Performance evaluation of standard grouted anchors versus expanded anchors

BRIDGING INFRASTRUCTURE & RESOURCES
GeoSaskatoon 2023
OCT 1–4

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ABSTRACT

Foundations and tiebacks with expanded elements have been used in the past, namely soil anchors, driven, vibrated and bored piles. This paper presents a test program conducted at a site in Ottawa, Ontario, Canada, comparing the performance of conventional tiebacks (strand anchor with gravity grouting) to shorter tiebacks with an expanded anchor. The conventional tiebacks (strand anchors) were 150 mm in diameter and were constructed to a depth of 28 m:18.0 m of unbonded length and 10 m bonded in dense sands with gravity grout. Tiebacks anchored with expanded elements were installed in a 228 mm diameter hole to a depth of 7 m and were expanded in loose to compact sands. The expanded element was initially 1.2 m long and about 0.95 m long after expansion. The remainder of the tieback was unbonded. The results of the tension tests conducted on both types of tiebacks showed that the tiebacks with expanded elements provided on average about three times the resistance measured for conventional anchors, even in less competent soils.

RÉSUMÉ

Des fondations et des tirants avec des éléments expansés ont été utilisés dans le passé, y-inclus des ancrages au sol, des pieux enfoncés, vibrés et forés. Cet article présente un programme d'essais mené sur un site à Ottawa, Ontario, Canada, comparant les performances d'un tirant conventionnel (ancrage à torons avec méthode d'injection par gravité) et d'un tirant plus court avec un ancrage expansé. Les tirants conventionnels (ancrages à torons) avaient un diamètre de 150 mm et ont été construits jusqu’à une profondeur de 28 m : 18,0 m de longueur non liée et 10 m liés dans des sables denses avec un coulis gravitaire. Des tirants ancrés avec des éléments expansés ont été installés dans un trou de 228 mm de diamètre et ont été expansés à une profondeur de 7 m dans des sables meubles à compacts. La partie expansée mesurait initialement 1,2 m de long et environ 0,95 m de long après l'expansion. Le reste du raccord n'était pas lié. Les résultats des essais de traction effectués sur les deux types de tirants ont montré que les tirants avec éléments expansés fournissaient en moyenne environ trois fois la résistance mesurée pour les ancrages conventionnels, même dans des sols moins denses.

Keywords: tieback, expanded tiebacks, anchors

1 INTRODUCTION

A conventional grouted ground anchor is a structural element installed in soil or rock that is used to transmit an applied tensile load into the ground. A ground anchor is installed within the bottom part of grout-filled drilled hole bonding a rod or one or more strands to the soil. The rod or strands are extended to the surface to form a “tieback”. The basic components of a grouted anchor consist of the following:

- Anchor
- Free stressing (unbonded length)
- Bonded length

Ground anchors and anchored systems have been used extensively in the past and are becoming increasingly more common and cost effective through improvement in design methods, construction techniques, and on-site testing (verification and validation). The support of excavation (SOE) for temporary conditions is generally stated to be for “short term” (generally 18 to 24 months); however, delays in construction schedules and unforeseen site conditions often result in longer implementation periods.

The benefits of anchored walls for SOE and retaining walls over sloped excavations and gravity retaining walls include unobstructed work area for excavations, reduced clearance requirement, ability to withstand large horizontal wall pressures without increasing wall cross-sections, elimination of the need for deep foundation support, elimination of the need for select backfill, and reduced construction time etc. (Sabatini et al., 1999).

As will be discussed herein, of the efficacy of ground anchors varies based on the anchor type, some of which are more effective than others in specific soil conditions. In this paper, two types of anchors are directly compared in terms of performance in loose to dense sandy soils.

2 GROUND ANCHORS

The schematic in Figure 1 shows the main components of a standard grouted ground anchor. As discussed by

Sabatini et al., (1999), the following three main variations of the grouted ground anchor are commonly used across North America:

- Straight shaft gravity-grouted anchor
- Straight shaft pressure-grouted anchor
- Post grouted anchor

A variation, though not commonly used in Canada is the underreamed ground anchor. The schematics (Sabatini et al., 1999) illustrate the different variations of grouted anchors.

