Revised guidance on repairing and rebuilding houses affected by the Canterbury earthquake sequence

November 2011
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**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 this document it is only a guide and, if used, does not relieve any person of the obligation to consider any matter to which that information relates according to the circumstances of the particular case. 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](http://www.dbh.govt.nz)
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 sequence. Publication of this document is a part of the Government’s support for long-term recovery in Canterbury. It gives robust and well-balanced engineering solutions that will reduce the risk of injury to people and damage to homes in future earthquakes.

This is a full update and supersedes the guidance published in December 2010 in response to the Canterbury earthquake of 4 September 2010 (sometimes referred to as the Darfield earthquake). Since the 2010 guidance was published there have been numerous aftershocks, large and small, including the disastrous 22 February 2011 aftershock, known as the Lyttelton aftershock. The revised document incorporates information gained from each significant aftershock and extensive scientific and geotechnical investigation into the impacts of the Canterbury earthquake sequence. In particular it draws on learnings about the effects of liquefaction. The scale of liquefaction in the Canterbury earthquake sequence, and the impact on residential dwellings, highlighted the importance of ensuring there are appropriate foundations on land that may be subject to liquefaction in major events.

As a result of this, and of further geotechnical research commissioned by the Department, the Canterbury Green Zone has been divided into three technical categories. These categories describe how the land is expected to perform in future large earthquakes and the foundations that are considered appropriate to reduce the risk of injury and damage.

The volume of repair and reconstruction activity is placing challenges on the insurance assessment, engineering design, construction and consenting capacity available in New Zealand. The reconstruction has and will continue to put pressure on New Zealand’s engineering resources, both structural and geotechnical. Given the numerous aftershocks, insurers and reinsurers need confidence that the rebuilding work is robust, will reduce the risk of damage in future large events and does not involve unnecessary expense.

There is also pressure on councils to process large volumes of consent applications. This has the potential to result in delays to homeowners and slow the re-establishment of the most affected communities.

Overseas experience of recovery from major events has shown that confusion, delays and additional design costs can occur if designers, insurers and councils have different perspectives. The Department’s guidance encourages consistency of approach. It identifies areas where costly investigations and design for properties are unnecessary and recommends site-specific investigations for properties in Technical Category 3, where significant land damage from liquefaction is possible in future large events. It provides solutions and construction methods that will meet the requirements of the Building Act and Building Code while avoiding ‘over-design’.

It also includes useful information on retaining walls for hillside properties, chimney repairs and repairs to wall and roof frame connections, steel and pole frames and masonry walls. This provides guidance for the many dwellings that have suffered minor damage to the superstructure, such as damaged chimneys and superficial cracking to cladding or linings.

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. Earthquakes and their effects are complex. Investigations into the full picture on how residential structures responded to liquefaction effects are ongoing. They include a trial, initiated by the Department, of new and innovative foundation solutions for land subject to liquefaction. The Department is developing additional guidance for foundations in Technical Category 3, based on the findings of the trial.

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

1. The Department of Building and Housing’s Engineering Advisory Group (Residential), consisting of:
   - Dave Brunsdon: Kestrel Group Ltd
   - Graeme Beattie: BRANZ Ltd
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   - Andrew King: GNS Science
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1. Introduction

1.1 BACKGROUND

Damage from the Canterbury earthquake sequence

The Darfield earthquake of 4 September 2010 was an internationally significant event that focused attention on damage to residential properties from liquefaction and lateral spreading. The 22 February 2011 Lyttelton aftershock caused further liquefaction that affected houses across a far wider area of Christchurch, as well as causing extensive rockfall and some landsliding in the Port Hills. Significant shaking damage was also observed in the hill suburbs.

Other significant aftershocks, most notably on 13 June 2011, again caused liquefaction in the low-lying areas worst affected in the 4 September 2010 and 22 February 2011 events, and further shaking damage to hillside properties.

As at the end of September 2011, approximately 385,000 insurance claims relating to 120,000 properties had been submitted to the Earthquake Commission (EQC). Of these properties, approximately 65,000 are likely to have experienced land damage as a result of the Canterbury earthquake sequence (ground deformation resulting from the effects of liquefaction, landslip and rockfall), ranging from very minor to very severe. The effects of liquefaction included differential and overall vertical settlement and lateral spreading, with the latter being the most damaging to buildings and infrastructure.

The majority of the dwelling damage claims not affected by land damage relate to minor damage such as damaged chimneys and superficial cracking to cladding/wall linings.

In many cases, damage will have increased following the subsequent major aftershocks.

Residential land zones

On 23 June 2011, the Government and the Canterbury Earthquake Recovery Authority (CERA) announced four residential land zones:

- Green – repair/rebuild process can begin
- Red – land repair would be prolonged and uneconomic
- Orange – ‘hold zone’, further assessment required; to be re-zoned Red or Green depending on further investigation
- White – ‘un-zoned’, parts of the Port Hills and CBD; still being mapped.

Subsequent announcements are addressing the resolution of properties that were initially designated within the Orange Zone and the lists are being progressively updated, see [www.cera.govt.nz](http://www.cera.govt.nz)

Guidance provided in this document focuses primarily on the Green Zone on the flat1 (liquefaction) and to a lesser extent the Port Hills areas affected by landslip, rockfall and shaking damage.

This document has been prepared in conjunction with work undertaken by Tonkin & Taylor Ltd for the Government, in order to coordinate the analysis and mapping of land and residential building damage.

1.2 OBJECTIVES

The principal objective of this document is to provide building repair and reconstruction solutions and options that:

1. are appropriate to the level of land and building damage experienced
2. take account of the likely future performance of the ground
3. meet Building Act and Building Code requirements
4. are acceptable to insurers and property owners.

Increasing the resilience of residential dwellings is also an underlying objective.

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1 The term ‘on the flat’ is used to distinguish the areas affected by liquefaction from the Port Hills area.
Increasing resilience however involves a range of possibilities. For houses on land that has the potential for future liquefaction, achieving optimum resilience would involve remediating the ground to remove or reduce this potential. While this approach may be preferable for new subdivisions where the cost per property can be minimised, it may not be practical for individual developed sites. In addition, it is not necessarily within the scope of insurance cover or regulatory requirements for a given level of damage.

The guidance provided in this document aims for a consistent approach to repair and rebuilding that minimises the individual investigation and design effort required for each property. It takes a prudent approach that is mindful of costs and risks, providing solutions and construction methods that aim to meet the requirements of the Building Act and Building Code. It also looks to satisfy the relevant insurance requirements without giving rise to ‘betterment concerns’. Independent costing advice indicates a strong positive benefit to cost in following the proposals in the document.

Owners may choose to specify additional measures to achieve greater levels of resilience, noting that this is likely to be outside the scope of insurance contracts and would also require specialist geotechnical engineering advice.

1.3 REGULATORY CONTEXT

All work undertaken to repair damage is ‘building work’ and needs to comply with Building Code requirements, whether or not a building consent is required.

After repair work that requires a building consent is carried out, a building needs to comply, as nearly as is reasonably practicable, with the provisions of the Building Code that relate to means of escape from fire and access and facilities for persons with disabilities. It must also continue to comply with the other provisions of the Building Code to at least the same extent as before the repair work.

However, the requirement for access and facilities for people with disabilities does not apply to private houses, while special fire safety requirements for houses are essentially limited to the installation of domestic smoke alarms. (Please note: If the house is not fully detached there may be other requirements.) This means the requirements can generally be satisfied by installing smoke alarms and by demonstrating that the overall performance of the house for structural safety, weathertightness, sanitary, etc, is no worse than before the application for building consent (ie, before the repair work).

Repairs being undertaken, therefore, do not require the building to be fully upgraded to comply with the performance requirements of the Building Code. Only the **scope of work being undertaken** needs to comply with Building Code requirements.

For more details on insurance and regulatory requirements, refer to section 8.

1.4 SCOPE

**Audience**

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

**Canterbury focus**

The options and recommendations in this document are specific to residential properties directly affected by the Canterbury earthquake sequence. The information on reducing the effects of liquefaction on residential properties should not necessarily be taken as a best practice guide for addressing liquefaction in other parts of Canterbury or New Zealand.

National best practice guidance for the design of residential dwellings to take account of potential liquefaction will be prepared in due course, and will draw upon information in this document.
Technical scope

This document is issued as guidance under section 175 of the Building Act 2004, so the methods and solutions presented here are not mandatory. It focuses primarily on solutions for Green Zone land on the flat.

The document focuses principally on one- and two-storey timber framed dwellings, which are the dominant form of construction in the affected area (ie, houses built to NZS 3604 or its predecessor Standard).

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

The guidance provides standard methods and solutions for the assessment, repair and rebuilding of foundation and floor elements. Advice on assessing the effects of land movement on houses and retaining walls on the Port Hills is also included, along with limited general information on repairs as in most cases specific advice will be required.

For superstructure damage resulting from strong ground shaking, standard repair methods can be used in most cases. Some guidance is included in this document, particularly for chimneys, plasterboard linings and unreinforced masonry.

Even though future liquefaction may occur within the Green Zone, and there remains uncertainty about the extent and severity of future ground deformations, this is expected to be manageable by appropriate design.

The 22 February 2011 aftershock brought a greater understanding of damage to houses from liquefaction, particularly the extent of ground damage that is likely to result in excessive settlement of the house. This has led to land on the flat being assigned into three technical categories based on the expected future liquefaction performance:

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

The guidance concentrates on areas where the overall settlement in a future earthquake is not expected to be excessive (ie, TC1 and TC2).

Houses in TC3, where overall house settlement may be significant in a future earthquake, will require deep geotechnical investigation and site-specific engineering design. It is likely that deep piles founded to a good bearing layer will be required, but other innovative and economic foundation system solutions, including ground treatment options, are being trialled. It is anticipated that further guidance on solutions in TC3 will be developed.

To mitigate the effects of liquefaction, as a guiding principle it is preferable to build using light materials rather than heavy materials. Light construction (roof, walls and floors) significantly reduces the imposed load on the subsoils, and therefore the potential for liquefaction-induced settlement – for example, as low as 30% of the imposed weight around the perimeter compared to a heavy roof, masonry cladding and concrete slab dwelling.

This document does however provide foundation solutions for TC1 and TC2 that enable other forms and weights of cladding material.

Table 1.1 summarises the future land performance criteria and the corresponding repair and reconstruction approaches for each technical category.
Table 1.1 Summary table of technical categories, land criteria and repair and rebuild approaches

<table>
<thead>
<tr>
<th>FOUNDATION TECHNICAL CATEGORY</th>
<th>LAND CRITERIA</th>
<th>WHERE NEW FOUNDATIONS ARE REQUIRED (INCLUDING FLOOR SLAB)</th>
<th>WHERE FOUNDATIONS ARE TO BE REPAIRED ONLY (INCLUDING FLOOR SLAB)</th>
<th>SUPERSTRUCTURE REPAIRS ONLY (NO FOUNDATION DAMAGE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC1</td>
<td>Future land damage from liquefaction is unlikely, and ground settlements are expected to be within normally accepted tolerances</td>
<td>Use foundations provided in NZS 3604 Timber Framed Buildings, as modified by B1/AS1 which requires ductile reinforcing in slabs (refer to the Department’s information sheet at <a href="http://www.dbh.govt.nz/seismicity-info">http://www.dbh.govt.nz/seismicity-info</a>)</td>
<td>Refer to section 4</td>
<td>Refer to section 4</td>
</tr>
<tr>
<td>TC2</td>
<td>Minor to moderate land damage from liquefaction is possible in future large earthquakes</td>
<td>New houses with light- or medium-weight cladding, light-weight roofing with suspended timber floors and foundations in accordance with NZS 3604(2)</td>
<td>Or Replace foundation with enhanced slab Options 1 to 4 as provided in section 5</td>
<td></td>
</tr>
<tr>
<td>TC3</td>
<td>Moderate to significant land damage from liquefaction is possible in future large earthquakes</td>
<td>Specific geotechnical investigations and engineering design required Deep piles (Option 5) if suitable bearing layer &lt;10 m Further guidance is being developed following testing of other foundation system options</td>
<td>Specific geotechnical investigation and engineering design required</td>
<td></td>
</tr>
</tbody>
</table>

(1) Solutions provided are minimum recommendations. Homeowners can always choose more robust options, noting the need to discuss this with the insurer.  
(2) Refer to Glossary.

The additional cost of constructing a more robust foundation and floor system than the minimum requirements of NZS 3604 is considered minor in the context of the overall repair or rebuilding cost (estimated at less than 5% of the total house cost, depending on the option selected). Furthermore, following the proposed solutions in this document is likely to cost less than the geotechnical and structural engineering investigation and design that would be necessary to provide an alternative solution on a house-by-house basis.

Individual house owners may wish to go beyond the solutions suggested in this document and specify a higher level of foundation performance or resilience. This document provides information on the relevant engineering principles and parameters for an enhanced foundation and floor system, which should assist engineers undertaking specific structural and geotechnical engineering design, and inform discussions with insurers as to whether the proposed solution falls within the scope of the insurance policy.
1.5 STRUCTURE OF THIS DOCUMENT

The document is structured in two parts, Part A and Part B.

Part A: Technical guidance

Part A contains technical guidance on assessment and repair or rebuild options as follows.

- Section 2 provides indicator criteria for repair and rebuild situations for foundations, along with suggested assessment approaches. This section applies both on the flat and in the Port Hills areas.
- Section 3 outlines the technical categorisation system for the Green Zone on the flat.
- Section 4 presents options for repairing foundations on the flat, including re-levelling.
- Section 5 sets out guidance for new foundations for rebuilt dwellings and foundations that are being fully replaced in existing dwellings on the flat.
- Section 6 provides guidance on the assessment of hillside properties and retaining walls.
- Section 7 provides guidance on superstructure damage assessment and repair.

Part B: Technical information

Part B contains supporting technical information on the general requirements of insurance contracts and building legislation as they relate to the repair and rebuilding of houses. Part B also outlines observed and future expectations for land and building performance.

- Section 8 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 9 summarises the observed land and building performance in liquefiable soil areas and in hillside areas.
- Section 10 outlines future expectations for land and buildings based on the observations made and also giving consideration to the changes to the seismicity in the area.

The appendices prefixed with the letter ‘A’ provide the method statements for repair and rebuilding of dwellings and guidance on repair and replacement of chimneys and concrete slabs.

The appendices prefixed with the letter ‘B’ summarise the effects of liquefaction and establish guidelines for the investigation and assessment of subdivisions.
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2. Foundation assessment criteria and approaches

This section provides recommended criteria for the different levels of repair for house foundations that have damage from the earthquakes. The information in this section applies irrespective of house location – ie, both on the flat and in the Port Hills areas. Suggested assessment approaches are also outlined.

Given the wide variation in location, distribution and effects of settlement damage within any one house, it is expected that a certain degree of judgement and practicability will be applied alongside these guidelines. Accordingly, the indicative criteria presented within this section are not intended as ‘absolutes’.

### 2.1 TYPICAL DWELLING FOUNDATION TYPES

Three broad groups of dwellings have been used in the subsequent sections of this document to describe dwellings on the flat, as represented in Figure 2.1.

The Type B and C house foundations have been further subdivided into those supporting light- and medium-weight claddings (B1 and C1) and those supporting heavy claddings such as brick veneer (B2 and C2) (see Table 2.1).

#### Table 2.1 House foundation and floor types on the flat

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Timber framed suspended timber floor structures supported only on piles. Stucco, weatherboard or light texture clad house.</td>
</tr>
<tr>
<td>Type B1</td>
<td>Timber framed suspended timber floor structures with perimeter concrete foundation. Stucco, weatherboard or light texture clad house.</td>
</tr>
<tr>
<td>Type B2</td>
<td>Timber framed suspended timber floor structures with perimeter concrete foundation. Brick or concrete masonry exterior cladding (veneer).</td>
</tr>
<tr>
<td>Type C1</td>
<td>Timber framed dwelling on concrete floor (slab-on-grade). Stucco, weatherboard or light texture clad house.</td>
</tr>
<tr>
<td>Type C2</td>
<td>Timber framed dwelling on concrete floor (slab-on-grade). Brick or concrete masonry exterior cladding (veneer).</td>
</tr>
</tbody>
</table>
In areas subject to liquefaction, the apparent damage to Type A buildings is generally easier and less costly to repair than for Types B and C. Type C buildings are typical of the newer subdivisions, with a significant number of buildings less than 10 years old. These buildings are typically supported on a shallow reinforced concrete perimeter strip footing, with concrete slab-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, these buildings will be difficult and more costly to repair.

2.2 ASSESSING FOUNDATION DAMAGE

For Type A and B dwellings, the foundation elements are discrete and identifiable (ie, timber or concrete short piles; perimeter concrete foundation walls). For Type C dwellings, the foundation includes the slab and the perimeter foundation beams.

Determining the level of foundation damage, and hence the degree of foundation structural repair or replacement required, involves consideration of the extent and interaction of three aspects:

1. differential and overall settlement of the dwelling
2. overall lateral extension or ‘stretch’ of the floor and foundations, and
3. damage to specific foundation elements.

For example, if significant differential and/or overall settlement (aspect 1) occurs, it can result in the need to rebuild foundations, even if there is only minor damage to the foundation or superstructure elements.

Conversely, severe damage to particular foundation elements (aspect 3) can be addressed via local repairs, if the differential and/or overall settlements are minor.

This section focuses on establishing the level of foundation damage in relation to aspects 1 and 2.

For aspect 3, this section will need to be read in conjunction with sections 4, 5 and/or 7, depending on the level of damage to the house. Section 4 is concerned with foundation repair and re-leveling. Section 5 is concerned with new foundations (including replacement foundations). Section 7 is concerned with superstructure damage.

For a dwelling to be considered not to have foundation damage requiring structural repair, several criteria need to be satisfied. Table 2.2 provides indicative criteria for situations where it is considered that no specific structural repairs to foundation elements will be necessary.

It is common for Type B house foundation walls and Type C floor slabs to have cracks caused by shrinkage, which were present before the earthquake sequence. Some of these may have been exacerbated by the earthquakes. When assessing the width of fresh cracks, or the increase in crack width caused by earthquake actions, there are key observations to establish the history.

In perimeter foundation walls, the presence of accumulated soil, moss or paint penetration in cracks indicates that there was a crack at that location prior to the earthquakes. The width may have increased as a result of the earthquakes. In tied floor slabs, shrinkage cracks are characterised by an increase in width from the perimeter edge beam to the body of the slab. Cracks wider than 1 mm at the edge of the floor are likely to be earthquake related, and are a good indicator of the amount of earthquake related stretch. These should also be reflected on the outside of the foundation. Further information on cracking in concrete slab-on-grade floors is given in Appendix A4.

Superstructure repairs may still be necessary even if there is no foundation damage (see section 7).
Table 2.2: Criteria for ‘No foundation damage requiring structural repair’ (all technical categories)

<table>
<thead>
<tr>
<th>DWELLING FOUNDATION TYPE</th>
<th>SETTLEMENT STATUS</th>
<th>LATERAL STRETCH STATUS</th>
<th>CRACK WIDTHS* / OTHER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Vertical differential settlement &lt;50 mm and floor slope less than 1 in 200 between any two points &gt;2 m apart</td>
<td>AND &lt;20 mm</td>
<td>Pile tilt &lt;15 mm per 1 m height and no floor framing damage</td>
</tr>
<tr>
<td>Type B</td>
<td>Vertical differential settlement &lt;50 mm and floor slope less than 1 in 200 between any two points &gt;2 m apart</td>
<td>AND &lt;20 mm</td>
<td>&lt;5 mm cracks in perimeter foundation</td>
</tr>
<tr>
<td>Type C</td>
<td>Vertical differential settlement &lt;50 mm and floor slope less than 1 in 200 between any two points &gt;2 m apart</td>
<td>AND &lt;20 mm</td>
<td>&lt;5 mm cracks in the floor slab</td>
</tr>
</tbody>
</table>

Notes
* Crack widths are those principally related to earthquake actions

2.3 INDICATOR CRITERIA FOR REPAIRS AND REBUILDS

Applicable standards for floor level tolerance

For in-service conditions, Verification Method B1/VM4 refers in an informative Appendix B to limiting a foundation design to a probable maximum differential settlement over a horizontal distance of 6 m to no more than 25 mm under serviceability limit state load combinations. This could result in a slope of 1 in 240 or 0.4% over the service life of the dwelling.

For construction tolerances (ie, as-completed conditions) the relevant Standards are NZS 3604, NZS 3109 and NZS 3114.

Table 2.1 of NZS 3604:2011 states that for timber framing, the maximum deviation from horizontal is 5 mm in 10 m, or a total of 10 mm over any length greater than 10 m. The bottom plate of a wall fits within the definition of ‘timber framing’, but in new concrete floor construction this would be expected to be packed to level.

The clearest requirement for floor level tolerances for houses is included in Table 2 of NZS 3124:1987. While this Standard refers to NZS 3604 and NZS 4229 for its application, the reference is unfortunately no longer reciprocal. NZS 3124 requires the variation in bearing surfaces for timber to be within ±5 mm, and also requires the maximum depression from a straight line between two high spots 3 m apart on a floor to be 8 mm. The maximum floor slope associated with the second criterion is 0.53% (1 in 190).

NZS 3109 and NZS 3114 provide a range of acceptable surface deviations for different situations of flatness and straightness. None of these are considered to comprehensively address the various situations covered by this document.

A survey of new concrete floors conducted by members of the Engineering Advisory Group in January and February 2011 found that an overall variation in floor level of between 15 mm and 20 mm was typical over a new concrete foundation slab. The same survey found that the average slopes between two points 2 m apart varied between 0.35% and 0.65% (approximately 1 in 300 and 1 in 150).

Furthermore, after the December guidance was issued, it was realised that the instruments typically being used by assessors to measure floor out of tolerances were only accurate to +/- 3 mm, a significant range of variation compared with the 5 mm tolerance originally allowed over 2 m in that document.

The above review of relevant Standards, consideration of finished floor level survey results, and the limitations of assessment measurement techniques has resulted in the indicator criteria provided in Table 2.3. These indicator criteria contain out-of-level tolerances and settlement limits that are considered to better reflect damage related to the earthquake rather than general (historical) settlement or initial construction tolerances.
Please note: these indicator criteria are less onerous than those contained in Table 4.1 of the December 2010 guidance document, reflecting the further research undertaken as outlined above. It should also be noted that there is a now a recommended maximum differential settlement of 50 mm over the floor.

Indicator criteria – Table 2.3

The indicator criteria contained in Table 2.3 can be used to indicate first whether a house is likely to need re-levelling, and then secondly, if it does, whether a re-level, a foundation rebuild or a house rebuild is likely to be required.

The indicator criteria provide guidance, rather than representing absolutes, as suggested by the dotted vertical lines between the columns.

The indicator criteria stated in column 2 of Table 2.3 are suggested threshold values – below these it is considered that no action is required to re-level or rebuild the floor. Where these thresholds are exceeded, the recommended process to follow will be determined by how much they are exceeded. This means that as long as the thresholds in column 3 are not exceeded, a re-level should be able to be undertaken. In the same way, if the thresholds in column 4 are not exceeded, a foundation rebuild should be an option. Finally, if the column 4 thresholds are exceeded, then a house rebuild is likely, depending on the cost of repair (column 5).

If the floor profile fits within the criteria in column 3, the expectation is that the re-levelling processes will result in a floor that is level within the criteria stated in column 2. These are the maximums of desired slope and differential displacement, and tighter tolerances should be targeted during re-levelling processes.

Some insurance policies may require a higher standard of reinstatement than suggested by column 2 of Table 2.3.

If there is a question around whether a specific criterion applies to a particular situation, professional engineering input should be sought.

Factors that need to be considered in relation to floor level differences in a house include:

- the intended use of the space
- construction materials of the floor surfacing
- practicality of the repair (ie, cost vs benefits)
- the effect of gradients on amenity of the space.

The criteria are intended for reasonably regular houses (for example the ‘L’ shaped dwelling shown in section 5). They may not be readily applicable to highly irregular shaped houses. In some cases, a house may have settled uniformly to the extent that it no longer has the required ground clearances around its perimeter (see section 2.6) or it will be susceptible to future flooding (see section 8.4). While the settlement characteristics, when compared to Table 2.3, may suggest no action is necessary, the clearance and flooding criteria will take precedence and a decision on the appropriate action will need to take this into account.
## Table 2.3: Indicator criteria for floor/foundation re-level or rebuild

<table>
<thead>
<tr>
<th>COLUMN 1</th>
<th>COLUMN 2</th>
<th>COLUMN 3</th>
<th>COLUMN 4</th>
<th>COLUMN 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor type</td>
<td>NO foundation re-level considered necessary</td>
<td>Foundation re-level indicated</td>
<td>Foundation rebuild indicated</td>
<td>House rebuild may be indicated</td>
</tr>
<tr>
<td>Type A</td>
<td>Timber framed suspended timber floor structures supported only on piles</td>
<td>The slope of the floor between any two points &gt;2 m apart is &lt;0.5% (1 in 200) [Note a] and The variation in level over the floor plan is &lt;50 mm</td>
<td>The variation in floor level is &gt;50 mm and &lt;100 mm Note that the floor re-level is expected to be achieved by packing the piles</td>
<td>The variation in floor level is &gt;100 mm [Note c] over the floor plan or The floor has stretched &gt;50 mm [Note d] Note that full or partial re-pling is expected to be undertaken to achieve a level floor</td>
</tr>
<tr>
<td>Type B</td>
<td>Timber framed suspended timber floor structures with perimeter concrete foundation</td>
<td>The slope of the floor between any two points &gt;2 m apart is &lt;0.5% (1 in 200) [Note a] and The variation in level over the floor plan is &lt;50 mm</td>
<td>The variation in floor level is &gt;50 mm and &lt;100 mm [Note b]</td>
<td>The variation in floor level is &gt;100 mm [Note c] over the floor plan or Individual cracks in the perimeter foundation are &gt;5 mm, or The floor has stretched &gt;20 mm [Note e]</td>
</tr>
<tr>
<td>Type C</td>
<td>Timber framed dwelling on concrete floor</td>
<td>The slope of the floor between any two points &gt;2 m apart is &lt;0.5% (1 in 200) [Note a] and The variation in level over the floor plan is &lt;50 mm and There are no cracks in ceramic floor tiles and There is no distress in vinyl floor coverings or carpet</td>
<td>The variation in floor level is &gt;50 mm and &lt;150 mm and Services are functioning</td>
<td>The variation in level over the floor plan is &gt;150 mm or There is irreparable damage to buried services within the house footprint</td>
</tr>
</tbody>
</table>
Explanatory notes to Table 2.3

a. Floor and superstructure damage repair may still be required, even if these indicator limits are not exceeded.
b. For veneer cladding to Type B construction, there may be a need to rebuild the veneer.
c. Pile packing in Type A and B construction is considered to be unstable at greater than 100 mm.
d. For most fully timber framed (Type A) buildings, an overall stretch of less than 50 mm can be pulled together again.
e. Where perimeter concrete foundation walls are present (Type B construction), there is unlikely to be an opportunity to pull the foundation together again.
f. This is an economic decision for any of construction Types A, B, or C on a particular property.
g. Any abrupt changes in floor level may require at least local re-levelling, depending on the type of floor covering.
h. Dwellings will have different degrees of damage, and in some cases the rebuilding of foundations may only be needed in the vicinity of the damage.
i. More restrictive limits may be appropriate if there is concern that distortions in the floor from earthquake damage may cause superstructure damage over time. For example:
   - damage to partitions (gravity load bearing and/or non-gravity load bearing) supported by a floor or foundation which undergoes angular distortion. Please note: damage limits applicable to specific types of partition are given in other Standards (eg, AS 2870 Table 8.1, ISO 4356 Annex D Table 1).
   - damage to external claddings leading to a contravention of the various Building Code performance requirements (eg, E2).

Figure 2.2 Diagrammatic representations of slope and overall variation limits from Table 2.3
2.4 EFFECT ON SUPERSTRUCTURE

While observations on the performance of the superstructure may indicate that differential settlement has occurred beneath a floor (e.g., creased wallpaper), the key check is to take levels on the floor surface or a common feature near the floor such as the top of skirting boards. Sticking doors and windows and cracked or wrinkled wall linings may suggest that the floor is no longer level, but shaking distortion can cause similar effects.

When the floor is re-levelled or rebuilt, the superstructure is likely to be stressed either because the floor was not level prior to the earthquake and the process has undone any remedial action taken on the superstructure prior to the earthquake, or because any deformations caused by shaking are still present.

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 2.3 for re-levelling, a re-levelling practitioner should be consulted to advise on the practicality of undertaking a re-level.

2.5 FLOOR LEVEL 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, or a pressure-sensitive instrument that displays floor level change from atmospheric pressure change. (Note: pressure sensitive instruments must be used with extreme care; they have an accuracy of ±3 mm and are subject to variations caused by, for example, differential heating from sunlight. They also should be re-calibrated prior to and after each use.)

