Gun Barrel Assessment of a Permanent CFRP Ground Anchor System

MATTHEW SENTRY[1,2], RIADH AL-MAHAIDI[3], ABELMALEK BOUAZZA[2], LEN CARRIGAN[1]

[1] Geotechnical Engineering, Tullamarine, VIC, 3043, Australia. email: matthew@geotech.net.au

[2] Department of Civil Engineering, Monash University, Clayton, 3800, VIC, Australia.

[3] Faculty of Engineering and Industrial Sciences, Swinburne University of Technology, Hawthorn, VIC, 3122, Australia.

ABSTRACT

The development of CFRP strand has enabled the permanent ground anchor industry to research into developing an environmental and chemically resistant permanent anchor system. Research at Monash University into development of permanent CFRP ground anchors has led to a full scale gun barrel assessment of a permanent CFRP ground anchor utilising a specifically designed bond type anchor head system and real time monitoring to provide a greater understanding to the CFRP performance when used in a ground anchor. Results of the test have indicated successful performance of the FRP giving the design engineers a greater understanding of the performance of the CFRP material performs compared to steel strand ground anchors.

Keywords: carbon fibre, ground anchor, anchorage system, gun barrel

INTRODUCTION

This project used the gun barrel technique to establish the performance of a production CFRP strand anchor under a controlled full scale test. The CFRP gun barrel assessment aimed to assess anchor bond performance and the load-extension relationship during the cyclic loading of the anchor.

EXPERIMENTAL APPROACH

Gun barrels are complex structures whereby large loads are applied to a series of strands embedded into a grouted steel pipe and tested to ultimate capacity. Gun barrel tests are full scale systems that can be fully monitored and tested at ground level in a controlled environment. After testing the unit can be dissected and inspected.

Gun barrel design

There are several sections to the gun barrel that require careful design, including the barrel, borehole and stressing head plate. Figure 1 provides the details of the design.

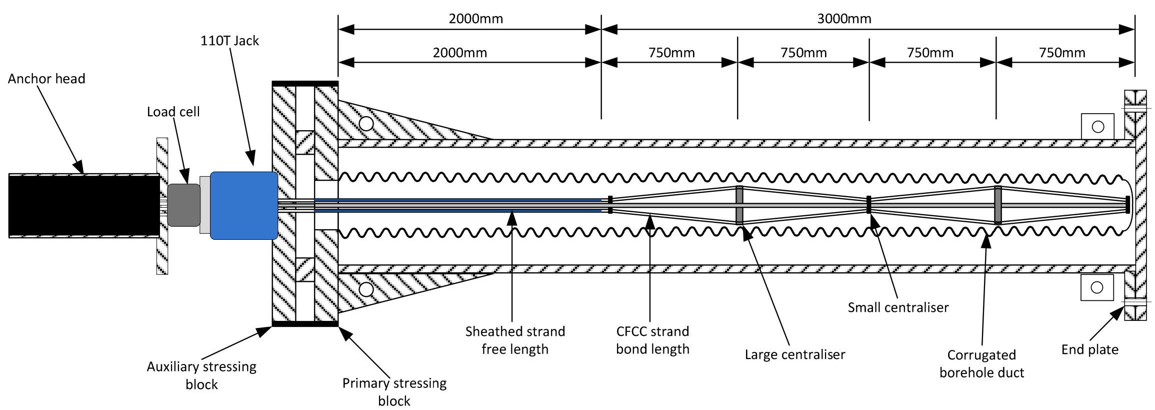

Figure 1: Gun barrel design drawings

Material selection

CFCC (Tokyo Rope) was selected as the CFRP material for the full scale gun barrel assessment. Research by Sentry et al. (2009b) established that this material showed no signs of deterioration under sustained loading in aggressive ground environments. Material properties for the CFCC strand are as per Table 1. A compact reliable anchorage head system has been developed (Sentry and Carrigan, 2009) for CFRP ground anchorage systems for CFRP materials with similar physical characteristics as steel strand (Sentry and Carrigan, 2009). A four strand gun barrel test was selected as the optimum size ground anchor which would provide adequate full scale information without requirements of additional testing equipment and support frames. From previous research (Sentry et al., 2009a) the minimum ultimate breaking load of CFCC has been shown to be between 18% and 38% higher than the manufacturers stated minimum breaking load. As such, the predicted breaking load for a four strand anchor would be in the order of 1100kN. A maximum test load of 800kN was adopted. A cementitious grout mix of 0.45:1 was used. Mixing was done using a high shear colloidal mixer.

Table 1: CFCC Material Properties (after Sentry et al., 2009b)

Property	CFCC
Diameter (mm)	15.2
Effective Cross Sectional Area (m	113.6
Minimum fibre volume ratio	0.62
Fibre Tensile strength (MPa)	4200
Resin Type	Modified epoxy
Resin Tensile strength (MPa)	80
Product	
Tensile strength (MPa)	2200
Elastic modulus (GPa)	141

Method of assessment

Testing was conducted by cyclically loading the CFRP anchor to maximum test load in 10% increments. Load- extension results were recorded by measuring the movement of the anchor head and stressing plate with respect to the gun barrel. The apparent free length of the anchor was calculated (Equation 1). Tendon bond performance was visually assessed by dissecting the gun barrel to identify where tendon debonding had occurred and if the debonding correlated with the calculated apparent free length.

$$App. free\ tendon\ length = \frac{A_t E_s \Delta}{P} \qquad \textbf{(Eq. 1)}$$

Where: A_t = cross sectional area; E_s = manufacture's modulus of elasticity; Δ = elastic displacement of tendon; P = proof load minus datum load (load at 10% proof load, T_w).

