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Design of Anchors in Weathered Greywacke - A Case Study in Wellington

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ABSTRACT

The variability in weathering conditions of Wellington greywacke whether among different sites or within the same site makes anchor design challenging for geotechnical engineers. Sacrificial ground anchors tests were analysed from 16 different projects located within the Wellington region. A correlation between the rock weathering grades and the bond capacities inferred from the anchors tests, and comparison with relative published data /research are presented in this paper. This correlation could be used as preliminary presumptive value to design the anchors. Quality logging of the target founding strata at the appropriate depth and understanding of the geological model is required to be able to utilise the correlation. Sacrificial anchor testing is recommended as the design progresses. A case study is also included to demonstrate a possible approach in designing anchors in such variable conditions. .

1 INTRODUCTION

Greywacke rock is the most abundant rock type in Wellington. The variability in weathering conditions of greywacke whether among different sites or even within the same site makes anchor design challenging. To account for this variability the anchor design must be a dynamic process which starts with an assumption about the design strength and evolves through the project after sacrificial and production anchor testing.

This paper explores the variability of greywacke through the review of ground anchor tests carried out at 16 locations in the Wellington region. It summarises the ranges of grout to ground capacities by each weathering grade. These ranges could be used by engineers to aid the selection of the initial design strength of anchors founded in greywacke. A case study is also included to demonstrate a possible approach in designing anchors in such variable conditions.

2 GREYWACKE WEATHERING

The bedrock which forms the foundation of the landscape in Wellington consist predominantly of sandstone and argillite - sand, silt and mud that have been buried and hardened. These rocks are often called “basement rocks” or “Wellington Greywacke”. All the basement rocks of wellington area are part of the Torlesse Complex. The layers of Torlesse sandstone (greywacke) are grey in colour, while the layers of mudstone (argillite) are dark grey to black (Begg, J. G. and Mazengarb, C. (1996)).

A brief description of the weathering classification of Greywacke is presented below (NZGS 2005):

- Grade 1, Unweathered (Fresh) Rock (UW): Rock mass shows no loss of strength, discoloration or other effects due to weathering. There may be slight discoloration on major rock mass defect surfaces or on clasts.
- Grade 2, Slightly Weathered (SW): The rock mass is not significantly weaker than when unweathered. Rock may be discoloured along defects, some of which may have been opened slightly.
- Grade 3, Moderately Weathered (MW): The rock mass is significantly weaker than the fresh rock and part of the rock mass may have been changed to a soil. Rock material may be discoloured, and defect and clast surfaces will have a greater discolouration, which also penetrates slightly into the rock material. Increase in density of defects due to physical disintegration process such as slaking, stress relief, thermal expansion/ contraction and freeze/thaw.

- Grade 4, Highly Weathered (HW): Most of the original rock mass strength is lost. Material is discoloured and more than half the mass is changed to a soil by chemical decomposition or disintegration (increase in density of defects/fractures). Decomposition adjacent to defects and at the surface of clasts penetrates deeply into the rock material. Lithorelicts or corestones of unweathered or slightly weathered rock may be present.
- Grade 5, Completely Weathered (CW): Original rock strength is lost and the rock mass changed to a soil either by chemical decomposition (with some rock fabric preserved) or by physical disintegration.
- Grade 6, Residual Soil (RS): Rock is completely changed to a soil with the original fabric estroyed.

3 GROUT TO GROUND CAPACITY DATA

A summary of the grout to ground capacity (minimum bond capacity) of greywacke material, obtained from sacrificial anchor test results carried out within Wellington, is presented in Figure 1. The data is collected from 16 projects within the greater Wellington region; indicative locations of anchors are presented in Figure 2. The anchors tested were embedded into greywacke material with the weathering grade varying between completely, highly and moderately weathered. The majority of the holes were logged in accordance with NZGS 2005. The grout diameter ranged between 100mm and 200mm and the bonded length between 1m and 8m.

