WHAT WE HAVE LEARNED ABOUT MICROPILE BEHAVIOUR FROM FIELD INSTRUMENTATION

By Daniela Ramirez

Abstract

This paper describes the monitoring of eight statically loaded micropiles that were each instrumented with a Contractometer. A Contractometer is an instrument that measures relative movement along the length of the micropile so that strain can be calculated. The data obtained from 8 cases using this instrument is presented here. The primary objective of this paper is to evaluate the measured distribution of strain in micropiles during static loading in order to gain insight into where micropiles develop their axial capacity. It was found that there was a difference between contractometer readings and dial gauge readings. This difference may be attributed to the micropile moving as a whole unit into the soil mass, and the compression of the soil below the micropile. Secondary factors affecting this difference are the accuracy of the Contractometer readings and other experimental errors. It was also found that negligible load transfer occurred along the cased length as the measured strain was generally constant and for some of the micropiles in rock, Contractometer measurements indicated that there was significant strain near the pile tip.

Introduction

Micropile soil-to-grout design bond stresses are typically verified by load testing prior to the installation of production micropiles. By measuring the distribution of strain in micropiles during loading, it is possible to interpret the load shedding characteristics which may improve design methods and installation procedures.

Most commonly, piles are tested by measuring pile-head deflections with a dial gauge during loading. This, however, provides little detail into how load is shed along the length of the micropile. This paper presents eight (8) cases where micropiles were instrumented with a Contractometer and load tested in compression. By embedding a Contractometer into each micropile, it is possible to evaluate the relative contribution of structural compression of the pile (elastic and/or plastic) to the total pile head deflection.

During each load test, internal strain measurements were obtained using a Contractometer, which is described below. The pile head deflection was measured using a conventional dial gauge. The following sections briefly describe: (i) the Contractometer, (ii) the methodology followed for compression tests and during interpretation of the test results, and (iii) pile behaviour during each load test.

Contractometer

A Contractometer measures relative movement between 6 nodes along the instrument (see Fig 1). The instrument acts like a tell-tale system. The custom spaced nodes are

Daniela Ramirez, P. Eng., Isherwood Geostructural Engineers, Mississauga, Ontario, Canada
daniela@isherwood.to

made of aluminum and each node is connected to a fiberglass rod that runs from the node to the pile head. The fiberglass rods are encased in HDPE tubing to allow them to move freely and to protect the instrument from damage during high pressure grouting. To measure the relative movement of each node, the fiberglass rods are connected to a potentiometer. By measuring displacement of the fiberglass rods at the pile head using the potentiometers, the relative displacement of nodes embedded in the pile grout can be obtained. A wide range of potentiometers are available ranging from 32 mm to 190 mm in length. The instrument accuracy is better than 1.0% of potentiometer length. Data can be captured during load tests using either a hand-held reader, or automated data logger. As noted above, Figure 1 shows a schematic of the Contractometer.

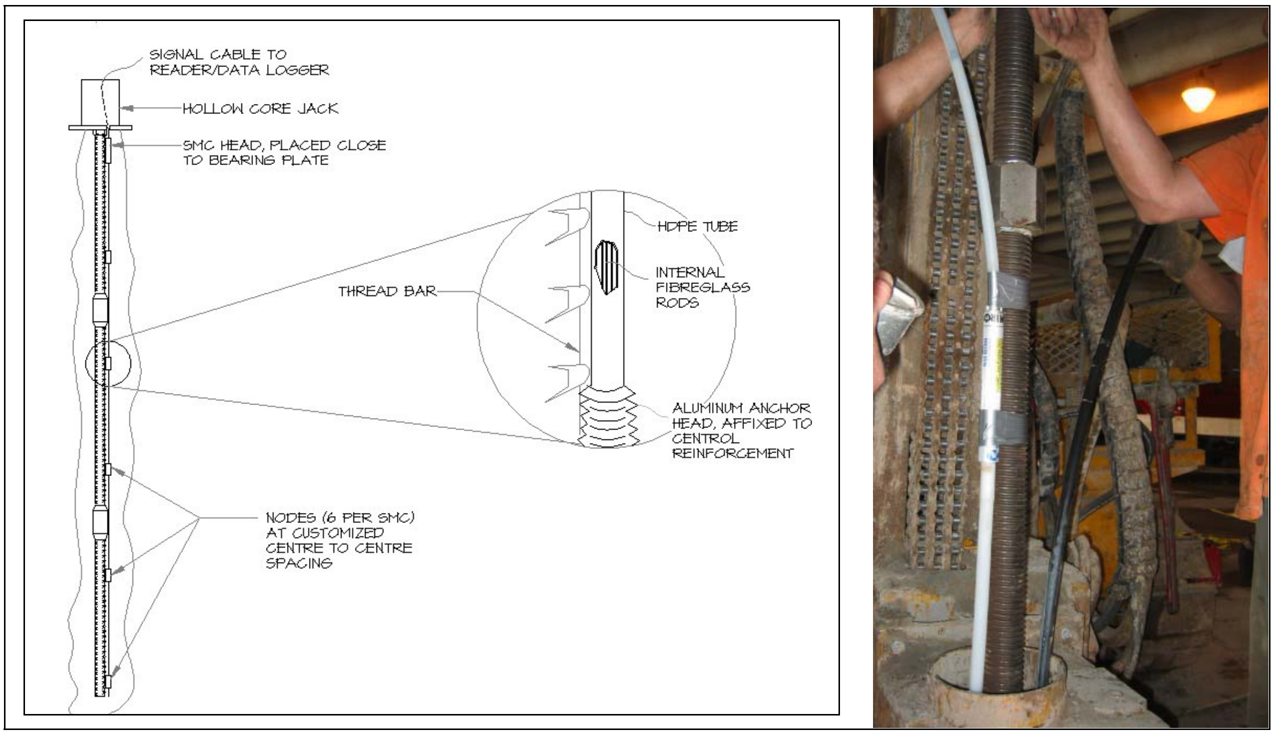

Figure 1. Schematic Representation of a Contractometer and Actual installed Contractometer

Methodology

The pile load tests reported below were generally conducted according to ASTM 1183. For each test, the axial load was applied in 8 equal increments up to two times the design load for the pile. The duration of each load increment varied but was generally 10 minutes. The plotted graphs take into account the deflections after the creep was measured; for example, if the movement before creep was 10 mm and after creep was 12 mm the latter value was used in the load deflection plot.

For a given load test, the internal distribution of strain in the micropile was calculated based on the relative displacement of Contractometer nodes divided by the node spacing. The measured strains are plotted in the following section for each micropile load case. In addition to the measured strain, two structural strain limits were obtained: one for the yield strain of the steel (casing and/or bar) and one for the crushing strain of the grout. In the figures presented below, the measured strain in each micropile is compared with structural strain limits to help with interpreting the pile performance. For the steel components in each pile, the yield strain was estimated by dividing the yield stress of the steel by the elastic modulus of steel, which was assumed to be 200Gpa. Consequently, the yield strain plotted below for each pile takes into account the type of steel used in its construction. For the grout, the crushing strain was assumed to be 15$\mu\varepsilon$ - 22$\mu\varepsilon$ based on unconfined compression tests.

Case 1 – Tremie grouted and pressure grouted micropile in Dense Silt

Case 1 involved a micropile installed in dense silt near a river. The micropile was tremie grouted and pressure grouted below the casing which was retracted in five steps: 3m per step. The pile comprised steel casing and grout from the ground surface to a depth of 7m followed by a grouted section from 7m to 19m. A 3168 mm^2 steel bar was centered in the pile extending from the pile head to the pile toe or tip. The pile was load to a maximum load of 2042 kN at which point one of the tension micropiles (providing reaction during the test) failed and the test was stopped.

Figure 2 shows measured pile compression vs. depth in addition to the calculated distribution of strain along the length of the pile for each load level. In this case, the accuracy of the Contractometer displacement at the nodes was 1.2mm since the potentiometers were 127 mm long.