An appropriate allowance should be made for differences in thicknesses of floor coverings.

Where measurements to determine the deviation in floor levels are critical, it is recommended they are undertaken by a Registered Professional Surveyor.

The degree of lateral extension of the ground floor plate of the house should be established. Note that this is different from the lateral movement of the ground beneath the house, and needs to be measured on the structure. This can be done by adding the widths of the earthquake-induced cracks 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 (Type A foundations), this will require a careful inspection of the exterior claddings at the bottom of ground floor walls for signs of lateral extension. Here, lateral extensions are likely to be concentrated at one or two discrete locations where connections in the framing have failed.

The degree of extension and/or flexural damage (if present) to the perimeter concrete foundation in Type B foundations 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, a feeler gauge 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. In wider cracks it should be possible to visually observe whether there is steel present.
2.6 GROUND CLEARANCE REQUIREMENTS

Type A and B dwellings

For new foundations, NZS 3604 requires a crawl space beneath the underside of floor joists of 450 mm and, to maintain flooring durability, wood-based flooring is required to be a minimum of 550 mm above the ground surface. Furthermore, NZS 3604 requires the tops of piles supporting timber floors to be not less than 150 mm above the finished ground level. This increases to 300 mm if the pile is timber and is cut off, and no bituminous damp proof course (DPC) is fitted between the pile and the bearer.

Type C dwellings

Table 18 and Figure 65 of E2/AS1 provide criteria for clearances to the ground from the finished floor level around the perimeter of a new slab-on-grade house. The required ground clearances are summarised as follows:

- Where the adjoining ground is protected by permanent paving:
  - for masonry veneer exterior wall covering:
    100 mm where the adjoining ground adjacent to the permanent paving is at least 150 mm below the floor level
  - for any other exterior wall covering: 150 mm, or

- Where the adjoining ground is not protected by permanent paving:
  - for masonry veneer exterior wall covering: 150 mm
  - for any other exterior wall covering: 225 mm.

For situations where foundations are being replaced beneath an existing dwelling that is to be retained, these ground clearance requirements should be met.

For existing buildings that are being repaired without the replacement of whole foundations, ground clearances should continue to be met to the same extent as prior to the earthquakes.

For properties in low-lying areas, there are additional considerations that need to be taken into account. Section 8.4 provides an overview of flood risk and floor level considerations.
3. Technical categorisation of the Green Zone on the flat

3.1 FOUNDATION TECHNICAL CATEGORIES

To clarify repair and reconstruction options and enable resources to be focused on areas of greatest risk, the CERA Green Zone on the flat has been divided into three foundation technical categories that reflect both the liquefaction experienced to date and future performance expectations.

These technical categories are intended to guide foundation choice pathways that owners, insurance companies, the EQC and their respective Project Management Offices (PMOs) can use to determine the appropriate foundation solution for each site.

The foundation technical categories are defined as follows:

- **TC1**: Future land damage from liquefaction is unlikely, and ground settlements are expected to be within normally accepted tolerances.
- **TC2**: Minor to moderate land damage from liquefaction is possible in future large earthquakes.
- **TC3**: Significant land damage from liquefaction is possible in future large earthquakes.

The technical categories are shown in the Foundation Technical Category Maps in Figures 3.1a to c on the following pages, colour-coded as follows:

- TC1 – Grey
- TC2 – Yellow
- TC3 – Blue.

These maps are indicative only and will change over time. To determine the foundation technical category for an individual site, follow the process outlined in section 3.2.

In the near future it is expected that additional analysis of suburb-wide geotechnical borehole and cone penetration test (CPT) investigation information will be undertaken as information comes available. On this basis, revised versions of the maps may be available during 2012.

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Figure 3.1a: Technical categories of the Greater Christchurch area on the flat – Northern Area (Waimakariri District)
Figure 3.1b: Technical categories of the Greater Christchurch area on the flat – Central Area (Christchurch City)
Figure 3.1c: Technical categories of the Greater Christchurch area on the flat – Southern Area (Selwyn District)
The future land performance expectations for each of the foundation technical categories are summarised below (noting that further information is provided in section 10).

Table 3.1: Expected future land performance

<table>
<thead>
<tr>
<th>FOUNDATION TECHNICAL CATEGORY</th>
<th>FUTURE LAND PERFORMANCE EXPECTATION FROM LIQUEFACTION</th>
<th>EXPECTED SLS LAND SETTLEMENT¹</th>
<th>EXPECTED ULS LAND SETTLEMENT¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC1</td>
<td>Negligible land deformations expected in a future small to medium sized earthquake, and up to minor land deformations in a future moderate to large earthquake.</td>
<td>0–15 mm</td>
<td>0–25 mm</td>
</tr>
<tr>
<td>TC2</td>
<td>Minor land deformations possible in a future small to medium sized earthquake, and up to moderate land deformations in a future moderate to large earthquake.</td>
<td>0–50 mm</td>
<td>0–100 mm</td>
</tr>
<tr>
<td>TC3</td>
<td>Moderate land deformations possible in a future small to medium sized earthquake, and significant land deformations in a future moderate to large earthquake.</td>
<td>&gt;50 mm</td>
<td>&gt;100 mm</td>
</tr>
<tr>
<td>Un-categorised</td>
<td>Land in the un-categorised area will contain properties that experience future land performance as per one of the above categories. It also includes urban non-residential land, unmapped rural land, the Port Hills and Banks Peninsula. A geotechnical engineer should be engaged to determine the appropriate solution for the property, based on a site-specific investigation.</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

1. Using recognised calculation methods such as the *New Zealand Geotechnical Society Earthquake Engineering Practice Guidelines* (NZGS, 2010)
2. Note that the differential settlement would be expected to be approximately half the total settlement values listed above
3. In terms of engineering design standards, ‘small to medium sized earthquake’ corresponds to a serviceability limit state (SLS) event with a nominal return period of 25 years, and ‘moderate to large earthquake’ corresponds to an ultimate limit state (ULS) event with a nominal return period of 500 years (refer to section 8.3).

These technical categories were derived from an analysis process which calculated a normalised index for each property. This index represents the demand expected to be imposed on a foundation by liquefaction-induced land deformation in future design level earthquake events, relative to the capacity of an enhanced foundation to withstand these demands. The analysis process is detailed in a separate technical report *Methodology for Compiling DBH Foundation Technical Category Map* (T&T, 2011).

TC1 is generally regarded as ‘good ground’, defined in NZS 3604 as being suitable for standard residential construction (subject to confirmation of bearing capacity from the standard NZS 3604 tests – Scala Penetrometer, hand auger). TC2 and TC3 are outside the definition of ‘good ground’ for standard residential construction, and are therefore not included within the scope of NZS 3604 with respect to foundations.

Further information about the technical categories and their relationship to future land and building settlement performance is provided in section 10.
3.2 Obtaining Technical Category Information

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

Insurers, their Project Management Offices (PMOs), building consent authorities, designers and builders will have access to the Canterbury Recovery Orbit website as necessary. This will allow them to access technical category and existing geotechnical information specific to the site, and provide a means to enter geotechnical data collected and facilitate building consent applications.

The intention is to review the maps at regular intervals based on additional specific information as it becomes available for the benefit of property owners who will repair or rebuild dwellings in the near future. A key part of this re-evaluation process will involve systematic collection of site-specific geotechnical investigation and foundation design information at building consent stage as properties are redeveloped or repaired. Site-specific information will be required to be submitted to the relevant building consent authority.

The proposed process for accessing and managing technical category information is represented in Figure 3.2. This process is subject to further development in conjunction with CERA and Christchurch, Waimakariri District and Selwyn District Councils, including the hosting and management of the web-based system.

Later stages will require key information to be submitted to the relevant building consent authority, including geotechnical investigation reports and other simple specific information completed on a web-based proforma. Cone Penetration Tests (CPT), borelog and lab testing electronic data files will also have to be provided to building consent authorities.

Part of the submitted proforma information will include any recommended change to the technical category by the geotechnical engineer for the area in the future. The revised maps will be based on a combination of area-wide information gathered through this process along with other site investigation information, rather than relying solely on information from individual sites. The maps will be revised on a regular basis.
Figure 3.2: Overview of proposed foundation technical category information management process (subject to further development with building consent authorities)

- Map loaded into the web-based system
- Geotechnical Review Group reviews concentrated clusters of suggested technical category changes and updates TC classifications and map
- Address checked against valuation reference number, QPID reference number, certificate of title, legal description and coordinates
- Database classifies property as either TC1, TC2 or TC3. A summary of land damage, settlement and flood risk is provided along with land repairs that need to be made
- Plot onto map as layer
- Query by authorised user
- Output as a summary page for authorised user
- Insurer/PMO or owner
- Technician/engineer undertakes investigation and design according to the technical category
- Engineer completes geotechnical investigation and report including web-based summary form capturing investigations data and any proposed TC change
- Technician/engineer completes web-based summary form capturing investigations data and any proposed TC change
- BCA checks electronically uploaded geotechnical reports submitted as part of a building consent, and releases to the web-based system as appropriate
- Processed by building consent authority
- Investigated by engineer/technician
- TC 3
- TC 1/TC 2
- TC 3
- TC 1/TC 2
3.3 CONFIRMING THE FOUNDATION TECHNICAL CATEGORY

The first step in investigating a dwelling involves confirming the site’s technical category before repair or replacement options for foundations can be considered. This process involves observing the land damage at the site, as outlined below. Some aspects of land damage may no longer be apparent for some properties, and the absolute level of land settlement may not be readily measurable. Damage to the dwelling will in most cases provide the best indication of the level of settlement experienced by the structure.

A movement from a lower technical category to a higher technical category (ie, from TC1 to TC2, or from TC2 to TC3) can be undertaken based on the judgement of a suitably qualified engineer. However, movement from a higher technical category to a lower one (ie, from TC2 to TC1 or from TC3 to TC2) cannot occur until confirmed following a review of geotechnical information from surrounding properties (the process for this is to be determined in conjunction with building consent authorities).

TC1 confirmation

Sites categorised as TC1 are not expected to display any signs of land damage.

If there has been any surface manifestation of liquefaction on the property during the sequence of earthquakes, or any deformation of the land that indicates liquefaction of subsurface layers, reclassification to TC2 or TC3 will be required.

TC2 confirmation

Some sites categorised as TC2 are expected to display some surface manifestation of land damage, or building damage consistent with land movement. As TC2 encompasses sites with a soil profile that is considered at some risk of ground damage from liquefaction in future earthquakes, many sites will not have discernible land movement or foundation damage from this earthquake sequence.

If damage to the land or foundations is greater than implied by the TC2 categorisation (ie, greater than 100 mm overall liquefaction-induced settlement or evidence of lateral spread in excess of 100 mm at the house site), then apply the approach outlined for TC3. This will involve working with a CPEng geotechnical engineer.

TC3 confirmation

Sites categorised as TC3 are considered incapable of supporting structures with shallow foundations, and can be expected to present signs of significant liquefaction-induced land deformation (ie, greater than 100 mm overall settlement).

If damage to the land or foundations is less than implied by the TC3 categorisation, then a deep geotechnical investigation (see section 3.4.2) undertaken by a CPEng geotechnical engineer may indicate that a TC2 categorisation is more appropriate. Specific design based on the deep geotechnical investigation and TC2 solutions signed off by a suitable qualified CPEng can be undertaken while building consent authorities consider reclassification.

3.4 GEOTECHNICAL INVESTIGATIONS REQUIRED

3.4.1 Shallow subsurface investigation for TC1 and TC2

The investigation to determine the suitability and bearing capacity of the soil (unless being carried out as a specific investigation and design by an appropriately qualified geotechnical engineer) shall follow the procedure as generally outlined in NZS 3604: 2011, with the following exceptions:
• While the prescribed depth of investigation of 2 m is typically acceptable, it is recommended that, where practical, 50 mm diameter boreholes for the examination of soil materials extend further, to between 3 and 4 m below ground level. Significant areas of Canterbury (in particular Christchurch) are underlain with organic peat deposits and it is important to check for the presence of these materials.

• ‘Soft or very soft peat’ in the defined exclusions from ‘good ground’ is to be replaced with ‘peat’ in the list of unacceptable materials.

• For foundation options 1–4 in section 5 of this document, Scala blows per 100 mm shall be minimum 2 blows (ie, 50 mm per blow) for ground deemed to have 200 kPa geotechnical ultimate bearing capacity. For other foundation types (eg, in TC1), 300 kPa will need to be confirmed in accordance with NZS 3604.

Shallow subsurface investigations can be carried out by a soils technician or other suitably trained and supervised person. In TC2 this needs to be under the guidance of a CPEng qualified engineer.

3.4.2 Deep geotechnical site investigation for TC3

The scope of a deep geotechnical investigation must be determined by a CPEng geotechnical engineer.

Residential sites in TC3 will require more significant geotechnical investigations than those required for TC1 and TC2. These are necessary to better understand local site conditions so informed engineering judgements can be made on the appropriate foundation solution for the site. Suburb-wide geotechnical investigations have recently been undertaken in most areas within TC3 in the Christchurch area. However, those investigations are typically spaced hundreds of metres apart and, due to the significant local variability in ground conditions in these areas, site-specific information is considered necessary to make good engineering judgements.

The geotechnical investigation process in TC3 should broadly follow the subdivision investigation requirements set out in Appendix B2, under the guidance of a CPEng geotechnical engineer. Generally at least two deep investigation points (CPTs, boreholes with SPTs, etc) to 10 to 15 m depth would be expected, supplemented by shallower investigation points using (for example) hand augers and Scala Penetrometer testing. Groundwater measurements following the investigations should also be undertaken. Liquefaction assessments should be carried out following the guidelines contained in section B2.4 of Appendix B2, and appropriate foundation or ground remediation solutions designed.

With time there may be generic solutions available based on research currently being undertaken that may reduce the level of deep investigation required.

This information is intended to give an advanced guide only to the likely investigation requirements in TC3 areas. It is subject to further clarification and refinement and may change when the TC3 elements of this document are updated in due course.

3.5 OVERVIEW OF THE PROCESS FOR REPAIRING AND REBUILDING HOUSES

Figure 3.3 provides a flowchart illustrating the general process for determining the level of repair or rebuild required for houses on the flat.

This figure indicates the four principal outcome options, with corresponding references to subsequent sections of this document:

• Repairing superstructure only (section 7)
• Repairing and/or re-levelling foundations (section 4 and Appendix A1) and then repairing superstructure (section 7)
• Replacing foundations (section 5 and Appendix A2) and then repairing superstructure (section 7)
• Rebuilding the dwelling on a new foundation (section 5).

Refer to Table 2.3 for guidance on whether to repair and re-level foundations, or to replace with new foundations.
Recommendations for the assessment and repair of damaged superstructure elements such as wall bracing, and wall and roof frame connections, are provided in section 7. Guidance on the approach for repairing or replacing unreinforced brick and stone masonry foundations and concrete block masonry foundations is also presented in section 7. For the assessment and repair of chimneys, refer to Appendix A3.

For dwellings in TC3, appropriate foundation repair solutions will involve undertaking a deep geotechnical investigation. Guidance on repairs to house foundations in TC3 is being developed and is not available at the time of publication of this document.

For all technical categories where no foundation damage is evident, and where the indicator criteria in Table 2.3 suggest that a re-level or rebuild is unnecessary, superstructure repairs can be undertaken in accordance with the recommendations in section 7, with no need for a subsurface investigation.
Figure 3.3 Determining the level of repair/rebuild required for Green Zone houses on the flat

1. Obtain initial TC classification from database
2. Determine if there is foundation damage (section 2)
3. Confirm TC classification on site (section 3.3)
4. TC classification confirmed
5. No foundation damage
6. Repair/re-level foundations (section 4)
7. Existing superstructure retained
8. Repair superstructure (section 7)
9. Foundation damage
10. New foundations (section 5)
11. New dwelling
12. TC re-classification recommended
13. Refer to geotechnical engineer

TC classification confirmed

New superstructure (eg, NZS 3604, NZS 4229)
4. Repairing house foundations

4.1 GENERAL

This section contains suggested approaches for the repair and reinstatement of house foundations where the level of damage does not require foundation replacement or complete rebuilding. Please note that these approaches will not suit all houses that are considered repairable, and that each house will require careful consideration.

Reference is made throughout this section to the standard foundation Types A, B and C as defined in Figure 2.1 and Table 2.1.

Situations involving the complete replacement of the foundations beneath an existing house are addressed in section 5.5.

*Repair approaches for TC3*

The foundation repair approaches outlined in sections 4.2 and 4.3 are not likely to be applicable to TC3 houses. Appropriate foundation repair solutions for TC3 will involve undertaking a deep geotechnical site investigation (refer to section 3.4.2) and making decisions based on the results of this investigation. Guidance on repairs to house foundations in TC3 is being developed and is not available at the time of publication of this document.

Specifically engineered solutions (eg, strong gravel raft/concrete raft combinations, deep piles, ground improvement) may be required to meet the performance requirements of the Building Code.

The approaches outlined in this section are not applicable for properties where lateral spreading of >50 mm across the building footprint could occur in a future SLS event.

For foundations on hillsides that rely on retaining walls for support of either the structure or the ground immediately above or below the structure, see section 6.

4.2 LOCAL REPAIRS (TC1 AND TC2)

An overview of the process for repairing existing foundations on TC1 and TC2 sites is provided in Figure 4.1. Re-levelling may also be required in conjunction with local repairs (see section 4.3).

For dwellings with Type A foundations, local settlement or pile damage can be addressed by repacking and/or pile replacement as appropriate.

If all piles are leaning in the same direction by more than 15 mm per 1 m of height, the overall bracing capacity should be reviewed against the provisions of NZS 3604.

For Type B foundations, local or partial replacement of the perimeter foundation wall may be all that is required to reinstate the foundation, provided adequate bearing is established from shallow subsurface investigations.

Figure 4.2 illustrates the approach that can be taken for local repairs for Type B foundations in TC1 and TC2 where only a small proportion of the foundation is damaged.

Figure 4.2 also shows a typical plan of a Type B foundation where settlement of only part of the foundation wall has occurred and local replacement only is required. In this scenario, a limited number of piles are also likely to have settled, and packing or replacement will be required, depending on the amount of settlement. The replaced section of foundation wall will need to have an enhanced strength and stiffness to span possible future differential settlements beneath it.

The wall section detailed in Figure 4.2 has sufficient strength and stiffness to span a 4 m loss of support for a single-storey dwelling with heavy wall cladding (eg, brick veneer), or a two-storey dwelling with a light- or medium-weight cladding. A suitable connection between the old and the new section of foundation wall must be provided.
If there is no reinforcing steel present in the existing foundation, starter bars should be epoxied or grouted into the existing concrete. If reinforcing steel is present, the existing concrete should be broken back to expose sufficient steel to allow it to be lapped onto the steel in the new section of foundation (see Figure 4.2).

For situations where more extensive settlement has occurred, the full replacement of the perimeter concrete foundation is likely to be required to provide an effective foundation, in addition to maintaining the style of the dwelling. A shallow subsurface investigation in accordance with section 3.4.1 will be required to confirm 300 kPa geotechnical ULS bearing capacity. If the full perimeter concrete wall is being replaced and the geotechnical ULS bearing capacity is confirmed to be greater than 300 kPa, the typical wall section shown in Figure 4.2 should be used. For lesser bearing capacities, specific design will be required.

For Type C dwellings, guidance for re-levelling the foundation is given in section 4.3, while the local repair of cracks in concrete foundations is outlined in Appendix A4. This guidance extends beyond cracks of 3 mm wide. While Table 2.3 indicates that a foundation rebuild will be necessary if the cracks in the floor slab are greater than 3 mm and the accumulation of crack widths is greater than 20 mm, a single crack of up to 20 mm may be repairable in the absence of differential vertical settlement greater than that given in column 2 of Table 2.3.
Figure 4.1: Overview of process for repairing foundations on TC1 and TC2 sites

- **Local repair of foundations**  (section 4.2)
- **Shallow subsurface investigation**
  - Geotechnical ULS bearing >300 kPa
  - Type A: Repair/replace piles in accordance with NZS 3604 and re-level as required  (section 4.2)
  - Type B: Enhanced foundation wall plus repair/replace piles in accordance with NZS 3604 and re-level as required  (section 4.2)
  - Type C: Repair cracks (App A4) and re-level as required  (Table 2.3 and App A1)
- Geotechnical ULS bearing <300 kPa
  - Specific engineering design
- **Engineer sign-off:** Construction is in accordance with NZS 3604 and section 4.2
  - Specific engineering design
Figure 4.2: Example of a partial foundation wall replacement

- Perimeter foundation has settled in the earthquake over this area due to liquefaction.
- Isolated piles have settled due to liquefaction.
- Remainder of perimeter foundation and piles are undamaged.

**Plan and cross section**

- Contours of increasing ground settlement
- Cross section through an enhanced foundation wall: Note that an increase in height will strengthen and stiffen the beam.
- If steel present in existing foundation, lap 300mm into new foundation and turn bar ends.
- If no steel present, drill and epoxy or grout two starter bars 200mm into existing fdn and lap 300mm into new fdn.

**Section through enhanced foundation wall**

- 2 HD16
- R6-200 ties

**Elevation of suggested joint between old and new foundation**

- New section of beam
- Old foundation
4.3 RE-LEVELLING FLOORS
(TC1 AND TC2)

4.3.1 Overview of re-levelling options

An overview of the process for re-levelling existing foundations on TC1 and TC2 sites is provided in Figure 4.3.

For Type A dwellings, the basic re-levelling operation will draw upon standard methods for re-levelling and re-piling houses. Method statements are given in Appendix A1.

For Type B and C dwellings, the four options considered most suitable for re-levelling are summarised in Appendix A1, along with detailed sample method statements.

For Type C dwellings, any services present beneath the foundation slab must be considered as there is a possibility they could be damaged during the re-levelling process. Type A and B dwellings are more likely to have the services suspended between the floor and the ground where any damage can be detected. However, Type B dwellings may include waste pipes that pass through or beneath the perimeter foundation wall, and care will be required to identify and protect these during any lifting operations.

Re-levelling foundations and floor slabs using any of the options listed in Appendix A1 is building work. Building work includes sitework, which is defined as ‘work on a building site, including earthworks, preparatory to, or associated with, the construction, alteration (repair), demolition or removal of a building’.

Underpinning grout or engineered resin forms part of the foundation system.

The building element being repaired is the foundation or floor. The work will need to comply with the applicable Building Code clauses, notably B1, B2, E1 and E2.

Table 4.1 summarises the re-levelling strategies and likely occupancy implications.
Figure 4.3: Overview of process for re-levelling foundations on TC1 and TC2 Sites

1. **Re-level floor/foundations (section 4.3)**

2. **Shallow subsurface investigation**
   - Geotechnical ULS bearing >300 kPa
   - Geotechnical ULS bearing <300 kPa
   - **Type A**
     - Re-level using standard methods (section 4.3, Table 4.1)
   - **Type B**
     - Re-level using approach depending on superstructure weights (section 4.3, Table 4.1)
   - **Type C**
     - Re-level using approach depending on superstructure weights (section 4.3, Table 4.1).
     - Repair cracks (App A4)

3. **Engineer sign-off:**
   - Construction is in accordance with section 4.3 and App A1
   - Specific engineering design
Table 4.1: Summary of foundation re-levelling approaches for TC1 and TC2 on the flat

<table>
<thead>
<tr>
<th>FOUNDATION TYPE</th>
<th>FOUNDATION RE-LEVELLING</th>
<th>Occupancy during re-levelling operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>Remove base skirt, disconnect services if adjacent to works, pack and (for some piles) re-pile affected area, reconnect services and re-skirt perimeter</td>
<td>Yes</td>
</tr>
<tr>
<td>Type B1</td>
<td>Disconnect services if adjacent to works, expose affected perimeter concrete foundation wall and re-level, re-pile affected floor area, inject relevant cracks in foundation wall, reconnect services and re-instate ground to foundation wall</td>
<td>Yes</td>
</tr>
<tr>
<td>Type B2</td>
<td>Disconnect services if adjacent to works, possibly partial removal of cladding, and re-level, re-pile affected floor area, inject relevant cracks in foundation wall, reconnect services and re-instate ground to foundation wall</td>
<td>No</td>
</tr>
<tr>
<td>Type C1</td>
<td>Re-level using low mobility grout or engineered resin Disclose and re-instate services, if necessary or Re-level using slab and edge foundation jacking and grout Disclose and re-instate services, if necessary or Re-level using screw piles and grout Disclose and re-instate services Seal and inject relevant cracks in slab</td>
<td>Case by case</td>
</tr>
<tr>
<td>Type C2</td>
<td>Disconnect services if adjacent to works, possibly partial removal of cladding, and re-level, inject relevant cracks in slab, reconnect services</td>
<td>Case by case</td>
</tr>
</tbody>
</table>

Notes:
1. It may be necessary to remove decking and paths in order to expose the foundation wall (Type B) or the perimeter foundation (Type C) for re-levelling and rebuilding works.
2. It may be necessary to demolish chimney bases if they are cast integrally with the foundation wall to allow the foundation wall to be lifted (Type B).
3. For definitions of light-, medium- and heavy-weight claddings see Glossary.
4.3.2 Re-levelling concrete or timber piles throughout (Type A)
These foundation systems are often present where the dwelling is clad with light-weight (eg, timber or fibre cement weatherboards, sheet claddings, EIFS) or medium-weight materials (eg, stucco).
In these instances, it may be possible to re-level the existing foundation or lift the superstructure, including the timber floor, and remediate any damage caused to the claddings and linings of the structure. A summary of the process is given in Table 4.1, with a more detailed process description included in Appendix A1.

4.3.3 Re-levelling perimeter concrete foundation wall (light- or medium-weight claddings) (Type B1)
These foundation systems are often present where the dwelling is clad with light-weight materials (eg, timber or fibre cement weatherboards, sheet claddings, EIFS) or medium-weight materials (eg, stucco).
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, without re-levelling the foundation wall. A summary of the process is given in Table 4.1 with a more detailed process description included in Appendix A1.

4.3.4 Re-levelling perimeter concrete foundation wall (heavy veneer cladding) (Type B2)
This continuous foundation wall is always present where the dwelling has a timber floor and heavy cladding materials (eg, brick or concrete masonry veneer).
In these instances, it can be very difficult to lift the foundation without causing significant damage to the veneer cladding. However, consideration should be given to re-levelling with the veneer in place and a decision made on the possibility of repairing the existing veneer rather than immediately demolishing and rebuilding once the foundation 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. The EECA Warm Up NZ programme might be an option.
All four re-levelling options given in Appendix A1 may be used. A summary of the process is given in Table 4.1 and a more detailed process description included in Appendix A1.

4.3.5 Re-levelling slab-on-grade floors (light- or medium-weight claddings) (Type C1)
In instances of slab-on-grade floors where the dwelling is clad with light-weight materials (eg, timber or fibre cement weatherboards, sheet claddings, EIFS) 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. A summary of the process is given in Table 4.1 with a more detailed process description included in Appendix A1.

4.3.6 Re-levelling slab-on-grade floors (heavy 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 can be very difficult to re-level the floor without causing significant damage to the veneer cladding. However, it is recommended that the re-levelling operation is undertaken with the veneer in place and a decision made on the possibility of repairing the existing veneer rather than immediately 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.
All four lifting options given in Appendix A1 may be used. A summary of the process is given in Table 4.1, with a more detailed process description included in Appendix A1.
5. New foundations

5.1 GENERAL

This section covers both foundations for new houses and situations where foundations are completely rebuilt for existing houses in the Green Zone on the flat. Refer to Table 2.3 for guidance on whether a foundation can be re-levelled or should be rebuilt.

New foundation options are outlined in sections 5.2 and 5.3, and guidance for specific engineering design is provided in section 5.4. Additional considerations for replacement foundations beneath existing houses are provided in section 5.5. Detailing considerations for services are outlined in section 5.6.

New foundations for the above situations will require a foundation system suitable for the foundation technical category confirmed for the site. The choice of foundation option for TC1 and TC2 will depend on the results of a shallow subsurface investigation (refer to section 3.4.1).

An overview of the process for new foundations on TC1 and TC2 sites is provided in Figures 5.1 and 5.2 respectively.

In TC1, foundation Types A and B can be built as per NZS 3604. Type C foundations will require reinforced concrete slabs as provided in NZS 3604 Timber Framed Buildings, as modified by B1/AS1, which requires ductile reinforcing in slabs: refer to the Department’s information sheet at http://www.dbh.govt.nz/seismicity-info

For all three foundation types, the geotechnical ultimate limit state soil bearing pressure must be greater than 300 kPa. Alternatively, a stiffened raft in accordance with section 5.3 may be used if the geotechnical ultimate limit state bearing pressure is greater than 200 kPa, otherwise a specific engineering design is required.

In TC2, new foundations will need to be capable of resisting tension effects from nominal lateral spreading. They must also be capable of accommodating settlement of the ground beneath the house. Options 1 to 5 in this section are considered to be suitable for TC2, although Option 5, deep piling, will require deep geotechnical investigation and specific design.

