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New Zealand Government

Department of
Building and Housing
Te Tari Kaupapa Whare

Guidance on house repairs and reconstruction following the Canterbury earthquake

A summary of geotechnical and structural engineering recommendations to guide house repairs and reconstruction

This document's status

This document is issued as guidance under section 175 of the Building Act 2004. While the Department has taken care in preparing the document it should not relied upon as establishing compliance with all relevant clauses of the Building Act or Building Code in all cases that may arise. The Document may be updated from time to time and the latest version is available from the Department's website at www.dbh.govt.nz

Foreword

The Department of Building and Housing has played a leading role in the Government's response to the Canterbury earthquake of 4 September 2010. Its deep base of skills in all areas of construction, building and remediation have been applied across the Government sector and in the Canterbury area to facilitate and speed recovery in Christchurch, Selwyn and Waimakariri.

This guidance document is part of the Government's ongoing support for Canterbury. It is one of a number of initiatives, at a national and local level, aimed at assisting all parties to work with a shared understanding and purpose to aid the recovery process and provide confidence to rebuild those communities more severely damaged in a timely way.

The approaches and options outlined in this guidance represent the combined views of experts from the public and private sectors. The Department acknowledges the work and initiative of the Earthquake Commission (EQC) for setting up an Engineering Advisory Group to investigate how residential structures responded to liquefaction effects. The Group included structural and geotechnical experts from the Department, BRANZ, Structural Engineering, Earthquake Engineering and Geotechnical Societies and remediation representatives. It sought input from international experts experienced in the effects of liquefaction on buildings.

The Department has taken the Group's findings and developed guidance on the technical aspects associated with the repair and reconstruction of houses damaged in the Canterbury earthquake. This guidance is complementary to the Government's recently released Geotechnical Land Damage Assessment and Reinstatement Report prepared by Tonkin & Taylor Ltd for the EQC.

All involved in developing this guidance recognised that a consistent technical approach to the repair and reconstruction between designers, insurers and councils is vital to minimise delays, constrain costs and aid the recovery.

Therefore, the document was developed and published in a short timeframe and in recognition that research into the earthquake and its effects is ongoing.

The Department is issuing the guidance before Christmas 2010 to provide time for familiarisation and training, and allow the guidance to be used in areas with minimal ground damage. However, geotechnical and structural investigations may result in alterations to the document in the first quarter of 2011, before reconstruction of houses or foundations in those areas seriously affected by liquefaction begins in earnest.

This document does not involve any changes to the New Zealand Building Code or subordinate documents. However, the Department of Building and Housing is undertaking further work to incorporate the learnings from the Canterbury earthquake, in particular the effects of liquefaction on buildings, into more general guidance for application across New Zealand where appropriate.

The Department welcomes feedback on this guidance document and thanks all those who have played a part in developing a valuable resource in such a short period of time.

David Kelly
Deputy Chief Executive Building Quality

Mike Stannard
Chief Engineer

Acknowledgments

In preparing this document the Department acknowledges and is grateful for the contributions from:

1. The Earthquake Commission (EQC)
2. The Engineering Advisory Group, initially engaged by EQC and subsequently by the Department of Building and Housing, consisting of:

Dave Brunsdon	Kestrel Group Ltd
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George Hooper	EQC
John Leeves	Tonkin & Taylor Ltd
Pat Moynihan	EQC
Rob Robinson	Remediation Specialist
Roger Shelton	BRANZ
Tim Sinclair	Tonkin & Taylor Ltd
John Snook	Canterbury Structural Group/NZ Structural Engineering Society
Mike Stannard	Department of Building and Housing

3. The wider geotechnical and structural engineering community in Canterbury, the insurance and contracting sectors and Christchurch City, Waimakariri District and Selwyn District Councils.

Contents

1. Introduction and scope

1.1 BACKGROUND AND PURPOSE

This document, issued by the Department of Building and Housing, provides technical guidance for repairing and rebuilding houses in the Canterbury region following the Canterbury earthquake. Publication of this document is a part of the Government's coordinated response during the transition to long-term recovery in Canterbury. The document supports this recovery by giving consistent engineering solutions that are robust, well considered and balance costs and risks.

The Canterbury earthquake of 4 September 2010 (sometimes referred to as the Darfield earthquake) was an internationally significant event that focused attention on damage to residential properties from liquefaction and lateral spreading. Approximately 160,000 insurance claims had been submitted to the Earthquake Commission (EQC) by early December 2010. Of these, approximately 16,000 of the claims for damage are likely to have a land component. The majority of damaged dwellings will have minor damage including damaged chimneys and superficial cracking to cladding/linings.

The volume of repair and reconstruction activity will place challenges on the insurance assessment, engineering design, construction and consenting capacity available. The reconstruction will put pressure on New Zealand's engineering resources, both structural and geotechnical, to develop specific solutions on a house-by-house basis in the normal manner. There will also be pressure on councils to process large volumes of consent applications. This may result in delays to homeowners and slow the re-establishment of the most affected communities. Insurers and reinsurers need confidence that the rebuilding work is robust without unnecessary expenses.

Overseas experience in recovery demonstrates how delays and additional costs can occur if designers, insurers and councils have different perspectives, that can lead to redesign and confusion.

The guidance aims to encourage consistency of approach and to avoid unnecessary and costly investigations and design for each property. It takes a prudent approach that is mindful of costs and risks. It provides solutions and construction methods that will meet the requirements of the Building Act and Building Code while avoiding 'over-design' and 'over investigation' where this is not warranted. Independent costing advice estimates a strong positive benefit to cost in following the proposals in this document.

Following the methods or solutions proposed in the document is not mandatory. Different and improved details and methods may well be developed as the recovery proceeds. The earthquake and its effects are complex. Investigations into the full picture on how residential structures responded to liquefaction effects are ongoing. It may well be that some aspects of the recommendations in the document are added to or changed over time.

1.2 SCOPE AND USE OF THIS DOCUMENT

1.2.1. Audience

This guidance is intended for the engineering design, construction and insurance sectors, local authorities, and their professional advisors and contractors.

1.2.2. Type of buildings

The guidance is complementary to the Government's recently released *Geotechnical Land Damage Assessment and Reinstatement Report* prepared by Tonkin & Taylor Ltd for the Earthquake Commission (referred to in this document as the *Tonkin & Taylor Stage 1 and Stage 2 Report*). Areas where land damage is evident (ie, Land Recovery Zones B and C) are the main focus for repair and reconstruction in this document.

The options and recommendations in this document are specific to houses directly affected by the Canterbury earthquake only. They do not apply to other types of buildings, nor do they apply to new houses in Canterbury or in the rest of New Zealand.

Although the document provides information on mitigating the effects of liquefaction on residential dwellings, this **should not** be taken as a best practice guide for addressing liquefaction in other parts of Canterbury or New Zealand.

The document focuses principally on one- and two-storey light timber framed dwellings, which are the dominant form of construction in the affected area. Accordingly, the document refers 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 concrete masonry). Assessment and repair specification for these types of building will require case-by-case consideration, although the guidance provided on repair and reconstruction of foundations and floors could well apply.

1.2.3 Type of damage

Most of the major damage to residential dwellings in the Canterbury 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. Standard and well understood repair methods can be used in these cases and some guidance, particularly for chimneys, is included.

Liquefaction gave rise to both differential settlement (vertical) effects and lateral spreading, with the latter being most damaging to buildings and infrastructure. This is the main focus for the document by providing standard methodologies and solutions for repair and rebuilding of foundation and floor elements.

1.2.4 Outline of document

The document includes the following information.

- Section 2 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.
- Section 3 summarises the land damage categories and recovery zones from the *Tonkin & Taylor Stage 1 and Stage 2 Report*. This section also makes observations regarding the future building performance and likelihood of liquefaction from a future earthquake event.
- Section 4 outlines repair criteria and assessment approaches.
- Sections 5 and 6 present re-levelling techniques and options for replacement foundation elements.
- Section 7 summarises the recommended engineering input during the repair and reconstruction phase.
- Section 8 briefly summarises the flood risk and floor level issues.
- Appendix 1 includes a standard explanation for the occurrence of liquefaction.
- Appendices 3 and 4 are method statements for repair and reconstruction.

1.3 FUTURE EXPECTATIONS

The widespread liquefaction in certain areas of Canterbury caused differential settlement, tilting and, in some cases, spreading of foundations. The Government has adopted land remediation approaches that will significantly reduce the extent of lateral spreading in those areas that underwent severe land damage in the Canterbury earthquake, from a similar earthquake event in future.

Liquefaction may occur in future earthquakes in the affected areas, and may again result in differential settlement. The recommendations reflect the basic engineering principle that wide, stiff and appropriately tied foundation systems will perform better than other foundation and floor forms.

If foundations do need to be rebuilt, the enhanced foundation options proposed will be slightly more expensive than the minimum un-reinforced option currently available through Building Code supporting documents (estimated at less than 1 to 3 percent of the total house cost, depending on the option selected). However, following the proposed solutions is likely to cost less than the geotechnical and structural engineering investigation and design that would be necessary on a house-by-house basis.

Individual house owners may wish to go above and beyond the solutions suggested in this document. They may specify a higher level of foundation performance. This document provides information on the relevant engineering principles and parameters to be adopted for an enhanced foundation and floor system. This will require specific structural and possibly geotechnical engineering input and discussions with insurers as to whether the system falls within the scope of the insurance policy.

1.4 OVERVIEW OF REPAIR STRATEGIES

Table 1.1 below summarises the principal building repair strategies corresponding to the recovery zones defined in the *Tonkin & Taylor Stage 2 Report.*

TABLE 1.1: LAND AND BUILDING REPAIR STRATEGIES

Recovery zone (from Tonkin & Taylor Stage 2 Report)	Land damage	Scenarios	Summary of repair strategies Depending on levels of building damage
A	No apparent land damage	A1	Repaired building – no special requirements
B	Minor or moderate land damage	B1	Repaired building – no special requirements **or**
		B2	Repaired building with new foundations to minimise superstructure damage from future liquefaction **or**
		B3	New building with foundations to minimise superstructure damage from liquefaction
C	Moderate, major or very severe land damage	C1	Repaired building – no special requirements **or**
		C2	Repaired building with new foundations to minimise superstructure damage from future liquefaction **or**
		C3	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 accommodate liquefaction effects (including lateral spreading)

Table 1.2 summarises the recommended design process elements for the foundations and other parts of the building corresponding to these repair strategies.

TABLE 1.2: SUMMARY OF DESIGN PROCESS ELEMENTS CORRESPONDING TO REPAIR STRATEGIES

Repair strategy		Design process	
		Walls, upper floors and roof	Foundation and floor
1.	Repaired building	Existing house repaired; plus addition of smoke detectors	Repairs where necessary
2.	Re-levelled and repaired building	Existing house repaired; plus addition of smoke detectors	Reinstatement only, via re-levelling (Section 5.2)
3.	New foundations and floors to minimise superstructure damage from future liquefaction	Existing house repaired; plus addition of smoke detectors	Guidance document solutions (Section 6)
4.	New building with foundations to minimise superstructure damage from future liquefaction	To non-specific design code requirements (eg, NZS 3604 or NZS 4229)	Guidance document solutions (Section 6)
5.	New building with foundations specifically designed to resist liquefaction (including lateral spreading)	To non-specific design code requirements (eg, NZS 3604 or NZS 4229)	Specific engineering design (Section 6)

The approaches and options outlined in this document (repair strategies 1 to 4 in Table 2) focus on meeting current regulatory requirements with a view to also satisfying any relevant insurance requirements. Owners may choose to specify additional measures for greater levels of protection against future liquefaction (repair strategy 5), but this is likely to be outside of insurance contracts and would require specialist geotechnical engineering advice.

1.5 REPAIR AND RECONSTRUCTION OPTIONS AND CRITERIA

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 up and construct new foundations and floors.

Where new foundation elements are considered necessary, enhanced foundation systems (eg, a stiffer and more effectively tied concrete slab placed on well compacted gravels) are recommended as the solution. The document outlines five concrete foundation and floor options for both foundation replacement and full reconstruction. The additional cost of constructing a more robust foundation and floor system than the minimum requirements of the light timber framed buildings Standard (NZS 3604) is considered minor in the context of the overall repair or rebuilding cost. Providing effective tie reinforcement in thicker concrete slab floors should significantly improve performance in future earthquake events in the affected areas. In certain instances (eg, single storey houses with lightweight claddings and roof), a NZS 3604 timber floor system is considered an acceptable reconstruction solution.

1.6 TIMEFRAMES FOR REPAIR AND RECONSTRUCTION

The land affected by liquefaction from the Canterbury earthquake is generally underlain by a one to two metres unsaturated upper layer overlying saturated fine grained sands or silty sands extending up to 10 m depth. It is understood from claimants, engineers and others that anecdotally the land was still settling up to the beginning of November 2010.

It is expected that pore pressures in the liquefied zone have not yet fully dissipated and the liquefied sands have not yet completely 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 minor (< 10 mm) and to be completed by the end of 2010. Survey monitoring and geotechnical investigations have been initiated to confirm this. Initial survey monitoring results appear to confirm that settlements are substantially complete.

On this basis it is recommended that any repair work to dwellings in the liquefied areas be undertaken from January 2011 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.

1.7 SITE VERIFICATION

Suburb geotechnical reports are being prepared by the EQC to investigate the deeper soil profiles and subsurface conditions for a number of suburbs affected by liquefaction in Christchurch.

Field investigations for individual sites may, therefore, be limited to Scala Penetrometer Testing and hand augers to confirm that the upper two metres 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 that details the observed damage and provides confirmation that the upper two metres has sufficient bearing capacity. For a summary of the relationship between individual site investigation and land damage see Figure 7.1 on page 52.

