Part A: Technical guidance

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2. Foundation assessment criteria and approaches

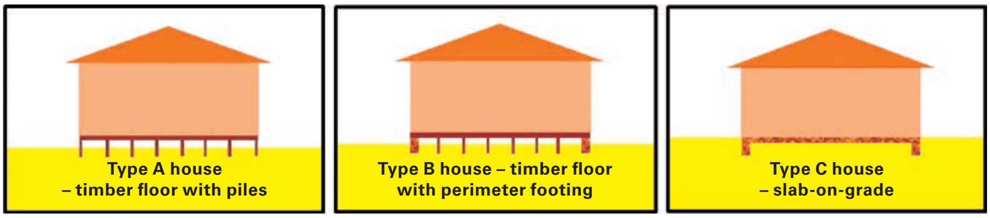
This section provides recommended criteria for the different levels of repair for house foundations that have damage from the earthquakes. The information in this section applies irrespective of house location – ie, both on the flat and on the Port Hills areas. Suggested assessment approaches are also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

Figure 2.1: Dwelling foundation Types A, B and C



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

Type A	Timber-framed suspended timber floor structures supported only on piles. Stucco, weatherboard or light texture-clad house.
Type B1	Timber-framed suspended timber floor structures with perimeter concrete foundation. Stucco, weatherboard or light texture-clad house.
Type B2	Timber-framed suspended timber floor structures with perimeter concrete foundation. Brick or concrete masonry exterior cladding (veneer).
Type C1	Timber-framed dwelling on concrete floor (slab-on-grade). Stucco, weatherboard or light texture-clad house.
Type C2	Timber-framed dwelling on concrete floor (slab-on-grade). Brick or concrete masonry exterior cladding (veneer).

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 relevelling. 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 before 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 and concrete perimeter foundations is given in Appendix A4.

Superstructure repairs may still be necessary, even if there is no foundation damage (see section 7).

Table 2.2: Indicator criteria for foundation damage not requiring structural repair (all technical categories)

Dwelling Foundation Type	Settlement Status		Lateral stretch status		Crack widths[1]/Other
Type A	Vertical differential settlement <50 mm and floor slope less than 1 in 200 between any two points >2 m apart	and	<20 mm [2]	and	Pile tilt <15 mm per 1 m height and no floor framing damage
Type B					<5 mm cracks in perimeter foundation
Type C					<5 mm cracks in the floor slab

(1) Crack widths are those principally related to earthquake actions
(2) A maximum lateral stretch of 20 mm is based on a resulting potential out of plumb of house end walls of 10 mm.

Some inconsistencies have been discovered in the advice given previously in the Guidance about dealing with cracks in slabs and foundation walls. Cracks can be caused by other than earthquakes, and shrinkage is a particular contributor to the formation of cracks in floor slabs. In perimeter foundation walls, cracks have often occurred at vents (where the cross-section is reduced) over the life of the foundation as a result of local foundation settlement unrelated to earthquake activity.

UPDATE:
December 2012
The 5 mm crack width criteria in Table 2.2 was aimed at distinguishing between foundation damage requiring specific engineering input and lesser structural damage that could be simply repaired if found to be caused by the earthquake. The crack-width criteria correlate well with work undertaken in the USA and reported in the January 2004 CUREE publication No. QED-02 titled 'General guidelines for the assessment and repair of earthquake damage in residential woodframe buildings'.

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 is 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 from 0.35% to 0.65% (approximately 1 in 300 and 1 in 150).

Furthermore, after the December 2010 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 than general (historical) settlement or initial construction tolerances.

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 relevelling, and then secondly, if it does, whether a relevel, a foundation rebuild or a house rebuild is likely to be required.

The indicator criteria provide guidance. They are not absolutes, as suggested by the dotted vertical lines between the columns.

UPDATE: December 2012

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 relevel 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 relevel should be able to be undertaken. If the limits in column 4 are exceeded a foundation rebuild should be an option. Finally, if the damage to the superstructure is uneconomic to repair, because the house has collapsed off the piles for example in floor Types A and B, then a complete house rebuild is indicated. If the floor profile fits within the criteria in column 3, the expectation is that the relevelling processes will result in a floor that is as near as reasonably practical to level and certainly within the criteria stated in column 2. These are the maximums of desired slope and differential displacement, and tighter tolerances should be targeted during relevelling 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.

UPDATE: December 2012
The criteria in Column 4 for Type B floors have been altered. Cracks >5 mm require structural repair as indicated in Table 2.2. Additional information has been provided about structural repairs of cracks in Appendix A4.

Table 2.3: Indicator criteria for floor/foundation relevel or rebuild (see also Figure 2.2)

Column 1	Column 2	Column 3	Column 4	Column 5
Floor type	NO foundation relevel considered necessary	Foundation relevel indicated	Foundation rebuild indicated (Partial or full)	House rebuild may be indicated
Type A Timber-framed suspended timber floor structures supported only on piles	The slope of the floor between any two points >2 m apart is <0.5% (1 in 200) [Note a] **and** The variation in level over the floor plan is <50 mm	The variation in floor level is >50 mm and <100 mm Note that the floor relevel is expected to be achieved by packing the piles	The variation in floor level is >100 mm [Note c] over the floor plan **or** The floor has stretched >50 mm [Note d] Note that full or partial re-piling is expected to be undertaken to achieve a level floor	The house has fully or partially collapsed off the piles and repair may be uneconomic This will relate to the degree of superstructure damage [Note f]
Type B Timber-framed suspended timber floor structures with perimeter concrete foundation	The slope of the floor between any two points >2 m apart is <0.5% (1 in 200) [Note a] **and** The variation in level over the floor plan is <50 mm	The variation in floor level is >50 mm and <100 mm [Note b]	The variation in floor level is >100 mm [Note c] over the floor plan **or** The floor has stretched >20 mm [Note e]	The house has fully or partially collapsed off the piles and repair may be uneconomic This will relate to the degree of superstructure damage [Note f]
Type C Timber-framed dwelling on concrete floor	The slope of the floor between any two points >2 m apart is <0.5% (1 in 200) [Note a] **and** The variation in level over the floor plan is <50 mm **and** There are no cracks in ceramic floor tiles **and** There is no distress in vinyl floor coverings or carpet	The variation in floor level is >50 mm and <150 mm **and** Services are functioning	The variation in level over the floor plan is >150 mm **or** There is irreparable damage to buried services within the house footprint	This will relate to the degree of superstructure damage [Note f]

UPDATE: December 2012

Note: Criteria are indicators only – a full assessment of the damage is required to make decisions on whether to repair or rebuild.

Explanatory notes to Table 2.3

a. Floor and superstructure damage repair may still be required, even if these indicator limits are not exceeded. Floor slopes are normally established by recording levels at the intersections of grid lines spaced at approximately 2 m in both directions and at obvious high spots and low spots.

UPDATE: December 2012

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 about 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 relevelling, 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. 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). AS/NZS 1170.0 Table C1 also provides guidance on acceptable deflection limits for wall linings.

UPDATE: December 2012

- damage to external claddings leading to a contravention of the various Building Code performance requirements (eg, E2).

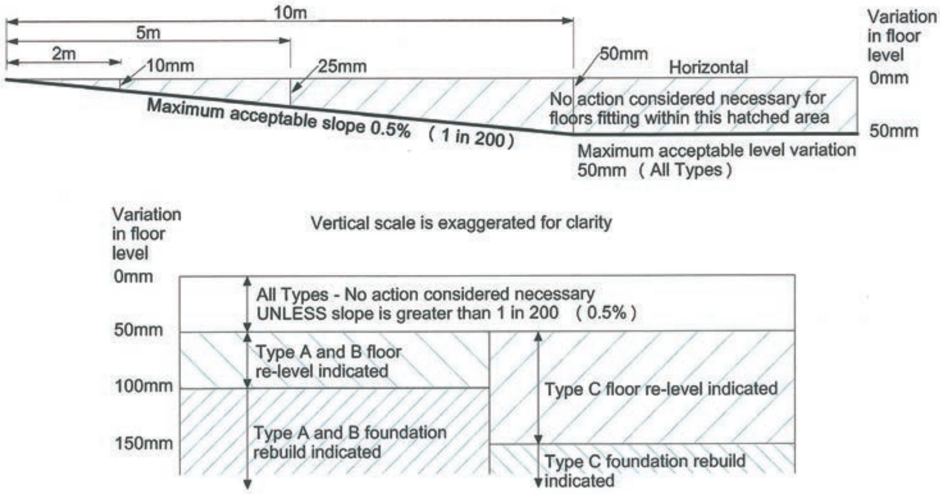
j. Foundation rebuilds are triggered by excessive differential settlements or excessive floor stretches, as covered in Table 2.3. However, the size of crack widths determines only whether or not a structural repair is required and this indicator criterion is already covered in the last column of Table 2.2.

k. The indicator criteria provide guidance, they are not absolutes, as suggested by the dotted vertical lines between the columns.

l. The column title which states "NO foundation relevel considered necessary" is intended to imply "– if all of the criteria below are met". Accordingly, all of the criteria listed below the title, which are actually upper limits on slopes and levels below which the floor must be performing, must be satisfied (ie "AND" should be used). When a relevel or rebuild is triggered by any of the situations described in the columns to the right of column 2, the recommendation is to at least regain all of the maximums stated in column 2.

UPDATE: December 2012

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 (eg, 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 relevelled or rebuilt, the superstructure is likely to be stressed either because the floor was not level before the earthquake and the process has undone any remedial action taken on the superstructure before 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 relevelling, a relevelling practitioner should be consulted to advise on the practicality of undertaking a relevel.

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 before and after each use.)

DELETION: December 2012

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

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 of 450 mm beneath the underside of floor joists. 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 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

UPDATE:
December 2012

To clarify repair and reconstruction options, residential properties in the CERA Green Zone on the flat have been assigned (on an area-wide basis) one of three foundation technical categories (TC1, TC2 and TC3) that reflect both the liquefaction experienced to date and future performance expectations.

The technical categories were established as a recovery measure and were intended to have a limited life. The technical categories will facilitate the recovery by providing an indication of what geotechnical assessments are required, and therefore:

- directing scarce engineering resources appropriately (given the observed building performance during the earthquake sequence and the knowledge of the ground that was available when they were established), and
- providing guidance on foundation solutions appropriate to both the ground on which houses are situated and the level of damage sustained by the house and land.

Over time it is anticipated that the technical categories will become less important because the detailed investigations being undertaken on TC3 properties (with results being captured in the Canterbury Geotechnical Database) will provide extensive knowledge of the subsurface ground conditions in these areas. This will enable appropriate foundations to be designed for future new building work without necessarily using the TCs as a starting point.

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. They are a starting point for assessing a particular site, in order to determine the appropriate foundation solution for each site.

UPDATE: December 2012

The foundation technical categories are defined as follows:

- **TC1:** Future land damage from liquefaction is unlikely, and ground settlements from liquefaction effects are expected to be within normally accepted tolerances. Once the TC is confirmed, shallow geotechnical investigations may be required (depending on the degree of damage, and in particular for a rebuild). If the 'good ground' test is met, NZS 3604 foundations (as modified by B1/AS1) can be used.
- **TC2:** Liquefaction damage is possible in future large earthquakes. Once the TC is confirmed, shallow geotechnical investigations may be required (depending on the degree of damage, and in particular for a rebuild) and, subject to establishing minimum bearing capacities, suspended timber floor or enhanced slab foundation options per section 5 can be used.
- **TC3:** Liquefaction damage is possible in future large earthquakes. Deep geotechnical investigation (or assessment of existing information) may be required (depending on the degree of damage, and in particular for a rebuild) and depending on the geotechnical assessment, might require specific engineering input for foundations.

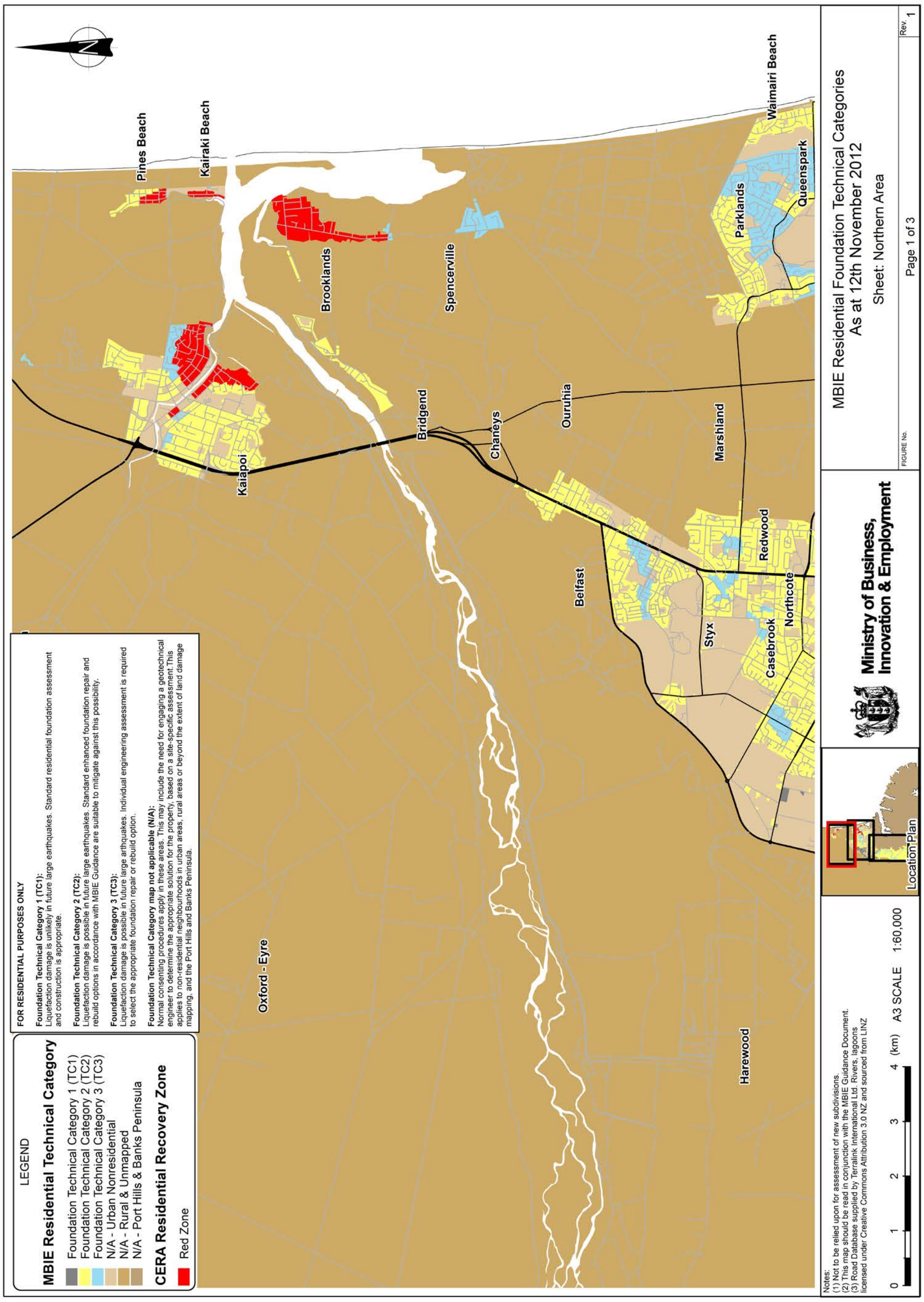
The technical categories are shown in the Foundation Technical Category Maps in Figures 3.1a to c on the following pages, colour-coded as follows:

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

UPDATE: December 2012

It is important to note that a property's technical category does not automatically determine the foundation options or actual future performance for that property, either of which can only be determined following an appropriate assessment. These assessments may lead to different outcomes than indicated by the property's technical category, in particular, TC3 properties may, after specific investigation, be found to be suitable for TC2-type foundations.

Figure 3.1a: Technical categories of the Greater Christchurch area on the flat – Northern Area (Waimakariri District) as at 12 November 2012



UPDATE:
December 2012
This map has been updated to reflect subsequent CERA land zoning decisions. In addition, checking to confirm whether properties were non-residential or on the Port Hills has resulted in about 1000 properties changing from a technical category to a not-applicable (N/A) category or vice-versa.

UPDATE: 01.09.12.
This map has been updated to reflect subsequent CERA land zoning decisions. In addition, checking to confirm whether properties were non-residential or on the Port Hills has resulted in about 1000 properties changing from a technical category to a not-applicable (N/A) category or vice-versa.

