CHALLENGES IN CONSTRUCTION MONITORING – ADAPTING TO UNFORSEEN CONDITIONS: A CASE STUDY IN RICCARTON, CHRISTCHURCH, NEW ZEALAND

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ABSTRACT

Geotechnical investigations are limited by the data available through subsurface investigations, which are typically isolated borings, providing snapshots of the subsurface profile. Difficulties can arise were the encountered profiles fail to identify isolated subsurface features. We present a case study of this situation during construction of a Multi-Unit Residential Building (MUB) in Riccarton, Christchurch, New Zealand. Initial investigations encountered interbedded silt and sand with gravel below 5.3 m and one location with peat soils, which were deemed an isolated feature. A gravel raft and concrete slab foundation was therefore designed. While excavating for construction, a linear peat feature was encountered, extending across the building footprint. The remedial solution for this required careful consideration and consultation with the owners and stakeholders. It was deemed appropriate to excavate and replace with ballast to minimise construction delays, however this presented challenges associated with dewatering, liquefaction and creation of sand boils at subgrade level caused by operating machinery. Concurrent to construction of the MUB gravel raft, consideration was given to the suitability of the foundations of the adjacent garage. The peat deposit trended towards the garage footprint and would likely contribute to the same construction challenges. To provide better understanding prior to construction commencing, additional investigation was undertaken in the garage footprint, which raised further uncertainty and ultimately triggered a foundation re-design to a pile supported solution. This project highlighted the difficulties faced within geotechnical investigations, and the importance of construction monitoring in conjunction with additional investigation to minimise project cost and time delays.

1 INTRODUCTION

The accuracy of geotechnical investigations is limited by the data obtained through subsurface investigations, which are typically limited by the project budget and site access. One way to improve understanding of site conditions, is to undertake monitoring at the time of construction. This allows for identification of any shallow features that were not previously encountered within the subsurface investigations. We present a case study of this situation during construction of a Multi-Unit Residential Building (MUB) in Riccarton, Christchurch, New Zealand. The site experienced damage as a result of the 2010-2011 Canterbury Earthquake Sequence, and as such the rebuild works are covered by an insurance claim. Due to privacy requirements associated with the insurance claim, the specific site address will not be discussed.

2 INITIAL GEOTECHNICAL INVESTIGATION

In 2014, a geotechnical investigation was required for the design of a new foundation system, for the replacement of the earthquake damaged MUB and adjacent garage at the site. To minimise disruption for the client, the original MUB remained on site at the time of the investigation, such that the required foundation design and consenting process could be undertaken prior to demolition; ultimately minimising disruption for the home owners.

2.1 SUBSURFACE INVESTIGATIONS

Due to the presence of the structures and associated hard surfaces (driveways, patios and pathways) which posed access constraints, as well as consideration for the project budget, a limited number of subsurface borings were undertaken across the approximately 1,300 m^2 site. This comprised seven hand auger boreholes to variable depths of 2.2 to 3.4 m and two machine boreholes to depths of 15.45 m. The shallow hand auger boreholes were undertaken in March 2014 and terminated at varying depths due to hole collapse or refusal on hard or dense material, and in one instance, refusal on inferred wood. The machine boreholes were undertaken three months later (June 2014) and extended through alluvial soils to the target depth.

The investigations (both hand auger boreholes and machine boreholes) indicated surficial topsoil and fill typically within the upper 1 m, extending to greater depths within HA01, HA02 and HA04 (to a maximum depth of 1.9 m).

This was underlain by alluvial soils of interbedded silt and sand within the upper 4.5 m to 5.3 m from which point alluvial gravels were encountered. A single layer of peat was encountered within machine borehole MB01 between 1.8 m and 2.2 m depth. Further, wood was encountered within the same borehole between 3.4 m and 3.6, then again from 4.5 to 4.7 m depth. The investigation locations are illustrated in Figure 1, with the locations of the original structures shown to illustrate the limited access. This number of investigations given the size of the site is typical for a standard geotechnical investigation, and is in excess of the minimum requirements stated within the Ministry of Business, Innovation and Employment guidelines, Parts A and E (2012; 2014).

