TESTING OF BOLT PRODUCT ANCHORS USING FISCHER RESIN AT PENWYLLT QUARRY, SOUTH WALES

Introduction

1 The two objectives of the tests were to demonstrate the adequacy of Fischer resin in conjunction with Bolt Product anchors when used in line with normal procedures together with the performance of the resin under wet conditions. These objectives were investigated through two test beds in one quarry. A subsidiary objective was to also show that South Wales limestone would behave adequately under test.

Testing

2 The first test bed was created with a set of 33 Bolt Product Type 304 Stainless Steel anchors with 100mm long shafts (Ref no GP8 -100-16A2) were placed in the quarry using Fischer V 360 S resin in two batches. The first in early November 2014 consisted of 5 anchors. The second on 29 November 2014 consisted of 28 anchors. To maintain speed of placing, only anchor 60 in the second batch was placed in a notch; the rest were not. All the anchors in the first batch were placed in notches. The final anchor was placed by 12.50 pm on 29 November. The second test bed was created with a further 12 out of 32 anchors were placed in the afternoon of 29 November with a different technique to test the influence of water on the curing of the resin. (This left a potential need to place a further 20 anchors to complete the second test bed of 32.)

3 The placement procedure for the first test bed was to drill the holes using a 16mm SDS drill, check for depth, blow the holes free of dust, then wash them several times using water and a bottle brush before notionally drying the hole using a chemise cloth. The anchors were degreased using lighter fluid and paper towel. Each hole was filled with resin and the anchor placed into the hole. A small sample of resin was taken in a short length of 15mm OD clear plastic pipe to provide for a reference if required and as a check against poor mixing. Records were also kept of which anchor was placed with which resin. The cartridges of resin were placed upright for approximately 2 hours before use to encourage any air within the two compartments of the cartridge to rise to the top and thus be expelled first. There was no indication of poor resin mixing at any point during the placement of the anchors. (Cartridge B had its nozzle changed since the resin had set in the time gap between placements of anchors 106 and 107.) Surplus resin was wiped away leaving a smooth profile. Two holes were found to have visible quantities of water in them. Owing to time constraints, anchors 110 and 118 were placed in them without removing the water.

4 The placement procedure for the second test bed was to drill each holes using a 16mm SDS drill, check for depth, blow the holes free of dust, then wash them several times using water and a bottle brush before finally filling each hole with water. Fischer resin was then placed in each hole to displace the water followed by a Bolt Product anchor.

5 The set of 33 anchors in the first test bed were extracted with an axial force on 30 November 2014. The pulling order reflected to a limited extent the placement order such that the resin for every anchor had had at least 24 hours curing time. The temperature was not measured but the day was mild with sunshine. The records for Cross Hands, some 30km to the east and at 170m ASL (compared to the quarry at 350m) indicate the minimum overnight temperature was 6.1C whilst those for Llangorse, some 30km to the west and at 250m ASL indicate the minimum temperature was 9.2C. This level of temperature is not thought to significantly impact on the curing time of the resin (Fischer claim 90 minutes for 5 to 10C) in relation to the 24 hour period.

6 The subsequent sub set of 12 anchors in the second test bed was extracted with an axial force on 18 April 2015. The delay in extraction was initially due to low temperature weather making the placement of the remaining 20 anchors unadvised because of the potential adverse effect on curing time. It was subsequently accepted by BCA's E&T Committee at its meeting on 15 March 2015 that if the sub set of 12 anchors performed acceptably and also were normally distributed, then there would be no need to place and test the remaining 20 anchors of the set. The results from this sub set were found to conform with this criteria so the remaining 20 anchors were not required.

Results

7 The peak forces recorded and other related records are given in Table 1. Related photos and movies, together with the spread sheet data calculations can be obtained from Bob Mehew. (Print outs and electronic copies will be lodged in the British Caving Library.)

8 The data from the set of anchors in the first test bed was tested for being normal distributed. The analysis indicated that complete set of anchors was not normally distributed. It is noted that Anchor 110 which failed at 10.2kN was thought to have not had its hole properly cleaned; the cured resin surface being significantly different to other resin samples in having sub millimetre sized bubbles sunken into the resin (hence reducing the resin to rock contact area). Excluding Anchor 110 from the normal distribution analysis produced a positive result. The mean value for the peak force to extract the remaining 32 anchors in the first test bed was 38.6kN with a standard deviation of 5.0kN (13% of mean). The 5% fractile value was 28.2kN which is comfortably above the acceptance criterion of 15kN for an axial pull.

9 Given the rejection of Anchor 110, Anchor 118 was also discounted as it also had water in the hole, even though it failed at a peak force of 39.8kN. This points to care being required in ensuring drilled holes are properly cleaned. Given the test bed situation where two people were working on the holes at the same time, it seems less likely that such a mistake might arise down a cave where work on a pitch is usually limited to one person. Following a review post the first report, it was found that the exclusion of both Anchors 110 and 118 from the normal distribution analysis produced a marginally negative result. The mean value for the peak force to extract the remaining 31 anchors in the first test bed was 38.7kN with a standard deviation of 4.9kN (13% of mean). The 5% fractile value was thus 28.5kN which is comfortably above the acceptance criterion of 15kN for an axial pull.

