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A Risk based Approach to Assessing the Suitability of Existing Geotechnical Data for Use in Design

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ABSTRACT: Lyttelton Port of Christchurch has undertaken multiple geotechnical investigations over the past circa 70 years and as such, has a wealth of geotechnical data in multiple formats. This is often the case for many large infrastructure developments worldwide. In order to evaluate the suitability of the data for use in geotechnical design, a risk based approach was developed. Initially, existing geotechnical data was assessed for quality and assigned "confidence levels". Depending on the proposed engineering works, the "consequence rating" of a failure occurring associated with the geotechnical design was then assessed. The "confidence level" in the geotechnical data was then combined with the "consequence rating" of geotechnical failure to present a quantifiable "risk level". This allowed various mitigation measures to be considered as options to reduce the inherent "risk levels". The risk based assessment provided a dynamic tool to assess the currently available geotechnical data for its adequacy for specific engineering works.

1 INTRODUCTION

This paper utilises Lyttelton Port of Christchurch (LPC) as a case study to demonstrate how a risk based approach to assessing the suitability of existing geotechnical data can be actively implemented in a working environment.

Like most ports, LPC has considerable land holding and a number of different uses / trades intertwined throughout the various areas. Over time, each project delivered has undertaken site specific investigations, such as geotechnical investigations, but the overall knowledge in terms of what is understood geotechnically is poor. Coffey was engaged to develop a method to best capture the port in its entirety from a geotechnical perspective and apply a risk based solution to determine what development projects may be achievable, and where, without any further geotechnical investigation.

The works entailed an initial assessment of the adequacy of the geotechnical data, its accuracy and reliability and hence confidence to rely upon. These were then associated with the potential development work at each area of the port to assess LPC's inherent risks. The result was the development of a user friendly tool to expedite more accurate cost estimation, programming and decision making of projects.

2 SITE DESCRIPTION

2.1 *Geological setting*

Lyttelton Port is located to the South of Christchurch at the toe of the steeply sloping land which forms the Banks Peninsular. The geological map indicates the predominant geology of the area to comprise basaltic to trachytic lava flows, interbedded with breccia and tuff of the Lyttelton Volcanic Group (Forsyth et al., 2008).

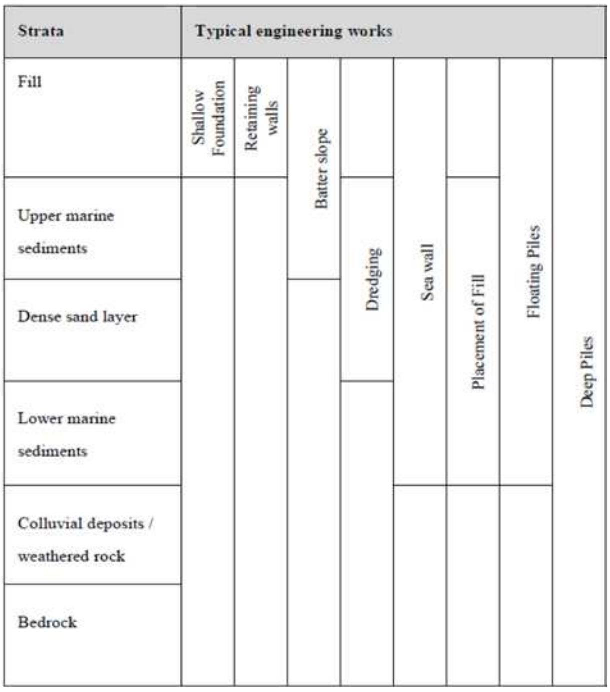
2.2 *Ground profile*

The natural ground profile encountered at the site generally comprises the following:
Upper marine sediments: Generally soft to firm silty clay and clayey silt.
Sand: Dense sand generally intersected within the Upper marine sediments or between the Upper and Lower marine sediments.
Lower marine sediments: Generally interbedded layers of clay, silt and sand.
Colluvial deposits / Weathered rock: A mixture of gravel, cobbles and boulders, sometimes in a silt / sand matrix.
Bedrock: Generally basalt of the Lyttelton Volcanic Group exhibiting varying states of weathering.

3 TYPICAL ENGINEERING WORKS

Different engineering works are supported by or constructed in different soil or rock strata. A lack of comprehensive knowledge of the “controlling” soil or rock strata by the design engineers may have an adverse fate of such works when built. A number of typical engineering works relating to controlling strata specific to LPC are presented in Table 1.