These geotechnical investigation inputs are considered to be the minimum requirements appropriate for this earthquake recovery effort. They are intended to efficiently utilise the limited geotechnical resources available. Individual property owners may elect to commission additional and more extensive geotechnical advice regarding their property.

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 (EQC Act) in relation to dwelling claims arising from the Canterbury earthquake. The land component of the claims is not addressed in this document.

The claimants' insurance policies are essentially a legal contract between the insured and the private insurer. The Earthquake Commission (EQC) cover insures the insured's dwelling and any structures appurtenant to the dwelling for the first $100,000 plus GST. The relevant insurance company will address the dwelling portion of the claim beyond this level in accordance with the individual terms and conditions of the contract.

For dwelling claims that cost less than $100,000 (plus GST), EQC may at its option (instead of paying the amount of the damage) replace or 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 circumstances permit and in a 'reasonably sufficient manner'. EQC's reinstatement or replacement obligation extends to the costs required to comply with any applicable laws and other fees payable in the course of reinstatement or replacement such as architects, surveyors and fees payable to local authorities.

For claims that cost less than $100,000 plus GST:

- 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).
- 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 can vary 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 it 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 wording is more like 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 sections below 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. 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 people 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 fire safety requirements for houses are essentially limited to the installation of smoke detectors. (If the house is not fully detached there may be other requirements.)
5. Therefore, requirements of s. 112 can generally be satisfied by installing smoke alarms and by demonstrating that the performance of other elements of the house, such as structural, weathertightness, sanitary, etc 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 to be new houses, and they would be required to comply with the current Building Code (refer to Appendix 2 for a more detailed list of requirements). Some of the specific Building Code requirements that relate to rebuilding in Canterbury are highlighted below.

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

8. 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/NZS 1170 are required to satisfy the 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 is an extreme action, or extreme combination of actions, that the building needs to withstand. ULS seismic loads for residential properties are based on a one in 500 year earthquake (a 10 percent chance of exceedance 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 that has been subjected to an ULS load.
    - A building is likely to collapse if it is subjected to a load that is significantly greater than the ULS load for which it has been designed to sustain.
    - All buildings are at risk of being subjected to a level of seismic shaking which is greater than their 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, that 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. Services should remain functional at the perimeter of and within the building. SLS seismic loads for residential properties are based on a one 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 (Clause 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 its life (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 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.

Building Code requirements to prevent flood damage (Clause E1.3.2)

19. Surface water from an event having a 2 percent annual probability shall not enter the building (Building Code Clause E1.3.2). This means that water from a one in 50 year flood shall not enter into the building.

Building Code requirements for external moisture (Clause E2)

20. To safeguard people from illness or injury that could result from external moisture entering the building, walls, floors, and structural elements in contact with, or in close proximity to, the ground must not absorb or transmit moisture that could cause undue dampness, damage to building elements, or both (Clause E2.3.3).

21. A means of satisfying this provision is provided in Acceptable Solution E2/AS1. Section 10 of E2/AS1 provides details for protection and separation of elements and minimum floor levels above ground. For concrete slab-on-ground with masonry veneer cladding, the height of the finished floor above adjacent ground shall be not less than 100 mm for paved ground and 150 mm for unpaved ground. For other claddings, the heights are 150 mm and 225 mm respectively (refer also to Table 18 and Figure 65 of E2/AS1).

Rebuilding in ground damaged areas of Canterbury

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

23. Houses that 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.

24. Land remediation is being undertaken in suburbs where severe land damage has already occurred to limit the extent of lateral spreading in the future. This will also limit the risk of foundation rupture, thereby satisfying Building Code Clause B1.3.1. However, to better satisfy Clause B1.3.2, 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'. This will limit the risk of loss of amenity through undue deformations. See Section 6 for further guidance on the type of foundations that may be appropriate.

25. When rebuilding on land that has suffered ground damage, to satisfy Building Code Clause E1.3.2 the floor level of the building needs to be higher than the 50 year flood level, or there need to be flood protection measures that will prevent water from a one in 50 year flood entering the building. This may mean that the building floor (if suspended) or platform needs to be raised in areas where there has been land settlement resulting in the land becoming lower than the one in 50 year flood level (refer also to Section 8).

26. It is recommended that services should enter the building at a few well defined, well recorded locations, through connections that are as flexible as possible. If they fail it should be in well defined locations outside the slab system so they are easy and quick to reconnect.

Superstructure

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

28. 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

29. 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 to paragraphs 22 and 23 above) using generic solutions proposed in Section 6.
30. 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] 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.
31. Part of the house may need complete replacement. Any new part of the house will need to meet all Building Code requirements (refer to paragraphs 24 and 25 above).

D) Repair of damaged houses in-situ

32. As per subsection A) above, the building work being carried out must comply with the current Building Code, but the rest of the house only needs 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. (If the house is not fully detached there may be other requirements.)
33. A range of issues need to be considered for repaired houses, and some of these are as follows.

Foundations and floors

- 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 the membrane is not broken. Large cracks may have already damaged the membrane, so the slab would need to be broken out and the 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 to NZS 3109, 3114, 3604 and 3404). Refer to Table 4.1 for the criteria to be used.
- Where the house foundations and floor have settled relative to the surrounding ground and the floor height above adjacent ground is now less than before, consideration is needed to ensure compliance with Building Code Clause E2.3.2 is no worse than before (refer to paragraphs 20 and 21 above). A possible solution might be the construction of a path at a lower level around the house with a small retaining wall at the outside edge of the path. If this is used, ensure that water is directed away from the house site.

  If the house was already built below the 50 year flood level, there will also need to be a check that the flood risk is no worse than before (refer to paragraphs 19 and 25 above).

[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.

Walls

- 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 weather tight 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.

Roofs

- 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 to Section 5.3 for repair options.

Services

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

2.2.2 Building Consents

The Building Act 2004 establishes a building consenting framework to ensure the right checks and balances are applied to building work, buildings are designed and constructed to meet the performance requirements of the Building Code and are, therefore, safe and meet expected quality requirements.

Traditionally, most building work has required a building consent from a local council before it can commence, to allow an independent third party check that the proposed building work will comply with the Building Code. Once the building consent has been issued, councils then undertake inspections of the building work at key points. When the building work is finished, councils can then issue a code compliance certificate if the building work satisfies the building consent.

Historically, not all building work has needed a building consent. Section 41 of the Building Act 2004 contains some specific exclusions – in particular, the types of building work described in Schedule 1 of the Act. More recently, additional exemptions were provided in the Canterbury Earthquake (Building Act) Order 2010. Following the earthquake the Department encouraged the Canterbury councils to adopt a risk-based consenting approach. A summary of the approach recommended to councils is set out in Table 2.1.

TABLE 2.1: SUMMARY OF THE RISKED-BASED CONSENTING PATHWAYS FOR BUILDING WORK	
Non-consented building work	• **Low risk building work automatically exempted from the usual consenting requirements because it meets one of exemptions (a)-(j) in Schedule 1 of the Building Act.** This essentially covers repair and replacement with comparable material, components or systems, including some structural repairs.
	• **Low risk building work that a council has previously decided does not require consent applications.** Council uses its discretion under item (k) in Schedule 1. Could be applied to any building work and would require council to publish scope and parameters.
	• **Low risk building work where a council decides on a case-by-case basis to exempt from requirement to obtain a consent.** Council uses its discretion under item (k) in Schedule 1. Could be applied to any building work, but targeted at LBP designers and builders, with no inspections.
Streamlined consented approach	• **Streamlined process for major earthquake repairs.** A case-by-case decision is made by the council to reduce the usual plan checks and inspections (due to criteria such as the competence of the practitioners, location of building, and type, nature and complexity of repair work etc).
	• **Streamlined process for new houses.** For new houses within the scope of the Simple House Acceptable Solution (or similar criteria), there will be less of the usual plan checks and inspections (level yet to be determined). These will be agreed between the applicant and council.
	• **Repairs and construction of commercial buildings with third party quality assurance.** This pathway is targeted at specialist design firms and construction companies. The applicant and council agree a risk profile and quality assurance plan, which is then implemented.
Standard consented building work	The standard building consenting, inspection and approval pathway is used for **higher risk building work** or where the other approaches are not appropriate.

Importantly, regardless of whether a building consent is required, all building work must comply with the Building Code (refer to s. 17 of the Building Act 2004).

Owners may prefer to have a record on the council property file of the work undertaken, even if the work is of lower risk and there is no need for council consent and inspection to ensure that the work meets Building Code requirements. Homeowners should keep a record (and photos) of all repair work done, regardless of whether a building consent is required.

As at the date this guidance was first published, the Building Amendment Bill (No. 3) (2010) has been introduced into the House. That Bill proposes a new stepped risk-based consent process, changing the current standard building consent process. When that Bill is passed, and the new stepped consenting process comes into force, this section of the guidance will be updated.

3. Future 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 4 September 2010 earthquake, a regional reconnaissance damage mapping exercise was undertaken by geotechnical engineers on behalf of EQC under the direction of Tonkin & Taylor Ltd.

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 opposite. 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 suburbs of greater Christchurch have been completed. The spatial distribution of the categories 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 categories of land damage

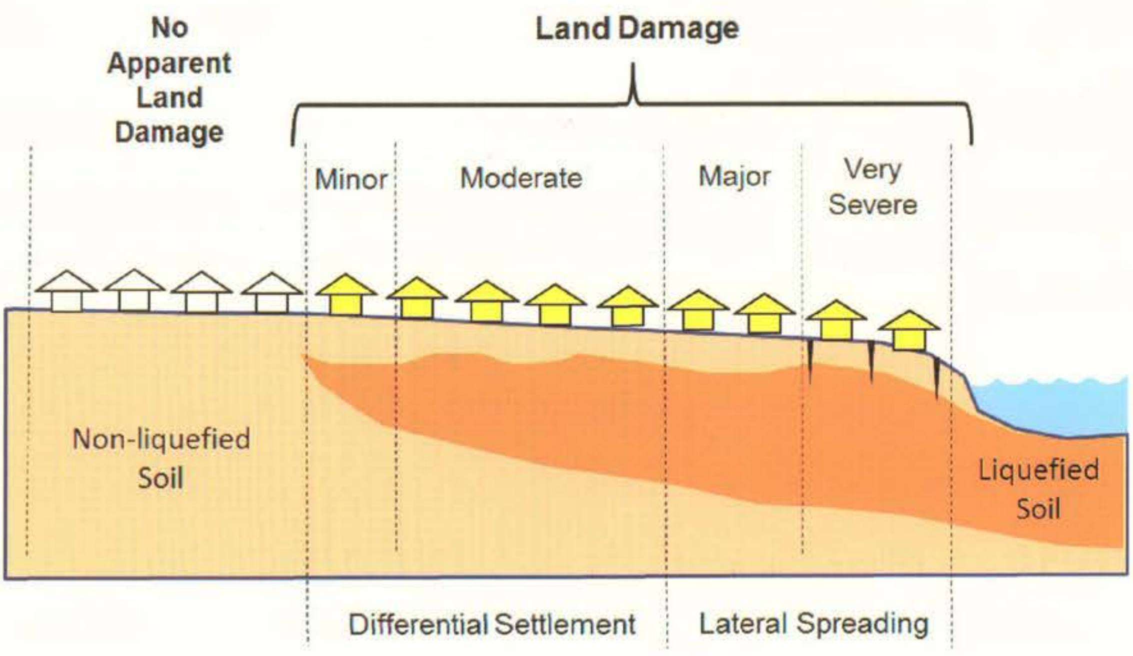


TABLE 3.1: LOCAL MAPPING CATEGORIES		
Land damage category	Description	Performance Level*
Very severe	• Extensive lateral spreading (>1 m) • Surface rupture, large open cracks, (>100 mm) • Extensive liquefaction (ejected sand) • Significant horizontal and vertical displacement >200 mm • Heavy structural damage to buildings • Dislocation of roads/services • Affected dwellings are beyond economic repair and in most cases likely to be uninhabitable	L5
Major	• Extensive liquefaction (ejected sand) • Large cracks from ground oscillations • Horizontal and vertical displacement >50 mm • Structural damage to buildings • Major differential settlement >1/100 • Damage to roads and failure of services • Affected dwellings are beyond economic repair and in most cases likely to be uninhabitable or only habitable in the short term	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 the cost to repair them	L2 to L3
Minor	• Shaking-induced damage – cyclic deformation • Minor ground cracking (tension) and buckling (compression) • No signs of 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 only	• No apparent land damage • No signs of liquefaction visible at the surface	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 Guidelines.

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 four metres 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 by earthquake shaking (no apparent land damage to minor land damage zone), and damage that resulted from liquefaction 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

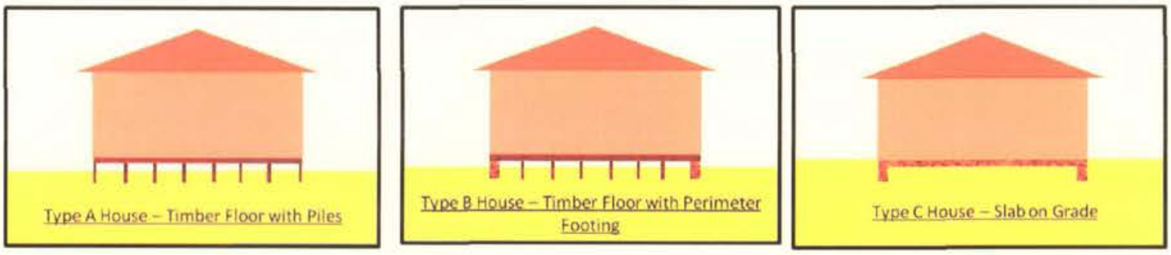
Severity	Repair cost (+ GST)	Description
Minor	<$10,000	Cracks in interior linings, non-structural cracks in the exterior.
Moderate	$10,000 to $100,000	Chimney damage, roof damage, minor structural damage, cracks in exterior linings which affect weathertightness.
Severe	>$100,000	Buildings out of level, 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: Dwelling Types A, B and C



The apparent damage to Type A buildings is generally easier and less costly to repair, provided there has not been sufficient lateral spreading to cause the piles to detach from the floor system and punch through the floor. 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 exceedance of one in 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 exceedance of one in 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.