Figure 3.1b: Technical categories of the Greater Christchurch area on the flat – Central Area (Christchurch City) as at 12 November 2012

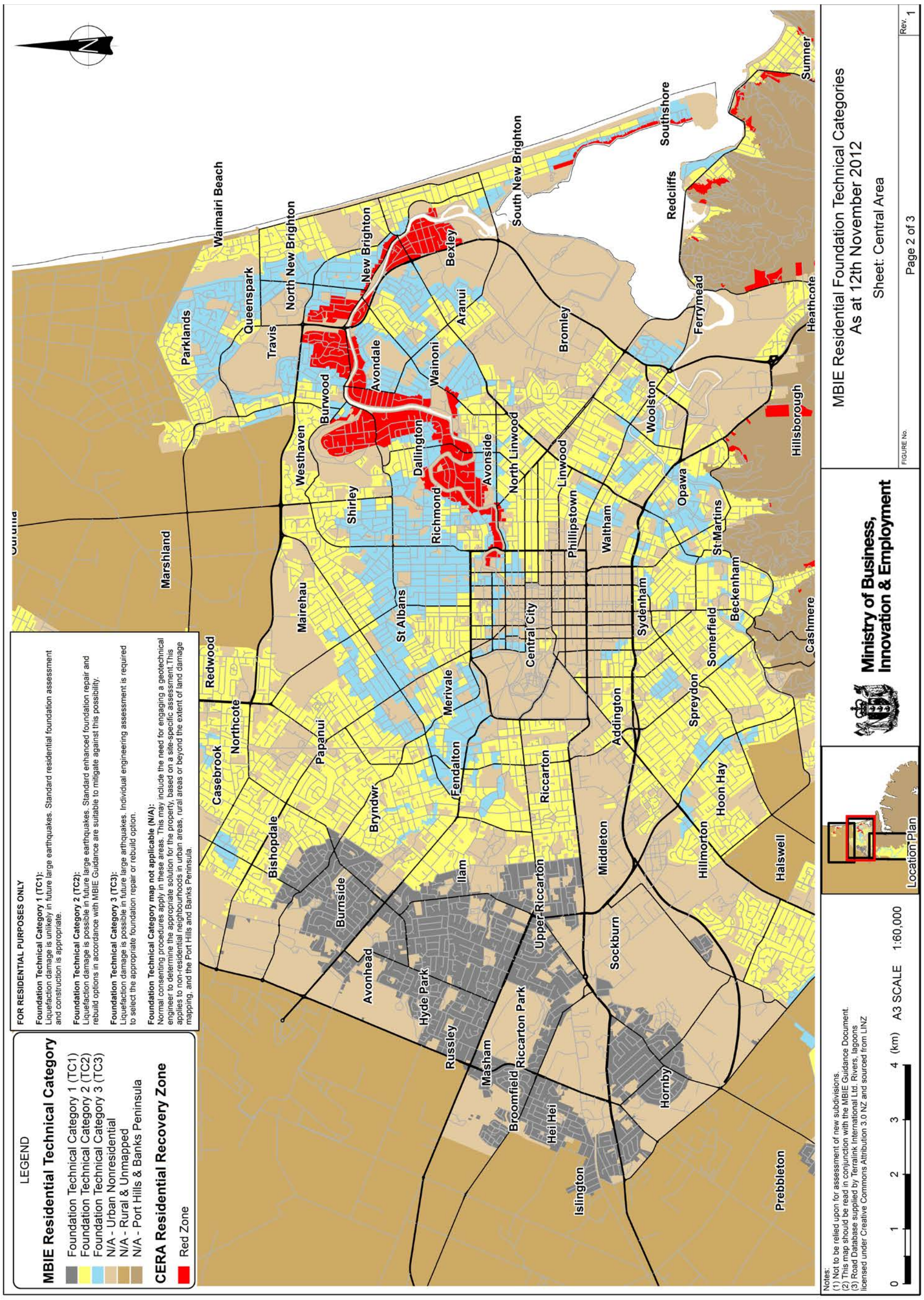
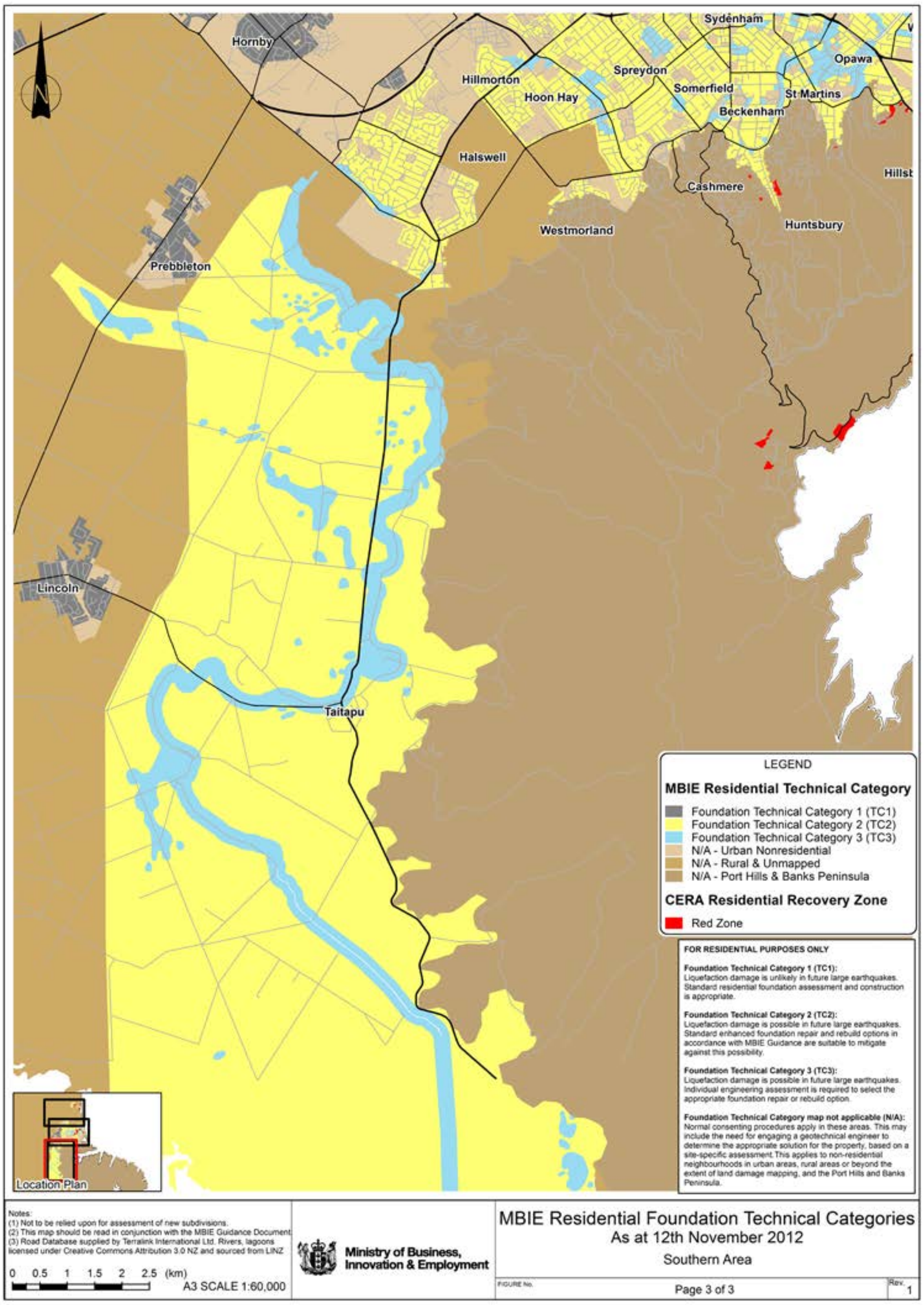


Figure 3.1c: Technical categories of the Greater Christchurch area on the flat – Southern Area (Selwyn District) as at 12 November 2012



The future land performance expectations for each of the foundation technical categories are summarised below (noting that further information is provided in section 10).

UPDATE:
01.09.12.
This map has been updated to reflect subsequent CERA land zoning decisions. In addition, checking to confirm whether properties were non-residential or on the Port Hills has resulted in about 1000 properties changing from a technical category to a not-applicable (N/A) category or vice-versa.

UPDATE: December 2012

Table 3.1: Index criteria for foundation technical categories

Foundation Technical Category	Future land performance expectation from liquefaction	Nominal SLS land settlement	Nominal ULS land settlement	Nominal Lateral Stretch
TC1 (where confirmed)	Liquefaction damage is unlikely in a future large earthquake	0–15 mm	0–25 mm	Generally not expected
TC2 (where confirmed)	Liquefaction damage is possible in a future large earthquake	0–50 mm	0–100 mm	<50 mm
TC3 (where confirmed)	Liquefaction damage is possible in a future large earthquake	>50 mm	>100 mm	>50 mm
Un-categorised	Land in the uncategorised 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. Normal consenting conditions apply. This may include the need for engaging a geotechnical engineer to determine the appropriate solution for the property, based on a site- specific assessment.	N/A	N/A	

UPDATE: December 2012

Note: 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 Part B, section 8.3) for importance level 2 structures.

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.

TC1 is based on observations of damage in the Canterbury earthquake sequence. In addition to such observations, TC2 includes locations where underlying soil types are potentially susceptible to liquefaction, as well as those areas where liquefaction was actually observed.

TC1 is generally regarded as most likely to be '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 Geotechnical Database as necessary canterburygeotechnicaldatabase.projectorbit.com. This facility will allow engineers to access technical category and existing geotechnical information specific to the site, and provides a means to enter the geotechnical data collected and facilitate building consent applications. Users must register to gain access to the information on this site. The Canterbury Geotechnical Database is administered by CERA.

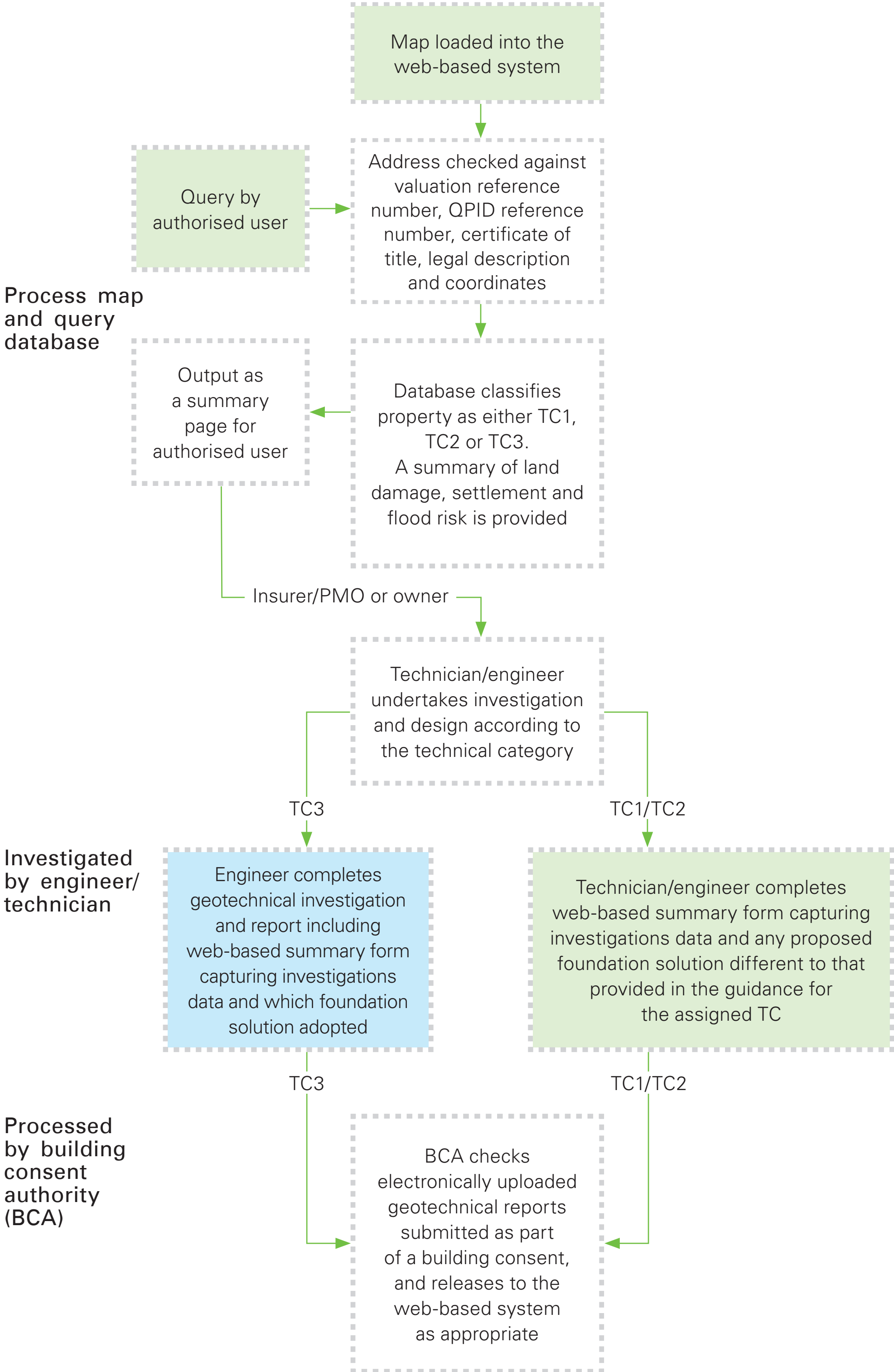
UPDATE: December 2012

Information from geotechnical assessments is currently being gathered and will be monitored on an area wide basis. This information includes indications of the severity of liquefaction observed at the property, and whether significant lateral spreading has occurred, along with flood depth parameters. This will inform repair/reconstruction pathways.

Key information needs 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.

UPDATE:
December 2012

Figure 3.2: Overview of the foundation technical category information management process



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.

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, treatment of the site as 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 surface manifestation of damage to the land or foundations is greater than implied by the TC2 categorisation, then apply the approach outlined for TC3. This will involve working with a CPEng. geotechnical engineer.

TC3 confirmation

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 the expected site behaviour is such that TC2 foundation solutions are suitable. Specific design based on the deep geotechnical investigation and TC2 solutions signed off by a suitably qualified CPEng. geotechnical engineer can be undertaken if approved through the BCA consenting process.

UPDATE:
December 2012

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.

  Note that the '300 kPa' and '200 kPa' values discussed above are only 'index' values for use in conjunction with NZS 3604 or this document. The actual geotechnical ultimate bearing capacity for a particular foundation for design purposes, when estimated from scala penetrometer test results, is subject to modifications that depend on the soil type, foundation geometry and water table depth. (Furthermore, scala penetrometer testing as a means of determining bearing capacities is only appropriate for residential structures, particularly those within NZS 3604). Where the specified '200 kPa' or '300 kPa' criteria are not met on a site, a specific engineering design calculation should be carried out to determine the actual static loads being applied to the foundations. In many cases this will allow the use of Options 1 to 4 on ground with less than '200 kPa' geotechnical ultimate, or for the appropriate resizing of other foundation footing dimensions without the need to excavate down to depths where 200 kPa or 300 kPa soils are located. Due regard must be given to soil type, foundation geometry and water table depth in carrying out these calculations. 150 kPa geotechnical ultimate (raw) should however be considered as the lower limit of acceptable soil strength, in the absence of specialist geotechnical advice. Due regard must always be given to other potential issues, for example peat deposits and non-engineered fill.

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, in consultation with guidance provided in this document.

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 that 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 is outlined in Part C and broadly follows the subdivision investigation requirements set out in Part D of the guidance and at www.dbh.govt.nz/subdivisions-assessment-guide. Generally at least two deep investigation points (CPTs, boreholes with SPTs, etc) to 10 to 15 m depth would be expected, where practical, supplemented by shallower investigation points using (for example) hand augers and Scala Penetrometer testing. (In some cases where CPT testing is hampered by gravel layers, a single borehole with SPT testing may be appropriate, augmented by shallower investigations). Groundwater measurements following the investigations should also be taken. Liquefaction assessments should be carried out following the guidelines contained in Part C, and appropriate foundation or ground remediation solutions designed.

UPDATE: December 2012

See Part C for further information on deep geotechnical site investigation requirements.

3.4.3 Individual investigations on land that is not categorised.

UPDATE: December 2012

Land that is not categorised is expected to display a wide range of liquefaction performance, depending on location. Reference should be made to GNS Science Consultancy Report 2012/218 'Review of liquefaction hazard information in eastern Canterbury, including Christchurch City and parts of Selwyn, Waimakariri and Hurunui Districts', and also to Part D of this document for guidance on an appropriate level of investigation and assessment. Following such an assessment, foundation solutions from the applicable section of these guidelines can be adopted.

In some areas (for example land that are within the Ecan/GNS assessment area defined as 'damaging liquefaction unlikely') it is expected that simple TC1-like assessment procedures will be appropriate for an individual house site; in other areas deeper geotechnical investigations will be required to determine appropriate foundation solutions. (In all areas due regard to other potential hazards is needed.)

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 relevelling 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).

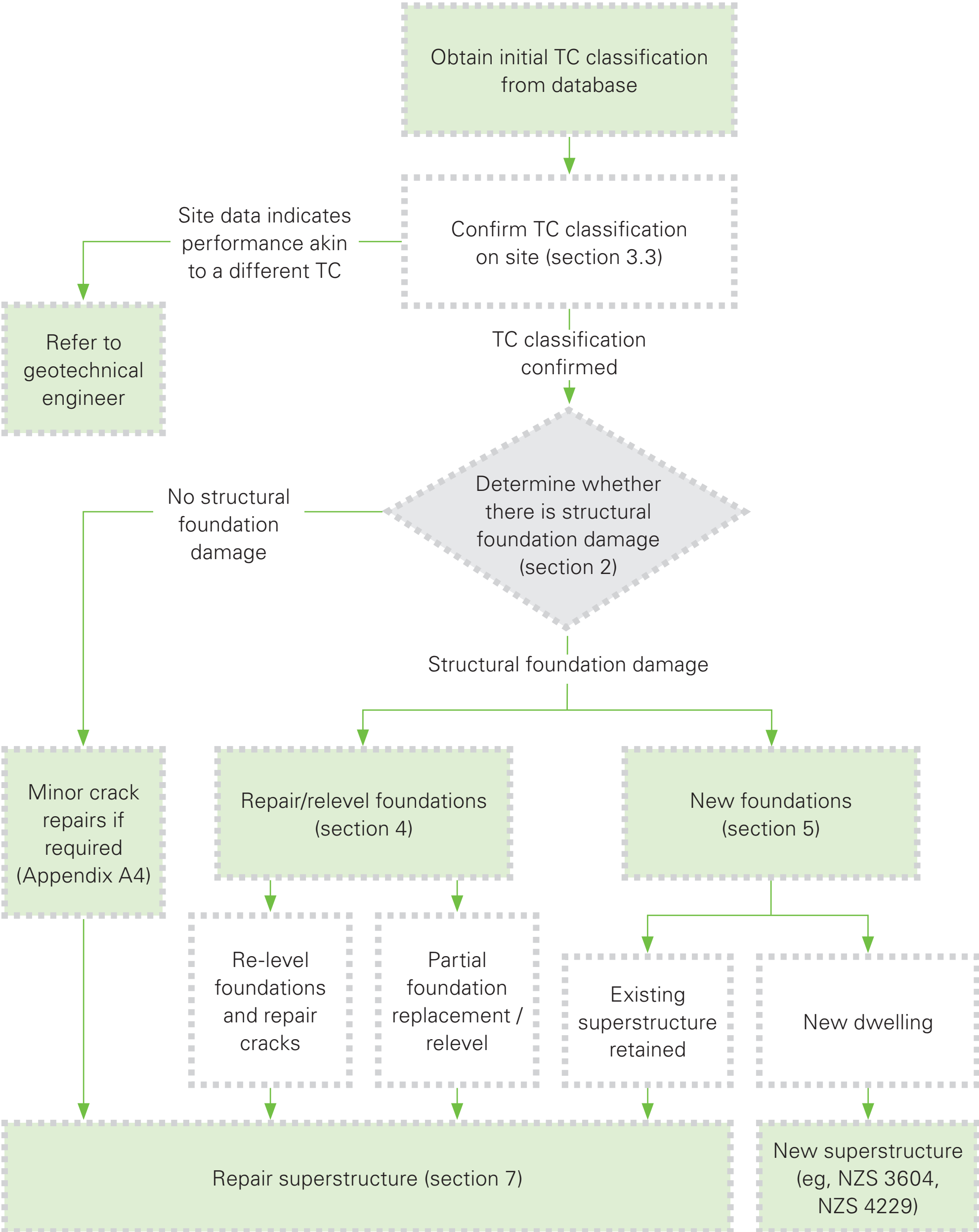
Refer to Table 2.3 for guidance on whether to repair and relevel foundations, or to replace with new foundations.

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 all technical categories where no foundation damage is evident, and where the indicator criteria in Table 2.3 suggest that a relevel or rebuild is unnecessary, superstructure repairs can be undertaken in accordance with the recommendations in section 7, with no need for a subsurface investigation.

