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Geotechnical issues in seismic assessments: When do I need a geotechnical specialist?

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ABSTRACT

The Canterbury Earthquakes Royal Commission recognised the need for greater focus on geotechnical investigations and assessment as part of engineering projects. The current revision of the New Zealand Society for Earthquake Engineering's (NZSEE) guidelines document "Assessment and Improvement of the Structural Performance of Buildings in Earthquakes" June 2006 (Red Book) has no specific guidance for consideration of geotechnical aspects as part of a detailed seismic assessment and mitigation design for an existing building. NZSEE and the Ministry of Business, Innovation and Employment (MBIE) have addressed this by adding a chapter on geotechnical assessment. That geotechnical chapter (C4) is in draft and will be formally released in early 2017. In parallel to Chapter C4, the New Zealand Geotechnical Society (NZGS) and MBIE are developing guidelines to help summarise current practice in earthquake geotechnical engineering. These documents provide guidance on geotechnical input, but only provide limited guidance on the question of when to get a geotechnical specialist involved. This paper highlights issues in building assessment and design which can arise if geotechnical issues are not adequately considered. These include; variability of ground conditions, "brittle" behaviour of some foundation types, changes in soil-foundation performance under cyclic loading, and soil-foundation-structure interaction.

Keywords: geotechnical, earthquake, seismic assessment, strengthening, soil-foundation-structure

1 INTRODUCTION

The Canterbury Earthquakes Royal Commission recognised the need for greater focus on geotechnical investigations and assessment as part of engineering projects.

The current revision of the New Zealand Society for Earthquake Engineering's (NZSEE) guidelines document "Assessment and Improvement of the Structural Performance of Buildings in Earthquakes" June 2006 (Red Book) has no specific guidance for consideration of geotechnical aspects as part of a detailed seismic assessment and mitigation design for an existing building, except with regards to seismic subsoil soil class. NZSEE and the Ministry of Business, Innovation and Employment (MBIE) have addressed this by adding a chapter on geotechnical assessment. That geotechnical chapter (Chapter C4) is in draft and will be formally released in early 2017 (NZSEE 2016).

In parallel to Chapter C4, the New Zealand Geotechnical Society (NZGS) and MBIE are developing guidelines to help summarise current practice in earthquake geotechnical engineering with a focus on New Zealand conditions, regulatory framework, and practice to promote consistency and improve geotechnical earthquake aspects of the performance of the built environment. These guidelines have been split into modules and are briefly described below (text based on, and abbreviated from MBIE & NZGS 2016). Modules 1, 3 and 5A are publicly available, the remainder are in production.

- *Module 1:* Overview of the guidelines: Provides an introduction and outlines the objectives of the guidelines. Includes procedure for estimating ground motion parameters for earthquake geotechnical engineering.

- *Module 2:* Geotechnical investigation for earthquake engineering: Explains the importance of developing a geotechnical model; provides guidance on planning a site investigation; describes the advantages and disadvantages of various investigation techniques; provides guidance on the preparation and considerations for geotechnical factual, interpretive, design and construction observation reports; recommends appropriate densities of investigation and sampling for sites; and discusses common problems encountered during investigations works.

- *Module 3:* Identification, assessment, and mitigation of liquefaction hazards: Describes liquefaction phenomena; provides guidance on identification of liquefaction hazards; discusses methodologies for assessing the risk of liquefaction triggering including a 'simplified procedure' appropriate for everyday engineering situations; discusses liquefaction induced ground deformation and procedures for assessment; discusses residual strength of liquefied soils and the effect on structures; and provides an overview of how the effects of liquefaction could be mitigated.

- *Module 4:* Earthquake resistant foundation design: Discusses building code foundation performance requirements during earthquakes; common foundation types and strategies for selection; issues affecting shallow foundation performance and appropriate design procedures; issues affecting earthquake performance, and advantages and disadvantages of various deep foundation types; and analysis and design requirements for deep foundations with earthquake loading.

- *Module 5:* Ground improvement: Considers ground improvement techniques to mitigate the effects of liquefaction, cyclic softening, lateral spreading and the partial loss of soil strength through increases in pore water pressure during earthquakes; provides guidance on the need for and extent of ground improvement required; discusses various ground improvement techniques including advantages, disadvantages and relative cost; provides design guidance for each technique; and discusses construction and verification considerations.

- *Module 5A:* Specification of ground improvement for residential properties in the Canterbury region: Provides guidance on specification requirements for selected improvement techniques for small scale works (single residential) along with preliminary and general, testing and earthworks specifications.

- *Module 6:* Retaining walls: Considers earthquake considerations for design of retaining walls.

Modules 1 to 6 provide guidance on geotechnical investigation, assessment and design, and Chapter C4 (draft) provides guidance on geotechnical input required in a seismic assessment; however only limited guidance is provided on when to get a geotechnical specialist involved in a project. Section 2 of this paper outlines scenarios which would trigger the need to engage a geotechnical specialist, Section 3 provides guidance on what should be considered in determining the level of geotechnical input that is required, and Section 4 outlines common geotechnical issues (traps) in seismic assessments and mitigation designs which geotechnical input could mitigate.