Figure 1: Site layout at the time of the 2014 investigation including the hand auger boreholes and machine borehole locations (aerial imagery sourced from Canterbury Maps, not to scale).

Groundwater was only encountered within hand auger boreholes HA03, HA05 and HA07; it was measured at depths of 1.0 to 1.1 m below ground level. In contrast, groundwater was encountered at 2.8 m depth within machine borehole MB01 (no groundwater reading was taken within MB02).

Concurrent to the geotechnical investigation, an environmental assessment was undertaken as the site was had been identified as potentially being a former landfill. Six samples were collected from a depth of 0.3 m below ground level for analysis. Results indicated concentrations of arsenic, cadmium and lead above the residential guideline criteria outlined by the Ministry for the Environment (2011; 2012). Therefore, material removed from site was not suitable for clean fill disposal and had to be disposed of at an appropriate landfill for the measured contaminants.

2.2 INITIAL GROUND MODEL

The site is located on a flat area within Christchurch City, and was therefore anticipated to be underlain by interbedded alluvial materials, consistent with the regional mapping by Brown and Weeber (1992). A stream is located 145 m to the south of the site and the Avon River is located 450 m north of the site, both suggesting the alluvial depositional model is appropriate for the site.

Considering the investigation data available, the subsurface investigations encountered broadly consistent materials. Given the isolated nature of the peat and wood, the geological model was deemed to comprise topsoil and fill within the upper 1 m (extending to greater depths in isolated areas), with alluvial soils of interbedded silt and sand, underlain by alluvial gravels from 5.3 m depth. Isolated pockets of organic material were deemed to be discontinuous, as is commonly encountered within alluvial deposits.

Due to the variable depths to groundwater between the hand auger boreholes (where encountered) and the machine borehole, the shallower water level was interpreted to be perched water due to the silty alluvial material, with the deeper groundwater encountered within the machine borehole to be reflective of the true water table.

2.3 FOUNDATION SOLUTION

Adopting the model outlined above, a foundation solution was derived to support both the replacement MUB and the adjacent garage structure. While both concrete slab and piled foundation options were presented to the client as suitable options, the adopted solution was selected as being a concrete slab supported on a reinforced gravel raft. Given the encountered surficial topsoil and fill encountered across the site, the gravel raft for the dwelling was proposed to be 1 m thick, and 0.5 m thick for the garage; both requiring soils with a geotechnical Ultimate Bearing Capacity of 200 kPa for support. Local over-excavation and backfilling was noted to be required in some areas to remove any uncontrolled fill extending beyond this depth.

3 FOUNDATION EXCAVATION AND CONSTRUCTION

3.1 INITIAL OBSERVATIONS AND RECOMMENDATIONS

Following removal of the original structures, excavation for the MUB foundation commenced in July 2017. The excavation was advanced to a depth of 1 m below adjacent ground level in preparation for construction of the gravel raft; at which time the first geotechnical observation of the subgrade material was undertaken.

Initially, the subgrade conditions appeared to be in line with the geological model, with isolated areas of uncontrolled fill. Instruction was given to remove this fill material under the observation of the project geologist. One of the areas of fill comprised a no fines gravel which formed a linear strip across the building platform in a broadly north to south orientation. This material was inferred to be free draining gravel associated with a pipe that was removed during excavation. Through removal of this gravel, a linear zone of peat material was uncovered. Given that some peat was anticipated in isolated areas through the initial geotechnical investigation, it was deemed that this was likely to be a shallow feature and it was recommended that this material be over-excavated.

During the over-excavation process, the peat was found to be more continuous than anticipated and included intact logs (Figure 2). Excavation continued to remove the peat, until an excavation measuring approximately 3 m below ground level (2 m below the base of the proposed gravel raft), 4 m wide and approximately 10 m long had been made. Through removal of this material, the geological model for the site was further developed to include a historic stream channel trending across the site, in which the organic matter forming the peat was deposited (Figure 3).

Figure 2: Excavation of peat, including intact logs.

