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REGULATING LIQUEFACTION RISK FOR RESIDENTIAL LAND DEVELOPMENT

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Abstract

Management of natural hazard risks, such as liquefaction, was a grey area for New Zealand's residential land development sector. The "February 2011 Christchurch Earthquake" – second most populated city in New Zealand- was one such event. The earthquake, paired with significant liquefaction, saw over 400,000tonnes of silt brought up affecting over 600,000 homes and costing over NZD $40 billion in damages, making it New Zealand's costliest natural disaster at the time. Our engineering community were well aware it could happen, but the risk was not perceived to be significant enough for residential dwellings. Hence, in 2021, just over ten years following the Canterbury earthquake, the regulations governing how residential structures are designed changed. The Auckland Council responded by publishing liquefaction hazard maps and implementing the new rules at the Building Consent stage of new residential developments. This paper discusses the process set up including hazard maps and standard foundation designs and presents the challenges and outcomes in implementing the change in Auckland. The change signals a significant move in how we regulate liquefaction risk for residential land development in New Zealand. The change presents challenges around ensuring the effectiveness of the regulations to capture the liquefaction risk and design for it whilst managing costs to the developer such that they are not escalated disproportionately. Ongoing adaptation and refinement of the liquefaction rules, the process, liquefaction hazard map, and standard liquefaction resilient foundation guidance will be essential in addressing these challenges.

Key words

Regulation, Earthquake, Liquefaction, Residential Land Development, Hazard Map, Consenting, Local Authorities.

1 Introduction

1.1 Strategic Context

1.1.1 Snapshot of New Zealand (NZ)

Located in the South Pacific Ocean, New Zealand is a relatively isolated country with a population of just over 5 million and mixed economy operating on free-market principles. Auckland is the largest commercial and financial hub of New Zealand. It is also the most populated with over 25% of the NZ population living in Auckland. Please refer to Figure 1 below for the location of Auckland and Christchurch within New Zealand.

1.1.2 New Zealand Geology

New Zealand sits between two tectonic plates being the Australian and Pacific plates shown in Figure 1 below. As such the country is rendered with volcanic activity, geothermal areas, and numerous fault lines (denoted red in Figure 1). Constant movement and relatively recent geological history of New Zealand mean that the country is subject to risk of earthquakes, liquefaction, and lateral spreading.

