Pullout performance of anchored earth systems

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ABSTRACT: Anchored earth is an alternative technology to reinforced soil and involves stabilising a wall using tendons and anchors. In this study the pullout resistance and corresponding displacement of square mild steel anchor plates was investigated. The anchor system was part of a 6.75m high trial wall constructed in Co Offaly. Three anchor sizes, with face dimensions of 100mm x 100mm, 200mm x 200mm and 300mm x 300mm, were investigated. Good repeatability of the pullout resistance – displacement was observed in comparable test series. However, both the peak pullout resistance and corresponding displacement did indicate some scatter. The early stiffness, at displacement less than 10mm, was consistent with the post-peak behaviour and was found to vary from softening, to plastic, to hardening behaviour. The peak pullout resistance was found to increase with area of plate anchor. The smallest plates (100mm x 100mm) reached peak resistance at displacement less than 5mm, while the large plates (200mm x 200mm and 300mm x 300mm) reached peak at similar values between 10 – 30mm. The peak pullout resistance for the 200mm x 200mm and 300mm x 300mm was found to reduce as the insitu vertical stress in the wall increased.

KEY WORDS: Anchored earth, experimental testing, trial wall, pullout testing.

1 INTRODUCTION

Anchored earth technology has been used to construct retaining walls for over 100 years [1]. The system consists of a facing element (nowadays a panel or segmental block system) and a connecting rod or tendon that connects the facing system to an anchor located in the retained fill, Figure 1. Anchored earth systems differ from conventional steel and geosynthetic reinforced wall technologies in that the resistance to outward movement is mobilised, primarily, as passive resistance against the anchor plate, rather than friction along the reinforcement element [1].

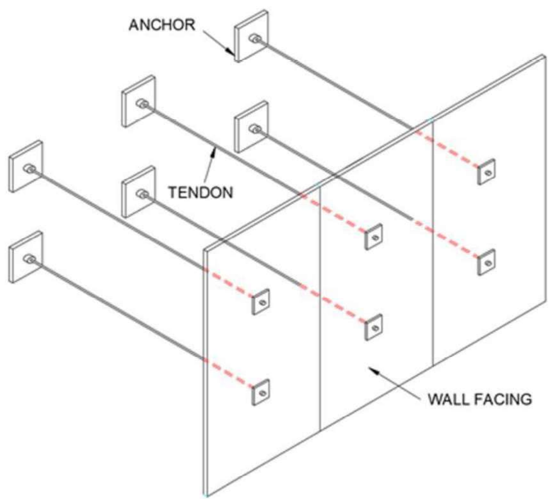

Figure 1. Schematic of an anchored earth structure [1].

Jones [1] reported on early anchored earth technologies, including an array of wooden timber reinforcement units developed in the USA by Munster [2] in 1925. A French engineer also developed a ladder wall in 1932, which consisted of precast concrete facing units, selected stone fill and ties with steel anchor plates [3]. The ladder system allowed the facing units to move relative to each other to accommodate settlement.

The first anchored earth wall in the UK was constructed in 1984 [4]. The wall, which was 6m high and 86m long, formed part of the A660 Otley bypass in West Yorkshire, UK. Different types of anchors, including plate anchors and anchor heads, were utilised on that project.

In this study the pullout behaviour of plate anchors is investigated in a full-scale trial wall. Three plate anchor face dimensions of 100mm x 100mm, 200mm x 200m and 300mm x 300mm were investigated. The data was assessed in terms of peak pullout resistance, stiffness of the pullout response and the impact of both plate size and insitu vertical effective stress on the behaviour of the plate anchors.

2 METHODOLOGY

A full-scale test wall was constructed in Co. Offaly at the Lusmagh Quarry belonging to Banagher Precast Concrete Ltd. The wall had a maximum height of 6.75m, Figure 2, and was faced with 0.14m thick concrete panels. The wall was reinforced with anchors consisting of 4.65m long high tensile steel tendons, 16mm in diameter, connected to steel anchor plates, installed at 0.75m horizontal and vertical centres.

