the managing organisation. It is proposed that specific training will be provided for technicians undertaking this role, who would in turn be operating under the ultimate direction of a Chartered Professional Engineer.

In the case where the rebuilding is to be managed or carried out by an individual property owner, the investigation must be carried out by a Chartered Professional Engineer (CPEng-Geotechnical).

For dwellings that are only being repaired with no new foundation elements, no 3604-type investigations are required.

Areas Not covered by Suburb Geotechnical Reports

For areas of land not covered by the zoning maps, it is recommended that an observational approach be undertaken to determine what level of future investigations should be required for any remedial works for reconstructed dwellings. In general, sites that have suffered from lateral spreading in the 2010 earthquake have suffered more extensive damage than those sites where liquefaction induced settlements alone have occurred.

On this basis we recommend the following approach be undertaken:

- On sites where lateral spreading has occurred, a site-specific geotechnical investigation and report is required which should include machine boreholes and/or CPTs. This work should be carried out by a specialist geotechnical Engineer (CPEng-Geotechnical) or specialist geotechnical company.
- On sites where liquefaction induced settlement occurred, an NZS 3604-type geotechnical investigation is required (unless one already exists for the specific site).

In the case where the rebuilding work is to be managed by EQC or the relevant Insurance Company, the NZS 3604-type investigations may be carried out by a technician under the employment of the managing organisation or a company under the direct control of the managing organisation. It is proposed that specific training will be provided for technicians undertaking this role, who would in turn be operating under the ultimate direction of a Chartered Professional Engineer.

In the case where the rebuilding is to be managed or carried out by an individual property owner, the investigation must be carried out by a Chartered Professional Engineer (CPEng-Geotechnical).

For repaired dwellings, no NZS 3604-type investigations are required.

The overall process outlined on the previous pages is summarised in Figure 7.2:

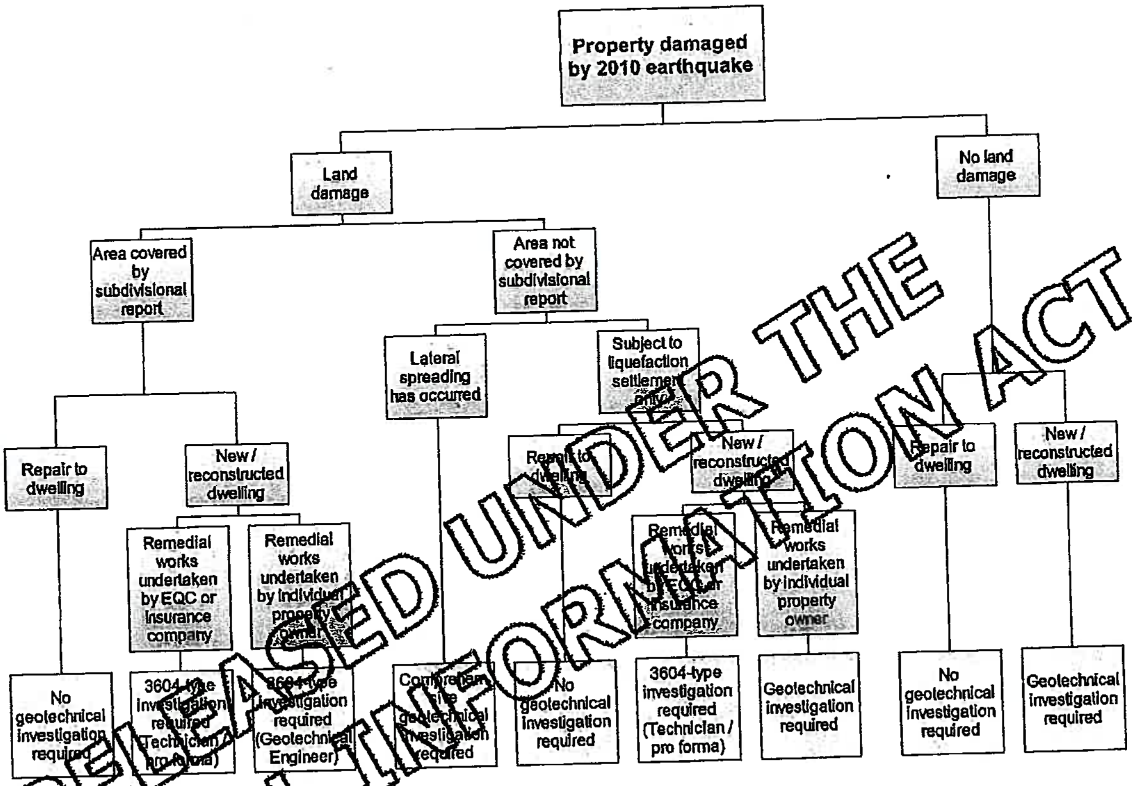


Figure 7.2: Summary of relationship between individual site investigation and land damage

7.2 During Construction Work and Upon Completion

Normal engineering inspections as per Council building consent requirements should be undertaken. Geotechnical and structural Producer Statement PS3 and PS4 certificates may be required, subject to building consent conditions.