At these levels of shaking, damage is expected. The geotechnical issue is what is expected of the ground under such high levels of shaking. An examination of the land and building performance under this earthquake, which approached that of a ULS level event, provides a guide.

An observation from the Canterbury earthquake is that there are significant advantages in people being able to remain in their homes for as long as possible after the event. This means employing building practices to limit the damage so that buildings remain habitable and ultimately gain a Green (Inspected) placard from council. Encouraging wide, stiff foundation systems such as stiff rafts (eg, waffle slab) or stiff inter-connected footings is considered to be the best way of improving performance with respect to both amenity and collapse, and thereby improving homeowners' confidence in repairing or rebuilding these locations.

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 (ie, 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.

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 (ie, no Red or Yellow placards issued by councils) and that the buildings have remained habitable.

Where buildings require demolition because they cannot be repaired within the building value, but have remained habitable (ie, a Green council placard), these buildings can be considered as having met the performance requirements of the Building Code.

Where major land deformation has occurred due to flow sliding and lateral spreading, and significant differential settlement and 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.

If houses are to be rebuilt in the very severe land damage zone without suburb-wide ground remediation measures being undertaken (Building Restriction zones), 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 COORDINATED LAND REMEDIATION

Tonkin & Taylor Ltd (T&T), on behalf of EQC, prepared the Stage 1 report on the earthquake presenting the damage categorisation, mapping methodology, information and results generated to 1 October 2010. That report developed land remediation concepts and then focused on the broad range of land remediation options. This report can be viewed on the EQC website (**www.eqc.govt.nz**).

A Stage 2 report (also on the EQC website) has subsequently been prepared by T&T. This report provides aggregated maps of land damage for the majority of residential properties affected by land damage arising from the Canterbury earthquake. The report presents practical remediation methods on a suburb-by-suburb basis. It looks at land performance and ways to repair the most severely damaged land to a level that if there was a similar earthquake in the future, this remediated land would not be as extensively damaged. Consequential damage to dwellings would also be significantly reduced in these areas.

The Stage 2 report has been developed around the targeted level of land performance that has been adopted by the Government. The land remediation methods set out in the report for each suburb or area are those which can meet the land performance standard adopted. The proposed land remediation exceeds the statutory obligations of EQC.
The Stage 2 report provides more detail about the land remediation options that T&T was asked to further develop within defined recovery zones, with specific reference to individual suburbs affected by significant land damage.

Table 3.3 summarises the recovery zones that are shown on the maps in the Stage 2 report. Remediation strategies and the processes to follow will depend on the particular requirements of each zone.

TABLE 3.3 – RECOVERY ZONES IN T&T STAGE 2 REPORT	
Recovery zone	Description
Zone A	In Zone A, the land for most properties has not been damaged, and therefore does not require remediation. Repairs and rebuilding of damaged buildings can begin, but consideration should be given to the potential for ongoing aftershocks to cause further minor building damage.
Zone B	Zone B land has suffered some land damage as a result of liquefaction. It is considered that this land has now mostly returned to its pre-earthquake strength, although the ground surface may be disturbed and require surface levelling and compaction. This can be undertaken as part of normal building works for each individual property. Necessary land and building work can begin now in accordance with council consent requirements. In cases where foundation repair or rebuilding works require consents, the suburb-wide geotechnical reports will assist in providing engineering guidance.
Zone C	Zone C is the land which has generally suffered very severe or major land damage, or is close to the areas of major remedial works. It includes a buffer area, where required, to provide adequate space to undertake the works and protect neighbouring buildings. Zone C also includes some areas of moderate land damage which require a wider-scale, coordinated remediation programme than the land in Zone B. Land remediation and building work in Zone C will require suburb-specific geotechnical reporting, engineering design and major remediation works. These will differ from suburb to suburb to meet the land performance standard as adopted by the Government. Repair or rebuilding of houses in this area will need to be staged so that repairs and rebuilding work can be undertaken in association with land and infrastructure remediation.

In areas where the land damage has been mapped, rebuilding can be undertaken in line with the land remediation process outlined for each suburb in the Stage 2 report. Various remedial options are presented for each suburb.

For properties that have been assessed by EQC in Zones A and B, repairs to land and buildings (including rebuilding) can be undertaken independent of works on public land and other properties in the same suburb. In undertaking repairs, it needs to be recognised that aftershocks greater than magnitude 4 can still occur well into 2011.

For properties in Zone C, repairs to land and buildings (including rebuilding) need to be coordinated. An indicative programme of repair for each of the recovery zones is also included in the Stage 2 report.

An example representation of the land recovery zoning is shown in Figure 3.3.

Figure 3.3: Example of Bexley Recovery Zone map

3.3 FUTURE BUILDING PERFORMANCE

Land that has liquefied in this event is also likely to be vulnerable to future liquefaction in future strong shaking events. Future events could be longer and more damaging, and extend to other areas that were not affected by this earthquake.

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 will limit the amount of differential movement experienced by the superstructure, and significantly reduce the damage following any future liquefaction event.

In a similar future event, housing stock that is 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 50 mm and to limit future sagging or hogging of the foundation to the criteria provided in Section 6.3. The issue of acceptable levels of differential settlement is addressed in Section 4.2.

For 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 and strong to ensure 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.

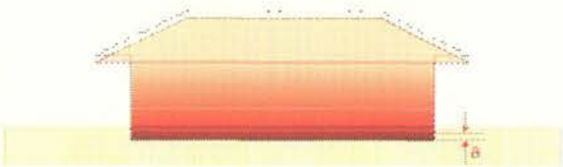
4.1 DEFINITIONS

Displacements

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

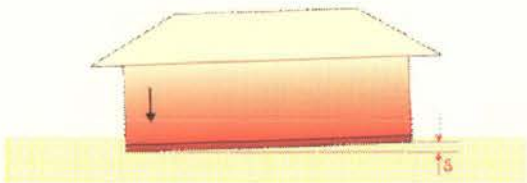
(i) Simple settlement cases

Uniform settlement



For uniform settlement, the complete foundation has settled by the same amount over the area of the foundation.

Tilt settlement

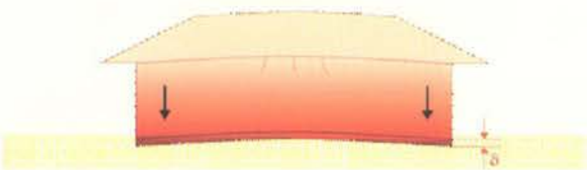


With tilt settlement, the whole foundation tilts as a rigid body.

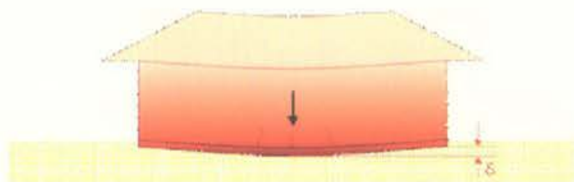
(ii) Differential settlement cases

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

Hogging



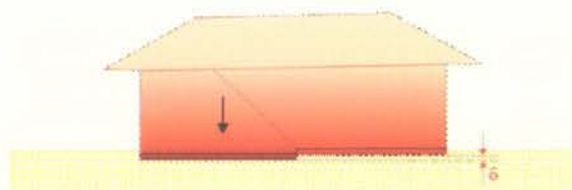
Sagging or dishing



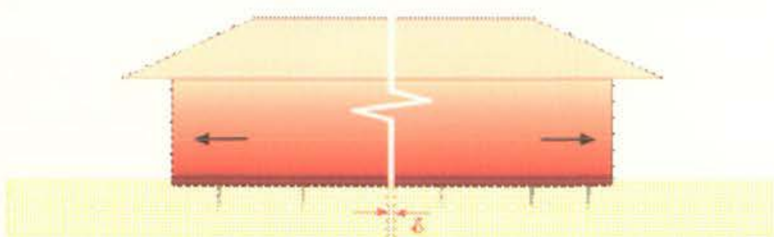
Racking/twisting

Twisting of the foundation can occur where all corners of the foundation have settled by different amounts.

Differential settlement – abrupt change



(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 (ie, 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 for standard house piles, 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

4.2.1 Repair/rebuild assessment categories and criteria

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

Situations have been observed with uniform sloping settlement greater than 100 mm causing little damage other than sticking doors, etc. While these cases are nominally beyond the parameters suggested in Table 4.1 for re-levelling, a re-levelling practitioner should be consulted to advise on the practicality of proceeding with a re-level.

The criteria in Table 4.1 are to provide guidance, rather than representing absolute criteria, as suggested by the dotted vertical lines between the columns. Many dwellings will have different elements of damage – for example, rebuilding of foundations may only be needed in the vicinity of the damage.

These criteria are intended for use by a range of industry personnel. Where questions relating to the applicability of the criteria to a particular situation are encountered, professional engineering input should be sought.

They are also intended to apply to reasonably regular houses (for example the 'L' shaped dwelling shown in Section 6), and may not apply to highly irregular houses.

The different slope criteria are represented in Figure 4.1 overleaf.

Any abrupt changes in floor level may require at least re-levelling, depending on the type of floor covering.

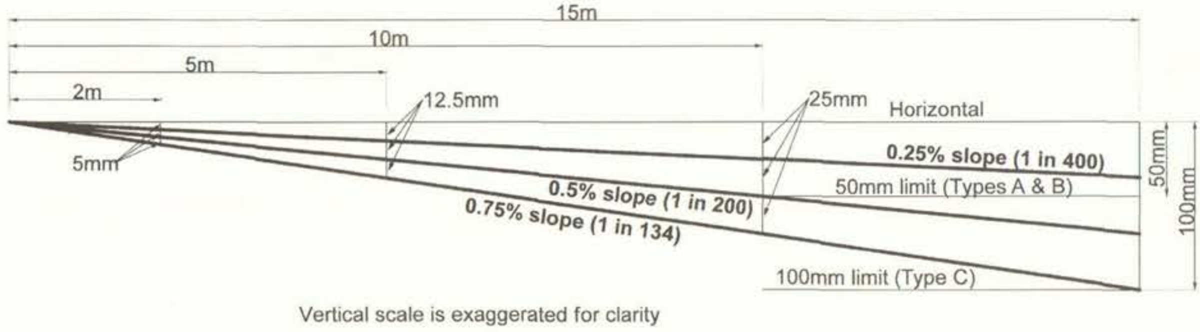
TABLE 4.1: REPAIR/REBUILD CATEGORIES AND CRITERIA

Floor Type	Decision parameters			
	NO action necessary	Foundation re-level required	Foundation rebuild required	House rebuild may be required
Type A Timber framed suspended timber floor structures supported only on piles	The slope of the floor between any two points >2 m apart is <0.25% (one in 400) [Note (a)]	The slope of the floor between any two points >2 m apart is 0.25%–0.75%	The slope of the floor between any two points >2 m apart is >0.75% (one in 134) OR The variation in floor level is >50 mm [Note (c)] over the floor plan OR The floor has stretched >50 mm [Note (d)]	The house has fully or partially collapsed off the piles and repair is not economic
Type B Timber framed suspended timber floor structures with perimeter concrete foundation	The slope of the floor between any two points >2 m apart is <0.25% (one in 400) [Note (a)]	The slope of the floor between any two points >2 m apart is 0.25%–0.50% OR Individual cracks in the perimeter foundation are <5 mm [Note (b)]	The slope of the floor between any two points >2 m apart is >0.50% (one in 200) OR The variation in floor level is >50 mm [Note (c)] over the floor plan OR Individual cracks in the perimeter foundation are >5 mm OR The floor has stretched >20 mm [Note (e)]	The house has fully or partially collapsed off the piles and repair is not economic
Type C Timber framed dwelling on concrete floor	The slope of the floor between any two points >2 m 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 >2 m apart is 0.25%–0.50% OR Cracks in the floor slab are <3 mm and the accumulation of cracks over the major orthogonal dimensions is <20 mm	The slope of the floor between any two points >2 m apart is >0.50% (one in 200) OR The variation in level over the floor plan is >100 mm OR There is irreparable damage to buried services within the house footprint	This will relate to the degree of superstructure damage [Note (f)]

Explanatory Notes:

(a) Reasoning covers human perception, and more applicable than overall slope
(b) Note that for veneer cladding, there may be a need to rebuild the veneer
(c) Pile packing unstable at greater than 50 mm
(d) For most fully timber framed buildings, an overall stretch of less than 50 mm can be pulled together again
(e) Where perimeter concrete foundation beams are present, there is unlikely to be an opportunity to pull the foundation together again
(f) This is an economic decision for each property

Figure 4.1: Diagrammatic representation of slope and category criteria



Note that beyond 10 m, the 50 mm criteria governs over the 0.5% criteria

4.2.2 Investigation approaches

The degree to which the damaged floor is out of level 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 concrete 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 5 mm) 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 can be situated either on the outside of the house or internally. 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 (ie, 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 differential settlement of the foundation under the earthquake action.

Repair options for brick chimneys are presented in Section 5.3.1.

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 (eg, 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 (eg, 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 (eg, 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 20 mm 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 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.

4.3.5 Unreinforced masonry and concrete block walls

A number of older houses were either constructed wholly from double skin unreinforced brick masonry or featured major brick boundary wall elements. Many of these types of house in the affected areas sustained significant damage. Unreinforced concrete block walls (commonly found in garages) are likely to have behaved no better than unreinforced brick masonry walls.

Unreinforced masonry structures require much more careful assessment than masonry veneer houses. The key issues to be established during assessment include the:

- adequacy and condition of lateral restraint at floor and roof levels
- effectiveness of connection between masonry wall elements
- adequacy and condition of the foundations
- condition of the mortar.