2 TRIGGER SCENARIOS FOR ENGAGING A GEOTECHNICAL SPECIALIST

There is limited guidance available on when to get a geotechnical specialist involved in a project. Although not an exhaustive list, the scenarios outlined below provides some guidance on when it would be prudent to engage a geotechnical specialist.

- Projects that have complex engineering geological considerations, and projects that have complex interaction between the structure and soils. These are discussed further in the following bullet points.

- Those undertaking the assessment:
    - do not have geotechnical skills and experience; or
    - are not experienced in the local geology and geohazards relating to that geology; or
    - are not experienced in the particular geotechnical issues relating to the site, e.g. local weak areas of soil.
    - do not have available geotechnical data relating to the site, or ground conditions could be variable.

- Geohazards are present which could materially impact on the performance of the building or the assessor is not skilled in identifying these hazards:
  - Vertical and lateral load-deformation behaviour (capacity and stiffness) of foundations[(a)]
  - Shaking hazard (seismic subsoil class not definitive)[(a)]
  - Liquefaction[(a)]
  - Lateral spread[(a)]
  - Retaining wall instability: Underslip[(a)] and overslip[(b)]
  - Slope stability: Underslip[(a)] and overslip[(b)]
  - Rockfall[(b)]
  - Fault rapture[(a)]
  - Inundation: Tsunami, dam break and tectonic lowering[(a)]

  Footnote: Based on current interpretation of the Building Act:
  [a] May be material to %NBS (New building standard)
  [b] To be reported but not material to %NBS.

- Foundation loads could exceed the dependable (reduced) bearing capacity (ϕR), i.e. load and resistance factored design (LRFD) requirements may not be met, and performance of the soil-foundation-structure beyond this limit (>ϕR) needs to be considered.

- The structure has a relatively low tolerance to foundation movements.

- Retaining structures are integral in the structure and the structure has a relatively low tolerance to movement of these walls; or loads imposed by these walls could be critical to the structure.

- If the benefits of the flexibility of the foundation soils are to be considered in assessing the structure's natural period, i.e. if anything other than rigid base is to be considered in assessing the building's period.

- Geotechnical conditions or soil-foundation-structure interaction could dominate the assessment of the building.

- New or modification to foundation elements required as part of the mitigation works. The integration of new elements and compatibility of these with existing is to be considered and understood. A critical issue is the relative stiffness of foundation elements and consequently the distribution of load.

3 COLLABORATION BETWEEN STRUCTURAL ENGINEER AND GEOTECHNICAL SPECIALIST: WHAT LEVEL OF GEOTECHNICAL INPUT IS REQUIRED?

It is recommended that the structural engineer and a geotechnical specialist have a review session early in each project to determine if further geotechnical input is required, i.e. if ground compliance and / or geohazards could have a significant impact on the assessment. If further geotechnical input is required, and once the ground model has been developed and geotechnical issues have been identified, the structural engineer and geotechnical specialist should meet again to explore the significance of these geotechnical issues (NZSEE 2016). The meeting should explore what further geotechnical and structural assessment and analysis is required considering the following (summarising information from NZSEE 2016):

- For each identified geotechnical issue, what is the likely impact of that issue on the building's seismic performance?

- Which issues could impact on the buildings % NBS?

- For those geotechnical issues which could be critical to the buildings % NBS what further geotechnical and structural analysis and assessment is required?

- What geotechnical parameters are to be provided to the structural engineer and in what form?

- Which of the following categories describes the %NBS assessment of the building (terminology taken from draft geotechnical chapter C4):
    - *Structure Dominated:* Foundations which can be relied on and unlikely to limit the seismic performance of the building.
    - *Interaction:* Possible displacement of the foundations could limit seismic performance of the building. Soil-foundation-structure-interaction is significant.
    - *Geotechnical Dominated:* A step change in the performance of the foundations limits the performance of the building.

- What is the cost / benefit of geotechnical investigations, and at what stage of the process should they be carried out.

It would be prudent to involve the client in the meeting (or a separate meeting) so that the needs and drivers for the client with respect to %NBS of the building can be understood (or discuss and agree with the structural engineer how communication with the client will happen and be disseminated).

A number of meetings with the structural engineer (and client) are likely to be required through the iterative process of the assessment.

4 COMMON GEOTECHNICAL ISSUES (TRAPS) IN SEISMIC ASSESSMENTS AND MITIGATION DESIGNS

Common traps which can be mitigated with specialist geotechnical input are briefly discussed below.