For further discussion with Council representatives

8. Other Considerations

8.1 Flood Risk

Comments are required from the respective councils as to whether the risk from flooding has substantially changed following the 2010 Earthquake, and what their current (and any proposed new) requirements are regarding minimum floor level requirements for dwellings in the critically affected suburbs.

8.2 Time Frames for Repair and Reconstruction

The land affected by liquefaction from the Darfield Earthquake is generally underlain by a 1 to 2 m stiff unsaturated upper layer overlying saturated fine grained sands or silty sands extending up to 10 m depth. It is understand from claimants, engineers and others that anecdotally the land is still settling as at the beginning of November 2010.

Based on this information, it is expected that pore pressures in the liquefied zone have not fully dissipated and the liquefied sands have not yet returned to their pre-earthquake densities. It is anticipated that by far the majority of the liquefaction induced settlement has occurred with the remaining movements expected to be completed in the next few months. Survey monitoring and geotechnical investigations have been initiated to confirm this.

On this basis it is recommended that any repair work to dwellings in the liquefied areas be undertaken once final settlements have ceased or the works be undertaken in a manner that can accommodate additional minor settlements (< 10 mm).

In areas where the upper soil layer has a higher clay content soil movements from seasonal wetting and drying (shrink/swell movements) could be expected to occur. These movements would generally be < 10 mm in most areas of Christchurch, but could be up to 30 mm. Based on the above, repaired or re-constructed floor systems should be designed to accommodate minor ground level fluctuations as have historically occurred.

References

New Zealand Geotechnical Society (NZGS, 2010) Guidelines for Geotechnical Earthquake Engineering Practice in New Zealand. Module 1 – Guideline for the identification, assessment and mitigation of liquefaction hazards. July 2010.

Tonkin & Taylor Ltd (T & T, 2010) Darfield Earthquake 4 September 2010 Geotechnical Land Damage Assessment & Reinstatement Report, Stage 1 Report for EQC

Tonkin & Taylor Ltd (T & T, 2010) Darfield Earthquake 4 September 2010 Geotechnical Land Damage Assessment & Reinstatement Report, Stage 2 Report for EQC

AS/NZS 1170 Structural Loadings Standard

NZS 3604: 1999 Timber Framed Buildings

Appendix 1:
Summary of the Effects of Liquefaction

The following explanation is provided for liquefaction, lateral spreading and bearing capacity failure associated with the 2010 Darfield earthquake:

> *Loose granular soil deposits try to densify when subject to strong earthquake shaking. If the soils are unsaturated then the ground surface will generally just settle as the soil densifies and compacts itself. Where these soils are saturated, the re-adjustment of particles within the soils leads to a build up of pressure within the pore water. The soils can only densify once the pore pressures begin dissipate. The rate at which these pore pressures dissipate; and hence the rate of settlement due to densification, is dependent upon the permeability of the soil. If the spoil permeability is very low then the pore pressure build up can exceed the effective overburden stress in the soil and the soil then liquefies. Dissipation of this groundwater pressure can lead to 'boiling' of the ground and the ejection of water and fine soils to the ground surface.*
>
> *The excess pore water pressures are expected to gradually dissipate after the seismic shaking has ceased. With time the liquefied ground becomes "solid" and usually rests in a slightly denser state than before. Anecdotal evidence from liquefied areas within Christchurch indicates the ejection of groundwater, silt and sand material to the ground surface generally continued for between 1 and 30 minutes after the primary ground shaking ceased.*
> *In general, the excess groundwater pressures due to seismic shaking are expected to take between 2 and 8 weeks to dissipate and essentially return to a level which existed prior to the earthquake. The ground surface is expected to creep and settle by a small amount while the excess pore pressures dissipate. It should be noted, however, that in some rare cases the groundwater pressures may take somewhat longer to dissipate if the ground conditions are particularly unfavourable.*
>
> *Liquefaction requires three key elements to occur:*
>
> *(a) The presence of loose, non-cohesive material that will densify under seismic shaking (loose fine sands and many loose silt-sand mixtures are particularly susceptible to liquefaction).*
>
> *(b) Ground saturation (i.e. the liquefaction susceptible material lies below the groundwater table), and,*
>
> *(c) Sufficient shaking to trigger liquefaction. In this regard it should be noted the level of seismic shaking to trigger liquefaction can vary significantly from site to site.*
>
> *Once liquefaction has occurred it can lead to a number of secondary effects, including:*
>
> *(a) Lateral spreading and the associated development of "graben" features (i.e. the ground shifts sideways and tension cracks develop where the ground has torn apart),*
>
> *(b) Bearing capacity failure of foundations,*
>
> *(c) Rotational slope failure or ground movement and the development of lines of differential settlement(i.e. a semi-circular rotational failure of the ground occurs and this creates a step in the ground surface at the head and toe of the failure surface),*
>
> *(d) Sand boils (i.e. liquefied material is ejected from within the ground to the surface through defects in the ground such as holes, structural penetrations, graben features and tension cracks),*
>
> *(e) Settlement of the ground surface which is additional to that which was caused by the initial shaking densification (usually from sand boils ejecting liquefied material); and,*
>
> *(f) The floatation of buried services and "buoyant" structures such as pipelines, manholes, swimming pools and tanks.*

Preliminary observations indicate lateral spreading, rotational failures and settlement have caused a large portion of the most severe building damage that is attributable to the 2010 Darfield earthquake. The other significant cause of building damage has been the collapse of pre-1940 unreinforced masonry or brick structures due to the shaking that occurred.

