

Observation of horizontal movement of a vertical soil nail retaining wall in firm to very stiff soil

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ABSTRACT

Soil nailing is a common type of construction for retaining walls. For retaining wall structures with “passive” nails, mobilisation of the nails is required in order to retain the ground. An approximately 400 m long vertical soil nail retaining wall of up to 7.5 m height has recently been completed at the NZ Transport Agency’s Waterview Connection Project in Auckland, New Zealand. The soil nails comprise inclined glass-fibre reinforced plastic (GRP) bars, drilled and grouted in predominantly firm to very stiff Tauranga Group alluvium and East Coast Bays Formation residual soil. The nails are connected to a vertical reinforced shotcrete facing, constructed in a top-down sequence. The wall and retained ground surface have been monitored for movements during and after construction using survey markers and in-ground inclinometers. This paper presents the results of the monitoring, including observation of movement associated with soil shrink and swell. The paper also discusses how the results are compared with the design prediction, as well as movements observed from bored pile retaining walls of similar retained height and ground condition in other parts of the project.

1 INTRODUCTION

A new retaining wall has recently been completed along the southern edge of the recently re-aligned Great North Road westbound off-ramp at the NZ Transport Agency’s Waterview Connection Project in Auckland, New Zealand. The Great North Road westbound off-ramp was required to be re-aligned to allow for a geometrically acceptable connection to be established between the existing State Highway 16 (SH 16) and the new Great North Road Interchange. The re-alignment works involved removal of the existing cantilevered post and panel retaining wall, and the excavation and construction of a new retaining wall to support the new alignment.

The new retaining wall consists of three types of wall structure:

- 1) Cantilevered reinforced concrete bored pile wall structure, which forms about twenty percent of the retaining wall, mainly within the eastern section.
- 2) Carrington Road overbridge retention, which is a retention system provided by the existing Carrington Road bridge south abutment columns.
- 3) Soil nail wall, which makes up the majority of the retaining wall and the focus of this paper.

Figure 1 below shows the aerial view of the completed retaining wall.



Figure 1: Aerial view of the Great North Road westbound off-ramp new retaining wall

The soil nail wall structure was monitored for movement, more extensively than the other wall structure types, during and after construction. This was because, besides the soil nail wall forming the majority of the retaining wall, the “passive” nails within the wall structure are required to mobilise to achieve the resistance required to retain the ground. Therefore, it was essential to monitor the soil nail wall movements to confirm that the wall has achieved the intended performance as predicted in the design.

This paper focuses on the results of the soil nail retaining wall monitoring results, in particular with respect to the wall horizontal movements, and provides discussion of the observations made from the monitoring outcome.

2 SOIL NAIL RETAINING WALL DESCRIPTION

The soil nail retaining wall section is approximately 400 m long in total; approximately 260 m long to the west of the Carrington overbridge and 140 m long to the east of the Carrington overbridge. The western soil nail wall has a maximum retained height of approximately 7.5m, and the eastern soil nail wall has a maximum retained height of 3.8 m. The nails comprise BluGeo Powerthread K60 glass-fibre reinforced plastic (GRP) 25 mm diameter solid bar, with associated glass-fibre nail plates, nuts and stainless steel couplers. The nail lengths vary from 5 m to 15 m long and the spacings vary from 0.8 m to 1.3 m depending on the ground condition and the retained height. The nails are placed and grouted into 150 mm diameter holes on a triangular grid.

The construction of the soil nail retaining wall was undertaken in a top-down sequence. The excavation and nail installation were carried out row by row, with the excavated face and nail heads shotcreted immediately upon completing the nail installation on each row. Following completion of the shotcrete and excavation works for the entire retaining wall, precast concrete panels were placed in front of the completed retaining wall. Bored drains, strip drains and weep holes were also installed within the retaining wall to maintain a drained retaining wall condition.

One of the typical sections of the soil nail retaining wall is illustrated in Figure 2 below.