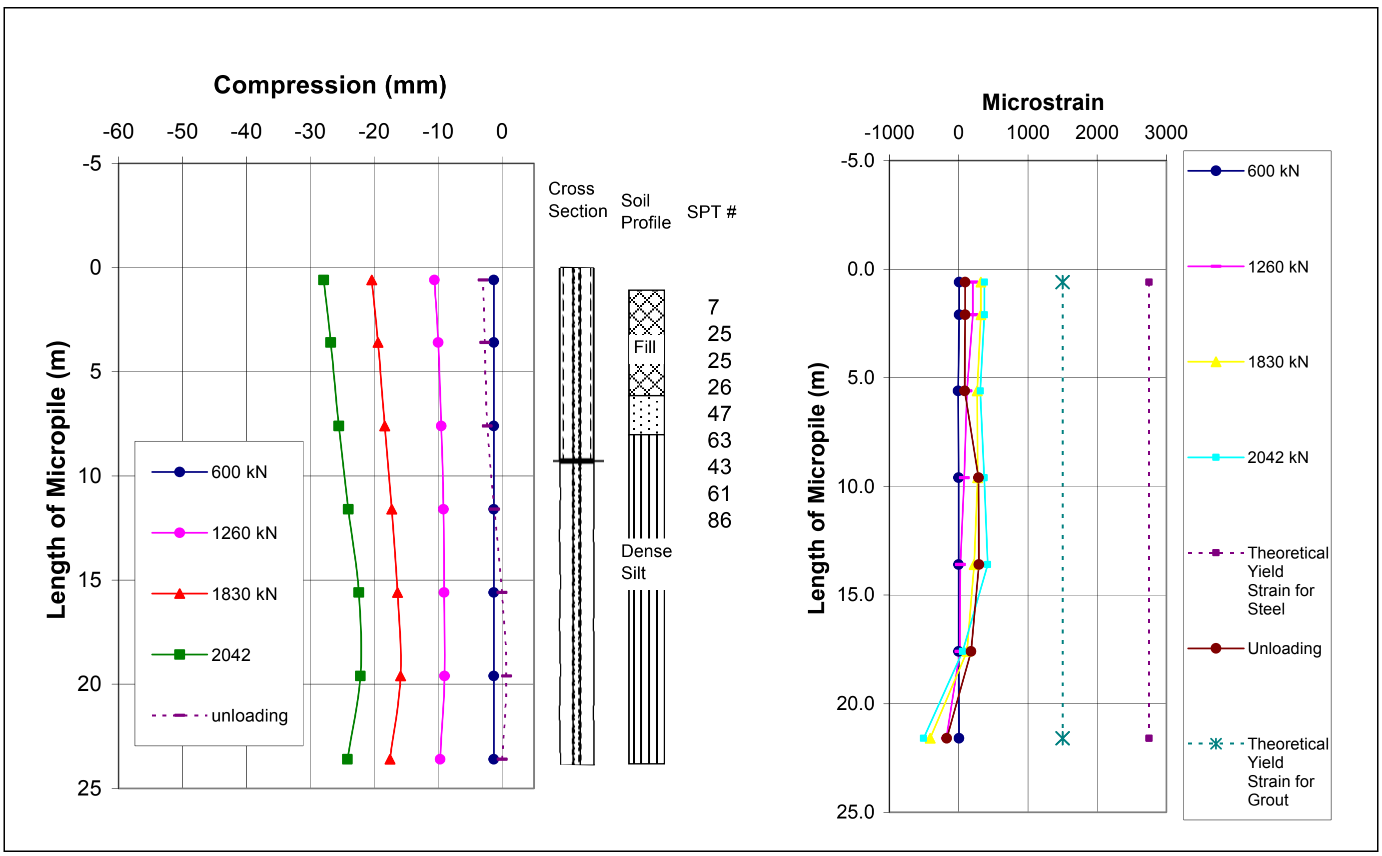

Figure 2. Case I Micropile compression vs. depth plot and strain vs. depth plot.

Figure 3 shows the load vs. movement plot. Two lines are shown in this plot the dial gauge readings and the contractometer top node readings. It can be seen that at a load of 1830kN the measured pile head deflection was 25 mm while the structural compression of the pile based on Contractometer measurements was only 5mm. The difference between both of these measurements could be due to either the micropile moving as a whole unit into the soil mass (slip), compression of the soil below the micropile, compression between the top node of the Contractometer and the dial gauge reading or/and the accuracy of the Contractometer readings. In this case, the difference between the structural compression of the pile and the pile head deflection is due primarily to the micropile moving a whole unit into the soil based on the load versus deflection behaviour of the pile.

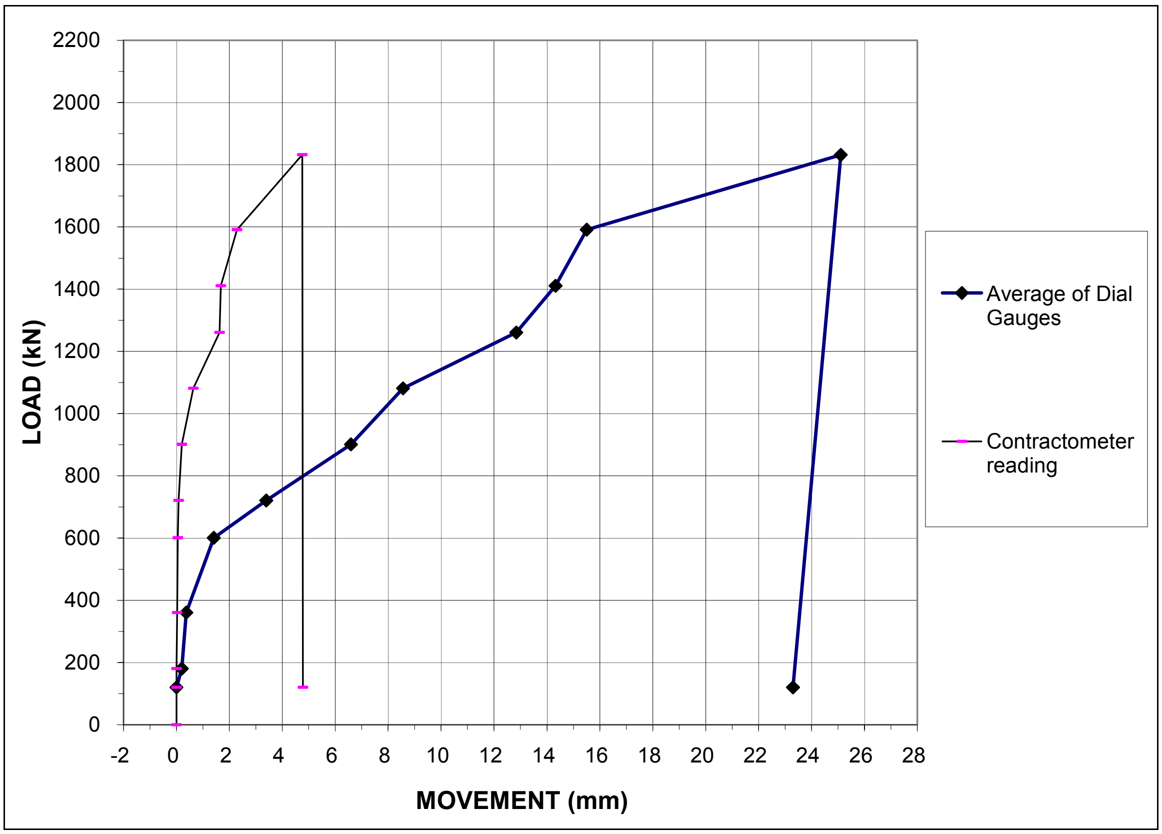

Figure 3. Case I micropile Load movement Plot

On the right hand side of Fig 2, the strain vs. depth plot indicates that there is no load shedding along the micropile until a depth of about 15 m where the strain begins to decrease. Given the constant strain in the cased portion of the pile, it appears that this section of the pile behaved like a free column. Lastly, the Contractometer readings for this micropile indicate tension near the toe. This is not possible in a compression element unless there is significant bending of the pile near its tip. However, the tension is more likely due to the resolution of the Contractometer which in this case is only 1.2mm.

Comparing the measured strain and structural yield strains, it can be seen that the load and consequent strain in the micropile is well below the structural limits of the pile. Therefore, it is concluded that the geotechnical capacity of the micropile rather than the structural capacity is governing the axial resistance.

Based on this pile load test, it was decided to try to increase the soil to grout bond by post grouting. As shown below for a second test conducted at this site, the bond adhesion and hence the capacity of the micropile was increased by post grouting.

Case 2-Tremie grouted, pressure grouted and post grouted micropile is dense sand with cobbles

For Case 2, a micropile was embedded in a pervious layer of sand with cobbles adjacent to the same river in Case 1. This micropile was tremie grouted, pressure grouted and post grouted. The pile was 16m long with an eight (8) m long casing from the surface and a concentric steel bar (3168 mm^2) running along the entire length of the pile. Figure 4 shows the measured pile compression and axial strain versus depth for the pile for axial loads up to 3000kN: 2.5 times the design load. The accuracy of the Contractometer was 1.2mm (same as in Case 1).

Figure 5 shows the load vs. movement. This figure indicates that at a 3000kN load, the measured pile head deflection was approximately 25 mm while the Contractometer measured 16 mm of pile compression. The difference between these measurements may be attributed to the micropile moving as a whole unit into the soil mass, and the compression of the soil below the micropile. Some of this difference may also be due to the accuracy of the Contractometer.

Referring to the right hand side of Figure 4, the measured strain immediately below the cased portion of the pile exceeds the yield strain of the steel bar. This indicates plastic compression of the pile beyond a load of 2400 kN. The data also suggests that there is negligible load shedding to the soil along the length of the casing where the strains are essentially constant.

Again, the Contractometer suggests tension in the lowest segment of the micropile; however, the compression over this interval is 1.8 mm which within the accuracy of the instrument. It is interesting to note that this micropile reached its structural limit before the full geotechnical capacity was mobilized. In this case, post grouting has had a significant impact on axial capacity of the pile.

