Auckland Regulatory Review of Excavation Induced Ground Settlement

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ABSTRACT

Auckland is experiencing a surge in land development including high levels of intensification. As a result of intensification, developments involving deep excavations and both temporary and permanent retaining measures are more common. Where excavations are undertaken, ground settlement around the excavation can occur and is often caused by the combined effects of consolidation due to dewatering and mechanically induced settlement behind retaining structures.

The effects of combined settlement are the most critical where excavations are undertaken close to site boundaries, near existing structures and infrastructures. If not appropriately managed or designed, damage can occur and result in unforeseen costs for remediation and legal actions. Consequently, to understand and assess the effect of deep excavations, consolidation due to dewatering and mechanically induced settlement behind temporary and permanent retaining structures have been the subject of more focus by geotechnical specialists and Auckland Council.

Auckland Unitary Plan chapters E12 (Land disturbance - District) and E7 (Taking, using, damming and diversion of water and drilling) provide regulatory requirements for an assessment of effects as a result of ground settlement. This paper explores how consolidation and mechanically induced settlement are geotechnically assessed to fulfil these requirements in Auckland.

Keywords: regulatory requirements, resource consent, consolidation, mechanical settlement

1 INTRODUCTION

Auckland, like many other cities and towns around New Zealand, has been experiencing a significant increase in land development and intensification. As land becomes more costly to acquire, there is an incentive for land developers and homeowners to develop vertically and close to site boundaries to maximise the land available. This can also require trenching works for underground services which can be of significant depth. Consequently, developments with deep excavations are becoming more prevalent.

Deep excavations usually require significant retaining structures and often extend below groundwater level. This can result in ground settlement around the area of excavation because of mechanically induced settlement behind retaining structures and consolidation in areas where the excavations intercept groundwater levels and require a groundwater take (the removal of groundwater as part of land drainage) and/or diversion (rerouting groundwater flows). The settlement can cause neighbouring structures and services to be displaced, rotated and damaged. The severity of settlement is determined by the nature of the underlying geology (including its consolidation history and yield stress) the depth of excavation, the design of the proposed retaining structures, extent and depth of dewatering, and the proximity of the excavation to any nearby structures and services.

To manage the hazards of ground settlement associated with deep excavations, Auckland Council (Council) uses the Auckland Unitary Plan (AUP) chapters, E12 (Land disturbance - District) and E7 (Taking, using, damming and diversion of water and drilling) to provide a framework for the regulatory requirements and assessment of effects as a result of ground settlement.

2 REGULATORY FRAMEWORK AND REQUIREMENTS

The AUP provides two chapters which include sections addressing the potential for ground settlement induced effects within and off site – E12 and E7. Chapter E12 addresses district land disturbance under section 31 of the Resource Management Act 1991 (RMA) and Chapter E7 covers regional effects because of take or diversion of groundwater under section 14(1) and (3) of the RMA.

The RMA classifies activities into different classes as permitted, controlled, restricted discretionary, discretionary, non-complying and prohibited. These activities increase with Council discretion and potential effects on the environment. Each category determines the criteria and level of assessment that Council considers as part of the consenting process and the nature of the conditions which may be imposed on the on any granted consent.

- Permitted activities do not require a resource consent; however, it may be needed to demonstrate compliance with general rules to show that the activity meets the requirements. If the activity exceeds permitted activity standards, it requires a resource consent and may be classed as a controlled, restricted discretionary, discretionary, or non-complying.
- Controlled activities typically are in keeping with the existing environment and anticipated effects are well understood and able to be mitigated by conditions. Therefore, controlled activities will be granted; however, Council may impose conditions of consent subject to the controlled activity status. If the activity exceeds the controlled activity standards, it may be considered as restricted discretionary.
- Restricted discretionary activities may be granted or refused and there is increased scope of discretion for assessment by Council relative to permitted and controlled activities.
- Discretionary activities allow Council to undertake a full assessment of relevant AUP provisions. This includes the restricted discretionary activity considerations.
- Non-complying activities are assessed by Council to determine if its adverse effects on the environment will be no more than minor or contrary to the objectives and policies of the AUP.
- Prohibited activities or proposals are expected to cause significant adverse effects on the environment which cannot be mitigated by conditions of consent, therefore will not be able to attain a resource consent without redesign to a lower activity status.

2.1 E12 (Land disturbance - District)

Any activity involving earthworks, irrespective of the area and volumes, must comply with E12.6.2 General Standards including E12.6.2(2) and E12.6.2(3) in the AUP. This includes the consequences of earthworks on neighbouring land or services.