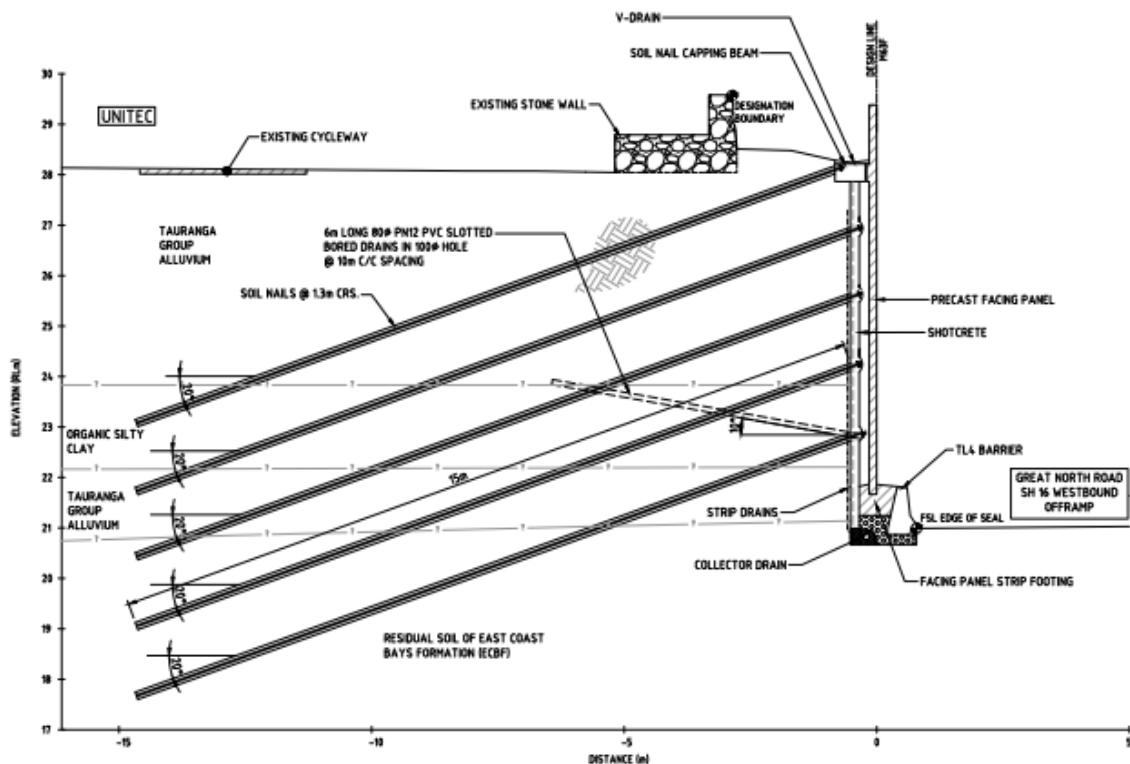


Figure 2: A typical section of soil nail retaining wall with 15 m long nails at 1.3 m spacing

3 GEOLOGY AND GEOTECHNICAL DESIGN PARAMETERS

The site is generally underlain by Tauranga Group alluvium ('alluvium') overlying East Coast Bays Formation (ECBF) residual soil ('residual soil'). The alluvium layer is approximately 5 m thick at the western end of the retaining wall increasing to about 10 m thick at the eastern end of the retaining wall. It generally comprises stiff, silty clay and clayey silt. A layer of firm silty clay with some organics of about 1 to 2 m thickness was also identified within the alluvium. The alluvium was assessed to be overconsolidated with an over consolidation ratio (OCR) of approximately 2. The residual soil is typically a stiff to very stiff clayey silt.

The geotechnical design parameters for the retaining wall design were developed and assessed based on in situ testing, laboratory testing and back analysis of historical surficial slope movement. The following parameters were adopted for the alluvium and the residual soil:

Table 1: Geotechnical design parameters adopted in the retaining wall design

Geological Unit	Unit Weight (kN/m ³)	Effective cohesion (kPa)	Effective friction angle (degrees)	Drained Young's Modulus, E' (MPa)
Tauranga Group Alluvium – stiff silty clay or clayey silt	18.5	5	29	15
Tauranga Group Alluvium – firm clay with organics	17	3	26	10
Residual ECBF soil	18.5	5	30	20

4 ASSESSMENT OF SOIL NAIL WALL MOVEMENT DURING DESIGN

During the design stage, the horizontal movements of the soil nail retaining wall were assessed using the following methods:

- 1) An empirical correlation from Clouterre (1991) as recommended by CIRIA C637 (2005) guideline; and
- 2) A finite element analysis using the computer software SIGMA/W.