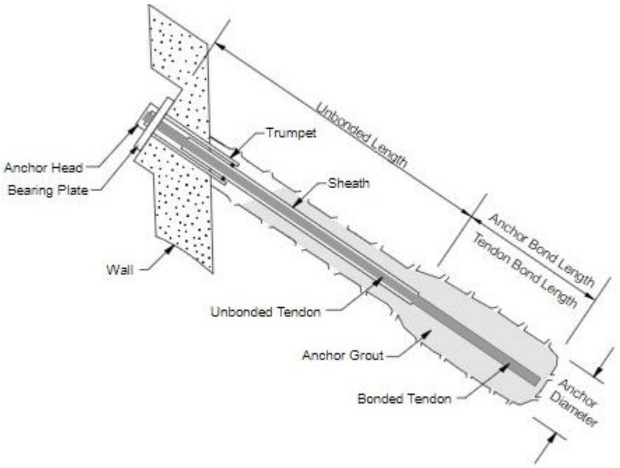

Figure 1. Components of ground anchor (Sabatini et al., 1999)

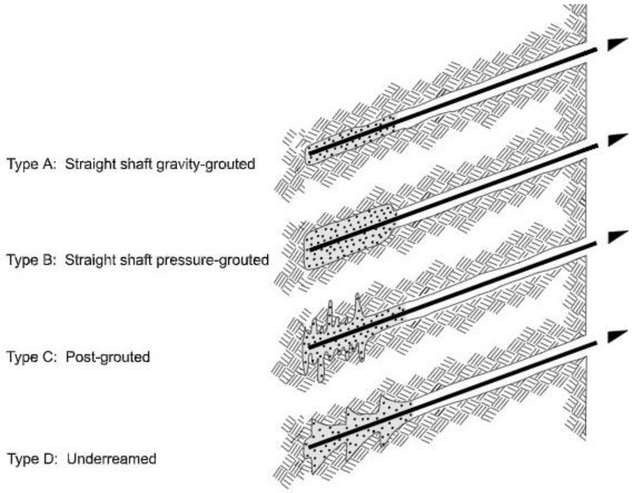

Figure 2. Main types of ground anchors (Sabatini et al., 1999)

3 EXPANDED ANCHORS

The concept of expanded anchor, also known as the expander body (EB), was first invented by the Swedish Engineer Bo Skogberg during the 1980's (Berggren et al., 1988) and later developed and evolved in Bolivia by Mario H Terceros. The EB consists of a folded steel "balloon" that is installed at the tip of a deep foundation element (pile) or a tieback (Fellenius et al., 2018; Terceros and Terceros, 2015). The EB is installed in a bored pile/anchor and then, injected with grout, producing an expanded element.

EB technology has been used successfully to increase the resistance of bored piles, anchors, and tiebacks in different soils. The expansion process compacts the surrounding soil and increases the toe size, thereby increasing the resistance of the pile/anchor in bearing and tension. Many studies have documented the increased resistance of piles using expander body (Herrera and Arce, 2016; Terceros A et al., 2022; Terceros and Terceros, 2015).

The EB is supplied in different sizes and different expanded diameters to match the intended application and soil type. The general diameter of the commonly used EBs, prior to expansion, ranges between 110 mm and 145 mm. The length of the units can be 1,200 mm and 1,500 mm. The full expansion of an EB leads to a final diameter of the EB to range between 400 mm to 800 mm depending on the EB model, with a corresponding shortening of the expanded element by up to about 300 mm. The expansion of an EB unit is illustrated in the photographic sequence shown in Figure 3 (after Terceros et al., 2015).

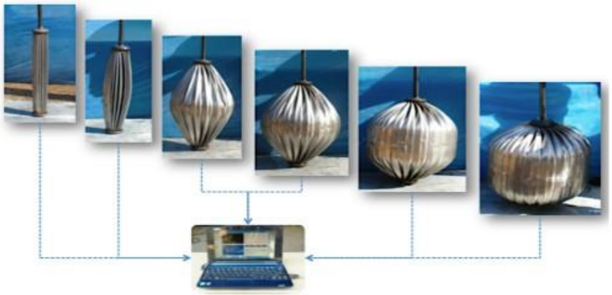

Figure 3. Expansion steps of the EB (Terceros and Terceros, 2015).

The grouting process of the liquid-tight EB takes place under controlled conditions without leakage; enabling measuring the gradual increase in EB volume and required inflation pressure, which can be correlated to resistance. All relevant parameters such as the flowrate, pressure and volume of grout can be recorded with a data acquisition system or manually using analog sensors. The applied grouting pressure reflects the soil resistance during expansion of the EB and is the measure of soil stiffness and strength at the time of inflation. The grouting record is obtained for each inflated EB and offers complete means of quality control (Terceros and Terceros, 2015).