This can include earthworks undertaken in a residential zone which are greater than 500 m^2 and/ or 250m^3. If the activity is found to be restricted discretionary, the Council has slightly different assessment criteria under E12.7.2(1)(c), E12.8.2(1)(c) and (j); however, the effects of instability on land, structures, and services remain critical to E12 assessment. One difference between the general standards and restricted discretionary, controlled or discretionary activity scope is that Council is no longer limited to the effects at or beyond the boundary of the property and assessment onsite can also be considered.

2.2 E7 (Taking, using, damming and diversion of water and drilling)

The requirement for a groundwater take or diversion can occur when excavations are at a depth which intercepts groundwater. The removal or diversion of groundwater from draining, piping or obstructing the flow of groundwater can trigger the requirement for a new regional consent issued under Chapter E7 rules, known as a water permit.

Any permitted activity must comply with E7.6.1.6 and E7.6.1.10 for the take and diversion of groundwater caused by an excavation. Excluding the items in E7.6.1.10(1), the activity must abide by the parameters outlined in E7.6.1.10(2) - (6). This includes the area of excavation, changes to groundwater levels, the duration of the water take/diversion and proximity to existing structures, other groundwater takes and sensitive overlays. Further, if the activity is permitted under E7.6.1.10, it must also meet the requirements in Section E7.6.1.6 for groundwater controls.

If found that the proposed deep excavations are not permitted, then Council has discretion to assess the consent in more detail under E7.8.2(4) and (10), including means of how the effects of groundwater induced settlement can be reduced on structures and services and requirements for monitoring.

The effects can therefore be generally segregated to mechanically induced settlement as a result of retaining wall deflection (under E12) and consolidation induced settlement as a result of dewatering (under E7). The conditions of consent (discussed below) can therefore be similar, as both Chapters are managing the effects of ground settlement, although serving different components of the RMA.

3 CONDITIONS OF CONSENT

Conditions of consent are regulatory tools used by Council to manage the risk of anticipated adverse effects on the environment and aid in certainty of outcomes expected as part of the Resource Consent process. Upon issue of a Resource Consent, conditions are included which adhere to the discretion under the AUP and may include conditions offered by the applicant following Section 108AA of the RMA. Common conditions of consent are discussed below to manage excavation induced ground settlement.

- **No instability offsite**

A condition of consent is included to ensure that should instability occur, it is rectified by the consent holder. This provides clarity around responsibility for potentially affected parties.

- **Supervision of Works**

Geotechnical reporting often includes recommendations for supervision or monitoring of works during earthworks and construction of geotechnical structures such as any retaining, counterfort drainage and foundations. This is considered standard practice as it serves not only for the geotechnical specialists to verify their ground conditions and assumptions but also to complete a producer statement and geotechnical completion report if required as part of project progression.

Supervision of works should be undertaken by a geotechnical specialist who is familiar with all geotechnical reporting, recommendations, engineering plans and codes of practice to ensure that the site is appropriately managed and supervised.

- **Settlement Monitoring Contingency Plan**

Predicting and then monitoring the effects of ground settlement form part of sound practices to reduce costly surprises and potential damage to property.

A Settlement Monitoring and Contingency Plan (SMCP) or Groundwater and Settlement Monitoring and Contingency Plan (GSMCP) are common means of managing the effects of ground settlement. The conditions including the settlement and groundwater monitoring, monitoring of the wall's deflection, screening of any potentially affected structures, services etc., visual inspections, surveys undertaken pre-, during and post-construction and remediation of any damages which may occur. This is supplemented with alert and alarm levels which are necessary to align observations and stipulate any contingency measures to be undertaken. The frequency of monitoring can be varied depending on the expected rates of movement, findings of the survey and subject to discussion between the geotechnical specialist and Council.

Monitoring is a useful tool to limit the effects of ground settlement, however, should not be relied upon as a standalone means of mitigation. SMCP and GSMCP are accompanied with other conditions or evidence to support management of deep excavations, such as a detailed construction methodology.

- **Detailed Construction Methodology**

While good structural design can minimise the effect of ground settlement, it cannot guarantee that some settlement will not occur. For the purposes of a Resource Consent only preliminary retaining wall design is required, as detailed design forms part of Building Consent processes. To provide flexibility with design and construction and account for available plant machinery and contractor experience, Council may accept that a detailed construction methodology is provided prior to the commencement of works onsite. This document should be written by or endorsed in writing by a Chartered Engineering Geologist or Chartered Geotechnical Engineer.

4 TYPICAL GEOTECHNICAL ASSESSMENT OF EFFECTS

Geotechnical specialists identify and assess geohazards and constraints in relation to land development. For deep excavations, this typically includes undertaking an assessment to quantify the level of anticipated total ground settlement, followed by an assessment of effects on surrounding land, structures, and services.