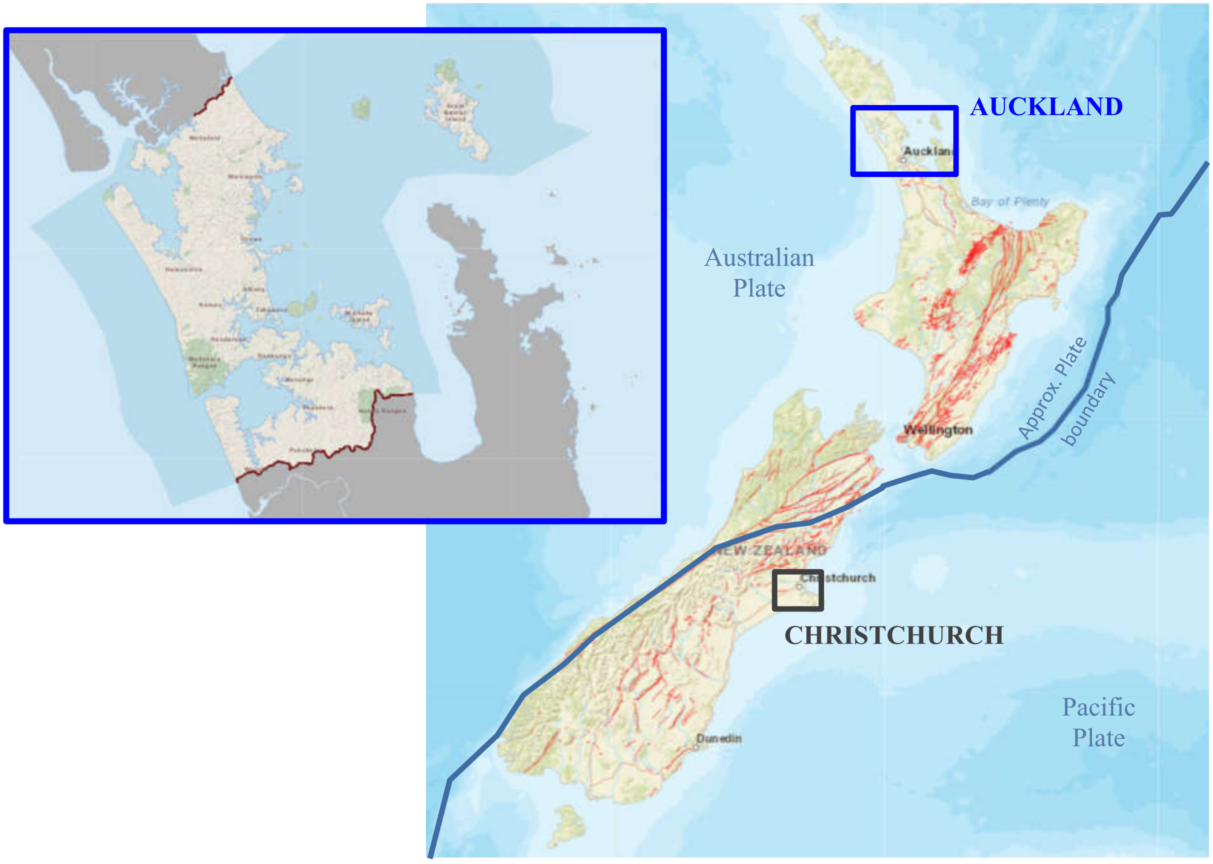

Figure 1. Map of New Zealand with active fault lines and the approximate plate boundary between the Australian and Pacific Tectonic Plates as shown in GNS Science [GNS.2024] (right) and close up of Auckland from Auckland Council website [Auckland Council.2024] (left)

As per Figure 2, the history of the land tells us that earthquakes with a magnitude of 7.0 or greater are always possible and have been occurring in general every 4 years Nationwide [Geonet.2024].

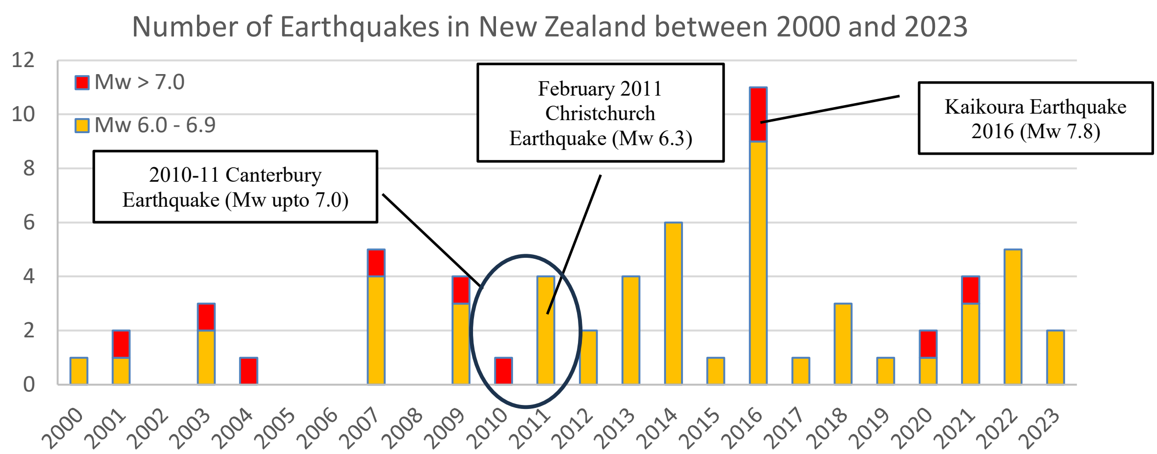

Figure 2. Graph showing the number of earthquakes with magnitude greater than 6.0 across New Zealand between 2000 to 2023 as per NZ geonet data [Geonet.2024]

1.1.3 Canterbury Earthquake

In 2010-11 a series of earthquakes and aftershocks occurred in the Canterbury region of New Zealand measuring magnitudes, Mw of up to 7.0 including the “February 2011 Christchurch Earthquake”. Significant liquefaction saw over 400,000 tonnes of silt bought up affecting over 600,000 homes. Emergency works to remove debris and reinstate essential infrastructure to reopen the city centre spanned over years. The economic loss is estimated to be more than NZD $40billion in damages making it New Zealand’s costliest natural disasters at the time [ICNZ.2024].