Using the Clouterre (1991) empirical correlation, it was calculated that the retaining wall could move up to 25 mm horizontally. However, the finite element analysis calculated a horizontal movement of up to 100 mm at the end of construction, which is significantly greater than the Clouterre (1991) approach. Figure 3 below shows a plot of the calculated horizontal displacement along the retained height of the soil nail retaining wall. The plot was produced from the finite element analysis which was carried out at the assessed critical location.

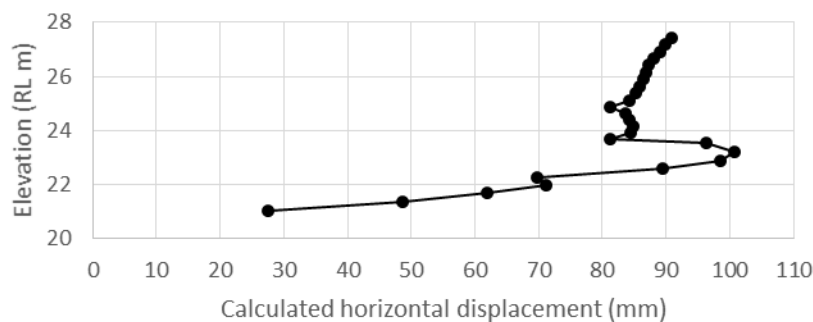


Figure 3: Plot of the calculated horizontal displacement of the soil nail retaining wall from the SIGMA/W analysis at the assessed critical location

It was also assessed in the plot above that the maximum horizontal movement could occur at the wall mid-height (i.e. bulging of the wall). In the case of Figure 3, the maximum horizontal movement was assessed to be influenced by the organic silty clay layer.

5 MONITORING INSTRUMENTS

During and after construction, the soil nail retaining wall was monitored for movements. The following instrumentation was installed on the retaining wall or within close proximity to the retaining wall:

- 1) Three in-ground inclinometers:
 - a. Two inclinometers were located at the section of the soil nail retaining wall to the west of the Carrington Road overbridge. The inclinometers were installed approximately 2 m upslope of the retaining wall design line prior to construction of the wall. One inclinometer was situated at the assessed critical location. The other one was situated at the location of the highest retained height. It was assessed that the critical location was not at the location of the highest retained height, but was rather driven by the underlying ground condition.
 - b. One inclinometer was located at the section of the soil nail retaining wall to the east of the Carrington Road overbridge, approximately 3 m upslope of the retaining wall design line. The inclinometer was a pre-existing instrument, which was installed when the cantilevered post and panel retaining wall was constructed

in the early 1990's. Following a check by an instrumentation technician, it was found that the instrument was still functioning. Therefore, it was decided to utilise the pre-existing inclinometer to monitor the eastern section of the soil nail retaining wall.

- 2) Approximately seventy survey markers were installed on the soil nail retaining wall as well as on the ground above the retaining wall. The soil nail retaining wall survey markers were installed on the capping beam at the top of the wall and on the surface of the shotcrete at approximately mid-height. They were spaced at approximately 20 m along the wall alignment. When the facing panels were installed, the survey markers located on the shotcrete were moved to the surface of the facing panels, placed at similar height. Additionally, survey markers were also placed on the ground surface of the park in the UNITEC complex above the western section of the soil nail retaining wall. The survey markers were installed in three rows at approximately 5 m, 10 m and 20 m away from the retaining wall capping beam. The survey markers were spaced at approximately 5 m in the direction parallel to the wall alignment within each row.

The monitoring was carried out from the start of the construction and continued for approximately 2.5 years. The inclinometer readings were generally taken weekly for the first 2 years, and then reduced to bi-weekly in the last 6 months of monitoring period. The survey marker readings were generally taken weekly for most of the monitoring period. However, not all survey markers were measured for the entire monitoring period. Only the ones that were deemed critical were kept and measured weekly until the monitoring period was concluded.

