Equipment & Techniques Committee

BRITISH CAVING ASSOCIATION

Anchor Tests 2011

Scope

This report details the complete series of anchor tests designed to find a replacement for the DMM Eco anchor carried out by the BCA Equipment & Techniques Committee during 2011.

Introduction

Following the cessation of production of the DMM Eco anchor it became necessary to source a replacement which would fulfil all the criteria decided by the Committee during their consultative process. The main requirement was that the anchors should attain an axial load of at least 25kN before failure. The logic for this standard was that most, if not all, of the other components in the equipment safety chain would have failed at this loading. As the vast majority of natural caves are in carboniferous limestone it was decided that the initial tests would be carried out in this substrate.

An identical looking product to the DMM anchor was offered by Jonathon Sims who had manufacturing contacts in China. An initial test batch of 200 anchors was acquired and designated "Peco Batch 1". Subsequently, a further production batch of 2000 anchors was ordered designated "Peco anchor Batch 2". As will be observed later in the report, four out of a sample of sixty four Batch 2 Peco anchors suffered catastrophic metallurgical failure below the 25kN threshold.

Further research identified another possible alternative supplied by Bolt Products manufactured in Germany to BS EN 959. The major difference with this anchor is that whilst it was still made with 8mm 316 stainless steel bar the two tangs of the anchor were twisted unlike the parallel bars of the Eco and Peco anchors. Another difference was that the eye of the anchor was slightly smaller than the Eco and Peco anchors although it was still of adequate size.

Method

All anchors were tested in batches of 32. The two types of chemical anchor mortars (i.e. resins) that were used for installing the anchors were RAWL R-KER Epoxy Acrylate Styrene free resin manufactured by RAWL fixings and Allgrip KMR-RES resin which is manufactured by Exchem UK. This is the unsaturated polyester resin in styrene that has been previously used for the setting of Eco anchors.

Test 1 - Peco Anchor Batch 2 – Allgrip KMR-RES - Horseshoe Quarry - Stoney Middleton
Test 2 - Peco Anchor Batch 2 – Allgrip KMR-RES - Ingleton Quarry
Test 3 – Peco Anchor Batch 1 – Allgrip KMR-RES - Ingleton Quarry
Test 4 - BP Anchor - RAWL R-KER - Ingleton Quarry
Test 5 - BP Anchor – Allgrip KMR-RES - Ingleton Quarry
See Appendix 1 - Test 1 (Purple) - Test 2 (Red) – Test 3 – (Green) – Test 4 – (Blue) – Test 5 - (Black)

All the anchors were installed in carboniferous limestone in compliance with the BCA E&T Committee document "Permanent Resin Bonded Anchors – Installation Procedure, Training and Documentation" (IPTD); which is the same as the recommend procedure by both resin manufacturers. The Peco anchors were installed into holes 18mm diameter x 10mm deep. The Bolt Products anchors were installed into holes 16mm diameter x 100mm deep. The holes in Ingleton Quarry were cleaned using water (pressure wash), brushed and washed until all the limestone dust had been removed. They were then dried using absorbent cloth. The holes in Horseshoe Quarry were dry cleaned using a brush and a blower until all the limestone dust had been removed.

Results

Test date: 24th June 2011
Anchor type: Peco Batch 2 (production batch)
Resin: KMR-RES
Location: Horseshoe Quarry - Stoney Middleton
Substrate – Black Layer – Stoney Middleton Sequence
During the test period it became apparent that the substrate was not as uniform or as structurally strong as was initially thought. There were areas where the thin substrate microstructure caused some placements to fail prematurely with resultant delamination. However, even with substrate failure the tests did indicate that the anchor placement system would give reasonable test results in thinly bedded and relatively weak bituminous limestone strata. More concerning was that two Peco anchors failed by fracture of the metal at the lower curvature of the eye. The load at deformation was consistent within a range of 10-16kN giving a mean of 13.6kN. The ultimate failure load i.e. the peak load at which the anchor started to egress from the resin or the load required to extract the anchor from the resin, whichever was higher, was within the range 16-35Kn with a mean of 27.44kN. Although the fracturing of the substrate did result in some low readings the mode of failure was consistently the anchor to resin bond except for the two anchors which fractured at the lower curvature of the eye. Peco anchors No. BCA 0182 and BCA 0004 suffered catastrophic metallurgical failure at 26kN and 16kN respectively.