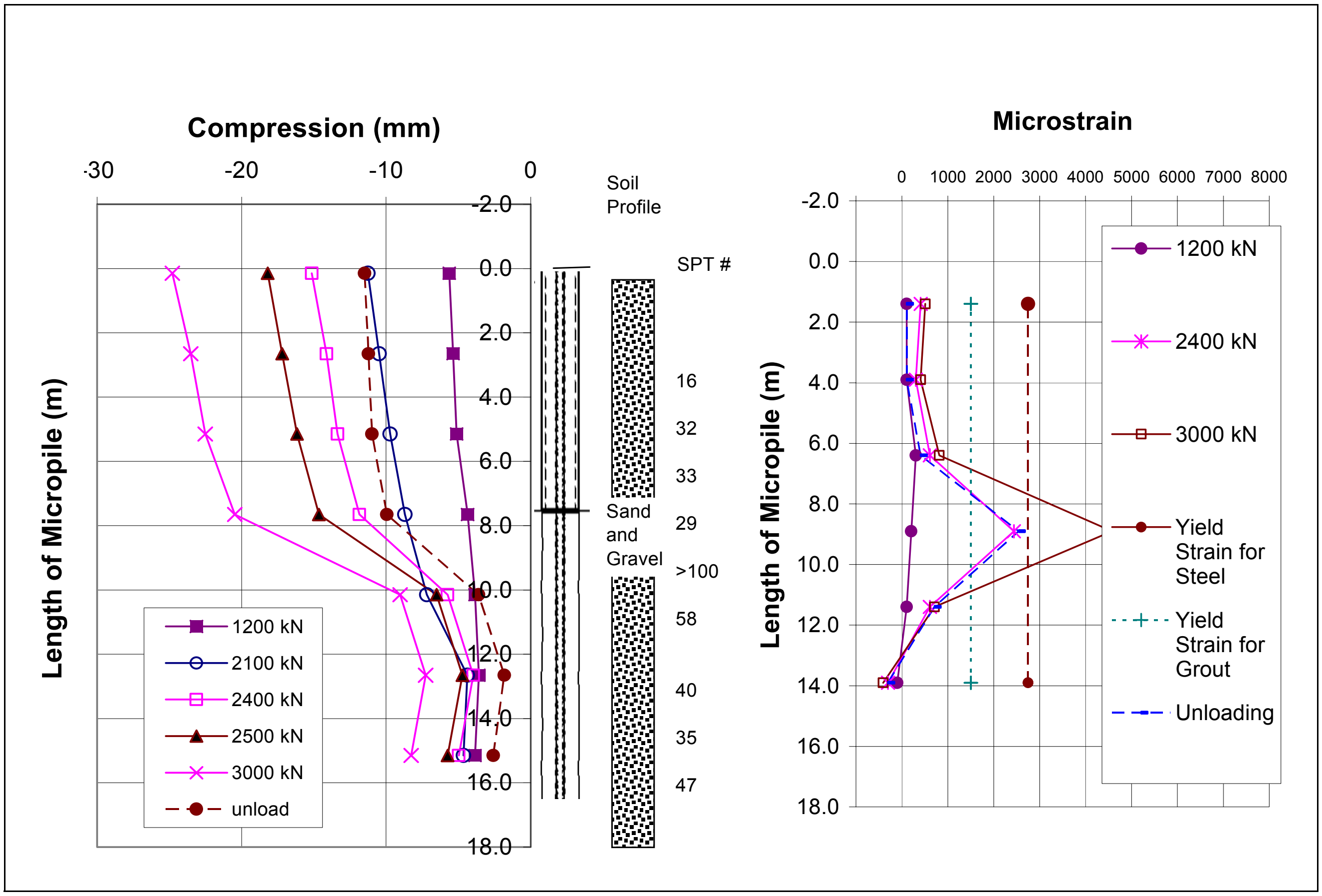

Figure 4. Case 2 Tremie grouted, pressure grouted and post grouted micropile is dense sand and cobbles

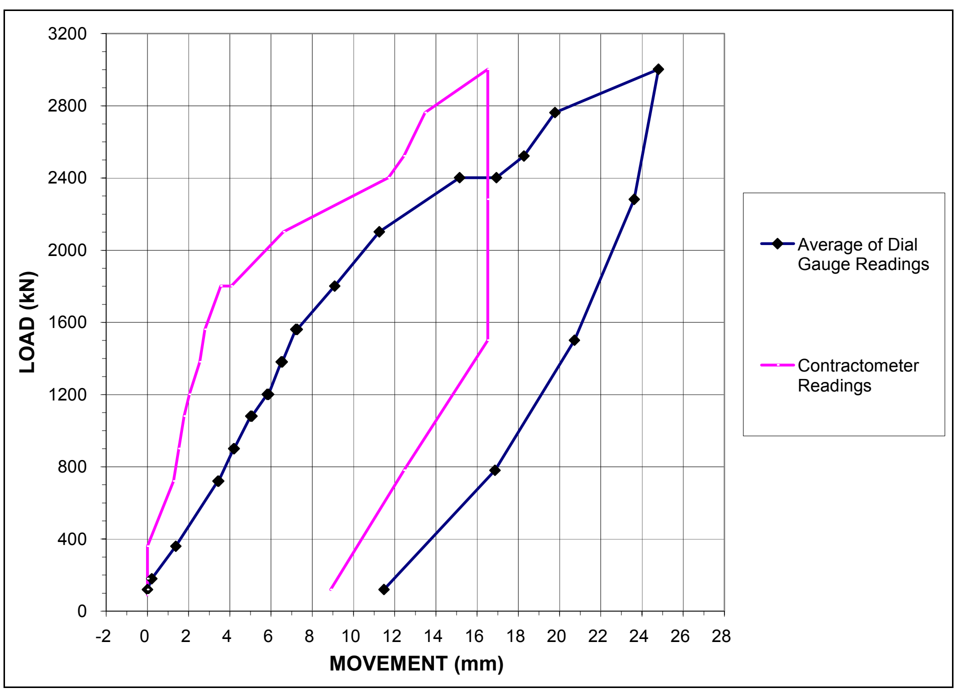

Figure 5. Case 2 Micropile Load vs. Movement Plot

Case 3 - Tremie grouted micropile in glacial till and weathered shale

In Case 3, a micropile was installed in a till layer underlain by weathered shale. The 6.5m long micropile was tremie grouted and was built with a 2.5m long casing from the ground surface and a 3168 mm^2 concentric steel bar from the pile head to the pile toe. This micropile was loaded to 1465 kN where the creep criteria of 2 mm per log cycle time was exceeded. The measured compression vs. depth and strain vs. depth is presented in Figure 6. The accuracy of the Contractometer in this case is 1.2 mm.

At an axial load of 1791kN, the dial gauge at the top of the micropile measured 37 mm while the Contractometer measured 16 mm (Refer to figure 7). Similar to Cases 1 and 2, the difference between these measurements can be attributed to the micropile moving as a unit into the soil mass. This is confirmed by the unloading deformation being almost the same as when the micropile was fully loaded.

Referring to the right side of Figure 6, load shedding to the soil appears to take place in the last 4 m of the micropile as indicated by the strains vs. depth (decreasing strain versus depth). At the end of the micropile, there is high compressive strain which suggests that there is yielding at the tip at a load of 1791 kN. This may be due to end bearing.