The anchor plates were manufactured from 10mm thick mild steel (S275), of different face dimensions; 100mm x 100m, 200mm x 200mm and 300mm x 300mm. The steel tendons had Lenton treaded tapered ends to hold the anchor plate in place. The plates sizes used at each location are summarised in Table 1. The numbered locations on the front of the wall are shown in Figure 3, with a cross section of the wall shown in Figure 4.

The concrete facing panels were cast with access holes to allow the anchor tendon to protrude at the wall face, allowing ease of access for pullout testing, Figure 5.

Kentledge, in the form of large concrete blocks, was placed on top of the wall to increase the vertical stress in the wall by 20kPa. The backfill consisted of 6I/6J fill compacted in accordance with the Specification for Road Works, Series 600 [5].

While the primary objective of this study was to evaluate the pullout resistance of the anchored earth elements, the face of the wall was also instrumented with Moiré tell-tales and survey targets, Figure 6. The tell-tales would indicate closure of the joints between adjacent panels, while the survey targets would indicate movement of the wall panels.

Figure 2. Image of test wall.

Table 1. Plate sizes at different locations in the wall.

Plate size	Location number
100mm x 100mm	1, 2, 9, 10
200mm x 200mm	5 – 8, 11 – 18, 23 – 26
300mm x 300mm	19 – 22, 27 – 32

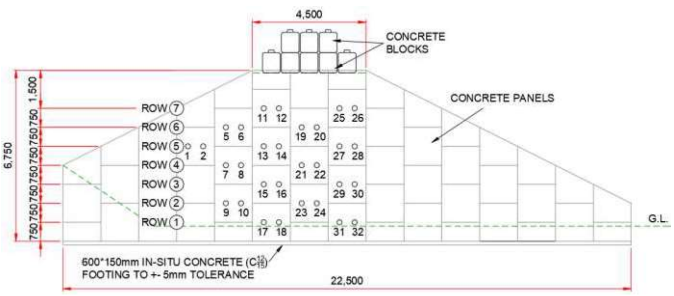

Figure 3. Front elevation of test wall.

2.1 Backfill properties

The Class 6I backfill [5] was produced from locally sourced crushed limestone rock.

Compaction testing in accordance with BS 1377-2 [6] determined the dry weight – moisture content relationship shown in Figure 7. The optimum moisture content was determined as 6.5%, with a maximum dry weight density of 22.3kN/m^3. The insitu moisture content during construction of the wall was about 3.7%, corresponding to a dry weight density of 20.5kN/m^3.

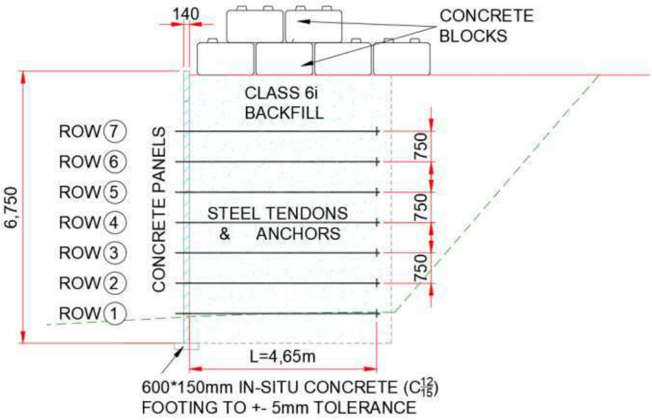

Figure 4. Cross section through the test wall.