> For dwellings in TC3, appropriate foundation repair solutions may involve undertaking a deep geotechnical investigation. Guidance on repairs to house foundations in TC3 is provided in Part C.

Figure 3.3: Determining the level of repair/rebuild required for Green Zone houses on the flat



UPDATE:
December 2012
Figure 3.3 has been amended to introduce the option of a partial repair of foundations.

3.6 Building consent information

See sections 8.2.4 and 8.2.5 of this guidance for information on building consent processes and the format supporting information should take.

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. 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**
> Appropriate foundation repair solutions for TC3 may 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 is provided in Part C.

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).

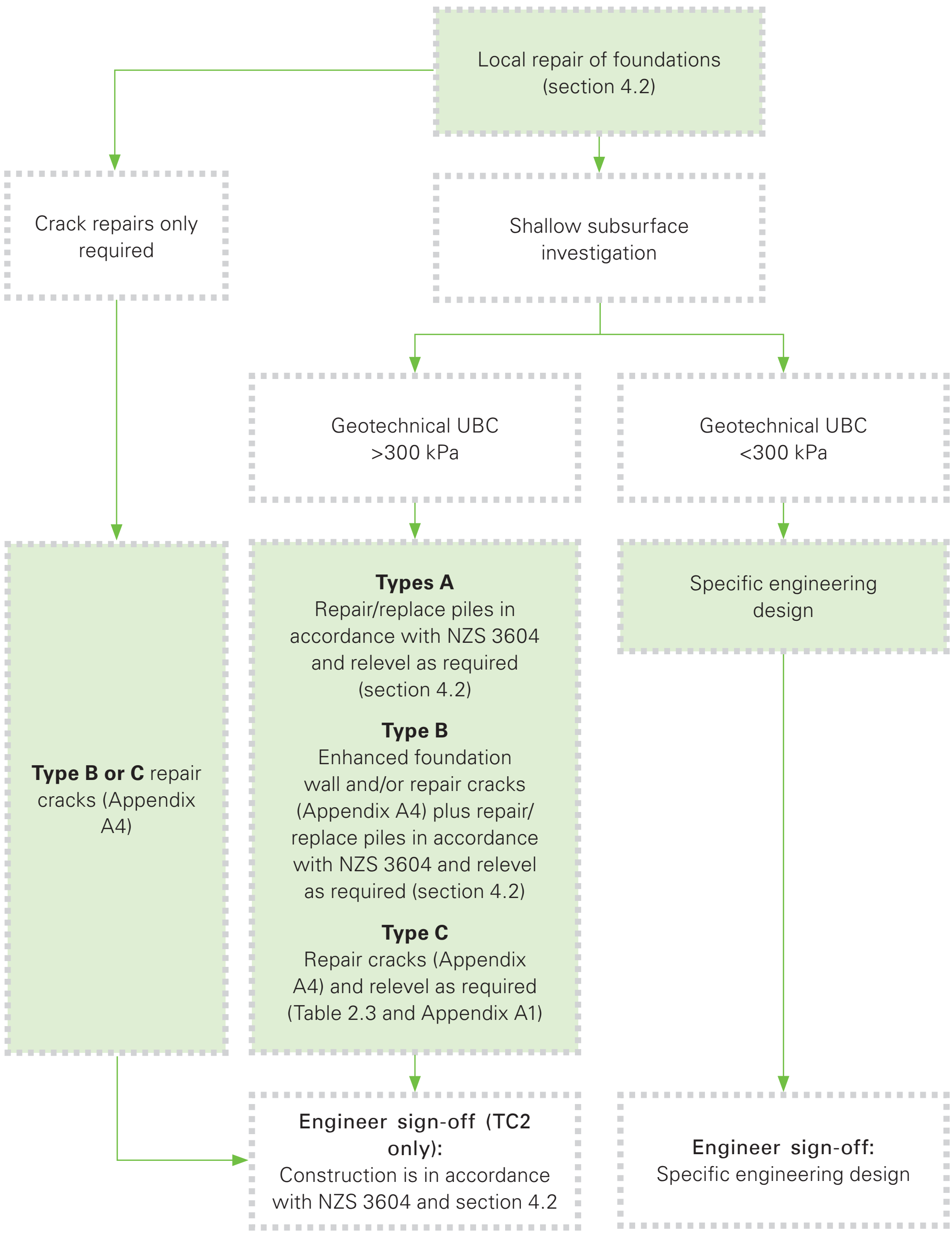
For dwellings with Type A foundations, local settlement or pile damage can be addressed by repacking and/or pile replacement as appropriate.

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.

UPDATE:
December 2012

Figure 4.1: Overview of the process for local repairs to repairing foundations on TC1 and TC2 sites



UPDATE:
December 2012

Figure 4.2 provides suggested options for repair or partial replacement for Type B foundations in TC1 and TC2 where only a small proportion of the foundation has settled.

Figure 4.2a shows a typical plan of such a Type B foundation where settlement of only part of the foundation wall has occurred. 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.

When damage is not sufficient to require replacement of sections of the perimeter foundation, (ie, the perimeter foundation is only moderately cracked) then the settlement may be corrected using an appropriate lifting or packing option in Figure 4.2. Crack repairs may be undertaken in accordance with Appendix A4.

If the section of foundation wall is to be replaced, it will need to have enhanced strength and stiffness to span possible future differential settlements beneath it.

The wall section detailed in Figure 4.2a 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 4.2a).

UPDATE:
December 2012

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 4.2a should be used. For lower bearing capacities, specific design will be required.

For Type C dwellings, guidance for relevelling the foundation is given in section 4.3, while repair of cracks in concrete foundations is outlined in Appendix A4. This guidance extends beyond cracks of 5 mm width. Table 2.2 indicates that a structural repair is not likely to be required if the crack is less than 5 mm, and the stretch is less than 20 mm, and the slope is less than 1 in 200, and the differential settlement is less than 50 mm. However, crack filling in accordance with Appendix A4 may be necessary to ensure the durability of any embedded reinforcing steel, or to provide support for some floor coverings (eg vinyl), or to provide an aesthetically acceptable appearance in the case of perimeter foundations.

UPDATE: December 2012

Figure 4.2: Options for addressing localised settlement of Type B perimeter concrete foundation beams (eg corners)

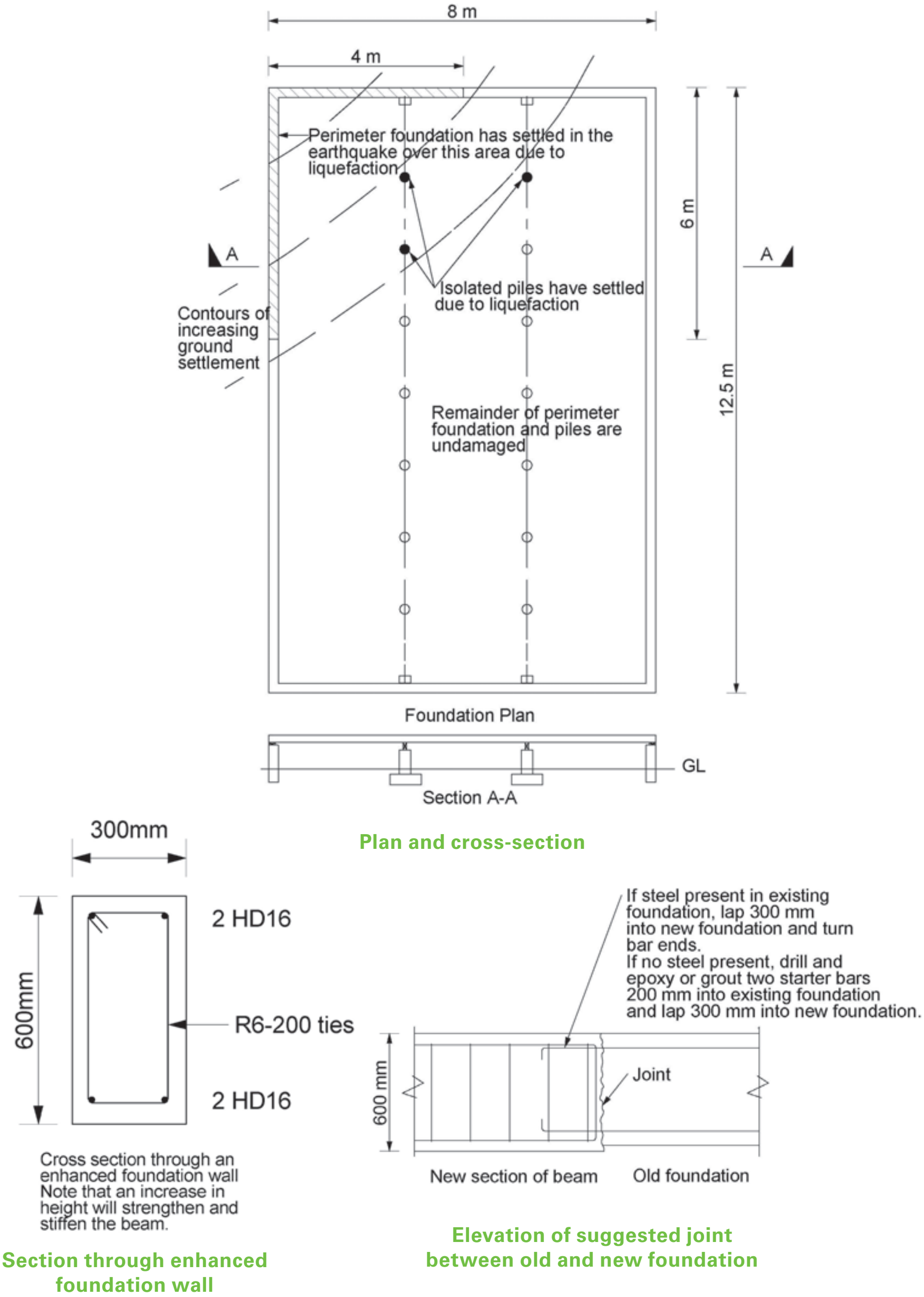
Type B foundation has settled locally

Options

Consideration	Pack off perimeter foundation beam up to 50 mm and fill cracks	Lifting Option 1 – jacking towards level and fill cracks	Lifting Option 2 – jacking off screw piles towards level and fill cracks	Lifting Option 3 – resin injection towards level and fill cracks	Lifting Option 4 – LMG injection towards level and fill cracks	Demolish and rebuild section
Ground bearing less than 300kPa	Suitable	Suitable (but may be restricted if ground support beneath jacking pads is <100kPa)	Suitable (remove piles once lifted)	Less suitable – care required to control flow May introduce uneven ground stiffness	Less suitable – may introduce uneven ground stiffness	Suitable – foundation can be widened to reduce bearing pressure
Vertical offset at individual cracks >10 mm	Less suitable Treatment of offset to be separately considered	Less suitable	Less suitable	Less suitable – care required to control flow	Less suitable	Suitable Mechanical connection provided
		Mechanical connection (eg dowels) may be required across cracks prior to lifting				
Heavy cladding (eg brick veneer)	Less suitable	Suitable if sufficient soil bearing strength (ie >100kPa)	Suitable (remove piles once lifted)	Suitable (depending on bearing)	Suitable (depending on bearing)	Suitable with cladding removal and rebuild

Note: Lifting Options 1 to 4 are presented in Appendix A1.

Figure 4.2a: Example of a partial foundation wall replacement



Plan and cross-section

Section through enhanced foundation wall

Elevation of suggested joint between old and new foundation

4.3 Re-levelling floors (TC1 and TC2)

4.3.1 Overview of relevelling options

An overview of the process for relevelling existing foundations on TC1 and TC2 sites is provided in Figure 4.3. Table 4.1 summarises the relevelling strategies and likely occupancy implications.

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

When timber and concrete piles must be packed to relevel the floor, a single packer (or two opposing wedges) should be used and should have an equivalent area to the smallest of the bearing areas of the pile top or the bearer originally in contact. The packer should be fixed with a minimum of two wire dogs and two skew nails (timber piles) or 4 mm wire and staples (concrete piles) or equivalent strength fixings. If the piles have a bracing function for the subfloor, then the required connections should be determined from NZS 3604. Settled stone piles should not be packed but replaced.

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

For Type C dwellings, any services beneath the foundation slab must be considered as there is a possibility they could be damaged during the relevelling 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 under the perimeter foundation wall, and care will be required to identify and protect these during any lifting operations.

Table 4.1 summarises the relevelling strategies and likely occupancy implications.

Building Code issues

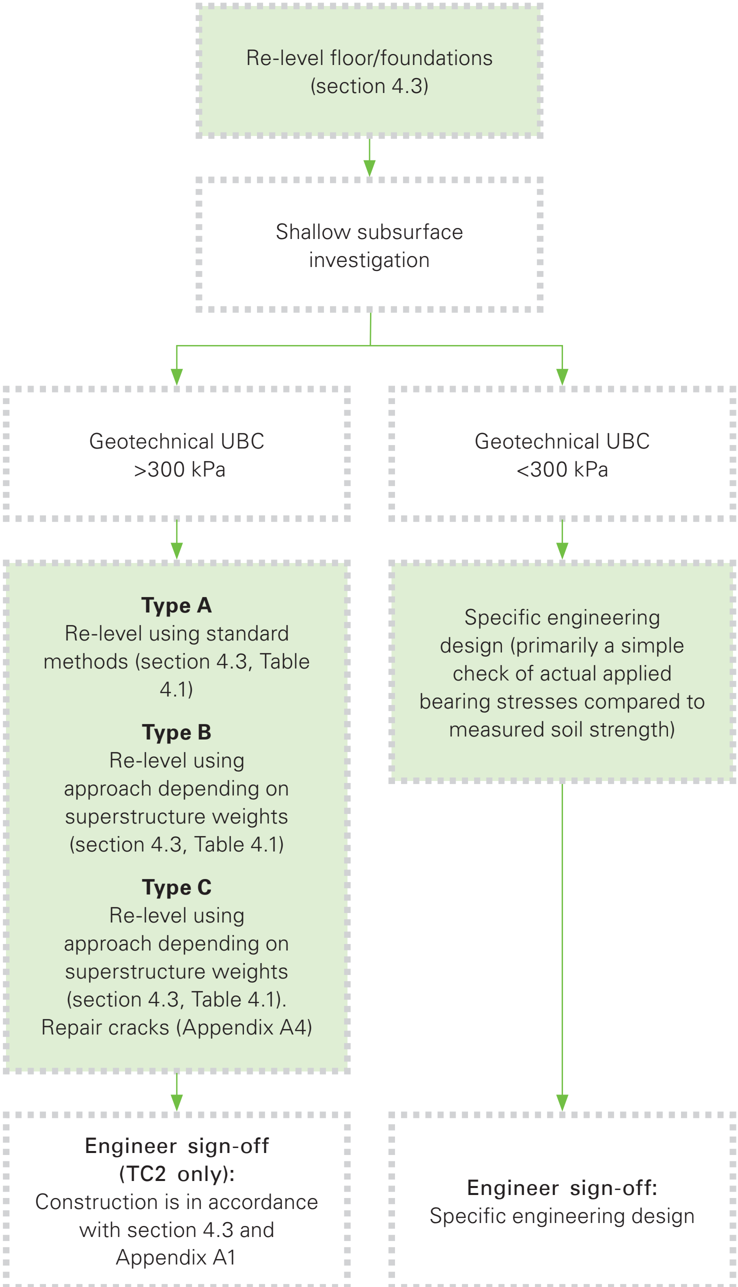
Re-levelling foundations and floor slabs using any of the options listed in Appendix A1 is building work. Building work includes sitework, which is defined as 'work on a building site, including earthworks, preparatory to, or associated with, the construction, alteration (repair), demolition or removal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

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

UPDATE: December 2012

For regulatory and Building Code issues relating to relevelling foundations and floor slabs, refer to sections 8.2, 8.4 and Appendix C1.

Figure 4.3: Overview of the process for relevelling foundations on TC1 and TC2 sites



UPDATE: December 2012

Table 4.1: Summary of foundation relevelling approaches for TC1 and TC2 on the flat

Foundation type	Foundation relevelling		
	Re-levelling strategy	Occupancy during relevelling operations	
Type A Foundation: Timber-framed suspended timber floor structures supported only on piles Cladding: Light- and medium-weight	Remove base skirt, disconnect services if adjacent to works, pack and (for some piles) repile affected area. Repiling may require lifting of flooring in some areas. Reconnect services and reskirt perimeter	Yes	Minor disruption to occupants during relevelling of piles
Type B1 Foundation: Timber-framed suspended timber floor structures with perimeter concrete foundation Cladding: Light- and medium-weight	Disconnect services if adjacent to works, expose affected perimeter concrete foundation wall and relevel, repile affected floor area. Repiling may require lifting of flooring in some areas. Inject relevant cracks in foundation wall, reconnect services and reinstate ground to foundation wall	Yes	As for Type A regarding pile relevelling. Relevelling the perimeter concrete foundation wall using low mobility grout or engineered resin may permit occupancy during the work. Jacking may require vacancy depending on which part of the foundation wall is to be relevelled
Type B2 Foundation: Timber-framed suspended timber floor structures with perimeter concrete foundation Cladding: Heavy-weight (veneer)	Disconnect services if adjacent to works, possibly partial removal of cladding, and relevel, repile affected floor area (may require lifting of flooring in some areas). Inject relevant cracks in foundation wall, reconnect services and reinstate ground to foundation wall	No	Perimeter will be disrupted to give access to foundation wall and will disrupt services Partial foundation wall and cladding removal and reinstatement is considered (see section 4.2)
Type C1 Foundation: Timber-framed dwelling on concrete floor (slab-on-grade) Cladding: Light- and medium-weight	Re-level using low mobility grout or engineered resin Disconnect and reinstate services, if necessary or Re-level using slab and edge foundation jacking and grout Disconnect and reinstate services, if necessary or Re-level using screw piles and grout Disconnect and reinstate services Inject relevant cracks in slab	Case by case	This procedure is generally limited to slabs with crack width <5 mm The process requires stripping out of the interior floor coverings

Foundation type	Foundation relevelling		
	Re-levelling strategy	Occupancy during relevelling operations	
Type C2 Foundation: Timber-framed dwelling on concrete floor (slab-on-grade) Cladding: Heavy-weight (veneer)	Disconnect services if adjacent to works, possibly partial removal of cladding, and relevel, inject relevant cracks in slab, reconnect services	Case by case	This procedure is generally limited to slabs with crack width <5 mm and only minor cracking to veneer mortar. The process requires stripping out of the interior floor coverings

Notes to Table 4.1:

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 relevelling 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 relevel 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 relevel the superstructure, including the floor, and remediate any damage caused to the claddings and linings of the structure, without relevelling 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. Consideration should be given to relevelling with the veneer in place. A decision should also be 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 Energy Efficiency and Conservation Authority (EECA) Warm Up NZ programme might be an option.