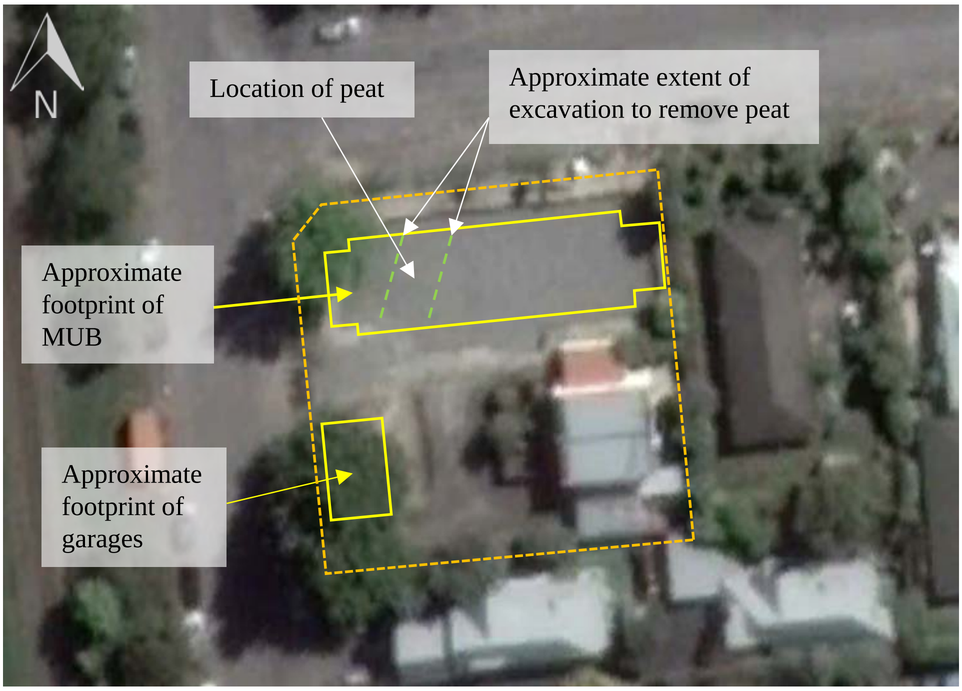

Figure 3: Location of encountered peat material (October 2017 aerial imagery sourced from Google Earth, not to scale).

As this feature had not been identified within the initial geological model, this instantly posed challenges around modifications to the foundation solution resulting in additional time and expenses for the client. All stakeholders were notified, including the project management firm, the construction firm and the body corporate representative, with discussions undertaken around the most appropriate way to proceed. At that stage, time was the critical factor and an instruction was given to proceed in the most appropriate manner to keep the project moving.

It was deemed appropriate to backfill the over-excavation with ballast to achieve the required level for construction of the gravel raft. Ballast was selected for this backfill over the sandy gravel (AP65) proposed for the gravel raft, as the interlocking form of the angular ballast gravel requires minimal compaction and would allow the project to proceed with the least time delays, while still providing the required geotechnical Ultimate Bearing Capacity of 200 kPa.

3.2 LIQUEFACTION OF SHALLOW SOILS

Within the subsurface investigations completed in early autumn and winter, groundwater was encountered at depths around 1 m within the hand auger boreholes, and at 2.8 m depth in the machine borehole. Given that the geological model had concluded that the shallower water was isolated areas of perched groundwater and that the excavation was planned to extend just beyond 1 m, little consideration was given to better constraining the depth to the water table.

Due to construction timing, excavation extended into August 2017, which experienced relatively high rainfall levels. Accordingly, groundwater was encountered at approximately 1.5 m depth during excavation associated with the peat removal. While shallower than the groundwater recorded within the machine borehole, this was deemed likely to correspond with standard seasonal fluctuations, and dewatering was undertaken. However, as contaminant levels in excess of the residential guidelines (Mfe, 2011b; MfE, 2012) had been identified within the environmental investigation, this could not be discharged into the stormwater system but needed to be transported to a managed waste facility. This added further delays to the project, as continuous dewatering was not possible and disposal of each truck load of water included an additional hours travel time to the waste facility.