6 OBSERVED MOVEMENTS FROM THE MONITORING RESULTS

The measured movements of the soil nail retaining wall from the inclinometer are summarised in plots presented in Figure 4 and 5 below. The presented measured movements were taken from the inclinometer located at the assessed critical location of the retaining wall, as it showed the most movements among the installed inclinometers.

Figure 4 below provides the measured horizontal movement along the wall depth from the reading of the inclinometer on the last day of the monitoring on 23 November 2016.

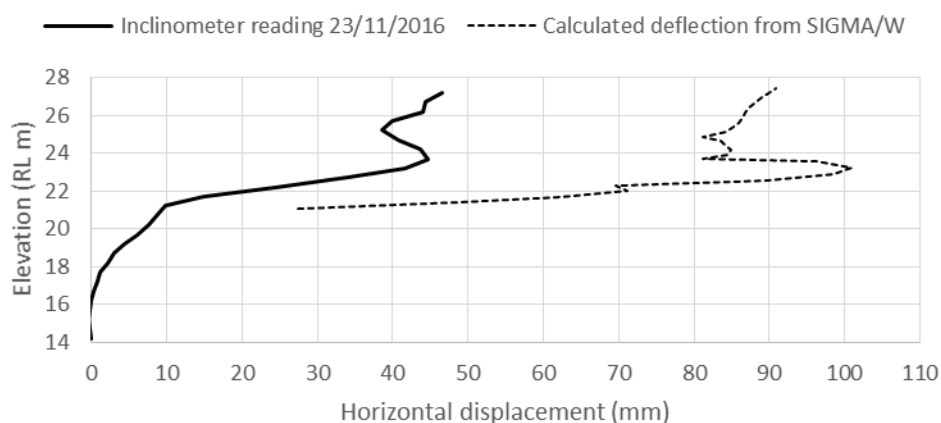


Figure 4: Inclinometer reading on 23 November 2016 at the assessed critical location

It can be observed from the inclinometer plot above that the measured deflection shape is generally in agreement with the predicted deflection from the finite element analysis.

Figure 5 below shows the readings from the inclinometer located at the assessed critical location, which were taken from the start of the wall construction to the conclusion of the inclinometer monitoring period on 23 November 2016. The plot is showing readings at three different elevations, RL 27.2 m which is the top of the wall, RL 23.2 m which is at the location of the organic silty clay layer and RL 21.2 m which is the bottom of the wall.

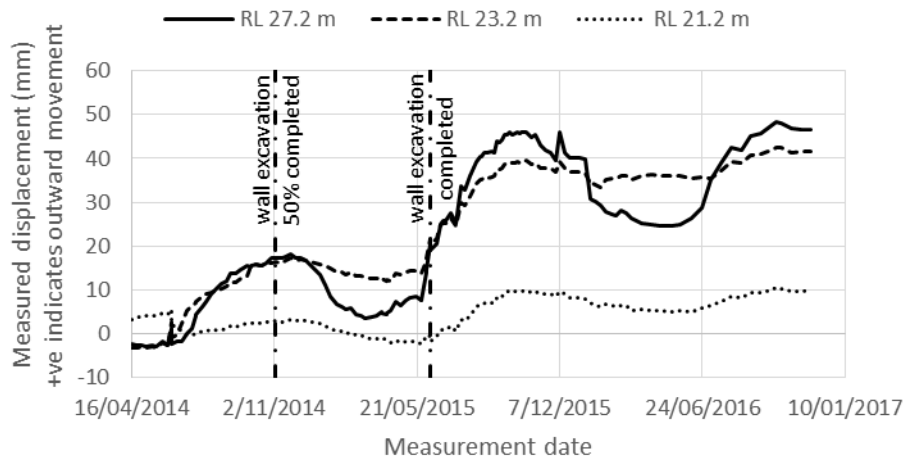


Figure 5: Inclinometer readings at the assessed critical location

Figure 6 below provides a summary of the horizontal movement readings from selected wall capping beam survey markers, which are located over the highest section and the assessed critical location of the soil nail retaining wall. The readings were taken from the start of the wall excavation to the conclusion of the survey monitoring period on 28 November 2016. It should be noted that the wall movement readings presented in Figure 6 below also contain a few inferred readings due to the survey markers being destroyed and re-established a number of times during construction. As observed in the plot below, the survey marker readings were in general agreement with the inclinometer readings.