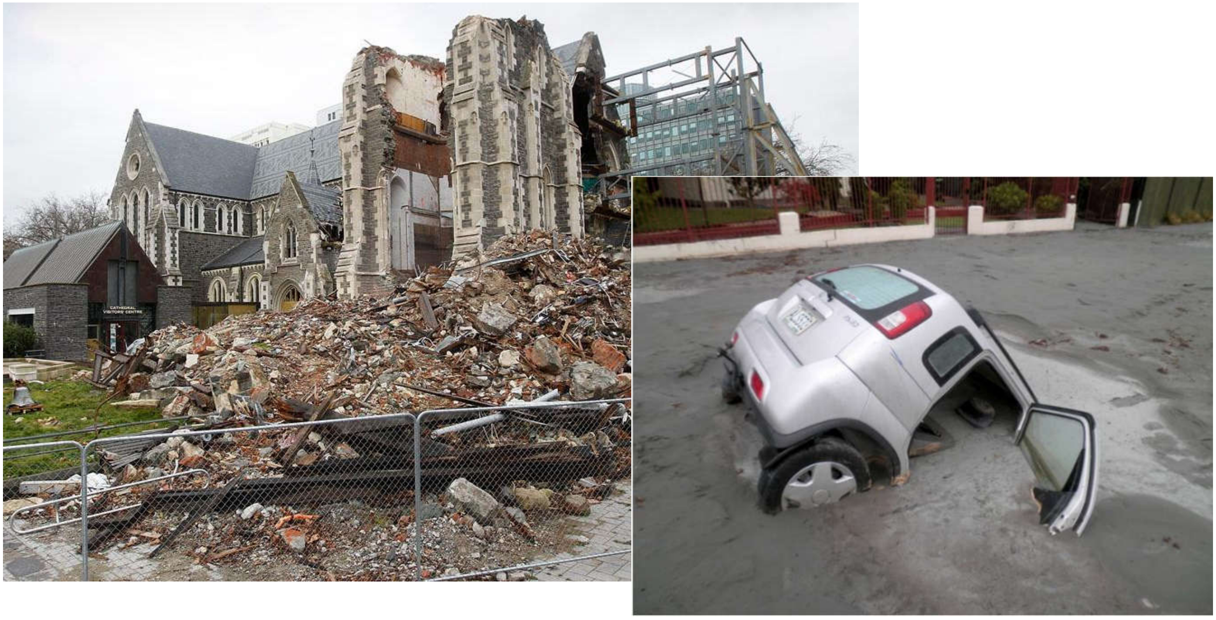

Figure 3. Photos from the 2010-11 Canterbury Earthquakes including this car (right) toppled into one of many large holes created by liquefaction (source: Stuff.co.nz and the Encyclopaedia of NZ)

1.1.4 Practice Prior to Regulatory Reform

In New Zealand, all residential dwellings are required to obtain a Building Consent to assess compliance with the NZ Building Act and Building Code. Acceptable Solution B1/AS1 in the NZ Building Code is widely cited as a means of compliance for the structural performance of residential building work, including foundations. This enabled liquefaction risk to be assessed by geo-professionals (i.e. Chartered Geotechnical Engineers or Professional Engineering Geologists) applying judgement without any regulations requiring minimum deep ground investigations.

Prior to the 2010-11 Canterbury earthquake, major fault lines were identified going through the wider Canterbury region. As such the city of Christchurch was identified as having a high seismic risk. The New Zealand Transport Agency bridge manual provided strict guidance on seismic design methodology and criteria for infrastructure projects [Waka Kotahi.2022]. However, the risk was not perceived to be significant enough for residential dwellings and the Building Act relied on professional judgement to assess the risk without regulations on deep ground investigations or standard liquefaction resistant foundation designs.

Following the 2010-11 Canterbury earthquake, the engineering community and government reacted to better manage the risk to building projects by producing several guidance documents and changes to the regulations within the Canterbury region. This helped fast track the rebuild and identify and manage high risk areas. Documents include:

- Standardised liquefaction resistant foundation designs [MBIE.2015].
- Liquefaction risk categorisation based on estimated liquefaction damage [MBIE, MfE.2017].
- Liquefaction hazard risk maps on the Christchurch City Council Website [CCC.2024].