10 E&T's acceptance criteria is

> *The standard for acceptance of an anchor type on the basis of an axial load is based on the 15kN axial load value as cited in Section 4.3.1 of the Mountaineering Equipment – Rock Anchors – Safety requirements and test methods BS EN 959 : 2007, as computed as the 5% fractile value as specified in Section 4.2 (3) of the Euro Code Basis of Structural Design Standard BS EN 1990 : 2002 from the results of a batch test of a minimum of 5 anchors provided there is supplementary information showing the distribution of results follows a normal distribution, else the minimum size of the batch test should be 32.*

So either the batch size needs to be 32 without normal distribution or above 5 with normal distribution. Since the results are very close, the force analysis is based on the reduced set of 31. Table 2 shows summary data for the range of anchors placed under the NCA and BCA schemes. Fischer V 360 S resin gave a better performance than KMR resin, assuming the difference in rock has no impact.

11 The data from the set of 12 anchors in the second test bed was tested for being normal distributed. The analysis indicated that this complete set of anchors was normally distributed. As a consequence, in accord with BCA's E&T view, no further anchors were placed for testing in this second test bed.

12 The mean value for the peak force to extract the 12 anchors in the second test bed was 35.6kN with a standard deviation of 5.4kN (15% of mean). The 5% fractile value was thus 22.4kN which is comfortably above the acceptance criterion of 15kN for an axial pull. These results are also incorporated in Table 2. Although there is a substantial reduction from 28 to 22kN by using Fischer V 360 S resin in 'wet' conditions, the reduction remains well above the acceptance criteria.

Observations

13 Several observations were made whilst pulling the anchors in the first test bed. The first was that the twisted shaft causes the anchor to turn on being extracted, as had been noted before. The design of the BCA anchor puller is such that this twisting force is transmitted through the U bolt and up the threaded bar shaft to the joint between it and the load cell. What was noticeable was that in many cases it was clear that the resin metal bond had broken and that the anchor was initially being extracted whilst leaving the resin in place. But part way out this mode of extraction suddenly changed and some, perhaps half of the resin in the hole was then pulled out, seemingly attached to the anchor. From memory, this change in mode was often around the same time that spalling of the rock became significantly. A few anchors came out and left the hole clear such that one could see down the hole. These showed the resin in place and with a neat imprint of the anchor. It would thus seem that a significant failure mode sequence was first the metal / resin bond failed. However the anchor was still held well in place by the mechanical interference between metal and resin. But after part extraction of the anchor, the remaining extraction would cause the resin / rock bond to fail in the top half of the hole whilst also causing the rock in the top 2 to 5 centimetres to spall. It would be interesting to see what force would be required if the twisting is restrained as might occur in a real life failure such as a falling person. But the BCA puller cannot be modified o safely carry such a load.

14 The second set of observations from the first test bed related to the degree of spalling occurring on extraction and the extent to which the hole was reusable for placing another anchor. The BCA puller was specifically designed to place the reaction force back into the rock well away from the zone of potentially affected rock. It is not clear if an extractor placing this reaction force back into the rock close to the anchor would substantially reduce the degree of spalling. Around 50% of the holes suffered sufficient spalling to make the location not reusable. This would make the anchor unattractive on conservation grounds.

15 The third observation from the first test bed is that failure to properly clean a hole before placing the resin can cause the anchor to system to significantly reduce its strength.

16 It was observed that the mode of extraction of anchors in the second test bed was the same as for the first test bed. However around 66% of the holes were considered reusable. It is postulated that this increase may be due to the lower mean value for the peak force to extract the anchors in the second test bed. But it is suggested that a 66% reusable is still unattractive on conservation grounds.

17 In all cases, the behaviour of the limestone represented by the Penwyllt Quarry bed reflected experiences in Yorkshire and Mendip limestone.

Conclusions

18 Fischer V 360 S resin is an acceptable alternative resin when used with Bolt Product anchors, even when placement conditions reflected the extreme case of using resin to displace water in flooded holes.

19 The testing indicates that simple extraction of Bolt Product anchors will create extensive spalling such that the vast majority of hole locations will be not reusable. It is suggested that this makes Bolt Product anchors are unattractive on conservation grounds.