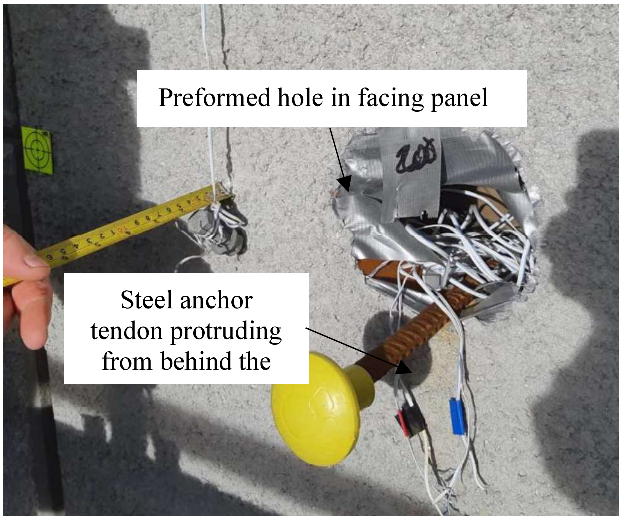

Figure 5. Anchor tendon protruding at face of wall through preformed hole in facing panel.

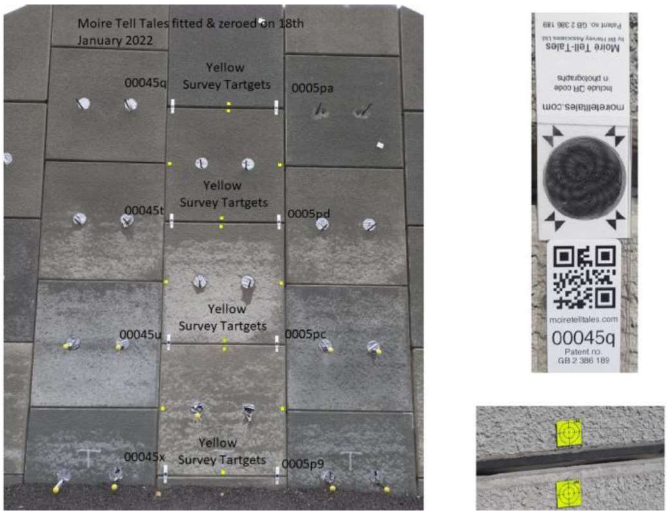

Figure 6. Location of Moiré tell-tales and survey target on front elevation of wall.

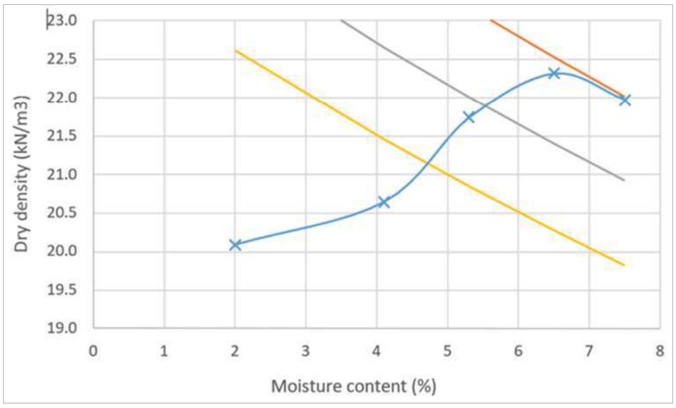

Figure 7. Dry-weigh moisture content relationship for the Class 6I fill used in this study.

Large (300mm x 300mm) shear box testing was conducted in accordance with BS 1377-7 [7]. The samples were prepared by removing all particle sizes greater than 20mm. The fill was compacted in the shear box using standard compaction (2.5kg rammer) at a moisture content of 4.5%, giving a dry weight density of 19.6kN/m^3, corresponding to 88% of maximum dry weight. Normal stresses of 50kPa, 100kPa and 200kPa were used in the shear box testing. The peak angle of friction was measured as 47.8° with an apparent cohesion of 8kPa.

2.2 *Construction of the wall*

The wall was constructed in accordance with EN 14475 [8]. The facing panels were stood vertical, and fill placed and compacted in 150mm layers, using Method 2 of Series 600 [5], until the location of the first layer of anchors was reached. The anchors were then installed, Figure 8, and the process repeated until the wall reached its full height.