In TC3 there is currently only one suggested foundation solution for new dwellings (Option 5 in this section). This is a deep piled raft option, but is expected to only be suitable when a dense bearing layer is at a depth of less than 10 m. Specific design will be required for any deep piled raft option or any alternative designs and will need to be undertaken in consultation with a geotechnical engineer.

Dwellings that require reconstruction because they are a total loss can normally be designed to provide more resilience than existing structures. It is noted that light dwellings are likely to perform better than heavy dwellings. They can be more easily re-levelled if damaged in a future large earthquake and are likely to undergo lower amounts of settlement. Therefore the use of light timber or steel framing, light-weight cladding systems and light-weight roofing materials is recommended wherever possible for rebuilding houses and building new houses.
Figure 5.1: Overview of process for new foundations on TC1 sites

- New foundations (section 5.2)
- Shallow subsurface investigation
- Geotechnical ULS bearing >300 kPa
  - Types A & B: Shallow pile foundation system in accordance with NZS 3604 (section 5.2)
  - Type C: Slab-on-grade foundations in accordance with NZS 3604 (tied slab) (section 5.2)
- Geotechnical ULS bearing <300 kPa
  - Specific engineering design
    - Note that if geotechnical ULS bearing is between 200 kPa and 300 kPa, stiffened raft from section 5.3 can be used
- Engineer sign-off: Construction is in accordance with NZS 3604 and section 5.2
- Engineer sign-off: Specific engineering design
The use of NZS 3604 for the design of the superstructure (ie, everything from the ground floor plate up) is acceptable for the construction of any house within the scope of NZS 3604 (ie, the dimensional limitations are adhered to, and the use is limited to Importance Level 2 (AS/NZS 1170.0)).
5.2 OVERVIEW OF NEW FOUNDATION OPTIONS

TC1
Type A dwellings within the scope of NZS 3604 generally could be founded on shallow piles, if ground conditions permit, in TC1. While Type B dwellings are now rarely constructed on the flat in Christchurch, they are still suitable for TC1. NZS 3604 Type C foundation options, (with B1/AS1 modifications) are considered suitable.3

TC2
A light clad house structure supported fully on short timber or concrete piles (Type A) is considered to be a valid option in TC2. It is the most easily repaired form of dwelling construction. Type B construction is also considered suitable for TC2 areas. Provisions are given in this section.

The principal objectives in designing new concrete slab foundation systems for rebuilding in TC2 ground damaged land should be that any settlements that occur in future earthquakes will be constrained to within the limits of Table 3.1. In many areas of greater Christchurch, the ‘good ground’ provisions of NZS 3604 may not apply, and therefore the concrete foundation and flooring provisions of that Standard should not be used in these areas.

Providing stiffened and better-tied-together floor slabs for Type C houses in TC2 areas will reduce hogging or other undue deformation of the slab as a result of future earthquake induced land damage and will enable them to be more readily re-levelled.

Foundation Options 1 to 4 in this section are considered to provide sufficient stiffness to accommodate the expected future ground movements for TC2 for all but two-storey houses with heavy-weight cladding extending over both storeys. Specific engineering design would be required in the case of heavy two-storey construction to stiffen the options to satisfy the performance criteria in section 5.4.

Options 1 to 4 are expected to be able to bridge a length of up to 4 m of settled soil (or sudden lack of support) beneath the foundation and cantilever a distance of up to 2 m over settled soil at the building footprint 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.

Flood risk mitigation requirements may require the building platform to be constructed to a height greater than the land surrounding the dwelling (see section 8). However, the potential for future liquefaction-induced settlement in properties in TC2 leads to the geotechnical requirement to limit the increase in mass added to the land.

The maximum recommended increase in height of building platforms4 beneath timber framed floors above surrounding land is 400 mm. The same maximum increase in height also applies to finished floor levels for concrete floor slabs (see the diagram overleaf). Greater increases may be allowable on a site-by-site basis following geotechnical investigation.

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3 Refer to http://www.dbh.govt.nz/UserFiles/File/Publications/Building/
4 See the glossary for definition of ‘building platform’.
TC3

For TC3, support for the structure from a level below the liquefiable soil (Option 5) provides the best prospect of maintaining the house on a level plane where the lateral spreading in an SLS event has been constrained to a maximum of 50 mm across a property. A maximum pile length of 10 m is expected to generally guard against pile instability if the ground becomes liquefied. Longer pile lengths can also make this a less economic option.

The recommended maximum increase in height above surrounding ground for building platforms and floor slabs should be determined from geotechnical investigations.

Further possible solutions for TC3 are under consideration at the time of publication of this Guide.

In uncategorised areas on the flat, a geotechnical engineer should be engaged to undertake a site-specific investigation to determine which of the above foundation technical categories best fits the site and recommend appropriate investigations and foundations accordingly.

A summary of proposed foundation solutions for the three technical categories is given in Table 5.1, and the corresponding geotechnical requirements are given in Table 5.2.
Table 5.1: Summary of proposed foundation solutions for rebuilt foundations or new foundations on the flat

<table>
<thead>
<tr>
<th>TC1</th>
<th>TC2</th>
<th>TC3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FUTURE LIQUEFACTION UNLIKELY</strong></td>
<td><strong>MINOR LIQUEFACTION LIKELY</strong></td>
<td><strong>FUTURE LIQUEFACTION EXPECTED</strong></td>
</tr>
<tr>
<td>NZS 3604 timber piles and floor or tied concrete slabs (as modified by B1/AS1) where good ground proven (shallow subsurface investigation required)¹</td>
<td>Light construction with timber floors and shallow piles as per NZS 3604 where good ground proven (shallow geotechnical investigation required)¹ or Enhanced perimeter foundation wall (see section 4.2) and shallow piles as per NZS 3604 (shallow geotechnical investigation required)¹ or Raft foundations (Options 1–4) or Specific engineering design</td>
<td>Deep piles (Option 5) with specific design or Other specific engineering design solutions (including ground improvement) (Deep geotechnical investigation required in all cases)²</td>
</tr>
<tr>
<td>otherwise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raft foundations (Options 1–5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific engineering design</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Shallow subsurface investigation – refer to section 3.4.1
2. Deep geotechnical investigation – refer to section 3.4.2
Table 5.2: Geotechnical requirements for rebuilt or new foundations on the flat

<table>
<thead>
<tr>
<th>FOUNDATION TECHNICAL CATEGORY</th>
<th>GEOTECHNICAL REQUIREMENTS</th>
</tr>
</thead>
</table>
| TC1                           | Foundations for new dwellings should include a shallow subsurface investigation to determine the bearing capacity of the soil.  
1. If the investigation determines the site is 'good ground' (geotechnical ULS bearing capacity is greater than 300 kPa), NZS 3604 timber piles or tied NZS 3604 slabs are acceptable.  
2. If the investigation determines the site’s geotechnical ULS bearing capacity is greater than 200 kPa but less than 300 kPa, use TC2 enhanced slab solutions (Options 1-5) or other specific engineering design.  
3. If the investigation determines the site’s geotechnical ULS bearing capacity is less than 200 kPa or affected by other hazards (eg, peat), foundations should be specifically designed. |
| TC2                           | Foundations for new dwellings should include a shallow subsurface investigation to determine the bearing capacity of the soil.  
1. If the investigation determines the site’s geotechnical ULS bearing capacity is greater than 300 kPa, NZS 3604 timber piled foundations (Type A) or an enhanced perimeter foundation wall as per Figure 4.2 (Type B) may be used.  
2. If the investigation determines the site’s geotechnical ULS bearing capacity is greater than 200 kPa, use enhanced slab TC2 solutions (Options 1-5) or other specific engineering design.  
3. If the investigation determines the site’s geotechnical ULS bearing capacity is less than 200 kPa, foundations should be specifically designed. |
| TC3                           | A site-specific deep investigation including CPTs and geotechnical analysis of the site is required to determine land performance in future SLS and ULS events.  
1. If the site has been or could be subject to lateral spreading of more than 50 mm (SLS) or 100 mm (ULS) strain across the site, specific engineering design is required to prevent that spreading, or the building must be designed to resist or otherwise accommodate that movement, or  
2. If analysis indicates that future land performance does not meet maximum SLS (50 mm) and ULS (100 mm) settlement requirements of TC2 (refer to Table 3.1), foundations should be specifically designed.  
3. If the analysis identifies future land performance does meet SLS and ULS settlement requirements, and lateral spread is not expected to exceed 50 mm (SLS) or 100 mm (ULS), light-weight construction or enhanced raft foundations are acceptable (ie, the site is found to be suitable for TC2 solutions).  
4. Technical solutions for TC3 are under consideration at the time of publication of this Guide. |

5.3 DESCRIPTION OF INDICATIVE NEW FOUNDATION AND FLOOR OPTIONS

Site investigation requirements are as outlined in Table 5.2.

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. There is also a tendency for finer subgrade materials to migrate into the tailings, particularly when wet and subjected to vibration. Compacted, well-graded sandy gravels will provide additional stiffness and therefore better performance in seismic conditions.
Insulation has not been shown beneath the floors in the proposed options. Insulation requirements will need to be established in conjunction with the insulating characteristics of the walls and roof of the dwelling.

The representative floor plan for which the development and modelling of these details has been based is shown in Figure 5.3. The details in this section should only be applied to simple house plan shapes such as rectangular, L, T or boomerang shapes.

Figure 5.3: Representative floor plan
5.3.1 Reinforced concrete floor construction in TC2

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

New flood freeboard requirements will also need to be considered if there has been uniform settlement over several properties (see section 8).

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.

The ground immediately beneath the compacted gravel fill must have a minimum geotechnical ultimate bearing capacity of 200 kPa, or the slab should be subject to specific engineering design.

External service lines will need to be beyond the outer extent of the gravel raft and/or have flexible connections (refer to section 5.6).
Option 2 – Construct a thick slab foundation over the existing soil.

The ground immediately beneath the slab must have a minimum geotechnical ultimate bearing capacity of 200 kPa, or the slab should be subject to specific engineering design. Please note that the thickness needs to increase to 400 mm for two-storey heavy-weight (brick veneer) construction.

The treatment of service lines as they enter and travel within the slab requires careful consideration (refer to section 5.6).
Option 3 – Construct a generic beam grid and slab foundation.

Figure 5.6: Enhanced foundation slab – Option 3 plan

Please note that reinforcing details are not sufficient for two-storey heavy-weight cladding (brick veneer).
The ground immediately beneath the slab must have a minimum geotechnical ultimate bearing strength of 200 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 1 m centres each way.

This option requires specific engineering design.\textsuperscript{5}

\textsuperscript{5} Refer also to U.S. Post Tensioning Institute publications: Design and Construction of Post-Tensioned Slabs-On-Ground and Construction and Maintenance Procedures Manual for Post-Tensioned Slabs-On-Ground
For both Option 3 variations, it may be easier and more economic to construct the concrete foundation by replacing the compacted hardfill and soil beneath the slab down to the underside of the beams with polystyrene pods.
Option 4 – Construct a waffle slab over the existing soil

Figure 5.9: Enhanced foundation slab – Option 4 plan

Please note that reinforcing details are not sufficient for two-storey heavy-weight cladding (brick veneer).
The ground immediately beneath the polystyrene and ribs must have a minimum geotechnical ultimate bearing strength of 200 kPa, or the system should be subject to specific engineering design. Shear ties in accordance with NZS 3101 are required in the ribs.

**Option 5** – Drive piles to a dense non-liquefiable bearing 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 in Figure 5.11 is based on a ribbed slab layout with beams at a maximum spacing of 3.5 m (as per the layout for Option 3).

This option has the advantage of limiting future settlement, particularly in SLS events, but it will require deep geotechnical investigations and specific engineering design (even for TC2).

The pile types indicated in Figure 5.11 are applicable to TC1 and TC2 only.

For TC3, deep piles require flexibility to take account of potential lateral movement of subsurface layers. Piles should be designed to accommodate a minimum lateral displacement of 300 mm, or greater if determined by the site-specific geotechnical investigation. In general, steel and timber piles, and concrete piles detailed for ductility, are considered capable of accommodating this minimum level of lateral displacement.
Notes:
1. For the concrete piles to support a two-storey dwelling with light-weight cladding and roof materials when spaced at 3.5 m centres, the maximum set may be 10 mm using a 750 kg hammer dropping 1 m. To support a two-storey dwelling with heavy cladding and roof materials, the maximum set must be 5 mm.
2. For the timber piles to support a two-storey dwelling with light-weight cladding and roof materials when spaced at 3.5 m centres, the maximum set must be 5 mm using a 500 kg hammer dropping 1 m. To support a two-storey dwelling with heavy cladding and roof materials, they must also be installed midway between beam intersections.
5.3.2 Timber floor construction in TC2

Timber floors in combination with light-weight claddings and roofing provide several advantages with regard to ease of repair and re-leveling.

A rebuilt timber ground floor should generally be constructed in accordance with NZS 3604. The advantage of this type of floor is that it is easy to re-level or repair because of the easy access, and its elemental nature allows straightforward replacement of damaged elements. Bracing demand will be low and standard details can be used.

The soil conditions at each site should be confirmed as suitable in accordance with the modified NZS 3604 procedure, as detailed in Table 5.2 and section 3.4.1.

Driven timber piles to NZS 3604 are suitable under suspended floors.

The level of timber floors should be set to provide a minimum crawl space under the joists of at least 450 mm (NZS 3604 requirement).

Type A dwellings

A one or two storey house with a light roof and light- or medium-weight wall cladding supported fully on an NZS 3604 shallow timber or concrete pile foundation is considered to be a valid option in TC2.

Type B dwellings

New foundation walls for one or two storey dwellings with light-weight cladding and roofing in TC2 should follow the details in Figure 5.12 below. Reinforcing details should be as shown in Figure 4.2.

Piles installed under foundation walls are not within the scope of NZS 3604. A suitable driving set will be required to achieve the required bearing capacity and the foundation wall will also need to be designed to span between the piles.

![Figure 5.12: Timber floor with perimeter walls](image)

Note: Reinforcement details as per Figure 4.2
The vents in the foundation wall must be positioned near the middle of the wall below the top reinforcing bar, and not notched out of the top of the wall as is common in older houses in Christchurch.

Floor construction details in NZS 3604 are generally adequate, but in practice the jointing between members often falls short of what is required. This is particularly important where resistance to lateral spreading is required. The following should be noted:

- Pile to bearer connection: Ordinary pile connections in Figure 6.3 of NZS 3604. Braced pile connections in Figures 6.6 to 6.8. Anchor pile connection in Figure 6.9.
- Bearer to foundation wall connection: See Figure 6.17 of NZS 3604.
- Bearer butt end joints: See Figure 6.19 of NZS 3604.
- Joist butt end joints: See Figure 7.1 of NZS 3604.

5.4 GUIDANCE FOR SPECIFIC ENGINEERING DESIGN

Other specifically designed solutions than those provided above may be devised. In these cases, the following criteria should be satisfied:

- A full geotechnical investigation of the site in accordance with Table 5.2 is to be carried out before designing the foundation system.
- Design for the potential for lateral ground spreading to the extent indicated from the geotechnical investigation.

For Type C house foundations in TC2 and TC3:

- Design Type C house foundations for the potential for differential settlement of the supporting ground that may create a length of no support for the ground floor of 4 m beneath sections of the floor and 2 m at the extremes of the floor (ie, ends and outer corners).
- Design to ensure that the floor does not hog or sag more than:
  - 1 in 400 (ie, 12.5 mm hog or sag at the centre of a 10 m length) for the case of no support over 4 m (see Figure 5.13), and
  - no more than 1 in 200 for the case of no support of a 2 m cantilever at the extremes of the floor (see Figure 5.13).
- 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.
- Settlement should be within the limits indicated in Table 5.3.

Table 5.3: Liquefaction settlement limits for new building foundations

<table>
<thead>
<tr>
<th>TYPE</th>
<th>SLS(1)</th>
<th>ULS(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total settlement (mm)</td>
<td>Less than 50 mm</td>
<td>Less than 100 mm</td>
</tr>
<tr>
<td>Differential settlement</td>
<td>Less than 1 in 300 (V:H)</td>
<td>Less than 1 in 100 (V:H)</td>
</tr>
</tbody>
</table>

(1) SLS – serviceability limit state
(2) ULS – ultimate limit state

Greater settlement than indicated in Table 5.3 may be able to be accommodated by using lightweight construction with specific consideration of repairability (refer to Table 8.1). There also may be cases in TC3 where the ULS total settlement limit may be able to be exceeded if the superstructure is specifically designed to take any increase in settlement limits.
5.5 REPLACING FOUNDATIONS
(RETAINING THE SUPERSTRUCTURE)

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 will be required to fully comply with the Building Code.

Figure 5.1 shows the process for TC1 and Figure 5.2 shows the process for TC2. A summary of the steps for each foundation type in TC1 and TC2 is provided in Table 5.4 and in more detail on subsequent pages.

Replacement approaches for TC3

The foundation replacement approaches outlined in sections 5.2 and 5.3 are not likely to be applicable to TC3 dwellings. Appropriate replacement solutions for TC3 will involve undertaking a geotechnical investigation and making decisions based on the results of this investigation.

Guidance for house foundation replacement options in TC3 is being developed and is not available at the time of publication. Specifically engineered solutions (eg, strong gravel raft/concrete raft combinations, deep piles, ground improvement) are required to meet the performance requirements of the Building Code.

The basis for acceptance and sign-off of building consent applications is that sign-off by a geotechnical engineer is required.

For foundations on hillsides that rely on retaining walls for support of either the structure or the ground immediately above or below the structure, see section 6.
Table 5.4: Summary of foundation rebuilding approaches for TC1 and TC2

<table>
<thead>
<tr>
<th>FOUNDATION TYPE</th>
<th>FOUNDATION REBUILD</th>
<th>OCCUPANCY DURING REBUILD OPERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type A</strong></td>
<td>Remove base skirt, disconnect services if adjacent to works, re-pile affected area, reconnect services and re-skirt perimeter</td>
<td>No</td>
</tr>
<tr>
<td><strong>Cladding</strong></td>
<td>Light- and medium-weight</td>
<td></td>
</tr>
<tr>
<td><strong>Foundation</strong></td>
<td>Timber framed suspended timber floor structures supported only on piles</td>
<td></td>
</tr>
<tr>
<td><strong>Type B1</strong></td>
<td>Disconnect services, remove perimeter concrete foundation wall and replace, re-pile, reconnect services and reinstate ground to wall</td>
<td>No</td>
</tr>
<tr>
<td><strong>Foundation</strong></td>
<td>Timber framed suspended timber floor structures with perimeter concrete foundation</td>
<td></td>
</tr>
<tr>
<td><strong>Cladding</strong></td>
<td>Light- and medium-weight</td>
<td></td>
</tr>
<tr>
<td><strong>Type B2</strong></td>
<td>Disconnect services, remove exterior cladding, remove perimeter concrete foundation wall, and replace, re-pile, reconnect services and reinstate ground to wall, replace cladding</td>
<td>No</td>
</tr>
<tr>
<td><strong>Foundation</strong></td>
<td>Timber framed suspended timber floor structures with perimeter concrete foundation</td>
<td></td>
</tr>
<tr>
<td><strong>Cladding</strong></td>
<td>Heavy-weight (veneer)</td>
<td></td>
</tr>
<tr>
<td><strong>Type C1</strong></td>
<td>Disconnect services, temporarily raise house, remove and replace slab, reinstate house and reconnect</td>
<td>No</td>
</tr>
<tr>
<td><strong>Foundation</strong></td>
<td>Timber framed dwelling on concrete floor (slab-on-grade)</td>
<td></td>
</tr>
<tr>
<td><strong>Cladding</strong></td>
<td>Light- and medium-weight</td>
<td></td>
</tr>
<tr>
<td><strong>Type C2</strong></td>
<td>Disconnect services, remove exterior cladding, remove house and replace slab, reinstate services, replace cladding</td>
<td>No</td>
</tr>
<tr>
<td><strong>Foundation</strong></td>
<td>Timber framed dwelling on concrete floor (slab-on-grade)</td>
<td></td>
</tr>
<tr>
<td><strong>Cladding</strong></td>
<td>Heavy-weight (veneer)</td>
<td></td>
</tr>
</tbody>
</table>

Please note that it may be necessary to remove decking and paths in order to expose the foundation wall (Types A and B) or the perimeter foundation (Type C) for re-levelling and rebuilding works.
Type A foundation – concrete or timber piles throughout

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.

Provided the geotechnical ULS bearing capacity is greater than 300 kPa, 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 5.4 with a more detailed process description included in Appendix A2. If the geotechnical ULS bearing capacity is less than 300 kPa, then specific engineering design is required.

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

There will be cases where only sections of the foundation wall will need to be replaced. The building work, which is the repair of a building element (the section of perimeter wall), needs to comply with the Building Code and therefore should be designed as if the perimeter foundation wall was new. For guidance, refer to section 4.2.

In TC1, provided the geotechnical ULS bearing capacity is greater than 300 kPa, this would amount to simple replacement of the existing foundation wall with an NZS 3604 foundation wall, as liquefaction and future settlement is not anticipated. Otherwise, specific engineering design is required.

In TC2, provided the geotechnical ULS bearing capacity is greater than 300 kPa, an enhanced reinforced foundation wall (refer to Figure 4.2 and section 5.3.2) would be required to withstand the differential settlement anticipated with future minor liquefaction. Otherwise specific engineering design is required.

The veneer may be rebuilt on the new foundation. Alternatively, the owner may choose an alternative lighter cladding system if desired and acceptable to the insurance company.

For cases where partial replacement of the perimeter foundation wall may be all that is required to reinstate the foundation, see Type B1 above and section 4.2 for guidance.

A summary of the process is given in Table 5.4 and a more detailed process description included in Appendix A2.

A summary of the process is given in Table 5.4 with a more detailed process description included in Appendix A2.

Type B2 perimeter concrete foundation wall (heavy veneer cladding)

In these instances, it may be very difficult to lift the superstructure, including veneer cladding, without causing irreparable damage to the cladding. It will probably 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.

In TC1, provided the geotechnical ULS bearing capacity is greater than 300 kPa, this would amount to simple replacement of the existing foundation wall with an NZS 3604 foundation wall, as damaging liquefaction and future settlement is not anticipated. Otherwise specific engineering design is required.

In TC2, provided the geotechnical ULS bearing capacity is greater than 300 kPa, an enhanced reinforced foundation wall (refer to Figure 4.2 and section 5.3.2) would be required to withstand the differential settlement anticipated with future minor liquefaction. Otherwise specific engineering design is required.

The veneer may be rebuilt on the new foundation. Alternatively, the owner may choose an alternative lighter cladding system if desired and acceptable to the insurance company.

For cases where partial replacement of the perimeter foundation wall may be all that is required to reinstate the foundation, see Type B1 above and section 4.2 for guidance.

A summary of the process is given in Table 5.4 and a more detailed process description included in Appendix A2.
Type C1 slab-on-grade floors (light- or medium-weight claddings)

The degree of settlement that has occurred in this instance will be such that the floor slab and edge thickening are expected to be heavily damaged and not easily repairable. The slab is likely to be deformed and cracked. The repair process will involve lifting the superstructure (including the bottom plates), demolishing the existing slab, building a new foundation, and re-installing the superstructure on the new foundation.

In TC1, provided the geotechnical ULS bearing capacity is greater than 300 kPa, the floor slab replacement may be in accordance with NZS 3604 (as modified by B1/AS1). If the geotechnical ULS bearing capacity is between 200 kPa and 300 kPa, stiffened raft foundations (Options 1 to 4 in section 5.3) are required. If the geotechnical ULS bearing capacity is less than 200 kPa, specific engineering design is required.

In TC2, provided the geotechnical ULS bearing capacity is greater than 200 kPa, the new foundation will need to be a stiffened raft foundation (Options 1 to 4 in section 5.3). If the geotechnical ULS bearing capacity is less than 200 kPa, specific engineering design is required.

Alternatively, replace the foundation with a shallow pile and timber floor option in accordance with NZS 3604. The superstructure is then reconnected to the new foundation system.

A summary of the process is given in Table 5.4 with a more detailed process description included in Appendix A2.

Type C2 slab-on-grade floors (heavy veneer cladding)

The process for Type C2 is the same as for Type C1, with the following additional guidance.

The veneer must be demolished to allow the superstructure to be lifted off the existing concrete slab, moved and temporarily stored elsewhere, and then re-positioned on the new stiffened raft foundation (Options 1 to 4 in section 5.3).

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

The veneer may be rebuilt on the new foundation. Alternatively, the owner may choose an alternative lighter cladding system if desired and acceptable to the insurance company.

A summary of the process is given in Table 5.4 with a more detailed process description included in Appendix A2.

5.6 SERVICES

If lateral spread or differential settlement of the ground occurs, there is potential for damage to services and provision must be made for the design and installation of services to minimise the effects of ground movement. This is particularly important when services penetrate through or are attached to concrete floor systems. Flexibility in service lines is the key to good performance.

Drinking water

Modern drinking water supply to a property is delivered via flexible ‘plastic’ pipes. When installed in a trench, they may be laid down in a snake pattern, which provides extra length should ground extensions occur. Where the pipe penetrates the foundation and the floor slab, a duct/sleeve 125 mm greater in diameter than the pipe should be provided to allow the pipe to move independently. The sleeve may be filled with a compressible filler, which allows differential movement but which also provides limited access beneath the slab should a leakage issue arise.

Sewer pipes

Sewer pipes from the house to the sewer in the street are generally formed in upVC plastic, which possesses some flexibility in itself. Waste pipes may pass through the floor of the dwelling to serve plumbing fixtures such as baths, showers, basins,
and soil pipes from toilets. These pipes will pass below the floor in Options 1 and 2 (see section 5.3.1), although there is scope (while maintaining the required falls) for passing the waste pipes through the beams and ribs of the foundation in Options 3, 4 and 5. If there is vertical or horizontal movement between the foundations and the ground in Options 3, 4 and 5, the expected failure plane is across the bottom of the beams or ribs. Consideration will need to be given to the connections beyond the outside face of the foundation.

Flexible connections should be considered between the straight lengths of pipe and located outside the building footprint. Greater pipeline flexibility is achieved by using rubber ring joint pipes. Consideration should also be given to the provision of greater falls in the lines than the minimums required by the Standards. This will make the continued operation of the system more viable should tilting of the ground occur during any future liquefaction event.

Where the pipes pass through the slab, a duct or sleeve is recommended (see Figure 5.14). Ideally, the duct should have a diameter 125 mm greater than the service pipe. Otherwise, a flexible seal should be employed to allow some movement between the pipe and the floor.

Where sewer pipes are installed in a trench parallel to the foundation, the branch drains, such as those connecting to gully traps, should contain a flexible connection adjacent to the foundation.

**Figure 5.14 Waste water pipe routing**
Plumbing codes require at least one gully trap on the perimeter of a house. Invariably, waste pipes pass through the foundation slab and discharge into the gully trap from above it. Sometimes the waste pipes enter via the side wall of the gully trap. It is recommended that the gully traps be encapsulated in concrete which is tied to the house foundation (hooped reinforcing bars), preventing differential movement should there be ground spreading or settlement adjacent to the foundation (see Figure 5.15).

Figure 5.15 Restraint of gully trap

**Stormwater pipes**

Where storm water pipes are installed in a trench parallel to the foundation, the branch connections to the downpipes should contain a flexible connection.

**Underground power and communications cables**

Fortunately, these cables are quite flexible. Underground power cables may be ducted or buried directly in a trench. In either case there is scope for accommodating unexpected extensions by ‘snaking’ the cables or looping within access chambers. Consideration should be given to accommodating the cables in oversize ducts where they pass through the floor.
6. Hillside properties and retaining walls

This section contains guidance information relating to the assessment of hillside property and retaining wall damage. The close location of the 22 February 2011 and 13 June 2011 aftershocks to the Port Hills of Christchurch resulted in wide-ranging damage to hillside houses and the ground around them.

6.1 CHARACTERISTICS OF HILLSIDE PROPERTIES

Hillside properties are generally more complex than level-ground properties, and do not lend themselves easily to a standard approach with regard to foundations and stability issues. In most cases, a suitably qualified CPEng geotechnical engineer or suitably experienced engineering geologist should be engaged to advise on site suitability, stability, foundations and retaining wall issues.

It should be noted that the presence of an existing house on a site does not necessarily mean that a prudent engineer or geologist will consider the site suitable for a new structure. In addition, Christchurch is likely to be subjected to an ongoing and active sequence of aftershocks for the foreseeable future due to the presence of the previously unknown fault zone that partly underlies the Port Hills. Further studies by various agencies are currently underway into other aspects that affect hillside properties. In particular, GNS Science is carrying out studies into seismic rockfall hazards. The enhanced seismicity referred to in section 8.3 needs to be allowed for in any consideration of future behaviour of both buildings and supporting structures, as well as land stability.

