Part D: Guidelines for the geotechnical investigation and assessment of subdivisions in the Canterbury region

Minimum requirements for geotechnical assessment for land development ('flatland areas' of the Canterbury region)

Contents

16. Geotechnical investigation and assessment

16.1 Introduction

In support of both plan change applications and subdivision consent applications, appropriate geotechnical investigations shall be carried out, and stand-alone geotechnical reports prepared by a Chartered Professional Engineer (CPEng.) with competence in geotechnical engineering. The reports shall combine all relevant geotechnical information in both a factual and interpretive manner, provide justifiable statements about all pertinent geotechnical aspects and consider relevant RMA section 106 issues.

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

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

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

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

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

- NZGS guidelines (2010) *Geotechnical Earthquake Engineering Practice Module 1 – Guideline for the identification, assessment and mitigation of liquefaction hazards.*

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

16.2 Site investigation

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Appropriate geotechnical investigations shall be carried out to enable the characterisation of ground-forming materials to at least 15 m depth below ground level, unless the ground is known to be of acceptable quality from lesser depths, for example, in areas known to be underlaid by competent gravels and deep groundwater profiles, or in hillside areas. Areas that are within the Ecan/GNS assessment area defined as 'damaging liquefaction unlikely' (refer to GNS Science Consultancy Report 2012/218 and the relevant data layer on the Canterbury Geotechnical Database or Ecan /TA GIS system) are also less likely to be subject to liquefaction hazard. Within such areas, investigations in most cases can be designed primarily for other geotechnical hazards. Liquefaction, however, must at least be considered by the geotechnical professional in all cases.

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

- CPT (Cone Penetrometer Test) testing
- physical drilling and sampling with SPT (Standard Penetration Testing) (refer NZS 4402.6.5.1:1988)
- testpit excavations (eg, in ground of acceptable quality from shallow depths)
- laboratory testing

as judged appropriate by a Chartered Professional Engineer (CPEng.) with competence in geotechnical engineering.

Scala Penetrometer testing (refer NZS 4402:1998 Test 6.5.2) is often useful as a shallow investigation tool in conjunction with the methods outlined above. However, Scala Penetrometer testing is not considered appropriate as the primary ground characterisation method for liquefaction purposes.

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Given the relative cost of CPT data it is considered best practice to push CPTs to refusal, however where there are very deep deposits of penetrable materials (for example in excess of 20 m) some judgement is required regarding the usefulness of the deeper information. It must be recognised also that early termination of CPT investigation depths may result in loss of potentially useful information regarding possible pile founding depths, ground improvement options, overall site settlements and general site characterisation. For this reason, termination of CPTs at a given depth is not recommended.

It is recognised that CPT data is generally superior to SPT data in determining liquefaction susceptibility. Therefore, CPTs will normally be carried out in preference to SPTs. CPT equipment should be calibrated, and procedures carried out, to ASTM D5778-12.

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In many areas of Canterbury however, liquefiable deposits contain interbedded layers of relatively stiff gravel deposits. Therefore, CPT testing alone may not penetrate deep enough to achieve the depth of ground characterisation required. Physical drilling, sampling and SPT testing may be required in this case.

Where ground conditions dictate the need for SPTs it is important that equipment is used that has been properly energy rated so that an appropriate energy ratio can be used to correct SPT 'N' values.

Geophysical methods such as MASW (multi-channel analysis of surface waves) can be useful in characterising ground conditions between borehole locations.

Knowledge of the geological depositional environment can also be a guide to identifying areas of likely liquefaction susceptibility.

These guidelines relate primarily to residential subdivisions – commercial and industrial subdivisions may require more substantial investigations.

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16.3 Site investigation density for overall ground characterisation

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

Investigation stage	Total number of test/investigation locations (cumulative)		
	Site 1 hectare or more	Site 2500 m^2 or more, but less than 1 hectare	Site less than 2500 m^2
Plan change	0.2 to 0.5 per hectare (minimum of 5)	2 to 5 total	2 total
Subdivision consent	0.25 per lot (minimum of 5) (urban) 1 per house site (rural)	5 total	1 per lot

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

For the purposes of this table, a minimum effective lot size of 600 m^2 may be used.

If initial investigations for a subdivision (carried out at minimum densities tabulated above for 'Plan Change') demonstrate an absence of liquefaction potential, the engineer may judge somewhat fewer test locations or shallower depths of investigation to be appropriate (however, potential geotechnical issues other than liquefaction must be considered in making this judgement). Conversely, higher densities may be required where particular site conditions (subsurface complexities, site geometry etc) exist. In commercial or industrial land, specific development proposals may also lead the engineer to judge that fewer or more test locations are appropriate.