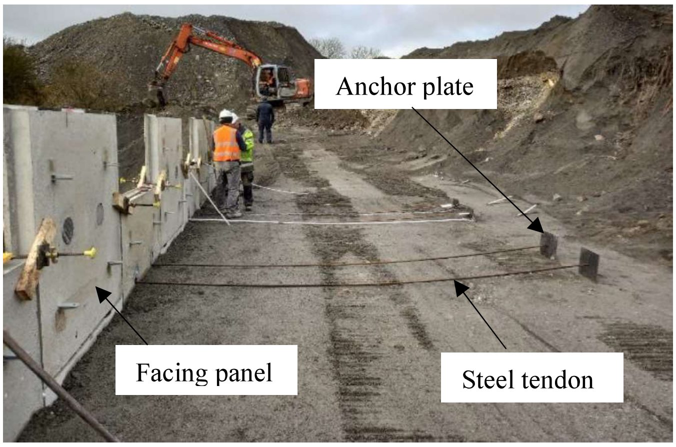

Figure 8. Construction of wall, including installation of anchors.

2.3 *Pullout testing*

Pullout testing of the anchors was conducted approximately 4 months after construction of the wall. Before testing occurred, the kentledge was placed on top of the wall to increase the vertical stress in the backfill.

A jack with a 20 tonne capacity was used to pull out the anchors. The tendons and threaded bars from the jack were connected using bespoke steel 'H' connectors, manufactured from 50mm wide x 10mm thick S275 steel. The 'H' section had a slotted profile to provide sufficient welding to ensure adequate tensile capacity between the tendon & the 15mm diameter threaded bar, Figure 9. The threaded bar, which was connected to the other end of the 'H' connector, passed through the hole in the centre of the jack and was locked off with a loading plate and wing nut.

The displacement of the jack during pullout was measured using a long-stroke linear voltage displacement transducer (LVDT) with a maximum displacement of 125.4mm. The experimental setup during a test is shown in Figure 10.

A preload of 0.5kN, corresponding to 1% of the tensile strength of the test tendon, was then applied. Pullout testing was conducted at 2mm/minute with pullout resistance and displacement recorded at 1-minute intervals. The horizontal displacements and loads were automatically logged by a Hydrotechnic Multi System 5060 data logger.

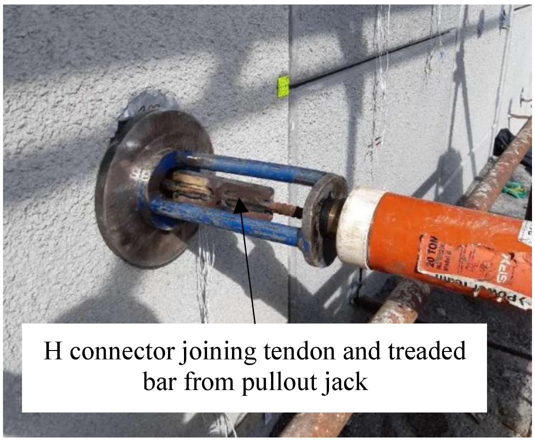

Figure 9. Connection between jack and anchor tendon during a test

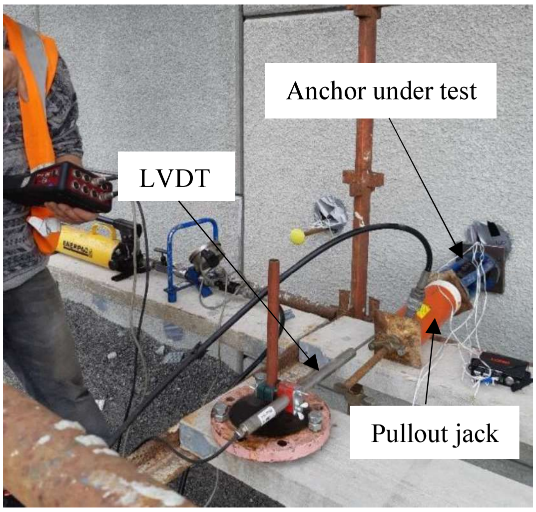

Figure 10. Experimental setup for conducting pullout testing.