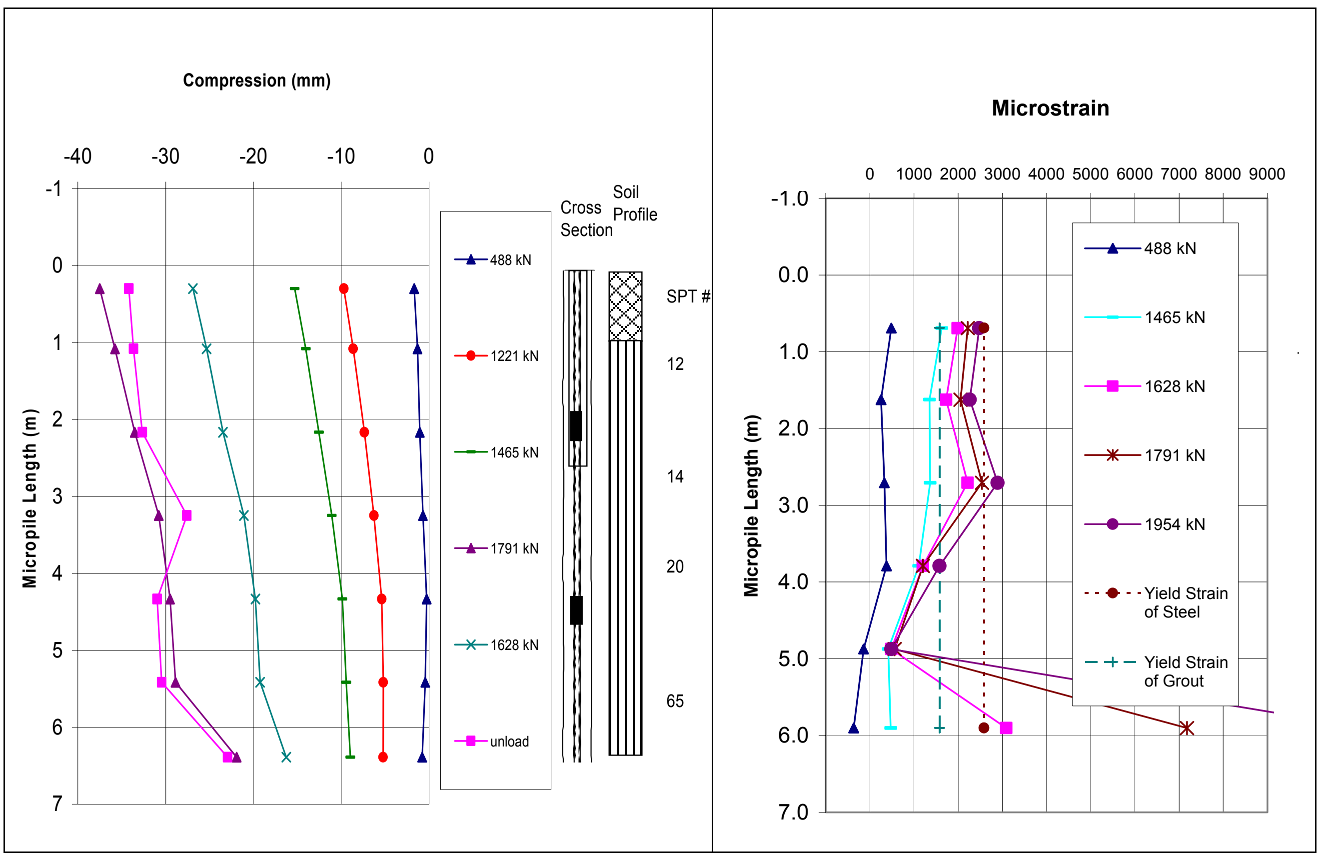

Figure 6. Case 3 Tremie grouted micropile in glacial till

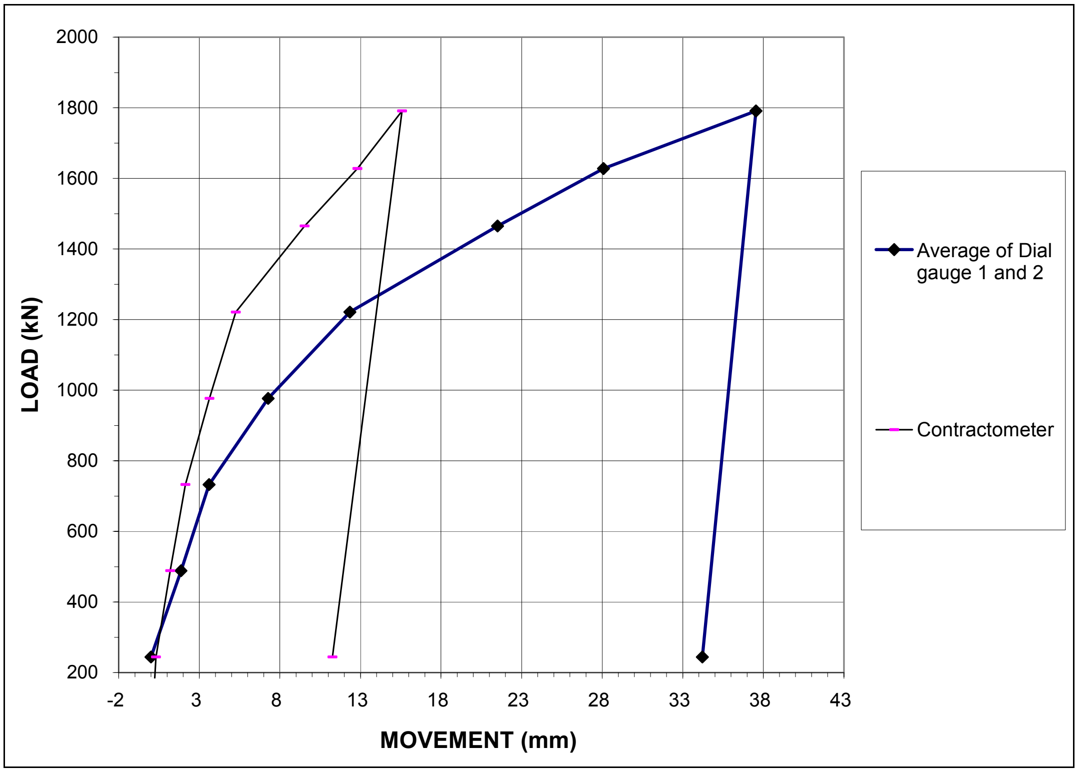

Figure 7. Case 3 Micropile Load vs. Movement Graph

As in Cases 1 and 2, there appears to be negligible load shedding along the casing length where the axial strain is essentially constant with depth. For this case, the unloading strain was omitted from the graph due to irregular readings. This micropile appears to have an ultimate geotechnical capacity that is comparable to the structural capacity of the micropile.

Case 4 – Self drilled micropile in bouldery glacial till

Case 4 micropile was installed in a bouldery glacial till. Its construction consisted of a self-drilled 15 m long Titan bar with a 3 m long top casing. It was tested to a maximum load of 2609 kN which was the maximum capacity of the loading jack used. At an axial load of 2609kN, the pile head deflection measured 15 mm deformation while the Contractometer measured 11 mm (see Fig 9). The accuracy of the Contractometer in this case is 0.6 mm. The difference may be attributed to elastic compression of the soil.

Fig 8 shows the pile compression vs. depth and strain vs. depth. It can be seen from the right hand side that the entire load is shed in the top ten (10) m of the micropile. There is virtually no strain below 10 m depth indicating that most of the load is transferred to the ground in the upper 4m of the very dense till (N_{SPT}>100 blows/ft). Thus, the pile is exhibiting socket like behaviour in the dense stratum. The strain vs. depth plot indicated that there was no load in the last 4m of the micropile and therefore the production micropiles were shortened.

