BUILD IT RIGHT
CANTERBURY

SUPPLEMENTARY GUIDANCE

November 2013

Guidance for building in toe slump areas of mass movement in the Port Hills (Class II and Class III)

Supplementary guidance to 'Guidance on repairing and rebuilding houses affected by the Canterbury earthquakes', December 2012.

Notes:

This guidance only applies to the GNS Science Class II and Class III areas of mass movement. **It does not apply to Class I areas.**

The principal users of this document will be professional geotechnical, structural engineers, designers and building control officials. The content of this document is therefore technical and written for a professional engineering and technical audience.

This guidance is issued under section 175 of the Building Act 2004.

1. What is the 'Stage 1 GNS report into ground damage on the Port Hills during the Canterbury earthquake sequence' all about?

A total of 36 hillside areas within the Port Hills have been identified by GNS Science as having been affected by varying degrees of mass movement during the 2010/2011 series of earthquakes. Mass movement is the geomorphic process by which soil and rock material moves downhill as a semi-coherent mass.

In fifteen mass movement sub-areas further investigation is required to determine whether there are potential impacts on life safety and/or significant damage to critical infrastructure might occur (GNS Science Class I relative hazard category). Of the remaining areas (GNS Science relative hazard categories Class II and Class III) it is considered that the potential impact of any further mass movement is to critical infrastructure and dwellings (residential property) and not a risk to life. The great majority of these areas exhibit a type of mass movement that has not previously been observed in our local soils, and has been referred to in the GNS Science report as toe slumping.

The GNS report is entitled: Canterbury Earthquakes 2010/11 Port Hills Slope Stability: Stage 1 report on the findings from investigations into areas of significant ground damage (mass movement). *GNS Science Consultancy Report 2012/317. Massey, C.I.; Yetton, M.D; Carey, J.; Lukovic, B; Litchfield, N; Ries, W; McVerry, G. 2013.* An electronic copy can be downloaded at: www.ccc.govt.nz/porthillsgeotech

The questions and answers below deal specifically with the toe slump type of mass movement.

2. What is toe slumping?

Most of the developed areas of the Port Hills have a slope angle of less than 15 - 20°, and are formed in loess-derived soil deposits (ie, clayey silt soils) that are typically underlain by volcanic materials. At the toe of many slopes, where loess-derived soils grade into alluvial soils and there is a permanent watertable, the recent earthquakes have triggered slumps of the toe slope. The slump movement mechanism currently is not well understood and more research and investigation is planned by GNS Science to better understand the process. Its present hypothesis is that very strong earthquake shaking creates a short period of high pore water pressure with an associated reduction in effective stress, during which the soil loses some of its shear strength and stiffness and is able to move downslope as a mass, while the shaking is occurring.

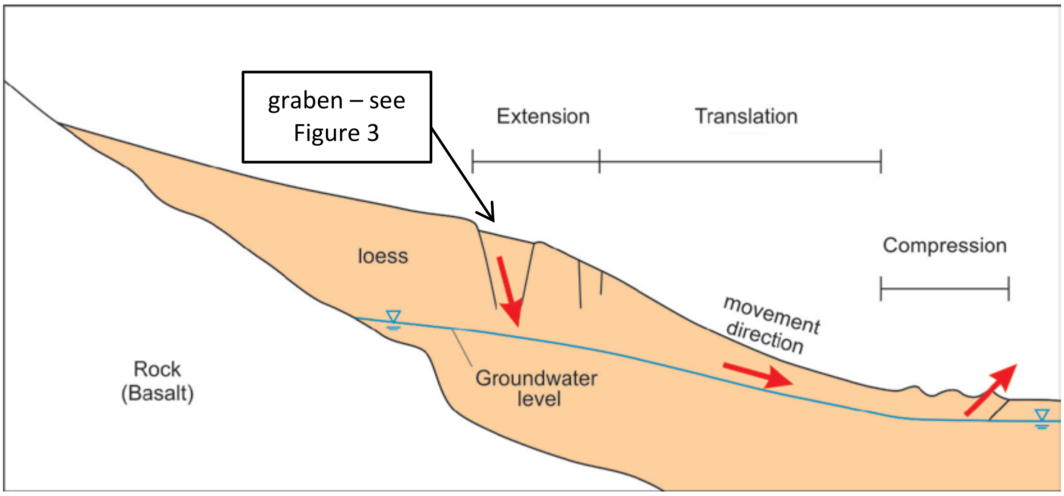

Figure 1: Schematic cross section indicating the typical toe slump surface geomorphology (based on GNS Science Report 2012/317)