3 RESULTS & DISCUSSION

In total 30 pullout tests were conducted. Figure 11 presents four pullout test results, where pullout force is plotted against displacement, for the anchors on Row 6, Anchors 5 ,6, 19 & 20 These anchors were all 200mm x 200mm. Good repeatability was observed in the four test results. The early stiffness, up to a displacement of 10mm, observed during pullout was consistent between all tests. This could be attributed to elastic deformation of the steel tendon, but further study of this is required. There was, however, some scatter in the observed peak pullout resistance, with peak resistance varying between 65 – 85kN and displacement corresponding to peak resistance varying from 20 – 37mm.

The experimental data is discussed in terms of the impact of anchor plate size and vertical stress on the anchors.

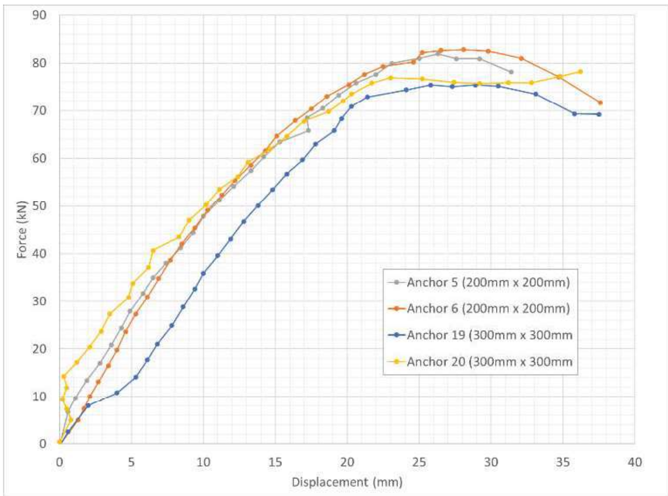

Figure 11. Pullout test results for Row 6 of wall.

3.1 *Impact of plate size on pullout resistance*

In this study three plate sizes were evaluated, 100mm x 100mm, 200mm x 200mm and 300mm x 300mm.

Figure 12 shows the pullout resistance – displacement relationship for 100mm x 100mm (Anchors 9 & 10) and 200mm x 200mm (Anchors 23 & 24) anchors at Row 2 in the wall. Good repeatability in comparable data was again observed. The 100mm x 100mm anchors appear to have a slightly stiffer response at small displacement than the larger 200mm x 200mm anchors. The smaller anchors also display a definite peak pullout, with the post peak behaviour displaying a plastic response or some softening in post peak behaviour. The 200mm x 200mm plates in contrast do not have a definite peak value and the force – displacement curve hardens at higher displacement. The peak pullout resistance was determined using intersecting lines representing best fit lines to the early and later linear portion of the data sets.

Figure 13 presents the pullout resistance – displacement data for Row 3, where Anchors 15 & 16 were 200mm x 200mm plates and Anchors 29 & 30 were 300mm x 300mm plates. Again, good repeatability is found between comparable data. The stiffness of all anchors on Row 3 was similar for small displacements. The smaller plate, Anchors 15 & 16, did not display a peak value, which was again estimated using intersecting lines.

The peak pullout resistance and corresponding displacement for each anchor is summarized in Table 2. In Row 2 the 200mm x 200mm plates had a higher peak pullout force at a slightly larger displacement compared with the 100mm x 100mm plates. However, the increase in peak pullout force was not proportional to the increase in the cross-sectional area of the plate. Similarly, for Row 3, the larger 300mm x 300mm plate had a higher peak pullout resistance than the 200mm x 200mm plates, but again the increase in resistance was not proportional to the increase in plate area.

The smaller 100mm x 100mm plates reached peak resistance at a much lower displacement than the 200mm x 200mm at the same elevation in the wall. In Row 3, both plate sizes, 200mm x 200m and 300mm x 300mm, had comparable displacements at peak pullout resistance.