The water level presented another unexpected challenge. With groundwater at a depth of 0.5 m below the base of the subgrade surface, the motion from the heavy machinery tracking across the site caused challenges to the working platform that the subgrade surface provided. The subgrade experienced a temporary loss of strength that resulted in liquefaction of the subgrade and sand boil formation across approximately one quarter of the excavation (Figure 4).

Figure 4: Sand boil formation at base of foundation excavation (August 2017).

Within this area that liquefied, the bearing capacity of the soil was measured to be less than the target geotechnical Ultimate Bearing Capacity of 200 kPa and remediation was required to create a suitable surface for placement of the gravel raft. Again, discussion with the stakeholders was required around possible solutions. Three possible solutions were discussed: modification to the foundation design, additional excavation and replacement with ballast, or alternatively allowing time for the soils to dry out. Due to timing constraints, it was decided to undertake further excavation across this area and backfill to remove the loose saturated soils followed by back filling the over-excavated area with additional ballast.

3.3 PEER REVIEW OF EXCAVATION AND BACKFILL

As a result of ongoing unforeseen circumstances and conditions, and to provide reassurance that best practices were being undertaken, the body corporate engaged a peer reviewer to assess the works to date and proposed remediation plans.

One of the concerns raised by the peer reviewer was the potential for the identified base of the peat layer to be a thin zone of silt and sand overlying further peat deposits, and they recommended the completion of additional hand auger boreholes at the base of the excavation to assess for further peat deposits. However, by this stage, the contractors had already followed the instruction to obtain ballast and backfill the excavation. In order to satisfy the peer reviewer, the ballast had to be removed to allow the additional testing to be completed. While this provided further delays to the project, the testing indicated that there was an additional layer of peat (less than 0.5 m thick) below the previous excavation depth that required removal. The removal of this additional material under the observation of the peer reviewer provided valuable reassurance to the property owners. From this point all parties were satisfied and the ballast backfill was able to be completed and the gravel raft construction could then commence.

4 GARAGE FOUNDATION SOLUTION

From the lessons learnt through construction of the dwelling foundation, critical thought was given to the suitability of the proposed garage solution with the additional knowledge gained and improvements to the geological model. The proposed garage solution initially comprised a concrete slab solution, supported on a 0.5 m thick reinforced gravel raft. However, the alignment of the peat channel within the building footprint suggested that this feature might continue towards the garages and similar problems may be encountered.

4.1 FURTHER INVESTIGATION

Preference was to minimise changes to the foundation design solution where possible, and to ideally remain with the original gravel raft design. Both geotechnical parties deemed that the completion of further subsurface investigations in the garage footprint may allow better constraint of the depth and thickness of peat, as well as providing information to assess if additional excavation was required. Therefore, four machine boreholes were drilled in an approximately diagonal line across the garage footprint to a depth of five meters. This layout was planned to intersect the peat feature, provided that it continued in the same trend as in the MUB footprint. The garage footprint, relative to the MUB, is shown along with the borehole locations in Figure 5.

Figure 5: Location of additional machine boreholes within the garage footprint (October 2017 aerial imagery sourced from Google Earth, not to scale).

Peat was encountered within boreholes G-BH01 and G-BH04, on opposing corners of the garage, with no peat encountered within the central boreholes. Peat was encountered below 1.4 m depth with a maximum thickness of 0.7 m. This pattern did not support the hypothesis that the peat feature extended in a single linear feature in this direction, but suggested that there may be a more complex pattern of isolated pockets or branching peat channels within the garage location.

4.2 DEVELOPMENT OF FOUNDATION SOLUTION

Given that the machine boreholes within the garage footprint suggested isolated areas of peat that did not extend through the middle of the footprint, consideration was given to the suitability of proceeding with the proposed gravel raft and concrete slab solution. Consolidation settlement of the peat layer was assessed by considering the peat properties and the load from the building. For analysis purposes, a worst case scenario was adopted, assuming the shallowest encountered peat layer within the garage machine boreholes (1.4 m) with the maximum encountered thickness (0.7 m) being continuous across the garage footprint.