This can be effectively illustrated through a plot showing settlement, distance and any structures and services which may be affected. If it is found that the degree of settlement and potential damage are unacceptable, further protection measures are explored to reduce the risk. This is typically undertaken by reducing the scale of or relocating the excavation, changing the construction methodology or altering the preliminary retaining design e.g. top-down construction methodology, increasing retaining wall stiffness etc., such that the effects are considered acceptable or within the tolerable thresholds for the potentially affected structure or service.

The geotechnical specialist defines and justifies the parameters and assumptions used in their assessment. This includes the geotechnical parameters of soils subject to ground settlement, groundwater levels and regime, the excavation depths, any surcharges applied and preliminary retaining wall design and construction. Any chosen parameter should be representative of site conditions and be substantiated with intrusive testing and site observations to ascertain the ground model and potentially affected structures and services.

4.1 Mechanical Settlement Assessment

Mechanical settlement assessment can be undertaken using empirical methods, such as Clough and O'Rourke (1990), semi-empirical methods, e.g. WALLAP calculations of the wall deflection, numerical methods using finite elements analysis or other techniques.

Cases in which empirical data may be appropriate to be relied upon are those where the risk or the consequences of settlement are low e.g. smaller excavations and limited structures proximal to the excavation. Care should be taken when relying on empirical data and considerations given to underlying assumptions, applicability to Auckland geology, proposed retaining methods and any site constraints. In medium and higher risk cases, where excavations are significant, located close to existing structures, services or site boundaries, modelling software may be more suitable to verify empirical calculations and confirm the anticipated settlement with distance from excavation.

Common assumptions around the effects of ground settlement are often presented but are lacking in the context of the proposed works. The assumption that the effects are limited only up to a distance from the excavation equal to the height of the retaining wall is incorrect. Work undertaken by Clough and O'Rourke (1990) and Wang et al (2010) revealed that the influence zone of ground settlement effects can be found up to a distance of 2 – 3.5 times the retained height. Therefore, excavation depth is not the only parameter to affect the extent of the settlement influence zone. Ground deformation is generally greatest within a distance of approximately 0.5 times or equal to the retained height (Ou et al., 1993 and Moorman 2004); however, in soft soils, this can be up to two times the retained height (Moormann, 2004).

The shape of ground deformation can differ depending on the subsurface material, the type of retaining and its support system (see *Figure 1* below). The work undertaken by Hsieh and Ou (1998) reports that spandrel type ground settlement is attributable to sandy materials and stiff clays and produces the greatest ground settlement next to the retaining wall. Conversely, concave type ground settlement is attributable to soft clays, such as those found in recent marine muds. Cumulative movement can occur, initiating with spandrel type movement, then incremental deep inward movement with time and excavation depth. Therefore, the geometry of ground deformation can exhibit cantilever and deep inward movement characteristics as part of total horizontal displacement and ground settlement.

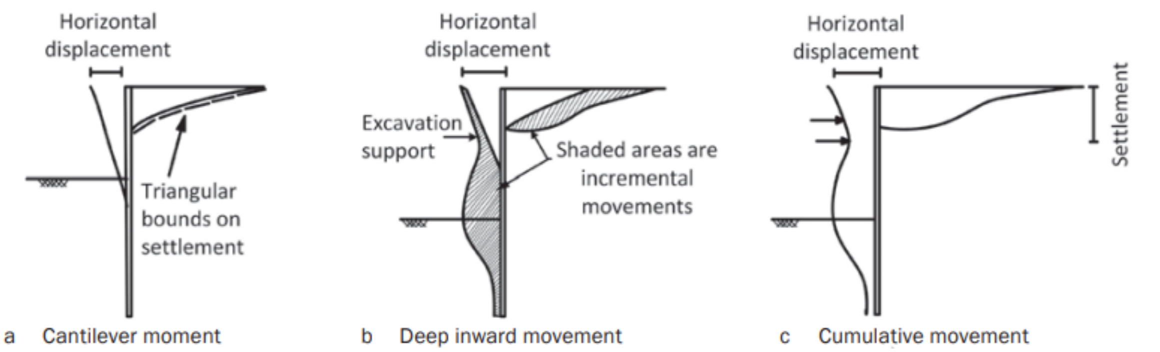

Figure 1. Typical ground settlement deformation as a result of retaining wall deflection and with time. (a) occurs with initial retaining wall construction can cause a spandrel type cantilever movement. As excavation continues with depth, excavation support is provided creating (b) deep inward movement occurs with incremental total settlement in a concave type ground settlement. Following the combination of (a) and (b) the cumulative movement and ground settlement shape is exhibited (c) and may vary depending on whether spandrel or concave type settlement was more dominant (CIRIA C760).