In 2021, the above was implemented as a mandatory requirement nationwide. More formally, changes were made to the Building Code. These changes which came into effect on 29 November 2021 revoked this compliance pathway for building foundations on sites where liquefaction risk had been identified.

This called for action for individual local authorities including Auckland Council to undertake hazard mapping to identify liquefaction prone areas within Auckland and set up consenting processes to implement the regulatory reform.

2 Methods

2.1 Auckland Liquefaction Hazard Map

The liquefaction hazard mapping commenced in 2019 by Auckland Council in collaboration with the University of Auckland to assess and categorise the liquefaction risk within Auckland. The key outcome was to identify areas requiring further deep ground investigations to ascertain liquefaction risk.

The Ministry of Business Innovation and Employment (MBIE) Liquefaction Guidance [MBIE, MfE.2017] list four levels of detail of liquefaction assessment studies as per Table 1 below. Given the large extent of the study area and lack of required density of geotechnical investigation data across most of the region, the hazard mapping was undertaken in two phases; Level A basic desktop assessment followed by calibration of the assessment in Level B. [Brightman, C and R Roberts.2021].

Table 1. Overview of levels of detail of liquefaction assessment studies

LEVEL OF DETAIL
Level A – Basic Desktop Assessment
Level B – Calibrated Desktop Assessment
Level C – Detailed Area-Wide Assessment
Level D – Site-Specific Assessment

Auckland Liquefaction Hazard Map

Level A assessment was the high-level categorisation of the city based on geology, groundwater and seismic hazard data. Level B assessment involved calibration of the above level A assessment against nearby existing deep ground investigations and topographic data in areas where sufficient data was available within the publicly available New Zealand Geotechnical Database (NZGD) and Tonkin and Taylor Limited's in-house geotechnical database. More detailed Level C and D assessment were not undertaken as part of this Auckland Liquefaction Hazard Mapping. However, this is an area of work we may consider delivering in the future when the budget allows.

The resulting liquefaction hazard maps are available to the public via our Auckland Council geospatial system, "Geomaps". Where both level A and B assessments are available for the site, reference is made to Table 2 to determine which assessment level is applicable for the proposed works. The map is referenced in all our regulatory reviews to identify the level of liquefaction risk and associated deep ground investigation and liquefaction foundation design requirements.
As per Figure 4 below, the Auckland liquefaction hazard map (Assessment level B) shows the majority

of Auckland coloured blue or green denoting very low to low liquefaction vulnerability categories. Only a relatively small portion of Auckland concentrated along the low-lying areas are coloured grey or light orange denoting liquefaction damage is "undetermined" or "possible" vulnerability categories respectively.

This point is further emphasized when you compare the liquefaction hazard map of Auckland vs a high seismicity area such as Christchurch in Figure 4 below. Unlike Auckland, the majority of the Christchurch is coloured light orange, orange or red denoting medium to high liquefaction vulnerability.