While the first two items can be addressed in repair measures, the latter two provide a more fundamental pointer as to the feasibility of repairs. If damage has occurred to the foundations or if only nominal foundations are present, and/or if the mortar between the masonry elements is in poor condition, then repairs are unlikely to be effective.

Damage to concrete block masonry walls is expected to be variable depending on the age of the wall and the standard to which it was constructed. The key aspect to be ascertained is whether or not grouting within the block cores and reinforcement is present.

Walls that have basketting reinforcement (ie, both horizontal and vertical) and that are adequately restrained at floor and roof level should have sustained only minor damage, with repairs to any cracking being achievable by grout or epoxy injection and re-pointing of affected mortar joints.

Engineering parameters for repairs to unreinforced structural masonry elements are referenced in Section 5.3.5.

5. Repairing houses

5.1 GENERAL

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

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

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).

An overall summary of the process is provided in Table 5.2, with detailed sample method statements included in Appendices 3 and 4.

Recommendations for repairs for 'above the floor plate' damage to superstructure elements such as to wall bracing, and wall and roof frame connections and also to chimneys are provided in Section 5.3.

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).*

TABLE 5.2: SUMMARY OF FOUNDATION RE-LEVELLING AND RE-BUILDING APPROACHES						
Foundation type	Foundation re-levelling			Foundation rebuild		
	Re-level strategy	Occupancy during re-level operations		Rebuild strategy	Occupancy during rebuild 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, pack and (for some piles) re-pile affected area, reconnect 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, reconnect services and reinstate ground to beam	Yes	As for Type A regarding piles. Re-levelling the beam using engineered resin may permit occupancy during the work. Beam jacking may require vacation 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, reconnect services and reinstate ground to beam.	No	As for Type A regarding piles. Replacing the beam will require vacation 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 floor area, inject relevant cracks in beam, reconnect 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 considered.	Disconnect services, remove exterior cladding, remove perimeter concrete foundation beam, decks and paths and replace, re-pile, reconnect 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 considered. Need to consider distress to the framing, trusses and bracing at this level of subsidence.

TABLE 5.2: SUMMARY OF FOUNDATION RE-LEVELLING AND RE-BUILDING APPROACHES (CONTINUED)							
Foundation type	Foundation re-levelling			Foundation rebuild			
	Re-level strategy	Occupancy during re-level operations		Rebuild strategy	Occupancy during rebuild operations		
Type C1 Timber framed dwelling on concrete floor (slab on grade). *Stucco, weatherboard or light texture clad house*	Re-level using engineered resin. Disconnect and reinstate services, if necessary. OR Re-level using slab and beam jacking and grout. Disconnect and reinstate services, if necessary. OR Re-level using screw piles and grout. Disconnect and reinstate services. Seal and inject relevant cracks in slab.	Subject to individual situations	This procedure is limited to slabs with crack width <3 mm. 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, reconnect 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 150 mm 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, reconnect services and reinstate paths and deck.	Yes	This procedure is limited to slabs with crack width <3 mm 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 150 mm may have caused severe damage to the timber framing, trusses and bracing.	

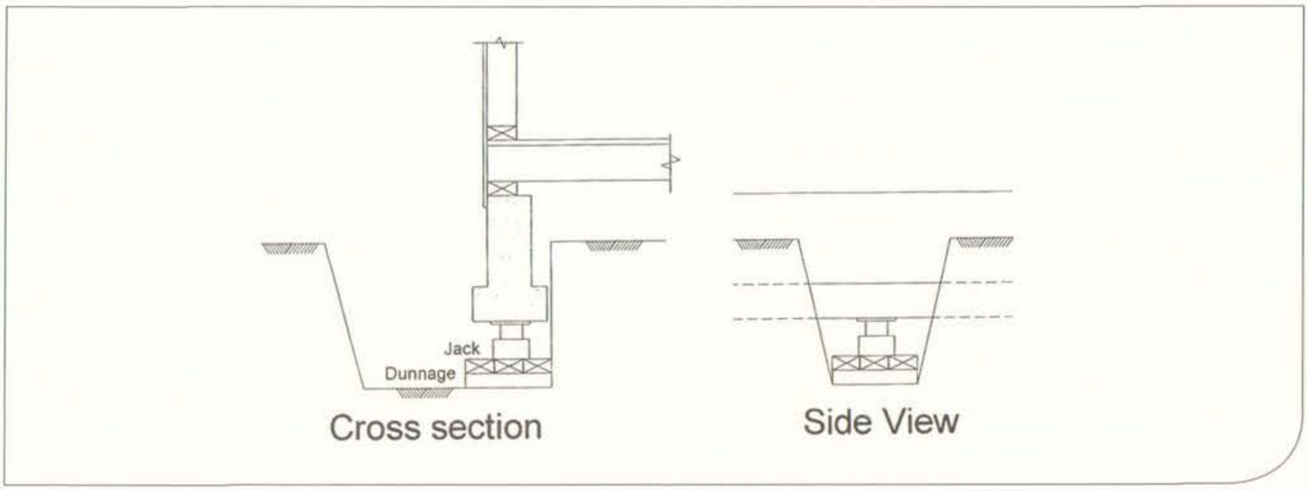
5.2 RE-LEVELLING OR REPLACING FOUNDATIONS AND FLOORS

5.2.1 Overview of re-levelling options

For Type A dwellings, the basic re-levelling operation will draw upon standard methods used for re-levelling and re-piling houses.

For Type B and C dwellings, the three options considered most suitable for re-levelling in these situations are summarised as follows:

- Lifting Option 1: Perimeter foundation re-levelling using portable jacks



Foundation re-levelling involves excavating pits at discrete locations to the perimeter of the foundation wall, and installing jacks in each pit to the underside of the wall or beam to raise it to the correct level. With the foundation repositioned, flowable grout is introduced to the cavity created under the raised foundation. Once the grout is cured, the jacks are removed and the pits refilled.

- Lifting Option 2: Perimeter foundation jacking using piles (screw or similar)

Foundation re-levelling using screw piles involves installing piles at discrete locations to the perimeter of the foundation wall, and installing under-beam shoes fitted with jacks to raise the foundation to the correct level. With the foundation repositioned, flowable grout is introduced to the cavity created under the raised foundation. Once the grout is cured the jacks are removed, and the screw piles removed. The screw piles may also be used as a permanent support.

- Lifting Option 3: Perimeter foundation jacking using engineered resin

This option is a proprietary lifting process where engineered resin is injected into the ground at multiple points along the foundation. The expanding resin lifts the foundation. The process also densifies the surrounding ground which serves as a reaction layer for the lifting operation.

For each of these three re-levelling processes, it is important that specialist contractors be used. It is imperative that the practitioners be able to demonstrate an appropriate track record with experienced personnel and purpose built equipment, together with suitable levels of quality control and sufficient resources for the projects.

5.2.2 Concrete or timber piles throughout (Type A)

These foundation systems are often present where the dwelling is clad with lightweight claddings (eg, timber or fibre cement weatherboards, sheet claddings, EIFS claddings) or medium-weight materials (eg, 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 3.

Rebuilding foundation

In these instances, it may be possible to lift the superstructure, including the floor, rebuild 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 4.

5.2.3 Perimeter concrete foundation wall (light or medium-weight claddings) (Type B1)

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

Re-levelling foundation

In these instances, it may be possible to re-level 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 3.

Rebuilding 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 4.

5.2.4 Perimeter concrete foundation wall (heavyweight veneer cladding) (Type B2)

This continuous foundation wall is always present where the dwelling has a timber floor and is clad with heavy cladding materials (eg, 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 re-levelling options in Section 5.2.1 may be used. A summary of the process is given in Table 5.2 and a more detailed process description included in Appendix 3.

Rebuilding foundation

In these instances, it may be very difficult to lift the superstructure, including veneer cladding, without causing irreparable damage to the veneer cladding. It will be necessary to demolish the veneer and rebuild it once the new foundation has been constructed and the house superstructure has been re-installed on the new 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 5.2.2 and then the veneer will be rebuilt on the new foundation. A summary of the process is given in Table 5.2 and a more detailed process description included in Appendix 4.

5.2.5 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 materials (eg, timber or fibre cement weatherboards, sheet claddings, EIFS claddings) or medium-weight materials (eg, stucco), it may be possible to re-level the superstructure, including the floor, and remediate any damage caused to the claddings and linings of the structure. All three re-levelling options in Section 5.2.1 may be used. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 3.

Rebuilding 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 (including the bottom plates) demolishing and rebuilding the slab and edge thickening, and re-installing the superstructure on the new slab. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 4.

5.2.6 Slab on grade floors (heavyweight veneer cladding) (Type C2)

Concrete slab on grade floor systems are often used with heavy cladding materials (eg, brick or concrete masonry veneer). In these instances, it is likely to be very difficult to re-level 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 and insulation is not already in place, the owner may choose to have insulation installed in the exterior walls at their own expense.

Re-levelling foundation

All three lifting options in section 5.2.1 may be used. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 3.

Rebuilding foundation

In these instances, the veneer must be demolished to allow the superstructure to be lifted off the existing concrete slab, moved sideways and then re-positioned on the new foundation.

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 5.2.5 and then the veneer will be rebuilt on the new foundation. A summary of the process is given in Table 5.2 with a more detailed process description included in Appendix 4.

5.3 REPAIRING SUPERSTRUCTURE ELEMENTS

5.3.1 Chimneys

Repaired chimneys must meet the Building Code performance requirements. The most relevant Building Code requirements are those relating to structure (Clause B1) and fire safety (Clause C). Any repairs or rebuilds must be done correctly to prevent the possibility of a potential house fire.

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

Environment Canterbury requirements

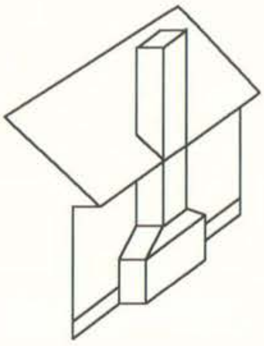
Outside Christchurch, Kaiapoi, Rangiora and Ashburton Clean Air Zone 1, open fires are permissible.

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 – see the Environment Canterbury website for details) 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

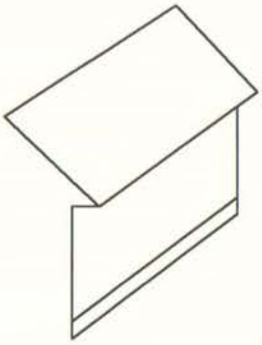
The following options are suggested for unreinforced masonry chimneys located on the outside of a dwelling:



Existing chimney prior to earthquake damage

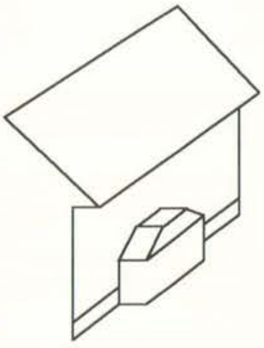
Unreinforced masonry or precast concrete blocks

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



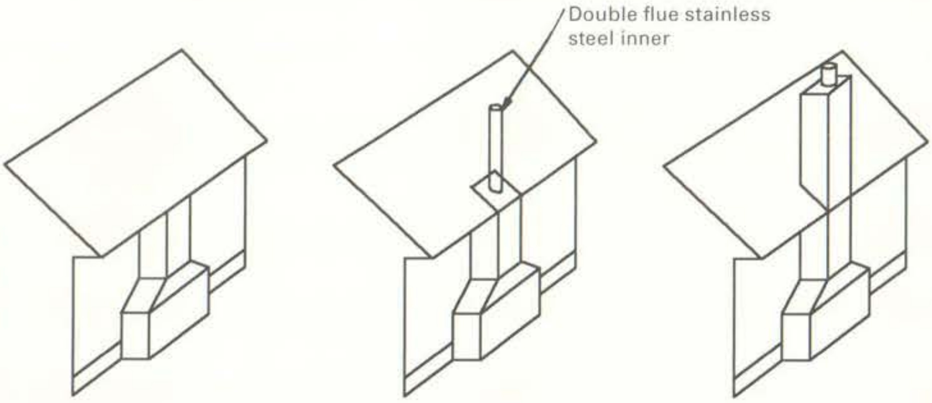
Repair Option 1:

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 10 mm 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 weatherprooof. 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 450 mm space inside framing.

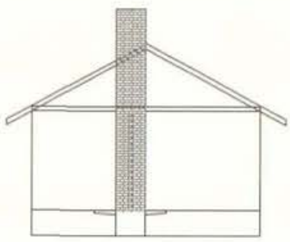
If the chimney has tilted away from the wall of the house by an amount greater than 10 mm at the eaves, then this is indicative of a failure of the soil beneath the chimney, which may have been the case before the earthquake occurred. Check for obvious signs of aging of the crack such as the presence 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 300 mm 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 percent (10 mm in one metre), 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.

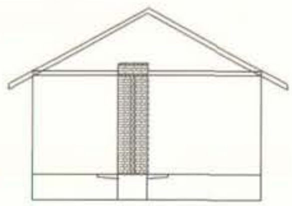
The following options are suggested for unreinforced masonry chimneys located within the dwelling.



Existing chimney prior to earthquake damage.

Unreinforced masonry or precast concrete blocks.

Damage sustained: Stack above roof has toppled.

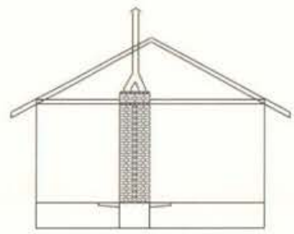


Condition of chimney breast and stack to roof is good.

Remediation Option 1:

Demolish chimney to a point just above the ceiling framing and cap. Repair roof frame and roof cladding.