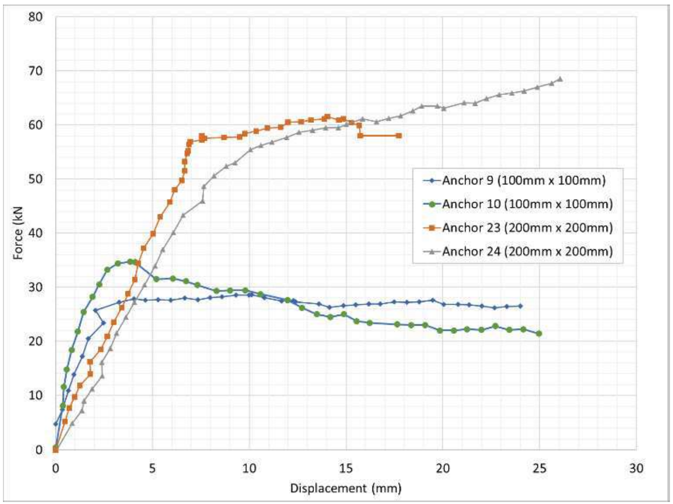

Figure 12. Pullout data for Row 2, Anchors 9 & 10 (both 100mm x 100mm) and 23 & 24 (both 200mm x 200mm).

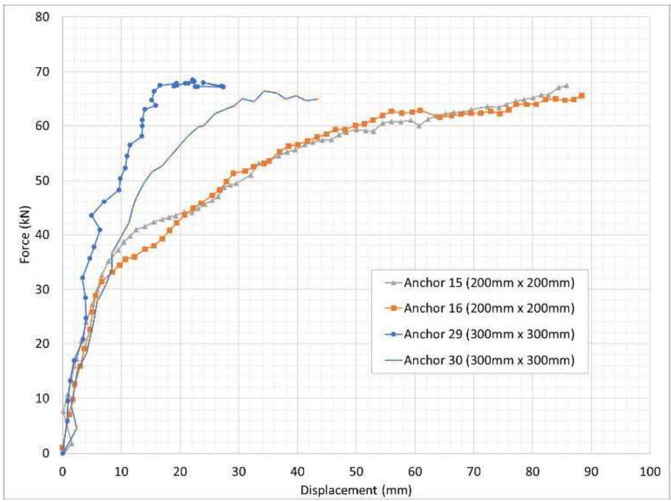

Figure 13. Pullout data for Row 3, Anchors 15 & 16 (both 200mm x 200mm) and 29 & 30 (both 300mm x 300mm).

3.2 *Impact of vertical stress on pullout resistance*

The impact of vertical stress on pullout resistance was assessed by comparing the pullout resistance of similar sized plates located at different elevations in the wall. The vertical stress was determined using the estimated insitu weight density of the fill, 20.5kN/m^3, taking into account the 20kPa surcharge stress at the top of the wall.

Figure 14 & Figure 15 shows the pullout resistance – displacement relation for the 200mm x 200m plates located in Rows 1 – 7 inclusive and 300mm x 300mm plates located in Rows 3 – 6 inclusive respectively. Both plate sizes displayed a linear and similar value of stiffness for a displacement less than 10mm.

Figure 16 presents the relationship between peak pullout resistance and insitu vertical effective stress. Overall, and irrespective of plate size, a reduction in peak pullout resistance with increased insitu vertical effective stress was observed. The reduction in pullout resistance with increased vertical stress, while counterintuitive, was not unexpected. Pullout testing [9, 10] on inextensible steel reinforcement had found enhanced interaction between the reinforcement elements and the surrounding soil at low normal stress, which is attributed to dilation in the well compacted granular fill near the top of the wall [10]. Typically, the interaction between the soil and inextensible reduces vertical stress to a depth of 6m and then remains relatively constant [9].

Table 2. Summary of peak pullout resistance and corresponding displacement for anchors on Rows 2 & 3.