Test date: 28th June 2011
Anchor type: PECO Batch 2 (production batch)
Resin: KMR-RES
Location: Ingleton Quarry
Substrate – Yorkshire Limestone
32 Peco anchors were randomly selected from the remainder of the batch and set in structurally solid limestone. As there was only one small area of the test bed where substrate failure occurred the results were generally in line with expectations. However, as in the test at Horseshoe Quarry, two Peco anchors fractured at the lower curvature of the eye. The load at deformation was consistent within a range of 11-15kN giving a mean of 13**.**28kN. The ultimate failure load, as described above in the tests at Horseshoe Quarry, was within the range 14 - 47kN. Giving a mean peak load force of 33.22kN. Although the fracturing of the substrate did result in some low readings the mode of failure was again consistently the anchor to resin bond except for the two anchors which fractured at the lower curvature of the eye.

Peco anchors No. BCA 0069 and BCA 0153 both fractured at 18kN and 14kN respectively. The main concern is that the lowest fracture load (14Kn) would technically make the anchor placement the weak link in the rigging system. The anchor in the photograph was cut to remove it from the placement.

Test date: 24th September 2011
Anchor type: Peco Batch 1
Resin: KMR-RES
Location: Ingleton Quarry
Substrate – Yorkshire Limestone

During the test period it became apparent that the chemical anchor mortar had not thoroughly mixed during application into the hole. This resulted in two relatively low readings. Anchor test number 10 was extracted at 26Kn. and anchor test number 13 was extracted at 18Kn. On closer inspection of the chemical mortar it was found to be granular which could indicate that thorough mixing had not occurred or that the resin required a longer curing time. The load at deformation was consistent within a range of 14-18kN giving a mean of 16.3kN. The ultimate failure load i.e. the peak load at which the anchor started to egress from the resin or the load required to extract the anchor from the resin, whichever was higher, was within the range 18-45Kn. with a mean of 34Kn.

Date: 22nd October 2011
Anchor type: Bolt Products 8mm x 100mm twisted stainless steel anchors
Resin: RAWL
Location: Ingleton Quarry
Substrate – Yorkshire Limestone

Thirty three Bolt Products anchors were installed in limestone (somebody couldn't count). During the test period it became apparent that the chemical anchor mortar had not thoroughly mixed during application into one of the holes. The peak load to remove this anchor was 36kN. RAWL have been contacted and from the information supplied by us have initiated an investigation. The failure mode is initially similar to a DMM Eco anchor with elongation of the eye towards the direction of the applied load. However, unlike an Eco anchor as it is extracted from the substrate the anchor twists, and along with it the load cell, until the load is released as the anchor suddenly and violently egresses from the resin. The load then gradually increases until the anchor starts to twist and the process is repeated. This behaviour continues until the anchor is extracted from the substrate. Generally the anchor's failure range was consistent; however anchor test numbers 20 and 26 were below 30kN. As the failure mode is anchor to resin bond this is probably due to poor mixing and adhesion of the resin. The deformation range was 18-23kN. The ultimate failure load i.e. the peak load at which the anchor started to egress from the resin or the load required to extract the anchor from the resin, whichever was higher, was within the range 24 - 47kN with a mean of 35.5kN. From the data gathered from these tests it is evident that the anchor and peak load forces are consistent and similar to the DMM Eco and Peco anchors.