Furthermore, topographical enhancement effects were noted in the February and June 2011 events (ie, increased accelerations on ridgelines, slope and cliff crests). These factors should also be taken into account.

Matters to consider in relation to site suitability and stability include:

- overall stability of site (slope angles, depth to rock, presence of watercourses, seepages or unusually damp areas)
- proximity to the base or crest of a steep slope or cliff (potential for instability and/or debris inundation)
- vulnerability to uphill hazards such as debris flows from steep land, rockfall hazard, consequences from retaining wall failures etc (Territorial authorities will likely require more than just the house platform to be protected from rockfall hazard. In addition to Building Act matters, public safety issues should be taken into account.)
- presence of and proximity to areas of past instability (landslip scars, surface or subsurface erosion)
- local stability of site (localised steepenings and scarps, unretained cuts and fills, vulnerable retaining structures, etc)
- existing earthworks or support systems on adjacent sites that might provide support to the site, add surcharge loads to the site or (in the case of cuts) decrease stability of the site
- vulnerability to stormwater inflows from upslope (eg, uphill catchment size, adverse road drainage conditions taking into account snow events)
- safe disposal options for stormwater and sewerage (soak holes and field tiles are generally not appropriate in Port Hills Loess).
- presence of non-engineered fill, buried weak layers and the like
- presence of subsurface erosion features (ie, ‘tunnel gullies’ or ‘under-runners’).
6.2 RETAINING WALLS

6.2.1 General considerations

Unlike a building structure where linings, for example, can often be removed, it is normally very difficult to determine the extent or severity of damage to most retaining structures. It is not normally practical to excavate retained fill to allow an examination of the rear of a wall, or to determine below-ground damage to embedded components. In most cases the only indication of the degree of damage will be the apparent movement of the wall, by viewing the exposed elements and deformation of land in proximity to the wall.

Given the largely uncertain nature of the construction of retaining walls and the inherent difficulty in predicting their future performance, particular care needs to be taken in assessing and reporting on these structures.

In the case of most retaining structures, horizontal translation is often acceptable (in the absence of any foundation issues) and it is normally vertical rotation or damage to structural components that will potentially lead to unacceptable stability issues. Where a wall has undergone such movement, however, it is important to consider possible damage to drainage systems, which could eventually result in adverse water pressure loadings on the wall.

In all cases, knowledge of the pre-earthquake condition is a considerable advantage in assessing damage to a wall. In many cases, especially for recently constructed engineered walls, building consent drawings should be available from the relevant territorial authority.

For all walls, the foundations should be assessed for movement, differential settlement, rotation, cracking, intact drainage measures, etc. The global stability of the wall should also be considered, that is, slope failures that encompass the entire wall (which might otherwise appear to be undamaged).

In assessing walls where EQC has been involved, it is important to remember that EQC only considers walls that support land within certain distances of insured assets (refer to section 8.1), and damage that is likely to occur as a result of the insured event within a 12 month ‘imminent loss’ timeframe. Damage and stability issues outside the EQC insured scope may also need to be considered.

Table 6.1 provides summary guidance on damage indicators for a range of retaining wall types and possible repair/replacement options.
### Table 6.1: Damage indicators and repair options for retaining walls

<table>
<thead>
<tr>
<th>WALL TYPE</th>
<th>DAMAGE INDICATORS</th>
<th>POSSIBLE OUTCOMES</th>
</tr>
</thead>
</table>
| Embedded (cantilevered) timber pole walls | • Rotation beyond vertical  
  • Obvious bending or fresh cracking of vertical members  
  • Horizontal extension in the plane of the wall reducing support to rails  
  • Land deformation behind or in front of the wall | Damaged walls can be demolished and rebuilt, or in some cases it may be possible to install additional poles or drilled-in anchors through the wall attached to a waler beam on the wall exterior (with obvious aesthetical implications) or, with some excavation, a waler beam can be hidden behind a wall and bolted to each post. |
| Timber crib walls (proprietary components) | • Rotation beyond 1:4.6 (in most cases this will leave a residual factor of safety in the order of 90% of original)  
  • Rotated headers >5%  
  • Significant loss of infill gravel  
  • Land deformation behind or in front of the wall | Damaged walls will probably need to be deconstructed and rebuilt, unless an alternative such as walers and tie-backs is used. |
| Timber crib walls (informal railway sleeper components) Typically non-engineered structures | • Rotation of more than 2 degrees or beyond vertical (this requires some knowledge or assumption of the pre-earthquake condition)  
  • Fresh cracking of timber components  
  • Significant loss of fill material  
  • Land deformation behind or in front of the wall | Severely damaged walls, particularly where they are providing critical support, should be dismantled and replaced with a properly engineered wall, or otherwise stabilised. It should be noted however that many of these walls were likely already suffering from durability issues prior to the earthquake events. |
| Concrete crib walls | • Rotation beyond 1:4.6 (in most cases this will leave a residual factor of safety in the order of 90% of original)  
  • Cracked stretchers  
  • Rotated headers >5%  
  • Significant loss of infill material  
  • Land deformation behind or in front of the wall | Damaged walls will likely need to be deconstructed and rebuilt, unless an alternative such as the construction of a new wall in front (where geometry permits), or installing tiebacks can be considered. |
| Concrete masonry block wall | • Rotation beyond vertical (or 1 degree beyond determined as-designed face geometry)  
  • Compression crushing within the front face  
  • Wall out of shape – ie, barrelling, bulging, etc  
  • Cracking in a yield line failure pattern  
  • Land deformation behind or in front of the wall | Damaged walls will need to be demolished and rebuilt. In some cases it will be possible to install drilled in anchors and a new facing of reinforced concrete, and cantilever posts in front of the wall (with obvious aesthetic implications) or possibly construct a new wall in front of the damaged one. |
| Stacked stone walls | • Barrelling of wall face  
  • Loss of wall elements  
  • Land deformation behind or in front of the wall | These are almost always non-engineered structures, and generally should be considered as facing walls only (in an engineering sense). In some rare instances, however, these walls have substantial wall thicknesses and are acting as gravity structures |
| Gabion basket walls | In most cases it is very difficult to determine gross rotational movement without knowing the original design configuration for the wall.  
  If it can be determined that horizontal panels are present within the retained fill (ie, ‘terramesh’ components) and there is no rotational movement beyond vertical, the wall is likely to be able to be left in place once disturbed backfill behind the wall is reconstituted. In some cases the upper layer of baskets has rotated and these can relatively easily be put back in place.  
  Rotational movement beyond 2 degrees or beyond vertical in non-terramesh basket structures is likely to be unacceptable and baskets should be deconstructed and rebuilt, or other stabilising measures put in place. |
6.2.2 General wall design principles

When designing replacement walls, some obvious basic considerations are as follows:

- Walls that have backfill that is not level have a significantly higher load on them, and this must be taken into account when evaluating design forces on the wall.
- Walls founded in sloping ground have much lower lateral resistance and foundation bearing capacity available to them (in particular embedded cantilever walls) and this must be taken into account – ‘rule of thumb’ design methods for walls on level ground can be dangerously inadequate on sloping ground.
- Stepped wall systems must take into account the surcharge loading from the wall above.
- On steep ground in particular, global stability issues must be considered, especially for gravity structures.
- Stiff non-yielding walls should be designed for at-rest pressures, not active pressures.
- Appropriate drainage measures behind a wall are critical – the use of no-fines ‘rounds’ is discouraged.

6.2.3 Walls deemed as ‘not requiring a building consent’

Walls less than a certain height (normally 1.5 m, but in some cases different heights are applicable) and that are not surcharged are often exempt from requiring a building consent (or are assumed to be exempt) under the Building Act 2004 (see Schedule 1). This has led to a great number of inadequately designed and constructed walls being present in the building stock. Walls that genuinely fall into the category of ‘not requiring a building consent’ are generally walls that are genuinely not surcharged (ie, not loaded by sloping backfill, traffic loads, building loads or stepped upper walls). It has been common practice to avoid the need for a consent by stepping a wall system to ensure each individual wall is less than the designated height. However, the lower wall in the stepped system is generally surcharged by the wall above, in which case a building consent is required.

If a wall genuinely does not require a building consent, it is important to note that there is still a legal obligation on the designer and builder (under section 17 of the Building Act 2004) to ensure the wall complies with the Building Code. This applies to the strength, stability and durability of the wall.
7. Superstructure assessment and repair recommendations

This section provides guidance on the assessment of superstructure damage and suggested remedial actions. Coverage is limited to structural elements such as bracing walls and framing. Guidance is general rather than specific because of the wide variety of situations encountered.

7.1 CHIMNEYS

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

Earthquake damage in chimneys may not always be easy to detect, particularly if the chimneys are situated internally with wall surrounds. A guide for the assessment, repair and rebuilding of chimneys is provided in Appendix A3.

7.2 WALL BRACING

7.2.1 Types of wall bracing

In timber framed houses built before 1978 (the first publication of NZS 3604), the wall bracing was generally provided by either flush timber braces or solid braces. The former are either 4”x 1” or 6”x 1” members on an angle, cut in flush with the surface of the studs, while the latter are either 3”x 2” or 4”x 2” blocks fitted between the studs on an angled line. The internal linings had no designated structural function.

Since the advent of NZS 3604, the lining materials (primarily plasterboard) have been relied upon to provide the bracing function in some (or all) walls of the dwelling and sometimes in conjunction with light gauge let-in steel angle braces. The strength and stiffness of the sheet linings coupled with their fixings provides strength to resist the lateral loads from earthquakes and wind.

Fibrous plaster sheets have been available for many years, and were also used as a sheet bracing material in the 1980s and 1990s. They provided a very smooth finish for wallpapering, but the sheets had square edges (ie, they were not tapered) and reinforcing tape, and feathered stopping was not used on joints. Cracking on joints between the sheets is often not on a single line because the stopping compound filled the gap between the sheets and if shrinkage occurred, the bond between the stopping compound and the sheet edge could fail on either sheet edge at the joint.

Fibrous plaster sheets used as bracing elements were required to have galvanised clouts at 200 mm centres on the perimeter of the bracing element. Glue was also used to fix the sheet to the framing. If fibrous plaster sheet bracing elements need to be re-fixed to the framing, clouts should be used at 200 mm centres to all framing. Fibrous plaster sheets sometimes contained heating elements (particularly when used on ceilings) and care should be taken to ensure the heating element has been decommissioned before re-fixing or replacing sheets.

Both forms of bracing are expected to ‘loosen’ to some extent after design level earthquake events. This typically involves a reduction in stiffness rather than loss of strength. Where movement damage in relation to fixings is apparent, it may be necessary to re-fix or replace affected bracing elements.

7.2.2 Identification of wall bracing damage

If it is necessary to re-fix and re-stop any joints on a plasterboard wall face, then the skirting boards should be removed to check the need to re-fix the sheets behind the skirting. If the cornice joints have broken, the cornice should also be removed for re-fixing the top edge of the sheets, and then replaced.
It has been reported that even quite minor damage in internal lining sheets has led to houses being perceived to be more flexible during more frequent service level events such as strong winds and small aftershocks than they were prior to September 2010. Re-fixing of sheets through the addition of more fixings between the existing fixings around the perimeter of sheets has been shown to restore the majority of the previous stiffness and all of the strength, and this is considered to be an acceptable repair for this level of minor damage.

Where there is evidence of significant racking of walls (e.g., major 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 walls may need to be re-plumbed and the wall linings replaced, re-stopped and re-decorated. In many instances, these wall linings will have a bracing function. In more modern houses, the council will hold a bracing plan on file from which the bracing elements may be identified. For older houses it can be assumed that diagonal timber braces will be present wherever the length of the wall allows their installation.

7.2.3 Repairing and replacing bracing elements

Table 7.1 summarises the decision criteria and actions relating to the repair and replacement of plasterboard lining.

Where minor cracking (i.e., <0.5 mm) is present at wall panel junctions, cosmetic repairs should suffice. Where larger cracking is in evidence at wall panel junctions, with minor movement of perimeter panel fixings (i.e., >0.5 mm), re-fixing around the perimeter of panels is recommended. All new fixings must meet the requirements of the Building Code.

Where there is significant damage to panels (e.g., diagonal cracking or panel fracture), and/or significant movement of perimeter panel fixings, the affected panels should be replaced with a comparable component (e.g., a standard or enhanced plasterboard system, as applicable), fixed as if a bracing element (i.e., maximum fastener spacing of 150 mm) and include the checking of framing fixings. The resulting bracing capacity will in all likelihood be improved over what was present prior to the work. A similar logic for replacing part of a wall or a foundation applies (refer to Figure 4.2).

A similar approach can be taken for the reconstruction of whole walls or rooms, where the limited extent of the work does not lead to the need to review the bracing of the building as a whole. It is however required that where all the bracing elements of a dwelling are being repaired or replaced, the bracing of the building as a whole must meet the requirements of NZS 3604.

If all linings are removed and replaced, the bracing performance of the complete house must achieve compliance with the Building Code. However, it is recommended that if a substantial proportion of the linings is being repaired or replaced, consideration should be given to providing bracing to NZS 3604, as modified by Amendment 10 to B1/AS1.

An alternative to re-fixing plasterboard bracing elements involves installing additional linings over the existing damaged linings, fixed at a bracing pattern. Over-lining can often be accommodated by removing skirtings and scotias and installing the new linings using fasteners with an increased length. Skirtings can then be re-fixed and scotias re-formed. A new architrave detail may need to be designed around window and door openings.

The addition of over-linings provides the opportunity to create small penetrations through the existing linings to check the bottom plate connections. External sheet cladding connections and joints should also be checked and re-fixed. If the cladding has a bracing function (likely in houses built since 1978), then the sheet fixings should be checked. If they are found to be damaged, appropriate fixings will need to be installed in intervening gaps and the finish reinstated. Any exterior sheet claddings with diagonal cracking should be replaced.
If damage to sheet bracing elements located in the drainage cavity is suspected but cannot be confirmed without unnecessary removal of the exterior cladding (e.g., brick veneer), reinstatement of the structure’s bracing capacity may be achieved by the addition of a high performance internal lining system.

Where the replacement of bracing elements allows access to wall cavities and insulation is not already in place, the owner may choose to have insulation installed in the exterior walls at their own expense. The EECA Warm Up NZ programme might be an option.
Table 7.1: Summary of actions relating to repair/replacement of plasterboard lining

<table>
<thead>
<tr>
<th>EXTENT OF WALL DAMAGE EVIDENT</th>
<th>REPAIR/REPLACEMENT ACTION</th>
<th>REVIEW OF BRACING REQUIREMENT</th>
<th>BUILDING CONSENT/COMPLIANCE BASIS</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Minor cracking at wall panel junctions (&lt; 0.5 mm)(^1). No signs of movement at skirting board. May include panel fracture, diagonal cracking or lining separation from wall framing.</td>
<td>Scraping out old stopping (taking care not to damage paper facing), re-stopping and repainting.(^{21})</td>
<td>Not required</td>
<td>Schedule 1(a) and 1(ah) exemption • Applies to bracing and non-bracing elements</td>
<td>Cosmetic repairs</td>
</tr>
<tr>
<td>2. Moderate cracking at wall panel junctions (&gt; 0.5 mm)(^2) with minor movement of perimeter panel fixings and movement of panels evident at skirting board.</td>
<td>Replacing affected panel(s) with comparable component or assembly (eg, standard or enhanced plasterboard [as applicable]), fixed as a bracing element(^4), checking and making good any damaged framing connections where reasonably practicable.</td>
<td>Not required</td>
<td>Schedule 1(a) and 1(ah) • Repairs in accordance with this guidance document</td>
<td>Superficial and localised repairs Note: where panels are replaced, compliance with other clauses of the Building Code (eg, B2, E3) must be achieved(^6).</td>
</tr>
<tr>
<td>3. (a) Significant damage to panels and significant lining separation from wall framing. (b) Damage to timber framing connections, walls out of plumb in either direction more than 10 mm per storey, or bottom plates have shifted from their original position.</td>
<td>Re-lining of whole walls or rooms using comparable component or assembly (eg, standard or enhanced plasterboard [as applicable]), fixed as a bracing element(^4), checking and making good any damaged framing connections where reasonably practicable.</td>
<td>A new bracing element at least matches the bracing capacity provided by the replaced element(^{23})</td>
<td>(a) Schedule 1(ah) exemption (b) Building consent or possible item (k) exemption required(^7), making reference to section 7 of this guidance document</td>
<td>Complete or substantial repairs See notes 6 and 7</td>
</tr>
</tbody>
</table>

Notes to Table 7.1:

1. The cracking is generally confined to the top and/or bottom corners of openings, extending vertically from the corner along the sheet joint.
2. Cracking will be evident as in (1) above, but there is also likely to be cracking of the joint at wall junctions. If any sheet edge damage is sufficient to prevent the sheet from being re-fixed between existing fixings, affected panels should be replaced.
3. The wall lining glue fixings may have detached from the studs intermediate between the sheet edges. This may be checked by striking the wall linings gently with the palm of a hand to detect ‘drumminess’ due to the disconnection of the glue fixing. Re-fixing with nails or screws at 200 mm centres, re-stopping and re-painting will be required. Note that the glue fixings were not necessary for the provision of bracing resistance when the panels were first installed.
4. Check bracing fixing patterns for proprietary plasterboard bracing systems in manufacturers’ literature. Bracing elements should have fixing spacings of 150 mm or less.
5. An estimation of the capacity of the replaced element may be determined from the fixing pattern and material used or from a bracing plan, if available.
6. Where the entire bracing system is replaced, the bracing performance of the complete house must achieve compliance with the Building Code (eg, demonstrating compliance with NZS 3604 by way of Amendment 11 to B1/AS1).
7. The compliance pathway sought by each practitioner/PMO will depend on their relationship with the council (eg, PMOs who have established relationships may seek an item (k) exemption because of their overarching quality assurance practices and use of third-party review) and the level of repair required. Please note: refer to Table 8.2 for a summary of the risk-based consenting pathways available.
7.3 WALL AND ROOF FRAME CONNECTIONS

Apart from where chimneys have fallen and broken timber members in the roof, generally there have been few instances of failure of framing members. Significant damage to the framing is unlikely unless there has been substantial spreading or abrupt-change differential settlement beneath the house. Lateral spreading of foundations and severe liquefaction has caused some framing members to fracture, but more often it is the joints between the members that pull apart.

Any damage to the wall framing members will need to be repaired 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).

However, studs and/or bottom plates of wall bracing elements may have lifted and possibly resettled. In some instances wall bottom plates that are nailed to the timber floor system have separated from the floor. Thick floor coverings, such as carpet, may disguise the fact that the plate has lifted, and a careful inspection should be made to establish whether plate lifting has occurred. Reinstate wall-to-floor connections and framing junctions wherever there is obvious distress. This may require the removal of linings for access.

For timber floors, re-nail bottom plates. For concrete floors, carefully check the integrity of any shot fired pin connections and replace with proprietary bolt anchors. Any bracing element stud-to-plate connections (such as nail straps) and plate-to-floor connections that are distressed should be replaced, as these are critical to the overall stiffness and strength of the system.

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), a check of all roof space connections will be necessary, and repairs undertaken to reinstate the bracing function of these elements. 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 10 mm from the wall/ceiling junction, it may be necessary to remove the ceiling or soffit linings to gain access to the joints so they can be reconnected.

7.4 LIGHT GAUGE STEEL FRAMING

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

Steel framing members are connected by shear connectors such as rivets and screws. If these have been significantly stressed, there is a potential for the fixings to pull through the thin metal edges of the members. If linings or claddings are removed because they are damaged beyond repair, a careful inspection of the framing connections should be made.

Otherwise, repair to light-gauge steel frame structures is similar to the above recommendations for light timber framing.
7.5 POLE FRAME STRUCTURES

Pole frame houses generally rely on either cantilever action of the poles or cross bracing between the poles for lateral load resistance. The nature of the system makes it suitable for sloping sites.

If cantilever action is relied on for bracing, a careful inspection where the pole is embedded in the ground to ascertain whether there has been any soil failure is recommended. Cross braces may not appear to be damaged but bolted connections can deform quite severely at the junction between the pole and the brace. If there is any doubt about the amount of damage present, the braces should be removed one at a time for inspection. Drilling the holes with a larger diameter drill and fitting a larger bolt is a suggested repair for damaged connections.

When pole frame structures are connected to stiffer elements such as reinforced concrete or masonry foundations, this induces large stresses in the connection as the lateral earthquake forces transfer to the stiffer element. Careful inspections of the junctions should be carried out for signs of distress.

7.6 UNREINFORCED BRICK MASONRY 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 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.

Following assessment, if it is established that damaged unreinforced brick masonry wall elements can be repaired, then the engineering principles applied to commercial buildings should be followed. For regulatory and insurance requirements, in most cases the repair methodology should focus on the reinstatement of pre-damage element strength rather than upgrading to a higher standard, noting the requirement of section 17 of the Building Act that all work must comply with the Building Code.

The core reference for unreinforced masonry buildings is contained in 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).
7.7 CONCRETE BLOCK MASONRY WALLS

Concrete block masonry walls have been used to build houses for many decades. While they have been more common as basement walls for houses on the hills, there are occurrences of superstructures that have been constructed with concrete block masonry.

Damage to concrete block masonry walls is expected to vary 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.

Unreinforced concrete block walls (commonly found in garages and sometimes in houses) are likely to have fared no better than unreinforced brick masonry walls.

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. Repairs to any cracking can be achieved by grout or epoxy injection and re-pointing affected mortar joints.

While it must be assumed that original construction details complied with the bylaw/approved New Zealand Standards relevant at the time, these were not as demanding as modern standards. Unreinforced construction, even if complying with NZS 1900 Chapter 6.2 Table 3 and dating from before 1986, has not performed well. Examples have been observed of houses constructed to this earlier Standard where the earthquakes have caused severe damage and near collapse of the dwelling.

An early consideration in the assessment process should be:

a. the extent of structural damage and the likely seismic performance of any repair, and
b. given (a), whether it is practical to demolish and rebuild to the same general form as existing.

While insurance expectations are that repairs should be to a level to reinstate the strength prior to the earthquake rather than to provide improved seismic performance, often the damage sustained by concrete block masonry walls is such that a repair is not practical and replacement is the only option. Any replacement will be required to satisfy the requirements of the Building Code.

The nature of block masonry construction means that any surface manifestation of rupture will generally indicate hidden damage to grout infill and corresponding loss of shear and flexural capacity as compared to the ‘unstrained’ wall, which will in most cases be difficult to restore.

If a section of wall is to be repaired, then:

- the reinstatement should also incorporate ‘newly grouted’ and ‘newly reinforced’ wall panels whose future performance can be reliably predicted, and
- conservative assumptions need to be made on the residual strengths of walls which are to remain.

For guidance as to whether or not repairs will be practicable for a particular area of wall:

- slight cracking (<1.0 mm) confined to mortar courses (eg, in a staircase pattern) and not extending into face shells may be repairable using injection joint reinforcing or similar techniques
- moderate cracking (>1.0 mm) in mortar courses and extending to rupture of face shells may indicate internal rupture and significant loss of strength that may not be repairable.

Decisions on repair will also need to consider:

- the date of construction and applicable Compliance Document
- the inferred quality of the original construction, and
- the extent of damage visible and inferred.
The recommended aim of repairs should be to achieve the better of:

- reinstating the pre-damage strength level at the position of rupture concerned, or
- providing minimum strength equivalent to demand from moderate earthquake excitation, as per the amended ‘dangerous building’ threshold (BA section 121/ CERA section 7).

In both cases, pre-damage stiffness may need to be compensated for either by adding reinforcing structural material or by other means.

**Unreinforced concrete block masonry**

NZS 1900 Chapter 6.2 (no longer a current Standard) includes a definition of previously permitted ‘unreinforced masonry’ that included:

- D12 vertical bars at wall corners and as trimmers around opening, and
- horizontal bond beams with minimum levels of continuous reinforcement as intermediate and/or top bonds, to tie the block panels together.

Unreinforced concrete block masonry of this form may well occur in residential construction (eg, basements) where gravity loads must be supported, but it will have minimal capacity to provide seismic shear resistance without the addition of supplementary elements.

Any repairs to earthquake-damaged unreinforced concrete block masonry need to target:

- adding structural basketting (eg, surface-mounted FPP or bonded metal strips, at chosen centres to control local failures), and
- providing alternative load paths for the potential loss of gravity support (eg, internal SHS props to underside of timber floor, or to support the top bond beam).

New vertical reinforcing can be inserted into selected vertical cells and grouted to provide supplementary vertical spanning capacity of block panels. However, supplementary horizontal reinforcement is normally only possible from interior surfaces using bonded surface strips or incorporating proprietary reinforcing into the horizontal mortar courses.

Note: Normally it will be difficult to add sufficient cross-sectional area using proprietary systems due to the size limitations in the proprietary bars.

**Partially filled vs fully grouted concrete block masonry**

Previous non-specific design standards for block masonry (eg, NZS 4229:1986) imposed restrictions on the use of partially filled masonry. Partial filled construction was only permitted in seismic Zones B and C, with Zone A applications requiring fully grouted treatment. The introduction of the 1999 version of this Standard saw a relaxation that allows partial filled construction in Zone A.

In repair or upgrade situations, a general requirement that designers ‘demonstrate that the existing masonry construction satisfied the requirements of B1/AS1’ for existing blockwork may bring with it obligations beyond merely the demonstration of a minimum flexural and/or shear capacity. For example, ‘upgrading’ the Canterbury Earthquake Region to Zone A standards (as required by Amendment 10 to B1/AS1) may require designers to fill all cells to ensure the equivalent of Zone A performance is achieved.

NZS 4229: 1999 allows the use of partially and fully grouted walls together.
Part B: Technical Information

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8. Insurance and regulatory requirements

8.1 INSURANCE REQUIREMENTS

This section focuses on insurance principles and requirements of the Earthquake Commission Act 1993 (EQC Act) for damage to residential buildings arising from the Canterbury earthquakes or aftershocks. This is a summary only and in the event of difference, the EQC Act will prevail.

Please refer to www.eqc.govt.nz for full details of the scope of EQC cover. Further information on claims to EQC arising from land damage or claims for damage to personal property can also be found at: www.eqc.govt.nz

8.1.1 Earthquake Commission (EQC)

EQC was established by the Government in 1945 to provide earthquake and war damage cover for purchasers of fire insurance. Later, cover for other natural disasters was included and, later still, cover for war damage dropped. EQC is a government-owned Crown entity.

EQC covers New Zealand residential property owners for some damage caused by earthquake, natural landslip, volcanic eruption, hydrothermal activity, tsunami; in the case of residential land, a storm or flood; or fire caused by any of these events.

EQC automatically covers people who hold fire insurance that covers their dwelling and personal property (most ‘home and contents’ policies include fire insurance cover).

The claimants’ insurance policies are a legal contract between the insured and the private insurer. EQC cover insures the insured’s dwelling and any structures associated with the dwelling up to a maximum of $100,000 plus GST. The private insurer will be liable for a damage claim beyond this level in accordance with the individual terms and conditions of the contract.

Dwellings are insured by EQC on a ‘replacement value’ basis. A ‘dwelling’ means any self-contained premises that are somebody’s home or holiday home or that are capable of being, and are intended by the owner to be, somebody’s home or holiday home. EQC also insures separate buildings used by the occupiers of a dwelling, such as a garage or shed.

EQC does not cover any dwelling that is not insured against fire, and it does not cover a dwelling if the relevant insurance policy has lapsed or has been cancelled at the time of the natural disaster, or where EQC has cancelled the EQC cover. Nor does it cover consequential losses that might occur after a natural disaster, such as theft or vandalism.

In most cases EQC will settle claims which exceed the maximum amount of EQC cover by paying that amount to the owner(s) of the dwelling or other person with an insurable interest in the dwelling (eg, a mortgagee bank). For any damage above that amount, an owner must claim against his or her private insurer.

Cover is also provided by EQC for land damage: refer to Figure 8.1 for an indication of the extent of land insured by EQC.
Under the EQC Act, a homeowner must ‘take reasonable precautions’ for the safety of their property. The owner must in particular take all reasonable steps to preserve the insured property from further natural disaster damage.

For dwelling claims where the damage does not exceed the amount of EQC cover available, EQC may, at its option (instead of paying the amount of the damage), replace or reinstate the building to a condition substantially the same as, but not better or more extensive than, the building’s condition when new. EQC’s obligation to reinstate or replace to ‘replacement value’ includes costs reasonably incurred in the course of reinstating or replacing the building, including fees for architects, surveyors and engineers, and fees payable to local authorities.