- Engineering geology skills in development of a ground model are essential. This includes consideration of land forms, geological processes, site history and geotechnical investigation data, to determine the likely site conditions and produce a ground model. Common examples of misunderstood or unforeseen ground conditions include:
    - Geological materials such as alluvium can be highly variable, both with depth and in plan. Soft silt beds and loose sand layers can exist even within thick layers of dense sand or gravel. Historic meandering rivers and streams could have been present and infilled flow channels with soft silt within a dense soil layer.
    - Unidentified infilled gulleys on a competent soil or rock surface can result in competent founding conditions being assumed when actual conditions are locally weak soil.
    - Basalt flows can be variable in extent and thickness requiring careful consideration if relied on as a founding layer.
    - In areas around faults, weak layers or fault gouge within the rock mass (being the product of tectonic shearing and/or weathering) can be present in a rock profile. These layers can have the strength of a soil, substantially reducing the capacity of foundations bearing above them.
    - Historic earthworks can modify a soil profile such that fills are present when competent natural ground is expected. Weak soil layers buried under engineered fill can also be present.
    - End bearing piles with a soft silt bed or liquefiable sand below the base can result in piles punching through and large differential displacements in the supported structure.
    - Highly sensitive soils such as Ash can have high in-situ strength but generally reduce to residual strength when reworked (e.g. during earthworks, augering for piles or under seismic loading). Design of foundations assuming peak strength values in this material can be catastrophic. These soils are subject to a step change in behaviour leading to possible poor seismic resilience.

  - Basalt and limestone can include voids making them problematic in construction of grouted anchors or piles.
  - Within alluvial soils or in terrains of historic slope movement, weak soil layers may exist allowing slope failures on relatively low slope angles in the event of seismic shaking.
  - Unfavourably oriented defects may exist in rock allowing wedge or planar failures of slopes under relatively low seismic shaking.

- Seismic subsoil class can be assessed incorrectly.
  - Published geological maps with depths to rock are available for some centres and provide a useful starting point for subsoil class assessment. It should be noted that these maps are prepared on a global scale and cannot be relied upon solely for a site specific assessment. For a site specific assessment, maps need to be used in conjunction with geological interpretation, historic investigations, prior experience at nearby sites, and if necessary physical site specific investigations. Where no site specific investigation is carried out, there should be confidence that the local geology is consistent and unlikely to vary.

- Geo-hazards such as cyclic softening or liquefaction are not identified. Presence of these hazards can result in:
  - Loss of support below shallow and pile foundations.
  - Loss of shaft / skin friction in piles or anchors.
  - Lateral loading on piles from cyclic displacement (ground lurch) or lateral spread.
  - Negative skin friction loading on piles.
  - Post-earthquake settlement.

- Unfavourable behaviour of foundations under cyclic loading.
  - Shaft resistance of piles and anchors can be significantly reduced when subject to cyclic loading.

- Anchors / micropiles are often used to supplement existing foundations and resist uplift loads from new bracing elements. Common issues around the use of these are listed below:
  - Where there has not been an appropriate ground model developed or geo-hazard assessment carried out, it is possible that these anchors could be constructed within liquefiable soils. Anchors may test up to required loads when constructed, however in a seismic event inducing liquefaction, grout to country bond strength can be significantly reduced and anchors may fail at a fraction of the design load.
  - Stiffness compatibility between existing foundations and new anchors should be considered. Anchors may be stiffer than existing foundations thus attract load in compression until they fail.
  - Reverse cyclic loading can result in substantially lower anchor / micropile capacity than that assessed by static load testing.
  - High strain and grout to country bond yielding in upper sections of bond length can occur, i.e. strain degradation of bond. A 10m bond length is unlikely to provide double the capacity of a 5m bond length. Bond lengths of greater than 10m are generally not recommended.
  - A poorly detailed or constructed test anchor can provide non-conservative and misleading results.
  - The capacity of an anchor / micropile determined by testing is dependent on the loading sequence and acceptance criteria applied. For this reason codes and guidelines specify these and should be followed.

5 CONCLUSIONS

- The Canterbury Earthquakes Royal Commission recognised the need for greater focus on geotechnical investigations and assessment as part of engineering projects.
- MBIE, NZSEE, and NZGS are addressing this by publishing guidelines (Modules 1 to 6) for earthquake geotechnical practice in New Zealand and adding a chapter on geotechnical assessment (Chapter C4) to the Red Book. Modules 1 to 6 provide guidance on geotechnical investigation, assessment and design, and Chapter C4 provides guidance on geotechnical assessment of existing buildings; however only limited guidance is provided on the question of when to get a geotechnical specialist involved.
- Section 2 of this paper outlines scenarios which would trigger the need to engage a geotechnical specialist, Section 3 provides guidance on what should be considered in determining the level of geotechnical input that is required, and Section 4 outlines common traps in seismic assessments and mitigation designs for which specialist geotechnical input could mitigate.
- It is recommended that the structural engineer and a geotechnical specialist have a review session early in each project to determine the scope of geotechnical input required, i.e. if ground compliance and/or geohazards could have a significant impact on the assessment.

6 REFERENCES

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