Test date: 2nd November 2011
Anchor type: Bolt Products 8mm x 100mm twisted stainless steel anchors
Resin: KMR-RES
Location: Ingleton Quarry
Substrate – Yorkshire Limestone

As a consequence of the high pull out loads experienced during these tests the mode of failure changed. Normally, in Eco & Peco anchors, the mode of failure is the anchor to resin bond. The Bolt Products anchors, in the majority of cases, experienced substrate failure and the resin/rock bond with it. On a number of the tests cone fracture and delamination of the substrate occurred followed by the failure of the resin to rock bond. However, as demonstrated in the photo opposite even with delamination the anchor placement still held 51.73kN. With the reduced hole size (16mm) the amount of resin in the placement is also reduced. This causes the resin to fragment and become almost pulverised by the load during extraction of the anchor. This pulverisation is more evident lower down in the placement.

An interesting observation was that the anchors were still holding only a little less than their peak loads when half to two thirds of their length had been extracted. In comparisons between the RAWL R-KER and the Allgrip KMR-RES the inclusion of styrene in the formulation means failure loads are 10kN higher with the Allgrip KMR-RES resin.

Another interesting observation was that the shank of the Bolt Products anchor unwound and elongated under loads approaching 50kN. (5th anchor from right picture below). The deformation loads were similar to the previous test. The ultimate failure load i.e. the peak load at which the anchor started to egress from the resin or the load required to extract the anchor from the resin, or substrate failure, whichever was higher, was within the range 32 - 63kN with a mean of 44.91kN.

Conclusions

From the data gathered from these tests it is evident that the combination of the Bolt Products 8mm twisted stainless steel bar anchor and the Allgrip KMR-RES produces strength well in excess of both the Eco and Peco anchors. Also Allgrip KMR-RES is far superior to the anchor manufacturers recommended resin. The reason the anchor manufacturer specifies the RAWL R-KER resin is that in Germany the use of styrene based resins is illegal for Health and Safety concerns. There is no such restriction in the UK.

The graph of ascending extraction loads in Appendix 2 demonstrates the difference in peak load force between the Bolt Products anchors installed with RAWL fixings resin and Allgrip KMR-RES. The graph of ascending extraction loads in Appendix 3 shows the comparative extraction loads of the two batches of Peco anchors and in Appendix 1 a comparison of all five test series.

Future Objectives

1. To test a number of the Bolt Products anchors with KMR-RES in shear (radial).
2. To conduct tests of anchor strengths in other weaker substrates as defined by the Equipment and Techniques Committee.