All four relevelling 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 relevel 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 relevel the floor without causing significant damage to the veneer cladding. However, it is recommended that the relevelling 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 in TC1 and TC2

5.1 General

UPDATE: December 2012

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. These foundation solutions are primarily for properties classified TC1 or TC2. Some of these foundation solutions may also be applicable on some sites currently classifed TC3, following site-specific investigation and assessment (refer to section 13.6). Refer to Table 2.3 for guidance on whether a foundation can be relevelled 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 Ministry's information sheet at www.dbh.govt.nz/seismicity-info

UPDATE: December 2012

For all three foundation types in TC1, the geotechnical ultimate bearing capacity must be greater than 300 kPa in order to use standard foundation details unmodified, without specific consideration of actual building weights, imposed bearing stresses and actual soil strengths. Alternatively, a stiffened raft in accordance with section 5.3 may be used if the geotechnical ultimate bearing capacity is greater than 200 kPa, otherwise a specific engineering design is required. (This will primarily consist of a simple calculation of specifically imposed bearing stresses and actual soil strengths (section section 3.4.1)).

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. Specific information regarding deep pile options is provided in Part C. The deep pile options will require deep geotechnical investigation and specific design.

> Refer to Part C for TC3 foundation options. 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 or repaired 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, particularly where liquefaction is possible.

UPDATE: December 2012

Figure 5.1: Overview of process for new foundations on TC1 sites

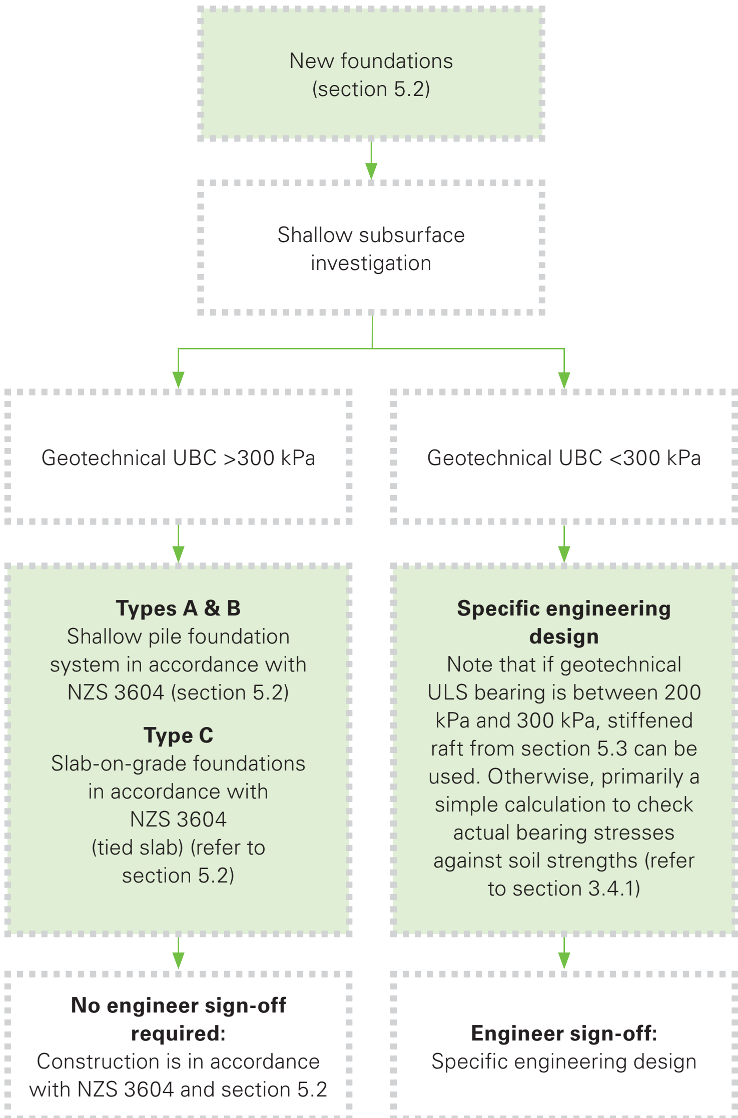
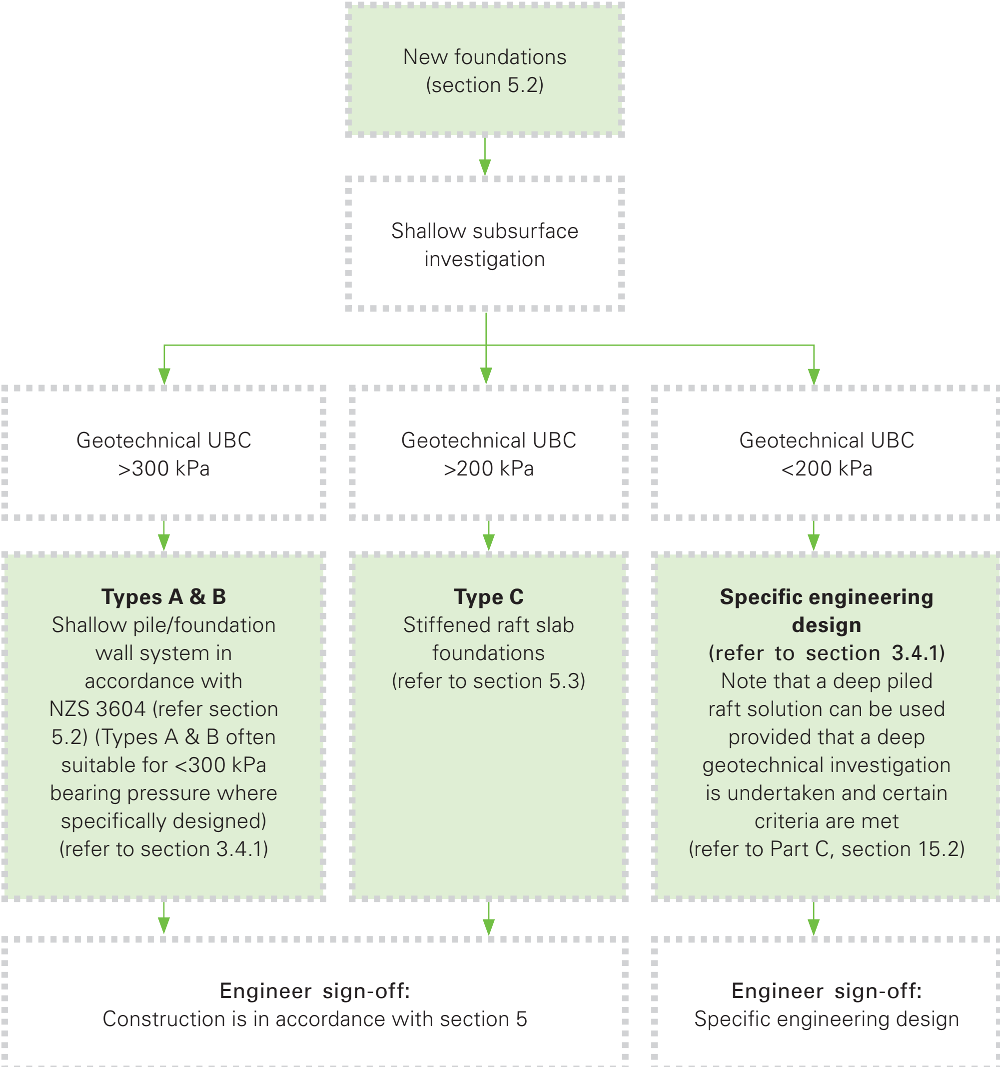


Figure 5.2: Overview of process for new foundations on TC2 sites



UPDATE:
December 2012

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 could generally 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.[1]

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 cope with settlements outlined in 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 without specific engineering design input (see section 3.4.1).

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 relevelled.

UPDATE: December 2012

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. Thickening of the slab in Option 2 will allow its use with heavy-weight (brick venner) cladding and a heavyweight roof. Structure cladding weight limits are also specified for Options 3 and 4, above for which specific engineering design would be required to stiffen the options to satisfy the performance criteria in section 5.4. A summary of the wall and roof cladding weight limits for Options 1 to 4 is provided in Table 7.2

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.

UPDATE: December 2012

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 platforms[2] above the surrounding land is 400 mm (refer to Figure 5.3). Greater increases may be allowable on a site-by-site basis following geotechnical investigation.

(1) Refer to www.dbh.govt.nz/UserFiles/File/Publications/Building/
(2) See the glossary for definition of 'building platform'.

Figure 5.3: Maximum building platform heights above surrounding ground (TC1 and TC2)

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.

UPDATE: December 2012

Table 5.1: Summary of proposed foundation solutions for rebuilt foundations or new foundations on the flat

TC1 Future liquefaction unlikely	TC2 Minor liquefaction likely and SLS spreading <50 mm	TC3 Future liquefaction expected and SLS spreading >50 mm
NZS 3604 timber piles and floor or tied concrete slabs (as modified by B1/AS1) where ULS bearing capacity > 300 kPa (shallow subsurface investigation required[1]) otherwise Raft foundations (Options 1-4) or Specific engineering design[3] (including deep piles)	Light construction with timber floors and shallow piles as per NZS 3604 where ULS bearing capacity > 300 kPa (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[3] (including deep piles)	Deep piles (section 15.2)[2] or Site ground improvement (section 15.3)[2] or Surface structures with shallow foundations (section 15.4)[2], whichever is the most appropriate for the site, or Specific engineering design[3]

(1) Shallow subsurface investigation – refer to section 3.4.1
(2) See Part C
(3) See section 3.4.1

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.

UPDATE: December 2012

Table 5.2: Geotechnical requirements for rebuilt or new foundations on the flat

Foundation technical category	Geotechnical requirements
TC1	Foundations for new dwellings should include a shallow[1] 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 1-4) or other specific engineering design (including deep piles). 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[1] subsurface investigation to determine the bearing capacity of the soil (or for deep piles, a deep investigation[2]). 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, or specific engineering design carried out. 2. If the investigation determines the site's geotechnical ULS bearing capacity is greater than 200 kPa, use enhanced slab TC2 solutions (Options 1 - 4) or other specific engineering design[1]. 3. If the investigation determines the site's geotechnical ULS bearing capacity is less than 200 kPa, foundations should be specifically designed[1]. TC2 sites generally require only a shallow investigation to provide the information necessary for foundation assessment. However, in some circumstances deep investigations may have been carried out in TC2 areas for other reasons. If a TC2 site has been 'well-tested' by the Canterbury earthquakes (refer to section 13.5.1) and damage to the land or foundations is not greater than implied by the TC2 categorisation, then the site observations implicit in the TC2 categorisation, as well as the actual site observations, provide strong evidence that the TC2 foundation assessment process is appropriate, at the discretion of a CPEng. geotechnical engineer. (In applying engineering judgement to reach a balance between predicted settlement and observed damage, consideration could be given to factors such as the severity of liquefaction and strength-loss predicted, the depth below the surface where liquefaction is predicted, and the thickness and quality of the surface crust).
TC3	A site-specific deep investigation[2] including CPTs or deep boreholes (or data from an appropriate area-wide investigation), and geotechnical analysis of the site is required to determine the land performance in future SLS and ULS events. 1. If data confirms TC3 performance then a range of technical solutions are given in Part C. 2. If the data shows the site has performance equal to a TC2 site then TC2 solutions from this document can be implemented. 3. In some cases, the data will show that the site is a 'hybrid' between TC2 and TC3 (ie, part of the site has TC2 characteristics and part has TC3 characteristics; solutions for this are contained in Part C.

(1) Shallow subsurface investigation – refer to section 3.4.1.
(2) Deep geotechnical investigation – refer to section 3.4.2.

5.3 Description of indicative new foundation and floor options

Site investigation requirements are as outlined in Table 5.2.

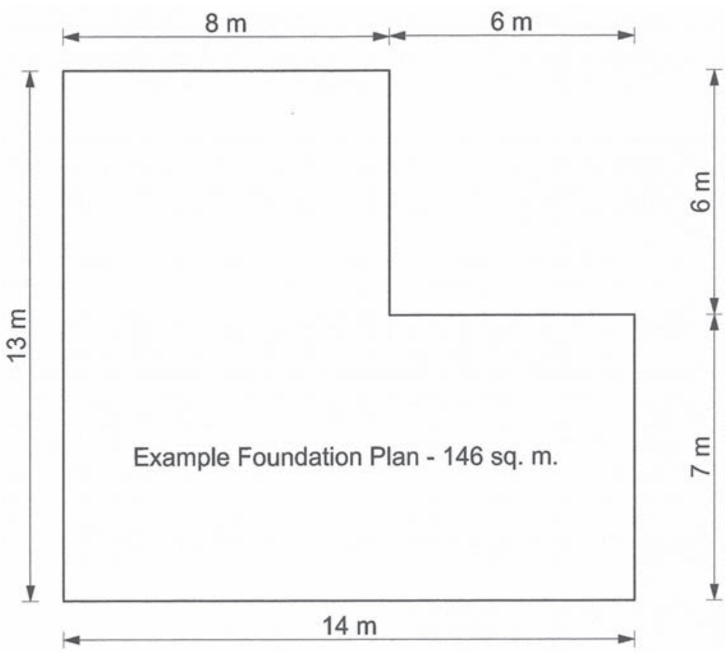
Site preparation should ensure that all grass and topsoil is removed before the placement of foundations or gravel fill. A well-graded sandy gravel aggregate that can be adequately compacted with a plate compactor (eg, pit run, river run, AP 40 or AP65) should be used as subgrade fill beneath any new concrete slabs. The aggregate should be placed in maximum 200 mm layers compacted with (as a minimum) a plate compactor. The top 75 mm of fill should be AP40 to ensure a finer grading in contact with the damp proof course where pit run or river run has been used for bulk filling.

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 on which the development and modelling of these details has been based on is shown in Figure 5.4. The details in this section should only be applied to simple house plan shapes such as rectangular, L, T or boomerang shapes.

Figure 5.4: 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. Note that for clarity the damp proof membrane (DPM) has not been shown in these representative details.

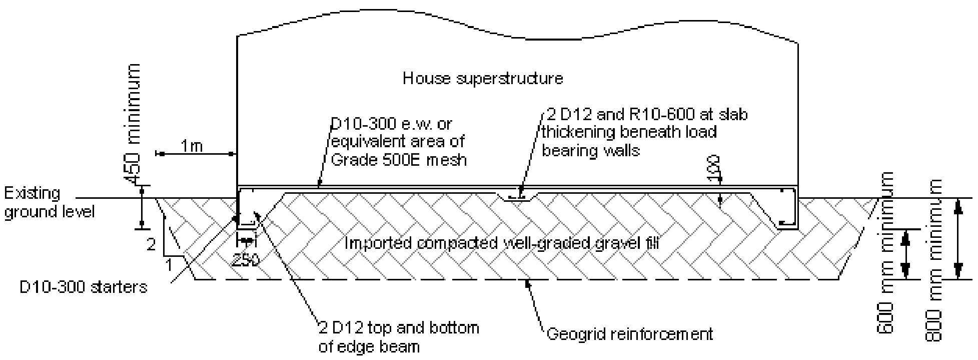
New flood freeboard requirements will also need to be considered if there has been uniform settlement over several properties (see section 8).

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 (see section 3.4.1).

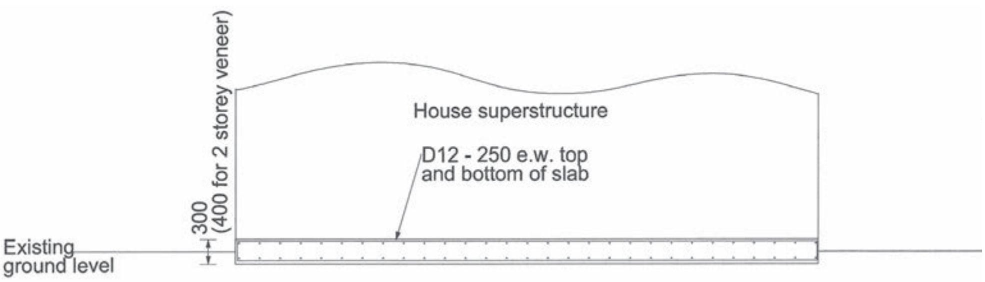
External service lines will need to be beyond the outer extent of the gravel raft and/or have flexible connections (refer to section 5.6).

Figure 5.5: Enhanced foundation slab – Option 1



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

Figure 5.6: Enhanced foundation slab – Option 2



Note: NZS ground clearances adjacent to house foundation must be complied with. DPC omitted for clarity.

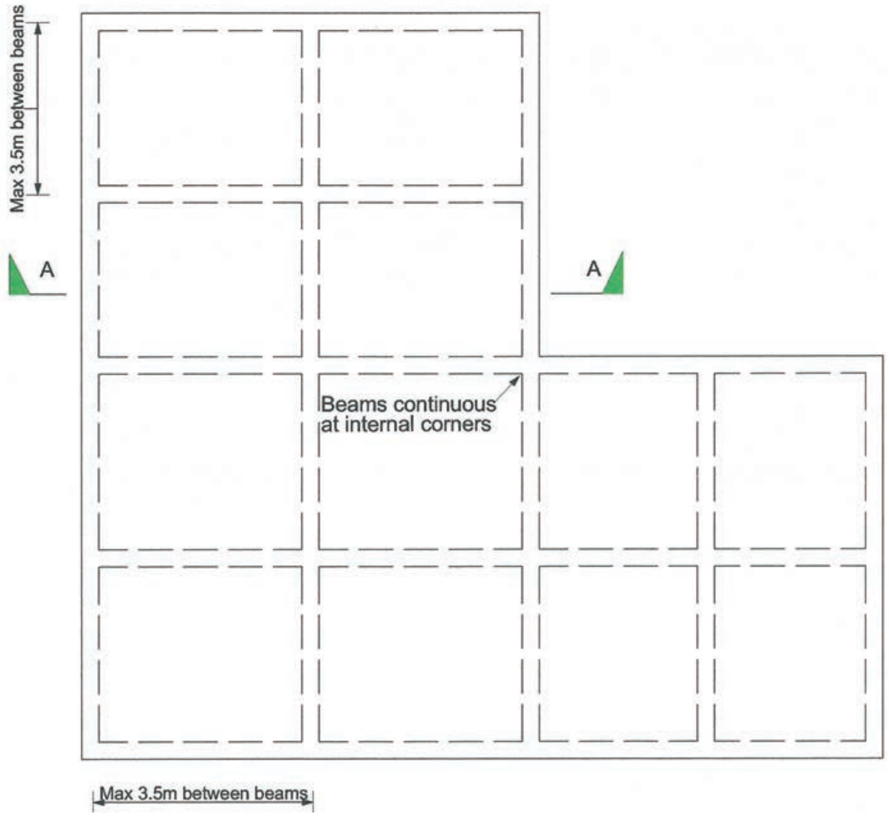
The ground immediately beneath the slab must have a minimum geotechnical ultimate bearing capacity of 200 kPa, or the slab should be subject to specific engineering design (see section 3.4.1). **Note: The thickness needs to increase to 400 mm for two-storey heavy-weight (brick veneer) construction with either a heavy or light roof cladding.**

UPDATE: December 2012

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.