Lateral spreading may occur if all or part of a sloping soil mass liquefies. In such instances liquefaction of deeper material may cause a "crust" to slide towards a topographically lower area such as a river bed or pond. Structures on the main slide are frequently moved without suffering significant damage; however, a graben feature (i.e. tension crack / tear zone) will form at the head of this type of slide. Buildings which are located across lateral spread graben zones, or a rotational failure surface, usually suffer considerable damage due to large differential settlement and/or lateral extension across the building.

During the post liquefaction period the ground surface may settle and/or creep as the soils re-consolidate to a denser state. Once the excess pore pressures have fully dissipated the geotechnical conditions, including soil density, strength, stiffness and bearing capacity, are expected to return to a condition close to, and perhaps slightly better than, that which existed prior to occurrence of the 2010 Darfield earthquake.

In general, all soils which experienced liquefaction during the 2010 Darfield earthquake are expected to be at risk of liquefaction due to a future severe seismic event.

There are a number of publications that provide further detailed discussion on liquefaction and its effects. For further information and detail the reader is referred to the recent draft NZ Geotechnical Society guidelines (Ref 1).

Appendix 2:
Provisions of the Building Code Relating to Houses (paraphrased)

The bullet points below are a summary only of some of the key building code clauses that need to be considered when repairing or rebuilding an earthquake damaged building. This Appendix is for the purposes of discussion only, and is not a substitute for the full building code clauses, set out in the Building Regulations 1992. It is important that the full building code is considered in light of the particular circumstances of each repair or rebuild.

B1 Structure.

- Buildings shall withstand the combination of loads they are likely to experience throughout their lives.
- Low probability of rupture, becoming unstable, collapsing
- Low probability of causing loss of amenity through undue deformation, etc
- Account shall be taken of all physical conditions likely to affect stability including dead and live loads, earth pressure, water and other liquids, earthquake, differential movement, etc
- Due allowance shall be made for the consequences of failure, variation in properties of materials and characteristics of the site, accuracy limitations inherent in methods used to predict the stability of buildings

Benchmark: NZS 3604

B2 Durability

- Building materials, components and construction methods shall be sufficiently durable to ensure the building, without reconstruction of major renovation, satisfies other building code requirements throughout the life of the building.

Benchmark: B2/AS1, NZS 3602, Timber,

C Fire Safety

E1 Surface Water

- Buildings and sitework shall be constructed in a way that protects people and other property from the adverse effects of surface water
- Surface water having a 10% probability of occurring annually and collected or concentrated by sitework shall be disposed of to avoid damage or nuisance to other properties
- Surface water from an event having 2% annual probability shall not enter building

E2 External Moisture

- Buildings must be constructed to provide adequate resistance to penetration by moisture from the outside
- Roofs to shed water
- Roofs and external walls must prevent penetration of water that could cause undue dampness, or damage to building elements

- Walls, floors and structural elements must not absorb or transmit moisture from the ground that could cause undue dampness, or damage to building elements
- Building elements susceptible to damage protected from adverse effects of moisture entering space below suspended floors
- Concealed spaces and cavities constructed to prevent condensation, fungal growth or degradation of building elements

Benchmark: E2/AS1

E3 Internal Moisture

- Adequate combination of thermal resistance, ventilation and space temperature must be provided to all habitable spaces, bathrooms, etc to prevent fungal growth on linings, etc or damage to building elements.

F4 Safety from falling

- Buildings constructed to reduce likelihood of accidental fall
- Barriers provided where people could fall 1 metre or more

F7 Warning systems

- Provide appropriate means of detection and warning for fire.

G1 Personal Hygiene

- Provide appropriate spaces and facilities for personal hygiene

G2 Laundering

- Provide adequate space and facilities for laundering

G3 Food preparation and prevention of contamination

- Provide space and facilities for hygienic storage, preparation and cooking of food

G4 Ventilation

- Means of ventilation with outdoor air providing adequate number of air changes to maintain air purity
- Removal of cooking fumes, moisture from laundering, showering, etc,

G5 Interior Environment

- Heating appliances installed in a way that reduces likelihood of injury

G6 Airborne and impact sound

- Building elements common between occupancies shall be constructed to prevent undue noise transmission

G7 Natural Light

- Habitable spaces shall provide adequate openings for natural light and visual awareness of the outside environment

G8 Artificial Light

- Adequate lighting to enable safe movement (> 20 lux)

G9 Electricity, G11 Gas,

- Where provided, electrical installations/gas systems shall be safe for their intended use.

