Anchor load test results in Wellington soil and rock

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Keywords: anchor, load test, bond capacity, stiffness

ABSTRACT

Vertical and horizontal ground anchors are used frequently in Wellington. This study presents summaries of the results of tension tests of ground anchors across 33 sites in Wellington. The study includes ground anchors in soil and in rock, and both sacrificial and production anchor tests. Results of limit bond stress and stiffness are presented for several weathering grades of greywacke rock, and for several categories of soil. Suggestions for preliminary design values of limit bond stress and stiffness are provided for several soil and rock categories.

1 INTRODUCTION

Vertical ground anchors are used frequently in the Wellington region to increase the structural capacity of existing buildings or to support new buildings. Horizontal ground anchors are used to provide support to retaining walls and/or as horizontal support to buildings sited on steep terrain.

Anchors comprise drilled holes, typically of 100mm to 200mm diameter and of 6m to 15m length, comprising a steel bar in their centre, with an annulus of grout. They can be installed with a gravity grout ("drill and drop") technique, whereby the hole is drilled (with or without casing), the bar is installed and the grout is installed, typically from the base via a grout tube. Alternatively, the hole can be drilled with a sacrificial drilling bit on the bar, and a weak grout used during drilling. Once complete, a thick grout is injected into the hollow bar which then flows out through holes in the bar. These are referred to as injection grouted anchors.

The vast majority of the anchors in this study are gravity grouted as this is the most commonly used technique in Wellington. Anchors can be tensioned, or can be left un-tensioned, the latter sometimes referred to as "passive anchors" or "soil nails". This paper makes no distinction between tensioned and un-tensioned, calling both "anchors". Some anchors contain steel tendons, but all the anchors included in this study contained bar only.

2 SCOPE OF STUDY

Load testing of anchors is routinely carried out in Wellington, as the costs are relatively low, and the information obtained is of significant value to the designer. In particular, the designer, knowing that load testing will be carried out, can make a design assumption that is less conservative than if no load testing were planned.

This paper presents a summary of the load tests carried out in tension on anchors installed within the Wellington region, extending from the city's southern suburbs, as far north as Pauatahanui, and as far north-east as central Lower Hutt. 124 tests across 33 sites are included, with the majority of the tests within Wellington's central business district and inner suburbs.

Underlying most of the region is greywacke rock, and this is the natural target stratum for anchoring where it is close to the surface. Overlying the rock on the hills is colluvial soil, typically silt and gravel, which can be an adequate layer for anchoring to low loads. On the flat ground lie deep expanses of alluvial soils, and these often contain dense sand and/or gravel layers which are satisfactory anchoring strata. The load test data presented here cover all the geological units discussed above.

There are typically two general types of load tests carried out – sacrificial and production. Sacrificial tests are carried out on anchors installed solely for the purpose of testing, and the testing continues until either the bond has failed, the steel has reached yield (or near it) or the reaction system has reached capacity. Several cycles of loading are typically applied in sacrificial tests. Production tests are carried out as checks on anchors intended for use in the structure. They typically are tested to a load somewhat above the design load, with few cycles to avoid damaging the bond. Production tests are typically more numerous than sacrificial tests, and therefore make up the majority of tests (about 60%) in this study.

3 TEST RESULTS

Test results are presented in Table 1 for greywacke and in Table 2 for soils. Mean values are given for strength and stiffness, with a lower quartile also provided for sample sizes of 8 or more. For strength, bond stress (i.e. applied load divided by bonded area) and load per bonded length data are provided.

For greywacke, analyses were carried out for each grade of weathering, with a distinct increase in strength and stiffness seen from CW to HW. The data did not display a significant difference in strength between HW, HW/MW and MW, hence the values for these designations are lumped together and presented alongside the separate results for HW and MW. MW did however show a distinct increase in stiffness from HW. The data for HW/MW were too inconclusive to warrant their own data column.

Stiffness values are presented as bulk stiffness – that is, the load divided by the deflection of the bar at the anchor head. Anchor stiffness is a function of both the elastic stretch in the bar and the slip that occurs between the grout and the ground. The data below indicate that the bulk stiffness of anchors increases markedly with increasing ground quality, suggesting that grout to ground slip may be the governing element of overall anchor stiffness.