Ground anchor testing in Wellington soils and weathered greywacke was also described in Christie et al (2015), in which the maximum bond capacity range obtained for completely weathered Greywacke was between 172kPa and 283kPa. These results can be considered consistent with the data summarised in Figure 1.

Bradshaw and Clayton (2013) discussed ground anchor testing for two projects in Karori, Wellington. Both project sites were noted to lack the typical greywacke weathering profile, instead moving quickly into slightly-weathered rock near surface. While largely unweathered, the rock was noted to be significantly weaker than might ordinarily be anticipated and the typical properties for a slightly weathered state were considered inappropriate. The maximum bond capacity range was between 200kPa and 300kPa. The ultimate bond capacities, from Bradshaw and Clayton (2013), for SW rock are not consistent with the results in Figure 1.

The weathering grades are listed below:

- Grade 2: Slightly Weathered;
- Grade 3: Moderately Weathered;
- Grade 3.5: Moderately to Highly weathered;
- Grade 4: Highly Weathered;
- Grade 4.5: Highly to completely weathered;
- Grade 5: Completely Weathered.

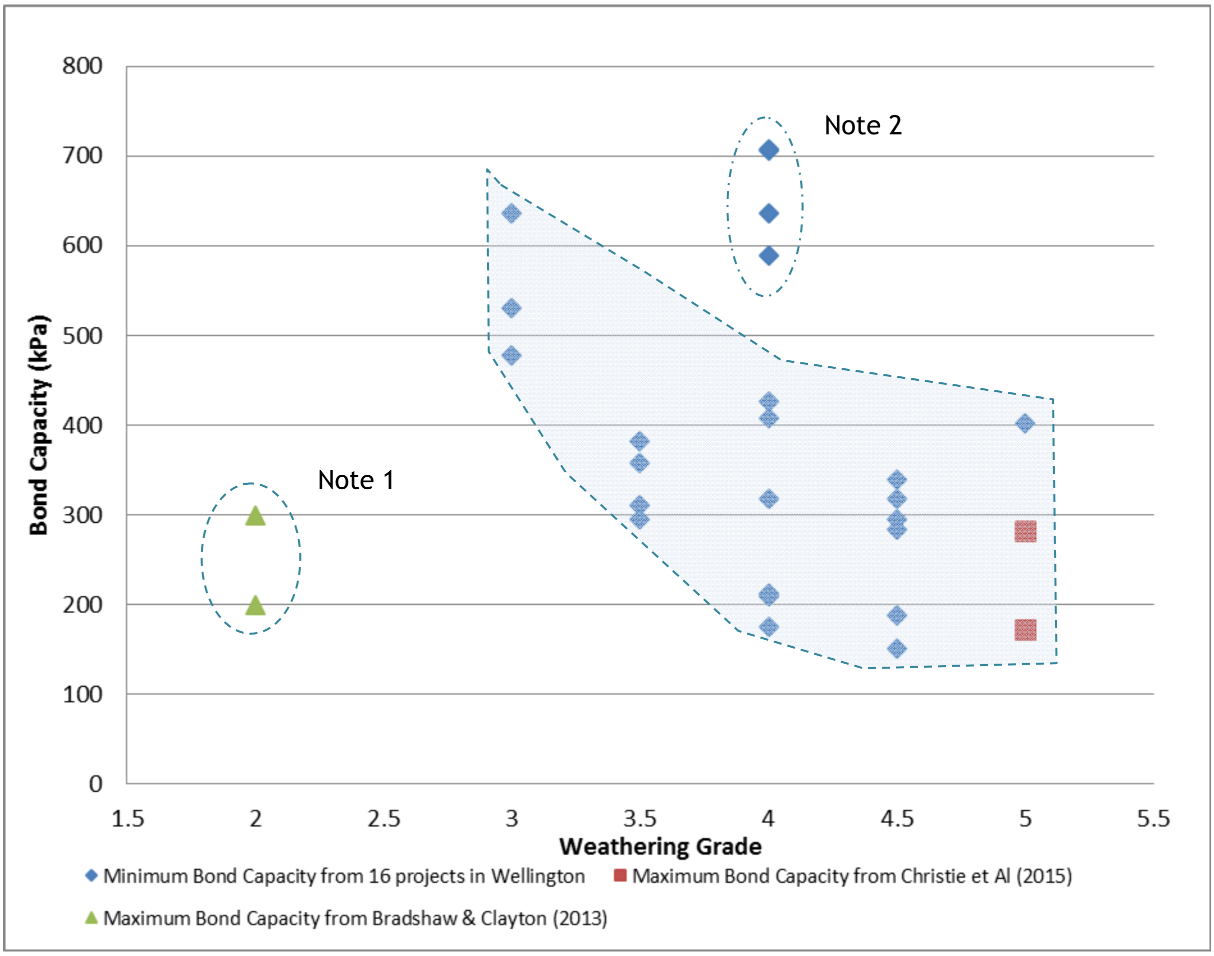

Figure 1. Anchor Bond Capacity

Note 1. Bradshaw and Clayton (2013) discussed ground anchor testing for two projects in Karori, Wellington. Both project sites were noted to lack the typical greywacke weathering profile, instead moving quickly into slightly-weathered rock near surface. While largely unweathered, the rock was noted to be significantly weaker than might ordinarily be anticipated and the typical properties for a slightly weathered state were considered inappropriate. The maximum bond capacity range was between 200kPa and 300kPa. The ultimate bond capacities, from Bradshaw and Clayton (2013), for SW rock are not consistent with the results in Figure 1.

Note 2. We believe that these higher bond capacities are outliers to this data set due to the use of high tensile capacity bars in this project. An increased data set size may confirm if this is indeed an outlier or not.