Row	Anchor No	Plate size (mm x mm)	Peak pullout force (kN)	Displacement at peak pullout force (mm)
2	9	100 x 100	28	4
	10	100 x 100	45	4
	23	200 x 200	58	7
	24	200 x 200	54	9
3	15	200 x 200	48	15
	16	200 x 200	54	24
	29	300 x 300	68	18
	30	300 x 300	76	16

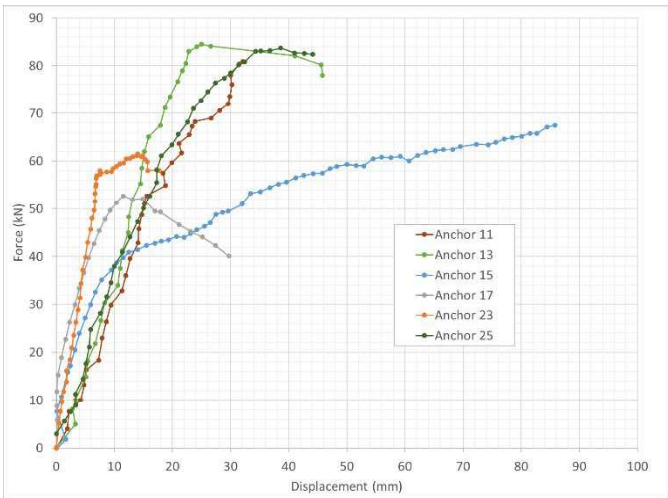

Figure 14. Pullout resistance – displacement relationships for 200mm x 200mm plates.

3.3 *Moiré Tell Tales*

The Moiré Tell Tales were used to measure the vertical panel displacement after the installation of the kentledge on top of the wall. No significant movement of the panels occurred, Table 3.

3.4 *Anchor post-construction excavation and inspection*

The backfill behind the top three rows (Rows 5, 6 & 7) of buried anchor plates was excavated. This action provided the opportunity to inspect the physical state and environment around the anchor plates. The granular backfill was very well compacted, cemented, and difficult to excavate with a spade.

The plates were intact and located in a vertical position, well embedded into the granular backfill. It was difficult to envisage the anchor plates moving through the granular backfill, Figure 17.

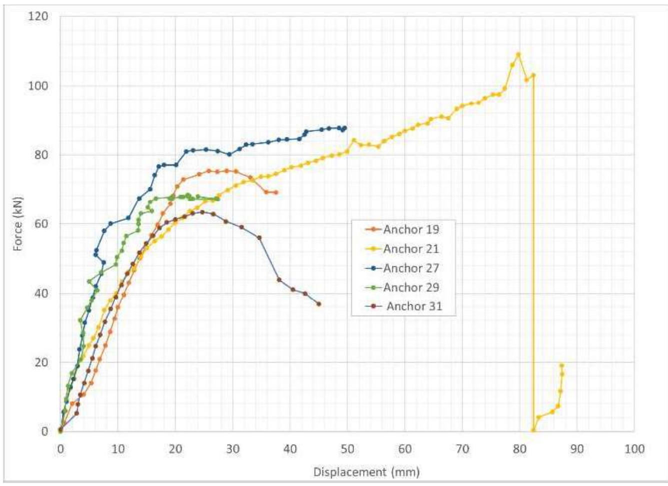

Figure 15. Pullout resistance – displacement relationships for 300mm x 300mm plates.

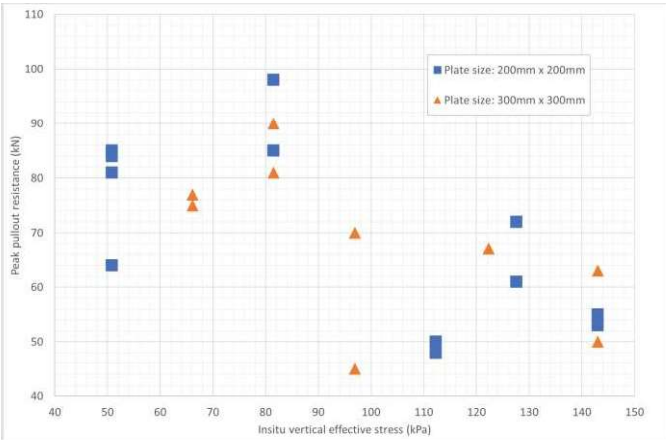

Figure 16. Relationship between pullout resistance and insitu vertical effective stress for 200mm x 200mm and 300mm x 300mm plates.