By increasing the gravel raft thickness to 1.0 m, the bearing capacity requirements for the garage slab would be met and small pressures would be transferred to the underlying peat layers. To provide further certainty of the suitability of this option, an additional four to six hand auger boreholes within the excavation footprint were proposed to assess whether there were shallower peat deposits than those seen within the machine borehole.

Geotechnically, while the four boreholes for a garage provides more information than would normally be available for a typical site, the information provided suggests a high level of complexity within the subsurface conditions that cannot be confirmed until excavation. As with the MUB foundations, it was possible that proceeding with a gravel raft solution would require additional excavation to locally remove peat. This additional excavation may extend below the water table, again introducing difficulties around material removal, backfill, de-watering and potential liquefaction. Further, the garage footprint extends in close proximity to the site boundary and a public footpath, where services are buried. Excavation to depths greater than the planned 1.0 m may trigger the need for temporary shoring to maintain integrity of the pathway.

A discussion with the stakeholders was then undertaken to consider the most appropriate solution moving forward for the garage. The project peer reviewer raised concerns over the potential for the fluctuating water table, specifically future decreases, which may drain the peat causing significant subsidence that would be beyond the extent of design tolerances. As a result of the potential subsidence along with the uncertainties surrounding the construction of a gravel raft, it was deemed that the additional time and expense associated with changing the foundation design to a pile supported system bearing on the underlying gravels at approximately 5.3 m depth, was worth accepting as it provided all parties with some certainty around costs and time frames.

While this alternative solution provides improved certainty, it is not without risk. There are different risks for the site for different pile solutions. Driven piles create vibrations which may damage the nearby buildings; screw piles may meet refusal on underlying logs, which may be difficult to discern from the target bearing within the gravels; and, bored and cast piles may need temporary casing as the hole wall may collapse during excavation. Given the risks associated with the different piling methods, screw piles were selected as these can be readily shifted as required for the encountered conditions (for example, if the pile meets shallow refusal on wood) and the amended concrete slab design will allow some level of tolerance in the spacing of piles to account for an adjustment that may be required. While no solution is without risk, this was considered the most reliable option for the site and completion of the job.

5 LESSONS LEARNT

This project has highlighted the uncertainties associated with geotechnical investigations, and the complications that can arise due to this uncertainty. While there is little that can practically be done to improve knowledge of subsurface conditions prior to commencing excavation for foundations, the completion of thorough observation during and after excavation can improve understanding and provide a final check of the actual bearing conditions.

At this property, the presence of the structure on site at the time of the initial investigation limited access and restricted the possible test locations. Therefore, even with greater budget for further investigation, there would have been only limited additional data that could be captured to improve knowledge of subsurface conditions. While this point is well understood by geotechnical professionals, it is something that the client may not intuitively understand and a discussion around these limitations before commencing a project may help to alleviate client concerns if variable subsurface conditions are encountered.

If all stakeholders understand the risk of uncertainties and support the completion of thorough subgrade observations, the project is likely to run more smoothly. Typically, subgrade inspections are seen by the client and construction contractors as an unnecessary halt point which acts to delay the project, as well as costing more money. With better communication at the start of the project and explanation of varying scenarios, stakeholders can be educated to understand the importance of these inspections and ideally appreciate the value they add to a project. Had this discussion been undertaken relative to this site prior to commencing works, we may have been able to avoid the need for a peer reviewer and the additional time and expense that this incurred.

Geological uncertainty can be limited at the time of subgrade observations by undertaking additional hand auger boreholes in a grid across the building footprint. While clients may be reluctant to cover the additional time and expense that this process would involve, it would provide greater understanding and improve confidence in the suitability of the selected solution. Had works been halted at the first sign of peat and the approach of additional hand auger boreholes across the footprint been implemented, it would have allowed a greater understanding and ultimately time to amend the foundation solution to the most appropriate option.

The key lesson from this project is to never underestimate the complexity of geology at a site. The tiny clues offered at the time of the 2014 investigation, such as isolated peat and hand auger borehole refusal on wood, provided valuable insight into the complexities of this site, which were realised by thorough observation and additional testing at the time of construction. This same approach should be taken to all sites; no matter how straight forward they initially appear.

6 ACKNOWLEDGEMENTS

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