For dwelling claims where the damage does not exceed the amount of EQC cover available, EQC has chosen to repair or reinstate the damage through its project manager Fletcher/EQR. For these claims:

- repairs to any damaged portion of a dwelling must be undertaken to a level that meets applicable laws (including current building regulations) (refer to section 8.2)
- the EQC Act definition of ‘replacement value’ provides that, where EQC opts to replace or reinstate, repair work will return a dwelling to a condition ‘substantially the same’ as its condition when new, but not better or more extensive. EQC is not required to replace or reinstate exactly or completely, but only as the circumstances permit and in a ‘reasonably sufficient manner’.
8.1.2 Private insurers

The following are the obligations of private insurers:

1. The reinstatement requirements of the private insurer will depend 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, or
   • 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 policy is more limited than the EQC cover and only provides for repair on an indemnity rather than a replacement basis.

8.2 REGULATORY REQUIREMENTS

8.2.1 Building Act 2004

This section sets out some of the matters under the Building Act 2004 that will need to be considered when houses damaged by the sequence of Canterbury earthquakes are being repaired or 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, the particular circumstances of each repair or reconstruction need to be considered.

Building activities must comply with the requirements of the Building Act 2004 (the Act) and the relevant regulations that have been made by Order in Council under the Canterbury Earthquake Recovery legislation. The Building Code is a regulation made under the Building Act 2004 (Schedule 1 of the Building Regulations 1992).

The Building Code is performance-based, outlining the performance that needs to be achieved under each of the Building Code clauses. Acceptable Solutions and Verification Methods published by the Department, if followed, will result in building work that is deemed to comply with the Building Code. However, alternative solutions can be proposed and consented if sufficient evidence to satisfy the ‘reasonable grounds’ test is provided to the building consent authority that Building Code performance requirements will be met. Much of the guidance in this document (eg, Options 1 to 5 of section 5.3) is not included in the current Acceptable Solutions. They are therefore alternative solutions. This document aims to provide ‘reasonable grounds’ for building consent authorities to consent such designs.

All building work must comply with the Building Code regardless of whether a building consent is required (Building Act section 17), or whether the building work is to construct a new building or carry out alterations or repairs to an existing building.

When deciding whether to grant a building consent, the building consent authority needs to be ‘satisfied on reasonable grounds that the provisions of the Building Code would be met if the building work were properly completed in accordance with the plans and specifications that accompanied the application.’ (Building Act section 49).

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6 Under section 7 of the Act, building work means work ‘for, or in connection with, the construction, alteration, demolition, or removal of a building …’ and includes sitework.
7 The circumstances when a building consent is not required are set out in section 41 of the Act, including work that is exempt from the requirement to obtain a building consent under Schedule 1 of the Act.
8 Alter, in relation to a building, includes rebuilding, re-erecting, repairing, enlarging, and extending the building.
Work related to the rebuild in Christchurch will include:

- repair of building elements or systems (eg, relevelling of floor slab and repair of any cracks in it, repair of bracing elements in superstructure and repair of cracks in internal or external walls (see section 8.2.2)), or
- replacement of all or parts of building elements (eg, a new foundation or replacement of part of the perimeter foundation wall), or
- the construction of completely new houses, whether on the same site or a new building site (see section 8.2.3).

8.2.2 Regulatory requirements for repairing damaged houses

All work undertaken to repair damage is ‘building work’ and needs to comply with Building Code requirements (section 17).

The obligations for most provisions of the Code apply to one of the following subjects:

- a building or household unit
- building elements
- building systems within a building
- building facilities.

Building work to alter or repair a building only has to comply with the scope of the relevant Building Code obligations that apply to that building work. For example, structural repairs to a wall only have to comply with the provisions of B1 that are applicable to that wall (a building element), not with the Code obligations that apply to a whole building or to other building elements/walls that are not being repaired.

There are however provisions in the Act that require other parts of a building being repaired to be upgraded as follows:

- Additional work is required for a building that is being repaired to ensure that for means of escape from fire and access and facilities for persons with disabilities, the building complies as nearly as is reasonably practicable with the requirements of the Building Code (section 112(1)(a)). Provisions for access and facilities for persons with disabilities do not apply to private houses, while special fire safety requirements for houses are essentially limited to the installation of domestic smoke alarms. (If the house is not fully detached there may be other requirements.)
- There is an exception to section 112(1)(a) that allows a partial upgrade (ie, less than ‘as nearly as reasonably practicable’) where even though the alterations will not comply with section 112(1)(a), the benefits of upgrading outweigh the detriment of not complying with section 112(1)(a) (section 112(2)).
- If the use of the building is changed or a household unit is added as part of the repairs, there are further upgrade requirements that a building must comply with (section 115).
- There are specific upgrade requirements for buildings to which the public has access to ensure reasonable and adequate provision by way of access, parking provisions and sanitary facilities for persons with disabilities (section 118).

There are prohibitions on certain types of repair, including that:

- a repair cannot result in a building complying with the Building Code to a lesser extent than before the repair (section 112(1)(b))
- a repair may not accelerate or worsen a natural hazard on the land or any other property (section 71). (Please note that earthquakes are not included in the definition of natural hazards (section 71(3)). Therefore, building on land with the potential to liquefy in an earthquake would not require the building consent authority to notify the Register-General of Land identifying a natural hazard (section 73)).
Section 112 of the Building Act

Section 112 of the Act contains specific requirements for alterations (referred to above) relating to the compliance of the altered building (which is the whole building as altered, not merely the alteration). It does not detract from the section 17 requirement that all building work must comply with the Building Code or the provisions of sections 67 to 70 on waivers or modifications to the Building Code.

Therefore, section 112(1)(b) prevents a building consent authority from issuing a building consent for an alteration if one of the effects of the proposed building work will be detrimental to the compliance of the existing building with the Building Code. Section 112(1)(b) states that before a building consent authority can issue a building consent for alterations, it must be ‘satisfied that, after the alteration, the building will continue to comply with the other provisions of the building code to at least the same extent as before the alteration’.

8.2.3 Regulatory requirements for rebuilding the entire house

Rebuilt houses are considered to be new houses, and they must comply fully with the Building Code subject to any waiver or modification granted by the territorial authority (Building Act section 67). Some of the specific Building Code requirements that relate to rebuilding in Canterbury are highlighted below.

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

To satisfy the objective B1.1(a) of the Building Code – to safeguard people from injury caused by structural failure – Clause B1 Structure requires new building work to have a low probability of rupture, becoming unstable or collapsing (Clause B1.3.1). This requirement has been well quantified 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 Clause B1.

Buildings that are designed using AS/NZS 1170 are required to satisfy the ultimate limit state primary design case.

Ultimate limit state (ULS)

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% 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 to collapse, when it is subjected to a ULS load.

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 which is significantly greater than the ULS load for which it has been designed, although this likelihood is reduced if the building is robust.
- All buildings are at risk of being subjected to a level of seismic shaking that is greater than their design ULS seismic load. It should be noted, however, that this probability of exceedance is considered to be acceptably low.

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

To satisfy the objective B1.1(b) of the Building Code – to safeguard people from loss of amenity caused by structural behaviour – Clause B1 Structure 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).

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’.
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 such as sewer and water connections, damage to sanitary fixtures (bathroom, kitchen, laundry), parts of the house being no longer available for use, significant cracking and deformation of flooring, or the building envelope not being weathertight.

For this document, loss of amenity is being taken as the exceedance of the following tolerable impact:

- **All parts of the structure shall remain functional so that the building can continue to perform its intended purpose.** Minor damage to structure. Some damage to building contents, fabric and lining. Readily repairable. Building accessible and safe to occupy. No loss of life. No injuries. Criteria on repairability are provided in Table 8.1.

Buildings designed using AS/NZS 1170 are required to satisfy the serviceability limit state primary design case, which reflects the requirement to prevent loss of amenity.

**Serviceability limit state (SLS)**

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 little or no structural damage when it is subjected to an SLS load. All parts of the building should remain accessible and safe to occupy.

Services should remain functional at the perimeter of and within the building. There may be minor damage to building fabric that is readily repairable, possibly including minor cracking, deflection and settlement that do not affect the structural, fire or weathertightness performance of the building. SLS seismic loads for residential properties are based on a one in 25 year earthquake (refer to AS/NZS 1170.0).

**Readily repairable**

Given the uncertainty of rebuilding on land where liquefaction has occurred in Canterbury, it is useful to base designs on minimising damage that might occur.

Table 8.1 provides criteria for the nature of future damage that corresponds to ‘repairability’. This covers both timber framed/light clad dwellings and concrete slab dwellings of any cladding type. It is intended that these criteria could only practically be applied to situations where lateral spreading of less than 50 mm across an individual site is expected under serviceability limit state seismic actions in the future.
Table 8.1: Serviceability limit state performance expectations for rebuilt houses

<table>
<thead>
<tr>
<th>KEY TERMS</th>
<th>ELEMENT</th>
<th>INTERPRETATION</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continue to function</td>
<td>Building</td>
<td>Occupiable as a dwelling (habitable)</td>
<td>Refer to Services below</td>
</tr>
<tr>
<td>Minor damage to structure</td>
<td>Foundation structure and floor</td>
<td>Timber: Able to be re-levelled using standard procedures</td>
<td>Require replacement of sections of subfloor cladding for re-levelling access</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete: No rupture but minor curvature possible</td>
<td>No opportunity for ground moisture ingress</td>
</tr>
<tr>
<td></td>
<td>Walls – exterior</td>
<td>Minor cracking at cladding panel joints and in plaster coatings (eg, EIFS)</td>
<td>Re mains essentially weathertight</td>
</tr>
<tr>
<td></td>
<td>Walls – interior</td>
<td>Minor cracking at lining joints</td>
<td>Lateral structural integrity maintained</td>
</tr>
<tr>
<td></td>
<td>Roof</td>
<td>Roof claddings sound, intact and securely attached</td>
<td>Capable of remaining weathertight</td>
</tr>
<tr>
<td>Some damage to building fabric and</td>
<td>Building</td>
<td>Some cracking of lining junctions above doorways and windows</td>
<td></td>
</tr>
<tr>
<td>lining</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Readily repairable</td>
<td>Doors – interior</td>
<td>Repairable without relocation of occupants for more than four weeks</td>
<td>Total cost of repairs at a level that is able to be covered by EQC (ie, within EQC insurance cap)</td>
</tr>
<tr>
<td>Building accessible and safe to</td>
<td>Doors – exterior and windows</td>
<td>Capable of being secured (ie, may need catch adjustment and easing)</td>
<td>Requires ability to occupy in this state for several months</td>
</tr>
<tr>
<td>occupy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Aspects</td>
<td>Services</td>
<td>No damage to water, gas, and electrical service connections</td>
<td>Special design of utility connections into house to allow some movement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Readily repairable damage to sewer and stormwater pipes</td>
<td>Any loss of service relates to network issues</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Use of chemical toilets</td>
</tr>
<tr>
<td></td>
<td>Residual wet silt beneath floor</td>
<td>Timber: May need to temporarily install polythene membrane over silt</td>
<td>Prevention of ground moisture from entering the living space</td>
</tr>
<tr>
<td></td>
<td>Weather tightness</td>
<td>Not compromised if extent of water ingress is small and the effects are controllable</td>
<td></td>
</tr>
</tbody>
</table>
Building Code requirements to prevent flood damage (Clause E1.3.2)

Surface water from an event having a 2% annual probability must not enter the building (Clause E1.3.2). This means that water from a one in 50 year flood must not enter the building.

Council requirements to satisfy this and other regulatory requirements are given in section 8.4.

Building Code requirements for external moisture (Clause E2)

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).

A means of satisfying this provision is provided in Acceptable Solution E2/AS1. Section 10 of E2/AS1 provides details for the protection and separation of elements and minimum floor levels above ground. Details are provided in paragraph 4.2.5.1 (refer also to Table 18 and Figure 65 of E2/AS1).

Rebuilding in ground damaged areas of Canterbury

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

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 to NZS 3604, 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. B1/AS1 was amended on 1 August 2011 to modify the referencing of NZS 3604 to exclude from the definition of ‘good ground’ any land in Canterbury that has the potential to liquefy. The Department has also issued guidance for the rest of New Zealand, recommending geotechnical investigations be undertaken when ground with the potential for liquefaction is identified (refer to http://www.dbh.govt.nz/liquefaction-construction-on-ground-guidance).

Superstructure

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

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

8.2.4 Building consent processes

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

Typically, most building work requires a building consent from a building consent authority before it can commence, to allow an independent third party to 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 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 Building Act. More recently, additional exemptions were provided in 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 8.2.

**Table 8.2: Summary of the risk-based consenting pathways for building work**

<table>
<thead>
<tr>
<th>Non-consented building work</th>
<th>Streamlined consented approach</th>
<th>Standard consented building work</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 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.</td>
<td>• 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, type, nature and complexity of repair work, etc).</td>
<td>• The standard building consenting, inspection and approval pathway is used for higher risk building work or where the other approaches are not appropriate.</td>
</tr>
<tr>
<td>• 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.</td>
<td>• 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.</td>
<td></td>
</tr>
<tr>
<td>• Low risk building work where a council decides on a case-by-case basis to exempt from requirements to obtain a consent. Council uses its discretion under item (k) in Schedule 1. Could be applied to any building work, but targeted at licensed building practitioner (LBP) designers and builders, with no inspections.</td>
<td>• 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.</td>
<td></td>
</tr>
</tbody>
</table>

1. Low risk building work is contained in sections (a) to (j) and (l) to (n) of Schedule 1 of the Building Act. It is work which is unlikely to fail to comply with the Building Code and, if it does, is unlikely to endanger people or any building, whether on the same land or on other property (Schedule 1(k)).

Importantly, regardless of whether a building consent is required, all building work must comply with the Building Code (refer to section 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 the work meets Building Code requirements. It is recommended that homeowners 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 Act 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.
8.3 SEISMICITY CONSIDERATIONS

The 2010/11 Canterbury earthquakes have increased the seismic risk for Christchurch over the next few decades. Based on new knowledge about this risk, and after consultation with seismologists and structural engineers, the Department, increased the seismic hazard factor, Z, in Christchurch from 0.22 to 0.3 from 19 May 2011.9

The minimum hazard factor Z (defined in Table 3.3 of NZS 1170.5) within the Christchurch City, Waimakariri District and Selwyn District Council boundaries shall be 0.3. Where factors within this region are greater than 0.3 as provided by NZS 1170 Part 5, then the higher value shall apply.

The hazard factor for Christchurch City, Selwyn District and Waimakariri District shall apply to all structure periods less than 1.5 seconds (which encompasses detached residential construction). All structures with periods in excess of 1.5 seconds should be subject to specific investigation, pending further research.

The revised Z factor is intended only for use in the design and assessment of buildings and structures, pending further research. Seismic hazard factors for geotechnical design and liquefaction analysis are being researched with the intention of publishing them shortly.

The additional bracing demand required for residential houses has been addressed by referencing NZS 3604 Chapter 5, Bracing Design, in Acceptable Solution B1/AS1. There are some exceptions: all the area within the Christchurch City Council boundary will be within Zone 2; and the lowest zone within the Selwyn or Waimakariri District Council boundaries will be Zone 2. This is consistent with the increased Z value of 0.3 in NZS 1170.5.

8.4 FLOOD RISK AND FLOOR LEVELS

This section summarises the issues and requirements for each of the territorial authorities when setting new finished floor levels for houses to be reconstructed or repaired in low lying areas. These notes have been provided by the relevant territorial authority and are current at the time of preparation of this document.

The current situation must be checked on a case-by-case basis with the relevant council11.

8.4.1 Christchurch City Council

Within Flood Management Areas

To assist Christchurch City Council (CCC) to manage the potential effects of flooding and inundation in Christchurch, especially as a result of climate change and sea level rise, Variation 48 to the Proposed Christchurch City Plan became operative on 31 January 2011. Variation 48 introduced a package of measures. The measures most relevant to finished floor levels are those for Flood Management Areas (FMAs).

FMAs are shown on the City Plan Series B Planning Maps (http://resources.ccc.govt.nz/files/OperativeVariation48PlanningMaps.pdf). 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.

9 Refer to http://www.dbh.govt.nz/bc-update-article-114
10 Refer to http://www.dbh.govt.nz/earthquake-concrete-slabs-guidance
11 Although voluntary, it may be an advantage to apply for and obtain a project information memorandum (PIM) from the relevant council before finalising building consent applications. This may assist to establish finished floor levels, finished ground levels and whether or not there will be any requirement for resource consent.
Some of these areas (most notably the Avon and the Lower Styx) were badly affected by the earthquakes. The overall Flood Management Area map may be viewed at http://resources.ccc.govt.nz/files/OperativeVariation48PlanningMaps.pdf

Variation 48 introduced flood risk and floor level assessments by requiring resource consents (under the Resource Management Act) for new developments in these defined FMAs.

If a house is to be rebuilt on the same or similar footprint as before, existing use rights under the RMA to rebuild at the original floor level may apply, and there may be no requirement for resource consent for rebuilding. However, compliance with the New Zealand Building Code will still be required (see ‘Outside Flood Management Area’ below).

All new buildings not on the same or similar footprint, or additions to buildings within the specified FMAs (with limited exceptions – eg, in living zones, additions to existing buildings of a maximum 25 m² 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.

Two of the main criteria for assessing buildings will be whether floor levels are above the 200 year flood level plus 400 mm freeboard and, in tidally influenced areas, at no less than 11.8 m above the Christchurch City Datum.

Building flood levels and hazards are assessed on a case-by-case basis. In most, but not all cases it will be obvious which of these two 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 neighbour approvals.

Filling within a FMA will also require 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 31 January 2011.

**Outside of Flood Management Areas or where existing use rights apply within the Flood Management Areas**

Outside of FMAs, flood management rules under the City Plan will not apply. Under the Building Act (bearing in mind that every building consent application will be considered on its merits), finished floor levels of new dwellings or dwellings that are reinstated on completely new foundations (eg, completely re-piled) or extended dwellings will need to be no less than the level established by a 2% AEP12 plus 400 mm freeboard, which in some cases may be higher than the original floor levels.

If there is an alteration or addition to, or a partial repair of the dwelling, then the existing floor level will still apply. See also minimum standards set out below to avoid hazard notices.

**Guidelines for avoiding hazard notices under the Building Act 2004**

A section 72 (hazard) notice under the Building Act 2004 may be issued by the CCC where building work is being carried out on land subject to a natural hazard. When considering whether a natural hazard exists, the Council has developed the following tests:

i. The threshold under section 71 of the Building Act for considering whether land or a building is likely to flood will be reached if Council records or analysis indicate that there is at least a 1% AEP.

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12 AEP means annual exceedence probability. A 2% AEP event is often referred to as a ‘1 in 50’ year event, a 1% AEP event is often referred to as a ‘1 in 100’ year event and a 10% AEP event is often referred to as a ‘1 in 10’ year event.
ii. If the inundation risk does not exceed 1% AEP, the land is not likely to be subject to the hazard for the purposes of section 71. However (iii), (iv) and (v) below also apply.

iii. The minimum finished floor level (FFL) in a non-Flood Management Area is set at the 2% AEP (Clause E1.3.2 of the Building Code) plus an allowance for freeboard, which is typically 400 mm.

iv. The minimum building platform level will be set at 2% AEP extending 1.8 metres beyond the foundations of the house.

v. A building is not to be located within the waterway set back required in the City Plan.

vi. If there is a risk that water may not be contained entirely within the legal road reserve beyond the 10% AEP event, flood depth must not exceed 0.4 m over the section surrounding the building platform and flow velocity must not exceed 1.0 m/s.

vii. In a Flood Management Area the finished floor level will be determined by the resource consent process (see ‘Within Flood Management Areas’), unless existing use rights apply.

Elements required for establishing existing use rights under the RMA

Existing use rights apply only in relation to the Resource Management Act 1991 (RMA). They do not allow rebuilding without a building consent and do not change the building consent process.

There are four elements that need to be met for a rebuild to claim existing use rights. The onus is on the property owner or applicant for consent to prove that these elements are met.

a. The residential use must have originally been lawfully established.

b. Effects of the use must be the same or similar in character, intensity and scale.

c. There must be no increase in the degree of non-compliance with the City Plan rules (other than the permitted extra 25 m² footprint.)

d. There must be no discontinuance of use for a period exceeding 12 months, unless a discontinuance of use is as a result of earthquake damage and is beyond the control of the building owner. The residential use does not cease because the occupation of the building ceases temporarily as a result of earthquake damage. However, if delays in recommending residential use are caused by the landowner, then the activity will be deemed to have discontinued.

8.4.2 Waimakariri District Council

Unless specifically required by their District Plan, Waimakariri District Council rely on compliance with the Building Code to establish finished floor levels. In particular, the minimum FFL will be set at 2% AEP (Clause E1.3.2), plus an allowance for freeboard.

8.4.3 Selwyn District Council

The limited number of houses to be reconstructed in Selwyn District are generally rural residential and, where affected by possible flooding, are capable of individual site-based solutions that will not affect neighbouring property.
This section outlines the current understanding of the performance of land and dwellings in the Canterbury earthquake sequence, particularly as it relates to the effects of ground liquefaction. A summary of the effects of liquefaction is presented in Appendix B1.

Local land damage maps of the most affected suburbs of greater Christchurch have been completed for residential properties. The spatial distribution of the categories of land damage is illustrated in a generic cross section shown in Figure 9.1.

9.1 OBSERVATIONS IN AREAS SUBJECT TO LIQUEFACTION

The Earthquake Commission (EQC) is required to undertake a geotechnical assessment of all insurance claims that contain land damage. Immediately following both the 4 September 2010 earthquake and 22 February 2011 aftershock, a regional reconnaissance damage mapping exercise was undertaken by geotechnical engineers on behalf of EQC. From this mapping study, areas of minor to very severe land damage were identified.
Land damage from the earthquakes generally comprised lateral spreading close to watercourses/streams/rivers (major to very severe) and liquefaction-induced differential settlements (minor to very severe). The major to severe lateral spreading was greatest closest to streams and drainage channels, but in some cases extended up to 400 m laterally from watercourses with up to 4 m lateral ground movement. Minor spreading extended well beyond this in some parts of Christchurch. Settlements of up to 200 mm from liquefaction occurred over large areas, with significant differential settlements occurring over short distances. In the worst-affected areas, more than 500 mm settlement occurred.

9.2 OBSERVATIONS IN AREAS SUBJECT TO LANDSLIDES AND ROCKFALLS IN THE PORT HILLS

A wide range of damage has been sustained by hillside properties. For the majority of properties, however, this has been limited to structural damage from earthquake shaking (although this damage has been severe in many cases, partially due to topographical enhancement effects – ie, increased ground accelerations on ridgelines, slope and cliff crests).

For some properties, further damage has been sustained due to movement issues with the land on which the dwelling is situated or from conditions some distance from the property. A listing of typical issues is given in Table 9.1.
Table 9.1: Land damage mechanisms on the hillsides and observed effects

<table>
<thead>
<tr>
<th>MECHANISM</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rockfall (cliff collapse above building)</td>
<td>A small number of houses have been destroyed or inundated at the base of cliffs, and other houses have sustained major to minor damage from rock impact. Some houses are identified as being at risk from future damage.</td>
</tr>
<tr>
<td>Rockfall (boulder roll)</td>
<td>A small number of houses have been totally destroyed, and other houses have sustained major to minor damage from boulder impact. Many houses are identified as being at risk from future damage.</td>
</tr>
<tr>
<td>Landslide (soil slope, wide area failure)</td>
<td>Several potential global landslip features have been identified and are currently being monitored and investigated to determine whether they pose an ongoing threat to a number of houses deemed to be either on or below the failure area.</td>
</tr>
<tr>
<td>Landslide (ground cracking)</td>
<td>Large numbers of soil cracks have been observed throughout the Port Hills – many of these are several hundred metres in length. The significance and implications of these features are yet to be determined.</td>
</tr>
<tr>
<td>Landslide (soil slope, localised failure)</td>
<td>Some localised soil slope failures have taken place that affect single dwellings by undermining foundations or depositing debris against building exteriors.</td>
</tr>
<tr>
<td>Landslide (cliff collapse below building)</td>
<td>A small number of houses have been undermined (or are threatened by undermining) from loss of ground due to cliff collapse. (This involves both soil and rock materials.)</td>
</tr>
<tr>
<td>Retaining wall failure</td>
<td>A number of retaining wall failures have been observed – from rotation, translation and structural failures. This has sometimes resulted in land instability that has also induced localised landslide failures.</td>
</tr>
<tr>
<td>Settlement (foundation failure)</td>
<td>Foundation settlement has been observed in a number of houses, likely due to high vertical accelerations greatly increasing bearing stresses and therefore settlements. In some cases, localised bearing capacity failures may have occurred due to the presence of weak fill, or saturation of soils from a number of potential sources.</td>
</tr>
<tr>
<td>Settlement (subsurface void collapse)</td>
<td>Tunnel gullies or ‘under-runners’ are common on the Port Hills – these are subsurface erosion features ranging in aperture from a few millimetres to 2 m or more. A number of these have collapsed during earthquake shaking, leading to ‘sinkholes’ and sometimes the undermining of overlying foundations.</td>
</tr>
<tr>
<td>Spring formation</td>
<td>Increases in pore water pressures in the underlying rock strata have resulted in the formation of surface springs in some places, in particular on the lower soil slopes. This has resulted in land and basement floodings, foundation settlement (due to saturation of the foundation soils) and slope failures or creep movements (due to saturation).</td>
</tr>
</tbody>
</table>

Some of the land issues listed above also have public safety implications that are beyond the scope of the Building Act.
9.3 OBSERVED BUILDING PERFORMANCE

Building damage can be divided into two broad categories: damage that was caused solely by earthquake shaking; and damage that resulted from ground deformation including liquefaction, lateral spreading or landslip.

While shaking damage to dwellings has been observed on the flat, the February and June 2011 aftershocks in particular caused significant shaking damage to hillside houses. The observed high vertical accelerations were responsible for severe damage sustained by tile roofs and brick veneers, and unreinforced foundations were often severely cracked.

(i) Simple settlement cases

<table>
<thead>
<tr>
<th>Uniform settlement</th>
<th>Tilt settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Uniform settlement diagram" /></td>
<td><img src="image2.png" alt="Tilt settlement diagram" /></td>
</tr>
</tbody>
</table>

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

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

Liquefaction effects on buildings

Liquefaction-induced ground movement has caused stretching, hogging, dishing, racking/twisting, tilt, differential settlement, differential displacement or any combination of the above to buildings. The severity of the damage is dependent on the damage type, the type of building, the building geometry and the amount of foundation movement that has occurred.

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

Differential settlement – abrupt change

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

(iii) Lateral stretching

Lateral stretching of a foundation may occur when the ground beneath it spreads laterally during the ground shaking. This action is often accompanied by liquefaction and associated ground settlement.

If the floor plate of the dwelling is not strong enough, then the lateral spreading will cause an extension of the floor plate (i.e., the concrete floor slab will crack or the timber floor will fracture generally at joints between framing members).

Combinations of any of the above settlement cases and also combinations of settlement and stretching are possible.
9.4 LINKING LAND AND BUILDING PERFORMANCE

The Building Code requirements are described in section 8. The Earthquake Loadings Standard, NZS 1170.5: 2004, is cited as a Verification Method (B1/VM1) for the satisfaction of Building Code performance requirements.

The NZS 1170.5 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 SLS levels of shaking, no significant building damage is expected. The geotechnical issue is what is expected of the ground under such levels of shaking. The ground shaking experienced in large areas of Christchurch on 22 February 2011 exceeded that of a ULS level event, while on 4 September 2010 it generally fell between a ULS and SLS event.

Liquefaction areas

In the areas where liquefaction occurred, 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 areas of liquefaction). A number of house foundations did rupture during the Canterbury earthquake sequence and were consequently close to collapse.

In the very severe land damage zone, the houses were in varying states. In many parts of this zone, the habitability of dwellings was compromised by excessive land movement.

Where buildings require demolition because they cannot be repaired within the building value, but have remained safely habitable, these buildings can be considered as having met the ULS performance requirements of the Building Code.

Hillside areas

The hillside areas are currently subject to ongoing work by Christchurch City Council, CERA, EQC and GNS Science to investigate causes and implications of various forms of damage. In particular, areas of rockfall, cliff collapse and boulder roll are being evaluated to determine appropriate remediation or retreat options. Some larger-scale apparent landslide mechanisms and wide-area ground cracking are also being investigated for similar reasons. Outside these areas it is envisioned that repairs and reconstruction will be able to proceed subject to site-specific investigation and design, as outlined in section 6.
10. Future liquefaction performance expectations for land and buildings

10.1 FUTURE LAND PERFORMANCE

Based on observations of the distribution of land damage in the Canterbury earthquake sequence, it is apparent that the performance of the ground across Canterbury in potential future seismic events will vary considerably from location to location. The potential for liquefaction (based on the soil type, soil strength and depth to groundwater) is variable across the region, ranging from negligible liquefaction potential in some areas to high liquefaction potential in other areas.