4 TEST PROGRAM

A test program was conducted at a site in Ottawa, Ontario, Canada, comparing the performance of a conventional tieback (strand anchor with gravity grouting) and a shorter tieback with an expanded anchor (EB). The objective of the test program was to establish the most economical and feasible tiebacks to be used for a temporary SOE. It should be noted that the test was intended to verify the ultimate load (failure) of the tiebacks. All test anchors were less than 5 m apart.

5 SUBSURFACE CONDITIONS

The location of the test anchors was selected by the Geotechnical Engineer (Kiewit) to be representative of the excavation site. Based on the borehole investigation and site observations, the following is a representative soil profile at the location of the anchor testing:

Three meters of loose to compact silt and sand fill, followed by loose to compact silty sand extending to a depth of 12.5 m. Below lies a layer of very stiff silty clay with some sand extending to 17.8 m, followed by compact to very dense sand and gravel extending beyond 25.0 m depth (the depth of exploration). The groundwater table was encountered at a depth of 6.1 m.

6 EXPANDED ANCHOR INSTALLATION DETAILS

Two test anchors were installed on June 20, 2022, by Marathon Underground Construction (Marathon). One of the test EB units was sized for an 800 mm expanded diameter and 1.2 m initial length (EB812). The second test EB was sized for a 600 mm expanded diameter and 1.2 m initial length (EB612). The hole was drilled by reverse circulation with combined air and water. A 230 mm o.d. temporary steel casing was pushed in place to a depth of 7 m while the hole was drilled. It should be noted that the assembly above the EB anchor was wrapped with a polyethylene sheet to prevent bonding. The preassembled typical EB setup shown in Figure 4 was then lowered in the bored hole. Thereafter, hole was tremie-grouted around the EB assembly and the casing was withdrawn.

The EB assembly consisted of the EB anchor, a Williams 46 mm threaded tieback rod, Grade 150 ksi, and a 100 mm o.d. steel pipe welded to the top plate of the EB, which would serve as the pressure grouting conduit. The rod was secured with a matching nut welded to the bottom EB plate and contained within the grouting pipe. The top 600 mm of the rod was wrapped in plastic sheathing for bond breaking. A steel cap with a mounted grouting assembly coupling was welded at the top of the grouting pipe which was about 500 mm above the top of the tieback rod to allow for upward movement of the rod during inflation of the EB body.

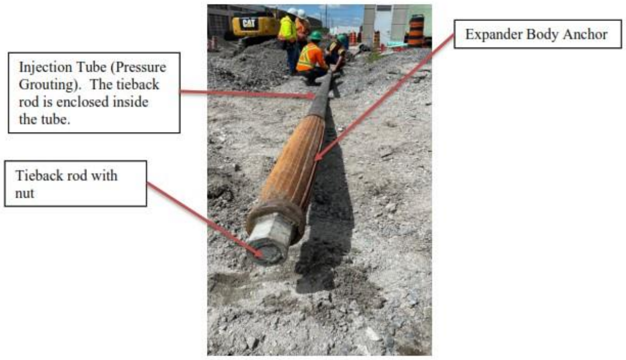

Figure 4. Expander Body Anchors (EB Anchors)

Four days after the initial installation, pressure grout was injected into the EB812 assembly through a sacrificial valve connected to the coupling on the capping plate. A purging valve mounted on the grouting manifold was used to purge the assembly (expelled air) until grout reached the cap. The purge valve was then closed, and grout was pumped under pressure until the EB anchor was fully inflated (about 325 to 350 liters). As no flowmeter was used, the pumped volume was estimated from the level of grout pumped out of the mixing drum at the grout plant. The grout pressure during pumping was noted and plotted against the cumulative pumped grout volume as shown in Figure 5.

Similarly, pressure grout was injected into the EB612 assembly, and the EB anchor was fully inflated (about 225 litre). The grout pressure during the pumping was plotted against the cumulative pumped grout volume as shown in Figure 6.