A series of strain gauges attached to the individual strands provided valuable insight into the distribution of loads along the length of the anchor.

RESULTS AND DISCUSSION

No strand movement was recorded at the distal end of the ground anchor. In addition, no movements were recorded within the anchor head. As such results were deemed to be accurately recording actual strand movement from within the anchor bond length.

Load-extension

Figure 2 shows the cyclic load-extension results from the 4 strand CFCC gun barrel test. Anchor performance displays a progressive increase in apparent permanent tendon displacement on the completion of each cycle as peak cycle loads increase. CFCC is a brittle-elastic material and the expected linear elastic extensions were observed with every load cycle with creep effects observed at each sustained peak load. Residual permanent extensions were observed upon unloading.

As no movement was observed at the distal end of the anchor all observed extensions at the anchor head was a result of strand elastic deformation. These results are in line with current steel strand load-extensions results indicating that CFCC strand performance is similar to steel strand ground anchors (Sentry, 2010).

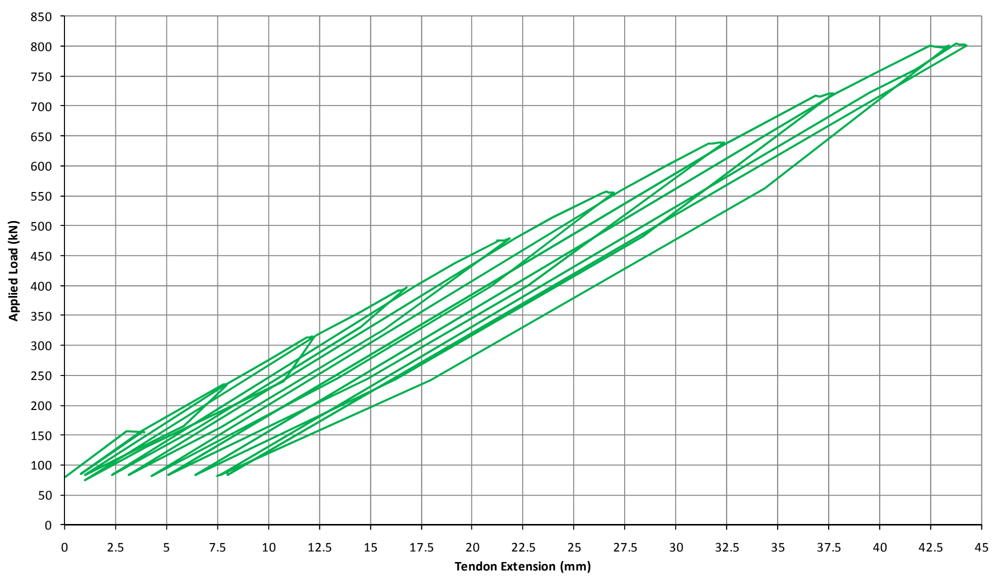

Figure 2: Load-extension results for 4 strand CFCC gun barrel test

Apparent free length and bond performance

From Equation 1, the apparent free length of the anchor as a result of load application and subsequent debonding of the strands within the bond length upon completion of all loading cycles was calculated at 3487mm, indicating that there was an apparent 1513mm of bonded CFCC strand. This apparent free length conformed within the steel strand boundary condition guidelines for apparent free lengths (BSI, 2000). To date there are no CFRP guidelines to assess the apparent free length conditions for permanent CFRP ground anchors.

Dissection of the gun barrel revealed that grout cracking along the strand as a result of progressive debonding terminated between 3.3 meters and 3.5 meters (Figure 3), verifying apparent free length calculations. Radial cracking within the grout was observed from the commencement of the bond length up to the termination of the apparent free length. The dissection of the ground anchor provided a visual check to verify the complete penetration of the grout and the integrity of the anchor post stressing.

Figure 3: Dissection of 4 strand CFCC gun barrel test: location of apparent free length

CONCLUSION

The four strand CFCC gun barrel assessment was successful in obtaining data for the anchor extensions during cyclic loading up to anchor proof load. Extensions were linear for each load cycle. Creep was observed at each sustained load increment. Apparent free length was calculated finding progressive failure within the bonded section of the ground anchor (3487mm into anchor) and conformed to international guidelines for steel strand ground anchors. To date there are no such guidelines for CFRP ground anchors.

No strand pull out was recorded at the distal end of the ground anchor. In addition, no movements were recorded within the anchor head.

Dissection and inspection of the gun barrel's ground anchor and grout post testing verified calculations and data analysis of apparent free lengths confirmed full grout penetration.

Results confirm the performance of CFCC strand as an alternative to steel strand ground anchors.

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