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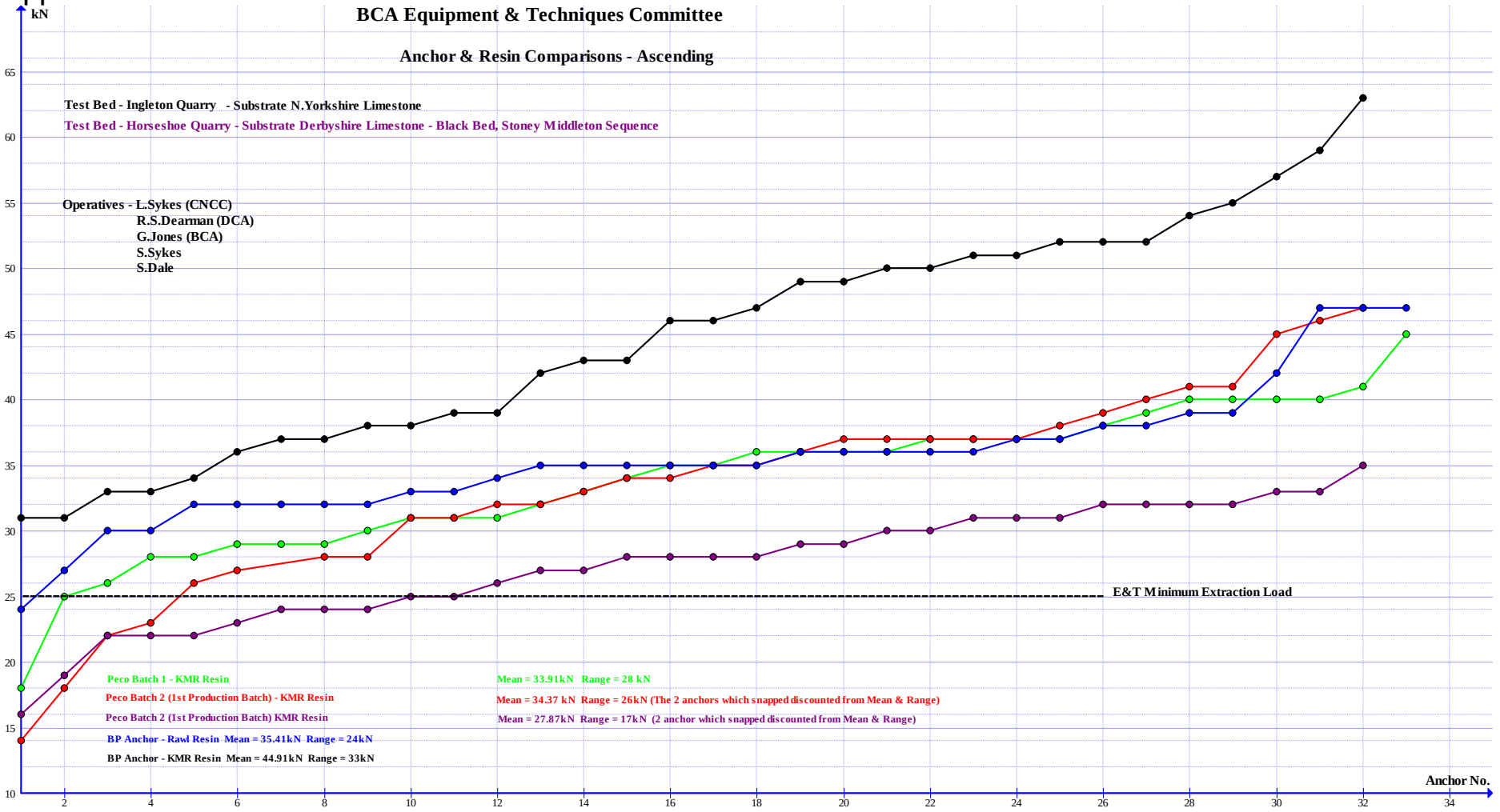
Anchor test team: R.S. Dearman, L. Sykes, G. Jones, S. Sykes, S. Dale