G12 Water Supplies

- Potable water for human consumption
- Hot water for washing/showering

G12 Foul Water

- Adequate plumbing and drainage system to carry foul water to appropriate disposal

H1 Energy Efficiency

- Buildings constructed to achieve adequate energy efficiency when heated or ventilated (note: levels of insulation required increased from October 2007)

Appendix 3:
Typical Repair and Rebuild Work and Need for Building Consent

To be prepared

	Type of work	Need for building consent	Comments
	Rebuild house	Yes	
	Rebuild foundations	Yes	

Appendix 4:
Outline Method Statements for Repairing Foundations and Floors

The tables on the following pages provide outline method statements for re-levelling foundations and floor slabs of existing houses as summarised in Section 5.1.

The steps outlined are broadly in the sequence recommended.

It is emphasised that these approaches will not suit all houses that are considered repairable, and that each house will require careful consideration.

Furthermore, these approaches address only the structural aspects, with reference to finishes only where they relate to re-levelling works.

All aspects associated with weathertightness and the making good of finishes are to be separately specified by appropriately qualified persons.

Outline Foundation and Floor Repair Method Statement

Type A: Pile Foundation and Light Clad Exterior Walls

Refer Section 5.1.1

Step	Activity	Comments/ References
1.	Remove the cladding attached to the exterior piles to expose the piles and retain if possible	
2.	Locate services entry points to the house and allow for disconnection or relief of these during the floor lifting operation	e.g. dig away soil at water, waste, power and telephone connections to allow these to lift with the house
3.	Check the vertical alignment of the piles. If existing piles are leaning at an angle of more than 15mm per 1m height then new piles will be required (see point 7 below).	
4.	Detach the piles from the bearers.	
5.	Install jacking equipment and sequentially lift the affected areas, ensuring that in this process there is no differential displacement created that would mean that the maximum vertical displacement of a point on a straight line between two other points on the floor 6m apart is more than 25mm. During the jacking process make allowance for lateral stability of the detached structure.	
6.	For floor lifts of up to 50mm at any pile, fit H5 treated timber packing (preferably as a single thickness piece) and connect to the existing pile top and the underside of the bearer as per the requirements of NZS 3604 (for piles without a bracing function: pairs of wire dogs and 100mm skewed nails for timber piles and 4mm wire and staples for concrete piles).	*If all piles are fixed in this manner then the lateral load resisting capacity ought to match what it was prior to the earthquake. However, this may be less than the requirements of NZS 3604:1999.*
7.	For lifts greater than 50mm at any pile, new piles will be required to be fitted that may be connected directly to the existing bearers either by scarfing and bolting or by fixing with wire dogs and skewed nails as above.	
8.	For dwellings that have settled more than 50mm, no pile tops shall be less than 150mm above the ground level (NZS 3604 requirement). If piles have settled to a level less than this then either packing or new piles will be required. Between 150mm and 300mm above the existing ground, a DPC should be installed between the pile top and the floor framing (*NZS 3604 requirement which is greater what might be existing pre-earthquake*). If no piles extend more than 300mm above the surrounding ground then it is likely that there will be no need for additional bracing (*this is less than for a new NZS 3604 building but would reinstate the house to its pre-earthquake condition*). For piles with greater than 300mm exposed height, consideration should be given to the installation of appropriate bracing in the two main orthogonal directions. This could include the addition of cantilever piles, anchor piles or braced piles (the latter case for pile heights greater than 600mm).	
9.	Re-attach the cladding to the outside of the piles.	
10.	Re-compact soil around the services. If the lifting process has reduced the cover to the services to a value less than allowed by the Building Code for safety reasons, then appropriate remediation will be required to satisfy the Building Code.	
11.	Superstructure deformations associated with this damage and repair are not considered to be sufficient to cause lateral stability issues in future earthquake events. There will likely be a need to re-stop some joints between the internal lining sheets and re-decorate parts of the interior of the house. External sheet cladding connections and joints must be checked and re-fixed in order to maintain weathertightness.	Ancillary attachments to the house such as heavy chimney foundations and breastworks, concrete steps, concrete terrace and timber deck areas will need to be remediated if their levels no longer align with the new floor level

Outline Foundation and Floor Repair Method Statement

Type B: Perimeter Concrete Foundation Wall

Refer Section 5.1.2 Light or Medium-weight claddings, and Section 5.1.3 for Heavy veneer claddings.

Preparatory Work

Step	Activity	Comments/ References
B1	Establish whether there is adequate bearing capacity for remedial works (e.g. using hand held scala penetrometer). It is recognised that there will be liquefiable soils at some depth beneath the house because this is the reason why it is in its current condition.	
B2	Locate services entry points to the house and allow for disconnection or relief of these (e.g. dig away soil at water, waste, power and telephone connections to allow these to lift with the house) during the floor lifting operation.	
B3	Check the vertical alignment of the internal piles. If existing piles are leaning at an angle of more than 50mm per 1m height then new piles will be required (see point 7 below). Leans of less than this value are not considered to be unacceptable if there is a perimeter foundation present.	
B4	Disconnect the internal piles from the bearers.	
B5	Demolish ancillary structures such as steps and terraces. Chimney foundations and breastworks may be lifted in the process described below if they are not being demolished.	