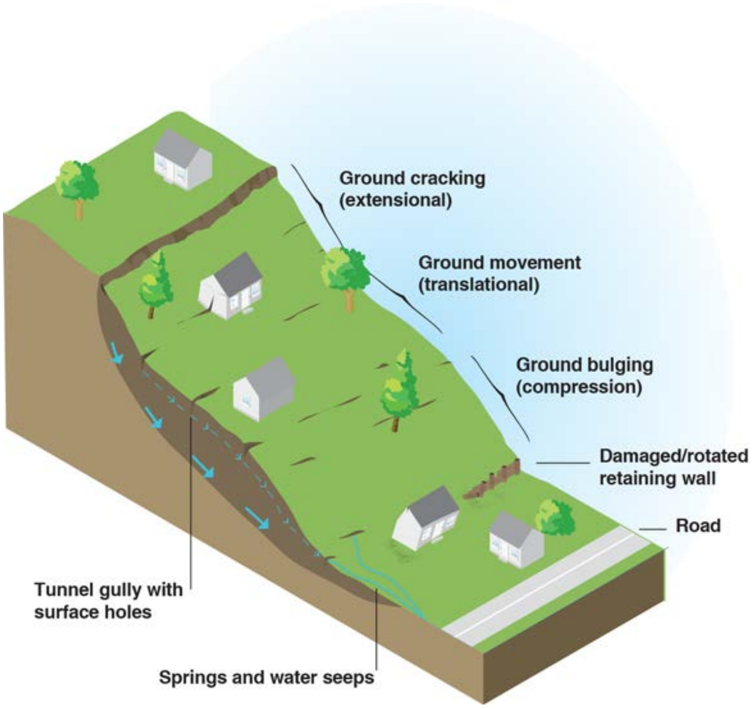

Figure 2: **Toe slump schematic**
(Image courtesy of GNS Science: Understanding hazard exposure from mass movement features in the Port Hills, October 2013)

Figure 3: **Graben formed in extension area of a mass movement feature**
(A graben is a depressed block of land bordered by parallel defects)

3. What are the implications for the toe slump areas?

During shaking from future large earthquakes the toe slump areas could be susceptible to renewed mass movement of a similar type to that which has already occurred. Further research is currently proposed by GNS Science on the likely earthquake motions necessary to trigger mass movements, and estimates of their frequency over time. At present it is thought that such events might be somewhere between an SLS (serviceability limit state) and a ULS (ultimate limit state) event. However, this is not as yet accurately defined.

There is a much lesser and presently only theoretical possibility that movement could also occur in extreme rainfall events, although to date this has not been observed.

The toe slump movement behaviour has been identified as presenting a low risk to life even if movement magnitudes are large, but has the potential to affect critical infrastructure and dwellings.

The nature of the ground, the mass movement processes and the net effects upon buildings and supporting infrastructure in these areas need to be understood and taken into account when planning a rebuild, and in some cases will also need to be considered when undertaking significant repairs.

Currently there is an assessed potential for the ground within a toe slump (as a whole) to move on average up to 0.5 m (but in some rare cases up to 1.5 m) downslope in response to another large earthquake. The movement affecting a single site within the mass will generally be less than this, and many sites within a toe slump area will not be affected at all by differential movements across the site following another large earthquake. It is differential movement that has the most significant potential to result in damage to structures on the land.

Movement can produce areas of tension (cracking) in the upper area of the mass, compression (bulging) in the toe areas of the mass, and block translation (generally sliding with lesser extents of cracking and bulging along with some plastic deformation ie, displacement without cracking) in the central portion of the mass.