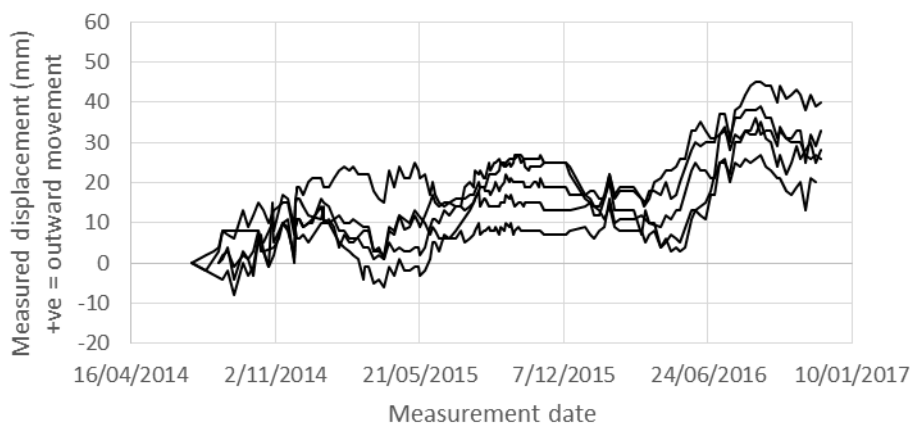


Figure 6: Summary of the top of wall survey marker readings at the assessed critical location

Survey markers located at the mid-height of wall were not observed to pick up as much movement compared to the top of the wall ones during the monitoring period.

Both the inclinometer and survey marker readings show that the magnitude of the wall horizontal movement calculated by the finite element analysis appears to be overestimated. This may have been influenced by a rather conservative soil stiffness parameters used for the analysis. However, Clouterre (1991) approach appears to have underestimated the movement magnitude. Therefore, careful consideration should be given when assessing the wall movements, in particular if there is any structure or object that is sensitive to movement above the wall. In the case of the Great North Road westbound off-ramp retaining wall, no sensitive structure nor object is present above the wall. Nonetheless, it is still essential to assess the wall movement to provide a measure on whether the soil nail retaining wall has or has not performed as expected on the field.

Furthermore, both the inclinometer and survey marker readings on Figure 5 and 6 also show that the soil nail retaining wall is responding to the seasonal shrink and swell movement of the soil. Up to 30 mm of horizontal movement was observed between the ‘trough’ (dry period) and the ‘peak’ (wet period). The inclinometer readings on Figure 5 also suggest the soil shrink-swell effect is mainly experienced by the soil in the near surface. No soil shrink-swell movement was observed in the survey markers located at the mid-height of wall. These findings show that designer should be mindful of the effect of soil shrink-swell to the soil nail retaining wall.

As an additional note, the soil shrink and swell movements were also picked up by the survey markers installed on the park ground inside the UNITEC complex. Figure 7 below provides a summary of the observed vertical movements of the ground surface due to the seasonal shrink and swell of soil. The survey makers observed up to 75 mm of settlement during the dry period.