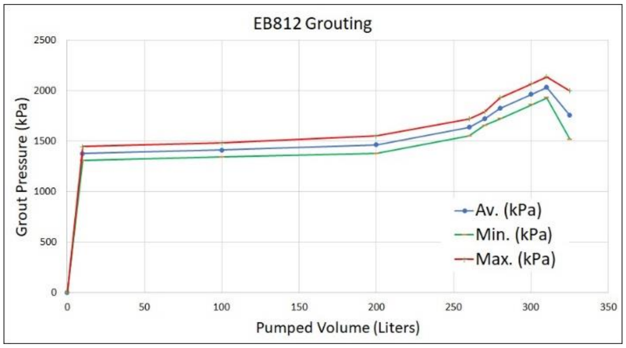

Figure 5. EB812 grouting data

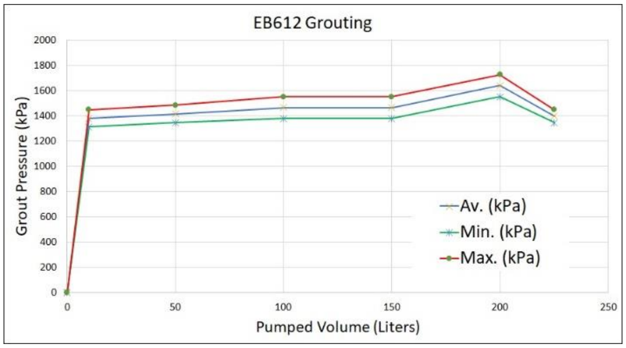

Figure 6. EB612 grouting data

7 CONVENTIONAL ANCHOR INSTALLATION DETAILS

Three gravity grout test anchors were installed in May 2022 and two additional gravity grouted test anchors were installed in June 2022. Each anchor was installed with 7 strands of 0.6-inch diameter, low relaxation, grade 270 ksi, conforming to ASTM A416. Details of the anchor installation are provided in Table 1. Note that all anchors were grouted by tremie method except anchor TA04, which was not post-grouted.

Table 1. Conventional anchor details

Test Anchor	Anchor diameter (mm)	Number of strands	Unbonded length (m)	Bonded length (m)	Total length (m)
TA01	150	12	12.5	9.0	21.5
TA02	150	12	14.0	9.0	23.0
TA03	150	12	14.0	9.0	23.0
TA04	150	12	18.0	10.0	28.0
TA05	250	12	18.0	10.0	28.0

8 CONVENTIONAL ANCHOR TEST RESULTS

All conventional anchors were tested by Marathon in accordance with the PTI DC35.1-14 recommendations. The design load (DL) in this case was specified at 720 kN. Note that the test were with cyclic loading (performance test); however, none of them reached the required test load of 1.33xDL due to excessive movements observed during the test. Tabulated and graphical results of all the five anchor tests are summarized in Table 2. The proof test load provided in Table 2 are the maximum sustained load prior to failure.

Table 2. Conventional anchor test results

Test Anchor	Maximum test load (kN)	Notes
TA01	150	Anchor pulled out about 300mm at 38% DL
TA02	150	Anchor pulled out about 200 mm at 45%DL
TA03	150	Anchor pulled out about 150 mm at 33%DL
TA04	150	Cyclic loading conducted, creep failure at 75% DL
TA05	250	Cyclic loading conducted, creep failure at 75% DL

Graphical test results for Anchors TA01, TA02, and TA03 are shown in Figure 7.