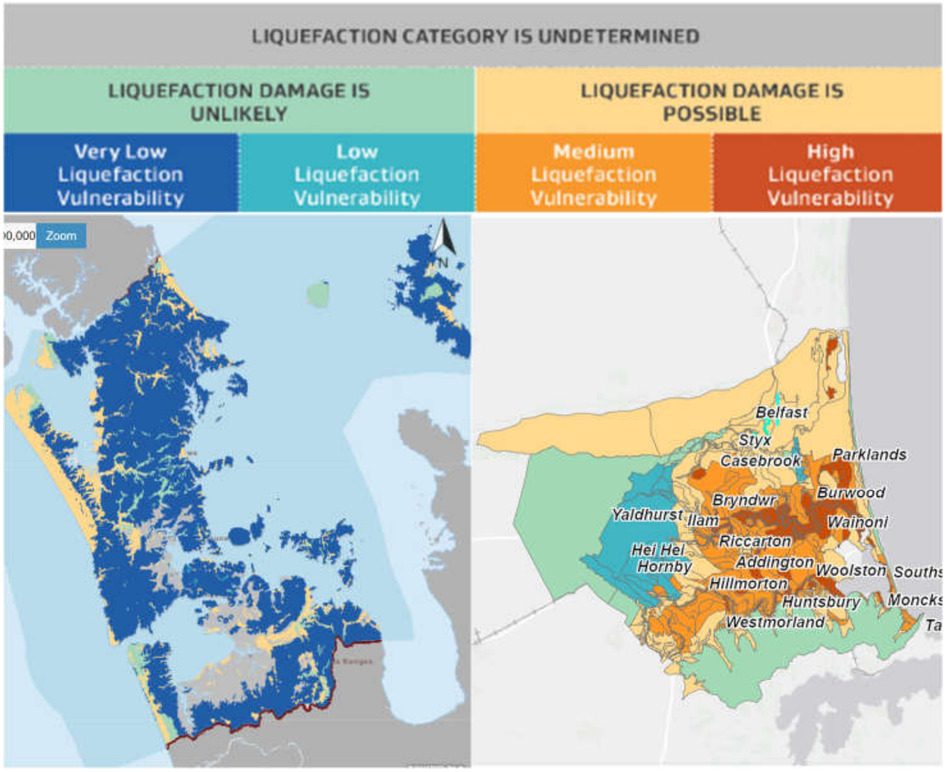

Figure 4. Liquefaction Hazard Map of Auckland Assessment Level B (left) and Christchurch (right) sourced from Auckland Council Public GiS Maps[Auckland Council.2024] and Canterbury Council maps [CCC.2024]

2.2 Minimum Deep Ground Investigation Requirement

A risk-based system was put in place whereby the level of deep ground investigations (assessment level) required to re-categorise the liquefaction hazard category is assessed as a function of:

- Scale of the proposed work plus;
- Liquefaction risk category as per Auckland Council Geomaps.

NZS1170 is the NZ Standard for structures and includes categorisation of structures into Importance Levels (IL) based on the consequence of the failure. ILs range from IL1 for minor structures (failure not likely to endanger human life) where the consequence of failure is low to IL5 exceptional structures where the consequence of failure is exceptional [NZS1170.2002]. IL1 structures such as in-ground swimming pools and sheds are not subject to these MBIE liquefaction requirements [MBIE,MfE.2017].

Large commercial/industrial buildings or residential buildings higher than 3 storeys are considered high risk and require specific investigation by suitably qualified and experienced geo-professionals. Designs must also be supported by a Producer Statement [EngNZ.2013].

Table 2 below shows the Assessment Level applicable for each development scenario (scale of proposed work) and liquefaction risk category combination. Assessment Level refers to the minimum deep ground investigation requirement, as shown in Table 3, ranging from no investigation required for level A applicable to sparsely populated rural areas (low scale) to a minimum of 2 deep ground investigations within or very close to the building footprint for Level D assessment applicable to small scale urban infill or greater scale development scenarios on high liquefaction vulnerability category areas.

Table 2. Assessment Level based on Development Scenario and Liquefaction Vulnerability Category [MBIE, Mfe.2017]

Development Scenario	**Liquefaction Vulnerability Category**			
	Liquefaction Category is Undertermined			
	Liquefaction Damage is Unlikely		Liquefaction Damage is Possible	
	Very Low	Low	Medium	High
Sparsely populated rural area	Level A	Level A	Level A	Level A
Rural-residential setting	Level A	Level B	Level B	Level B
Small-scale urban infill	Level B	Level B	Level B	Level D
Commercial or industrial development	Level B	Level B	Level C	Level D
Urban residential development	Level B	Level C	Level C	Level D

Notes: Refer to Table 3 below for deep ground investigation requirements associated with each Assessment Level.

Table 3. Indicative spatial density of deep ground investigation required by Assessment Level [MBIE, Mfe.2017]

Assessment Level	**Avg Investigation Density**	**Average Sapcing Between**	**Minimum total number of investigations**
Level A	0.01 to 1 per km	1 to 10 km	-
Level B	0.5 to 20 per km	220 to 1400 m	3 for each geological sub-unit
Level C	0.1 to 4 per Ha	50 to 320 m	5 if area >1 Ha 3 if area 0.25 – 1 Ha 2 if area < 0.25 Ha
Level D	2 to 40 per Ha	15 to 70m	2 within or very close to the building footprint

Notes: Deep ground investigations to characterise the ground to at least 10 – 15 m depth below ground level for residential or light commercial development [MBIE, Mfe.2017].

2.3 Standard Liquefaction Resistant Foundations

The standard liquefaction resistant foundations presented in the MBIE ‘Repairing and rebuilding houses affected by the Canterbury earthquakes” version 3a Guidance documents [MBIE.2015] are divided into three categories; Technical Category 1 (TC1), Technical Category 2 (TC2) and Technical Category 3 (TC3) based on the estimated liquefaction ground damage.