4.2 Groundwater Drawdown and Settlement Assessment

The method of analysis used should be proportionate to the complexity of the geological and hydrogeological conditions including historical groundwater regimes and the nature and extent of the proposed groundwater take and diversion. In order to apply appropriate parameters, onsite intrusive testing and groundwater level monitoring is typically required. At a minimum, Council requires onsite intrusive investigations to at least the depth of anticipated excavation and the monitoring of groundwater levels e.g. dip test or automatic loggers at least 3 times over a 3 week period following drilling. If possible, groundwater level monitoring over a number of months is preferred to capture any seasonal variations. Deviations from this process will require justification from the applicant and subject to Council review under E7.

In complex conditions, numerical methods allow for finite element or finite difference analyses and models for consolidation and groundwater effects e.g. PLAXIS. These can provide insight in the ways which soils perform when undergoing consolidation settlement in three dimensions. Granular soils are typically more permeable and resistant to ground movements as a result in changes to pore water pressure and effective stress, in comparison to cohesive soils. Cohesive, soft soils such as alluvial clay and silt in Puketoka Formation soils can exhibit large consolidation settlement over time. Consolidation settlement can be complex and varies with subsurface geology. It is particularly sensitive to soil permeability and varying thicknesses and lithologies which can persist in unknown geometries below structures and services even in what is anticipated to be homogeneous material of uniform thickness. Numerical analyses can provide a high level of detail in their outputs, but their value is restricted by the input parameters. Where insufficient or questionable information is available, the outputs may not be reflective of consolidation effects and behaviour and should be treated with scrutiny (CIRIA 750).

Where the geologic setting is simpler, consolidation calculations can use analytical methods to estimate the time for groundwater drawdown. Analytical methods use a mathematical model to represent the geology and many assume a single value of permeability and assess flows in two dimensions in cross section e.g. Bear (1979) and Terzaghi and Peck (1948). With deep excavations, plane flow systems are commonly assessed, capturing the length of the excavation and radial flows at the corners of the excavation. This can be used to predict anticipated groundwater flows and settlement at the locations of any structures and/or services which may be affected.

Consolidation settlement may not be as significant contributor to total settlement in comparison to mechanical settlement, however, forms part of the total settlement effects.

4.3 Assessment of Effects

Assessment of effects is a description of all the environmental effects that an activity may impose on the environment. For ground settlement, this includes all anticipated adverse effects as a result of the excavation, temporary and permanent supports and the retaining wall construction process on adjacent properties, land, structures and services. The level of assessment should be equivalent to the risk and be undertaken in collaboration with Geotechnical and Structural Engineers. The assessment should include all potentially affected existing properties, structures and services, the maximum allowable horizontal deformation and induced total and differential settlement behind temporary and permanent supports to maintain serviceability of affected structures and services.

The assessment of effects can include empirical comparisons which classifies potential damage to a building into different categories of damage, based on estimated total settlement. One of the methods introduced by Burland (1995) is the Burland Scale, which is commonly used by geotechnical specialists. The Burland Scale groups building damages into aesthetics, serviceability and stability. These factors are all relevant when considering the effects of ground settlement in a regulatory assessment.

There are assumptions associated with using the Burland Scale that limits its use, but which are often overlooked. This includes the assumption that buildings have not endured any damage prior to ground settlement. In cases where a structure has historically endured damage or is a heritage building (and over 100 years old), relatively small ground settlement levels may result in more severe damage which may not be anticipated (Portugal et al. 2005). Therefore, considerations need to be made to the existing condition of any potentially affected structures or services.

Ground settlements occur behind the retaining wall and due to the groundwater drawdown generally reduces with distance from the excavation. The greatest ground settlement is expressed at the ground surface; therefore, shallow foundations and paved surfaces commonly exhibit more obvious signs of cracking and damage. Underground services usually endure less ground settlement, being located at depth. That being said, underground services in Auckland include those of brittle construction type, such as clay, which can crack impairing serviceability, if the ground surrounding them is displaced. Therefore, consideration needs to be made for the age, condition, location, depth and construction type of structures and services.

5 CONCLUSION

There is an increase in deep excavations in Auckland to support land development and intensification. As a result of this trend, there is also increased risk of ground settlement.

AUP Chapters, E12 and E7 provide the regulatory requirements which Council uses to undertake an assessment of effects resulting from ground settlement. The discretion for assessment and conditions imposed on a Resource Consent is determined by the activity class and information provided by the applicant.

There are a number of methods which can be used to predict ground settlement. The chosen assessment approach should be proportionate to the level of risk and appropriate for the complexity of the geological and hydrogeological conditions. Once the mechanical, consolidation and total settlements have been quantified, an assessment of effects should be undertaken in collaboration with a geotechnical specialist and structural engineer. The effects of endured ground settlement should include potentially affected structures and services on neighbouring properties, their age, condition, location, depth and construction.

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