Lifting Option 1: Perimeter Foundation Jacking Using Portable Jacks

Step	Activity	Comments/ References
B1.1	Clear the perimeter of the foundation and at a spacing of about 2m around the perimeter of and under the foundation, excavate a 500mm square hole beneath the foundation to a suitable bearing layer. Install dunnage and jacks. It is preferable to have a series of jacks available to allow the foundation to be lifted sequentially by maximum 3mm increments. Start the lifting process by creating a planar floor plate, even if this is sloping, and then sequentially lift the foundation until a horizontal floor plate is achieved. The jacks may alternatively be placed adjacent to the outside face of the foundation and an "L" shaped shoe used to lift on the edge of the foundation, reacting on timber or steel dunnage. Ensure that the services are able to accommodate the lift heights or otherwise detach these before the lift begins.	
B1.2	Concurrently with the beam jacking, jack the underside of the bearers beneath the house to create and maintain the planar floor.	
B1.3	Seal each side of the space between the foundation and the dunnage, fit grout injection ports and pump non-shrink flowable grout under the elevated foundation. Leave to cure for 12-24 hours and remove the jacking equipment.	
B1.4	Fill the space between the underside of the foundation and the ground with concrete and re-instate the adjacent ground.	
B1.5	Seal the inside and outside faces of the foundation beam at each crack in the foundation beam and epoxy grout the crack.	
B1.6	Re-connect any services that had been disconnected prior to the lift.	
B1.7	Re-instate the adjacent ground.	
B1.8	Superstructure deformations associated with this damage and repair are not considered to be sufficient to cause lateral stability issues in future earthquake events. There will likely be a need to re-stop some joints between the internal lining sheets and re-decorate parts of the interior of	

	the house. External sheet cladding connections and joints must be checked and re-fixed. Cracks in EIFS claddings can be repaired and re-painted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.	

Lifting Option 2: Perimeter Foundation Jacking Using Piles (Screw or similar)

Step	Activity	Comments/ References
B2.1	Clear the perimeter of the foundation and at a spacing of about 2m around the perimeter and install proprietary screw piles to the required depth to obtain sufficient bearing capacity.	
B2.2	Ensure that the services are able to accommodate the lift heights or otherwise detach these before the lift begins.	
B2.3	Fit the lifting components to the tops of the screw piles and the under the edge of the foundation. Lift the foundation sequentially by a small amount (3mm maximum increments). Start the lifting process by creating a planar floor plate, even if this is sloping, and then sequentially lift the foundation until a horizontal floor plate is achieved.	
B2.4	Install grout injection ports and fill the space between the underside of the foundation and the existing ground with grout. Wait for 24 hours before removal of the screw piles (if they are to be removed).	
B2.5	The screw piles may be left in place or removed.	
B2.6	Concurrently with the foundation beam jacking, jack the underside of the bearers beneath the house to create and maintain the planar floor.	
B2.7	For floor lifts of up to 50mm at any pile, fit H5 treated timber packing (preferably as a single thickness piece) and connect to the existing pile top and the underside of the bearer as per the requirements of NZS 3604 (for piles without a bracing function: pairs of wire dogs and 100mm skewed nails for timber piles and 4mm wire and staples for concrete piles).	
B2.8	For lifts greater than 50mm at any pile, new piles will be required to be fitted that may be connected directly to the existing bearers either by scarfing and bolting or by fixing with wire dogs and skewed nails as above.	
B2.9	Seal the inside and outside faces of the foundation at each crack and epoxy grout the crack.	
B2.10	Re-connect any services that had been disconnected prior to the lift.	
B2.11	Re-instate the adjacent ground.	
B2.12	Superstructure deformations associated with this damage and repair are not considered to be sufficient to cause lateral stability issues in future earthquake events. There will likely be a need to re-stop some joints between the internal lining sheets and re-decorate parts of the interior of the house. External sheet cladding connections and joints must be checked and re-fixed. Cracks in EIFS claddings can be repaired and re-painted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.	

Lifting Option 3: Perimeter Foundation Jacking Using Urethane Foam

Step	Activity	Comments/ References
B3.1	Ensure that the services are able to accommodate the lift heights or otherwise detach these before the lift begins.	
B3.2	Set out laser for monitoring floor movement.	
B3.3	Commence injection below the perimeter foundation beam to improve the soils.	
B3.4	Carry out injection in a controlled manner, monitored by a laser and staff, to gradually raise the foundation to the required level.	
B3.5	Concurrently with the foundation beam lifting, jack the underside of the bearers beneath the house to create and maintain a planar floor.	
B3.6	For floor lifts of up to 50mm at any pile, fit H5 treated timber packing	

	(preferably as a single thickness piece) and connect to the existing pile top and the underside of the bearer as per the requirements of NZS 3604 (for piles without a bracing function: pairs of wire dogs and 100mm skewed nails for timber piles and 4mm wire and staples for concrete piles).	
B3.7	For lifts greater than 50mm at any pile, new piles will be required to be fitted that may be connected directly to the existing bearers either by scarfing and bolting or by fixing with wire dogs and skewed nails as above.	
B3.8	Seal the inside and outside faces of the foundation at each crack and epoxy grout the crack.	
B3.9	Re-connect any services that had been disconnected prior to the lift.	
B3.10	Re-instate the adjacent ground.	
B3.11	Superstructure deformations associated with this damage and repair are not considered to be sufficient to cause lateral stability issues in future earthquake events. There will likely be a need to re-stop some joints between the internal lining sheets and re-decorate parts of the interior of the house. External sheet cladding connections and joints must be checked and re-fixed. Cracks in EIFS claddings can be repaired and re-painted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.	