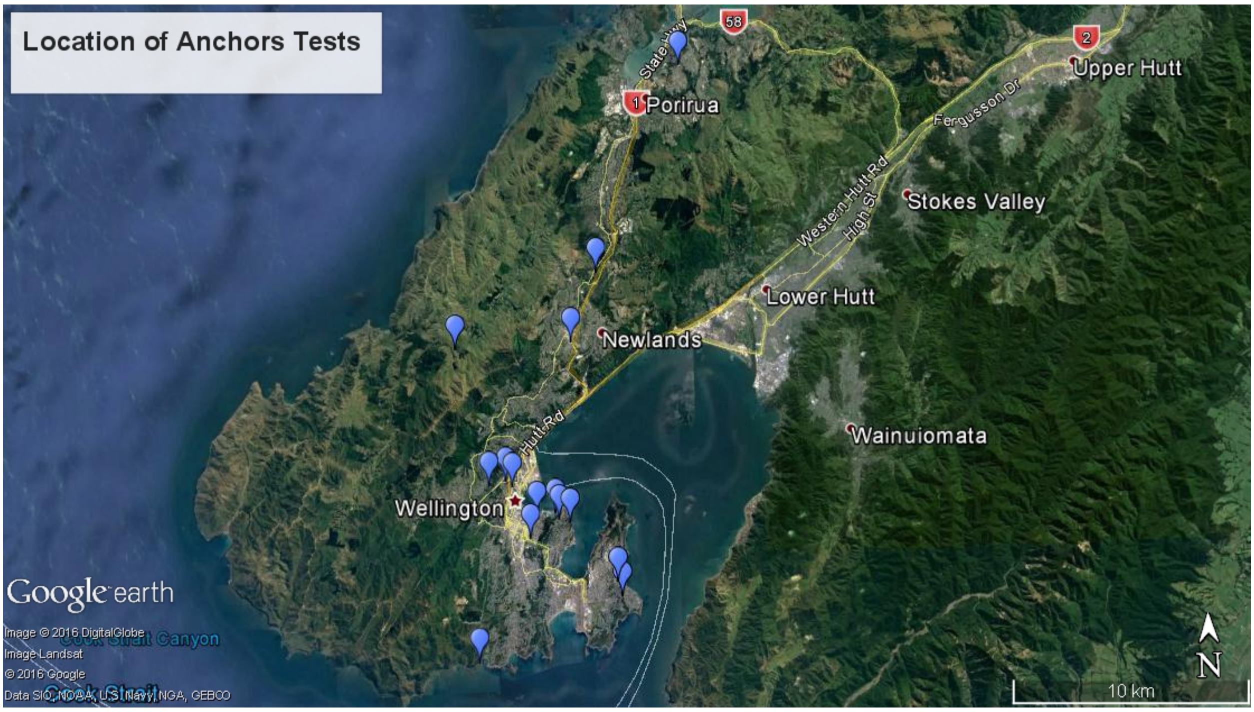

Figure 2. Indicative locations of sacrificial anchors tests

The variability of bond capacity depends on several factors including the degree of weathering in rock, methodology of testing, anchoring system, workmanship/experience of the contractor and disturbance to the anchor prior to testing.

The range of bond capacities inferred from the testing data is between 450kPa and 650kPa for MW rock, between 300kPa and 400kPa for MW to HW rock, between 200kPa and 700kPa for HW rock, between 150kPa to 350kPa for CW to HW rock and between 170kPa to 400kPa for CW.

The current scatter presented in Figure 1 suggests that there is a negative correlation between the weathering grade and bond capacity. However to reliably mathematically define this correlation more data is needed.

4 CASE STUDY

The following is a case study of a new commercial development in Porirua, Wellington. The development of the proposed building required a (maximum) 9m high cut in completely to highly weathered greywacke material. In plan the cut would be an 'L shape' running along the northern and western boundaries of the site. Due to the boundary constraints an anchored shotcrete retaining wall was designed for the 9m cut along the northern boundary of the site and cantilever steel post wall for the adjacent 6m cut along the western boundary.

During the design stage, and based on previous data for rock with similar weathering, the assumed bond capacity was taken as 300kPa. Prior to drilling of production anchors, four sacrificial anchor tests were carried out at different locations and heights, to confirm the assumed bond capacity of rock. The results of bond capacities deduced from tests varied between 150kPa and 340kPa.

Changing the design for all anchors using the minimum bond capacity obtained from test results increased the anchors' lengths and total cost. Therefore the anchors' design in our model was optimised using the specific bond capacity inferred from test results for each row of anchors.