Table 1. Typical engineering works related to controlling strata



Strata	Typical engineering works							
Fill	Shallow Foundation	Retaining walls	Batter slope		Sea wall		Floating Piles	Deep Piles
Upper marine sediments				Dredging		Placement of Fill		
Dense sand layer								
Lower marine sediments								
Colluvial deposits / weathered rock								
Bedrock								

4 GEOTECHNICAL DESIGN RISK ASSESSMENT

The risk assessment process fundamentally follows the Australian / New Zealand standard (AS/NZS ISO 31000:2009) risk assessment procedure, where risk level is defined as the product of:

- the propensity of a hazard occurring; and,
- the consequence if the hazard does occur.

However, this has been adapted to meet LPC’s specific requirements. LPC’s geotechnical risks for specific engineering works have been assessed as the product of:

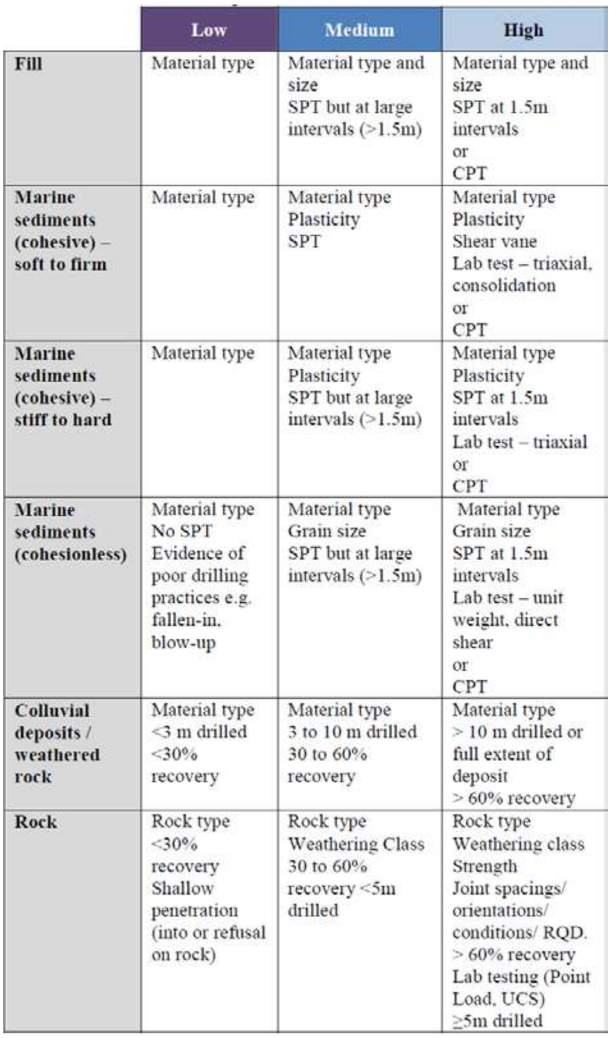
- the (lack of) confidence in the existing geotechnical data (Section 4.1); and,
- the consequence of a geotechnical failure (as a result of reliance on the existing geotechnical data for design) (Section 4.2).

The risk assessment relates to geotechnical design risk only and does not take into account weak soils or rocks and construction risks. The various elements that form the geotechnical design risk assessment are discussed in further detail in the following sections of this paper.

4.1 *Confidence in existing geotechnical data*

Existing geotechnical investigation data kept by LPC was collated and reviewed.

Table 2. Confidence in data criteria



	Low	Medium	High
Fill	Material type	Material type and size SPT but at large intervals (>1.5m)	Material type and size SPT at 1.5m intervals or CPT
Marine sediments (cohesive) – soft to firm	Material type	Material type Plasticity SPT	Material type Plasticity Shear vane Lab test – triaxial, consolidation or CPT
Marine sediments (cohesive) – stiff to hard	Material type	Material type Plasticity SPT but at large intervals (>1.5m)	Material type Plasticity SPT at 1.5m intervals Lab test – triaxial or CPT
Marine sediments (cohesionless)	Material type No SPT Evidence of poor drilling practices e.g. fallen-in, blow-up	Material type Grain size SPT but at large intervals (>1.5m)	Material type Grain size SPT at 1.5m intervals Lab test – unit weight, direct shear or CPT
Colluvial deposits / weathered rock	Material type <3 m drilled <30% recovery	Material type 3 to 10 m drilled 30 to 60% recovery	Material type > 10 m drilled or full extent of deposit > 60% recovery
Rock	Rock type <30% recovery Shallow penetration (into or refusal on rock)	Rock type Weathering Class 30 to 60% recovery <5m drilled	Rock type Weathering class Strength Joint spacings/ orientations/ conditions/ RQD. > 60% recovery Lab testing (Point Load, UCS) ≥5m drilled

Borehole logs and Cone Penetration Test (CPT) soundings revealed that the test types, frequencies and quality of testing differed considerably both horizontally (between areas of the port) and vertically (between strata). Confidence in the available geotechnical data was therefore assessed stratum by stratum by looking generally at data quality, appropriateness of test methods, adequacy and coverage. Given that only a high level review was required, the data for each area and strata was classified into only three levels of confidence – i.e. “high”, “moderate” and “low”.