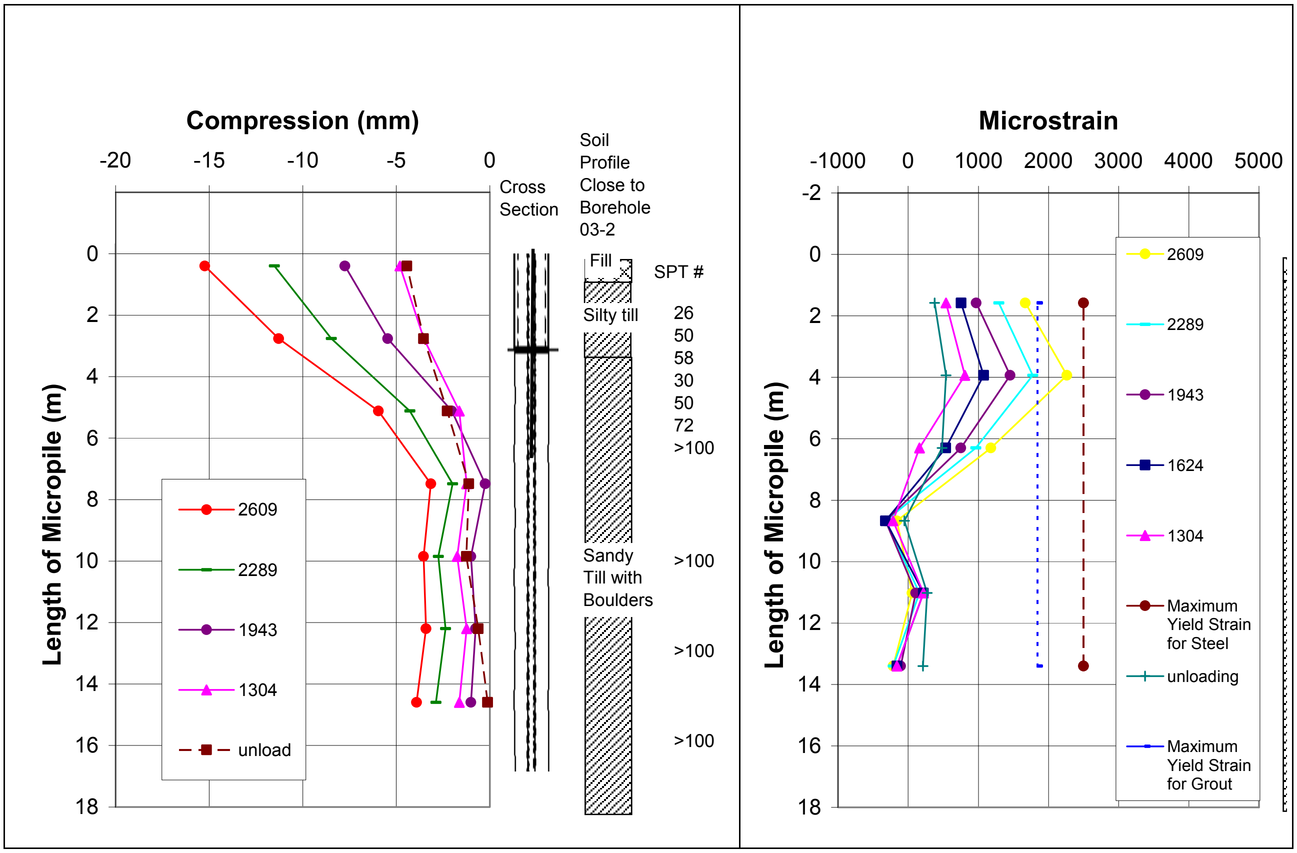

Figure 8. Self drilled micropile in boulder-lain glacial till

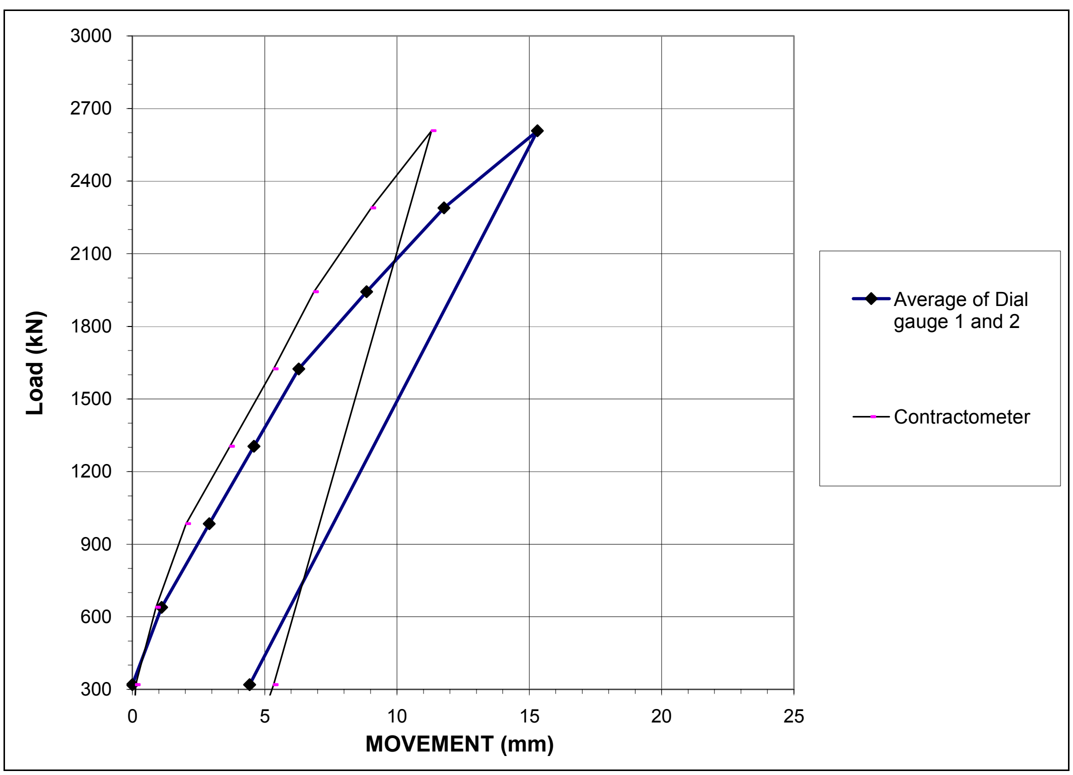

Figure 9. Case 4 Micropile Load vs. Movement Graph

Case 5 – Tremie grouted and pressure grouted micropile in glacial till and shale

Case 5 micropile was installed through a sequence of glacial tills underlain by shale. This micropile was tremie grouted. An attempt at pressure grouting was unsuccessful due cross communication with nearby drilled hole. The first micropile consisted of a 23 m long, 193 mm diameter casing embedded 600 mm into shale. The rock socket was drilled with a 165 mm bit and two 2581 mm^2 bars were installed in the rock socket. The drilled diameter along the casing length is only 3 mm larger than the casing diameter and no grout was observed at the surface around the outside of the casing. The deflection vs. depth and strain vs. depth plots are shown in Figure 10. The accuracy of the Contractometer in this case is 0.5mm.

At a load of 3465kN, the measured pile head deflection was 38 mm while the Contractometer measured 26 mm. The back calculated load at the bottom of the casing (assuming the casing behaved as a column) is the same as the applied load. See figure 11. Therefore, there is no evidence of load shedding along the cased length of the pile.

Referring to Fig 10, there appears to be irregular strain within the rock socket; however the general trend is toward zero strain. There is again high compressive strain near the toe of the pile. This may be attributed the high horizontal stresses in the micropile pinching on the Contractometer tubing or end bearing.

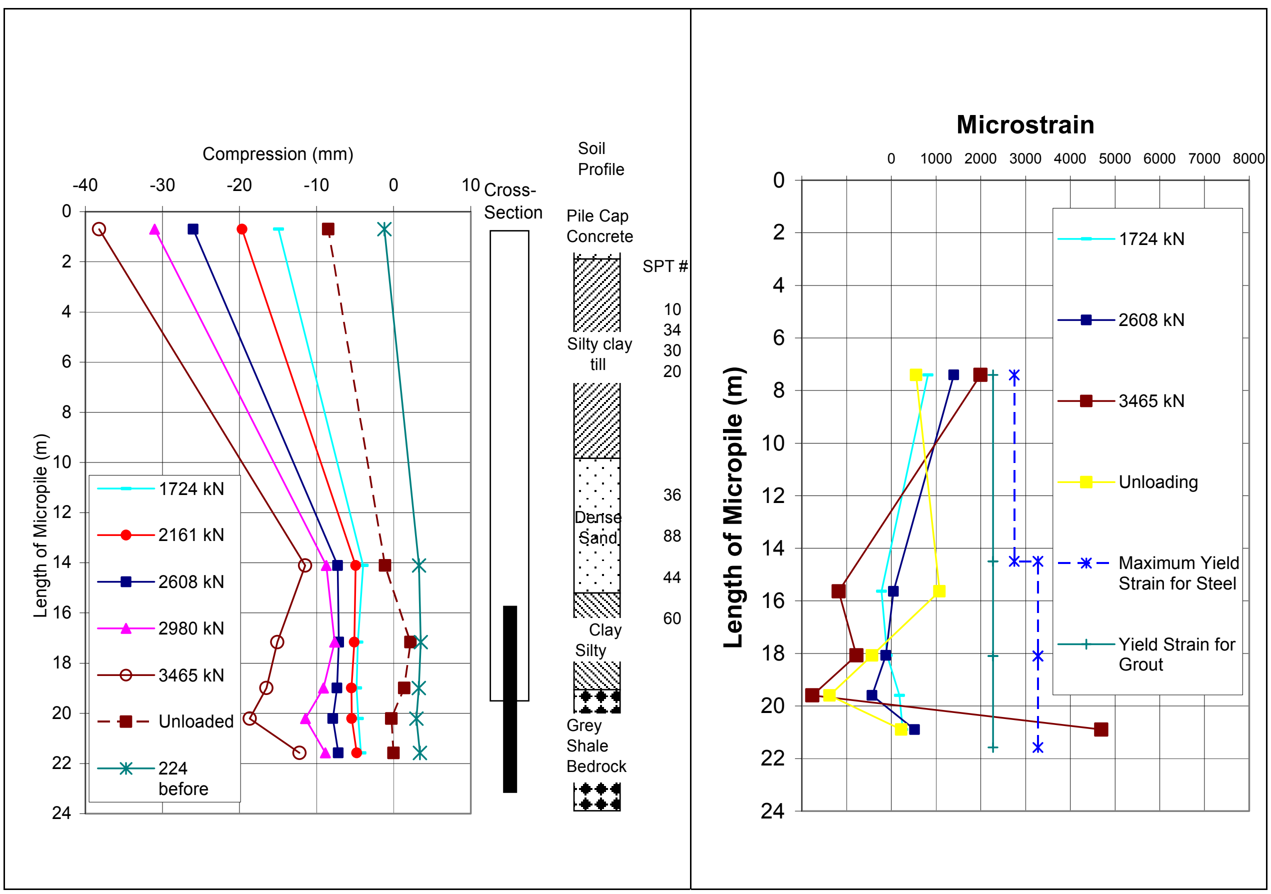

Figure 10. Tremie grouted and pressure grouted micropile in glacial tills and shale