Table 1: Greywacke parameters

119/212 (8) denotes a lower quartile of 119, a mean of 212 and a sample size of 8. Lower quartile values are only presented for sample sizes of 8 or more.

	CW	CW/HW	HW	MW	Combined HW, HW/MW and MW
Number of sites	2	2	10	3	15
Number of tests	8	4	32	15	56
Range of bonded lengths (m)	3.5 – 4	2 – 3	2 - 8	1 – 14	1 – 14
Average bonded length (m)	3.8	2.75	3.8	7.4	4.8
Range of grout diameters (mm)	100 – 150	100 – 135	100 - 200	100 – 200	100 – 200
Maximum load achieved (kN)	315	439	1500	2200	2200

	CW	CW/HW	HW	MW	Combined HW, HW/MW and MW
Average bond stress achieved (kPa), not necessarily limit stress	119	214	437	329	410
Bond stress at limit (kPa)	-/136 (5)	-/170 (3)	-/459 (6)	NR	269/537 (9)
Bond stress at 25mm displacement (kPa)	-/153 (2)	-/207 (1)	366/515 (10)	-/228 (5)	246/474 (17)
Load per bonded length at limit (kN/m)	-/56 (5)	-/86 (3)	-/194 (6)	NR	128/242 (9)
Load per bonded length at 25mm displacement (kN/m)	-/54 (2)	-/85 (1)	167/244 (10)	-/144 (5)	154/234 (17)
Stiffness (kN/mm)	8/11 (8)	-/19 (3)	23/36 (32)	33/55 (15)	24/43 (56)

For soils, the division into categories was more subjective and several grouping combinations were possible. The groupings presented below represent the most useful and consistent reporting in the author's opinion.

Table 2: Soil parameters

	D-VD gravel and sand	MD-D sand and silty sand	St-VSt silt/clay with some gravel content	F-H Silt
Number of sites	6	3	1	7
Number of tests	22	4	15	13
Range of bonded lengths (m)	4.5 – 10.1	6.0 – 12.5	3 – 5	2 – 7
Average bonded length (m)	6.7	10.75	4	5.3
Range of grout diameters (mm)	100 – 220	150 – 200	100	75 – 150
Maximum load achieved (kN)	2700	730	575	272
Average bond stress achieved (kPa), not necessarily limit stress	210	123	218	79
Bond stress at limit (kPa)	-/303 (3)	NA	-/271 (1)	-/79 (5)
Bond stress at 25mm displacement (kPa)	119/212 (8)	-/98 (2)	-/363 (5)	-/56 (5)
Load per bonded length at limit (kN/m)	-/167 (3)	NA	-/85 (1)	-/31 (5)
Load per bonded length at 25mm displacement (kN/m)	75/115 (8)	-/54 (2)	-/114 (5)	-/20 (5)
Stiffness (kN/mm)	29/36 (21)	-/29 (4)	13/16 (15)	4/7 (11)

Notes on the tables:

CW – Completely weathered; HW – Highly weathered; MW – Moderately weathered
VD – Very dense; D – Dense; MD – Medium Dense
F – Firm; St – Stiff; VSt – Very stiff; H – Hard
NR – Not reliable, there were only two tests in MW that reached their limit, and they were significantly different values.
NA – Not applicable – none of the tests reached the apparent bond limit.
Stiffness was calculated as (max load) / (max deflection), unless the deflection exceeded 25mm, in which case it was calculated as (load at 25mm deflection) / 25mm

Most of the groups showed a wide variability in the limit bond stresses. The HW greywacke group showed the most variability, with limit bond stresses varying from 51 to 1009 kPa. The second lowest limit value was 170 kPa. It is suspected that the two lowest values are both from errors during drilling or grouting, rather than variability in the ground conditions. The range in anchor stiffness values within groups was similarly wide.

One site (on The Terrace) represents 60% of the data for highly weathered greywacke 54% of the data for all greywacke. There is therefore a possible over-reliance on the one site, although the values from this site do not differ greatly from typical numbers for other sites.

4 COMPARISON WITH MEMORIAL PARK DATA

In a separate study, Christie et al (2015) reported on sacrificial anchor load tests for Memorial Park in Wellington. The programme included load tests on ten injection grouted anchors and five gravity grouted anchors, with tests carried out in soil and rock. Grout diameters ranged from 100 – 180 mm.