- TC1 – Conventional NZS3604 foundations [NZS3604.2011].
- TC2 – Foundation options range between conventional NZS3604 foundations to ground improvements pending on shallow ground conditions.
- TC3 – Specific liquefaction design.

Experience from the 2010-11 Canterbury earthquake suggest the cost of these TC2 foundations are generally similar to conventional NZS3604 foundations given 300kPa ultimate bearing capacity can be demonstrated [MBIE,MfE.2017].

2.4 Compliance Pathway for Auckland Council

As mentioned previously, Importance level 1 (IL1) structures, as defined by NZ Standards [NZS1170.2002] are not subject to these MBIE liquefaction requirements. Where the MBIE liquefaction requirements apply, reference is made to the liquefaction vulnerability category from publicly available hazard maps.

Where the liquefaction vulnerability category is low or very low, no further assessment is required for liquefaction. Note when referring to the Auckland Council liquefaction hazard map, where both level A and B assessments are available, reference is made to Table 2 to determine which assessment level is applicable for the proposed works.

Where the liquefaction vulnerability category is undetermined or possible, then three options are available:

- Option 1 – undertake deep ground investigations as per MBIE liquefaction requirements [MBIE,MfE.2017] to re-categorise the liquefaction vulnerability category to very low, low, medium or high and design foundations accordingly. Note reference to nearby existing deep ground investigation results is acceptable.
- Option 2 – adopt standard liquefaction resistant foundation designs as per the standard liquefaction resistant foundation guidance [MBIE.2015].
- Option 3 – peer review by an external geotechnical consultant on Auckland Council's geotechnical panel.

Given Auckland is in a low seismic area (as defined by the hazard factor) [MBIE.2024], an alternative consenting pathway is available for low scale works, such as minor alterations or small-scale urban infill developments, that enables TC2 standard liquefaction resilient foundations to be adopted where the site is categorised as undetermined or possible liquefaction vulnerability within Auckland.

3 Results

3.1 Cost Implications to the Developer

One of the challenges of this regulatory reform is managing cost implications to the developer. Deep ground investigations are expensive relative to shallow hand auger borehole investigations traditionally associated with residential land development in Auckland.

Geotechnical investigation for a simple 2 lot subdivision on a $600m^2$ full section, typical of a small scale urban infill project in Auckland, would cost in the order of NZD $4,000 including reporting. The addition of one 15m deep machine borehole would incur additional costs in the order of NZD $8,000 to $15,000. Effectively, the addition of one deep ground investigation could increase the geotechnical investigation fee by more than two-fold.

As such, in the context of regulatory engineering for residential development, it is important that our review is risk based. This is to prevent costs to the developer escalating disproportionately to the risk.

3.2 Consideration of Scale of works in Auckland

MBIE liquefaction requirements make consideration to the scale of the project in several ways being:

- MBIE liquefaction requirements are not applicable to IL1 buildings [NZS1170.2011].

- Pathway for low scale urban infill and minor alteration projects to adopt TC2 foundations which includes the conventional NZS3604 foundation pending on shallow ground conditions.
- The minimum level of deep ground investigation required (assessment level) is a function of the liquefaction vulnerability category and scale of the project.
- Acceptance of reference to nearby existing deep ground investigations.
- Specific design and Producer statement(s) required for large commercial/industrial buildings or residential buildings higher than 3 storeys.

The above are working well to ensure what we require is proportional to the scale of the works proposed.

3.3 Consideration of Liquefaction Risk in Auckland

As per Figure 4, the liquefaction hazard map shows the majority of Auckland is categorized as having very low to low liquefaction vulnerability. As such, for the most of Auckland, no further liquefaction investigation and assessment is required.

Furthermore, in recognition of the low seismicity of the Auckland region (defined by the hazard factor z) [MBIE.2024], an alternate consenting pathway is available for low scale urban infill and minor alteration projects which enables TC2 foundations to be adopted where the liquefaction vulnerability category of the site is “possible” or “undetermined” within Auckland (low seismicity area). Experience from the 2010-11 Canterbury earthquake suggest the cost of these TC2 foundations are generally similar to conventional NZS3604 foundations given 300kPa ultimate bearing capacity can be demonstrated [MBIE,MfE.2017].