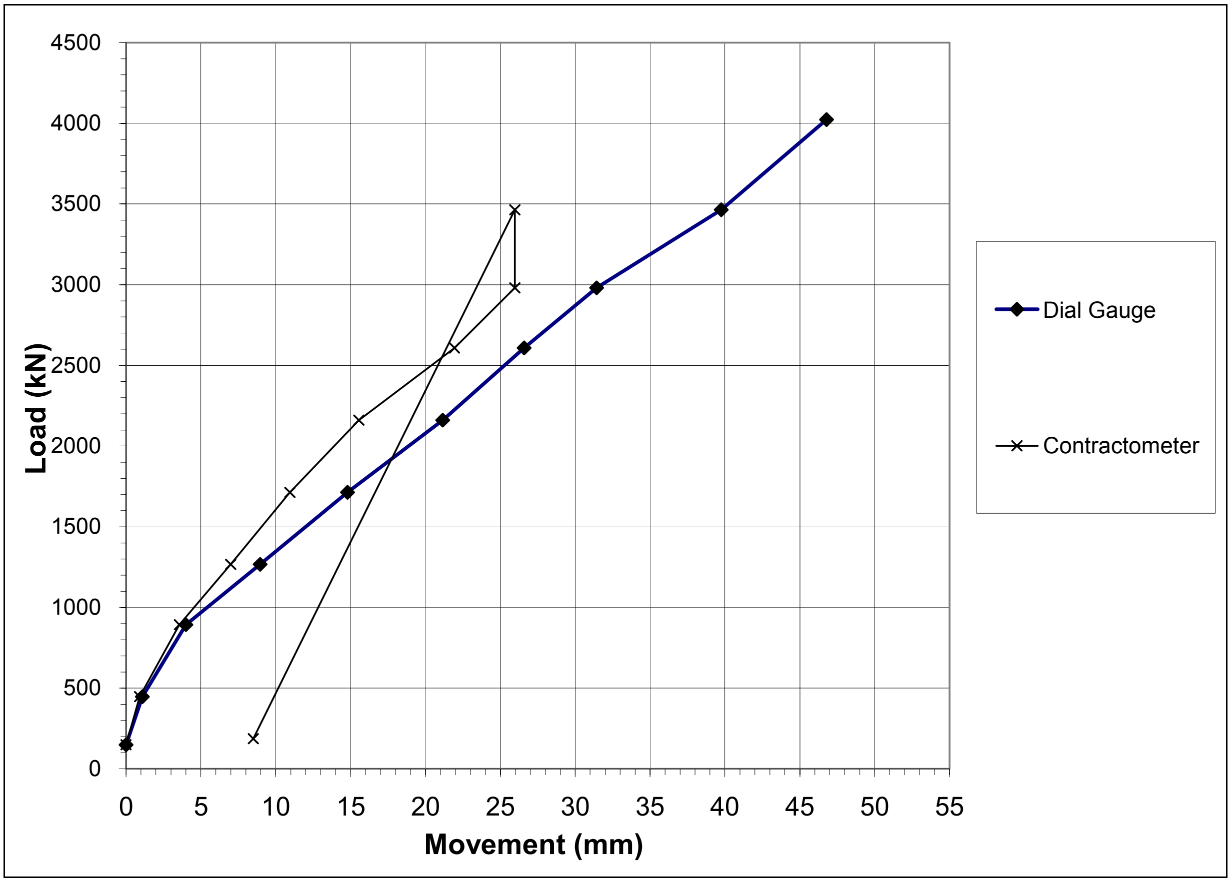

Figure 11. Case 5 Micropile Load vs. Movement Graph

Case 6 – Tremie grouted and pressure grouted micropile in glacial tills and shale

Case 6 involved construction of a micropile in rock. This pile comprised an 18 m long casing (273 mm outside diameter) embedded 600 mm into shale. The rock socket was drilled with a 240 mm bit and three #18 bars were installed in the rock socket. This micropile was tremie grouted and then pressure grouted. The casing was observed to move up 250 mm when the grout pressure was applied. The accuracy of the Contractometer in this case is 0.5mm. The deflection vs. depth and strain vs. depth plots are shown in figure 12.

In this case, at an axial load of 7004kN, the measured pile head deflection was 54 mm while the Contractometer measured 36 mm. See figure 13. The back calculated load at the bottom of the casing is less than the applied load and therefore load shedding appears to have occurred along the casing. These results are unlike all other cases where there is an absence of significant load shedding along the casing. In this case, the skin friction developed along the cased portion of the pile may be attributed to successfully pressure grouting the micropile and getting grout around the outside of the casing. The strain vs. depth plot on the right hand side of figure 12 shows high strain at the end of the pile. This strain is larger than the yield strain for the steel.

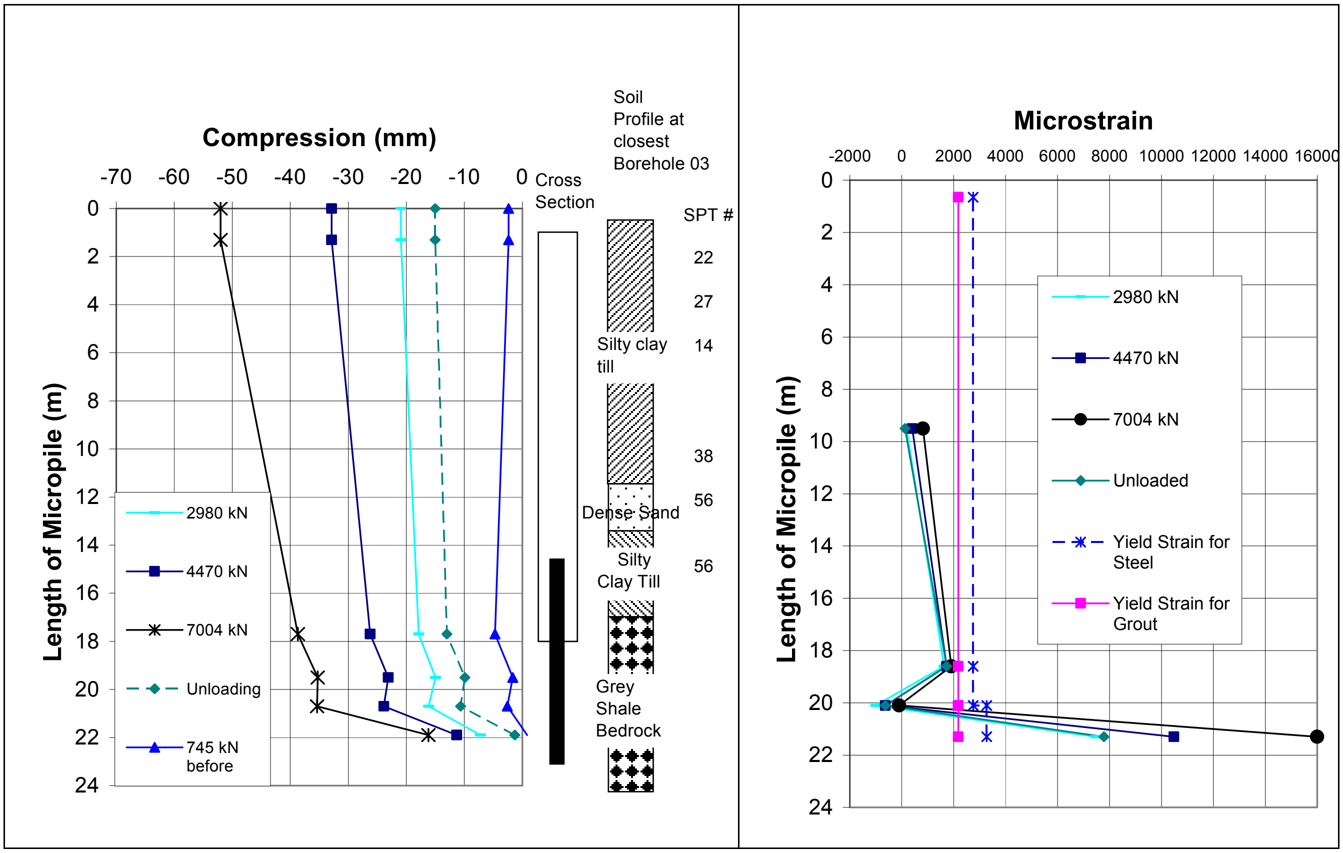

Figure 12. Tremie grouted and pressure grouted micropile in glacial tills and shale