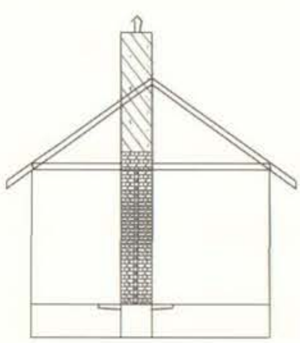
SEAL FIREPLACE TO PREVENT FUTURE USE.



Condition of chimney breast and stack to roof is good.

Remediation Option 2:

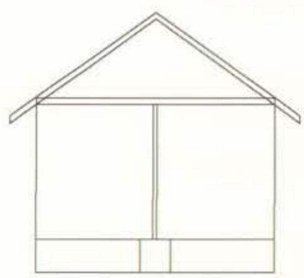
Demolish chimney to a point just above the ceiling framing and fit steel flue from burner and flash at roof line. Combine flues if back to back stacks present. Install metal heat shield to vent brick chimney stack to exterior.



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.

5.3.2 Wall bracing

Where there is evidence of significant racking of walls (eg, 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 redecorated. Trims (eg, scotias, skirtings) will need to be removed and possibly replaced if damaged during removal.

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.

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

5.3.4 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.

5.3.5 Unreinforced masonry and concrete block walls

If following assessment it is established that damaged unreinforced masonry wall elements can be repaired, then the engineering principles applied to commercial buildings should be followed. For regulatory and insurance requirements, for most cases the focus for the repair methodology should be the reinstatement of pre-damage element strength rather than upgrading to a higher standard. If however a residential building is two or more storeys and contains three or more household units as defined in the Building Act, then council's Earthquake Prone Buildings Policy should be referred to.

The core reference for unreinforced masonry buildings is the NZ Society for Earthquake Engineering's 2006 guidelines document *Assessment and Improvement of the Structural Performance of Buildings in Earthquakes*. Useful (more conservative) parameters for existing materials can be obtained from the earlier versions of the same document, including the 1995 Draft Guidelines (particularly Table Appendix H (Typical Securing Details) and Table 6.1/Strength values for existing materials).

Repair treatment to double skin masonry needs to differentiate solutions between inner (load bearing) and outer (weatherskin).

6. Rebuilding houses

6.1 GENERAL

For the areas significantly affected by liquefaction-induced lateral spreading where most houses are to be rebuilt, the land is still susceptible to liquefaction in future earthquakes. The land remediation measures being undertaken by the Government are intended to significantly reduce the extent of lateral spreading. Rebuilt houses will however still require a foundation system capable of resisting some tension effects from nominal lateral spreading, and also be capable of accommodating settlement of the ground beneath the house.

The principal objectives therefore in designing new foundation systems for rebuilding on ground damaged land should be (i) to provide sufficient stiffness to remain in a near flat plane after a future earthquake, and (ii) to be capable of being re-levelled as a single body where necessary.

To achieve these objectives the designer will need to go beyond the unreinforced slab-on-grade floor system permitted by NZS 3604 as it is too flexible and it lacks the in-plane strength to resist significant lateral spreading without separating or rupturing. In certain areas of greater Christchurch the 'good ground' provisions of NZS 3604 do not apply, and therefore the foundation and flooring provisions of that Standard in these areas cannot be used. This section outlines the alternative design options which are recommended for houses being rebuilt on ground damaged land.

Support for the structure from a level below the liquefiable soil provides the best prospect of maintaining the house on a level plane where the lateral spreading risk has been mitigated. However, observations have shown that long piles have not performed well in areas subject to lateral spreading. If settlement of the ground occurs there is also potential for greater damage to services. The long pile lengths required can also make this a less economic option.

A light clad house structure supported fully on short timber or concrete piles is also considered to be a valid option. While not meeting the stiffness objective outlined above, it is the most easily repaired form of dwelling construction.

For Building Restriction Zones, specific engineering design is required for the foundations of any new dwellings, and this must take into account the potential for significant lateral spreading unless site land remediation is undertaken. Refer to Section 6.3 for suggested criteria.

The use of NZS 3604 for the design of the super-structure (ie, everything from the ground floor plate up) 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).

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 major earthquakes.

These options are intended for application in areas (suburbs) where coordinated land remediation work to reduce the future risk of lateral spreading will be undertaken. As outlined in Section 3, it is considered appropriate to allow for potential lateral spreading of up to 50 mm horizontally for all areas other than in Building Restriction Zones. These options are expected to be able to bridge a length of up to four metres of settled soil (or sudden lack of support) beneath the foundation and cantilever a distance of up to two metres over settled soil at the building foot-print extremities, within acceptable deformation limits.

While it is not envisaged that these foundation and floor options will require specific engineering design, their documentation will require oversight by structural engineers.

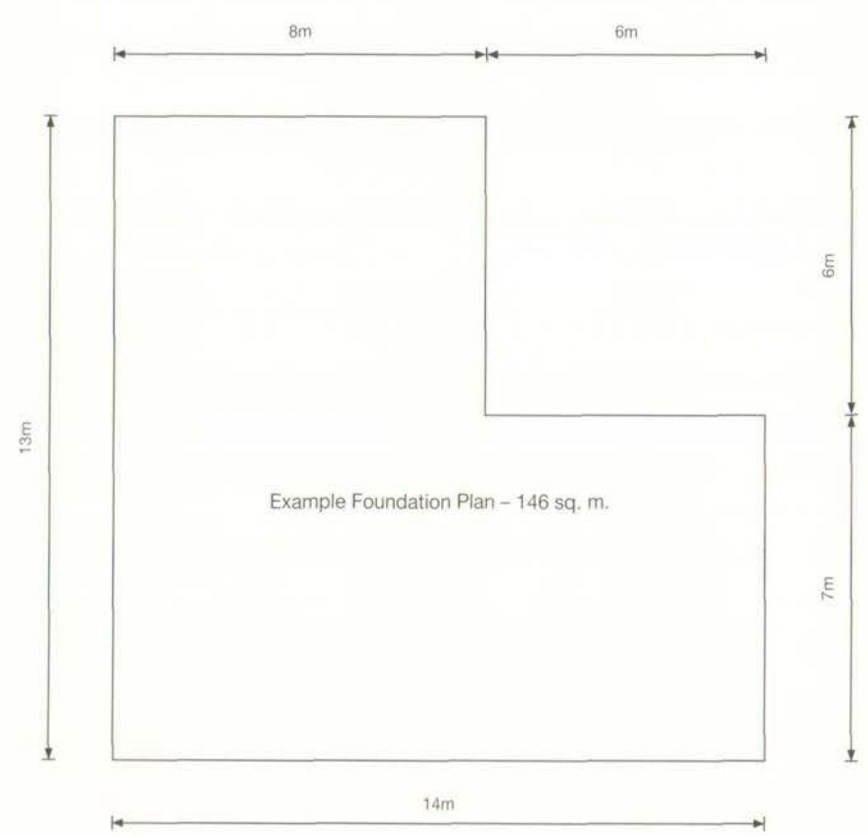
Site preparation should ensure that all grass and topsoil is removed prior to the placement of foundations or gravel fill. A well-graded aggregate (AP 40 or similar) should be used as subgrade fill beneath any new concrete slabs. The aggregate should be placed in maximum 200 mm layers compacted with (as a minimum) a plate compactor. Poorly graded river gravels (tailings or 20/40 rounded river stone) that have commonly been used in Christchurch as subgrade material should not be used. This type of material is prone to forming unstable stone arrangements (bridges) that may collapse with future vibrations leading to a localised loss of support to the overlying slab.

Site investigation requirements are outlined in Section 7.1.

The representative floor plan for which the development and modelling of these details has been based is shown below. The details in this section should only be applied to simple plan shapes such as rectangular, L, T or boomerang shapes.

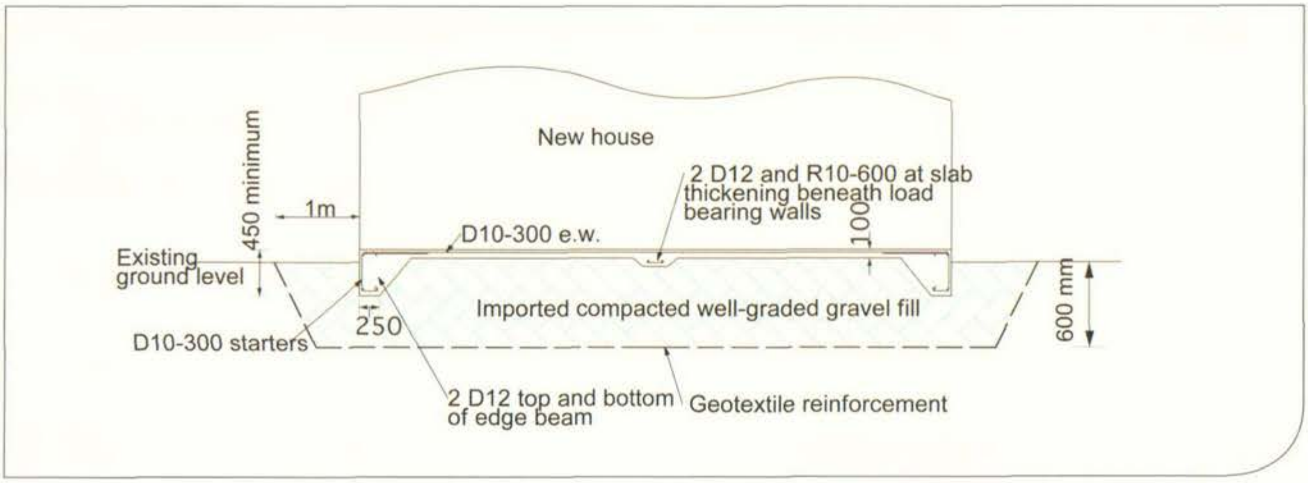
6.2.2 Floor construction – reinforced concrete

Several options may be employed, but each has limitations which must be recognised. In all options the NZS 3604 ground clearances adjacent to the house foundation must be complied with. Also, the damp proof membrane (DPM) has not been shown for clarity in these representative details.



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).

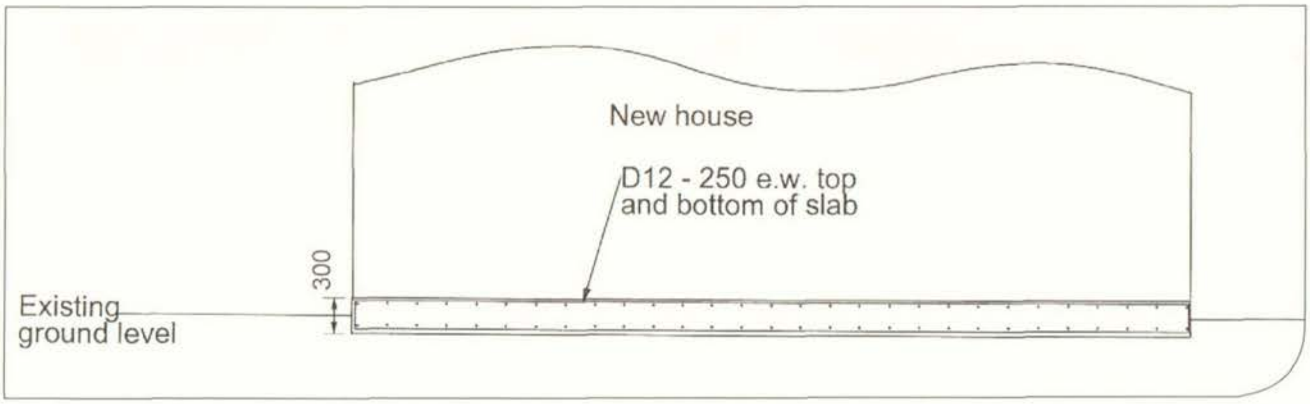
External service lines will need to be beyond the outer extent of the gravel raft.



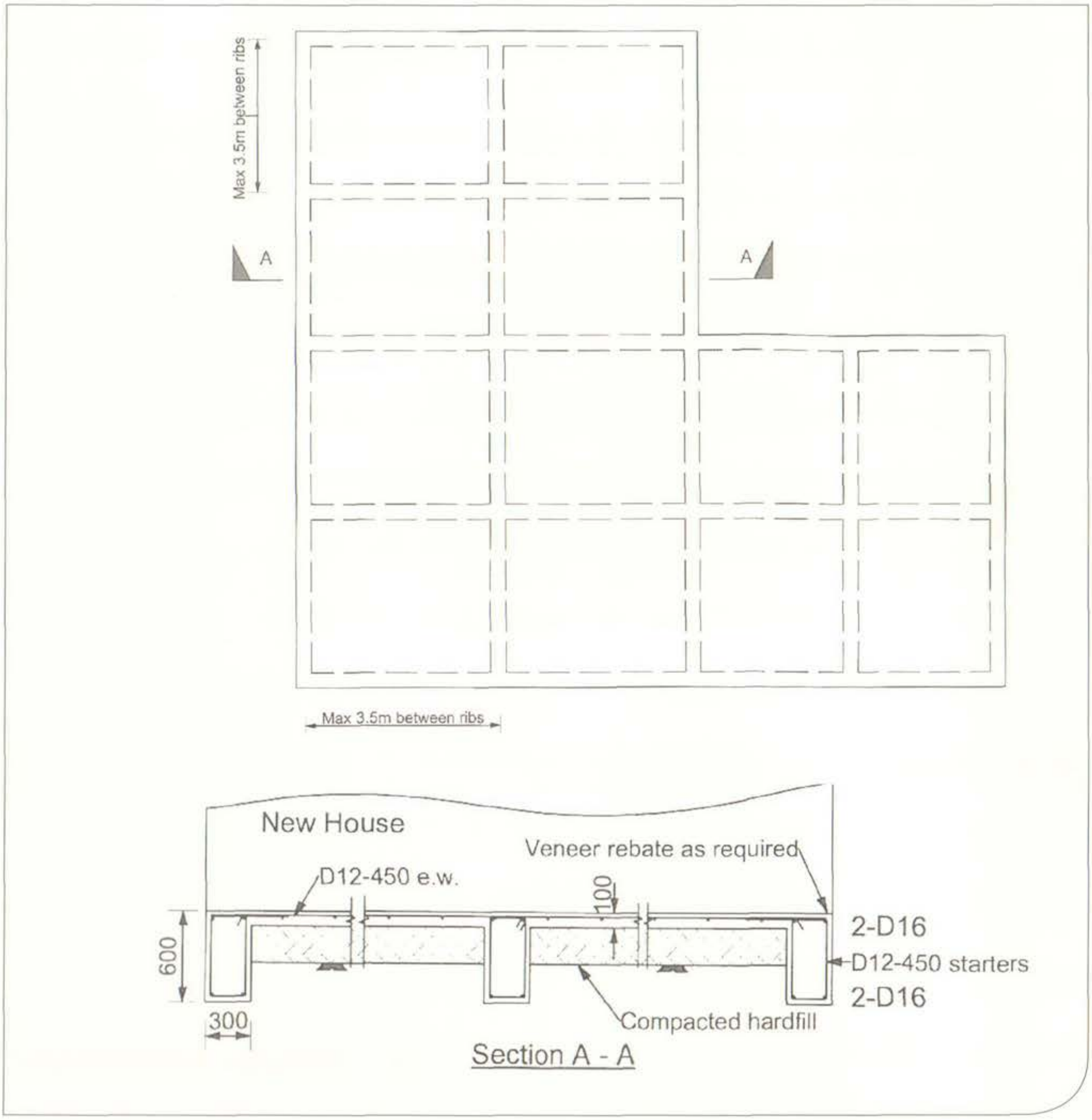
Option 2 – Construct a thick slab foundation over the existing soil.