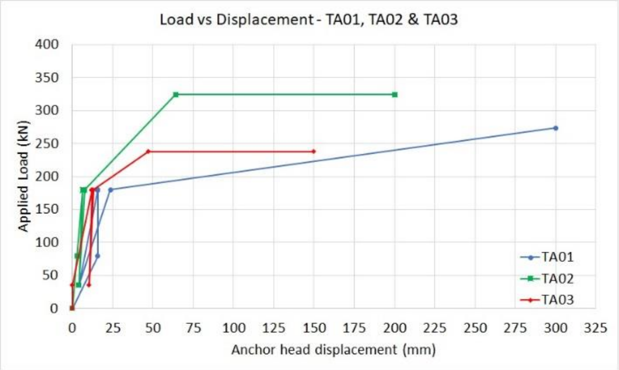

Figure 7. Test results for Anchors TA01, TA02, and TA03

Graphical test results for Anchors TA04, and TA05 are shown in Figure 8

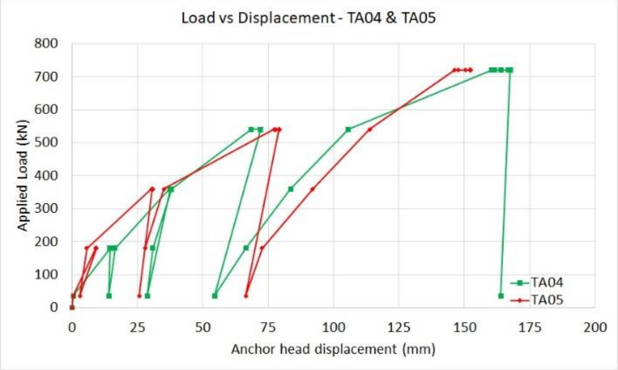

Figure 8. Test results for Anchors TA04, and TA05

9 EB ANCHOR TEST SETUP AND DETAILS

A reaction beam with center access for the anchor rod projection was placed by Marathon, centered over the anchor location.

A 300-ton hollow hydraulic cylinder (provided by Marathon) and a 200-ton Geokon Model 3000 load cell (provided by SACL) were used to apply and measure the load. Two Novotechnik TRS electronic displacement transducers (DT) were used to monitor the vertical displacement of the anchor head at opposite ends of the top bearing plate. Displacement measurements were referenced to two tripods, one on each side of the reaction beam. Figure 9 shows a photo of the test setup at the anchor head.

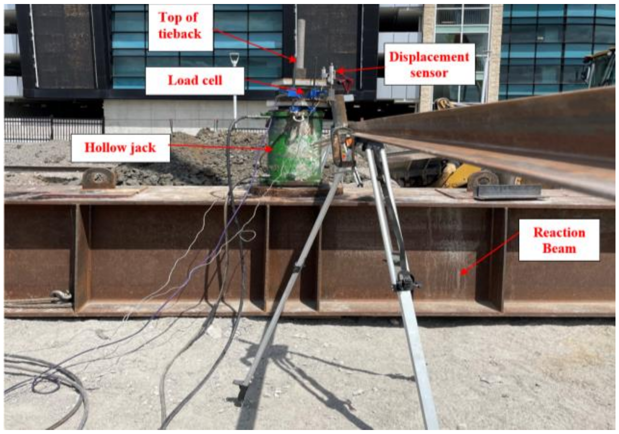

Figure 9. Pile head and test instrumentation setup

10 EB ANCHOR TEST PROCEDURE

While anchor testing is conventionally performed per the Post Tensioning Institute (PTI) guidelines, the EB anchors were tested to failure in accordance with ASTM Standard D3689-07 (2022), Procedure A. A target test load of 1,400 kN, which is close to the yield strength of the rod, was used to set the load increments. As such, 20 equal increments of 70 kN, each sustained for 4 minutes, until a failure load was reached. The anchor was then unloaded in 5 decrements.

11 EB ANCHOR TEST RESULTS

EB812

A practical load limit of the anchor was encountered at about 1,350 kN at which the load could not be sustained without continuous pumping. The anchor was unloaded after a total movement of about 59.4 mm in five equal decrements sustained for 4 minutes each. The net displacement was about 41.5 mm after full unloading (about 17.9 mm elastic rebound). The measured load-movement data is shown in Figure 10. A second cycle of continuous loading to about 950 kN was initiated after unloading. Preselection of the 950 kN load was done in accordance with the PTI testing procedure (1.33 times design load) to check for creep movements. No creep movement was observed.

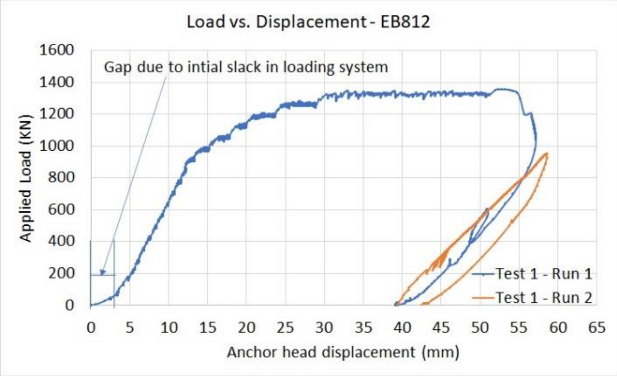

Figure 10. Applied load vs displacement – EB812

EB612

This anchor was loaded in 17 equal increments of 70 kN, each sustained for 4 minutes, until a total load of about 1,200 kN was reached, at which point higher loads could not be sustained. The anchor was unloaded in 5 decrements each sustained for 4 minutes. A total movement of about 53.2 mm was recorded before unloading. The net displacement was about 36.6 mm after full unloading (about 16.6 mm elastic rebound). The measured load-movement data is shown in Figure 11.