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16.4 Liquefaction assessment

In addition to standard geotechnical characterisation, the site data shall be analysed using the methods outlined below to determine liquefaction susceptibility and in particular likely ground deformations under design serviceability limit state ('SLS') and ultimate limit state ('ULS') ground motions (It is important to note that the methods outlined below **must be employed** when using these guidance documents).

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16.4.1 Liquefaction analysis methodologies (minimum requirements)

A standard liquefaction analysis methodology shall be used, as outlined below, in conjunction with specified input ground motions and, where appropriate, observations of land damage from recent seismic events. Other methods or adjustments that are not included in this document (for example 'thin layer' correction techniques) do not form part of this standardised methodology.

Ground input motions

Refer to Appendix C2, Guidance on PGA values for geotechnical design in Canterbury.

Liquefaction hazard, liquefaction-induced settlements and lateral spread

Refer to the following documents or methodologies:

- For background information: refer to the latest edition of NZGS guidelines *Geotechnical Earthquake Engineering Practice Module 1 – Guideline for the identification, assessment and mitigation of liquefaction hazards* (current edition July 2010).
- For specific analysis methodology for liquefaction triggering: refer to Idriss & Boulanger 2008 *Soil Liquefaction During Earthquakes* – EERI monograph MNO12. This is to be modified for fines correction, settlement calculation, surface crust assessment and site observations in accordance with Appendix A of this (subdivision) document. (**Note:** this requirement is only for the purposes of determining settlement deformations and their comparison with the limits set out in Table 16.1).
- Where land is within 200 m of a free edge then the potential effects of lateral spreading shall be assessed.
- It is hoped that, with time, a modified methodology for liquefaction settlement/damage calculation (that will be depth weighted) will be derived from extensive site data and damage observations in the recent earthquake sequence. This will be incorporated into these requirements at an appropriate stage.
- Modification by reference to soil deposit ageing is not considered appropriate in the Canterbury region.

16.5 Broad classification of land

The site's liquefaction characteristics shall be assessed against the limits in the guidance document as summarised below in Table 16.1.

Liquefaction characteristics need to be assessed over the full depth of the soil profile investigated. However, when comparing calculated settlement values to the index values in Table 16.1, calculations may be limited to the upper 10 m of the soil profile (this does not in any way imply that potential issues do not need to be considered below 10 m depth, this is simply a calculated 'index' number for comparison to the index values in Table 16.1). Settlements resulting from soil liquefaction at depths greater than 10 m do contribute to total ground settlements, which can be important in areas of high flooding hazard or for proper functioning of some utilities. Therefore, the amount of ground settlement resulting from deep liquefaction should also be estimated when evaluating deep soil profiles where liquefiable soils with low resistances are encountered.

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Table 16.1: Liquefaction deformation limits and house foundation implications

Technical Category	Liquefaction deformation index limits				Likely implications for house foundation (subject to individual assessment)
	Vertical settlement		Lateral spread (across a house site)		
	SLS	ULS	SLS	ULS	
TC1	15 mm	25 mm	nil	nil	Standard NZS 3604 – like foundations with tied slabs*
TC2	50 mm	100 mm	50 mm	100 mm	The Ministry's enhanced foundation solutions (section 5.2) of the 2011 *Repairing and rebuilding houses affected by the Canterbury earthquakes*
TC3	>50 mm	>100 mm	>50 mm	>100 mm	The Ministry's TC3 foundation solutions, but preferably ground treatment to upgrade land to align with TC2 characteristics.

Note: Certain foundation details included in NZS 3604 are precluded from use (refer to Building Code Acceptable Solution B1/AS1 at www.dbh.govt.nz/compliance-documents#b1.

Where investigations have shown that a mix of land classifications might apply across a site, the site should either be classified as a whole according to the most conservative result on the site, or micro-zoned into multiple classifications on a conservative basis. (This might require further investigations to more tightly define these areas). The geotechnical report shall identify likely requirements for construction of buildings to meet the design requirements as prescribed by the Ministry, with respect to liquefaction and lateral spread. In addition to this, the geotechnical report in all cases should address all other geotechnical aspects (soil types, static bearing capacities, settlements, stability, RMA section 106 hazards etc).

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16.6 Land already classified TC1 by the Ministry

Where land that is already subject to a Technical Category classification of TC1 by the Ministry is to be further subdivided, then it may be assumed that the land remains as TC1 for liquefaction assessment purposes subject to the following:

- Visual assessment and reasonable enquiry does not suggest that the original TC1 classification is inappropriate.
- Normal geotechnical investigations are undertaken for the purposes of evaluating all other potential geotechnical issues.