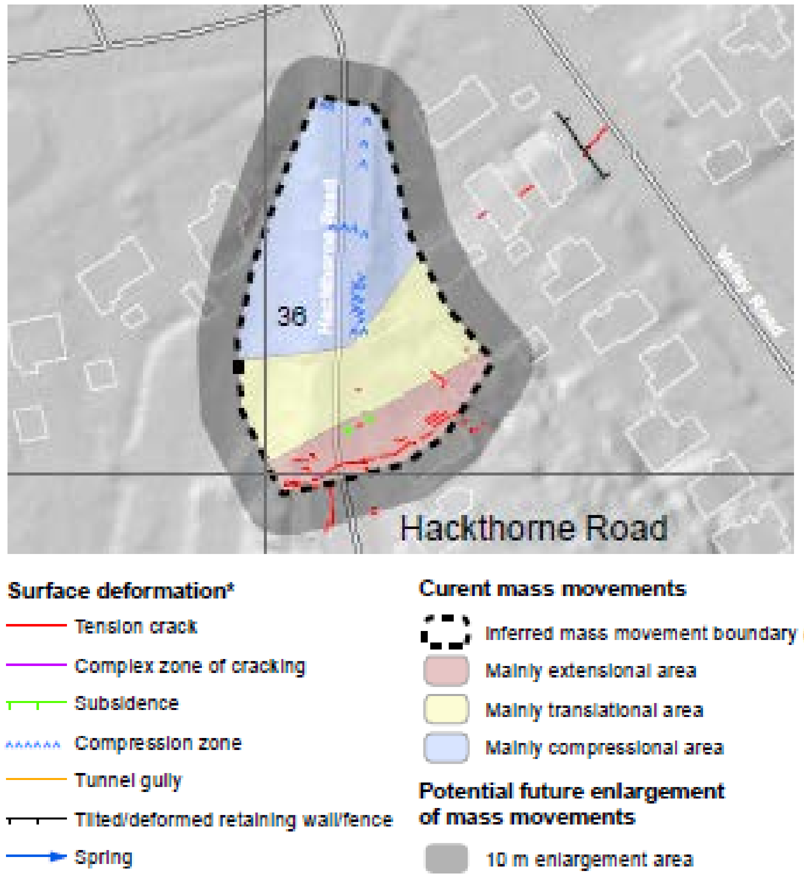

Figure 4: An example of toe slump mass movement area (based on GNS Science Report 2012/317) showing the main geomorphic features

A number of geotechnical conclusions about the future performance of these toe slump areas can be reached:

1. There is a risk that similar levels of mass movement and associated deformation patterns may occur in response to future large earthquakes (possibly between the SLS and ULS events);

2. In some areas, downslope extension (in the order of a few hundred mm) may occur across a building platform, typically manifesting as a number of cracks (often with a smaller vertical displacement) in the tensional and translational portions of the mass area. Compression bulges may form in the lower portion of the mass;

3. There is a potential for loss of local foundation support from the ground, or uneven loading due to ground bulging;

4. Not all toe slumps initiated by the recent Canterbury Earthquakes have been identified, as the mapping to date has concentrated on the current residential areas. It is therefore possible that toe

slumps or the geological conditions required for toe slumps exist in current non-residential areas of the Port Hills and Banks Peninsula.

4. How have houses performed in the toe slump areas?

To inform the content of this guidance MBIE commissioned a survey of 105 houses in some of the toe slump areas. Where buildings had been subjected to ground deformations, a number of observations were made of patterns of both poor building response and also relatively good building response.

4.1 Structural systems and building elements that did not perform well and would be difficult to repair:

It should be noted that while the observed performance of the following structural systems and building elements was poor (in that they resulted in more damage than was sustained by alternative forms of construction), the dwellings were not required to be designed to withstand significant ground displacement. In addition the poor performance may well have been exacerbated by poor design, detailing, construction or maintenance. Nonetheless, buildings with these features were observed to result in consistently poor performance:

4.1.1 Heavy wall and roof cladding systems

4.1.2 Horizontal and vertical structural irregularity

4.1.3 Structures with complicated load-paths

4.1.4 Brittle building elements

4.1.5 Conventional slabs on grade (eg, NZS 3604 type construction)

4.1.6 Mixed foundation systems

4.1.7 Down-stands in slabs or foundations

4.1.8 Long plan footprint in the down-slope direction

4.1.9 Complex level variations and in particular split levels

4.1.10 Masonry block basements. These have typically behaved well as a structural unit, often moving as a rigid block without significant internal deformation. The problem comes from the relationship between the basement area and the house structure above, and particularly the house structure adjacent to the basement (where attached). The difficulty of subsequent repair/relevelling and the impact of the basement's movement on the attached structure, services and waterproof tanking should not be underestimated.

4.1.11 Non-structural linking elements that rigidly connect the house to the ground

4.1.12 Inadequate separation between the main house and secondary add-ons such as footpaths, steps, patios, driveways, pools, retaining walls and other hard landscaping features.