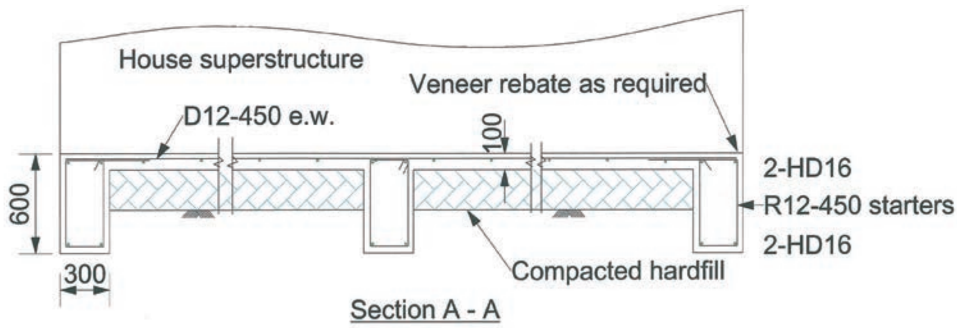
Figure 5.7: Enhanced foundation slab – Option 3 plan



Note: Reinforcing details are not sufficient for two-storey heavy-weight cladding (brick veneer) with a heavy roof but can be used for a two-storey heavy-weight cladding with a light-weight roof.

UPDATE: December 2012

Figure 5.8: Enhanced foundation slab – Option 3 cross-section



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 (see section 3.4.1).

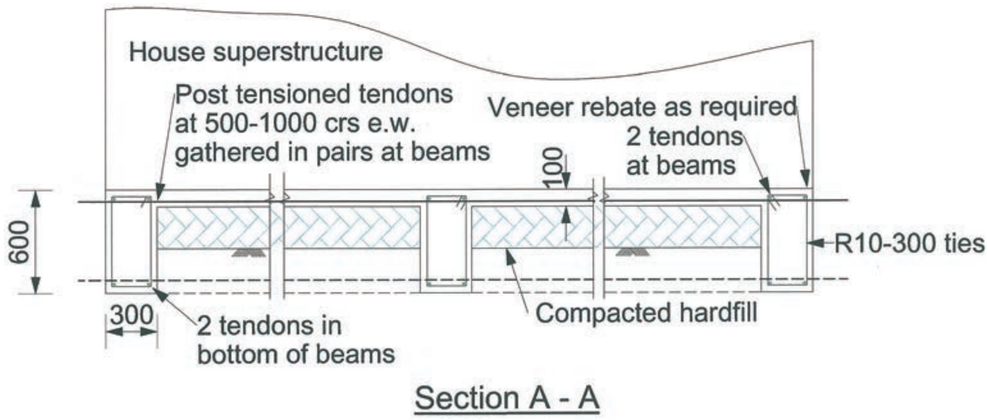
A variation to this option involves post-tensioning the slab using single 12.9 mm or 15.2 mm strand tendons in an unbonded format. The factory-applied greased and sheathed strands are supported in the slab on bar chairs and tensioned through mono-strand anchorages fixed at both ends through the perimeter 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.[3]

UPDATE: December 2012

Figure 5.9: Enhanced foundation slab – Option 3 variation with post tensioning



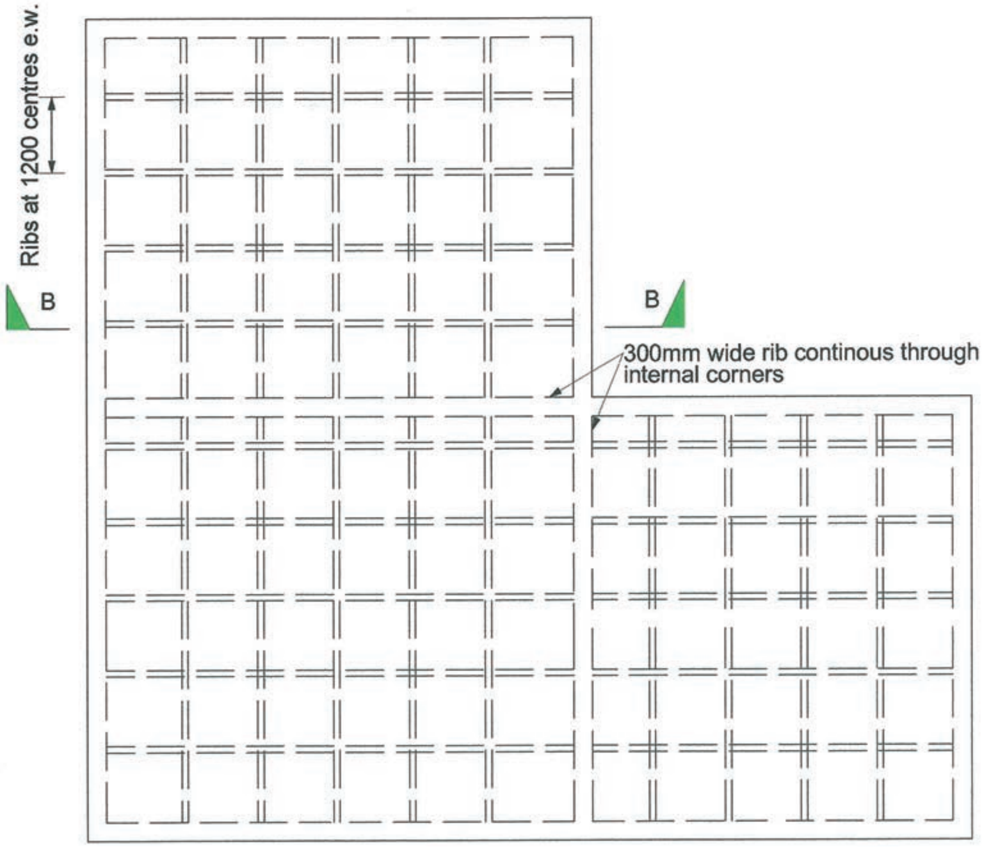
Note: Post tensioning strands are either 12.9 mm or 15.2 mm diameter and factory coated with grease inside an HDPE sheath, giving an overall outside diameter of 17 to 20 mm respectively. Strands are tensioned to provide 0.5-1.0 MPa compressive stress in the concrete.

For both Option 3 variations, it may be easier and more economical 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.

(3) 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

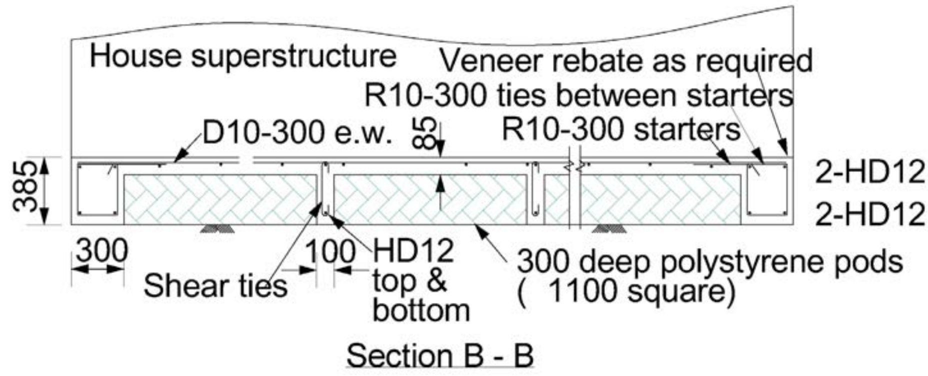
Option 4 – Construct a waffle slab over the existing soil

Figure 5.10: Enhanced foundation slab – Option 4 plan



Note: Reinforcing details are not sufficient for two-storey heavy-weight cladding (brick veneer) with either a heavy or light roof.

Figure 5.11: Enhanced foundation slab – Option 4 cross-section



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 (refer to section 3.4.1). Shear ties in accordance with NZS 3101 are required in the ribs.

UPDATE:
December 2012

DELETION:
December 2012
Guidance on the use of deep piles is contained in Part C. Figure 5.11 has been deleted and is superseded by new guidance in Part C.

Option 5 – Deep piles

Install piles to a dense non-liquefiable bearing layer and construct a floor slab (refer to section 15.2)

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 relevelling.

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 relevel 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

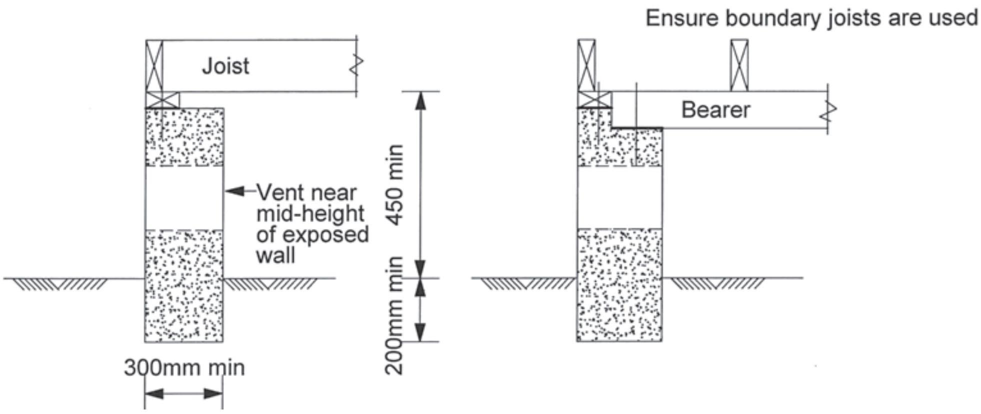
A one or two storey house with a light roof and light- or medium-weight wall cladding supported fully on an NZS 3604 shallow timber or concrete pile foundation is considered to be a valid option in TC2.

Type B dwellings

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

Deep piles installed under foundation walls are not within the scope of NZS 3604.
A suitable driving set and founding depth 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



Note: Reinforcement details as per Figure 4.2a

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

UPDATE:
December 2012

In many cases the '300 kPa' requirement for 'good ground' or the '200 kPa' requirement for Options 1 – 4 may not be met. Often, simple calculations of actual bearing stresses will allow redimensioning of foundations (refer section 3.4.1 for details). In other cases, specifically designed solutions other than those provided above may be devised. In these cases, the following criteria should be satisfied:

- Geotechnical investigations of the site in accordance with Table 5.2 are 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

- Design Type C house foundations for the potential for differential settlement of the supporting ground that will allow a maximum unsupported length 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, 5 mm hog or sag at the centre of a 4 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.
- Designs should accommodate settlements as indicated in Table 5.3.

Table 5.3: Liquefaction design settlements of new building foundations in TC2

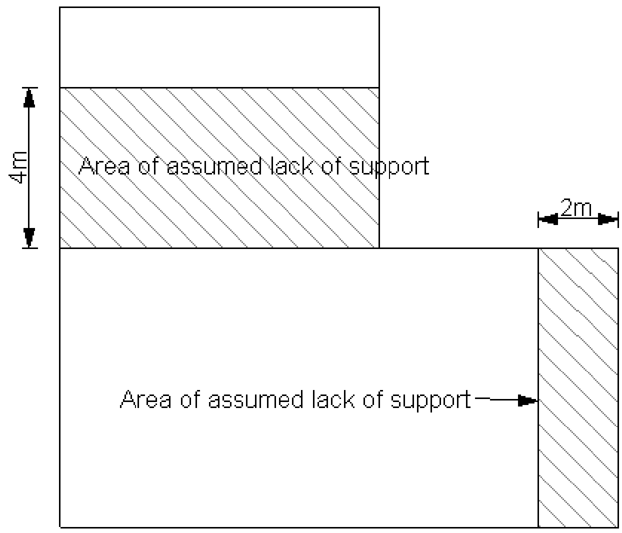
Type	SLS[1]	ULS[2]
Total settlement (mm)	Up to 50 mm	Up to 100 mm

(1) SLS – serviceability limit state
(2) ULS – ultimate limit state
(3) Part C covers liquefaction settlement limits for foundations in TC3.

UPDATE: December 2012

Where possible, reinforced concrete foundation systems should have sufficient stiffness to permit relevelling 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. Timber floors are expected to be readily relevellable by the packing of piles.

Figure 5.13: Foundation plan showing design criteria for specific design



Typical areas of lack of support for design

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

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 given in Part C. Specifically engineered solutions (eg, stiffened surface structures, deep piles, ground improvement) are required to meet the performance requirements of the Building Code.

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.

UPDATE: December 2012

Table 5.4: Summary of foundation rebuilding approaches for TC1 and TC2

Foundation type	Foundation rebuild		
	Rebuild strategy	Occupancy during rebuild operations	
Type A Foundation: Timber-framed suspended timber floor structures supported only on piles Cladding: Light- and medium-weight	Remove base skirt, disconnect services if adjacent to works, repile affected area, reconnect services and reskirt perimeter Re-establish minimum ground clearances in accordance with section 2.6	No	Usually only minor disruption to occupants. Need to consider distress to framing, trusses and bracing at this level of foundation damage
Type B1 Foundation: Timber-framed suspended timber floor structures with perimeter concrete foundation Cladding: Light- and medium-weight	Disconnect services, temporarily raise house as necessary, remove perimeter concrete foundation wall and replace, repile, reconnect services and reinstate ground to wall Re-establish minimum ground clearances in accordance with section 2.6	No	As for Type A regarding pile relevelling. Replacing the wall will require vacancy as the perimeter of the house will be disrupted
Type B2 Foundation: Timber-framed suspended timber floor structures with perimeter concrete foundation Cladding: Heavy-weight (veneer)	Disconnect services, remove exterior cladding, temporarily raise house as necessary, remove perimeter concrete foundation wall, and replace, repile, reconnect services and reinstate ground to wall, replace cladding Re-establish minimum ground clearances in accordance with section 2.6	No	Perimeter will be disrupted to give access to wall and will disrupt services
Type C1 Foundation: Timber-framed dwelling on concrete floor (slab-on-grade) Cladding: Light- and medium-weight	Disconnect services, temporarily raise house superstructure, remove and replace slab, reinstate house and reconnect services.	No	Severely cracked slab with differential settlement over 150 mm may have caused severe damage to the timber framing, trusses and bracing

Foundation type	Foundation rebuild		
	Rebuild strategy	Occupancy during rebuild operations	
Type C2 Foundation: Timber-framed dwelling on concrete floor (slab-on-grade) Cladding: Heavy-weight (veneer)	Disconnect services, remove exterior cladding, temporarily raise house superstructure, remove and replace slab, reinstate house and reconnect services, replace cladding	No	Severely cracked slab with differential settlement over 150 mm may have caused severe damage to the timber framing, trusses and bracing

Note: 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 relevelling 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 repile 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 (see section 3.4.1).

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 (see section 3.4.1).

In TC2, provided the geotechnical ULS bearing capacity is greater than 300 kPa, an enhanced reinforced foundation wall would be required to withstand the differential settlement anticipated with future minor liquefaction. Refer to Figure 4.2a and section 5.3.2 for indicative cross-sections. Otherwise, specific engineering design is required (see section 3.4.1).

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 (see section 3.4.1).

In TC2, provided the geotechnical ULS bearing capacity is greater than 300 kPa, an enhanced reinforced foundation wall (refer to Figure 4.2a and section 5.3.2) would be required to withstand the differential settlement anticipated with future minor liquefaction. Otherwise specific engineering design is required (see section 3.4.1).

The veneer may be rebuilt on the new foundation. Alternatively, the owner may choose an alternative lighter cladding system if 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. If foundation Option 1 is used then the house will need to be temporarily moved off the site to allow construction of a compacted gravel raft.

In TC1, provided the geotechnical ULS bearing capacity is greater than 300 kPa, the foundation 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) could be used or specific engineering design. If the geotechnical ULS bearing capacity is less than 200 kPa, specific engineering design is required (see section 3.4.1).

In TC2, provided the geotechnical ULS bearing capacity is greater than 200 kPa and there are no other geotechnical constraints (eg, peat deposits), 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 (refer to section 3.4.1).

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.

UPDATE: December 2012

The veneer must be demolished to allow the superstructure to be lifted off the existing concrete slab. 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. If foundation Option 1 is used then the house will need to be temporarily moved off the site to allow construction of a compacted gravel raft.

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 expense.

The veneer may be rebuilt on the new foundation. Alternatively, the owner may choose an alternative lighter cladding system if 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 Garage structures and outbuildings

Uninhabited detached garages (ie, that are not constructed as an integral part of a house) and outbuildings are considered to be Importance Level 1 (IL1) structures. If these structures are currently habitable or of significant value, Importance Level 2 (IL2) applies. Refer to DBH Codewords No 35 – March 2009 'Guidance on garage classification' www.dbh.govt.nz/codewords-35-1.

UPDATE: December 2012

IL1 structures have no seismic load requirements (under AS/NZS 1170.0) at Serviceability Limit State (SLS), and therefore have no amenity requirements relating to liquefaction deformations at SLS levels of shaking. This leaves a 'life safety' design requirement at Ultimate Limit State (ULS) for a 1/100 year event, which should be able to be provided in most cases on a TC2 site by a suitably detailed structure on a TC1 type foundation system. Alternatively, a specific design can be determined by applying the 1/100 year design event loadings at ULS.

Conversely, attached or integral garages need to be designed to the same level of performance as the main structure.

Refer to Section 11.3 for garage structures and outbuildings on properties designated as TC3.

5.7 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 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 and 4. If there is vertical or horizontal movement between the foundations and the ground in Options 3 and 4, 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.

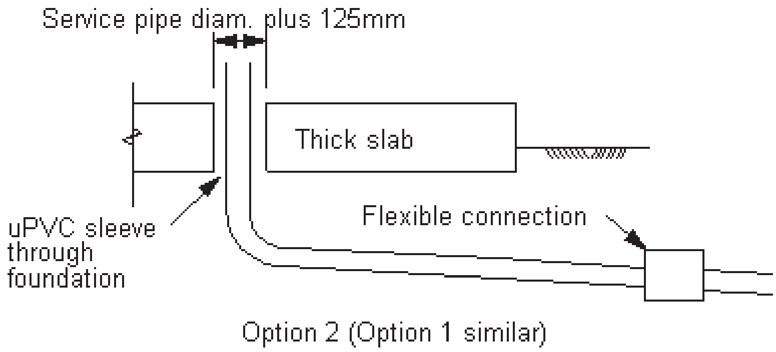
Flexible connections should be considered between the straight lengths of pipe, and located outside the building footprint. Greater pipeline flexibility is achieved by using rubber ring joint pipes.