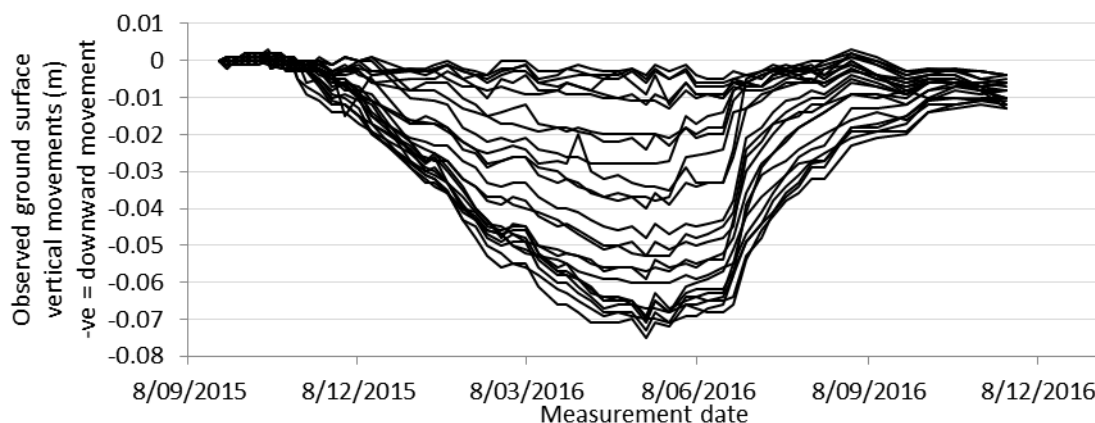


Figure 7: Recorded vertical movement of the ground surface in the park inside the UNITEC complex

7 COMPARISON WITH BORED PILE RETAINING WALL

Directly opposite to the Great North Road westbound off-ramp retaining wall, along the northern edge of the SH 16 eastbound, a new retaining wall (‘north retaining wall’) has also recently been completed as part of the Waterview Connection Project. The north retaining wall has a similar retained height, and was constructed in a similar geological condition to the Great North Road westbound off-ramp retaining wall. But the majority of the north retaining wall was a bored pile retaining wall. A part of the bored pile retaining wall was cantilevered, and another part was tied-back with ground anchors. As a comparison, Figure 8 below provides a summary of the horizontal movement readings from survey markers installed on the retaining wall. It can be observed from the plots that the bored pile retaining wall did not experience as much horizontal movement or the soil shrink-swell effect comparatively to the soil nail retaining wall.

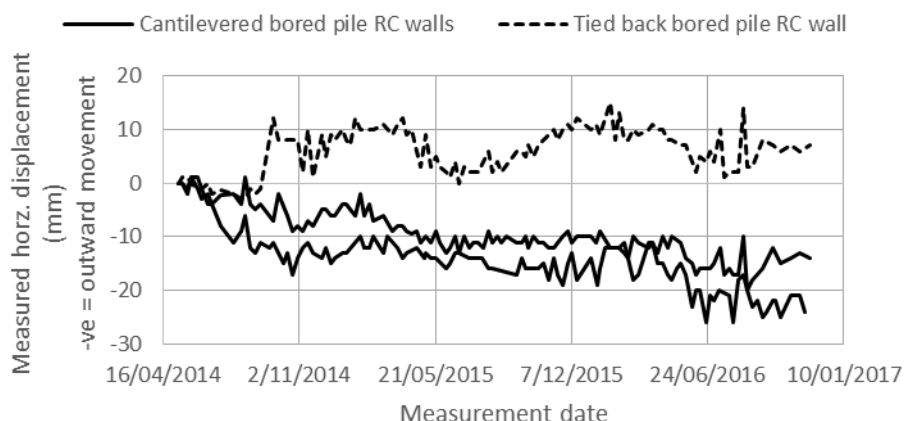


Figure 8: Survey marker readings from the new bored pile retaining wall along the northern edge of the SH 16 eastbound

8 CONCLUSION

Soil nail retaining wall relies on the mobilisation of the “passive” nails to develop the resisting forces for retaining the ground behind it. Therefore, it is recommended that the movement of the soil nail retaining wall be assessed during the design stage to provide a measure on whether the soil nail retaining wall has or has not performed as expected on the field. It may also be essential to assess the movements using more than one approach, e.g. an empirical correlation approach accompanied by finite element or finite difference analyses.

Soil nail retaining walls can also be subject to seasonal soil shrink and swell movements. In the case of the Great North Road westbound off-ramp retaining wall, where the site is generally underlain by Tauranga Group alluvium overlying East Coast Bays Formation (ECBF) residual soil, up to 30 mm of horizontal movement was observed between the ‘trough’ (dry period) and ‘peak’ (wet period).

For retaining walls with structures or objects that are sensitive to movement above the wall, it may be wise that other types of retaining wall, such as bored pile retaining wall, be considered to allow for better control to movements.

9 ACKNOWLEDGEMENTS

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