Outline Foundation and Floor Repair Method Statement

Type C: Slab on Grade Floors

Refer Section 5.1.4 for Light or Medium-weight claddings, and Section 5.1.5 for Heavy veneer claddings

Preparatory Work

Step	Activity	Comments/ References
C1	Establish whether there is adequate bearing capacity for remedial works (e.g. using hand held scala penetrometer). It is recognised that there will be liquefiable soils at some depth beneath the house because this is the reason why it is in its current condition.	
C2	Locate services entry points to the house and allow for disconnection or relief of these (e.g. dig away soil at water, waste, power and telephone connections to allow these to lift with the house) during the floor lifting operation.	
C3	Demolish ancillary structures such as steps and terraces. Chimney foundations and breastworks may be lifted in the process described below if they are not being demolished.	

Lifting Option 1: Perimeter Edge Beam Jacking Using Portable Jacks

Step	Activity	Comments/ References
C1.1	Clear the perimeter of the foundation and at a spacing of about 2m around the perimeter of and under the foundation excavate a 500mm square hole beneath the foundation to a suitable bearing layer. Install dunnage and jacks. It is preferable to have a series of jacks available to allow the foundation to be lifted sequentially by maximum 3mm increments. Start the lifting process by creating a planar floor plate, even if this is sloping, and then sequentially lift the foundation until a horizontal floor plate is achieved. Concurrently with the perimeter edge beam jacking, drill and inject grout through the floor slab on a suitable grid pattern, monitoring the slab lift. This is a specialist process requiring skilled operators. The jacks may be placed adjacent to the outside face of the foundation and an "L" shaped shoe used to lift on the edge of the foundation, reacting on timber or steel dunnage. Ensure that the services are able to accommodate the lift heights by exposing and allowing them to lift with the beam or otherwise detach these before the lift begins	
C1.2	Seal each side of the space between the foundation and the concrete pad, fit grout injection ports and pump non-shrink flowable grout under the elevated foundation. Leave to cure for 12-24 hours and remove the jacking equipment.	
C1.3	Fill the space between the underside of the foundation and the ground between the jacks with grout.	
C1.4	Take up all floor coverings in the areas where the floor has been lifted.	
C1.5	Seal the outside face of the edge beam at each crack and epoxy grout the crack.	
C1.6	Re-connect any services that had been disconnected prior to the lift.	
C1.7	Re-instate the adjacent ground.	
C1.8	Re-lay the floor coverings.	
C1.9	Superstructure deformations associated with this damage and repair are not considered to be sufficient to cause lateral stability issues in future earthquake events. There will likely be a need to re-stop some joints between the internal lining sheets and re-decorate parts of the interior of the house. External sheet cladding connections and joints must be checked and re-fixed. Cracks in EIFS claddings can be repaired and re-	

	painted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.	

Lifting Option 2: Perimeter Edge Beam Jacking Using Piles (Screw or similar)

Step	Activity	Comments/ References
C2.1	Clear the perimeter of the foundation and at a spacing of about 2m around the perimeter and install proprietary screw piles to the required depth to obtain sufficient bearing capacity.	
C2.2	Ensure that the services are able to accommodate the lift heights or otherwise detach these before the lift begins.	
C2.3	Fit the lifting components to the tops of the screw piles and the under the edge beam. Lift the edge beam sequentially by a small amount (3mm maximum increments). Start the lifting process by creating a planar floor plate, even if this is sloping, and then sequentially lift the edge beams until a horizontal floor plate is achieved. Concurrently, with the perimeter edge beam jacking, drill and inject grout through the floor slab on a suitable grid pattern, monitoring the slab lift. This is a specialist process requiring skilled operators.	
C2.4	Install grout injection ports and fill the space between the underside of the foundation and the existing ground with grout. Wait for 24 hours before removal of the screw piles (if they are to be removed).	
C2.5	The screw piles may be left in place or removed.	
C2.6	Take up all floor coverings in the areas where the floor has been lifted.	
C2.7	Fit injection ports in the floor slab on a grid of 1.5m eachway and inject grout beneath the slab while monitoring the slab lift. This is a specialist process requiring skilled operators.	
C2.8	Seal the outside face of the foundation at each crack and epoxy grout the crack.	
C2.9	Re-connect any services that had been disconnected prior to the lift.	
C2.10	Re-instate the adjacent ground.	
C2.11	Re-lay the floor coverings.	
C2.12	Superstructure deformations associated with this damage and repair are not considered to be sufficient to cause lateral stability issues in future earthquake events. There will likely be a need to re-stop some joints between the internal lining sheets and re-decorate parts of the interior of the house. External sheet cladding connections and joints must be checked and re-fixed. Cracks in EIFS claddings can be repaired and re-painted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.	