Report compiled by L. Sykes, R.S. Dearman
Photographs: G. Jones, L. Sykes

Appendix 1


BCA Equipment & Techniques Committee
Anchor & Resin Comparisons - Ascending
kN
Test Bed - Ingleton Quarry - Substrate N.Yorkshire Limestone
Test Bed - Horseshoe Quarry - Substrate Derbyshire Limestone - Black Bed, Stoney Middleton Sequence
Operatives - L.Sykes (CNCC)
R.S.Dearman (DCA)
G.Jones (BCA)
S.Sykes
S.Dale
E&T Minimum Extraction Load
Peco Batch 1 - KMR Resin
Mean = 33.91kN Range = 28 kN
Peco Batch 2 (1st Production Batch) - KMR Resin
Mean = 34.37 kN Range = 26kN (The 2 anchors which snapped discounted from Mean & Range)
Peco Batch 2 (1st Production Batch) KMR Resin
Mean = 27.87kN Range = 17kN (2 anchor which snapped discounted from Mean & Range)
BP Anchor - Rawl Resin Mean = 35.41kN Range = 24kN
BP Anchor - KMR Resin Mean = 44.91kN Range = 33kN
Anchor No.
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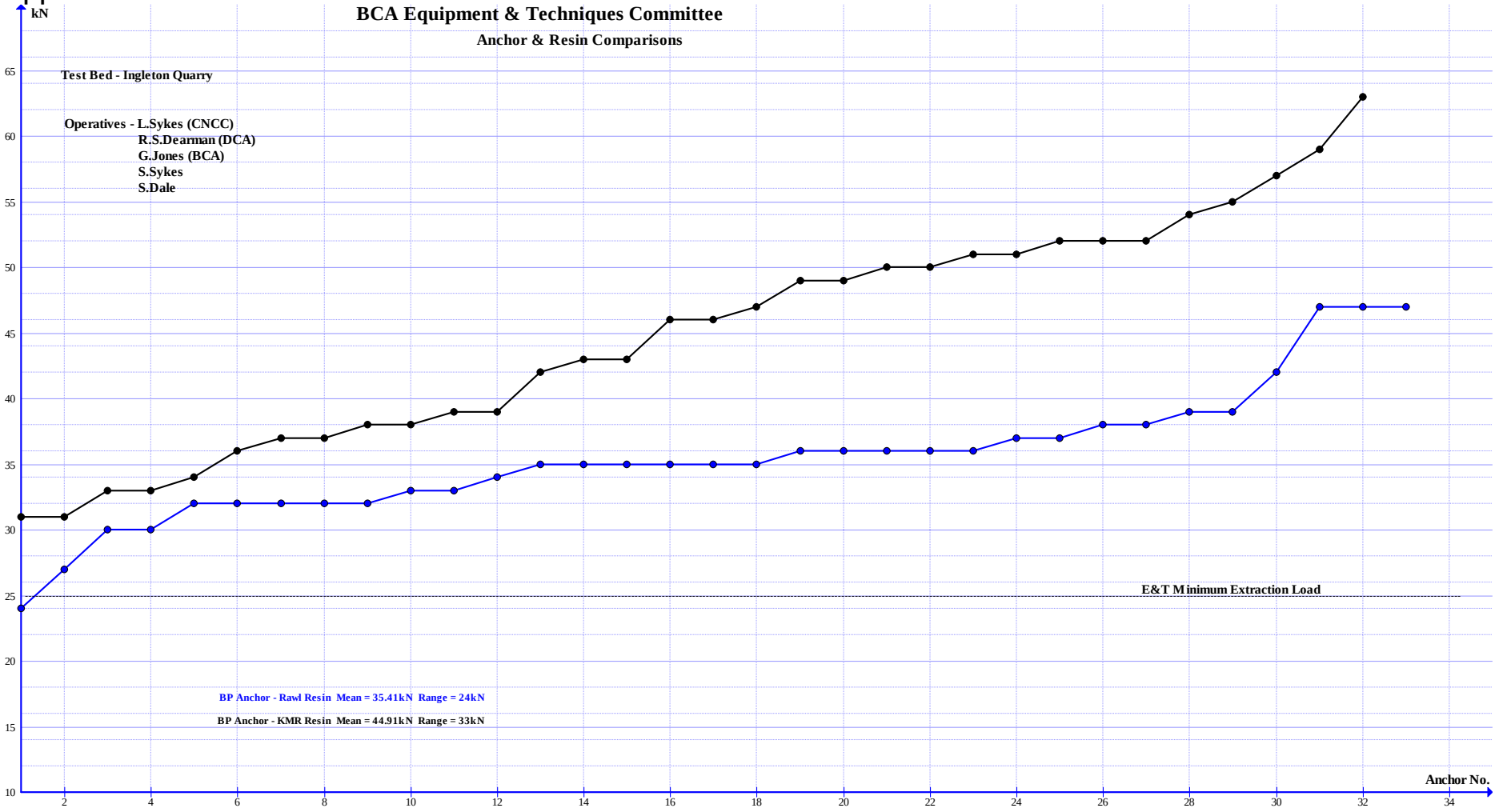
Appendix 2