Figure 5: Rupture at interface between single and two storey parts of house

Figure 6: Rupture of concrete floor slab

Figure 7: Rupture of concrete foundation beam and brittle cladding

4.2 Structural systems and building elements that performed well and would be relatively easy to repair:

4.2.1 Light-weight strip cladding such as timber or cement based weatherboard, vertical timber shiplap or board and batten.

4.2.2 Braced timber pole foundations with light-weight timber framed superstructures.

4.2.3 Braced, conventionally piled houses with light-weight timber framed superstructures.

4.2.4 Small overall plan footprints.

4.2.5 Short plan dimensions down slope.

4.2.6 Houses consisting of linked (but structurally separate) modules.

5. How should houses and foundations be designed in toe slump areas?

The design of building foundations and associated services should take account of potential renewed movement in these toe slump areas that may occur in response to shaking from larger seismic events that fall between the SLS and ULS design levels. Regulatory requirements for buildings are covered in section 8.2.3 of the MBIE guidance ‘Repairing and Rebuilding Houses Affected by the Canterbury Earthquakes’ (December 2012). By following this technical guidance for repair or rebuild of residential properties on the

Port Hills, the building consenting process will be made significantly more straightforward. Compliance with the guidance provides the BCA with the reasonable grounds needed to issue the consent. It is aimed at assisting engineers and designers to produce designs that meet the performance objectives of the Building Code. Refer to Question 8 for demonstrating compliance with the Building Code.

As with any seismic design, some damage could be expected in a seismic event, however houses should be robust, and generally repairable following events of ULS or less. The GNS Science Report indicates that toe slump mass movement is likely to be initiated in a seismic event that is in excess of an SLS event but less than a ULS event. Therefore designs should take into account likely movements, particularly as there remains considerable uncertainty about the mechanism for the cause of movement and the amount of shaking that could trigger mass movement. A degree of resilience and repairability needs to be designed into new building work.

Rupture of main structural building elements has been observed in existing houses with certain building features and house layouts in the toe slump areas The Building Code requires buildings or building elements to be designed to "withstand the combination of loads that they are likely to experience … throughout their lives". (B1.2). In addition, "Buildings, building elements and siteworks shall have a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing during construction or alteration and throughout their lives." (B1.3.1). ULS is the state where design actions approach design capacity and reliable structural performance can no longer be predicted beyond this point. The low probability of rupture in the Building Code equates to ULS requirements. If ground movement can be anticipated in a less than ULS event, then such ground movement should be considered in the design process. The need to design robustness into house structures is accentuated by the current uncertainty over the return period of events that might cause mass movement areas to reactivate.
Based on the observation of building performance in these Class II and III areas, following the MBIE guidance will provide enhanced resilience and a degree of repairability.

The following are some general foundation and services design principles that are appropriate in toe slump areas. The italicised commentary provides some background for each guidance clause and is based on evidence gathered from the engineering observations of Port Hills' properties in the Class II and Class III areas of mass movement.

During the assessment process, it was apparent that although distinct styles of land damage occurred in tension and translation areas, the structural forms considered best able to reduce the likelihood of rupture or limit damage to repairable levels in these areas were essentially the same. Consequently the recommendations for tension and translation areas are identical. The land damage observed in compression areas is different and the recommendations for rebuild and repair in those areas are distinctly different.

The GNS Science maps include a 10 m wide buffer zone (called an 'enlargement area') where, following further work by GNS Science, the mass movement boundaries might extend out to. Until that work is complete, all recommendations in this guidance document also apply to those 'enlargement areas'.

5.1 Recommendations for all areas (tension, translation, and compression)

5.1.1 Professional geotechnical and structural engineering advice should be provided at the beginning of the concept design process, to ensure appropriate design concepts are adopted that account for the potential ground displacements at the site (as outlined later in this document) and the particular features of the site.

Considerable time and expense may be saved if there is engineering input into the concept stage of a project; this avoids redesign or expensive engineering work-arounds for a house that is otherwise not designed sympathetically with its geological setting. For the toe slump areas, specialist geotechnical and structural engineers should be involved at the outset so that the design of the house is appropriate for the site and its specific conditions.

5.1.2 Primary design considerations should include resilience to ground movement, repairability, and the ability to be simply relevelled if necessary.

Many houses in the toe slump areas were not critically damaged, but due to their fundamental design and construction, the damage that did occur (even where relatively minor) is extremely difficult to repair. The design should emphasise an ability to provide tolerance to land movements in order to limit structural damage, and to permit future repair of damage that may occur.