Lifting Option 3: Slab and Edge Beam Jacking Using Urethane Foam

Step	Activity	Comments/ References
C3.1	Ensure that the services are able to accommodate the lift heights or otherwise detach these before the lift begins.	
C3.2	Take up all floor coverings in the areas where the floor is to be lifted	
C3.3	Set out laser for monitoring floor movement.	
C3.4	Commence injection below the edge beam to improve the soils.	
C3.5	Carry out injection in a controlled manner, monitored by a laser and staff, to gradually raise the edge beam to the required level.	
C3.6	Once the edge beams have been raised to the final level commence injection via the ports in the floor slab to fill the space created between the raised slab and the basecourse. Further controlled injection via these ports will raise the slab to the same level as the edge beams. This may be done concurrently with the edge beam lifting.	
C3.7	Seal the outside face of the foundation at each crack and epoxy grout the	

	crack.	
C3.8	Re-connect any services that had been disconnected prior to the lift.	
C3.9	Re-instate the adjacent ground.	
C3.10	Re-lay the floor coverings.	
C3.11	Superstructure deformations associated with this damage and repair are not considered to be sufficient to cause lateral stability issues in future earthquake events. There will likely be a need to re-stop some joints between the internal lining sheets and re-decorate parts of the interior of the house. External sheet cladding connections and joints must be checked and re-fixed. Cracks in EIFS claddings can be repaired and re-painted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.	

Appendix 5:
Outline Method Statements for Replacing Foundations and Slab on Grade Floors

The tables on the following pages provide outline method statements for replacing foundations and floor slabs in existing houses, as summarised in Section 5.2.

The steps outlined are broadly in the sequence recommended.

It is emphasised that these approaches will not suit all houses that are considered repairable, and that each house will require careful consideration.

Furthermore, these approaches address only the structural aspects, with reference to finishes only where they relate to foundation replacement works.

All aspects associated with weathertightness and the making good of finishes are to be separately specified by appropriately qualified persons.

Outline Foundation and Floor Replacement Method Statement

Type A: Pile Foundation and Light Clad Exterior Walls

Refer Section 5.2.1

Step	Activity	Comments/ References
A1	Remove the cladding attached to the exterior piles to expose the piles.	
A2	Locate services entry points to the house and disconnect to allow the house to be lifted without damaging the services.	
A3	Demolish or disconnect from the foundation of the house any chimney foundations, steps or terraces that may prevent the house from being lifted.	
A4	Disconnect all existing piles from the bearers.	
A5	Fit a multiple lifting system (e.g. house mover's jacking system) around the perimeter of the house and within the footprint if the sagging between the perimeter lift points is going to be excessive. Incrementally jack the house to a common horizontal floor plane sufficiently high above the ground to allow the construction of a new pile system. The maximum general height above the ground required by the house mover is 1.6m so that their equipment can be used to best advantage beneath the house. Secure the house against possible instability of the temporary supports during the re-piling operation.	
A6	Pull together any gaps that had opened in the floor plate during the earthquake and splice joints between ends of joists and bearers that have parted. Repair any tension failures of bottom plates (likely to be at plate joints rather than in an individual piece). This will require removal of either linings or claddings in the area of the failure, for access.	
A7	Remove all piles that have settled more than 50mm beyond the expected new common level or piles raked at an angle of greater than 15mm per 1m height.	
A8	If the proportion of piles requiring replacement exceeds 50%, install a new system of timber or concrete piles in accordance with the requirements of NZS 3604.	*Refer to Section 2.2.1 B) 10 of this document - this may well be to a higher standard than the pile system employed prior to the earthquake but is considered beneficial at only a small additional cost*
A9	Lower the superstructure on to the completed pile array and connect all piles to bearers in accordance with the requirements of NZS 3604.	
A10	Re-connect all services previously disconnected.	
A11	Fit new base boards to the perimeter piles.	
A12	Re-instate the adjacent ground.	
A13	Re-lay the floor coverings.	

Outline Foundation and Floor Replacement Method Statement

Type B: Perimeter Concrete Foundation Wall

Refer Section 5.2.2 Light or Medium-weight claddings, and Section 5.2.3 for Heavy veneer claddings.