The ground immediately beneath the slab must have a minimum ultimate bearing strength of 300 kPa, or the slab should be subject to specific engineering design.

The treatment of service lines as they enter and travel within the slab requires careful consideration.



Option 3 – Construct a generic beam grid and slab foundation.

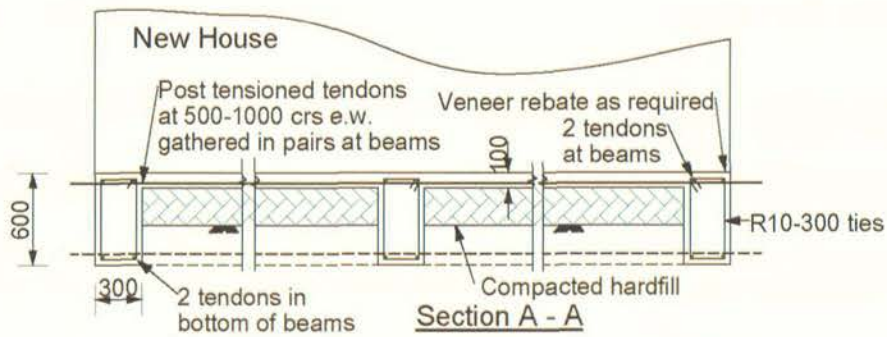


The ground immediately beneath the slab must have a minimum ultimate bearing strength of 300 kPa, or the slab should be subject to specific engineering design.

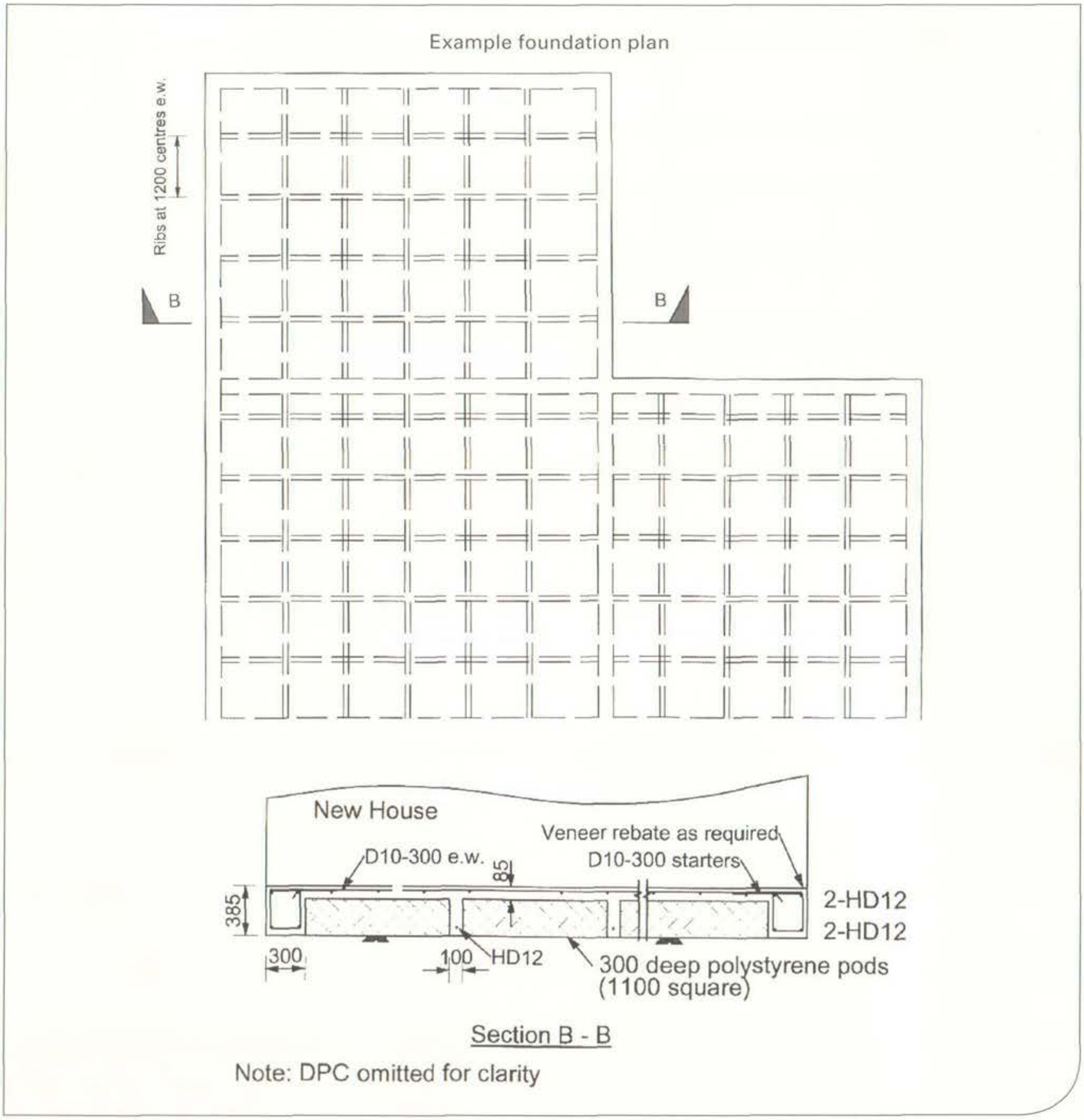
A variation to this option involves post-tensioning the waffle slab, using single 12.9 mm or 15.2 mm strand tendons in an un-bonded format. The factory applied greased and sheathed strands are supported in the slab on bar chairs and tensioned through mono-strand anchorages fixed at both ends through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

Post-tensioned slabs are tensioned to between 0.5 and 1 MPa (in time) to overcome drying shrinkage and give some bridging capacity. Spacing of the tendons is nominally one metre centres each way.

This option requires specific engineering design.



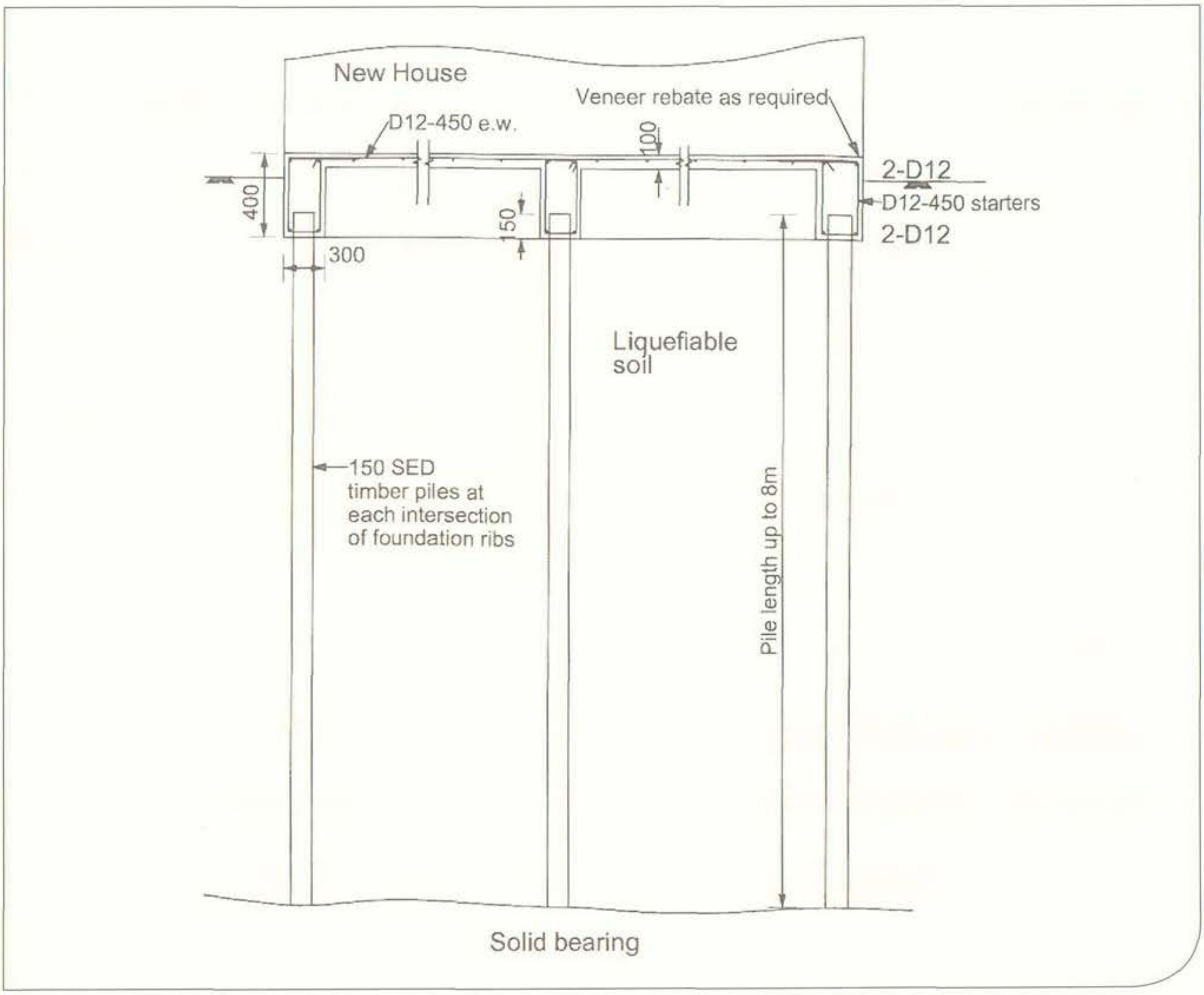
Option 4 – Construct a stiffened waffle slab over the existing soil.



The ground immediately beneath the polystyrene and ribs must have a minimum ultimate bearing strength of 300 kPa, or the system should be subject to specific engineering design.

Option 5 – Drive piles to solid bearing beneath a liquefiable layer and construct a floor slab with reinforced beams on pile rows in both directions to tie the tops of the piles together (no special soil preparation).

The option indicated below is based on a ribbed slab layout with ribs at a maximum spacing of 3.5 m (as per the layout for Option 3).



6.2.3 Floor construction – timber

Timber floor framing built in accordance with NZS 3604 in conjunction with timber piles driven to solid bearing at appropriate centres (ie, a variation of Concrete Option 5 above) constitutes a floor plate with good vertical stiffness, provided that the piles are properly connected to the bearers. This approach is likely to require a geotechnical investigation to establish pile lengths.

While a timber framed floor on standard house piles constructed in accordance with NZS 3604 is not sufficiently stiff to avoid vertical deformation, it is recognised that timber framed construction is easy to repair because it has easy access and an elemental nature, thus allowing easy replacement of any damaged elements. A light clad house structure supported fully on NZS 3604 pile systems is therefore considered to be a valid option.

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 is carried out before designing the foundation.
- Design for the potential for lateral ground spreading of up to 50 mm, 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 four metres beneath sections of the floor and two metres at the extremes of the floor (ie, ends and outer corners).
- Design to ensure that the floor does not hog or sag more than:
  - one in 400 (ie, 12.5 mm hog or sag at the centre of a 10 m length) for the case of no support over four metres, and
  - no more than one in 200 for the case of no support at the extremes of the floor.
- 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 required 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 Penetration Tests together with groundwater monitoring and laboratory testing (PSD and at times Atterberg limits). While Scala Penetrometer Testing is not capable of extending to sufficient depth to determine the full liquefaction risk, it may adequately determine the depth of any stiff overlying raft if present.

Any requirement for a full geotechnical report with field investigations (boreholes or Cone Penetration Tests) for all sites that have suffered land damage from the recent earthquake would have major impacts on reconstruction timeframes and also cost implications. A pragmatic approach is therefore considered necessary to ensure timely reconstruction in accordance with broader community recovery programme objectives.

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.

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 the Earthquake Commission (EQC) for the land remediation work. As outlined in Section 3.2, the Tonkin and Taylor Ltd Darfield Earthquake Stage 2 Report contains maps which identify three land zone categories.

These maps mainly cover the suburban areas worst affected by land damage, but do not extend into the residential rural areas or into the less damaged suburban areas outside the areas identified on the land damage maps.