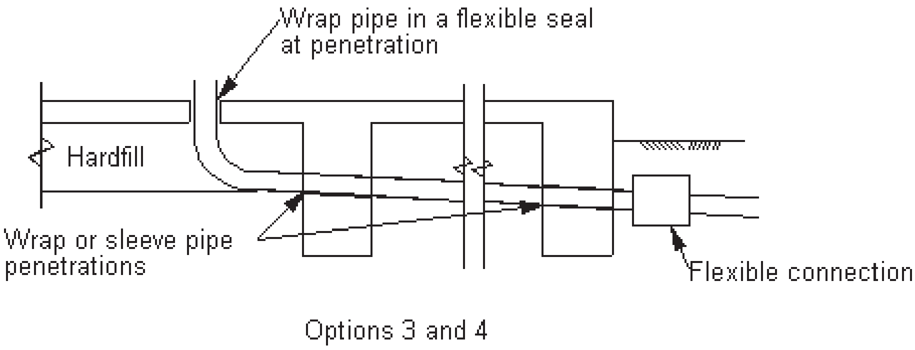
Consideration should also be given to the provision of greater falls in the lines than the minimums required by the Standards. This will make the continued operation of the system more viable should tilting of the ground occur during any future liquefaction event.

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.

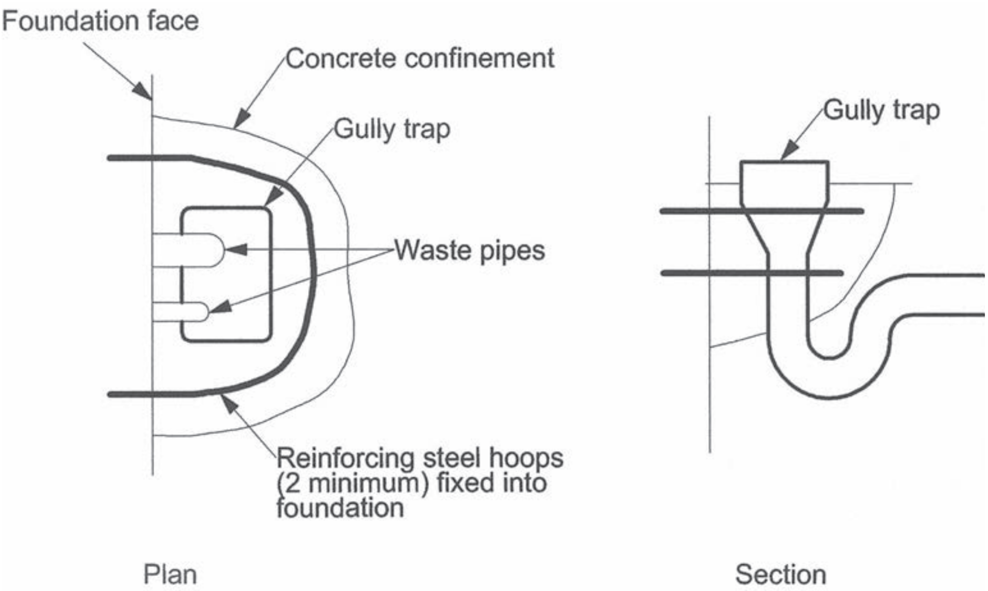
Figure 5.14: Waste water pipe routing





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, 13 June 2011, and other 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.

Three studies on the life safety risks associated with cliff collapse or falling boulders have been commissioned for the Port Hills area. These studies include: The GNS Science study for the Christchurch City Council; a 'ground truthing' of the GNS model undertaken by the Port Hills Geotechnical Group for the Christchurch City Council; and a 3D rock fall study undertaken for CERA.

UPDATE: December 2012

The GNS Science study is investigating 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 of 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

Wall type	Damage indicators	Possible outcomes
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 is used such as walers and tie-backs.
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 before the earthquake events.

Wall type	Damage indicators	Possible outcomes
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-terrameshed 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) 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, repair, and rebuild 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 on 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 refixed 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 refixing 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 refix or replace affected bracing elements.

7.2.2 Identification of wall bracing damage

If it is necessary to refix and restop any joints on a plasterboard wall face, then the skirting boards should be removed to check the need to refix the sheets behind the skirting. If the cornice joints have broken, the cornice should also be removed for refixing 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 before 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. This is considered to be an acceptable repair for this level of minor damage.

Where there is evidence of significant racking of walls (eg, 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 replumbed and the wall linings replaced, restopped and redecorated. 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 (ie, <0.5 mm) is present at bracing sheet junctions, cosmetic repairs should be enough. Where larger cracking is in evidence at sheet junctions, with minor movement of perimeter sheet fixings (ie, >0.5 mm), refixing around the perimeter of sheets is recommended. All new fixings must meet the requirements of the Building Code.

Where there is significant damage to sheets (eg, diagonal cracking or panel fracture), and/or significant movement of perimeter sheet fixings, the affected sheets should be replaced with a comparable component (eg, a standard or enhanced plasterboard system, as applicable), fixed as if a bracing element (ie, maximum fastener spacing

of 150 mm). Include the checking of framing fixings. The resulting bracing capacity will in all likelihood be an improvement over what was present before to the work. A similar logic for replacing part of a wall or a foundation applies (refer to Figure 4.2a).

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.

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 lining is being repaired or replaced, consideration should be given to providing bracing to NZS 3604, as modified by Amendment 11 to B1/AS1.

UPDATE:
December 2012

An alternative to refixing 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 refixed 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.

Further details of repair approaches are given in BRANZ Bulletin 548, published in June 2012 and available for free download from www.branz.co.nz/cms_show_download.php?id=c31dd5e0aeb804b21e506c379238dba9432c6f71

UPDATE:
December 2012

External sheet cladding connections and joints should also be checked and refixed. 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 (eg, 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.

Table 7.1: Summary of actions relating to repair/replacement of plasterboard lining

Extent of wall damage evident	Repair/replacement action	Review of bracing requirement	Building consent/ compliance basis	Comments
1. Minor cracking at sheet joints (< 0.5 mm) (Note a) No signs of movement at skirting board	Scraping out old stopping (taking care not to damage paper facing), restopping and repainting Check for 'drumminess' of sheets (Note c)	Not required	Schedule 1(a) and 1(ah) exemption • Applies to bracing and non-bracing elements	Cosmetic repairs
2. Moderate cracking at sheet joints (> 0.5 mm) (Note b) Minor movement of perimeter sheet fixings or movement of sheets evident at skirting board	Refixing of sheets adjacent to existing fixings and restopping of joints. When sheet edges are too damaged to allow refixing, replacing affected sheet(s) with comparable component or assembly (eg, standard or enhanced plasterboard (as applicable)), fixed as a bracing element (Note d), check and make good any damaged framing connections where reasonably practicable Check for 'drumminess' of sheets (Note c)	Not required	Schedule 1(a) and 1(ah) • Repairs in accordance with this guidance document	Superficial and localised repairs Note: where panels are replaced, compliance with other clauses of the Building Code (eg, B2, E3) must be achieved (Note f)

Extent of wall damage evident	Repair/replacement action	Review of bracing requirement	Building consent/ compliance basis	Comments
3. Cracking damage within sheets. Damage may include: (a) significant lining separation from wall framing (b) damage to timber-framing connections (c) walls out of plumb in either direction more than 10 mm per storey, or (d) bottom plates have shifted from their original position	If the diagonal cracks at the corners of openings are <50 mm long and where wall-to-ceiling or wall-to-wall junctions show stress by visible cracking, fastener movement, wallpaper creasing or similar, refixing of the sheets adjacent to existing fixings and restopping of joints If the diagonal cracks at the corners of openings are >50 mm long and where wall-to-ceiling or wall-to-wall junctions show stress by visible cracking, fastener movement, wallpaper creasing or similar, replace affected sheet(s) with a comparable component or assembly (eg, standard or enhanced plasterboard as applicable), fixed as a bracing element (Note f). Check and make good any damaged framing connections where reasonably practicable. Check for 'drumminess of sheets (Note c)	A new bracing element at least matches the bracing capacity provided by the replaced element (Note e)	Schedule 1(ah) exemption for any sheet replacement and/or refixing Schedule 1(a) exemption for any framing and/ or connection work if it does not involve complete or substantial replacement of any component or assembly contributing to the building's structural behaviour If framing and/or connections work involves complete or substantial replacement of any component or assembly contributing to the building's structural behaviour then building consent or possible item (k) exemption required (Note g), making reference to section 7 of this guidance document	Possibly complete or substantial repairs (Notes f and g)

Notes :

a. The cracking is generally confined to the top and/or bottom corners of openings, extending vertically from the corner along the sheet joint.

b. Cracking will be evident as in (1) above, but there is also likely to be cracking of the joint at wall junctions

c. The wall-lining glue fixings may have detached from the studs intermediate between the sheet edges or screw fixings may have been partially pulled through the sheet at studs intermediate between 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 or loss of screw fixing. Re-fixing with nails or screws at 200 mm centres, restopping and repainting will be required. Note that the glue fixings were not necessary for the provision of bracing resistance when the sheets were first installed.

d. Check bracing fixing patterns for proprietary plasterboard bracing systems in manufacturers' literature. Bracing elements should have fixing spacings of 150 mm or less.

e. 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.

f. 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).

g. 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. Note: refer to Table 8.2 for a summary of the risk-based consenting pathways available.

UPDATE:
December 2012

7.3 Repairing lathe and plaster interior wall linings

Lathe and plaster does not provide a wall-bracing function in houses but because it is very stiff, it tends to be the first line of resistance to racking under earthquake actions, before diagonal timber bracing in the framing takes up the load. Three options for lathe and plaster repair are:

1. Minor cracks – rack out and restop

   The crack in the plaster is prepared in a similar fashion to minor cracks in the joints between plasterboard sheets. The crack is successively filled with the inclusion of reinforcing tape. For this solution to be viable, the plaster must still be well connected to the wooden lathe strips. If the plaster feels loose and drummy when tapped, the repair should follow case 2 or 3 below. Overlaying with plasterboard sheets is not recommended because it is not easy to ensure that the sheet fixings are into the timber framing.

2. Some plaster fall-out – patch with new plasterboard and make good

   If the area is extensively cracked or feels loose when touched then removal of the plaster in the damaged area is recommended (the area should not be overlaid with plasterboard sheets). This may involve careful removal of the trims such as skirtings and scotias and retention for re-use. If the lathes are still sound the damaged plaster may be replaced with plasterboard, with junctions stopped to provide a smooth finish. If the lathes are damaged, they should be removed and an appropriate packing thickness of up to about 20 mm placed over the studs, and fixed with 8 g x 45 mm long high thread countersunk wood screws at 300 mm centres. Plasterboard may then be fixed through the packing with sufficiently long screws to penetrate the studs with sheet junctions stopped to provide a smooth finish.

3. Major "drumminess" or damage to plaster or plaster fallout – remove and reline with plasterboard, stop and paint/wallpaper.

   In instances of severe damage to the plaster, the plaster and lathes should be removed and replaced with plasterboard sheets. These may be fixed directly to the framing, or over-packing to take up the thickness of the removed lathe and plaster. This provides an opportunity for the bracing (likely to be either flush timber or solid timber) and its connections to be checked for damage.

7.4 Wall and roof frame connections

Apart from where chimneys have fallen and broken timber members in the roof, there have generally 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 refixed. 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, renail 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.

7.5 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.

7.6 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 of where the pole is embedded in the ground is recommended to ascertain whether there has been any soil failure. 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.

7.7 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 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).

7.8 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 before 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.

UPDATE: December 2012

Table 7.2: Summary cladding weight chart for rebuilds in properties classified as TC1, TC2 or TC3

Technical Category	Foundation type	Options	Wall cladding – Maximum recommended weights	Roof cladding – Maximum recommended weight
		The following cladding weights are default listings only, which may be varied by specific engineering design		
TC1	NZS 3604 Type C [1]		H	H
	NZS 3604 Type A [1]		M	H
	NZS 3604 Type B [1]		H	H
TC2	NZS 3604 Type A		M	L
	NZS 3604 Type B (enhanced)		Single storey M	L
			Two storey M	L
	Concrete Raft (Simple floor layout) Refer to section 5.3	Options	Single storey	Single storey
		1	H	H
		2 (300 mm)	H	H
		3	H	H
		4	H	H
		Options	Two storey	Two storey
		1	M	L
		2 (300 mm)	M	H
		2 (400 mm)	H	H
		3	H	L
		4	M	L
TC2 / TC3	Hybrid	Timber floor	M	L
		Concrete floor	Single storey H	H
			Two storey M	L
TC3	Deep Piles	Concrete raft Options 2,4 modified	H	H
	Site Ground Improvement	For use with all TC2 foundation options and cladding weights		
	Surface Structures (Simple floor layout) Refer to section 15.4	Type 1, 2	M	L
		Type 3	Single storey M	L
			Two storey M	L

(1) Refer to section 2.1 for descriptions of house foundation types.

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 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 focus on:

- 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.

UPDATE: December 2012

7.9 Rebuild cladding and roofing recommendations

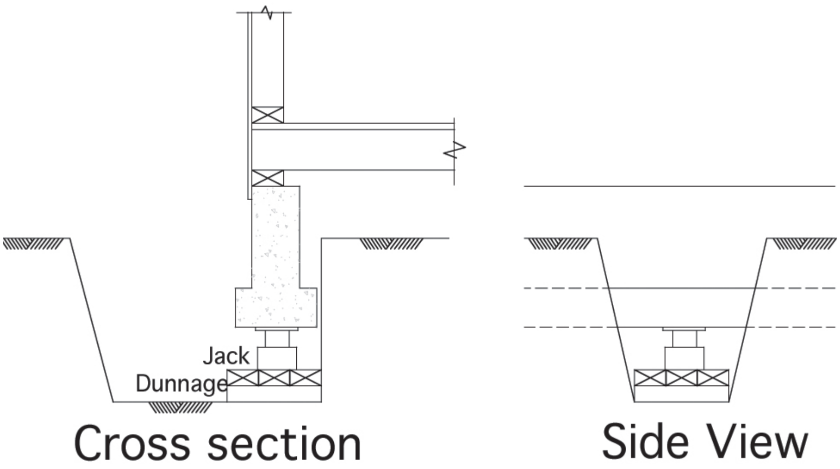
If the superstructure is being rebuilt, follow the relevant Building Code requirements. Acceptable Solutions B1/AS1 (which references NZS 3604) provides solutions for structural requirements and E2/AS1 for wall cladding and roofing details.

Table 7.2 summarises the maximum weight of wall and roof cladding materials that can be used when following this guidance, depending on the foundation option chosen. Refer to glossary for details of heavy (H), medium (M) and light (L) wall and roof materials. While the chart illustrates maximum recommended weights, the use of lesser weight claddings will reduce the overall weight of the superstructure leading to greater resilience in possible future earthquake events.

Appendix A1: Re-levelling systems and outline method statements for relevelling 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 relevelling foundations that have settled.

Figure A1.1: Lifting option 1 – Perimeter foundation jacking using portable jacks

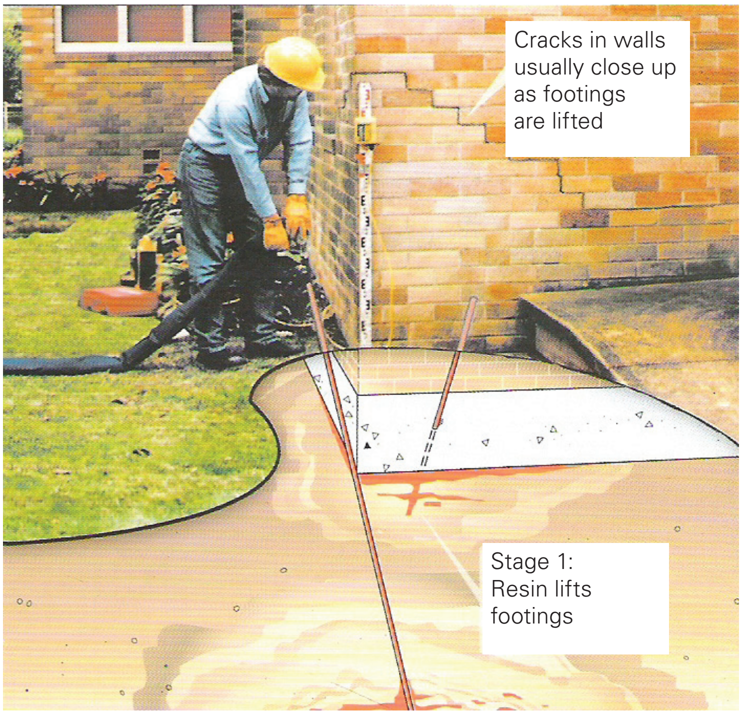


Foundation relevelling involves excavating pits at discrete locations to the perimeter of the foundation wall, and installing jacks in each pit to the underside of the wall to raise it to the correct level. With the foundation repositioned, flowable grout is introduced to the cavity created under the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

Figure A1.2: Lifting option 2 – Perimeter foundation jacking using piles (screw or similar)

Foundation relevelling 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.

Figure A1.3: Lifting option 3 – Perimeter foundation jacking and slab relevelling 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. This should be carried out by specialist contractors using materials that meet the following minimum requirements:

- Inert and non-toxic
- Non-leaching
- Warranted durability for 50 years – no significant loss of density, corrosive strength, or shrinkage, demonstrated by proven in-ground history or accelerated testing.

Figure A1.4: Lifting option 4 – Perimeter foundation jacking and slab relevelling 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 relevelling processes, it is important that specialist contractors be used who are familiar with and adhere to the ASCE standard ASCE/G-I 53/10 "Compaction Grouting Consensus Guide". 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 relevelling foundations and floor slabs of existing houses as summarised in section 4.

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 relevelling works.

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

UPDATE: December 2012 There are several references in the repair method statements where the advice on crack filling has been altered based on further advice to the EAG.

A1.1 Foundation relevelling method statements

A1.1.1 Type A: Pile foundation and light-clad exterior walls repair method statement

Refer to section 4.3.2.

Step	Activity
1.	Remove the cladding attached to the exterior piles to expose the piles and retain if possible.
2.	Locate services entry points to the house and allow for disconnection or relief of these during the floor-lifting operation. For example, dig away soil at water, waste, power and telephone connections to allow these to lift with the house.
3.	Check the vertical alignment of the piles. If existing piles are leaning at an angle of more than 15 mm per 1 m height, new piles will be required (see point 7 below).
4.	Detach the piles from the bearers.
5.	Install jacking equipment and sequentially lift the affected areas. Make sure that 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.
6.	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 before the earthquake. However, this may be less than the requirements of NZS 3604.