Table 3. Moiré tell-tales vertical displacement

Moiré Tell Tale no.	Settlement
0005pc	0.1mm
0005p9	0.1mm
00045x	0.3mm
00045u	0.4mm
0005pa	0.4mm
00045q	0.5mm
00045t	0.3mm
0005pb	0.3mm

Row 5 contained all plate sizes, 100mm x 100mm, 200mm x 200mm & 300 x 300mm. The 100mm x100mm plates (Anchors 1 & 2) when exhumed had rotated by approximately 45 degrees from the vertical. The 200mm x 200mm (Anchor 13) & the 300mm x 300mm plates (Anchors 27 & 28) displayed evidence of slight deformation. However, Anchor 14 (200mm x 200mm) was the only plate that displayed any noticeable bending or deflection - approximately 12mm at the centre of the plate, Figure 18.

In this study, geotechnical considerations were found to be secondary to the mechanical characteristics of the reinforcing tendon and anchor plates.

Figure 17. Exhumed Anchor 28.

Figure 18. Deformed Anchor 14 following exhumation

3.5 *Implications for design*

The design of plate anchors is detailed in BS 8006-1 [11]. The length of the tendon is dictated by both internal and external stability considerations. BS 8006-1 [11] suggests minimum lengths for reinforcing elements, typically 0.7 x the height of the structure. No guidance is given on the allowable operational deformation of the wall. BS 8006-1 [11] does suggest that the construction tolerances are limited to ± 25mm over a 4m length.

Adopting a displacement limit of 10 – 20mm in the anchor system would reduce the long-term capacity of the anchors to the range of 30 – 60kN depending on anchor size.

The data presented from this study indicates that peak resistance is not likely to be the controlling factor in design. To ensure that the facing is compliant with the displacement survivability limit state, the facing deflection should be not greater than 20mm.

4 CONCLUSION

This study presents pullout testing on a 6.75m high trial anchored earth wall constructed in Co Offaly. The wall was reinforced with three different size plate anchors, which were connected to the concrete facing units by high tensile steel tendons. The wall had concrete facing panels and the backfill was Class 6I/6J high quality granular material. Kentledge was used to apply a 20kPa surcharge load to the top of the wall.

Good repeatability of the pullout resistance – displacement curves, particularly at displacement less than 10mm, was observed in all tests conducted. However, there was significant scatter in the peak pullout resistance and corresponding displacement. The post peak behaviour was also found to vary, with softening, plastic displacement and hardening all observed. The smaller 100mm x 100mm plate failed at small displacements, less than 5mm, while the displacement at peak resistance for the 200mm x 200mm and 300mm x 300m plates were largely consistent and were in the range 10 – 30mm.

The peak pullout resistance was found to be proportional to the anchor plate size, increasing as the area of the anchor plate increased. The peak pullout resistance also varied with insitu vertical stress, reducing as the vertical stress increased. This response is in keeping with pullout testing on inextensible steel reinforcement reported in the literature [9, 10].

The measured displacement of the anchor may be attributed to elastic deflection of the tendon & anchor plate. However, further analysis of the data is required. The passive resistance of the backfill was secondary to the mechanical properties of the tendons and anchor plates used in this study when high quality granular backfill was used.

When the horizontal deflection was limited to 10 – 20mm, the horizontal force that the anchor can resist was 30 – 60kN, depending on the anchor size. The working resistance of the anchor is considered the best approach to take in analyzing pullout data.

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