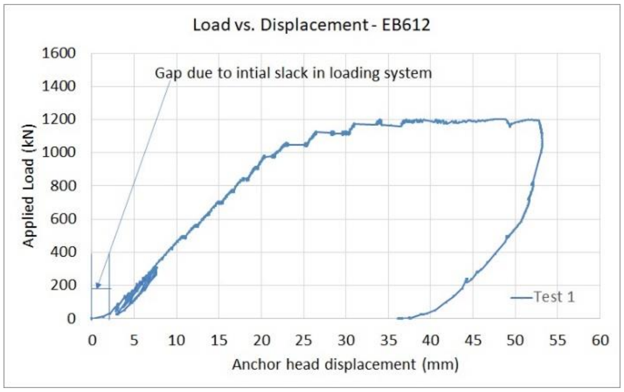

Figure 11. Applied load vs displacement – EB612

12 COMPARISION OF TEST RESULTS

As shown clearly from the test results, conventional anchors at this site performed with very soft behavior marked by excessive movement and substantial creep during early loading stages. While the deeper conventional anchors (TA04 and TA05) sustained somewhat higher loading than the shallower ones (TA01, TA02, and TA03), there is clear evidence that post grouting of the anchors did not have any effect on anchor performance. This can be seen in the test results shown in Figure 8 since Anchor TA04 was not post grouted.

A direct comparison of the performance of the EB anchors versus the conventional anchors is difficult since the main criterion for anchor performance is stability. The conventional anchors pulled out prematurely and an accurate test of their stiffness (creep test) at lower loads was not possible since they rely mainly on friction which deteriorates with large displacement.

The performance of the expanded anchors was more robust throughout the test. At certain stages of the loading, EB anchors appeared to show slight strain hardening (see Figure 10 and Figure 11). Furthermore, even after pullout failure, reloading to lower load levels produced near zero creep showing even stiffer response than the original loading stage to the same load. This is evident in comparing Run 1 and Run 2 in the EB812 test results shown in Figure 10; keeping in mind that the maximum load in Run 2 (950 kN) was sustained for four minutes with no creep movement. A photo of the extracted test EB is shown in Figure 12.

Figure 12. Exhumed EB anchor

13 DISCUSSION AND RECOMMENDATIONS

There were signs of sand boils rising into casings of piles drilled at the site after the testing, which could explain a possible loss of density in the bond zone. Possibly, the deeper sands where the conventional anchors were embedded had changed into a loose state due to the drilling process. Unfortunately, there were no detailed investigations to assess the conditions causing the loose behavior. Regardless of the deep sand conditions, the EB test anchors were purposefully installed in shallow loose to compact sands with the objective of improving the soils to a denser consistency around the anchors and achieving higher performance without deep drilling. With the effect of the inflation process preloading the anchor reaction, it is anticipated that movements would be small when the actual tieback load is applied. Furthermore, since a large portion of the EB anchor resistance is developed in bearing, an increase in resistance with anchor movement can be expected as the bearing sands are further densified. Hence, the EB anchors can be expected to show larger stiffness when reloaded. As opposed to post grouting in conventional anchors, EB inflation is contained, and the grout bulb is near symmetrically shaped (see Figure 12) optimizing the anchor efficiency. In contrast, free post-grouting in loose sands is unpredictable and may find paths of least resistance to migrate away from the anchor system with little or no benefit to the performance of the anchor. This characteristic gives EB anchors a significant advantage in excavation support by reducing the risk of brittle pullout failures and fatigue from cyclic loading.

In conclusion, the EB anchors at this site showed three to five times the capacity of much deeper conventional anchors with substantial bonded length varying between 8 and 10 m. These anchors have also been successfully used in marine clays where conventional anchors are practically not feasible. Expanded anchors (EBs) are versatile and should be considered as a viable alternative in many difficult soil conditions.

14 ACKNOWLEDGEMENTS

The authors wish to extend their gratitude to Dr. Bengt H. Fellenius for his valuable input and guidance.

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