5.1.3 NZS 3604 on its own is not an acceptable solution for toe slump areas.

Hillside houses, and in particular those in toe slump areas, require specific engineering design input to ensure the foundations and superstructure are appropriate for the site conditions. A greater attention to resilience and repairability is required. All new houses in the toe slump areas should have specific engineering design, with emphasis on the guidance provided in this document (although NZS3604 might be used for certain parts of the superstructure that are not affected by toe-slump design considerations).

5.1.4 Simple plan shapes and foundation systems, and lighter weight buildings are desirable to reduce the risk of damage. Horizontal and vertical structural regularity should be provided as much as possible.

Keeping the overall plan dimensions of the house small will help to minimise the impact of random cracking and horizontal and vertical differential ground movement. In particular, keeping the plan dimension of the house small in the downslope direction should minimise the impact of ground movement on the structure. Where the plan footprint of a house is large, or where there is significant plan or vertical irregularity, then splitting the house into smaller, seismically separated structural modules is expected to improve the performance of the house overall.

Horizontal and vertical regularity are fundamental requirements for good seismic design, regardless of the type or location of the building. Irregular house layouts (in terms of structural stiffness distribution) can cause large torsional demands on the structure. These can in turn cause large deformations that increase the levels of damage in non-structural elements of the house (ie, cladding, glazing and services). This damage can be avoided while still achieving an overall irregular shape by designing the house as a series of distinct and separate structural modules.

5.1.5 Direct load paths should exist.

Houses with simple, direct load paths are recommended. Land deformations (eg, differential settlements, lateral stretching) in the toe slump areas will apply additional stresses at connections between walls and floors and walls and roofs. It is particularly important that horizontal loads can be transferred effectively through the connections into the walls. One example of an indirect load path is where a floor frames into the mid height of a wall. This will introduce bending forces in the wall framing under horizontal loading that may not have been allowed for.

5.1.6 Split levels should be avoided.

Differential movement between levels introduces concentrated forces at the floor/wall junctions. Proper integration of the foundations of the two parts of the house will lessen the risk of damage at the junctions. Single continuous rigid floor plates provide improved performance to the superstructure.

5.1.7 Where foundation or structural elements extend into the ground to any significant depth, the effect of passive pressures (during a mass movement event) on these elements, which get transferred to the structure, should be taken account of in the design.

Soil movements from future events may impose lateral displacements on foundation elements and other embedded structural elements such as downstand walls and integral retaining walls. These displacements create loads that are applied to the supported structure and may cause damage unless the structure is designed to accept them, or special detailing is used to allow for the likely movements (sliding details, pins, weak links, and the like).

5.1.8 Cladding and roofing systems should be capable of accommodating deformations imposed through the structure by future ground movements.

Based on observed damage in the toe slump areas, rigid wall cladding systems performed poorly (compromising weathertightness), due largely to their inability to deform with the structure. Weatherboard systems appeared to perform well.

5.1.9 Retaining structures should be separated from the house wherever possible.

Where retaining of the slope is required, separating the retention system from the house allows the house to respond independently to ground shaking or displacements. Timber pole walls have performed well and can handle ground movements better than rigid retaining wall systems. Retaining walls that are not overly sensitive to ground movement can be used in the subfloor space to accommodate basement level garaging or habitable space, with appropriate structural separations. This also facilitates repairs to the house if required.

5.1.10 Where waterproofing is required, provide robust waterproofing membranes and drainage systems to retaining structures capable of tolerating movement without rupture. For basements, if an integral backfilled wall is unavoidable, allow for access for the repair of damaged water-proofing and sub-soil drainage.

Basement waterproofing has traditionally been a major serviceability issue on the Port Hills. It is very difficult to properly fix a leaking basement wall, and significant seismic shaking may contribute to the problem by both potentially changing groundwater regimes and also damaging tanking and subsoil drainage infrastructure. For these reasons it is recommended to either separate any subfloor retaining wall from adjacent habitable space, or alternatively detail robust waterproofing systems that can be accessed from upslope for repair if necessary.

5.1.11 Consideration should be given to articulating service connections to the house and ease of access for repair.

It is important that piped or ducted services to a property are resilient and if damaged, relatively easily repairable. Services sheared off or stretched can be very difficult and expensive to fix when buried beneath concrete slabs-on-grade. Services in an open subfloor space are accessible, and also possess a degree of tolerance to lateral movement when appropriately detailed.