Step	Activity
7.	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.
8.	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 before 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.)
9.	Reattach the cladding to the outside of the piles.
10.	Re-compact soil around the services. If the lifting process has reduced the cover to the services to a value less than allowed by the Building Code for safety reasons, appropriate remediation will be required to satisfy the Building Code.
11.	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.

A1.1.2 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

Step	Activity
B1	Establish whether there is adequate bearing capacity for remedial works (eg, using a hand-held Scala Penetrometer). It is recognised that there will be liquefiable soils at some depth beneath the house because this is the reason for its current condition.
B2	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.
B3	Check the vertical alignment of the internal piles. If existing piles are leaning at an angle of more than 50 mm per 1 m height, new piles will be required. Leans of less than this value are considered to be acceptable if there is a perimeter foundation present.
B4	Disconnect the internal piles from the bearers.
B5	Demolish ancillary structures such as steps and terraces as necessary. Chimney foundations and breastworks may be lifted using the process described below if they are not being demolished.

Lifting option 1: Perimeter foundation jacking using portable jacks

Step	Activity
B1.1	Clear the perimeter of the foundation. 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.
B1.2	Concurrently with the wall jacking, jack the underside of the bearers beneath the house to create and maintain the planar floor.
B1.3	For floor lifts of up to 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).
B1.4	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.
B1.5	Seal each side of the space between the foundation and the dunnage, fit grout injection ports and pump non-shrink flowable grout under the elevated foundation. Leave to cure for 12 to 24 hours and remove the jacking equipment.
B1.6	Fill the space between the underside of the foundation and the ground in each pit with concrete, backfill the pits and reinstate the adjacent ground.
B1.7	Seal the exposed cracks in edge beams and fill the cracks in accordance with Appendix A4.4.
B1.8	Reconnect any services that had been disconnected before the lift.
B1.9	Reinstate the adjacent ground.
B1.10	For assessment of and repairs to the superstructure, refer to section 7.

UPDATE:
December 2012

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

Step	Activity
B2.1	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.
B2.2	Ensure the services can accommodate the lift heights or detach these before the lift begins.
B2.3	Detach the piles from the bearers.
B2.4	Fit the lifting components to the tops of the screw piles and 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.
B2.5	Install grout injection ports and fill the space between the underside of the foundation and the existing ground with grout. Wait for 24 hours before removing the screw piles (if they are to be removed).
B2.6	The screw piles may be left in place or removed.
B2.7	Concurrently with the foundation wall jacking, jack the underside of the bearers beneath the house to create and maintain the planar floor.
B2.8	For floor lifts of up to 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).
B2.9	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.
B2.10	Seal the exposed cracks in edge beams and fill the cracks in accordance with Appendix A4.4.
B2.11	Reconnect any services that had been disconnected before the lift.
B2.12	Reinstate the adjacent ground.
B2.13	For assessment of and repairs to the superstructure, refer to section 7.

UPDATE:
December 2012

Lifting option 3: Perimeter foundation jacking using engineered resin

Step	Activity
B3.1	Ensure the services can accommodate the lift heights or detach these before the lift begins.
B3.2	Set up laser equipment for monitoring floor movement.
B3.3	Detach the piles from the bearers.
B3.4	Install injection ports to the predetermined pattern and spacing along that section of foundation to be relevelled. 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.
B3.5	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.
B3.6	Concurrently with the foundation wall lifting, jack the underside of the bearers beneath the house to create and maintain a planar floor.
B3.7	For floor lifts of up to 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).
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 exposed cracks in edge beams and fill the cracks in accordance with Appendix A4.4.
B3.10	Reconnect any services that had been disconnected before the lift.
B3.11	Reinstate the adjacent ground.
B3.12	For assessment of and repairs to the superstructure, refer to section 7.

UPDATE:
December 2012

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

Step	Activity
B4.1	Ensure the services can accommodate the lift heights or detach these before the lift begins.
B4.2	Set up laser equipment for monitoring floor movement.
B4.3	Detach the piles from the bearers.
B4.4	Install injection ports to the predetermined pattern and spacing along that section of foundation to be relevelled. 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.
B4.5	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.
B4.6	Concurrently with the foundation wall lifting, jack the underside of the bearers beneath the house to create and maintain a planar floor.
B4.7	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).
B4.8	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.
B4.9	Seal the exposed cracks in edge beams and fill the cracks in accordance with Appendix A4.4.
B4.10	Reconnect any services that had been disconnected before the lift.
B4.11	Reinstate the adjacent ground.
B4.12	For assessment of and repairs to the superstructure, refer to section 7.

UPDATE:
December 2012

A1.1.3 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

Step	Activity
C1	Establish whether there is adequate bearing capacity for remedial works (eg, using a hand-held Scala Penetrometer).
C2	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.
C3	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.

UPDATE:
December 2012

Lifting option 1: Perimeter foundation jacking using portable jacks

Step	Activity
C1.1	Take up all floor coverings in the areas where the floor is to be relevelled (lifted).
C1.2	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.
C1.3	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.
C1.4	Concurrently with the perimeter edge beam jacking, drill and inject grout through the floor slab on a suitable grid pattern, monitoring the slab lift to match the wall lifting.
C1.5	Start the edge beam lifting process by creating a planar floor plate, even if this is sloping, and then sequentially lift the foundation wall and slab until a horizontal floor plate is achieved.
C1.6	Install grout injection ports and pump non-shrink flowable grout under the elevated foundation. Leave to cure for 12 to 24 hours and remove the jacking equipment.
C1.7	Fill the space between the underside of the foundation and the ground at the jack pits between the jacks with grout or concrete.
C1.8	Seal the exposed cracks in the outside face of the perimeter edge beam and fill the cracks in accordance with Appendix A4.4.
C1.9	Reconnect any services that had been disconnected before the lift.
C1.10	Reinstate the adjacent ground.
C1.11	Relay the floor coverings.
C1.12	For assessment of and repairs to the superstructure, refer to section 7.

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

Step	Activity
C2.1	Take up all floor coverings in the areas where the floor is to be relevelled (lifted).
C2.2	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.
C2.3	Ensure the services can accommodate the lift heights or detach these before the lift begins.
C2.4	Fit the lifting components to the tops of the screw piles and under the edge beam. Lift the perimeter edge beam sequentially by a small amount (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.
C2.5	Install grout injection ports and fill the space between the underside of the foundation and the existing ground with grout. Wait for 24 hours before removal of the screw piles (if they are to be removed).
C2.6	The screw piles may be left in provided a permanent connection is made between the beam and the piles.
C2.7	Seal the exposed cracks in the outside face of the perimeter edge beam and fill the cracks in accordance with Appendix A4.4.
C2.8	Reconnect any services that had been disconnected before the lift.
C2.9	Reinstate the adjacent ground.
C2.10	Relay the floor coverings.
C2.11	For assessment of and repairs to the superstructure, refer to section 7.

UPDATE:
December 2012

UPDATE:
December 2012

Lifting option 3: Perimeter foundation jacking and slab relevelling using engineered resin

Step	Activity
C3.1	Take up all floor coverings in the areas where the floor is to be lifted.
C3.2	Ensure the services can accommodate the lift heights or detach these before the lift begins.
C3.3	Install grout injection ports to the predetermined pattern under the foundation wall and slab. Set up laser equipment for monitoring floor movement.
C3.4	Commence injection below the edge beam to lift the foundations and floor slab.
C3.5	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.
C3.6	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 relevel 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.
C3.7	Seal the exposed cracks in the outside face of the perimeter edge beam and fill the cracks in accordance with Appendix A4.4.
C3.8	Reconnect any services that had been disconnected before the lift.
C3.9	Reinstate the adjacent ground.
C3.10	Relay the floor coverings.
C3.11	For assessment of and repairs to the superstructure, refer to section 7.

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

Step	Activity
C4.1	Take up all floor coverings in the areas where the floor is to be lifted.
C4.2	Ensure the services can accommodate the lift heights or detach these before the lift begins.
C4.3	Install grout injection ports to the predetermined pattern under the foundation wall and slab. Set up laser equipment for monitoring floor movement.
C4.4	Commence injection below the edge beam to lift the foundations and floor slab.
C4.5	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.
C4.6	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 relevel 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.
C4.7	Seal the exposed cracks in the outside face of the perimeter edge beam and fill the cracks in accordance with Appendix A4.4.
C4.8	Reconnect any services that had been disconnected before the lift.
C4.9	Reinstate the adjacent ground.
C4.10	Relay the floor coverings.
C4.11	For assessment of and repairs to the superstructure, refer to section 7.

UPDATE:
December 2012

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.

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 relevelling 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.

Step	Activity
A1	Remove the cladding attached to the exterior piles to expose the piles.
A2	Locate services entry points to the house and disconnect to allow the house to be lifted without damaging the services.
A3	Demolish or disconnect from the foundation of the house any chimney foundations, steps or terraces that may prevent the house from being lifted.
A4	Disconnect all existing piles from the bearers.
A5	Fit a multiple lifting system (eg, 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.
A6	Pull together any gaps that had opened in the floor plate during the earthquake and splice joints between ends of joists and bearers that have parted. Repair any tension failures of bottom plates (likely to be at plate joints rather than in an individual piece). This will require removal of either linings or claddings in the area of the failure for access.
A7	Remove all piles that have settled more than 100 mm beyond the expected new common level or piles raked at an angle of greater than 15 mm per 1 m height.
A8	Replace removed piles with timber or concrete piles in accordance with the requirements of NZS 3604.
A9	Lower the superstructure on to the completed pile array and connect all piles to bearers in accordance with the requirements of NZS 3604.
A10	Reconnect all services previously disconnected.
A11	Fit new base boards to the perimeter piles.
A12	Reinstate the adjacent ground.

Type B: Perimeter concrete foundation wall replacement method statement

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

Step	Activity
B1	Establish whether there is adequate bearing capacity for remedial works (eg, using a hand-held Scala Penetrometer).
B2	Locate services entry points to the house and disconnect to allow the house to be lifted without damaging the services.
B3	Check the vertical alignment of the internal piles. If existing piles are leaning at an angle of more than 50 mm per 1 m height, new piles will be required. Leans of less than this value are considered to be acceptable if there is a perimeter foundation present.
B4	Disconnect the internal piles from the bearers and the outer bearers, and plates from the existing perimeter foundation.
B5	Demolish ancillary structures such as chimney foundations, steps and terraces.
B6	Fit a multiple lifting system (eg, 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. 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 part 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.
B7	Pull together any gaps that had opened in the floor plate during the earthquake and splice joints between ends of joists and bearers that have parted. Repair any tension failures of bottom plates (likely to be at plate joints rather than in an individual piece). This will require removal of either linings or claddings in the area of the failure for access.
B8	Demolish the existing damaged perimeter foundation and construct a new foundation, reinforced as detailed in Figure 4.2 or 5.12, as appropriate. Install replacement piles.
B9	After 7 days, slide the superstructure over the new foundation, lower it on to 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.
B10	Reconnect all services previously disconnected.
B11	Reinstate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.

Type C: Slab-on-grade floor replacement method statement

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

Step	Activity
C1	Establish whether there is adequate bearing capacity for a new floor slab (eg, using a hand-held Scala Penetrometer).
C2	Locate services entry points to the house and disconnect these remote from the foundation pad.
C3	Remove any fixtures such as toilet pans and cabinets such as kitchen cabinets and benches that will hinder the lift and lateral shift of the structure.
C4	Remove plasterboard linings from one side of the internal walls to a height of about 600 mm above the floor. (If it can be determined which side of the wall has the bracing system applied, 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.
C5	Disconnect all hold-down fixings (ie, bolts or bent bars) to allow the superstructure to lift above the floor slab.
C6	In both orthogonal directions, install 200 mm x 50 mm or 250 mm x 50 mm timber members through the space created in the walls and screw to the wall framing. This is an operation best undertaken by a specialist house moving company that has the correct equipment and the experience with such lifts. The heavy timber members serve to couple the wall frames together and brace the superstructure to allow it to be lifted fractionally off the floor slab.
C7	Install a multiple lifting system beneath the temporary bracing members and lift the framing off the floor slab by 150 mm and support on blocks. Reinstall the lifting system, now jacking on the underside of the bottom plates.
C8	Pull together any gaps that had opened in the framing during the earthquake and repair any tension failures of bottom plates (likely to be at plate joints rather than in an individual piece).
C9	Install steel sliding beams and slide the superstructure to the side of the site to allow 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).
C10	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.
C11	Reconnect all services previously disconnected.

Step	Activity
C12	The earlier removal of the wall linings will expose the bracing elements in the structure. For houses built before 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 reinstate the bracing element by back-blocking the horizontal joint and fixing the replacement linings in accordance with the bracing product manufacturer's specification. In other areas, the lower section of removed plasterboard may be replaced with a new section of plasterboard without the back-blocking. See section 7 for guidance.
C13	Re-stop the wall linings, refit any trims that were removed and redecorate.
C14	External sheet cladding connections and joints must also be checked and refixed. 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 renailed to the framing in the affected area.
C15	Relay the floor coverings.
C16	Reinstate the adjacent ground and landscape any areas affected by the lateral shifting of the superstructure.

Appendix A3: Assessment and repair options for chimneys damaged in the Canterbury earthquake sequence

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 Ministry'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: 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 Ministry'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 Ministry 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.

UPDATE: December 2012

Acceptable Solution B1/AS3 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/AS3) 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 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

UPDATE: December 2012

Environment Canterbury has Home Heating Rules for various parts of the Canterbury region. The Home Heating Rules and maps of Clean Air Zones can be found at: ecan.govt.nz/advice/your-home/home-heating/pages/Default.aspx. 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.

UPDATE: December 2012

Kaiapoi Clean Air Zone 2 has no restrictions provided only dry wood is burned.

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.

UPDATE: December 2012

Rangiora Clean Air Zone 2 has no restrictions provided only dry wood is burned.

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 unless a resource consent has been granted
- 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.

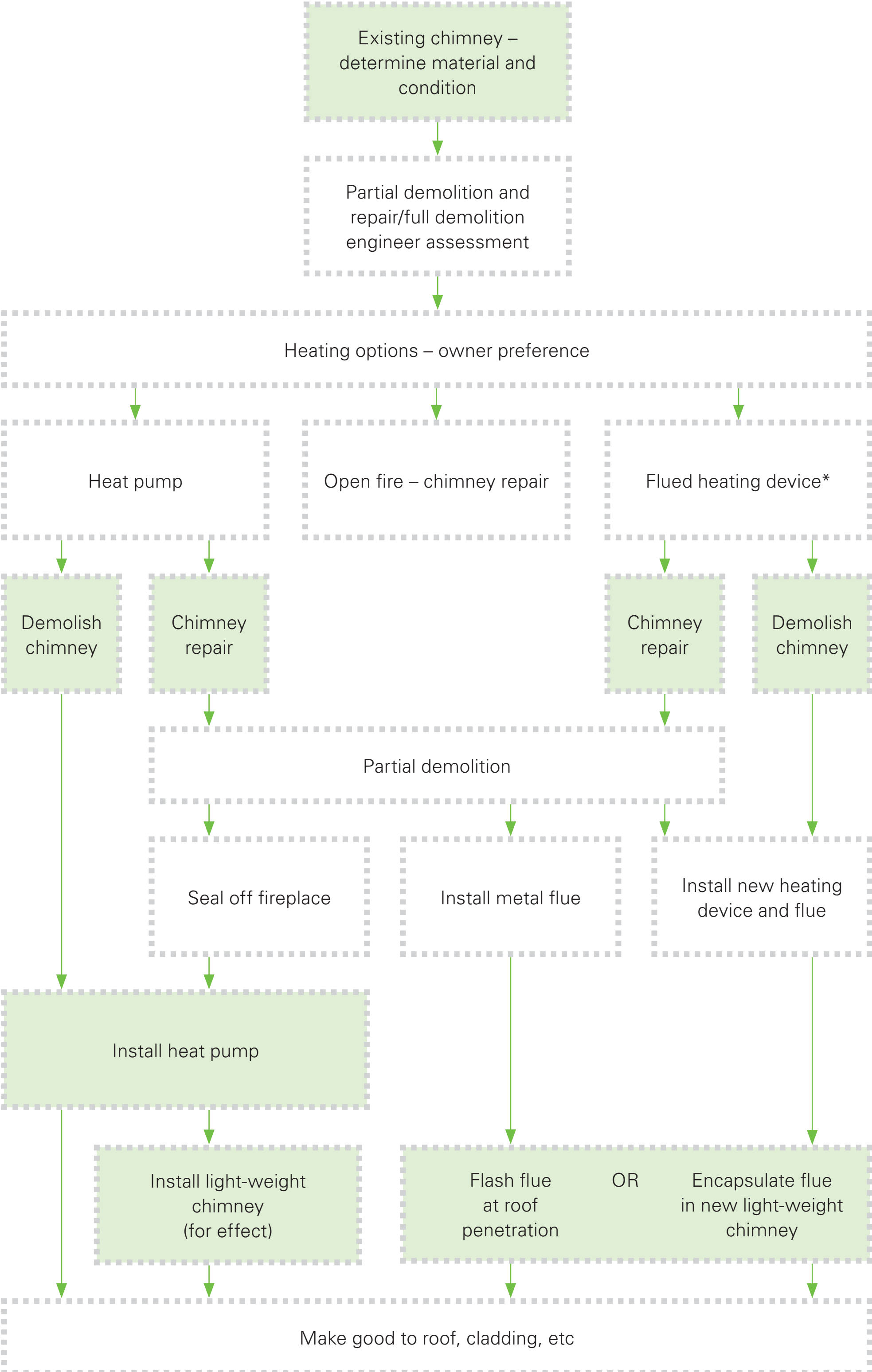
UPDATE: December 2012

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 on the heating device, the inner flue will have a 150 mm minimum diameter and the space between concentric casings is 25 mm, which results in a 250 mm diameter for the outer casing. A 25 mm clearance must be provided between the outer casing 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 A3.2: Process for assessment and decision on repair or replacement of chimneys



Note: Approved heating unit – log burner/pellet fire/gas fire.

UPDATE:
December 2012
Figures A3.3 and A3.4 from the November 2011 version of this guidance contained incorrect information regarding the requirements for ventilation of chimneys. It is very important that the space between the metal inner flue and the old brick chimney flue is ventilated to the outside when a solid fuel burner is installed in the fireplace. To this end, the intermediate casing must extend down through the concrete cap. The three new figures Figure A3.3, A3.4 and A3.5 provide correct information on ventilation..

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 (see Figure A3.5). If the brick chimney is replaced above the roof and an open fire is retained, then a stainless steel box sized to fit snugly into the remaining section of chimney below the roof and sealed to the existing chimney with a fire cement seal at its bottom edge is recommended. A concrete cap should be formed around the new stainless steel flue on top of the remaining brickwork and the upper section of brickwork rebuilt as a veneer, fixed to the box with metal ties (see Figure A3.3). 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. This may mean that the section of brick above the roof will have to be shorter than the original length.