The result of the above is that for the majority of the Auckland region and for small scale urban infill or minor alteration projects within Auckland, the rule change is relatively inconsequential to the final foundation cost given 300kPa ultimate bearing capacity can be demonstrated.

3.4 Industry Feedback

Since its implementation in 2021, over 100 Building Consents have been assessed to date against the new MBIE liquefaction requirements at the time of preparing this paper. In the early days, there was considerable resistance to the changes by some geotechnical consultants blindsided by the change. MBIE liquefaction requirements are relatively new to the industry so sometimes it is just a matter of helping the consultant navigate the new rules and understand their options.

Three years in to implementing the changes, the industry has, for the most part, accepted the changes. There has been good uptake of our acceptance of nearby existing deep ground investigations to re-categorize the liquefaction vulnerability of the site with the NZGD platform frequently referenced by consultants for this data.

However, there are still discrepancies in how geotechnical consultants interpret and navigate the new rules. As the industry starts to test their boundaries, grey areas of note have and continue to emerge. Especially around the criteria for re-categorizing the liquefaction vulnerability category based on deep ground investigations and liquefaction assessment results and associated selection of standard liquefaction resistant foundations. For example, the MBIE liquefaction requirements [MBIE,MfE.2017] references the liquefaction induced settlement to define the degree of liquefaction damage. However, acceptable solutions MBIE Modules include more sophisticated assessment methodologies to define the degree of liquefaction damage. There is an opportunity for improvement here to incorporate/amalgamate the liquefaction damage criteria for the risk categorization with existing well-established liquefaction damage assessment methodologies, namely LSN and LPI analysis methodology of assessing the degree of liquefaction damage presented in MBIE Module 3 [NZGD,MBIE.2021] to inform the liquefaction vulnerability category and associated standard liquefaction resistant foundations.

3.5 Next Steps

Some potential next steps include the following:

- The MBIE liquefaction requirements are relatively new to the industry. As such the need to increase exposure of this rule change to the industry has been highlighted. Auckland Council's next step in this space is to continue presenting the rules and regulatory expectations to the industry in the form of engineering forums and presentations.
- The MBIE liquefaction requirements and associated requirement for minimum deep ground investigations has meant that a sizable number of deep ground investigation data is now available to feed back into our liquefaction hazard map. We encourage the industry to actively share and grow the pool of data available on platforms such as The New Zealand Geotechnical Database (NZGD). With more deep ground investigations added to the pool of data, we envisage the liquefaction hazard map will be continuously refined with time.
- On going adaptation and refinement of the new MBIE liquefaction requirements [MBIE, MfE.2017] and standard liquefaction resistant foundation guidance [MBIE.2015] will be essential to ensure the effectiveness of this regulatory reform as our understanding of the MBIE liquefaction requirements mature.
- Since the new MBIE liquefaction rules were implemented, several local authorities including Auckland Council have and/or are in the process of producing liquefaction hazard maps and implementing the rule change for their respective local areas. The learnings shared between local authorities will prove to be invaluable.
- The current liquefaction hazard map for Auckland is limited to Level A and Level B assessments. Auckland Council may consider delivering hazard maps for Level C and Level D assessments subject to budget constraints.

4 Conclusion

Internationally, regulation of liquefaction risk for residential land development is not new. And there are plenty of examples worldwide of what success looks like in the residential field such as Japan [National Geographic. Jan 2024]. The NZ Transportation Agency has such regulations for our state highway infrastructure [NZTA Bridge Manual.2022]. With the new MBIE liquefaction rules we have now developed and deployed such a system for the residential space.

The MBIE liquefaction requirements are envisaged to capture liquefaction risk and design for it, creating more resilient buildings to house Kiwis (New Zealanders). The system is not perfect, but with further deep ground investigations and liquefaction assessments undertaken throughout the city, we envisage the liquefaction hazard map, MBIE liquefaction rules [MBIE,MfE.2017], standard liquefaction resistant foundation guidance [MBIE.2015] and the process to be refined with time. This will be essential to ensure the effectiveness of these regulations and address the evolving challenges of striking the right balance between adequately managing the risk and keeping costs to developers proportional to the risk.

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Assets & Technical Advisory) and Regulatory Engineering (now Regulatory Engineering and Resource Consents) teams for creating the processes within Auckland Council to implement the change.

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