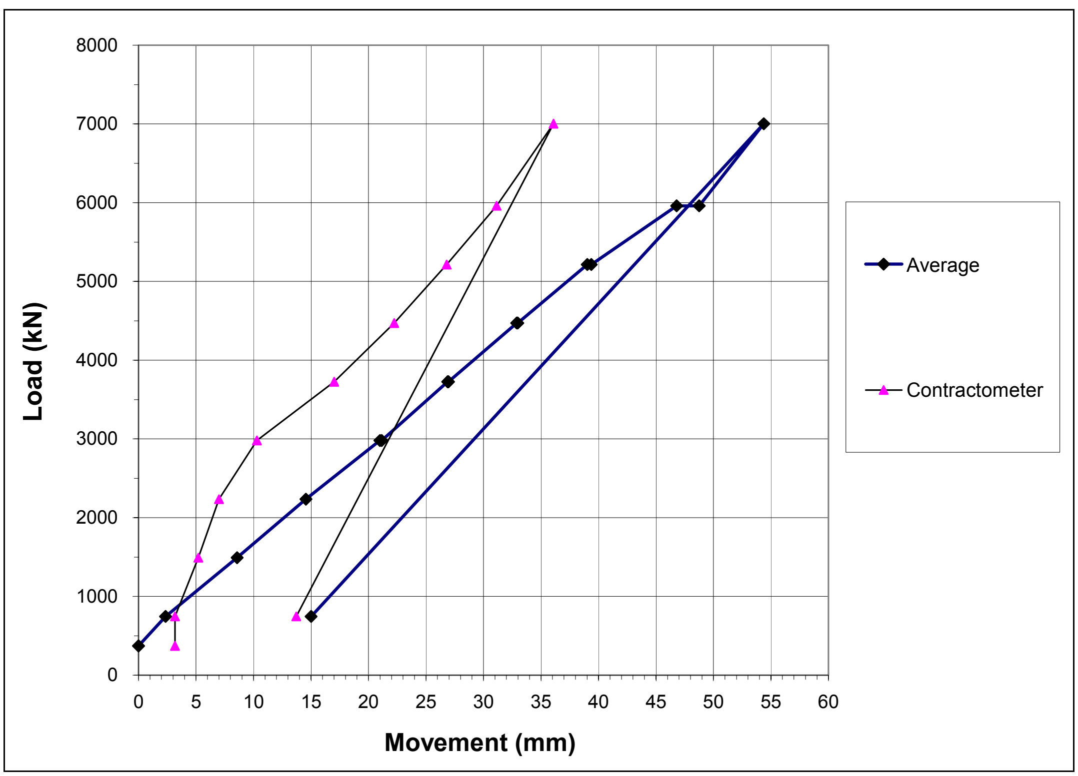

Figure 13. Case 6 Micropile Load vs. Movement Graph

Case 7 – Tremie grouted and pressure grouted micropile in Argillite Rock

Case 7 involved installation of a micropile through very soft clay and embedded in an Argillite Rock. This micropile was tremie grouted and pressure grouted and its construction consisted of a 36.4 m long casing (143 mm outside diameter) embedded in rock. The pile was constructed with a 4.4 m long rock socket drilled with a 143 mm bit. A concentric (3168 mm^2) bar was installed in the rock socket. The accuracy of the Contractometer in this case is 1.3mm. The measured deflection vs. depth and strain vs. depth is shown in Figure 14. The micropile was tested to a maximum load of 2900 kN, which was the maximum load of the reaction supports.

At an axial load of 2906kN, the measured pile head deflection was 60 mm while the Contractometer measured 53 mm. See figure 15. The difference may be attributed in part to the accuracy of the Contractometer and compression of the soil and rock. Referring to the right side of Fig 14, the Contractometer readings indicate that there is no strain in the micropile in the rock socket. Consequently, load shedding may have occurred in the bouldery zone above the rock or the bedrock. Alternatively, the bedrock level may be higher than suggested by the borehole. The Contractometer results on the left hand side of Fig 14 indicate that plastic compression (up to 23mm) has occurred along the cased length, as shown in the unloading line. Based on the load deflection behaviour of the pile head, the geotechnical capacity was not reached.

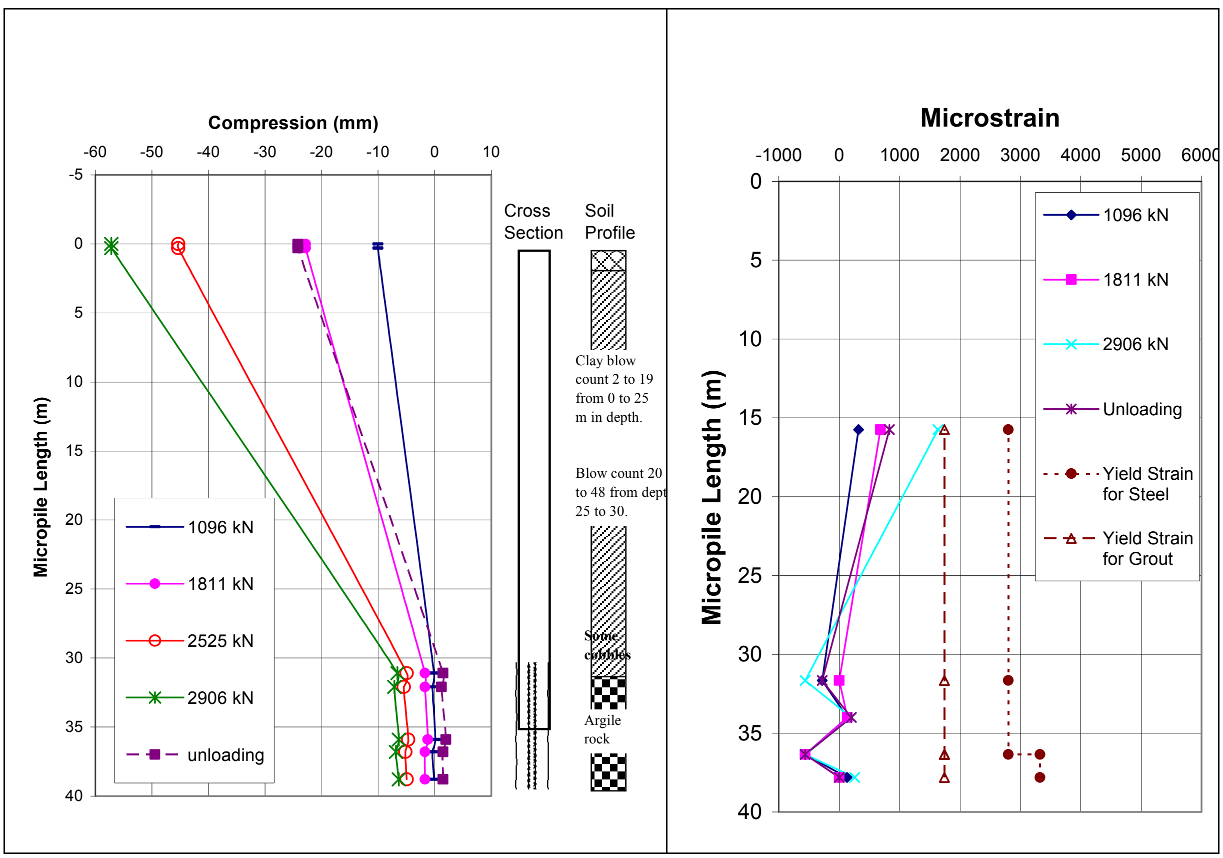

Figure 14. Tremie grouted and pressure grouted micropile in Argillite Rock

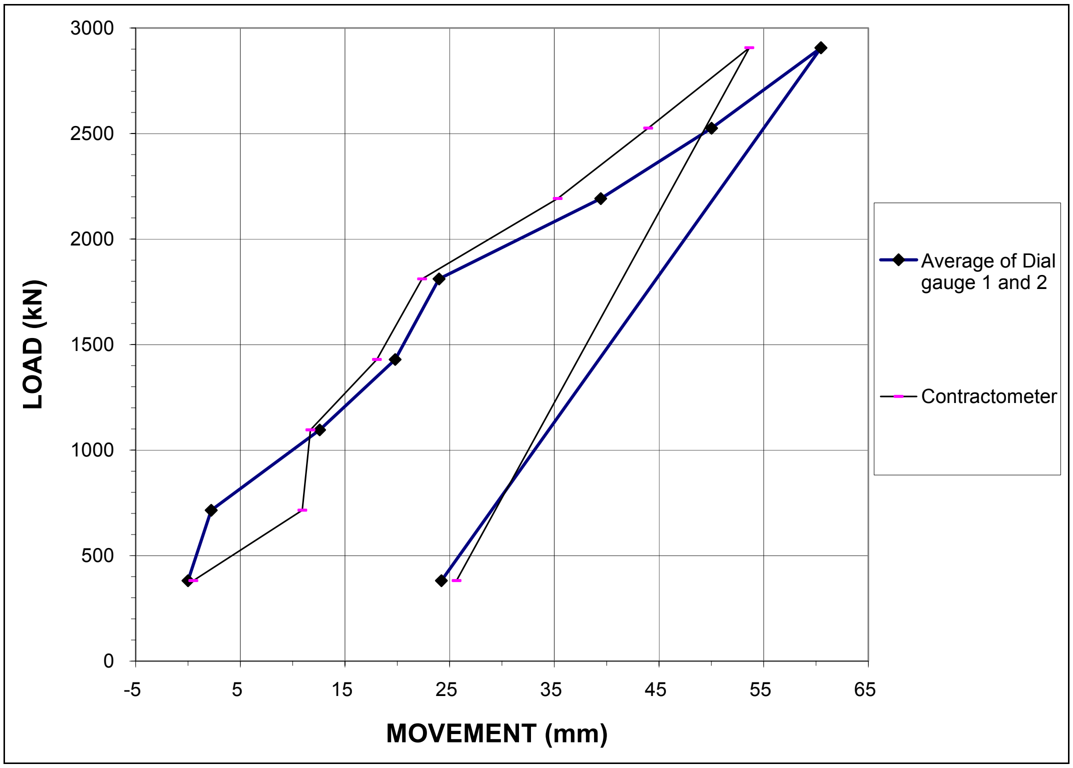

Figure 15. Case 7 Micropile Load vs. Movement Graph

Case 8 – Tremie grouted and pressure grouted micropile in Weathered Shale

In Case 8, a micropile was installed in shale. The pile was tremie grouted and pressure grouted and its structural elements consisted of a 14.3 m long 194 mm diameter casing and a 3168 mm^2 concentric bar embedded into shale. The deflection vs. depth and strain vs. depth plots are shown in Figure 16. The maximum tested load was 2644 kN where one of the reaction micropiles failed. The accuracy of the Contractometer in this case is 1.3mm.