5.1.12 Both ground extension and compression are possible across the building footprint, depending on the location and size of the dwelling within the toe slump area. Where this is the case foundations should be designed to withstand these movements.

Careful reference to the GNS Science maps will be required, as well as consideration of the likely accuracy of these maps.

5.1.13 Design features reports should be submitted with building consent applications (refer Question 8).

5.2 Tension and translation area recommendations

5.2.1 House structures should be designed to ensure that they can accommodate horizontal and vertical differential ground movements across a ground crack of up to 50 mm and still be readily repairable, and also movements of 200 mm without risk of collapse. Consideration of how a repair might be affected after such an event should be part of the design process.

These dimensions have been estimated based on the median crack widths and offsets observed in the original toe slump area mapping. However, where a house will straddle a mapped crack of wider aperture than 200 mm, then wider apertures should be allowed for in the design against collapse.

5.2.2 Houses supported on timber piles or poles are strongly preferred (or equivalent style of construction), with a subfloor crawl space of at least 450 mm to allow access for repairs. Attention to connections between the foundation elements and the superstructure should be carefully considered, to cope with expected ground movements. Floors should be constructed as structural diaphragms with adequate chords (A chord is a structural member that usually borders the diaphragm and resists the tension or compression loads developed in the diaphragm).

The recommended alternative to conventional slab-on-grade foundations is to support timber-subfloored houses on timber pile (ie, short timber piles) or pole foundations. These systems introduce a degree of flexibility into the foundation system, improve the ability of the structure to handle ground movement, and greatly improve the repairability of the house foundations and services. Architectural considerations of this form of construction can be met by appropriate detailing.

It is important to ensure that the floor platform remains intact to protect the superstructure from excessive damage. For example, particle board flooring is not expected to perform as well in the long term compared to a well-constructed plywood floor diaphragm.

5.2.3 Concrete slab systems are not preferred, but if used they should be designed for loss of support over half the footprint of the house. Floor plate curvatures under differential ground settlement in the load combination of G + 0.3Q should be less than 1 in 400 (eg,10 mm sag at the centre of an 8 m length) in the case of a spanning loss of support, and no more than 1 in 200 for a cantilever loss of support. Concrete foundation systems also need to be able to withstand stresses induced from sliding of the ground under half of the building footprint.

The style of land movement observed in the toe slump areas typically involves the lateral and vertical movement of blocks of loessial soils with considerable cohesion, resulting in separation of these semi-rigid blocks. There is little apparent cushioning. Houses with rigid foundations spanning across land cracks have therefore been subject to removal of support that may extend over 8-10 m, approximately half the length of the average house in the toe slump areas.

5.2.4 Linking elements attached to the structure should be detailed to allow for displacements resulting from differential ground movement eg, sliding joint type connections for elements providing vehicle or pedestrian access to the house.

Non-structural elements that link different levels of a house should be structurally separated. In particular, external stairs, driveways, etc that create rigid structural connections between the ground and the house should have sliding connections or be structurally separated so that the house can respond independently to the ground movement.

5.2.5 Deep piles are not recommended.

The locations and depths of the zones in which the displacements are occurring are extremely difficult to determine, and there may also be multiple shear zones. Estimations of lateral displacement and associated lateral loadings on deep piles are similarly extremely difficult. If deep piles are considered, designs should be conservative in the treatment of lateral displacement and soil pressures.

5.3 Compression area recommendations

5.3.1 In compression areas, the expected land damage mechanisms include loss of support (ie, from compressional bulging). It is not possible to determine the likely shortening of the land under a building footprint, but houses should be designed for unsupported lengths of 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). Floor plate curvatures under differential ground settlement in the load combination of G + 0.3Q should be less than 1 in 400 (ie, 5 mm hog or sag at the centre of a 4 m length) and no more than 1 in 200 for the case of no support of a 2 m cantilever at the extremities of the floor. Reinforced concrete slab foundations capable of withstanding the imposed loadings from these mechanisms are likely to be the most appropriate form of foundation system in these areas.

A TC3 type 2B surface structure is considered appropriate, with the underlying gravel layer reduced to 150 mm minimum thickness (but dependant on actual ground conditions). Alternatively a TC2 type 2 slab on grade can be used, underlain with a 600 mm reinforced gravel raft (ie, a hybrid concrete slab foundation from section 15.4.6 of the MBIE guidance). A further alternative is the use of a relevellable double slab system that meets the requirements of section 15.4.8 of the MBIE guidance.