For any given site, the actual degree of liquefaction in future events will also be variable, depending on the location of the earthquake in relation to the site, the depth of rupture, the magnitude of the event and the duration of shaking. Furthermore, the surface manifestation of damage (degree of land settlement, sand boils, surface rupture, lateral spread, etc) will vary depending on subsurface stratigraphy and geometrical landform differences (e.g., relative levels, proximity to free edges such as rivers, ground slope etc).

It is considered that land that liquefied in either of the 4 September 2010, 22 February 2011 or 13 June 2011 events has a relatively high likelihood of liquefaction in future strong shaking events. However, the degree and consequences of liquefaction will be highly variable. Furthermore, future events could be of longer duration, higher energy, and in different locations, therefore other areas that were not affected by the recent earthquakes may be affected in future strong shaking events.

It is possible to improve the performance of land by various means to reduce the severity and impact of liquefaction. It is also feasible to increase the resilience of foundation systems to reduce the impacts of liquefaction on building structures where the land liquefaction performance is within certain limits.

Land that has been shown to be most susceptible to severe damage in the recent events has been zoned ‘Red’ by the Government and CERA, where it is difficult to improve the future performance without large scale civil engineering works that would require the demolition of whole suburbs to efficiently complete. In the ‘Red Zone’, it is seen as impractical, uneconomic and too disruptive to undertake such extensive works. However, most land in the remaining areas on the flat (the ‘Green Zone’) is expected to be repaired on an individual basis should land remediation be required; otherwise foundation systems can be constructed to cope in an appropriate manner with the expected future liquefaction performance of the land.

Foundation Technical Category Maps for areas on the flat

Foundation Technical Category Maps for each of Christchurch City, Waimakariri District and Selwyn District have been prepared in conjunction with this document. These maps are shown in Figures 3.1a, b and c. It should be noted that these plots may well change in some areas over time as further geotechnical information is gathered, both from general and site-specific investigations. As indicated in section 3, current site-specific information will be available online (details to come).

The foundation technical category areas have been identified as being at low, medium and high probability of future liquefaction, primarily based on the performance of land from the 4 September 2010 earthquake and 22 February 2011 aftershock, together with observed land performance from a number of the large aftershocks experienced up to and including 13 June 2011. In addition to this, borehole data, together with limited historic groundwater data, were considered in the preparation of the maps.

Because the 22 February 2011 aftershock was located immediately to the southeast of central Christchurch, it was considered a good test case for the central, southern and eastern areas of Christchurch.
The Selwyn District and portions of northern Christchurch up to Waimakariri District experienced ground accelerations significantly less than the surrounding areas, and therefore the land performance from the earthquakes in these areas gives less of a guide to future seismic land performance. For this reason, the foundation technical categories for these areas are only partly based on observed performance from the earthquakes, and take more account of known soil types and groundwater depths.

In the near future it is expected that additional analysis of suburb-wide geotechnical borehole and Cone Penetrometer Test (CPT) investigation information will be undertaken as information becomes available. On this basis, revised versions of the maps may be produced in the future.

The correlation between the three foundation technical categories and observed land performance is summarised in Table 10.1.

<table>
<thead>
<tr>
<th>FOUNDATION TECHNICAL CATEGORY</th>
<th>OBSERVED LAND PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC1</td>
<td>TC1 covers those areas of greater Christchurch where no significant land deformation occurred as a result of liquefaction from either the 4 September 2010 earthquake or the 22 February 2011 aftershock and there is generally greater than 3 m depth to groundwater.</td>
</tr>
<tr>
<td>TC2</td>
<td>TC2 covers those areas of greater Christchurch where no or negligible land deformation occurred as a result of liquefaction from the 4 September 2010 earthquake and only small amounts of land deformations occurred as a result of the 22 February 2011 aftershock. It also includes some areas in Selwyn District and northern Christchurch that did not suffer land damage but are considered at some risk of potential ground damage from liquefaction until proved otherwise.</td>
</tr>
<tr>
<td>TC3</td>
<td>TC3 covers those areas of greater Christchurch where land deformation occurred as a result of liquefaction from the 4 September 2010 earthquake and moderate to severe land deformations occurred as a result of or the 22 February 2011 aftershock, together with the areas identified at high future probability of ground damage.</td>
</tr>
<tr>
<td>Un-categorised</td>
<td>Un-categorised areas include: parks, commercial areas and properties greater than 4,000 m², together with those areas that were not mapped for damage from the 4 September 2010 or the 22 February 2011 earthquakes.</td>
</tr>
</tbody>
</table>
10.2 FUTURE BUILDING PERFORMANCE

The future performance expectations of property owners, insurance companies and territorial authorities is likely to include building some resilience into reconstructed dwellings so the overall performance of dwellings will be better than the performance observed from the Canterbury earthquake sequence. The seismic risk for the region has increased in the short to medium term, and the construction of more resilient structures will help to significantly limit losses and disruption from future earthquakes. At the same time, it is impractical to expect no damage in a future event. The philosophy of the Building Code is to limit damage in small to medium sized earthquakes, particularly to critical elements, while preventing collapse of structures in large earthquakes.

The performance expectations that repaired and reconstructed dwellings should meet are as follow:

1. Existing structural elements should not comply to any lesser extent than before the alteration, notwithstanding any Gazetted change in seismic hazard for the site.
2. New structural elements are required to meet the performance requirements of the Building Code.
3. New dwelling foundations are constructed to accommodate the land performance expectations in Table 3.1.
4. Foundation solutions for new dwellings should include provision for some resilience to be incorporated into the structure.

In areas where future land damage is considered unlikely (TC1), the practical approach for new construction is to ensure the foundation is tied together (e.g., reinforced slab). In many cases where land damage is expected to be moderate (TC2), it is more practical to manage building performance by improving building and foundation resilience to ground movements, rather than trying to prevent the land from being damaged in a future moderate to large earthquake. This is easier to achieve with reconstructed dwellings than by adding resilience to repaired dwellings.

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 building distortion.

Repaired foundations

Those dwellings with foundations that can be repaired (see section 4) will need to be assessed on a case-by-case basis to determine the degree of additional resilience that can be practically included in the repair at reasonable cost. Accordingly, a different approach is recommended for rebuilt foundations (see section 5). This may require ground strengthening to improve liquefaction performance or reduce liquefaction susceptibility.

Housing stock that is repaired without any foundation improvement is likely to have a similar level of foundation performance to that observed in the recent Canterbury earthquake sequence, when subjected to future similar levels of shaking.

New foundations and new dwellings

For new foundations beneath existing superstructures and new dwellings, the foundations should be designed to be able to resist possible lateral spreading of the ground beneath the foundation and to limit future distortion of the foundation to the criteria provided in Table 3.1.

Where possible, the foundation system should have sufficient stiffness to permit re-levelling by jacking at perimeter points, accompanied by pressure grouting or resin injection beneath the house interior. 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.
The repair and new foundation options outlined in this document should only be applied to sites where future lateral spreading of less than 50 mm in the serviceability limit state can occur.

Where houses are rebuilt, the option exists to build light-weight dwellings and 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 better tolerate differential ground settlement than the unreinforced slabs and unconnected strip footings present in many of the damaged dwellings. This will limit the amount of differential movement experienced by the superstructure, and significantly reduce damage following any future liquefaction event.

In TC1, the future ground deformation expectations are such that the NZS 3604 shallow piled foundations and slab-on-grade foundations (with B1/AS1 modifications), will provide appropriate future foundation performance. NZS 3604 infers from its definition of ‘good ground’ that settlements of up to 25 mm are acceptable.

In TC2, future land deformations expected beneath the dwelling may result in total and differential settlements as indicated in Table 5.3. Stiffened slab options, as described in section 5, are proposed for TC2 to provide an appropriate future foundation performance.

In TC3 (subject to confirmation by specific investigation), the potential future land deformations are likely to be greater than could be expected to be accommodated by any of the solutions proposed for TC1 and TC2, with the exception of Option 5 in section 5.3.

Possible solutions for TC3 are under consideration at the time of publication of this Guide.

Expectations for services in liquefaction areas

The potential for lateral spreading and liquefaction on a property will place excessive stress on services that connect between the street and the dwelling unless they are designed to accommodate the expected movements. Guidance on measures to alleviate the stress on services is provided in section 5.6.

It is also recommended that extra grade be provided for piped services that rely on gravity for operation (eg, sewer and stormwater), together with more flexibility at service connections.

Subdivisions

Any proposed future residential subdivisions should not rely on the Foundation Technical Category Maps for foundation design or other geotechnical guidance. Site-specific investigations should be undertaken as required by the relevant territorial authority, including the advice of a suitably qualified geotechnical engineer.

A set of guidelines for the investigation and assessment of subdivisions has been prepared and is included in Appendix B2 of this document. It is recommended that all subdivisions are investigated following these guidelines, and the land is categorised into one of the three foundation technical categories. At subdivision consent stage, appropriate general foundation solutions should be proposed for buildings on the land. In some cases it will be advantageous for the land to be improved on a subdivision-wide basis, so a different foundation technical category (and therefore set of foundation solutions) is appropriate.
Appendices

A1 Re-levelling systems and outline method statements for re-levelling and repairing foundations and floors in TC1 and TC2 99
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Appendix A1: Re-levelling systems and outline method statements for re-levelling and repairing foundations and floors in TC1 and TC2

The four foundation lifting methods presented below have all been used extensively over many years for re-levelling foundations that have settled.

Lifting option 1: Perimeter foundation jacking 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 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, along with under-wall shoes fitted with jacks or bolted jacking brackets 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. The screw piles may also be used as a permanent support.

Lifting option 3: Perimeter foundation jacking and slab re-levelling 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. This process also densifies the adjacent ground which serves as a reaction layer for the lifting operation.
Lifting option 4: Perimeter foundation jacking and slab re-levelling using thixotropic (low mobility) grout

This process involves drilling and inserting grout injection ports at predetermined locations and depths beneath the structure to permit the injection of grout. The thixotropic or low mobility grout (LMG) is introduced in a number of stages and at optimum pressures into the ground beneath the foundations (typically 1 m to 3 m below the foundations) to raise the ground immediately below the structure together with the structure back to its original level. This process has been shown to improve the ground bearing capacity.

For each of these four re-levelling processes, it is important that specialist contractors be used. Practitioners must 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.

The tables on the following pages provide suggested outline method statements in their broadly recommended sequence for re-levelling foundations and floor slabs of existing houses as summarised in section 4.

Please note:

These approaches will not suit all houses that are considered repairable; each house will require careful consideration.

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

All aspects associated with weathertightness and making good finishes shall be separately specified by appropriately qualified persons.

Please note:

These approaches will not suit all houses that are considered repairable; each house will require careful consideration.

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

All aspects associated with weathertightness and making good finishes shall be separately specified by appropriately qualified persons.
## FOUNDATION RE-LEVELLING METHOD STATEMENTS

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

Refer to section 4.3.2.

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Remove the cladding attached to the exterior piles to expose the piles and retain if possible.</td>
</tr>
<tr>
<td>2.</td>
<td>Locate services entry points to the house and allow for disconnection or relief of these during the floor lifting operation. For example, dig away soil at water, waste, power and telephone connections to allow these to lift with the house.</td>
</tr>
<tr>
<td>3.</td>
<td>Check the vertical alignment of the piles. If existing piles are leaning at an angle of more than 15 mm per 1 m height, new piles will be required (see point 7 below).</td>
</tr>
<tr>
<td>4.</td>
<td>Detach the piles from the bearers.</td>
</tr>
<tr>
<td>5.</td>
<td>Install jacking equipment and sequentially lift the affected areas. Make sure no differential displacement is created throughout this process that exceeds the requirements in Column 2 of Table 2.3. During the jacking process make allowance for lateral stability of the detached structure.</td>
</tr>
<tr>
<td>6.</td>
<td>For floor lifts of up to 100 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 use 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, 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.</td>
</tr>
<tr>
<td>7.</td>
<td>For lifts greater than 100 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.</td>
</tr>
<tr>
<td>8.</td>
<td>For dwellings that have settled more than 100 mm, no pile tops should be less than 150 mm above the ground level (NZS 3604 requirement). If piles have settled to a level less than this, 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 (this NZS 3604 requirement may be greater than what was in place prior to the earthquakes). If no piles extend more than 300 mm above the surrounding ground, additional bracing is unlikely to be needed. (This is less than the requirement 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 installing 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.)</td>
</tr>
<tr>
<td>9.</td>
<td>Reattach the cladding to the outside of the piles.</td>
</tr>
<tr>
<td>10.</td>
<td>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, appropriate remediation will be required to satisfy the Building Code.</td>
</tr>
<tr>
<td>11.</td>
<td>For assessment of and repairs to the superstructure, refer to Section 7. Ancillary attachments to the house such as heavy chimney foundations and breastworks, concrete steps, and concrete terrace and timber deck areas will need to be remediated if their levels no longer align with the new floor level.</td>
</tr>
</tbody>
</table>
TYPE B: PERIMETER CONCRETE FOUNDATION WALL REPAIR METHOD STATEMENT

Refer to section 4.3.3 for light- or medium-weight claddings and section 4.3.4 for heavy veneer claddings.

Preparatory work

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Establish whether there is adequate bearing capacity for remedial works (e.g., 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 for its current condition.</td>
</tr>
<tr>
<td>B2</td>
<td>Locate services entry points to the house and allow for disconnection or relief of these during the floor lifting operation. For example, dig away soil at water, waste, power and telephone connections to allow these to lift with the house.</td>
</tr>
<tr>
<td>B3</td>
<td>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, new piles will be required. Leans of less than this value are considered to be acceptable if there is a perimeter foundation present.</td>
</tr>
<tr>
<td>B4</td>
<td>Disconnect the internal piles from the bearers.</td>
</tr>
<tr>
<td>B5</td>
<td>Demolish ancillary structures such as steps and terraces as necessary. Chimney foundations and breastworks may be lifted using the process described below if they are not being demolished.</td>
</tr>
</tbody>
</table>

Lifting option 1: Perimeter foundation jacking using portable jacks

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1.1</td>
<td>Clear the perimeter of the foundation. 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. Make sure no differential displacement is created throughout this process that exceeds the requirements in column 2 of Table 2.3. 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 the services are able to accommodate the lift heights or detach these before the lift begins.</td>
</tr>
<tr>
<td>B1.2</td>
<td>Concurrently with the wall jacking, jack the underside of the bearers beneath the house to create and maintain the planar floor.</td>
</tr>
<tr>
<td>B1.3</td>
<td>For floor lifts of up to 100 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 use pairs of wire dogs and 100 mm skewed nails for timber piles and 4 mm wire and staples for concrete piles).</td>
</tr>
<tr>
<td>B1.4</td>
<td>For lifts greater than 100 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.</td>
</tr>
<tr>
<td>B1.5</td>
<td>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 to 24 hours and remove the jacking equipment.</td>
</tr>
<tr>
<td>B1.6</td>
<td>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.</td>
</tr>
<tr>
<td>B1.7</td>
<td>Seal the inside and outside faces of the foundation wall at each crack in the foundation wall and epoxy grout the crack.</td>
</tr>
<tr>
<td>B1.8</td>
<td>Reconnect any services that had been disconnected prior to the lift.</td>
</tr>
<tr>
<td>B1.9</td>
<td>Reinstate the adjacent ground.</td>
</tr>
<tr>
<td>B1.10</td>
<td>For assessment of and repairs to the superstructure, refer to section 7.</td>
</tr>
</tbody>
</table>
Lifting option 2: Perimeter foundation jacking using piles (screw or similar)

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2.1</td>
<td>Clear the perimeter of the foundation. At a spacing of about 2 m around the perimeter install proprietary screw piles to the required depth to obtain sufficient bearing capacity.</td>
</tr>
<tr>
<td>B2.2</td>
<td>Ensure the services can accommodate the lift heights or detach these before the lift begins.</td>
</tr>
<tr>
<td>B2.3</td>
<td>Detach the piles from the bearers.</td>
</tr>
<tr>
<td>B2.4</td>
<td>Fit the lifting components to the tops of the screw piles and under the edge of the foundation. Lift the foundation sequentially by a small amount (increments of 3 mm maximum). 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. Make sure no differential displacement is created throughout this process that exceeds the requirements in column 2 of Table 2.3.</td>
</tr>
<tr>
<td>B2.5</td>
<td>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 removing the screw piles (if they are to be removed).</td>
</tr>
<tr>
<td>B2.6</td>
<td>The screw piles may be left in place or removed.</td>
</tr>
<tr>
<td>B2.7</td>
<td>Concurrently with the foundation wall jacking, jack the underside of the bearers beneath the house to create and maintain the planar floor.</td>
</tr>
<tr>
<td>B2.8</td>
<td>For floor lifts of up to 100 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 use pairs of wire dogs and 100 mm skewed nails for timber piles and 4 mm wire and staples for concrete piles).</td>
</tr>
<tr>
<td>B2.9</td>
<td>For lifts greater than 100 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.</td>
</tr>
<tr>
<td>B2.10</td>
<td>Seal the inside and outside faces of the foundation at each crack and epoxy grout the crack.</td>
</tr>
<tr>
<td>B2.11</td>
<td>Reconnect any services that had been disconnected prior to the lift.</td>
</tr>
<tr>
<td>B2.12</td>
<td>Reinstate the adjacent ground.</td>
</tr>
<tr>
<td>B2.13</td>
<td>For assessment of and repairs to the superstructure, refer to section 7.</td>
</tr>
</tbody>
</table>

Lifting option 3: Perimeter foundation jacking using engineered resin

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B3.1</td>
<td>Ensure the services can accommodate the lift heights or detach these before the lift begins.</td>
</tr>
<tr>
<td>B3.2</td>
<td>Set up laser equipment for monitoring floor movement.</td>
</tr>
<tr>
<td>B3.3</td>
<td>Detach the piles from the bearers.</td>
</tr>
<tr>
<td>B3.4</td>
<td>Install injection ports to the predetermined pattern and spacing along that section of foundation to be re-levelled. Commence injection below the perimeter foundation wall, making sure no differential displacement is created throughout this process that exceeds the requirements of column 2 of Table 2.3.</td>
</tr>
<tr>
<td>B3.5</td>
<td>Carry out injection in a controlled manner, monitored by suitable equipment such as a laser and staff, to gradually raise the foundation to the required level.</td>
</tr>
<tr>
<td>B3.6</td>
<td>Concurrently with the foundation wall lifting, jack the underside of the bearers beneath the house to create and maintain a planar floor.</td>
</tr>
<tr>
<td>B3.7</td>
<td>For floor lifts of up to 100 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 use pairs of wire dogs and 100 mm skewed nails for timber piles and 4 mm wire and staples for concrete piles).</td>
</tr>
</tbody>
</table>
APPENDIX A1: RE-LEVELLING SYSTEMS AND OUTLINE METHOD STATEMENTS FOR RE-LEVELLING AND REPAIRING FOUNDATIONS AND FLOORS IN TC1 AND TC2

B3.8 For lifts greater than 100 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 For assessment of and repairs to the superstructure, refer to section 7.

Lifting option 4: Perimeter foundation jacking using thixotropic or low mobility grout (LMG)

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B4.1</td>
<td>Ensure the services can accommodate the lift heights or detach these before the lift begins.</td>
</tr>
<tr>
<td>B4.2</td>
<td>Set up laser equipment for monitoring floor movement.</td>
</tr>
<tr>
<td>B4.3</td>
<td>Detach the piles from the bearers.</td>
</tr>
<tr>
<td>B4.4</td>
<td>Install injection ports to the predetermined pattern and spacing along that section of foundation to be re-levelled. Commence injection below the perimeter foundation wall, making sure no differential displacement is created throughout this process that exceeds the requirements of column 2 of Table 2.3.</td>
</tr>
<tr>
<td>B4.5</td>
<td>Carry out injection in a controlled manner, monitored by suitable equipment such as a laser and staff, to gradually raise the foundation to the required level.</td>
</tr>
<tr>
<td>B4.6</td>
<td>Concurrently with the foundation wall lifting, jack the underside of the bearers beneath the house to create and maintain a planar floor.</td>
</tr>
<tr>
<td>B4.7</td>
<td>For floor lifts of up to 100 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 use pairs of wire dogs and 100 mm skewed nails for timber piles and 4 mm wire and staples for concrete piles).</td>
</tr>
<tr>
<td>B4.8</td>
<td>For lifts greater than 100 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.</td>
</tr>
<tr>
<td>B4.9</td>
<td>Seal the inside and outside faces of the foundation at each crack and epoxy grout the crack.</td>
</tr>
<tr>
<td>B4.10</td>
<td>Reconnect any services that had been disconnected prior to the lift.</td>
</tr>
<tr>
<td>B4.11</td>
<td>Reinstate the adjacent ground.</td>
</tr>
<tr>
<td>B4.12</td>
<td>For assessment of and repairs to the superstructure, refer to section 7.</td>
</tr>
</tbody>
</table>
TYPE C: SLAB-ON-GRADE METHOD STATEMENT

Refer to section 4.3.5 for light- or medium-weight claddings and section 4.3.6 for heavy veneer claddings.

Preparatory Work

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Establish whether there is adequate bearing capacity for remedial works (e.g., using a hand-held Scala Penetrometer).</td>
</tr>
<tr>
<td>C2</td>
<td>Locate services entry points to the house and allow for disconnection or relief of these during the floor lifting operation. For example, dig away soil at water, waste, power and telephone connections to allow these to lift with the house.</td>
</tr>
<tr>
<td>C3</td>
<td>Demolish ancillary structures such as steps and terraces as necessary. Chimney foundations and breastworks may be lifted using the process described below if they are not being demolished.</td>
</tr>
</tbody>
</table>

Lifting option 1: Perimeter foundation jacking using portable jacks

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1.1</td>
<td>Take up all floor coverings in the areas where the floor is to be re-levelled (lifted).</td>
</tr>
<tr>
<td>C1.2</td>
<td>Ensure the services can accommodate the lift heights by exposing and allowing them to lift with the wall, or detach these before the lift begins.</td>
</tr>
<tr>
<td>C1.3</td>
<td>Clear the perimeter of the foundation. 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 wall to be lifted sequentially by increments of 3 mm maximum. Make sure no differential displacement is created throughout this process that exceeds the requirements of column 2 of Table 2.3. Alternatively, the jacks may be placed adjacent to the outside face of the foundation wall and ‘L’ shaped shoes bolted to the wall to act as a lifting bracket.</td>
</tr>
<tr>
<td>C1.4</td>
<td>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 wall lifting.</td>
</tr>
<tr>
<td>C1.5</td>
<td>Start the edge beam lifting process by creating a planar floor plate, even if this is sloping, and then sequentially lift the foundation wall and slab until a horizontal floor plate is achieved.</td>
</tr>
<tr>
<td>C1.6</td>
<td>Install grout injection ports and pump non-shrink flowable grout under the elevated foundation. Leave to cure for 12 to 24 hours and remove the jacking equipment.</td>
</tr>
<tr>
<td>C1.7</td>
<td>Fill the space between the underside of the foundation and the ground at the jack pits between the jacks with grout or concrete.</td>
</tr>
<tr>
<td>C1.8</td>
<td>Seal the outside face of the edge beam at each crack and epoxy grout the crack.</td>
</tr>
<tr>
<td>C1.9</td>
<td>Reconnect any services that had been disconnected prior to the lift.</td>
</tr>
<tr>
<td>C1.10</td>
<td>Reinstate the adjacent ground.</td>
</tr>
<tr>
<td>C1.11</td>
<td>Relay the floor coverings.</td>
</tr>
<tr>
<td>C1.12</td>
<td>For assessment of and repairs to the superstructure, refer to section 7.</td>
</tr>
</tbody>
</table>
### Lifting option 2: Perimeter foundation jacking using piles (screw or similar)

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2.1</td>
<td>Take up all floor coverings in the areas where the floor is to be re-levelled (lifted).</td>
</tr>
<tr>
<td>C2.2</td>
<td>Clear the perimeter of the foundation. At a spacing of about 2 m around the perimeter, install proprietary screw piles to the required depth to obtain sufficient bearing capacity.</td>
</tr>
<tr>
<td>C2.3</td>
<td>Ensure the services can accommodate the lift heights or detach these before the lift begins.</td>
</tr>
<tr>
<td>C2.4</td>
<td>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 (increments of 3 mm maximum). 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. Make sure no differential displacement is created throughout this process that exceeds the requirements of column 2 of Table 2.3. 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. This is a specialist process requiring skilled operators.</td>
</tr>
<tr>
<td>C2.5</td>
<td>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).</td>
</tr>
<tr>
<td>C2.6</td>
<td>The screw piles may be left in provided a permanent connection is made between the beam and the piles.</td>
</tr>
<tr>
<td>C2.7</td>
<td>Seal the outside face of the perimeter edge beam at each crack, and epoxy grout the crack.</td>
</tr>
<tr>
<td>C2.8</td>
<td>Reconnect any services that had been disconnected prior to the lift.</td>
</tr>
<tr>
<td>C2.9</td>
<td>Reinstate the adjacent ground.</td>
</tr>
<tr>
<td>C2.10</td>
<td>Relay the floor coverings.</td>
</tr>
<tr>
<td>C2.11</td>
<td>For assessment of and repairs to the superstructure, refer to section 7.</td>
</tr>
</tbody>
</table>

### Lifting option 3: Perimeter foundation jacking and slab re-levelling using engineered resin

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3.1</td>
<td>Take up all floor coverings in the areas where the floor is to be lifted.</td>
</tr>
<tr>
<td>C3.2</td>
<td>Ensure the services can accommodate the lift heights or detach these before the lift begins.</td>
</tr>
<tr>
<td>C3.3</td>
<td>Install grout injection ports to the predetermined pattern under the foundation wall and slab. Set up laser equipment for monitoring floor movement.</td>
</tr>
<tr>
<td>C3.4</td>
<td>Commence injection below the edge beam to lift the foundations and floor slab.</td>
</tr>
<tr>
<td>C3.5</td>
<td>Carry out injection in a controlled manner, monitored by a laser and staff or similar, to gradually raise the perimeter edge beam to the required level. Make sure no differential displacement is created throughout this process that exceeds the requirements of column 2 of Table 2.3.</td>
</tr>
<tr>
<td>C3.6</td>
<td>Once the edge beams have been raised to the final level, it may be necessary to commence additional injection via the ports in the floor slab to re-level it. 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.</td>
</tr>
<tr>
<td>C3.7</td>
<td>Seal the outside face of the foundation at each crack and epoxy grout the crack.</td>
</tr>
<tr>
<td>C3.8</td>
<td>Reconnect any services that had been disconnected prior to the lift.</td>
</tr>
<tr>
<td>C3.9</td>
<td>Reinstate the adjacent ground.</td>
</tr>
<tr>
<td>C3.10</td>
<td>Relay the floor coverings.</td>
</tr>
<tr>
<td>C3.11</td>
<td>For assessment of and repairs to the superstructure, refer to section 7.</td>
</tr>
</tbody>
</table>
Lifting option 4: Perimeter foundation jacking and slab re-levelling using thixotropic or low mobility grout (LMG)

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>C4.1</td>
<td>Take up all floor coverings in the areas where the floor is to be lifted.</td>
</tr>
<tr>
<td>C4.2</td>
<td>Ensure the services can accommodate the lift heights or detach these before the lift begins.</td>
</tr>
<tr>
<td>C4.3</td>
<td>Install grout injection ports to the predetermined pattern under the foundation wall and slab. Set up laser equipment for monitoring floor movement.</td>
</tr>
<tr>
<td>C4.4</td>
<td>Commence injection below the edge beam to lift the foundations and floor slab.</td>
</tr>
<tr>
<td>C4.5</td>
<td>Carry out injection in a controlled manner, monitored by a laser and staff or similar, to gradually raise the perimeter edge beam to the required level. Make sure no differential displacement is created throughout this process that exceeds the requirements of column 2 of Table 2.3.</td>
</tr>
<tr>
<td>C4.6</td>
<td>Once the edge beams have been raised to the final level it may be necessary to commence additional injection via the ports in the floor slab to re-level it. 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.</td>
</tr>
<tr>
<td>C4.7</td>
<td>Seal the outside face of the foundation at each crack and epoxy grout the crack.</td>
</tr>
<tr>
<td>C4.8</td>
<td>Reconnect any services that had been disconnected prior to the lift.</td>
</tr>
<tr>
<td>C4.9</td>
<td>Reinstate the adjacent ground.</td>
</tr>
<tr>
<td>C4.10</td>
<td>Relay the floor coverings.</td>
</tr>
<tr>
<td>C4.11</td>
<td>For assessment of and repairs to the superstructure, refer to section 7.</td>
</tr>
</tbody>
</table>
Appendix A2: Outline method statements for replacing foundations and slab-on-grade floors in TC1 and TC2

The tables on the following pages provide outline method statements in their broadly recommended sequence for replacing foundations and floor slabs in existing houses, as summarised in section 5.5.

Please note:
These approaches will not suit all houses that are considered repairable; each house will require careful consideration.
These approaches address only the structural aspects, with reference to damage to finishes only where they relate to re-levelling works.
All aspects associated with weathertightness and making good finishes shall 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. See section 7 for guidance.
TYPE A: PILE FOUNDATION REPLACEMENT METHOD STATEMENT

Refer to section 5.5.