The simplified in-house criteria adopted for such classification are presented in Table 2 above.

As it is likely that soil conditions between test locations will be inferred if no more data is available, areas between such test locations were also classified by “interpolation” and were assigned the same inferred class as the test locations if stratigraphy was easily identifiable but subject to distance (distance was dependent on how variable the adjacent data was). If not, the confidence is dropped by 1 or 2 categories.

To aid the calculation of risk levels, numerical values were assigned to the three levels of confidence in the geotechnical data, as shown in Table 3.

Table 3. Confidence in geotechnical data

Confidence in geotechnical data	
3	**Low confidence in data / no data**
2	**Moderate confidence in data**
1	**High confidence in data**

Maps were produced of the entire port area, stratum by stratum, with each map showing the distribution of the three levels of confidence in the geotechnical data. An example map is presented in Fig. 1. These maps provide a very useful tool for the port planners to quickly see the spread of the quality of geotechnical data across the port horizontally and vertically. However, the vertical dimension is variable and dependent on the thicknesses of the stratum and strata above.

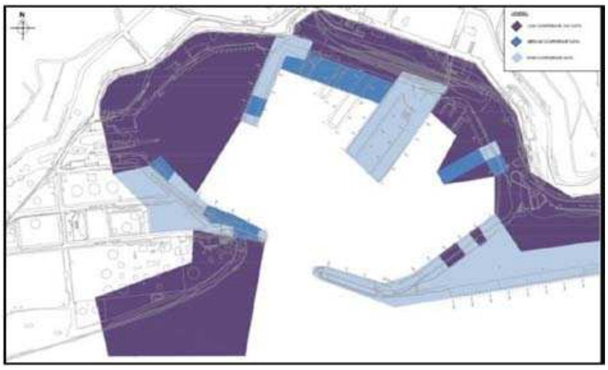


Fig. 1 Example confidence in geotechnical data map - Lower marine sediments

4.2 *Consequence of geotechnical failure*

The criteria to assess the level of consequence of a geotechnical hazard occurrence are largely dependent on the client’s requirements to manage risk and their view of the consequence of hazard occurrence. Typically, for many projects five consequence categories are adopted as shown in Table 4, together with the criteria. Subject to LPC’s optimisation of the criteria in Table 4, the inherent risks for proposed engineering works can be readily assessed.

Table 4 Consequence of hazard occurrence

Consequence		
5	Catastrophic	Single fatality through accident, irreversible environmental harm, greater than $25M financial loss, major national TV/news coverage with government intervention
4	Major	Severe permanent harm to personnel, significant environmental damage with wide spread impact, $10M - $25M financial loss, adverse & extended national media coverage
3	Serious	Permanent harm to personnel, moderate damage to the environment with significant cleanup costs, $1M - $10M financial loss, adverse capital city media coverage
2	Minor	Temporary harm to personnel, minimal damage to the environment with small or no cleanup costs, reportable to authorities, $100K - $1M financial loss, adverse local media coverage
1	Insignificant	No injuries or illness, or minor injury requiring first aid, negligible release or environmental damage contained on site and not reportable to authorities, less than $100K financial loss, no media attention

4.3 *Design risk assessment for engineering works*

Depending on the proposed engineering works, the controlling stratum can be identified from Table 1. Then from the map of the controlling stratum discussed in Section 4.1, the confidence level (a numerical value between 1 and 3) is selected for a particular discrete area of the port.

Subsequently from Table 4, the consequence rating of a failure (another numerical value between 1 and 5), mainly based on assumptions of economic value and importance of the discrete areas within the port relative to one another, may then be assigned.

The confidence in the geotechnical data and consequence of hazard occurrence are combined to calculate a “risk level” allowing comparative assessment of proposed engineering works relating to the discrete areas of the port. The geotechnical design risk evaluation matrix is presented in Table 5.

Table 5. Geotechnical design risk evaluation matrix

	CONSEQUENCE OF HAZARD OCCURRENCE	Insignificant 1	Minor 2	Serious 3	Major 4	Catastrophic 5
CONFIDENCE IN DATA	3 (low)	3 - LOW	6 - MEDIUM	9 - MEDIUM	12 - HIGH	15 - HIGH
	2 (medium)	2 - LOW	4 - LOW	6 - MEDIUM	8 - MEDIUM	10 - HIGH
	1 (high)	1 - LOW	2 - LOW	3 - LOW	4 - LOW	5 - MEDIUM