BCA Equipment & Techniques Committee
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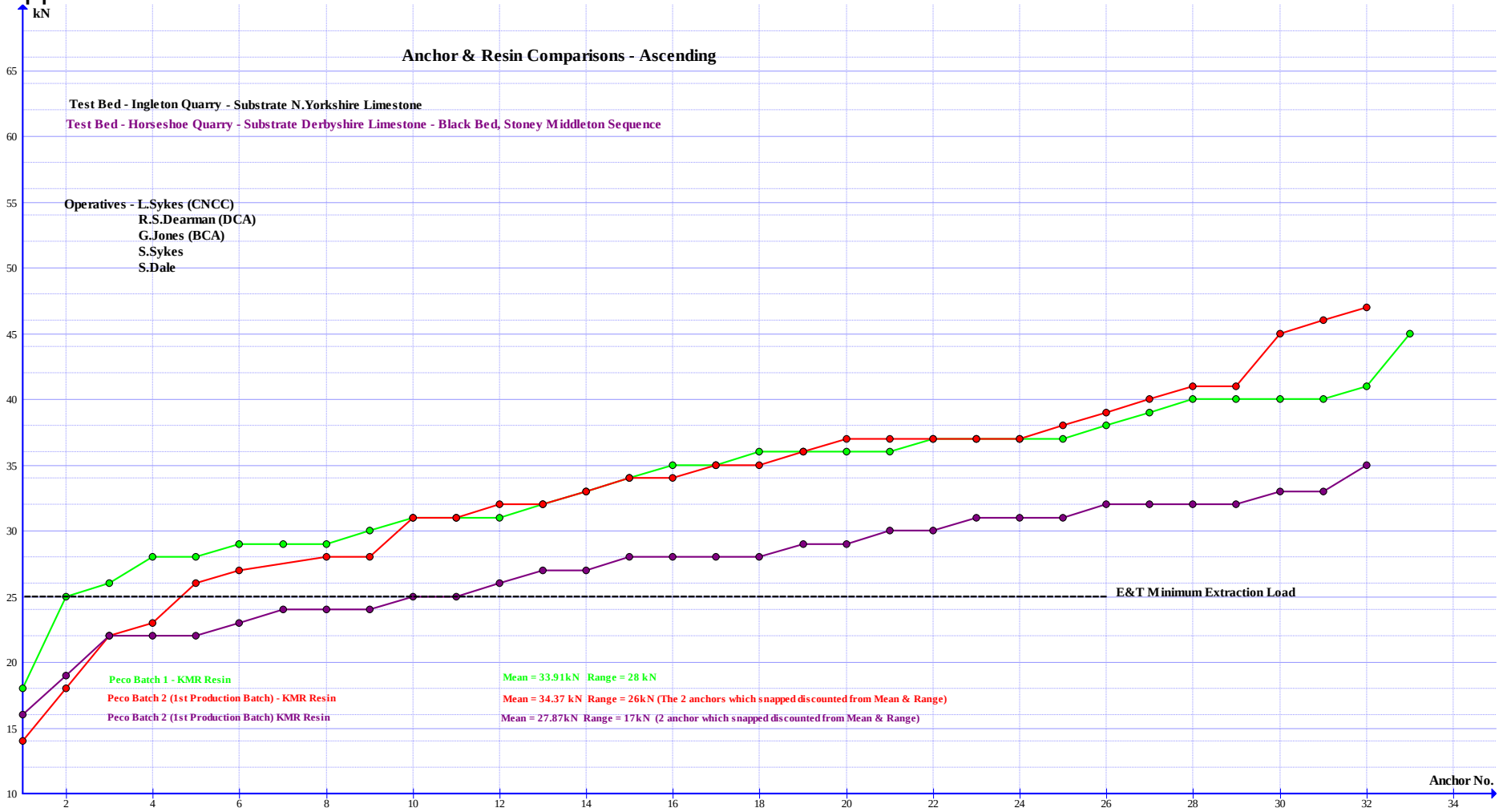
Appendix 3


kN
Anchor & Resin Comparisons - Ascending
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Test Bed - Horseshoe Quarry - Substrate Derbyshire Limestone - Black Bed, Stoney Middleton Sequence
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