16.7 Land already classified TC2 by the Ministry

Where land that is already subject to a Technical Category classification of TC2 by the Ministry is to be further subdivided, and the original parcel size is less than 2500 m^2, then it may be assumed that the land remains as TC2 for liquefaction assessment purposes subject to the following:

- Visual assessment and reasonable enquiry does not suggest that the original TC2 classification is inappropriate.
- Normal geotechnical investigations are undertaken for the purposes of evaluating all other potential geotechnical issues.
- Hybrid TC2/TC3 foundations, or TC3 surface structure foundations are recommended in the geotechnical report.

In the absence of the above a full investigation, and analysis in accordance with section 16.4 shall be undertaken to determine the liquefaction characteristics and land performance, and appropriate foundation solution for the site.

16.8 Site investigation density at building consent stage

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

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

For building sites on TC3-like land, deep investigations and liquefaction assessments should be initiated as outlined in Part C, as well as a shallow investigation as judged necessary by the geotechnical engineer.

16.9 Engineering Advisory Group recommendations regarding liquefaction performance for new subdivisions (Advisory only)

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

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

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> **Note:** It is strongly recommended that residential lots in new subdivisions meet the performance criteria specified for TC1 or TC2.

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Appendix D1: Liquefaction Calculation Methodology

To standardise the outcomes of land assessment for new subdivisions, for the purposes of this document the calculation of liquefaction triggering and its effects shall be carried out using the method outlined in Idriss & Boulanger 2008 *Soil Liquefaction During Earthquakes* – EERI monograph MNO12. However, the following modifications are to be applied to this method:

- For estimating apparent fines content (FC) for use in the CPT fines correction set out in Idriss & Boulanger (2008) (equation 78), where soil samples are not being retrieved: refer to Robertson and Wride (1998) *Evaluating Cyclic Liquefaction Potential Using the Cone Penetration Test,* Can. Geotech. J. 35(3), 442-459. ie, – (a) if Ic < 1.26, apparent FC = 0%; (b) if 1.26 < Ic < 3.5, apparent FC (%) = 1.75 $Ic^{3.25}$ - 3.7; and (c) if Ic > 3.5, apparent FC = 100%.
- For estimation of post liquefaction-induced settlements in CPT analyses, refer to Zhang, Robertson & Brachman (2002) Estimating Liquefaction-Induced Ground Settlements from CPT for Level Ground, Can. Geotech. J. (39), 1168-1180. In particular, Appendix A of that paper provides useful guidance on calculating volumetric strains. Note: the input parameters of FOS and $(q_{c1n})_{cs}$ are to be derived from the method of Idriss & Boulanger (2008), as modified above.
- For surface crust assessment: refer to Ishihara (1985) *Stability of Natural Deposits During Earthquakes*, Proc. of the 11th International Conference in Soil Mechanics and Foundation Engineering, pages 321-376 – Figure 88 page 362. (Reproduced as Figure 107 on page 157 of Idriss & Boulanger (2008) (optional).
- For refinement of SLS assessment: observations of damage or lack thereof in areas deemed to have been 'sufficiently tested at SLS' by recent seismic events can be used to judge the applicability, or not, of settlements calculated at the design SLS level (optional). This is to be achieved by reference to the PGA conditional median contours and associated conditional standard deviations contained in the paper (Bradley and Hughes 2012) and kmz file that can be found at the Canterbury Geotechnical Database https://canterburygeotechnicaldatabase.projectorbit.com.
  - As an initial screening tool, where a site has experienced at least 170% of design SLS (using the conditional median pga values from one of the three compiled events corrected to a M7.5 event; ie $PGA_{7.5}$ = PGA/MSF), then the site can be regarded as having been 'sufficiently tested' for an SLS event.
  - If this screening test is not met, then the site can be evaluated by calculating the 10 percentile PGA from each of the three compiled events (i.e. the median value less 1.28 standard deviations, again magnitude scaled to M7.5). If one of these values equals or exceeds the design SLS event then the site can be regarded as having been 'sufficiently tested' for an SLS event. (At this level it is likely that most sites will have been tested to SLS or beyond by enough of a margin that in future SLS events the land damage will likely be no worse than already experienced at that site).

- To calculate the 10 percentile PGA, use $PGA_{10} = PGA_{50}*exp(-1.28*\sigma_{lnPGA})$, where PGA_{50} is the conditional median PGA and σ_{lnPGA} is the conditional standard deviation of PGA at a site.
- For consistency with the methodology used to analyse liquefaction triggering, the Magnitude Scaling Factor of Idriss & Boulanger (2008) should be used – ie $MSF = [6.9*exp(-M/4)]-0.058 \leq 1.8$. Thus, $PGA_{10\_7.5} = PGA_{10}/MSF$.

Note: This does not imply that these methodologies are mandated for applications outside the scope of this document.