Referring to Fig 17, at an axial load of 2644kN, the measured pile head deflection was 10.5 mm while the Contractometer measured 4.3 mm. The difference is likely due to deformation of the weathered rock. On unloading, there was some residual compression in the pile. The residual compression may be due in part to the accuracy of the Contractometer (1.3mm in this case). As in the other cases, however, it is not possible to assess other causes of the residual compression without more sophisticated methods of analysis. The strain vs. depth plot indicates that this micropile was tested below its structural capacity. Consequently, any residual compression must be due to the yielding within the soil.

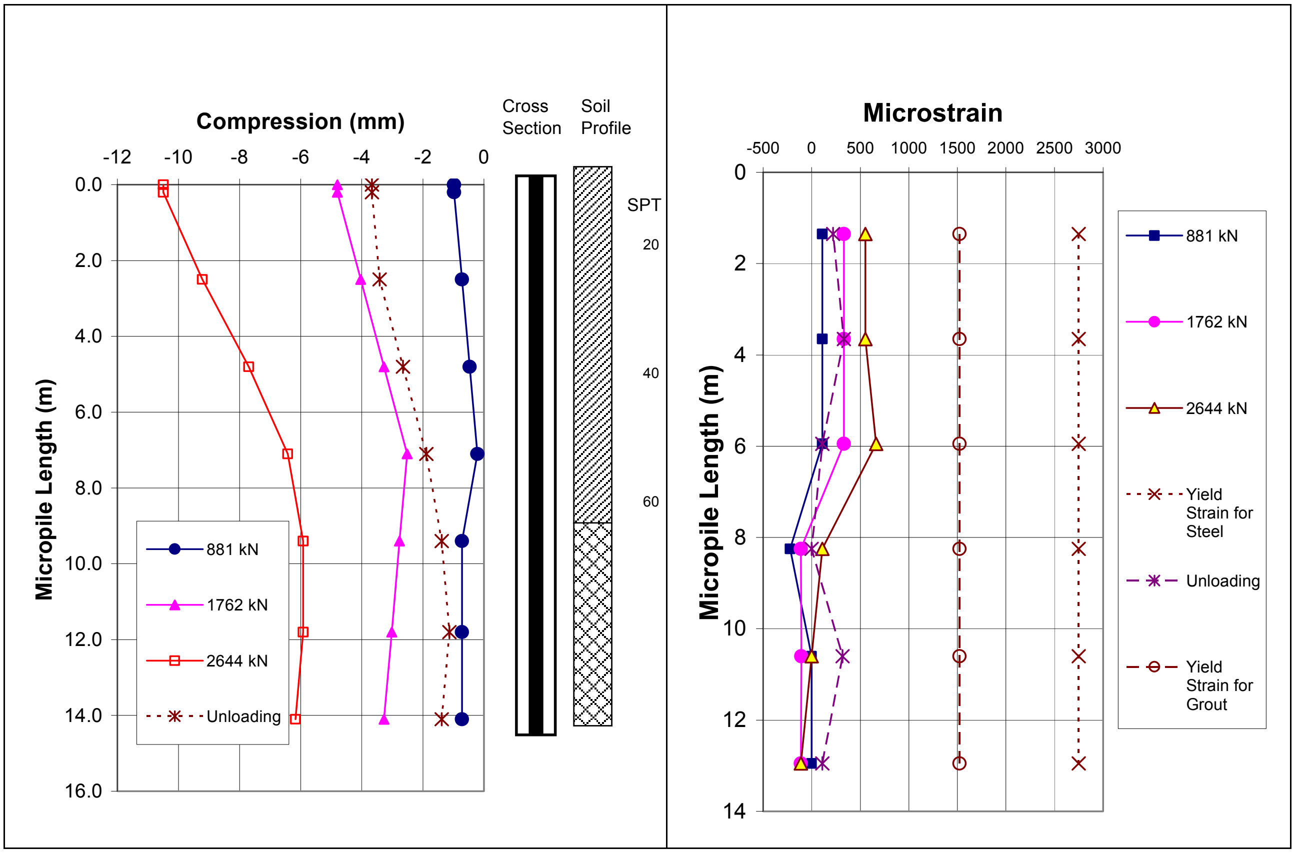

Figure 16. Micropile embedded in Shale Rock

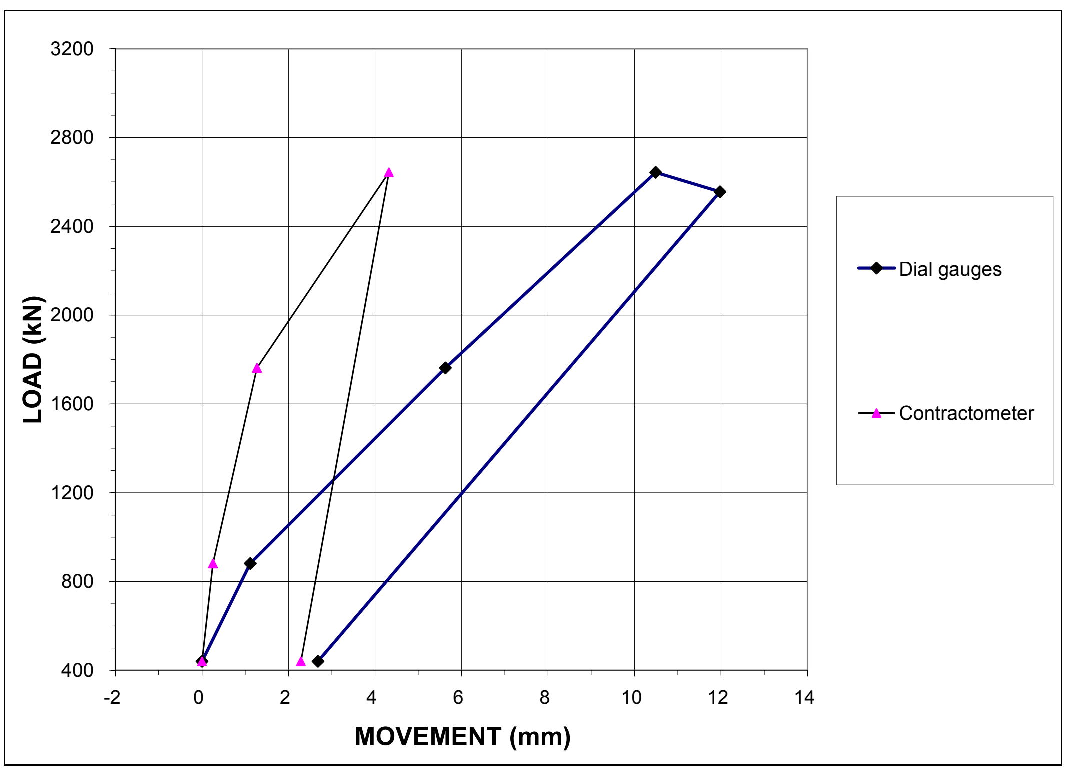

Figure 17. Case 8 Micropile Load vs. Movement Graph

Conclusions

The results of 8 axially loaded and instrumented micropiles were presented and analyzed. Plots of the measured compression versus depth and strain vs. depth enable some interpretation of the load shedding characteristics of each test. In most cases it was found that negligible load transfer occurred along the cased length as the measured strain was generally constant.

In the 8 cases presented only in case II and III resulted in comparable structural and geotechnical capacities. Case II indicated structural plasticity below the casing. The results of this study, however, seem encouraging and they suggest that it may be possible to build micropiles that have comparable structural and geotechnical capacities.

For some of the micropiles in rock, Contractometer measurements indicated that there was significant strain near the pile tip. Although it is difficult to determine the exact cause of this, it could be due to end bearing of the micropile or residual load due to cycling of loading while performing the test. The potential end bearing warrants further investigation since micropiles are designed accounting for skin friction only and neglecting end bearing.

In most cases, the difference between the Contractometer and dial gauge readings may be attributed primarily to the micropile moving as a whole unit into the soil mass, and the compression of the soil below the micropile. Secondary factors affecting this difference are the accuracy of the Contractometer readings and other experimental errors.

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Jim Bruce, Daniela Ramirez & Peter Lausch. The SMART Contractometer – Its Application to Micropile Quality Assurance. Geo^3 – ADSC conference paper. October 2005.