Suburb geotechnical investigations and reports will be undertaken by EQC for a number of the mapped suburbs worst affected by land damage. There are two reports being produced for the worst affected suburbs:

1. Geotechnical Factual Report – suburb specific
2. Geological Interpretative Report – suburb specific

These are being prepared to provide data and information for the following purposes:

1. For the detailed design of the land remediation
2. For building consent applications
3. For council infrastructure repair

The suburb geotechnical reports will investigate the deeper soil profiles for that specified area. The factual reports will compile all new investigation data and all existing geotechnical data held by the council. The geological interpretative report will provide an interpretation and understanding of the geological subsurface profile for that suburb.

Some further limited geotechnical input will be required to confirm that the surface crust on an individual property provides adequate building capacity for the static case and recommendations for foundation design as discussed below.

For properties in the Selwyn District reference should also be made to future council commissioned geotechnical reports when they become available.

Areas covered by suburb geotechnical reports
In the areas covered by the suburb geotechnical reports, deep subsoil investigations (ie, boreholes or Cone Penetration Tests) will not be required on individual sites. In these areas, for **reconstructed** 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 NZS 3604 for the normal static conditions, excluding the effects of liquefaction.

Field investigations may therefore be limited to Scala Penetrometer Testing (DCP) and hand augers to confirm that the upper two metres of land meets NZS 3604 requirements for static bearing (ie. ultimate bearing capacity of 300 kPa). 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 two metres provides sufficient bearing capacity. An example template for such an investigation report is included in Appendix 5. If the bearing capacity of the upper two metres is less than 300 kPa (ULS), then conventional methods to address this issue should be applied such as utilising wider or deeper footings.

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 should be carried out by a Chartered Professional Engineer (CPEng-Geotechnical).

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

Areas NOT covered by suburb geotechnical reports

For areas of land not covered by the suburb geotechnical reports, 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 it is recommended that the following approach be adopted.

- 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 has 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.

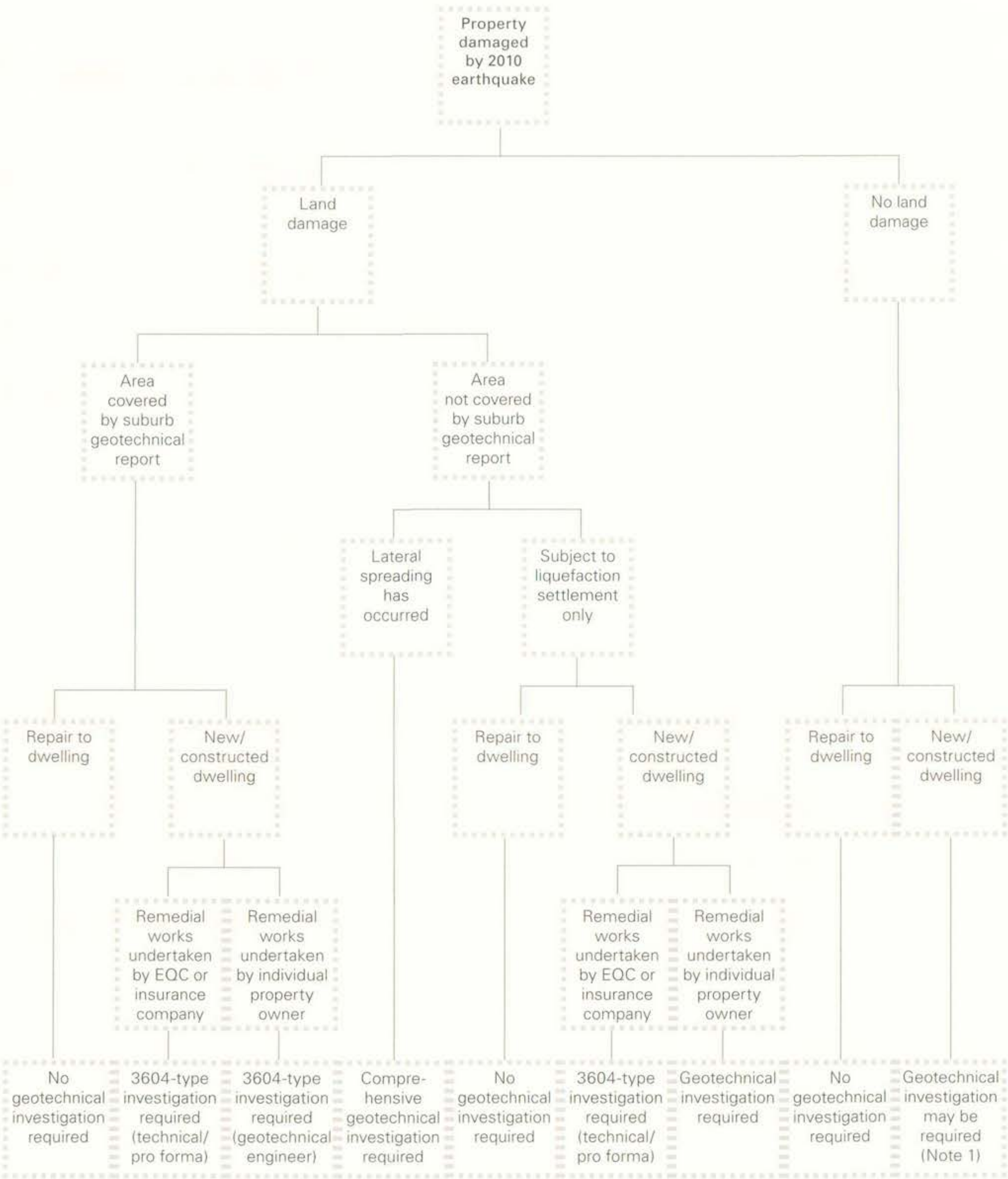
In the case where the rebuilding is to be managed or carried out by an individual property owner, the investigation must be overseen by a Chartered Professional Engineer (CPEng – Geotechnical). The extent of the investigation should be determined by the engineer on a case-by-case basis.

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

For new or reconstructed dwellings, the level of site investigation should be determined on a case-by-case basis, with the report overseen by a geotechnical engineer.

The overall process outlined on the previous pages is summarised in Figure 7.1.

Figure 7.1: Summary of relationship between individual site investigation and land damage



Note 1: The extent of the investigation, if required, should be determined on a case by case basis and should be overseen by a Geotechnical Engineer.

These geotechnical investigation inputs are considered to be the minimum requirements needed for this earthquake recovery effort. They are intended to efficiently utilise the limited geotechnical resources available. Individual property owners may elect to receive additional and more extensive geotechnical advice regarding their property.

With respect to structural design inputs, as mentioned in Section 6.2, it is envisaged that much of the foundation and floor detailing can be undertaken by architects and architectural draftspersons, provided that there is appropriate oversight by Chartered Professional Structural Engineers.

7.2 DURING CONSTRUCTION WORK AND UPON COMPLETION

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.

Christchurch City Council

For all earthquake consented building work, especially in Zones A, B and C, Council requires producer statements from all contractors and subcontractors declaring that work on key elements of the building project (eg, foundations, structural, weathertightness, plumbing and drainage, floor relevelling) complies with the Building Code.

Preferably these statements will be provided by licensed building practitioners.

The Christchurch City Council has developed a risk based building consenting process outlined in a separate document. All project hub offices and project management offices must follow and comply with the requirements of this document.

Selwyn District Council

Selwyn District Council will nominate required inspections at the time of issuing consent.

8. Flood risk and floor levels

This section briefly summarises the issues and requirements for each of the territorial local authorities to setting new finished floor levels for houses to be reconstructed in low lying areas. These notes are current at the time of preparation of this document (ie, end of November), and the current situation must be checked on a case-by-case basis with the respective council.

Christchurch City Council

Flood Management Areas are shown on the City Plan Series B Planning Maps. They are located around the Lower Styx, Avon and Heathcote Rivers, in the Lansdowne Valley and also in some low lying coastal areas including Redcliffs and Sumner. Some of these areas (most notably the Avon and the Lower Styx) were badly affected by the earthquake. The City has confirmed that it will proceed with the implementation of Variation 48, with the 'go live' date to be in early 2011 (exact date to be advised).

If a house is to be rebuilt on exactly the same footprint as before, existing use rights under the Resource Management Act to rebuild at the original floor level are likely to apply, so long as this is at or above the Building Act 2004 – one in 50 year flood level plus freeboard.

However all new buildings not on the same footprint, or additions to buildings, within the specified Flood Management Areas (with limited exceptions eg, in living zones, additions to existing buildings of a maximum of 25 m^2 in any five year period) will require resource consent as restricted discretionary activities. These consents will enable site specific assessments in respect of flood-related issues, the consideration of which is an important part of the rebuild because of sea level rise.

Two of the main criteria for assessment of buildings will be whether floor levels are above 200 year flood levels plus 400 mm freeboard, and in tidally influenced areas, at 11.8 m above Christchurch City Datum (Datum is a drainage reference level significantly below sea level and ground level).

In most, but not all cases it will be obvious which of these two levels is the higher level, and therefore the dominant criterion. These are not rules but effectively 'default positions'. There are also other assessment criteria which will be considered – for example, the effectiveness and environmental impact of any proposed (flood) mitigation measures, the effect on other properties of disturbances to surface drainage, etc. It is important to note that these resource consents will not require public notification or neighbours' approvals.

Filling within a Flood Management Area will also require a resource consent, except where the filling is only to achieve a building platform at the identified minimum floor level. Applications for resource consents for filling will require an assessment of whether there are other adversely affected parties.

The new rules will not apply to any development proposal where a land use consent or a building consent has already been issued prior to the date of the Variation being made operative. However, if a resource consent or a building consent application in a Flood Management Area is lodged with the Council, but the consent has not been issued before the 'go live' date, it will be caught by Variation 48.

Waimakariri District Council

Waimakariri District Council (WDC) is still gathering data to gauge the effects of the earthquake on their stormwater system and existing minimum house floor levels, and the number of houses affected.

WDC would like to see all reconstructed dwellings in low-lying areas with floor levels at the same level as the existing house, noting that many of those are of timber floor framing. They are likely to be addressing this on a case-by-case basis.

Selwyn District Council

The limited number of houses to be reconstructed in Selwyn District are all rural residential, and where affected by possible flooding, are capable of individual site-based solutions that won't affect neighbouring property.

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

New Zealand Society for Earthquake Engineering *Assessment and Improvement of the Structural Performance of Buildings in Earthquakes,* June 2006

Standards Australia and Standards New Zealand AS/NZS 1170 Structural Loadings Standard (various parts)

Standards New Zealand NZS 3604: 1999 Timber Framed Buildings

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

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

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 soil 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 one and 30 minutes after the primary ground shaking ceased.*
>
> *In general, the excess groundwater pressures due to seismic shaking are expected to take between two and eight 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 (ie, the liquefaction susceptible material lies below the ground-water 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 (ie, 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 (ie, 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 (ie, 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 (ie, tension crack/tear zone) will form at the head of this type of slide. Buildings that 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 (NZGS, 2010).

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 or major renovation, satisfies other Building Code requirements throughout the life of the building.

Benchmark: B2/AS1; NZS 3602

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 percent 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 a 2 percent annual probability shall not enter a 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 must be protected from adverse effects of moisture entering space below suspended floors.
- Concealed spaces and cavities must be 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.

G13 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

OUTLINE METHOD STATEMENTS FOR REPAIRING FOUNDATIONS AND FLOORS

The tables on the following pages provide suggested outline method statements for re-levelling foundations and floor slabs of 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 re-levelling works.

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

TYPE A: PILE FOUNDATION AND LIGHT CLAD EXTERIOR WALLS REPAIR METHOD STATEMENT

Refer to Section 5.2.2.

STEP	ACTIVITY
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 *eg, 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 15 mm per 1 m 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 6 m apart is more than 25 mm. During the jacking process make allowance for lateral stability of the detached structure.
6.	For floor lifts of up to 50 mm 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 100 mm skewed nails for timber piles and 4 mm 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 50 mm at any pile, new piles will be required to be fitted that may be connected directly to the existing bearers. Timber piles may be connected either by scarfing and bolting or by fixing with wire dogs and skewed nails as above. Concrete piles should be set so that the bearer rests directly on the pile once installed, and the two connected with wire and staples.
8.	For dwellings that have settled more than 50 mm, no pile tops shall be less than 150 mm 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 150 mm and 300 mm above the existing ground, a DPC should be installed between the pile top and the floor framing *(NZS 3604 requirement, which may be greater than pre-earthquake).* If no piles extend more than 300 mm 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 300 mm 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 600 mm).
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 redecorate 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.*

TYPE B: PERIMETER CONCRETE FOUNDATION WALL REPAIR METHOD STATEMENT

Refer to Section 5.2.3 light or medium-weight claddings and Section 5.2.4 for heavy veneer claddings.