If a solid fuel burner is installed during the repair process, the space between the burner flue and the new brickwork must be ventilated. To achieve the required ventilation, an inner and an outer casing are installed from the new concrete cap to the top of the new chimney flue (see Figure A3.4). A purpose-built stainless steel cap should be installed as formwork for the cap and to envelope the top of the remaining chimney.

The reinforced concrete cap should be 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).

Alternatively, the new brick veneer chimney may be omitted (see Figure A3.5).

Details of the three options are given in Figures A3.3, A3.4, and A3.5 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.

> **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.

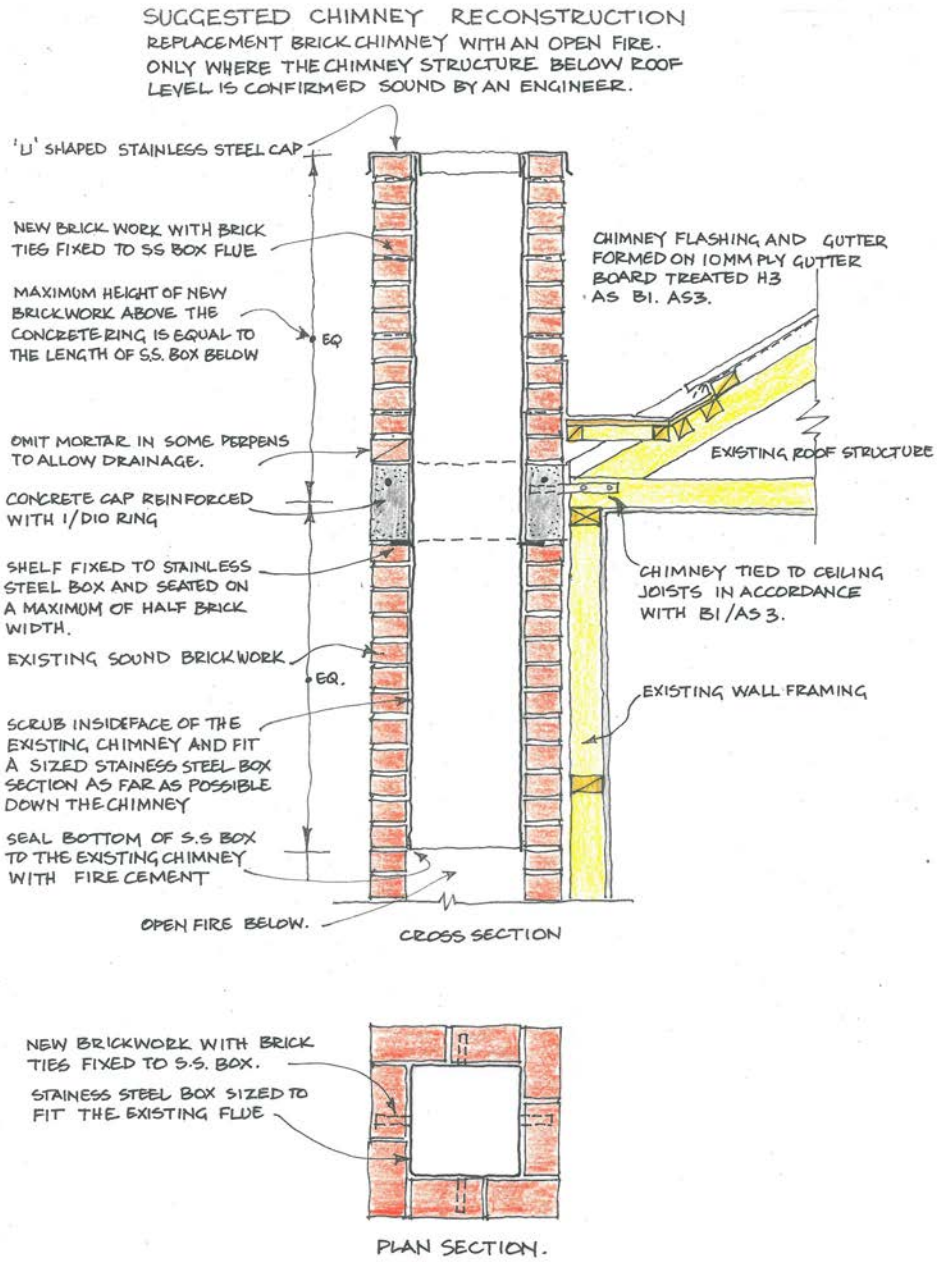
A3.8 Acknowledgement

The assistance of Fletcher EQR and the Home Heating Association of NZ in the preparation of this Appendix is greatly appreciated.

UPDATE:
December 2012

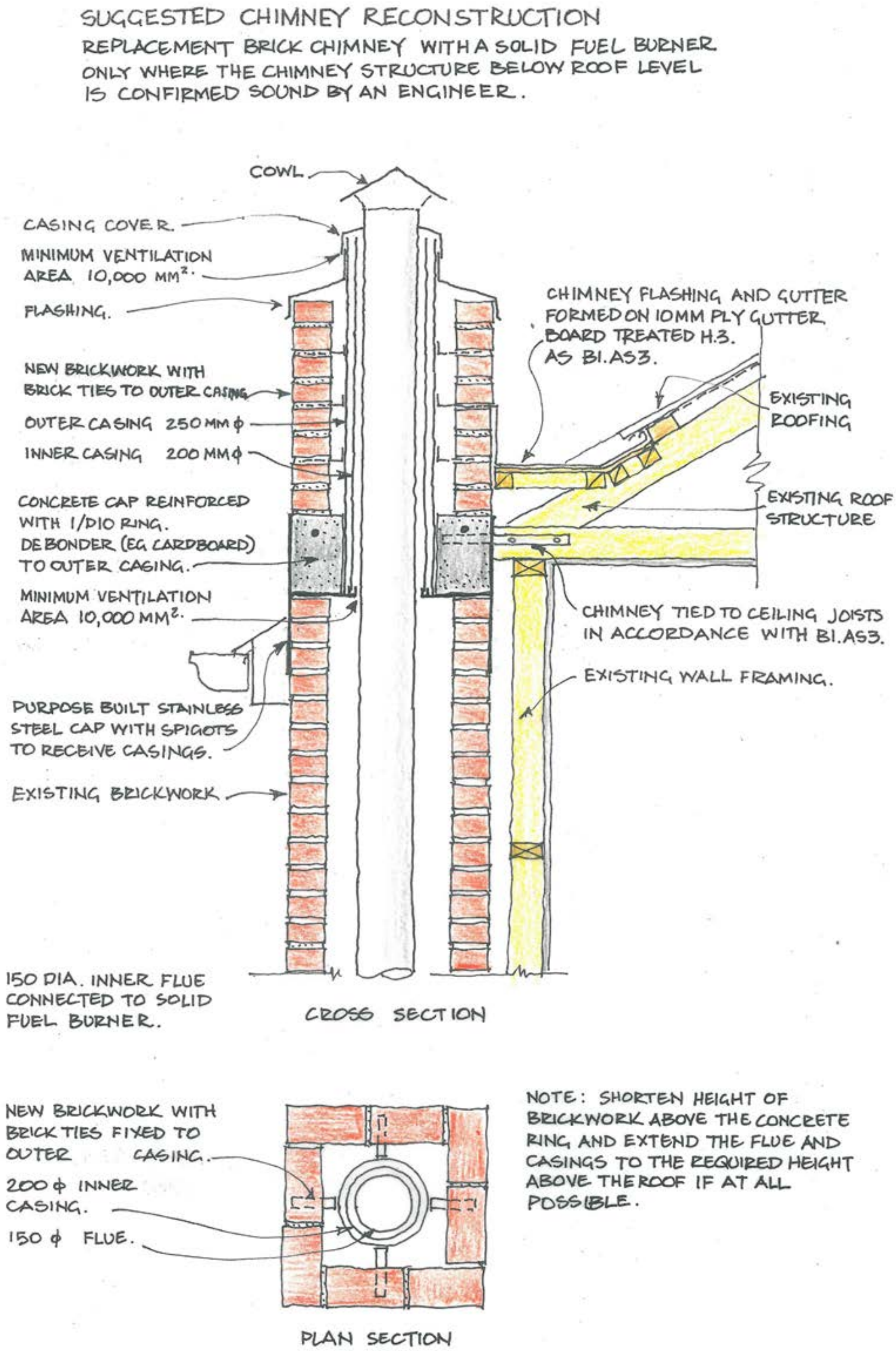
UPDATE:
December 2012

Figure A3.3: Chimney Option 1



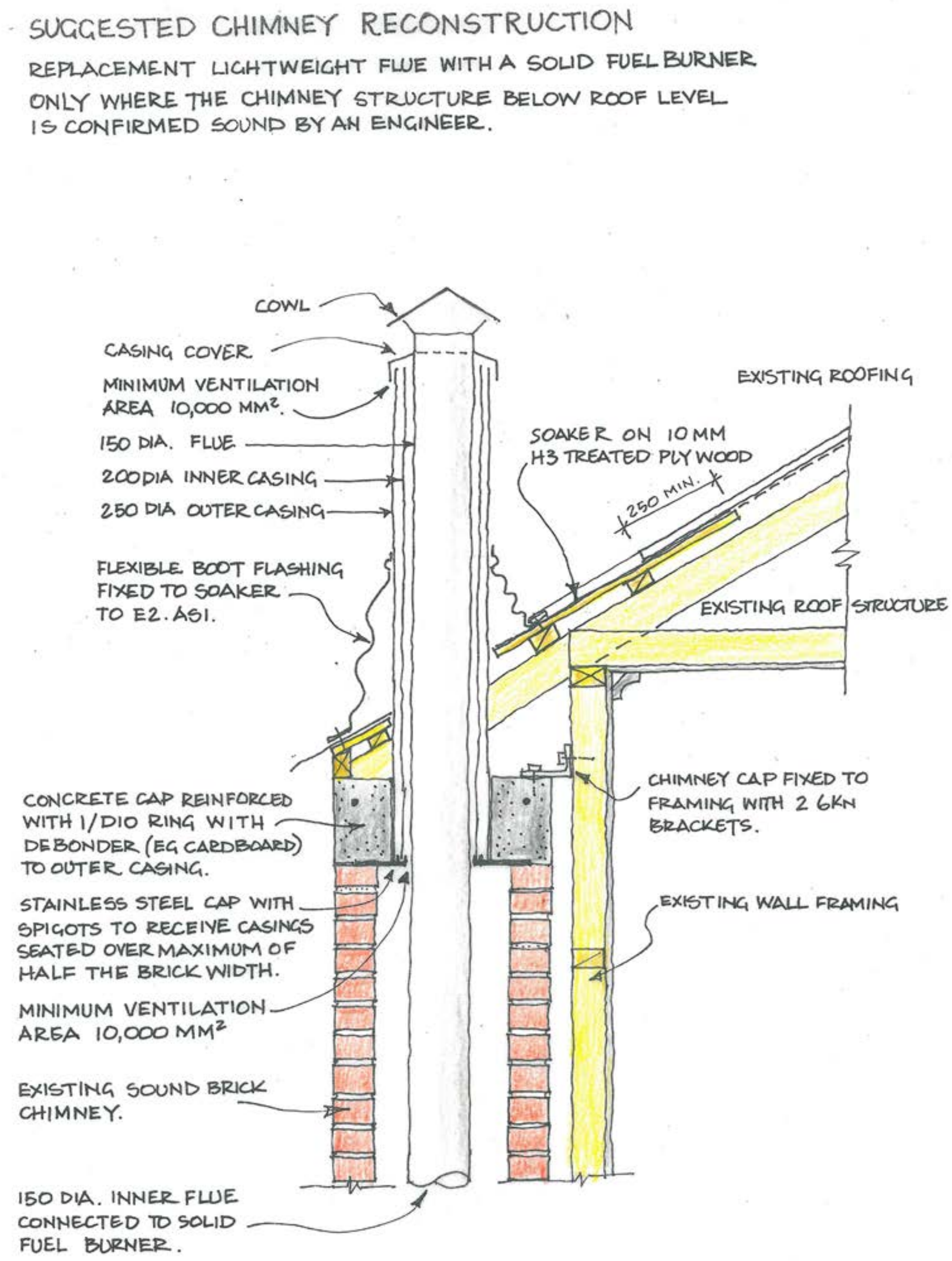
UPDATE:
December 2012

Figure A3.4: Chimney Option 2



UPDATE:
December 2012

Figure A3.5: Chimney Option 3



Appendix A4: Assessment and repair options for concrete floor slabs and perimeter foundation walls damaged in the Canterbury earthquake sequence

A4.1 Background

This appendix contains information on the assessment and repair of concrete floor slabs and foundation wall elements. Discussions subsequent to the publication of the Ministry's December 2010 document have highlighted the need for greater guidance on floor slabs and foundation walls.

UPDATE:
December 2012
Appendix A4 has been updated to provide additional guidance related to cracks in perimeter foundation walls

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 – floor slabs

UPDATE:
December 2012

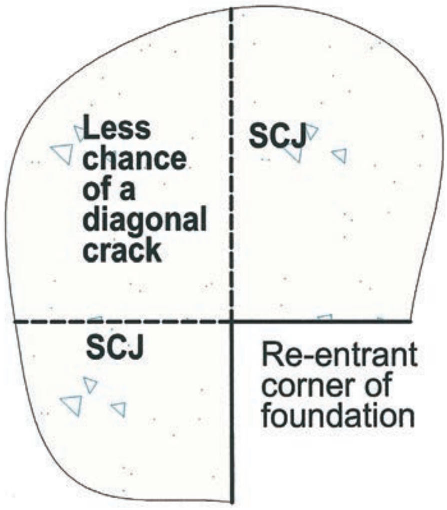
To counteract the effects of random cracking of new floor slabs, shrinkage control joints are deliberately cut in the slab to a depth of one quarter of the slab thickness, generally within 24 hours of the slab being poured. These do not prevent the floor from cracking, but they seek to ensure the cracks 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.

UPDATE:
December 2012

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



UPDATE:
December 2012

A4.2.2 Slab reinforcement

Floor slabs in houses designed in accordance with NZS 3604 before the 2011 citation update (see below) 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 Ministry 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).

UPDATE:
December 2012

A4.2.3 Perimeter foundation wall reinforcement

Perimeter foundation beams constructed since 1944 are expected to contain reinforcement. This may be only one plain round bar but in more recent years the bars will be deformed. Since 1978 there has always been a requirement for at least one D12 bar at the top of the wall and one D12 bar at the bottom. Walls greater than 450 mm high should have bars at maximum 450 mm centres up to the height of the wall. The presence of horizontal reinforcing steel should control the amount of cracking present in a foundation wall unless it has been affected by severe lateral ground spreading, in which case the bars may have yielded. Its presence should also minimise the vertical offset that occurs at vertical cracks.

UPDATE:
December 2012

A4.2.4 Slab/foundation connection

It is now a requirement, via the citation of NZS 3604 as an Acceptable Solution to the Building Code , that all slab on grade floors are reinforced. This ensures that the slab is tied to the edge foundation and that a tension tie is provided in both directions over the footprint of the dwelling. Between 1990 and 2011, slabs for single-storey dwellings could be constructed with no reinforcing steel present. Restraint of the slab was provided by an upstand from the edge of the foundation around the perimeter of the slab.

Before 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

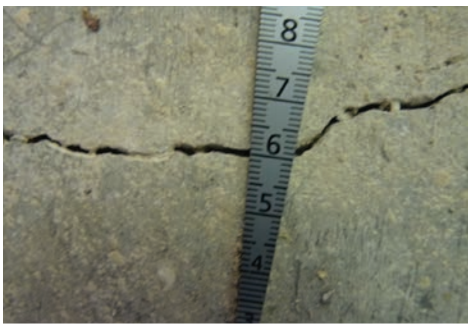
A4.3.1 Investigation and diagnosis

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

30-year-old slab



6-month-old slab

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.

UPDATE: December 2012

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 (Type C dwellings). 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.

UPDATE: December 2012

When the crack in a floor slab 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 filling the low side with floor levelling compound (FLC) or breaking back the slab on either side of the crack and refilling with concrete. All three 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 that have separated are seen, repairs should follow the methods outlined in this guidance document.

UPDATE: December 2012

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 overall 'stretch' of the floor is greater than 20 mm, reconstruction of all or part of the slab is likely to be necessary in order to maintain the plumb of the walls of the superstructure.

A4.3.2 The damp proof membrane (DPM)

Damp proof membranes are installed beneath slabs during construction of a building to prevent moisture vapour 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 Type C 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.

UPDATE: December 2012

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

A4.4.1 Repair criteria

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

UPDATE: December 2012

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.

UPDATE: December 2012

Table A4.1: Floor slab and perimeter foundation wall crack widths and repair approaches (in the absence of vertical misalignments)

	No action necessary	Repair by epoxy injection	Repair by grout injection	Break out and recast
Crack widths	Less than 1 mm	Between 1 mm and 10 mm	Between 10 mm and 20 mm	Greater than 20 mm
Considerations		Vertical misalignments across cracks are sufficiently minor to have negligible effect on the finished surface		

UPDATE: December 2012 The update of the crack width criteria to 5 mm aligns with Table 2.2 and relaxes the need for engineer involvement.

These criteria are intended to provide guidance, rather than represent absolute criteria. However professional engineering input into the diagnosis and repair specification should be sought where cracks greater than 5 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 relevelling. **No** crack repairs should be undertaken **before** the relevelling is completed except where the crack repair is required to contain the grout being used to relevel 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.

UPDATE: December 2012

There are other grouts suitable for this purpose, but they are usually applied in wet conditions, as might be expected in a perimeter foundation wall. Guidance given below for slab repairs assumes that the slabs are dry (ie. interior 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.

UPDATE:
December 2012

A4.4.3 Repair processes – floor slabs

> **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.

UPDATE:
December 2012

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 30 mm deep with a crack-chasing grinder. Any deeper chase may cut through the slab steel, if it is present.

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. The following guidance is provided 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 on to 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 on to 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.

UPDATE:
December 2012

A4.4.4 Repair processes – perimeter foundation walls

The guidance given in A4.4.3 is generally applicable to perimeter foundation walls, particularly with regard to crack cleaning. Access will not always be available to the inside face of the wall. Crack-filling materials should be chosen to suit the width of the crack and their ability to fill the cavity without excessive slumping. Walls constructed since 1944 are expected to have at least one reinforcing bar present. The crack-filling product should provide protection to the bar(s), particularly from moisture on the outside face of the wall.

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. 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 Ministry 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)[1].

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.

(1) Refer to www.dbh.govt.nz/earthquake-concrete-slabs-guidance