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Remove the cladding attached to the exterior piles to expose the piles.</td>
</tr>
<tr>
<td>A2</td>
<td>Locate services entry points to the house and disconnect to allow the house to be lifted without damaging the services.</td>
</tr>
<tr>
<td>A3</td>
<td>Demolish or disconnect from the foundation of the house any chimney foundations, steps or terraces that may prevent the house from being lifted.</td>
</tr>
<tr>
<td>A4</td>
<td>Disconnect all existing piles from the bearers.</td>
</tr>
<tr>
<td>A5</td>
<td>Fit a multiple lifting system (eg, a 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 2 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. If there is space on the site or alternative space nearby to which the dwelling may be temporarily moved, this is another option.</td>
</tr>
<tr>
<td>A6</td>
<td>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.</td>
</tr>
<tr>
<td>A7</td>
<td>Remove all piles that have settled more than 100 mm beyond the expected new common level or piles raked at an angle of greater than 15 mm per 1 m height.</td>
</tr>
<tr>
<td>A8</td>
<td>Replace removed piles with timber or concrete piles in accordance with the requirements of NZS 3604.</td>
</tr>
<tr>
<td>A9</td>
<td>Lower the superstructure on to the completed pile array and connect all piles to bearers in accordance with the requirements of NZS 3604.</td>
</tr>
<tr>
<td>A10</td>
<td>Reconnect all services previously disconnected.</td>
</tr>
<tr>
<td>A11</td>
<td>Fit new base boards to the perimeter piles.</td>
</tr>
<tr>
<td>A12</td>
<td>Reinstate the adjacent ground.</td>
</tr>
</tbody>
</table>
# TYPE B: PERIMETER CONCRETE FOUNDATION WALL REPLACEMENT
## METHOD STATEMENT

Refer to section 5.5 for light- or medium-weight claddings and heavy-weight claddings.

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Establish whether there is adequate bearing capacity for remedial works (e.g., using a hand-held Scala Penetrometer).</td>
</tr>
<tr>
<td>B2</td>
<td>Locate services entry points to the house and disconnect to allow the house to be lifted without damaging the services.</td>
</tr>
<tr>
<td>B3</td>
<td>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, new piles will be required. Leans of less than this value are considered to be acceptable if there is a perimeter foundation present.</td>
</tr>
<tr>
<td>B4</td>
<td>Disconnect the internal piles from the bearers and the outer bearers and plates from the existing perimeter foundation.</td>
</tr>
<tr>
<td>B5</td>
<td>Demolish ancillary structures such as chimney foundations, steps and terraces.</td>
</tr>
<tr>
<td>B6</td>
<td>Fit a multiple lifting system (e.g., a 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 to replace damaged/leaning piles and demolish and construct a new perimeter foundation. This requirement is to aid the removal and replacement of the damaged piles and, particularly, the perimeter foundation walls with mechanical equipment. It also prevents the need to demolish parts of the foundation wall 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 partial rebuild of the foundation and then in the other direction to complete the rebuild. This is a specialist operation requiring skilled operators. If there is space on the site or alternative space nearby to which the dwelling may be temporarily moved, this is another option.</td>
</tr>
<tr>
<td>B7</td>
<td>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.</td>
</tr>
<tr>
<td>B8</td>
<td>Demolish the existing damaged perimeter foundation and construct a new foundation, reinforced as detailed in Figure 4.2 or 5.12, as appropriate. Install replacement piles.</td>
</tr>
<tr>
<td>B9</td>
<td>After 7 days, slide the superstructure over the new foundation, lower it onto the piles and foundation and reattach the plates to the foundation in accordance with NZS 3604. Reattach the piles to the bearers with stapled wire (concrete piles) or wire dogs and skew nails (timber piles), packing as required.</td>
</tr>
<tr>
<td>B10</td>
<td>Reconnect all services previously disconnected.</td>
</tr>
<tr>
<td>B11</td>
<td>Reinstate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.</td>
</tr>
</tbody>
</table>
TYPE C: SLAB-ON-GRADE FLOOR REPLACEMENT METHOD STATEMENT

Refer to section 5.5 for light- or medium-weight claddings and heavy veneer claddings.

<table>
<thead>
<tr>
<th>STEP</th>
<th>ACTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Establish whether there is adequate bearing capacity for a new floor slab (eg, using a hand-held Scala Penetrometer).</td>
</tr>
<tr>
<td>C2</td>
<td>Locate services entry points to the house and disconnect these remote from the foundation pad.</td>
</tr>
<tr>
<td>C3</td>
<td>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.</td>
</tr>
<tr>
<td>C4</td>
<td>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, this should be left untouched and the lining on the other side 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 heavy-weight exterior claddings, remove all the cladding and leave the lining intact on the inside face.</td>
</tr>
<tr>
<td>C5</td>
<td>Disconnect all hold down fixings (ie, bolts or bent bars) to allow the superstructure to lift above the floor slab.</td>
</tr>
<tr>
<td>C6</td>
<td>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 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.</td>
</tr>
<tr>
<td>C7</td>
<td>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. Reinstall the lifting system, now jacking on the underside of the bottom plates.</td>
</tr>
<tr>
<td>C8</td>
<td>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).</td>
</tr>
<tr>
<td>C9</td>
<td>Install steel sliding beams and slide the superstructure to the side of the site to allow the new floor to be constructed. 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 rebuild of the foundation and then in the other direction to complete the rebuild. If there is space on the site or alternative space nearby to which the dwelling may be temporarily moved, this is another option. Construct new floor slab in accordance with the requirements for the TC (see section 5.5).</td>
</tr>
<tr>
<td>C10</td>
<td>After 7 days, slide the superstructure over the new foundation, and lower to its final position. Reattach 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.</td>
</tr>
<tr>
<td>C11</td>
<td>Reconnect all services previously disconnected.</td>
</tr>
<tr>
<td>C12</td>
<td>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 using 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 re-establish 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. See section 7 for guidance.</td>
</tr>
<tr>
<td>C13</td>
<td>Re-stop the wall linings, re-fit any trims that were removed and redecorate.</td>
</tr>
<tr>
<td>C14</td>
<td>External sheet cladding connections and joints must also be checked and re-fixed. If the cladding has a bracing function, the sheet fixings must be checked and, if damaged, fixings must be installed in the intervening gaps. See section 7 for guidance. 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.</td>
</tr>
<tr>
<td>C15</td>
<td>Relay the floor coverings.</td>
</tr>
<tr>
<td>C16</td>
<td>Reinstate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.</td>
</tr>
</tbody>
</table>
A3.1 BACKGROUND AND CONTEXT
This appendix contains information about the assessment of chimney damage and the selection of repair or rebuild options. The time that has passed since the publication of the Department’s guidance document in December 2010 has allowed for greater guidance information to be formulated for assessing and repairing damaged chimneys.

A3.2 OVERVIEW
Chimney failures were widespread in the Christchurch area following the 4 September 2010 earthquake and were often the most obvious sign of earthquake damage at any property.

Further failures occurred in the 22 February 2011 aftershock. Older chimneys tend to be constructed with clay bricks, cemented together with cement or lime mortar. The predominance of brick veneer cladding on Christchurch houses meant that the chimney was built to match the veneer and, if it was situated on the exterior of the house, it was often built integral with the veneer. Many older houses were also constructed with unreinforced brick load bearing walls and the chimneys were built integral with the wall (see Figure A3.1).

Figure A3.1. Failed double skin unreinforced masonry wall showing chimney cast integrally with the wall*

* Note that the chimney is no longer in service and the roof has been re-clad.
Other older chimney styles included precast pumice concrete blocks which provided for vertical bars to be grouted into the four corners of the chimney, although sometimes no reinforcement or grout was ever installed.

Modern brick chimneys are built to satisfy the provisions of the Building Code with a reinforced concrete flue within the brickwork and tied to the house framing.

Chimneys cantilever (unsupported) above the roof of the house and are heavy. This makes them particularly susceptible to the lateral ground motions of an earthquake. If they are not properly designed, they will fail at the roof level, toppling on to either the roof or the ground beside the house.

The 22 February 2011 aftershock had an unusually large vertical acceleration component (greater than 1 g) and this caused some of the weaker chimneys in the hill suburbs to lift off and impact down on their foundations. Combined with the high horizontal acceleration component, this caused them to bulge outwards, often pushing the adjacent wall linings into the surrounding rooms.

A3.3 CURRENT LEGISLATION FOR CHIMNEYS

The Department’s document Canterbury Earthquake Recovery Information for Home Owners and Building Practitioners – Building Work that does not require a Building Consent as at 20 September 2010 notes that repairing or replacing a chimney or flue does not require a building consent.

However, despite this exemption, repaired or new chimneys must still meet the Building Code performance requirements. The most relevant Building Code requirements are those relating to Structure (Clause B1), Fire Safety (Clause C) and External Moisture (Clause E2). Any repairs or rebuilds must be done correctly to prevent the possibility of a potential chimney collapse, house fire or weathertightness failure.

The Department issues Acceptable Solutions and Verification Methods (Compliance Documents) under the Building Act that correlate to clauses in the Building Code. These documents are voluntary but, if they are followed, the work will be Building Code compliant.

Verification Method B1/VM3 provides full details for the construction of new chimney foundations, fireplaces and chimneys, covering brick chimneys with and without liners, and pumice concrete.

Restraint details for the chimney stack at the ceiling level and at floor levels are also provided, along with a table of extra bracing demands on a supporting NZS 3604 or NZS 4229 structure. Users of this table (Table 2 in B1/VM3) are reminded that they should use the earthquake Zone A demands if the house is located in Christchurch City, Waimakariri District, or Selwyn District as of 19 May 2011.

Acceptable Solution C/AS1 Part 9 details modifications to three Standards for solid fuel appliances (AS/NZS 2918), gas burning appliances (NZS 5261) and oil fired appliances (AS1691) for each type to satisfy the Building Code requirements, particularly with respect to the provision of restraint against earthquake actions. C/AS1 also stipulates required minimum dimensions and clearances for fireplaces and flues to ensure the risk of outbreak of fire is kept to an acceptable minimum.

Acceptable Solution E2/AS1 notes that the intersection of roofs and chimneys is a ‘very high risk area’ for potential weathertightness issues. Accordingly, E2/AS1 requires treatment of the roof in the chimney penetration area.

Compliance Documents may be downloaded for free from www.dbh.govt.nz/building-code-compliance-documents-downloads
As noted above, various Standards are relevant for the consideration of chimney repairs and rebuilds. These are:

- NZS 1170.5 Structural Design Actions – Earthquake Actions – New Zealand
- NZS 3101 Concrete Structures Standard
- NZS 3109 Concrete Construction
- NZS 4210 Masonry Construction: Materials and Workmanship
- AS/NZS 2918 Domestic Solid Fuel Heating Appliances Installation
- NZS 5261 Gas Installation
- AS 1691 Domestic Oil-fired Appliances – Installation

A3.4 ENVIRONMENT CANTERBURY CLEAN AIR REQUIREMENTS


Outside the Christchurch, Kaiapoi, Rangiora and Ashburton Clean Air Zones 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.

In Kaiapoi Clean Air Zone 1 – it is illegal to use an open fire or a solid fuel burner that is older than 15 years (ie, from the 15th anniversary of its first installation, as recorded on a building permit or consent) without a resource consent.

In Rangiora Clean Air Zone 1 – it will be illegal to use an open fire or a solid fuel burner that is older than 15 years (ie, from the 15th anniversary of its first installation, as recorded on a building permit or consent) without a resource consent from May 2012.

In Ashburton Clean Air Zone 1:

- an open fire must not be used
- a solid fuel burner not approved by Environment Canterbury that was installed before 1 January 2001 must not be used
- a solid fuel burner not approved by Environment Canterbury that was installed after 1 January 2001 must not be used after 15 years from that date
- a solid fuel burner approved by Environment Canterbury must not be used after 15 years from installation.

EECA is taking the opportunity to encourage the replacement of inefficient smoke producing open fireplaces with more efficient wood burners, pellet burners, gas burners or heat pumps, but the owner has the right to request a rebuild to match the style originally present. This is particularly important for heritage structures where the chimneys are an important part of the house style. This can still be achieved, however, while using lighter materials and more earthquake-resistant construction.

A3.5 CHIMNEY CONSTRUCTION MATERIALS AND CHIMNEY CONDITION

If the chimney has failed there will be an opportunity to discover its construction. Careful inspection preferably by an engineer, or otherwise a brick layer, will be required to determine the status of the remaining structure. This will determine possible repair options or whether complete demolition of the chimney is necessary.

A3.5.1 Recognising materials

Brick chimneys are likely to have a brick exterior if they are part of a brick veneer clad house. Similarly, they may have a stucco exterior coating if they are part of a stucco clad house. Pumice concrete chimneys may also be overclad with stucco.

The crack pattern on the exterior may be the key to deciding which type is present. Pumice concrete stack blocks are approximately 150 mm high whereas brick courses are approximately 75 mm high.
Pumice concrete chimney construction

If built correctly, there will be vertical reinforcing bars in each corner of the pumice concrete stack and the chimney ought not to be stressed significantly by the earthquake. However, it has been known for the grout to be left out of the corner ducts preventing the reinforcing steel from working as intended.

If present, crack patterns in pumice concrete chimneys generally follow the horizontal joints between blocks. Fine cracks would suggest that the chimney is reinforced. If the cracks are wider and/or the blocks are displaced from each other horizontally, it is likely that there is no grout in the corner ducts. Placing reinforcement in the ducts and grouting in accordance with B1/AS3 may be all that is necessary to repair damaged pumice concrete chimneys. However, a check should be made to ensure the chimney is correctly restrained to the structure at the roof and floor levels.

Clay brick chimney construction

Clay brick chimneys will have been constructed with either lime or cement mortar. Lime mortar can be easily scraped from the joints and, because of its weak nature, chimneys constructed with lime mortar are likely to have many cracks through the mortar joints if the chimney has not already fallen in the earthquake. Chimneys with cement mortar are more likely to survive an earthquake because of the greater bond between the mortar and the bricks.

Concrete brick chimney construction

Concrete brick chimneys are associated with more modern construction and the bricks will be joined together with cement mortar. Chimneys in the hill suburbs have been subjected to very high vertical accelerations, which may have been sufficient to cause the bond between the mortar and the bricks to be broken. If unreinforced, these chimneys are not expected to be any stronger than clay brick chimneys with lime mortar.

A3.6 ASSESSMENT OF DAMAGED CHIMNEYS

The flowchart in Figure A3.2 provides a process for assessing and deciding on repair or replacement of chimneys. While the aim may be to install a clean heating device such as a heat pump, the owner may wish to retain the style of the house by rebuilding the chimney.

A3.7 REPAIR AND REBUILD OPTIONS

A3.7.1 Exterior chimneys

Chimney damaged over full height

If the chimney is damaged over its full height, it is very likely that it will need to be demolished. The options include installing a heat pump and making good the wall and roof where the chimney was situated, or rebuilding the chimney to the requirements of the Building Code. Detailed construction information is contained in the Acceptable Solutions B1/AS1, B1/AS3, C/AS1 and E2/AS1 for heavy chimney construction.

If a solid fuel burner, pellet burner or gas fire is to be installed, this equipment will have a metal flue which can be extended above roof level or enclosed in a light-weight chimney surround to keep the weight of the new construction to a minimum. Externally, below roof level this surround may be timber framed and clad with 20 mm thick brick slips or plastered to match the surrounding wall cladding.

The framing should be at maximum 600 mm centres with dwangs at maximum 1200 mm centres. It should be clad with 9 mm fibre cement sheets fixed at 150 mm centres with 40 mm x 2.5 mm galvanised or 316 stainless steel flat head nails. Brick slips require correct backing substrate and adhesive products and should be supported by 20 x 10 mm x 1.2 mm stainless steel angles fixed to the frame at maximum 2 m centres.
Appropriate clearance between the framing and the flue is paramount. Where the flue is enclosed and/or within and above the roof space, a triple flue is necessary. Generally, depending upon the heating device, the inner flue will have a 150 mm minimum diameter and the space between concentric flues is 25 mm, which results in a 250 mm diameter for the outer flue. A 25 mm clearance must be provided between the outer skin and any framing. The minimum inside dimension for the framing is therefore 300 mm. Free-standing solid fuel burners may have a single skin flue up to ceiling level. Inbuilt burners with ‘zero clearance cabinets’ can be built into framed-up walls. In the case of an open fire, the inner flue is commonly 250 mm diameter.

While the weight of this style of chimney is significantly less than a traditional brick chimney, it should still be tied to the house framing at the roof and floor levels.

Proprietary light-weight chimney options made up to a standard design or to replicate the original brick chimney, and fit over a timber or steel framework secured to the house, include Heritage Replica Chimneys (brick slips), Quake Safe Chimneys (moulded fibreglass) and Chim-Lite Chimneys (pressed steel).
Figure A3.1: Process for assessment and decision on repair or replacement of chimneys

- Existing chimney – determine material and condition
- Partial demolition and repair/full demolition engineer assessment
- Heating options – owner preference
  - Heat pump
  - Open fire – chimney repair
  - Flued heating device*

- Demolish chimney
- Chimney repair
- Flame heating device
- Install heat pump
- Install light-weight chimney (for effect)
- Seal off fireplace
- Install metal flue
- Partial demolition
- Make good to roof, cladding, etc.
- Install new heating device and flue
- Flash flue at roof penetration
- OR
- Encapsulate flue in new light-weight chimney

* Approved heating unit – log burner/pellet fire/gas fire.
Chimney damaged over part of its height

A careful inspection should be made to determine the extent of damage. It is likely that the section above the roof will be the worst affected, but this does not preclude the presence of damage below the roof line. If there is any doubt about the structural integrity of the chimney over its full height, it should be confirmed as safe by an engineer or demolished.

If it is established that the chimney is sound below the roof, it is still not recommended that the section above the roof be rebuilt with similar heavy materials if this can be avoided. Instead, the chimney should be dismantled to a point below the roof plane and a light-weight flue installed. In either case, a structural metal flue should be installed and grouted in place to provide additional strength to the chimney. It is important that the flue extends the maximum possible distance down the existing brick flue to provide the anchorage for the section cantilevering above the roof. At a minimum, the length below the roof should equal the length above the roof.

If the metal flue is connected to a wood burner, pellet burner or gas burner, the space between this flue and the brickwork must be ventilated.

For open fires, a range of flue diameters for this purpose are manufactured, noting that only a flue tested for the particular heating device should be used. In conjunction with the metal flue, a reinforced concrete ring should be cast over the top of the remaining flue and tied to the roof framing with a 50 mm x 4 mm metal strap bolted or coach screwed to the roof framing with three M12 coach screws (see B1/AS1, Figure 6).

Details of the two options are given in Figures A3.3 and Figure A3.4 of this document.

A3.7.2 Internal chimneys

Chimney damaged over full height

It is more difficult to determine the condition of an internal chimney because these are generally enclosed within wall framing and not easy to inspect. However, a damaged internal chimney poses a greater fire hazard than an external chimney so if there is any doubt about the integrity of the flue, the surrounding wall linings should be removed for a thorough inspection.

It is recommended that if there is any concern about the chimney it should be demolished and replaced with a modern metal flue system, in conjunction with a solid fuel burner, pellet fire or gas fire. Alternatively, other heating options could be chosen that do not require a flue, such as a heat pump.

The design of the exterior portion of the chimney can be replicated, if required, to maintain the style of the house – refer to light-weight chimney information under A3.7.1.

Chimney damaged only over the upper part of its height

If it can be confidently established that the chimney is damaged over only the upper section, then it should be possible to demolish the damaged section and cap the lower section, installing a metal flue system and light-weight surround in much the same manner as the exterior chimney case. To maintain the style of the exterior of the house, a fibreglass, pressed steel or brick slip system is recommended.

A rebuild of the upper section of the chimney with new or recycled bricks is not recommended because this will add significant weight to the unreinforced lower section. Therefore, while the upper section will be soundly constructed, there is the potential for this weight to cause collapse of the lower section in future events. This may also lead to a massive section of chimney falling through the roof rather than individual bricks that may be supported by the roof cladding.
Please note: Second-hand brick use must be supported by a bond strength test on the mortared bricks. This is a relatively simple test that is carried out by BRANZ and other agencies.

A3.8 ACKNOWLEDGEMENT

The assistance of Fletcher EQR in the preparation of this Appendix is gratefully acknowledged.

Figure A3.3: Chimney Option 1
Figure A3.4: Chimney Option 2

SUGGESTED CHIMNEY RECONSTRUCTION
OPTION 2: ONLY WHERE THE CHIMNEY STRUCTURE
BELOW ROOF LEVEL IS CONFIRMED AS
SOUND BY AN ENGINEER.

- COWL
- 250% INNER FLUE
- 250% OUTER FLUE
- 900 DMA. INTERMEDIATE FLUE
- FLEXIBLE BOOT FLASHING ON
  SOAKER TO 1B/AS1
- CONCRETE CAP WITH
  1/100 RESISTANCE RING
- EXISTING SOUND BRICK
  CHIMNEY

NOTE: WHERE A COUPLED FUEL
BURNER IS INSTALLED THERE
MUST BE A HEAT RESISTANT
SEAL BETWEEN THE INNER
FLUE AND THE PARING.

EXISTING CONSTRUCTION VARIATIONS:
- OVERHANG WIDTH
- SOFFIT CONSTRUCTION
- EXTERNAL CLADDING
- CHIMNEY BASE AND
  SKID.

CROSS SECTION THROUGH TYPICAL
EXISTING CHIMNEY.
Appendix A4: Assessment and repair options for concrete floor slabs damaged in the Canterbury earthquake sequence

A4.1 BACKGROUND
This appendix contains information on the assessment and repair of concrete floor slabs. Discussions subsequent to the publication of the Department’s December 2010 document have highlighted the need for greater guidance on concrete floor slabs.

A4.2 OVERVIEW
Concrete as a construction medium has been used extensively for many years and offers an economical and durable foundation and flooring material. The product can be cast to suit specific shapes and applications and is manufactured, supplied and placed under strict guidelines. It does however have one drawback: as it cures and gains strength, it shrinks. Shrinkage typically occurs in thin section floor slabs such as those used in houses at a rate of 1 mm per 1 metre length of slab, continuing for up to 2 years.

The shrinkage can be minimised by good mix design and control, correctly detailed and placed reinforcing, adequate curing and correctly detailed and positioned shrinkage control joints. These practices will not eliminate the cracking, but they do ensure the cracks are minimised and confined to acceptable locations.

A4.2.1 Normal crack control
To counteract the effects of random cracking of new floor slabs, shrinkage control joints are deliberately cut in the slab to a depth of one quarter of the slab thickness, generally within 24 hours of the slab being poured. These do not prevent the floor from cracking, but they seek to ensure the cracks form in predetermined lines, delineated by the saw cuts. As an alternative, a crack former can be cast in the bottom of the slab to cause the initiation of cracks in predetermined positions. It effectively reduces the thickness of the slab at that point, creating a weakness where the crack will form.

At internal corners of a concrete slab, the concrete can shrink away from the corner in two orthogonal directions, thus creating a diagonal crack from the corner into the slab. Placing a shrinkage control joint (SCJ) in each of the two directions at the corner will mitigate the potential for the diagonal crack to form (see Figure A4.1).

Random cracks can still occur despite shrinkage control measures. This can result from excessive delays before the cutting is carried out, the concrete mix being too wet at the time of pouring, or incorrect curing, in which case the shrinkage is greater than expected and is not totally accommodated by the shrinkage control cuts or formers.

Figure A4.1. Shrinkage control joints (SCJs) positioned to mitigate against diagonal cracks forming

A4.2.2 Slab reinforcement
Floor slabs in houses designed in accordance with NZS 3604 prior to the 2011 update may or may not be reinforced. The reinforcement may be mesh, polypropylene fibre or rebar. The function of the reinforcement is to prevent the occurrence of large single shrinkage cracks by forcing the cracks to be greater in number but much finer, and therefore acceptable.
It was never intended by the NZS 3604 drafting committee that it would be required to prevent tension failure of the slab when subjected to ground spreading beneath.

For the Canterbury earthquake region, the Department has issued an amendment to the citation of NZS 3604 requiring all slabs to be reinforced with ductile reinforcing steel or ductile mesh. Shrinkage control joints must still be cut in reinforced slabs at maximum 6 m centres, and bays may have a length-to-width ratio of up to 2.1. If the slab is not reinforced, the length of bays between joints must be a maximum of 3 m and the ratio of bay length to bay width must not exceed 1.3:1. See section A4.7 for slab reinforcement recommendations for new houses built within the Canterbury earthquake region (ie, Christchurch, Selwyn and Waimakariri territorial authority areas).

**A4.2.3 Slab/foundation connection**

It is currently acceptable in NZS 3604 buildings for the slab to be either mechanically connected to the foundation (reinforcing bars passing between the two) or, for single-storey buildings only, supported on the inside edge of the foundation with no mechanical connection, but with the foundation having an upstand outside of the slab. In the latter case, the expectation is that the slab will be retained by the foundation upstand.

Prior to the first publication of NZS 3604 (in 1978), it was possible for the slab to be fully disconnected from the foundation and sitting on top of the foundation over its full width. The 1987 Edgecumbe earthquake highlighted the shortcomings of this detail. Slabs were observed to slide over the foundation walls, severing services and causing misalignment of brick veneer claddings.

All foundation walls constructed since 1978 are expected to contain at least two D12 longitudinal steel bars, one at the top of the foundation and the other(s) at the bottom, with tie bars at a maximum of 600 mm centres between the top and bottom bars.

**A4.3 SLAB CRACKING: DIAGNOSIS OF LIKELY CAUSE AND IMPLICATIONS**

**A4.3.1 Investigation and diagnosis**

Crack widths in slabs may be determined by laying a graduated steel rule over the crack or by inserting a triangular probe which has width graduations marked up its length (see Figure A4.2).

The presence of floor coverings can mask the existence of cracks in the floor. Some floor coverings can accommodate separation of the slab at cracks. Ceramic floor tiles are probably the most susceptible to cracking in the slab (see Figure A4.3). At the other end of the spectrum, carpet will span over cracks up to 10 to 15 mm without any obvious distress, provided it has an underlay, although over time the crack may become obvious as the carpet wears. Vinyl floor coverings may stretch or crack depending on their age and the amount of foot traffic over the crack.
Figure A4.2 Typical shrinkage cracking in concrete slabs

Figure A4.3 Cracking of ceramic floor tiles over a shrinkage control joint in a floor not affected by earthquake

Random cracks in the floor slab which reduce in width to close to indiscernible as they approach the perimeter foundation (or any internal foundation) are shrinkage cracks and are not caused by an earthquake.

As shrinkage cracks occur frequently in concrete floor slabs, it is considered that small cracks (up to 1 mm, see Figure A4.2), whether caused by an earthquake or by shrinkage, can be left unrepaired, unless the shrinkage has had a visible effect on the floor covering.

Fine vertical cracks of uniform width in the exterior foundation of the house are likely to be caused by shrinkage, and may align with shrinkage control joints cut in the floor slab. Cracks in the foundation that widen with height are a good indicator that there has been some differential settlement of the foundation, which may be the result of the earthquake or they may be caused by long-term differential settlement of the foundations on weak soils.

When the crack is greater than 10 mm and up to 30 mm, there is a potential for there to be a vertical differential displacement across the crack. Any differential displacement will need to be remedied if the covering is vinyl flooring. For carpet coverings, a differential displacement of up to 2 mm is likely to be accommodated. Options for remediation include grinding the concrete on the high side of the joint or breaking back the slab on either side of the crack and refilling with concrete. Both cases aim to achieve a maximum slope of the floor of 1 in 200 (0.5%).

NZS 3604 limits the dimensions of floor slabs to a maximum of 24 m between free joints or between free joints and slab edges to further control shrinkage in large slabs. Free joints provide no restraint against spreading action in floor slabs and a clean separation of the slabs on either side of the joint may be expected. If free joints are encountered that have separated, repairs should follow the methods outlined in this document.
The assessment and repair decisions in relation to individual cracks must take into account the overall movement of the structure and slab. For example, if the slope of the slab in the vicinity of the crack is greater than 1 in 200, or the overall ‘stretch’ of the floor is greater than 20 mm, reconstruction of all or part of the slab is likely to be necessary.

**A4.3.2 The damp proof membrane (DPM)**

Damp proof membranes are installed beneath slabs during construction of a building to prevent moisture vapour from rising from the soil beneath into the concrete by capillary action and then into the interior of the building.

Polyethylene sheet is the most common DPM used beneath house floors and this product has the ability to stretch significant distances. When slab cracks are greater than 100 mm wide, there may be an associated rupture of the DPM which will need to be made good before the section of concrete is recast. If the crack is too small to see the bottom, there is very little likelihood that the DPM has been ruptured.