Preparatory work

STEP	ACTIVITY
B1	Establish whether there is adequate bearing capacity for remedial works (eg, 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 (eg, 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 50 mm per 1 m height then new piles will be required. Leans of less than this value are considered to be acceptable if there is a perimeter foundation present.
B4	Disconnect the internal piles from the bearers.
B5	Demolish ancillary structures such as steps and terraces as necessary. 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
B1.1	Clear the perimeter of the foundation and, at a spacing of about 2 m centres around the perimeter of and under the foundation, excavate 500 mm square access pits beneath the foundation to a suitable bearing layer. Install dunnage and jacks. It is preferable to have a number of jacks available to allow the entire foundation to be lifted sequentially by maximum 3 mm increments. Detach the piles from the bearers. 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	For floor lifts of up to 50 mm 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 100 mm skewed nails for timber piles and 4 mm wire and staples for concrete piles).
B1.4	For lifts greater than 50 mm 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.
B1.5	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.
B1.6	Fill the space between the underside of the foundation and the ground in each pit with concrete, backfill the pits and reinstate the adjacent ground.
B1.7	Seal the inside and outside faces of the foundation beam at each crack in the foundation beam and epoxy grout the crack.
B1.8	Reconnect any services that had been disconnected prior to the lift.
B1.9	Reinstate the adjacent ground.
B1.10	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 redecorate 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 repainted. 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
B2.1	Clear the perimeter of the foundation and, at a spacing of about 2 m around the perimeter, install proprietary screw piles to the required depth to obtain sufficient bearing capacity.
B2.2	Ensure the services are able to accommodate the lift heights or otherwise detach these before the lift begins.
B2.3	Detach the piles from the bearers.
B2.4	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 (3 mm 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.
B2.5	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).
B2.6	The screw piles may be left in place or removed.
B2.7	Concurrently with the foundation beam jacking, jack the underside of the bearers beneath the house to create and maintain the planar floor.
B2.8	For floor lifts of up to 50 mm 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 100 mm skewed nails for timber piles and 4 mm wire and staples for concrete piles).
B2.9	For lifts greater than 50 mm at any pile, new piles will be required to be fitted that may be connected directly to the existing bearers. Timber piles may be connected either by scarfing and bolting or by fixing with wire dogs and skewed nails as above. Concrete piles should be set so that the bearer rests directly on the pile once installed, and the two connected with wire and staples.
B2.10	Seal the inside and outside faces of the foundation at each crack and epoxy grout the crack.
B2.11	Reconnect any services that had been disconnected prior to the lift.
B2.12	Reinstate the adjacent ground.
B2.13	Superstructure deformations associated with this damage and repairs 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 redecorate 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 repainted. 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 engineered resin

STEP	ACTIVITY
B3.1	Ensure 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	Detach the piles from the bearers.
B3.4	Commence injection below the perimeter foundation beam to improve the soils.
B3.5	Carry out injection in a controlled manner, monitored by a laser and staff, to gradually raise the foundation to the required level.
B3.6	Concurrently with the foundation beam lifting, jack the underside of the bearers beneath the house to create and maintain a planar floor.
B3.7	For floor lifts of up to 50 mm 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 100 mm skewed nails for timber piles and 4 mm wire and staples for concrete piles).

B3.8	For lifts greater than 50 mm at any pile, new piles will be required to be fitted that may be connected directly to the existing bearers. Timber piles may be connected either by scarfing and bolting or by fixing with wire dogs and skewed nails as above. Concrete piles should be set so that the bearer rests directly on the pile once installed, and the two connected with wire and staples.
B3.9	Seal the inside and outside faces of the foundation at each crack and epoxy grout the crack.
B3.10	Reconnect any services that had been disconnected prior to the lift.
B3.11	Reinstate the adjacent ground.
B3.12	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 redecorate 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 repainted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.

TYPE C: SLAB ON GRADE FLOORS REPAIR METHOD STATEMENT

Refer to Section 5.2.5 for light or medium-weight claddings, and Section 5.2.6 for heavy veneer claddings.

Preparatory work

STEP	ACTIVITY
C1	Establish whether there is adequate bearing capacity for remedial works (eg, 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 (eg, 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 as necessary. 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
C1.1	Take up all floor coverings in the areas where the floor is to be re-levelled (lifted).
C1.2	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.
C1.3	Clear the perimeter of the foundation and, at a spacing of about 2 m centres around the perimeter, excavate 500 mm square access pits beneath the foundation to a suitable bearing layer. Install dunnage and jacks. It is preferable to have a number of jacks available to allow the entire foundation beam to be lifted sequentially by maximum 3 mm increments. Alternatively, the jacks may be placed adjacent to the outside face of the foundation beam and 'L' shaped shoes bolted to the beam to act as a lifting bracket.
C1.4	Concurrently with the perimeter edge beam jacking, drill and inject grout through the floor slab on a suitable grid pattern, monitoring the slab lift to match the beam lifting.
C1.5	Start the edge beam lifting process by creating a planar floor plate, even if this is sloping, and then sequentially lift the foundation beam and slab until a horizontal floor plate is achieved.
C1.6	Install 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.
C1.7	Fill the space between the underside of the foundation and the ground at the jack pits between the jacks with grout or concrete.
C1.8	Seal the outside face of the edge beam at each crack and epoxy grout the crack.
C1.9	Reconnect any services that had been disconnected prior to the lift.
C1.10	Reinstate the adjacent ground.
C1.11	Re-lay the floor coverings.
C1.12	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 redecorate 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 repainted. 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
C2.1	Take up all floor coverings in the areas where the floor is to be re-levelled (lifted).
C2.2	Clear the perimeter of the foundation and, at a spacing of about 2 m around the perimeter, install proprietary screw piles to the required depth to obtain sufficient bearing capacity.
C2.3	Ensure the services are able to accommodate the lift heights or otherwise detach these before the lift begins.
C2.4	Fit the lifting components to the tops of the screw piles and under the edge beam. Lift the perimeter edge beam sequentially by a small amount (3 mm 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.
C2.5	Concurrently with the perimeter edge beam jacking, drill and inject grout through the floor slab on a suitable grid pattern, monitoring the slab lift to match the beam lift.
C2.6	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).
C2.7	The screw piles may be left in place, provided a permanent connection is made between the beam and the piles.
C2.8	Seal the outside face of the perimeter edge beam at each crack, and epoxy grout the crack.
C2.9	Reconnect any services that had been disconnected prior to the lift.
C2.10	Reinstate 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 redecorate 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 repainted. 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 engineered resin

STEP	ACTIVITY
C3.1	Ensure 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 perimeter 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 hardfill. Further controlled injection via these ports will raise the slab to the same level as the perimeter edge beams. This may be done concurrently with the perimeter edge beam lifting.
C3.7	Seal the outside face of the foundation at each crack and epoxy grout the crack.
C3.8	Reconnect any services that had been disconnected prior to the lift.
C3.9	Reinstate 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 redecorate 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 repainted. It may be necessary to apply a new texture coating if the texture match cannot be made during the crack repair.

Appendix 4

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 5.3.

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 weather tightness and the making good of finishes are to be separately specified by appropriately qualified persons.

In each of the types described below, once the house has been re-established on the new foundation system, consideration will need to be given to the reinstatement of the internal linings and external claddings. This will be dependent on the degree of deformation that the house has undergone during the earthquake and the subsequent lifting.

TYPE A: PILE FOUNDATION AND LIGHT CLAD EXTERIOR WALLS REPLACEMENT METHOD STATEMENT

Refer to Section 5.2.2.

STEP	ACTIVITY
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 (eg, 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 1.6 m 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 50 mm beyond the expected new common level or piles raked at an angle of greater than 15 mm per 1 m 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	Reconnect all services previously disconnected.
A11	Fit new base boards to the perimeter piles.
A12	Reinstate the adjacent ground.

TYPE B: PERIMETER CONCRETE FOUNDATION WALL REPLACEMENT METHOD STATEMENT

Refer to Section 5.2.3 light or medium-weight claddings and Section 5.2.4 for heavy veneer claddings.

STEP	ACTIVITY
B1	Establish whether there is adequate bearing capacity for remedial works (eg, using a 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 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 50 mm per 1 m height then new piles will be required. Leans of less than this value are considered to be acceptable 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 (eg, 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 installation of steel sliding beams and slide the superstructure to the side of the site for the 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 may be necessary to shift it first in one direction to undertake a part rebuild of the foundation and then in the other direction to complete the rebuild. This is a specialist operation requiring skilled operators.
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 1.4 m centres (900 mm centres if proprietary anchors are used). Re-attach the piles to the bearers with stapled wire (concrete piles) or wire dogs and skew nails (timber piles).
B10	Reconnect all services previously disconnected.
B11	Reinstate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.

TYPE C: SLAB ON GRADE FLOORS REPLACEMENT METHOD STATEMENT

Refer to Section 5.2.5 light or medium-weight claddings and Section 5.2.6 for heavy veneer claddings.

STEP	ACTIVITY
C1	Establish whether there is adequate bearing capacity for a new floor slab (eg, using a 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 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 lift and lateral shift of the structure.
C4	Remove plasterboard linings from one side of the internal walls to a height of about 600 mm above the floor. (If it can be determined which side of the wall has the bracing system applied, then this should be left untouched and the other side lining removed). For light and medium-weight wall claddings, remove the plasterboard linings from the inside face of the exterior walls to a height of about 600 mm above the floor. (There may be bracing elements included on these wall lines which will require reinstatement once the house is re-established on the new foundation). For heavyweight exterior claddings, remove all the cladding and leave the lining intact on the inside face.
C5	Disconnect all hold down fixings (ie, bolts or bent bars) to allow the superstructure to lift above the floor slab.
C6	In both orthogonal directions, install 200 mm x 50 mm or 250 mm x 50 mm 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 150 mm and support on blocks. Re-install 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 rebuild.
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, installed at 900 mm maximum centres.
C11	Reconnect 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 reinstate the bracing element by back-blocking the horizontal joint and fixing the replacement linings 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 without the back-blocking.
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 repainted 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	Reinstate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.

Appendix 5

SAMPLE TEMPLATE FOR A SCALA PENETROMETER INVESTIGATION FOR THE STATIC BEARING CAPACITY OF RESIDENTIAL FOUNDATIONS

Refer to the sample template overleaf.

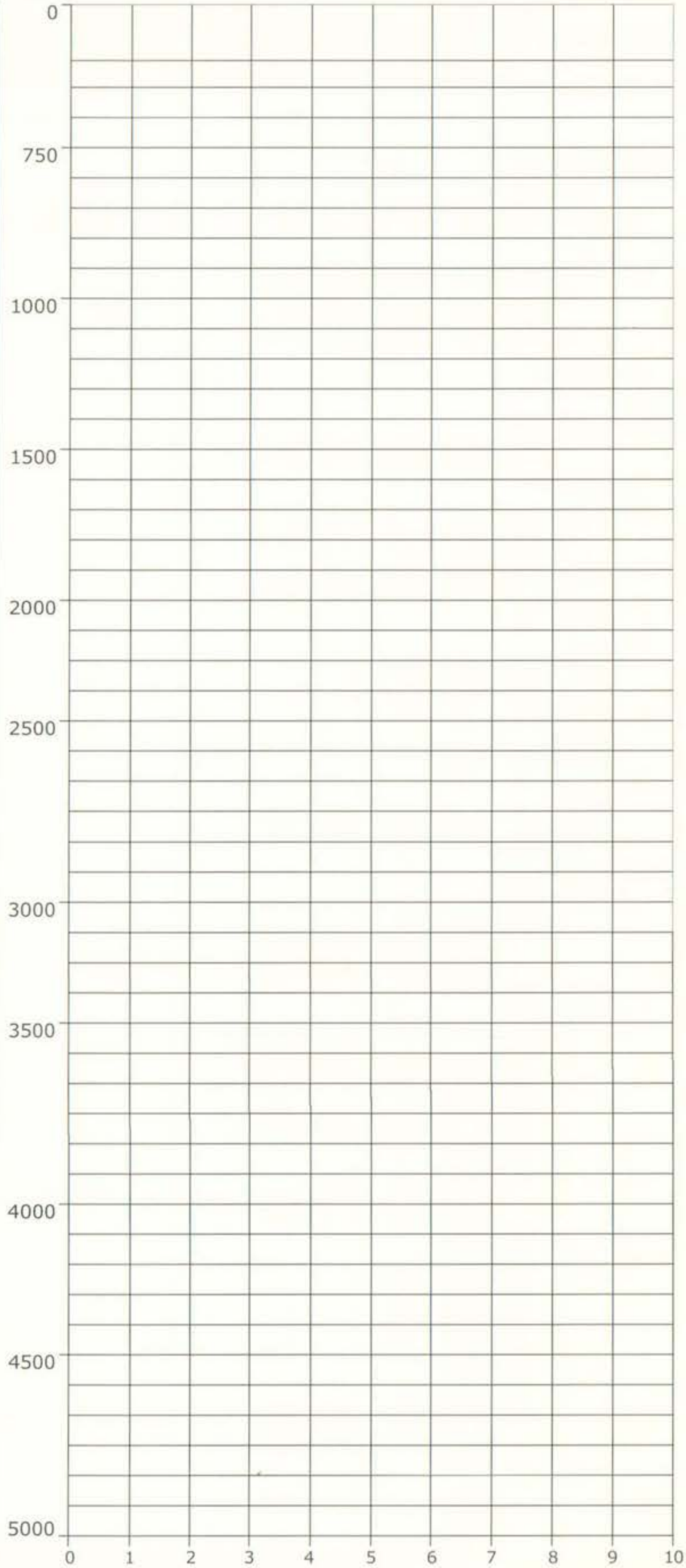
SCALA PENETROMETER LOG

Owner:
Address:
Suburb:
RL:

Date:
Operated by:
Logged by:
Checked by (CPEng):

Test No.
Sheet
of

mm Driven	No. of Blows	mm Driven	No. of Blows
50		2550	
100		2600	
150		2650	
200		2700	
250		2750	
300		2800	
350		2850	
400		2900	
450		2950	
500		3000	
550		3050	
600		3100	
650		3150	
700		3200	
750		3250	
800		3300	
850		3350	
900		3400	
950		3450	
1000		3500	
1050		3550	
1100		3600	
1150		3650	
1200		3700	
1250		3750	
1300		3800	
1350		3850	
1400		3900	
1450		3950	
1500		4000	
1550		4050	
1600		4100	
1650		4150	
1700		4200	
1750		4250	
1800		4300	
1850		4350	
1900		4400	
1950		4450	
2000		4500	
2050		4550	
2100		4600	
2150		4650	
2200		4700	
2250		4750	
2300		4800	
2350		4850	
2400		4900	
2450		4950	
2500		5000	



Test Method Used: NZS 4402:1988 Test 6.5.2 Dynamic Cone Penetrometer