In compression areas, observed ground movements have been less damaging than those in tension areas. There has also been an apparent degree of cushioning to foundations due to the softer soils and influence of a higher water table. While the style of movement is different from that experienced elsewhere on the flat land, similar repair methodologies are applicable. A relevellable slab or suspended timber floor with an underslab and load spreading reinforced gravel raft (to also provide a platform to relevel from) is considered to be the most appropriate type of foundation system in these areas. Although specific engineering design is required, the concepts embodied in the TC3 Type 2B foundation system are recommended.

5.3.2 In the compression areas in particular (being generally at the base of the slope and encroaching on the valley floor) issues such as potentially liquefiable soils, peat and other compressible soils may be present that require additional engineering design input.

The normal engineering issues relating to the development of hillside residential sites are not superseded by the guidance presented above. The advice given should be carefully considered during development in association with all the usual factors encountered on similar sites.

6. What other things need to be taken into consideration?

1. The implications of large scale cuts and fills and how they might behave in a future event should be considered in the development of a site.

2. For repair of ground cracks, especially when immediately adjacent to foundations, refer to http://www.eqc.govt.nz/canterbury-earthquakes/land-claims/guide-to-settlement-of-canterbury-port-hills-land-claims

3. Toe slump movements are unlikely to be the only potential issue on a site. In all areas there may be other geotechnical considerations that impose additional constraints on a building. Uncontrolled fill, subsurface erosion features and susceptibility to rainfall induced instability (for example) are also common issues on the Port Hills. Refer to section 6.1 of the MBIE guidance.

7. What about repairs to foundations?

Where foundation sections are being replaced, upgrade if practical to do so. If repairs are being contemplated for foundation cracking that could be repaired in-situ, proceed with the repair following a structural check to ensure the overall integrity of the foundation has not been compromised.

8. How do I demonstrate compliance with the Building Code?

A Design Features Report (DFR) will need to be submitted with the consent documentation, along with design calculations that demonstrate how the building will cope with the deformations outlined in this guidance.

The nature of this guidance is such that there are many ways in which to ensure a house is designed to cope with the nature of the site it is located on. A Building Consent Authority (BCA), if it is to grant a building consent on reasonable grounds, will need to be able to understand how the house design has been determined. A DFR that sets out how the guidance has been considered and incorporated into the design will greatly assist the BCA in determining if, on reasonable grounds, it can grant a building consent. With the exception of compression areas (if the particular solutions that are suggested are adopted) design calculations will also be required to demonstrate how the design incorporates the potential deformations on the site, as outlined in this document. Refer Appendix B of MBIE 'Guidance on the use of Certificates of Work, Producer Statements, and Design Features Reports by Chartered Professional Engineers under the new Restricted Building Work Regime'.

9. What about areas of the Port Hills that are geologically and topographically similar to the identified toe slumps, but where no toe slumping has been identified?

In the Port Hills there are many slopes – the majority of which are currently non-residential – that are similar to the slopes where known toe slumps (and other mass movements) have occurred in response to the recent Canterbury Earthquakes. In future earthquakes, such as an Alpine Fault event or another local earthquake with a new epicentre, renewed movement of the existing toe slumps (and other mass

movements) may occur, and new toe slumps and other mass movements could also be generated in different locations to those already identified.
If this were to happen, new mass movements are most likely to occur in similar settings to those that have already been observed. The GNS Science report 2012/317 gives an example of the main geological and topographical features relating to the toe slumps triggered during the recent earthquakes:

"The mapped toe-slump failure types occur near the toe of slopes formed of mixed colluvium, alluvium and loess inclined between 5° and 20°, at elevations between 5 and 20 m above sea level and where the groundwater levels in the toe areas are close to the surface."

For slopes outside of the currently identified mass movement boundaries (as set out in the GNS Science report 2012/317) that exhibit similar geological and topographical features as the known mass movements, it would be reasonable to assume that such slopes may also potentially be susceptible to future mass movement if an earthquake event were to occur. In such settings, investigations should include a geomorphological assessment of whether any evidence of such movement (cracking, terracettes, bulging etc) is present; if so then foundations should be designed accordingly.

New subdivisions in these areas may be controlled by the relevant Territorial Authority and therefore early consultation is advised.