NZS 3604 has minimum particle size requirements for the grading of the compacted fill beneath the floor slab to prevent moisture from rising through the fill. In Canterbury, many of the houses with slab-on-grade foundations have a fill layer of rounded stones (tailings) over which the DPM has been placed. There is very little likelihood that moisture will permeate upwards through this sort of fill material. If liquefaction has occurred beneath the foundation, it is possible that fine sand particles have migrated into the gaps between the tailings material. This creates the potential for moisture vapour to more easily reach the underside of the DPM. DPMs that were damaged and not repaired during initial installation may allow moisture vapour to pass through the damaged areas into the concrete floor slab more easily with the sand in the tailings.

There are concrete surface coatings available that act as a vapour barrier and eliminate both dampness and water penetration if there is concern about the integrity of the DPM. These products would be suitable for use where there is a repaired section of slab or crack over an inaccessible DPM.

**A4.4 CRACK TREATMENT METHODS**

**A4.1 Repair criteria**

Table A4.1 below should be used as a general guide as to the nature and scale of repairs required to cracks in floor slabs in the absence of vertical misalignments or other earthquake-induced effects.

The repair materials considered most appropriate are epoxy resin for cracks up to 10 mm wide and cementitious grouts and mortars for cracks wider than 10 mm. These widths are offered as a guide only; variations can be made to these parameters in the hands of experienced operators.

<table>
<thead>
<tr>
<th>Floor slab crack widths</th>
<th>NO ACTION NECESSARY</th>
<th>REPAIR BY EPOXY INJECTION</th>
<th>REPAIR BY GROUT INJECTION</th>
<th>BREAK OUT AND RECAST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 mm</td>
<td>Between 1 mm and 10 mm</td>
<td>Between 10 mm and 20 mm</td>
<td>Greater than 20 mm</td>
<td></td>
</tr>
</tbody>
</table>

Table A4.1: Floor slab crack widths and repair approaches (in the absence of vertical misalignments)
These criteria are intended to provide guidance, rather than representing absolute criteria. However professional engineering input into the diagnosis and repair specification should be sought where cracks greater than 3 mm are purely related to earthquake (and don’t involve shrinkage considerations) and in all cases where cracks greater than 20 mm wide are encountered.

Repair decisions and specifications should also take into account other structural repairs being undertaken, such as re-levelling. No crack repairs should be undertaken before the re-levelling is completed except where the crack repair is required to contain the grout being used to re-level the slab.

In preparing this guide it has been assumed that the polythene DPM is intact in most cases, as indicated by research and observations in the field. Limited capillary action is expected through the rounded stones that have been commonly used as hardfill in Canterbury (see also section A4.3.2).

A4.4.2 Repair materials

Epoxy resin injection

The majority of professional injection processes offer either low pressure, two-part metering and pumping kits, or batch premixed and pressure pumping kits.

Pre-packaged hand-held self mixing epoxy resin cartridges are readily available for minor work.

Cementitious (cement) grout injection

Grout for crack repair comes in packages for mixing in high speed shear mixers and can be placed using low pressure, low volume displacement pumps.

There are other grouts suitable for this purpose, but they are usually applied in wet conditions. This guide is applicable for use on interior (dry) slabs.

Grout is used in this Guide to describe both epoxy resin and cementitious grout. The reader should refer to the relevant section header to verify which grout is being described.

Repair mortars and cast concrete

Large cracks (>20 mm and say up to 50 mm) with no vertical displacement differential can be repaired with proprietary mortar. Cracks that have been broken out to correct vertical displacement (level tolerances) and to reconnect rebar may be repaired with fresh concrete.

A4.4.3 Repair processes

Please note: it cannot be assured that a crack will not reopen after the completion of any of the processes described below.

By virtue of their location, floor slab crack repairs only offer access to the top surface. Cleaning of the crack, successfully injecting the correct grout and filling the crack completely all require good operator skills.

The repair process usually involves the following steps:

1. Establishing the cause and extent of the crack – length, width and depth.
2. Clearing away any detritus from inside the crack and then cleaning the crack surfaces of dust, dirt, sand or water.
3. Preparing the surface of the crack for injection.
4. Injecting a suitable material.
5. Making good the affected area.

Crack cleaning

A clean crack can be re-bonded, thus resealing the slab. If the crack is not cleaned correctly, the injected resin or grout will only act as a gap filler and leave potential moisture paths either side of the grout.

If the crack is recent, clean and dry with no contaminants, proceed directly to surface preparation.

For cracks that are contaminated with sands and silts (liquefaction product), cleaning will require the use of high pressure water and air and a wet vacuum.

Should contamination be involved or suspected, and the crack is fine (say less than 2 mm) and cannot be cleaned with any certainty, it is suggested that the crack be chased out to 6 to 10 mm wide and 25 to 40 mm deep with a crack chasing grinder.
Surface preparation

Once the crack is cleaned and dried, the adjacent slab surface should be lightly sanded and vacuum cleaned to remove any remaining surface laitance. Care is needed to ensure any material removed from the surface is not allowed to enter the cleaned crack. Careful use of sanders or grinders fitted up to a vacuum will give the required outcome.

If there is a minor vertical offset (<2 mm) across the crack, this may be remedied by grinding the high side of the crack before cleaning and filling is carried out. The distance over which the grinding would be required beyond the crack will be determined by the floor covering to be subsequently laid. An alternative would be to use floor levelling compound to smooth the surface.

Crack injection

The crack width largely determines the product and process to be used. For cracks with no vertical displacement:

1. Widths from 1 mm up to about 3 mm should be filled with a medium viscosity epoxy resin injected through self-sealing surface ports placed (glued) at about 100 mm centres along the crack. The open crack between the ports should be sealed with a temporary surface sealant.
2. This injection process sometimes requires more than one application as the resin can flow from the bottom of the crack in areas where the crack width is slightly wider and spread onto the DPM. Usually a second, partial application will complete the process and fill the crack.
3. Widths between 3 mm and say 10 mm should be filled using a low viscosity (no-sag paste type) epoxy resin injected through a tube inserted near the base of the crack. This allows the resin to fill and fan out before moving the tube along the crack but keeping the nozzle embedded in the grout.
4. For crack widths between 3 mm and 5 mm, if a flattened injection nozzle is not suitable, drilling 5 mm diameter holes 75 mm deep through the crack at 100 mm centres before final cleaning of the crack will allow the grout to fill correctly.
5. Crack widths in excess of 10 mm and up to 50 mm are usually filled with proprietary cement grout or flowable mortar. The cracks are cleaned in the usual manner involving water/air blasting and vacuum cleaning and drying. The grout/mortar is mixed in accordance with the manufacturer’s direction and the thoroughly mixed grout pumped through a tube at nominal pressure filling the crack from the base. Commence injecting at one end of the crack and proceed to the other without removing the injection hose from the body of the grout. Clean off excess grout and allow to cure.

Slab breaking out and local recasting

For cracks that are greater in width than 20 mm and/or involve vertical offsets of greater than 2 mm at the crack, the slab may need to be broken back on either side. The break back distance will need to be sufficient to achieve a minimum floor slope of 1 in 200 in the repaired area. Saw cutting should be used to define the extent of breaking out, and to achieve a clean finishing line. Care must be taken to ensure the DPM is not disturbed. Should the DPM be disturbed during the breaking back process, lay new DPM material over the disturbed area and tape the edges to the existing DPM to restore the vapour barrier.

Cracks of this width are likely to be associated with fracture of mesh reinforcement. If broken reinforcing steel is encountered in the breaking back process, new steel must be lapped onto the steel on the two sides of the joint. Sufficient break back is required on both sides of the crack to ensure compliant lapping of the reinforcement can be achieved (ie, grids should overlap).

If no reinforcing steel is encountered, then a minimum width of break out of 200 mm and replacement with new concrete is recommended, provided the slope on the new concrete is not greater than 1 in 200.
A4.5 UNDERFLOOR HEATING

The two common methods of underfloor heating are electrical resistance elements (wires) and hydronic systems (fluid flowing in pipes) buried in the concrete. A rupture of either of these will cause a failure of the system. Because the elements of each type are continuously bound to the concrete, even a small crack opening (greater than may be expected from controlled shrinkage) may fracture the element.

Prior to any repair work being undertaken on the crack, a test of the underfloor heating system should be carried out to ascertain whether it is still working and, in the case of the hydronic system, not leaking. If the system has failed, careful breaking back of the slab on either side of the crack will be required to allow effective repairs to be made to the system. The repaired system should then be trialled before the crack repair is undertaken.

A4.6 STRUCTURAL SLAB OVERLAYS

Slab overlay options are not recommended as an option for floor levelling for the following reasons.

A particular concern with the addition of slab overlays is that there is a risk of reflective cracking from the slab beneath. Advice from the concrete placing industry is that the minimum overlay slab thickness should be 100 mm to prevent curling of the concrete during curing and to minimise the possibility of reflective cracking. If the lowest point in the damaged slab is 200 mm below the highest point, the maximum thickness of the overlay will be 300 mm. This will add considerable weight and expense.

Bonded reinforcing ties to the existing perimeter foundation wall and to the existing slab on a grid of a maximum of 1 m centres are required for connection of the overlay slab to the existing slab to ensure uniform distribution of the curing shrinkage and a tie coat of cement slurry is required to bond the new concrete to the old concrete.

The cost of preparing the damaged slab and the volume of new concrete required indicates that it would generally be simpler and more effective to remove the old slab foundation and cast a new one.

A4.7 SLAB REINFORCEMENT FOR NEW HOUSES IN CHRISTCHURCH, SELWYN AND WAIMAKARIRI TERRITORIAL AUTHORITY AREAS

Experience in these recent Canterbury earthquakes has shown up the brittleness of traditionally used reinforcing mesh. In many instances, the mesh has fractured as the slab has been dragged apart under lateral spreading of the ground beneath. The 66X meshes normally used have low ductility characteristics, with a uniform elongation of only 1.5% as observed in many mesh failures.

Since 2006, NZS 3604 has called for reinforcing mesh in floor slabs constructed in accordance with that Standard to be either Grade 500N or Grade 500E. The required properties for these grades are contained in AS/NZS 4671:2001. Of particular importance are the uniform elongation requirements (5% for class N and 10% for class E) and the ratio of the maximum tensile strength to the yield strength (minimum of 1.08 for class N and 1.15 for class E).

In August 2011, the Department referenced NZS 3604:2011 as an Acceptable Solution in the B1 Structure Compliance Document with some changes to the requirements for reinforcing in slabs of NZS 3604 buildings for the whole of New Zealand. The reinforcing mesh must now be Grade 500E only.

It is recommended that new slabs be reinforced with either ductile deformed reinforcing bars (eg, D10 bars at 300 mm centres each way or D12 bars at 450 mm centres each way) (an alternative solution) or equivalent strength earthquake ductility class (500E) reinforcing mesh. This reinforcement will provide adequate resistance to future ground spreading actions beneath the suggested new foundations given in section 4.
At the time of publication, it is understood that Grade 500E reinforcing steel mesh complying with AS/NZS 4671:2001 is now available. Alternatively, lower grade ductile mesh may be used provided the uniform elongation characteristics are sufficient and the weight of mesh specified is 500 divided by the minimum yield stress of the steel in the mesh multiplied by 2.27 kg/m² or 1.15 kg/m² in each direction (the requirement for Grade 500 mesh in NZS 3604).13

It is important that the mesh is supported at the correct height in the fresh concrete for good bond and shrinkage control, and chairs should be provided to maintain a 30 mm top cover. Reinforcing mesh fabric laps need to be a minimum of one grid wire spacing plus 50 mm, but not less than 150 mm.

13 Refer to www.dbh.govt.nz/earthquake-concrete-slabs-guidance
Appendix B1: Summary of the effects of liquefaction

The following explanation is provided for liquefaction, lateral spreading and bearing capacity failure associated with the Canterbury earthquake sequence.

Loose granular soil deposits tend to compact (‘contract’) when subject to shearing from strong earthquake shaking. If the soils are unsaturated, the ground surface will generally just settle as the soil densifies. Where these soils are saturated, however, the readjustment of the soil particles within the soils as it tries to contract leads to a build-up of pressure within the inter-granular (‘pore’) water, which has to be ‘squeezed out’ of the inter-granular spaces (‘voids’) to allow this contraction of the soil particles to occur.

In liquefiable soils, the soil permeability is not high enough to allow rapid dissipation of this excess pore water pressure. During strong earthquake shaking, the rapid rate of increase in the pore water pressure can cause the pore water pressure to exceed the soil overburden pressure. (The overburden pressure is derived from the weight of the overlying soil mass and gives rise to the soil’s frictional strength.) Once this occurs, the soil inter-granular contact pressure (and therefore the soil’s frictional strength) is lost – the soil then behaves as a dense fluid – ie, it ‘liquefies’. Liquefaction requires three key elements to occur:

- the presence of loose, non-cohesive material that will tend to densify under seismic shaking (loose fine sands and many loose silt-sand mixtures are particularly susceptible to liquefaction)
- ground saturation (ie, the material susceptible to liquefaction lies below the groundwater table), and
- sufficient shaking to trigger liquefaction – it should be noted that 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:

- lateral spreading and the associated development of ‘graben’ features (ie, the ground shifts sideways and tension cracks develop where the ground has torn apart)
- bearing capacity failure of foundations
- 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)
- 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)
- settlement of the ground surface additional to that caused by the initial shaking densification (usually from sand boils ejecting liquefied material)
- the floatation of buried services and ‘buoyant’ structures such as pipelines, manholes, swimming pools and tanks.

Observations indicate lateral spreading, rotational failures and settlement have caused a large portion of the most severe building damage attributable to the Canterbury earthquake sequence.

Lateral spreading may occur if all or part of a sloping soil mass liquefies and results in the horizontal movement of the ground surface. Liquefaction of deeper material may cause a ‘crust’ to slide towards a topographically lower area such as a river bed or pond. Lateral spreading can occur with or without permanent stretch (ie, strain) at the ground surface. Where there is permanent ground surface strain, surface cracks and fissures (ie, graben feature or tension crack/tear zone) will occur. The foundations of buildings located in these areas can potentially suffer from damage due to the lateral extension forces generated and any design will have to consider these. Horizontal movement can also occur without ground surface strain where the main slide occurs as a single mass.
In these areas buildings with shallow foundations can move without suffering significant damage. However, where deep piles are embedded into a deeper bearing layer this may give rise to issues of pile verticality and any design would need to address this. Lateral spreading is principally only likely in TC3. Further guidance for TC3 foundations is to be developed.

The excess pore water pressures are expected to gradually dissipate after the seismic shaking has ceased. With time, the liquefied ground stabilises 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 fully dissipate and essentially return to a level which existed prior to the earthquake. 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. It should also be noted that ground settlements may result in groundwater levels becoming closer to the surface (i.e., reduced crust thickness).

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

In general, all soils that experienced liquefaction during any of the events in the Canterbury earthquake sequence are expected to be at risk of liquefaction during 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, see the recent NZ Geotechnical Society guidelines (NZGS, 2010).
Appendix B2: Guidelines for the investigation and assessment of subdivisions

MINIMUM REQUIREMENTS FOR GEOTECHNICAL ASSESSMENT FOR LAND DEVELOPMENT (CANTERBURY REGION)

B2.1 INTRODUCTION

In support of both Plan Change applications and Subdivision Consent applications, appropriate geotechnical investigations shall be carried out, and stand-alone geotechnical reports prepared by a suitably qualified and experienced geotechnical engineer (CPEng). The reports shall combine all relevant geotechnical information in both a factual and interpretive manner, provide justifiable statements about all pertinent geotechnical aspects and consider relevant RMA section 106 issues.

In Canterbury, the requirements for geotechnical assessments for subdivisions are set out to a certain degree in the following documents (all available online):

- Christchurch City Council – Infrastructure Design Standards
- Selwyn District Council – Engineering Code of Practice

Additional guidance is given in the following Standards (available from Standards New Zealand):

- NZS 4431 Code of Practice for Earth Fill for Residential Development
- NZS 4404: 2010 Land Development and Subdivision Infrastructure.

However, these documents do not give specific guidance on the assessment of liquefaction risk. In the first instance, for liquefaction assessments reference should be made to the following New Zealand Geotechnical Society publication (available online):


In conjunction with these documents, the minimum requirements for assessing liquefaction for land development in Canterbury are summarised below.

B2.2 SITE INVESTIGATION

Appropriate geotechnical investigations shall be carried out to enable the characterisation of ground forming materials to at least 15 m depth below ground level, unless the ground is known to be of acceptable quality from lesser depths (for example, in areas known to be underlain by competent gravels and deep groundwater profiles, or in hillside areas).

Following an appropriate desktop study to evaluate existing subsurface information in the vicinity of the site, deep investigations shall consist of one of, or an appropriate mix of:

- CPT (Cone Penetrometer Test) testing
- SWS (Swedish Weight Sounding) testing
- Dynamic Penetrometer Testing
- physical drilling and sampling with SPT (Standard Penetration Testing)
- testpit excavations (eg, in ground of acceptable quality from shallow depths)
- laboratory testing as judged appropriate by a suitably qualified and experienced geotechnical engineer (CPEng).

Scala Penetrometer (‘DCP’ or ‘Dynamic Cone Penetrometer Testing’) testing is often useful as a shallow investigation tool in conjunction with the methods outlined above. However, Scala Penetrometer testing is not considered appropriate as the primary ground characterisation method.

In many areas of Canterbury, liquefiable deposits contain interbedded layers of relatively stiff gravel deposits and, therefore, CPT testing alone may not penetrate deep enough to achieve the depth of ground characterisation required.

Geophysical methods such as MASW (multi-channel analysis of surface waves) can be useful in characterising ground conditions between borehole locations.
Knowledge of the geological depositional environment can also be a guide to identifying areas of likely liquefaction susceptibility.

**B2.3 SITE INVESTIGATION DENSITY FOR OVERALL GROUND CHARACTERISATION**

The following minimum investigation density guidelines are recommended for deep investigations:

<table>
<thead>
<tr>
<th>INVESTIGATION STAGE</th>
<th>TOTAL NUMBER OF TEST/INVESTIGATION LOCATIONS (CUMULATIVE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site over 1 hectare</td>
</tr>
<tr>
<td>Plan change</td>
<td>0.2 to 0.5 per hectare (minimum of 5)</td>
</tr>
<tr>
<td>Subdivision consent</td>
<td>0.25 per lot (urban)</td>
</tr>
<tr>
<td></td>
<td>0.5 per lot</td>
</tr>
</tbody>
</table>

Note: The lower end of the recommended minimum range might be appropriate where investigations show ground conditions to be reasonably consistent (especially if MASW or the like is being used between investigation locations), while the upper end of the range may be more appropriate if ground conditions prove to be highly variable.

For the purposes of this table, a minimum effective lot size of 600 m² may be used.

If initial investigations demonstrate a lack of liquefaction potential, the engineer may judge fewer test locations or shallower depths of investigation to be appropriate. Conversely higher densities may be required where particular site conditions (subsurface complexities, site geometry etc) exist. In commercial or industrial land, specific development proposals may also lead the engineer to judge that fewer or more test locations are appropriate.

**B2.4 LIQUEFACTION ASSESSMENT**

In addition to standard geotechnical characterisation, the site data shall be analysed using recognised methods to determine liquefaction susceptibility and in particular likely ground deformations under design serviceability limit state (‘SLS’) and ultimate limit state (‘ULS’) ground motions.

**B2.4.1 Liquefaction analysis methodologies (minimum requirements):**

Recognised standard liquefaction analysis methods shall be used, in conjunction with specified input ground motions and, where appropriate, observations of land damage from recent seismic events.

**Ground input motions**

Refer to the latest data published by GNS Science on Canterbury seismicity and design peak ground accelerations for geotechnical analysis – note that this supersedes the updated ‘Z’ and ‘R’ values published by the Department in May 2011, which should not now be used for geotechnical purposes. (in press)
Liquefaction hazard, liquefaction induced settlements and lateral spread

Refer to the following documents or methodologies:

- Observations of damage or lack thereof in areas deemed to have been ‘sufficiently tested at or near ULS’ by recent seismic events can be used to judge the applicability or not of settlements calculated at the design SLS level (optional).

- It is hoped that, with time, a modified methodology for liquefaction settlement/damage calculation will be derived from extensive site data and damage observations in the recent earthquake sequence. This will be incorporated into these requirements at an appropriate stage.
- Modification by reference to soil deposit ageing is not considered appropriate in the Canterbury region.

**B2.5 BROAD CLASSIFICATION OF LAND**

The site’s liquefaction characteristics shall be assessed against the deformation limits in this guidance document, as summarised below in Table B2.1.

### Table B2.1: Liquefaction deformation limits and house foundation implications

<table>
<thead>
<tr>
<th>TECHNICAL CATEGORY</th>
<th>LIQUEFACTION DEFORMATION LIMITS</th>
<th>LIKELY IMPLICATIONS FOR HOUSE FOUNDATIONS (SUBJECT TO INDIVIDUAL ASSESSMENT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vertical settlement</td>
<td>Lateral spread</td>
</tr>
<tr>
<td></td>
<td>SLS</td>
<td>ULS</td>
</tr>
<tr>
<td>TC1</td>
<td>15 mm</td>
<td>25 mm</td>
</tr>
<tr>
<td>TC2</td>
<td>50 mm</td>
<td>100 mm</td>
</tr>
<tr>
<td>TC3</td>
<td>&gt;50 mm</td>
<td>&gt;100 mm</td>
</tr>
</tbody>
</table>

* Note that certain foundation details included in NZS 3604 are precluded from use in Canterbury (refer to: www.dbh.govt.nz/information-sheet-seismicity-changes).
The geotechnical report shall identify likely requirements for construction of buildings to meet the design requirements as prescribed by the Department of Building and Housing, with respect to liquefaction and lateral spread. In addition to this, the geotechnical report should address all other normal geotechnical aspects (soil types, static bearing capacities, RMA section 106 hazards etc).

**B2.6 SITE INVESTIGATION DENSITY AT BUILDING CONSENT STAGE**

The density and depth of ground investigation at building consent stage will vary depending on the information already available from earlier stages of investigation.

For land that fits into TC1 and TC2, the Department’s guidelines require as a minimum a shallow investigation to be carried out at each house site (similar to a normal NZS 3604-type investigation), and as a minimum four test locations for each house site would be required. The geotechnical engineer may judge it appropriate to carry out deeper or more intense investigations than this, particularly in TC2 if the previous subdivision consent level of investigation indicated a high variability in the assessed liquefaction potential.

For building sites in TC3 (or for sites where no previous ground characterisation and liquefaction assessment has been carried out), deep investigations and liquefaction assessments similar to those carried out at subdivision stage should be initiated (a minimum of one to two per house site), as well as a shallow investigation as judged necessary by the geotechnical engineer.

**B2.7 (ADVISORY ONLY) ENGINEERING ADVISORY GROUP RECOMMENDATIONS REGARDING LIQUEFACTION PERFORMANCE FOR NEW SUBDIVISIONS**

The expectations of a now risk-adverse public (who will be increasingly aware of the significance and in particular the cost implications of the three foundation technical categories) is such that developers should consider the potential advantages of the following:

- Incorporating building consent-level investigations at subdivision consent stage.
- Undertaking subdivision-wide ground remediation to bring liquefaction deformation performance characteristics up to the equivalent of TC1 performance (ie, ready to receive NZS 3604-cited foundations). This is particularly important where multi-section remediation is the most appropriate approach (for example, along river margins).
- Where it is not considered practical or economic to provide TC1-compliant building platforms, to provide TC2-compliant building platforms.
- On land that will remain in the TC3 category (which will be well signalled on LIMs and the like), to provide (as a package with the land sale) a cost-effective means of compliance with the Department’s requirements for buildings on this type of land.

Please note: It is recommended that residential lots in new subdivisions be provided as either TC1 or TC2.
References


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

Standards New Zealand, NZS 3604: 2011 Timber Framed Buildings

Standards New Zealand, NZS 3124:1987 Specification for Concrete Construction for Minor Works

Standards New Zealand, NZS 4229:1999 Concrete Masonry Buildings Not Requiring Specific Engineering Design


The following terms are used throughout this document.

<table>
<thead>
<tr>
<th>TERM</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCA</td>
<td>Building consent authority</td>
</tr>
<tr>
<td>Building platform</td>
<td>For properties potentially affected by flooding (see sections 5.2 and 8.4), a prepared mass of compacted soil to provide a base on which to construct a dwelling.</td>
</tr>
<tr>
<td>CPT</td>
<td>Cone penetrometer test</td>
</tr>
<tr>
<td>Deep piles</td>
<td>Non-3604 piles (driven, bored or screw) that are designed to transmit foundation loads to a deeper bearing stratum.</td>
</tr>
<tr>
<td>EIFS</td>
<td>Exterior insulation finishing system</td>
</tr>
<tr>
<td>Foundation damage</td>
<td>In the context of this document, damage (differential settlement, cracking, stretching, tilting, twisting) to foundation elements (individually or collectively) resulting from land or structure movement (vertical or horizontal) attributable to the earthquake sequence. Refer also to Table 2.2 and 2.3.</td>
</tr>
<tr>
<td>Foundations</td>
<td>Building element that transmits loads from the structure directly to the ground.</td>
</tr>
<tr>
<td>Geotechnical ultimate limit state bearing capacity</td>
<td>The ‘geotechnical ultimate limit state’ bearing capacity is the calculated ultimate bearing capacity of the soil in geotechnical terms. The ‘structural’ (or ‘dependable’, ‘allowable’, ‘reduced’) ultimate limit state bearing capacity is the geotechnical ultimate bearing multiplied by a strength reduction factor (normally in the vicinity of 0.5), to be compared with fully factored loads as per AS/NZS 1170. The ‘allowable bearing capacity’ is the geotechnical ultimate limit state bearing capacity divided by a factor of safety (often 3), to be compared with unfactored working loads (ie. the old ‘working stress’ method).</td>
</tr>
<tr>
<td>Good ground</td>
<td>Ground that has static bearing capacity (geotechnical ultimate) of 300 kPa or better and is free of other hazards, as defined in NZS 3604:2011.</td>
</tr>
<tr>
<td>Heavy roof</td>
<td>A roof with roofing material exceeding 20 kg/m² but not exceeding 80 kg/m² of roof area (eg, concrete and clay tiles).</td>
</tr>
<tr>
<td>Heavy wall cladding</td>
<td>A wall cladding having a mass exceeding 80 kg/m², but not exceeding 220 kg/m² of wall area. Typical examples are clay and concrete masonry veneers.</td>
</tr>
<tr>
<td>LBP</td>
<td>Licensed building practitioner</td>
</tr>
<tr>
<td>Light roof</td>
<td>A roof with roofing material not exceeding 20 kg/m² of roof area (eg, sheet metal roofing and metal tiles)</td>
</tr>
<tr>
<td>Light wall cladding</td>
<td>A wall cladding having a mass not exceeding 30 kg/m². Typical examples are weatherboards.</td>
</tr>
<tr>
<td>Medium wall cladding</td>
<td>A wall cladding having a mass exceeding 30 kg/m² but not exceeding 80 kg/m² of wall area. (a typical example is stucco cladding).</td>
</tr>
<tr>
<td>NZS 3604</td>
<td>All references in this document to NZS 3604 are to the most recent publication of NZS 3604, this being NZS 3604: 2011, unless specifically stated. References include modifications made to NZS 3604 in Acceptable Solution B1/AS1.</td>
</tr>
<tr>
<td>Piles</td>
<td>A block or column-like member used to transmit loads from the building and its contents to the ground (from NZS 3604:2011). Generally, house piles are founded at a shallow depth (&lt;1.2 m) when the ground is ‘good ground’ as defined in NZS 3604. However, the presence of poor soils and liquefiable soils below the house may result in the need to install piles founded at significantly greater depths.</td>
</tr>
<tr>
<td>Slab-on-grade</td>
<td>Also known as slab-on-ground (refer to NZ3 3604).</td>
</tr>
<tr>
<td>SLS</td>
<td>Serviceability limit state. Refer to AS/NZS 1170.</td>
</tr>
<tr>
<td>SPT</td>
<td>Standard penetration test.</td>
</tr>
<tr>
<td>Superstructure</td>
<td>That portion of the dwelling above the underside of the wall bottom plate.</td>
</tr>
</tbody>
</table>
# Glossary of Terms

<table>
<thead>
<tr>
<th>TERM</th>
<th>DEFINITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A dwelling</td>
<td>Timber framed suspended timber floor structures supported only on shallow piles.</td>
</tr>
<tr>
<td>Type B dwelling</td>
<td>Timber framed suspended timber floor structures with perimeter concrete foundation and shallow piles in the interior space.</td>
</tr>
<tr>
<td>Type C dwelling</td>
<td>Timber framed dwelling on concrete ground floor.</td>
</tr>
<tr>
<td>ULS</td>
<td>Ultimate limit state. Refer to AS/NZS 1170.</td>
</tr>
</tbody>
</table>