4.4 *Mitigation options to improve confidence in design*

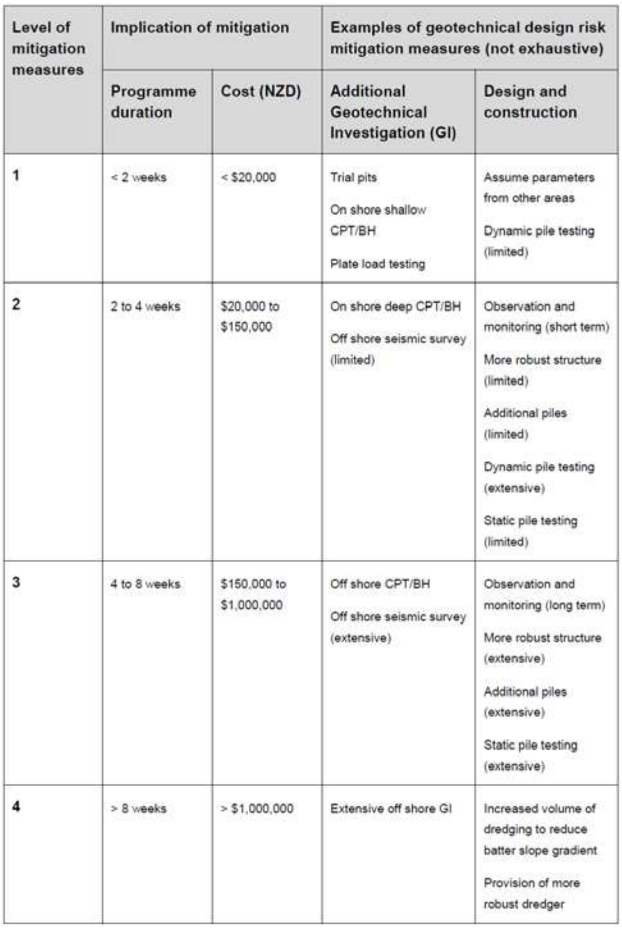
To reduce the geotechnical risk (‘risk level’) at design stage, mitigation options may be implemented in order to:

- increase the confidence in the geotechnical data; or,
- counter data uncertainty by mitigation via design and construction.

Both of which will reduce geotechnical risk at the design stage.

Mitigation options should be ranked in an attempt to provide a comparison between levels of mitigation and potential impacts on programme and cost.

Table 6. Mitigation options ranking



Level of mitigation measures	Implication of mitigation		Examples of geotechnical design risk mitigation measures (not exhaustive)	
	Programme duration	Cost (NZD)	Additional Geotechnical Investigation (GI)	Design and construction
1	< 2 weeks	< $20,000	Trial pits On shore shallow CPT/BH Plate load testing	Assume parameters from other areas Dynamic pile testing (limited)
2	2 to 4 weeks	$20,000 to $150,000	On shore deep CPT/BH Off shore seismic survey (limited)	Observation and monitoring (short term) More robust structure (limited) Additional piles (limited) Dynamic pile testing (extensive) Static pile testing (limited)
3	4 to 8 weeks	$150,000 to $1,000,000	Off shore CPT/BH Off shore seismic survey (extensive)	Observation and monitoring (long term) More robust structure (extensive) Additional piles (extensive) Static pile testing (extensive)
4	> 8 weeks	> $1,000,000	Extensive off shore GI	Increased volume of dredging to reduce batter slope gradient Provision of more robust dredger

Table 6 above outlines indicative mitigation options alongside corresponding programme and cost implications.

The information presented in Table 6 is provided as an example only.

5 CONCLUSIONS

The geotechnical design risk assessment provides a dynamic tool to assess, at a high level, the current availability and suitability of geotechnical data specific to areas of the port. The risk assessment provides varying levels of mitigation measures relating to typical engineering works in order to reduce geotechnical risk at design stage.

Feedback from LPC indicated that they found the solution to be of huge value to the port, in particular in the pre-feasibility stages of their billion dollar repair and investment programme. The solution provided the LPC project management team with a method to follow in which they could determine ‘most likely’ options for certain areas of the port and also discount options for other areas. LPC reported that the tool aided in allowing preliminary decisions to be made without further expensive and time consuming investigations.

This case study sets out a process which can easily be adapted for any large infrastructure project where there already is a wealth of geotechnical database. Of course, the consequence of hazard occurrence (Table 4) would need to be modified based on specific owner’s criteria and the mitigation options (Table 6) will need to be updated with time and / or adapted to the local practices.

ACKNOWLEDGEMENTS

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REFERENCES

AS/NZS ISO 31000:2009, Australian / New Zealand Standard, Risk Management - Principles and Guidelines

Forsyth, P.J.; Barrell, C.J.A.; Jongens, R. (compilers) 2008. Geology of the Christchurch area. Institute of Geological & Nuclear Sciences 1:250 000 geological map 16. 1 sheet + 67p. Lower Hutt, New Zealand. GNS Science.