All rock anchors extended into CW greywacke, with peak bond stress values of 172 – 283 kPa reported, somewhat higher than the mean limit bond stress values in Table 1. Peak bond stresses in soils varied from 130 kPa in Upper Pleistocene Alluvium (clayey gravelly silt), 155 – 292 kPa in Lower Pleistocene Alluvium (clay silt sand and gravel mixtures) and 110 – 183 kPa in Colluvium / Residual Soil (clay silt sand and gravel mixtures).

Christie et al do not specifically report the densities of the various soil layers, so comparison with the figures in Table 2 is challenging. The average peak bond stress value reported in soil by Christie is 181 kPa, with all soil layers containing gravels, which shows a degree of consistently with the D-VD gravel and sand column of Table 2.

5 COMPARISON OF INJECTION GROUTED VERSUS GRAVITY GROUTED

Christie et al reported results on injection grouted and gravity grouted anchors in Lower Pleistocene Alluvium at Memorial Park. Injection grouted anchors had a peak bond stress of 155 to 260 kPa, and gravity grouted anchors a peak bond stress of 196 to 292 kPa, indicating that gravity grouted anchors had a slightly higher strength.

At a site in central Wellington, forming part of the current study, with the bonded length in MD – VD sands and gravels, an injection grouted anchor (described by the contractor as "installed under grout flush") had a peak bond stress of 360 kPa with a stiffness of 29 kN/mm. The limit bond strength was not clearly reached. A gravity grouted anchor at the same site, but installed by a different contractor, reached limit bond stress at 185 kPa, with a stiffness of 20 kN/mm. Thus, at this site, the injection grouted anchors had a much greater strength and slightly greater stiffness, although this could be at least partially a reflection of the difference in technique between contractors.

6 CONCLUSIONS

6.1 Preliminary bond capacities

Taking into account the results of this study, and that of Christie et al, the following tentative recommendations for preliminary design of ground anchors in Wellington are presented. As the variability amongst the soil or rock categories is substantial, load testing should be carried out on site to confirm the design values. When using these (or any) values, increases in total anchor strength for bonded lengths beyond 6m or 8m may not be achieved.

The values chosen are intended to represent a range approximating the lower quartile to the mean. It is considered that designing for the lowest recorded value in each group is unreasonably conservative, as these may be a result of drilling or grouting errors. Such errors could of course occur in any given job, but it is hoped that any such errors are detected by project quality assurance, in particular load testing on production anchors.

Table 3: Suggested preliminary bond capacities

Material	Preliminary ultimate bond capacity (kPa)
CW greywacke	110 – 150
HW/MW greywacke	300 – 500
D-VD gravel and sand	150 – 230
MD-D sand and silty sand	90 – 150
F-H silt	50 – 80

6.2 Stiffness

In some cases, particularly in the strengthening of existing structures containing brittle elements, deflection may the governing criterion in design. For example, deflections of more than 10mm or 15mm may not be acceptable, in which case an understanding of stiffness of proposed anchors becomes important. In such cases, use of the stiffness values in the bottom row of Tables 1 and 2 could be considered for preliminary design. As discussed in Section 3, the values reported are bulk stiffness values, so could be too high if used for anchors with long unbonded lengths.

As nearly all anchors in the study returned a stiffness value, there is more data for stiffness than for strength, and hence the lower quartiles and averages in Tables 1 and 2 are considered likely to be more reliable. However, the range within categories is high, so stiffness values should also be checked by site-specific load testing.

6.3 Injection Grouting

On the small sample size in the study and presented by Christie et al, it is inconclusive as to whether injection grouting provides a stronger bond than gravity grouting in Wellington soils.

6.4 New Zealand Geotechnical Database

The knowledge of bond capacity within the geotechnical community could be advanced by allowing anchor load test results to be uploaded to the New Zealand Geotechnical Database. It is suggested that uploaded information should include a log of the ground conditions, whether the anchor was horizontal or vertical, the steel used, the free length, the bonded length, the grout diameter and a table showing the load cycles, with deflections and duration of load at each load increment.

7 ACKNOWLEDGEMENTS

Thanks to my colleagues Ollie Van Rooyen and Neil Charters for their reviews of the text.

REFERENCES

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