Step	Activity	Comments/ References
B1	Establish whether there is adequate bearing capacity for remedial works (e.g. using a hand held scala penetrometer). It is recognized that there will be liquefiable soils at some depth beneath the house because this is the reason why it is in its current condition.	
B2	Locate services entry points to the house and disconnect to allow the house to be lifted without damaging the services.	
B3	Check the vertical alignment of the internal piles. If existing piles are leaning at an angle of more than 50mm per 1m height then new piles will be required. Leans of less than this value are not considered to be unacceptable if there is a perimeter foundation present.	
B4	Disconnect the internal piles from the bearers and the outer bearers and plates from the existing perimeter foundation.	
B5	Demolish ancillary structures such as chimney foundations, steps and terraces.	
B6	Fit a multiple lifting system (e.g. house movers jacking system) around the perimeter of the house and within the footprint if the sagging between the perimeter lift points is going to be excessive. Incrementally jack the house to a common horizontal floor plane sufficiently high above the ground to allow the installation of steel sliding beams and slide the superstructure to the side of the site to replacement of damaged/leaning piles and the demolition and construction of a new perimeter foundation. This requirement is to aid the removal and replacement of the damaged piles and, particularly, the perimeter foundation beams with mechanical equipment. It also prevents the need to demolish parts of the foundation beam adjacent to the lifting jacks, which could lead to collapse of the temporary support. If lack of space on the site prevents the superstructure from being fully removed from the foundation, it will be necessary to shift it first in one direction to undertake a part re-build of the foundation and then in the other direction to complete the re-build.	
B7	Pull together any gaps that had opened in the floor plate during the earthquake and splice joints between ends of joists and bearers that have parted. Repair any tension failures of bottom plates (likely to be at plate joints rather than in an individual piece). This will require removal of either linings or claddings in the area of the failure, for access.	
B8	Demolish the existing damaged perimeter foundation and construct a new foundation, reinforced with a minimum of 4 D12 bars	
B9	After 7 days, slide the superstructure over the new foundation, lower it onto the piles and foundation and re-attach the plates to the foundation with the equivalent of 1 M12 bolt at 1.4m centres. Re-attach the piles to the bearers with stapled wire (concrete piles) or wire dogs and skew nails (timber piles).	
B10	Re-connect all services previously disconnected.	
B11	Re-instate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.	
B12	Re-lay the floor coverings.	

Outline Foundation and Floor Replacement Method Statement

Type C: Slab on Grade Floors

Refer Section 5.2.4 Light or Medium-weight claddings, and Section 5.2.5 for Heavy veneer claddings.

Step	Activity	Comments/ References
C1	Establish whether there is adequate bearing capacity for a new floor slab (e.g. using a hand held scala penetrometer). It is recognized that there will be liquefiable soils at some depth beneath the house because this is the reason why it is in its current condition.	
C2	Locate services entry points to the house and disconnect these remote from the foundation pad.	
C3	Remove any fixtures such as toilet pans and cabinets such as kitchen cabinets and benches that will hinder the lateral shift of the structure.	
C4	Remove plasterboard linings from the internal walls and the inside face of the exterior walls to a height of about 600 mm above the floor.	
C5	Disconnect all hold down fixings (i.e. bolts or bent bars) to allow the superstructure to lift above the floor slab.	
C6	In both orthogonal directions, install 200mm x 50mm or 250mm x 50mm timber members through the space created in the walls and screw to the wall framing. This is an operation best undertaken by a specialist house moving company that has the correct equipment and also the experience with such lifts. The heavy timber members serve to couple the wall frames together and brace the superstructure to allow it to be lifted fractionally off the floor slab.	
C7	Install a multiple lifting system beneath the temporary bracing members and lift the framing off the floor slab by 150mm and support on blocks. Reinstall the lifting system, now jacking on the underside of the bottom plates.	
C8	Pull together any gaps that had opened in the framing during the earthquake and repair any tension failures of bottom plates (likely to be at plate joints rather than in an individual piece).	
C9	Install steel sliding beams and slide the superstructure to the side of the site to allow replacement of a new slab and edge thickening. If lack of space on the site prevents the superstructure from being fully removed from the foundation, it will be necessary to shift it first in one direction to undertake a part re-build of the foundation slab and then in the other direction to complete the re-build.	
C10	After 7 days, slide the superstructure over the new foundation, and lower to its final position. Re-attach the bottom plates to the new floor at the same locations as the removed bolts. Approved proprietary hold down bolts are the best for this purpose.	
C11	Re-connect all services previously disconnected.	
C12	The earlier removal of the wall linings will expose the bracing elements in the structure. For houses built prior to the 1970s the bracing is more likely to be let in 6″ x 1″ diagonal timber members or fitted 4″ x 2″ diagonal frames. In this case, no special hold down requirements will be needed. Newer houses will be utilizing sheet bracing (primarily plasterboard) and the bracing elements will need to be identified. Council records should show the positions. In these areas, it will be necessary to replace the bracing sheets with new sheets extending between the top and bottom plates and fixed in accordance with the bracing product manufacturer's specification. In other areas, the lower section of removed plasterboard may be replaced with a new section of plasterboard with nogs fitted between the studs to support the otherwise free edges of the sheets.	
C13	Re-stop the wall linings and refit any trims that were removed and redecorate.	
C14	External sheet cladding connections and joints must also be checked and re-fixed. If the cladding has a bracing function then the sheet fixings must	

	be checked and if damaged, fixings must be installed in the intervening gaps. Cracks in EIFS claddings can be repaired and re-painted but it may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair. If there is severe cracking in the EIFS cladding, the polystyrene backing will need to be re-nailed to the framing in the affected area.	
C15	Re-lay the floor coverings.	
C16	Re-instate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.	

Appendix 6:

Sample Template for a Scala Penetrometer Investigation for the Static Bearing Capacity of Residential Foundations

To be prepared