With variable rock strengths and weathering the designer may select optimal rather than conservative design parameters; in this case the probability (and risk) of anchor failure dramatically increases. On this project an optimal design was adopted and the risk was efficiently managed by allowing for verification testing of anchors and then optimization of design using those test results.

Communication with relevant stakeholders at the design stage is necessary to impart understanding that deriving the right bond capacity for design is an iterative process.

5 CONCLUSION

The grout to ground capacity of Greywacke rock is variable across Wellington and depends on the grade of weathering in addition to other factors such as grout diameter and bonded length. We have plotted the relationships between (1) the grout diameter and bond capacity (2) bonded length and bond capacity, as well as (3) weathering of Greywacke and bond capacity. There was no discernable trend in the relationships between grout diameter and bond capacity as well as bonded length and bond capacity. From the data studied and presented above, it appears that there is a correlation between weathering and anchor bond stress. We propose that this can be used to develop presumptive bond strength in the absence of other data. The author acknowledges that with more data, the trend may change. Quality logging of the target founding strata at the appropriate depth and understanding of the geological model is required to be able to utilise the correlation. Other factors, such as drilling method, also need to be taken into account.

Because anchor load testing is relatively cheap (compared to, say, pile load testing), it is regularly used, which allows slightly more optimistic assumptions to be made at the design stage. FHWA GEC 007 (2015) recommends two verification tests (often called “sacrificial” tests) within each soil strata and production tests on 5% of production anchors. Depending on the size of the project and complexity of ground the number of sacrificial tests may vary, however the values obtained from different tests will help the designer in understanding the strength of ground and optimising the design.

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