Acknowledgements

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Table 1 Type 304 BP anchors using Fischer V 360 S resin Penwyllt 29 & 30 November 2014 and 18 April 2015

Pulling order	BP no.	Peak force kN	comment	notched	resin sample	resin	reusable	location	photos	
1	60	36.46		yes	before & after	B	no	0	2568, 2571 to 76	
2	58	26.84		no	after	A	no	0	2568, 2577 to 79, 81	
3	59	41.01		no	after	A	no	0	2568, 2582 to 85	
4	56	41.78		no	after	A	no	0	2568, 2586 to 93	
5	57	36.51		no	after	A	yes	1	2568, 2594 to 98	
6	101	25.26		no	after	B	yes	1	2570, 2599 to 2604	photos show 111 incorrectly numbered
7	102	43.87		no	after	B	yes	1	2570, 2605 to 09	
8	103	37.61		no	after	B	yes	1	2570, 2610 to 12	note 12 shows resin at bottom of hole
9	104	36.53		no	after	B	yes	1	2569, 2613 to 16	
10	105	30.02		no	after	B	yes	1	2569, 2617 to 21	
11	106	37.24	1st movie from note made at time, shows time in sync between cameras	no	after	B	yes	1	2569, 2622 to 26	
12	127	44.46	2nd movie based on times of cameras, placed preceding week	yes	no	A	?	0	2627 to 30	
13	128	39.93	placed preceding week	yes	no	?	?	0	2631 to 36	
14	107	40.93	3rd movie based on times of cameras	no	after	B new nozzle	?	0	2637 to 42	note 42 shows resin at bottom of hole
15	109	39.84		no	after	B new nozzle	?	0	2644 to 55	

16	125	43.12	placed preceding week	yes	no	A	?	0	2656 to 60	
17	108	37.36		no	after	B new nozzle	no	0	2661 to 83	
18	110	10.24	found with water in hole, now ? If properly cleaned	no	after	C	yes	1	2684 to 89	85, 6 & 7 show curious surface to resin indicative of poor bonding to rock
19	123	46.16	placed preceding week	yes	no	A	yes	1	2690 to 93	
20	111	42.04		no	after	C	yes	1	2694 to 98	note these photos are correctly labelled
21	112	38.49		no	after	C	?	0	2699 to 702, 04 & 05	note 705 shows resin at bottom of hole
22	115	38.5		no	after	C	?	0	2706 to 14	
23	114	41.91		no	after	C	yes	1	2722 to 28	
24	113	37.19		no	after	C	no	0	2729 to 37	
25	118	32.85	water logged hole	no	after	C	yes	1	2739 to 41	
26	122	47.36		no	no	A	no	0	2742 to 45	
27	117	37.52		no	after	C	no	0	2747 to 51	note 51 shows resin at bottom of hole
28	116	37.17		no	after	C	no	0	2752 to 57	
29	129	35.75	placed in vertical face	no	after	C	no	0	2758 to 64	
30	130	35.42	placed in vertical face	no	after	C	yes	1	2765 to 67	
31	119	39.26	placed in vertical face	no	after	C / D	yes	1	2768 to 70	
32	120	44.27	placed in vertical face	no	after	D	yes	1	2771 to 74	
33	124	41.14	placed in vertical face into notch, placed preceding week	yes	no	A	yes	1	2776 & 77	
							sum	16		

									2793 to 99	photos of field note book records
									2790	photo of all anchors
									2792	photo of all resin samples
									2563	location of work
							based on photos			
1	126	33.08	placed with resin displacing water filled in hole	no	after	D	yes	1	3488 to 89	
2	161	39.67	placed with resin displacing water filled in hole	no	after	D	no	0	3486 to 87	
3	162	37.32	placed with resin displacing water filled in hole	no	after	D	yes	1	3483 to 85	
4	163	39.26	placed with resin displacing water filled in hole	no	after	D	yes	1	3482	
5	164	40.66	placed with resin displacing water filled in hole	no	after	D	yes	1	3480 to 81	
6	165	28.68	placed with resin displacing water filled in hole	no	after	D	yes	1	3479	
7	166	36.75	placed with resin displacing water filled in hole	no	after	D	no	0	3473 to 75	
8	167	28.3	placed with resin displacing water filled in hole	no	after	E	yes	1	3476 to 78	
9	168	30.87	placed with resin displacing water filled in hole	no	after	E	yes	1	3469 tp 72	
10	169	28.83	placed with resin displacing water filled in hole	no	after	E	no	0	3467 to 68	
11	170	42.58	placed with resin displacing water filled in hole	no	after	E	no	0	3463 to 66	
12	172	41.5	placed with resin displacing water filled in hole	no	after	E	yes	1	3460 to 62	
							sum	8		

Table 2 Summary Data for all resin placed anchors used in the NCA & BCA Scheme

Anchor Type	*No. tested*	*mean kN*	*SD kN*	*% SD*	*k*	*5% fractile value kN*
DMM Eco	*23*	*39.8*	*9.5*	24	*2.16*	*19.4*
Pico trial batch	*33*	*33.6*	*5.2*	15	*2.08*	*22.8*
Pico batch 2 Horseshoe Quarry #	*30*	*27.9*	*4.1*	15	*2.08*	*19.4*
Pico batch 2 Ingleton #	*30*	*34.9*	*6.2*	18	*2.08*	*22*
Bolt Products / Rawl resin	*33*	*35.2*	*4.7*	13	*2.08*	*25.4*
Bolt Products / KMR resin	*32*	*44.9*	*8.7*	19	*2.08*	*26.8*
S Wilson field work using Fischer	*36*	*35.7*	*1.1*	3	*2.04*	*33.5*
BP / Fischer resin Penwyllt quarry &	*31*	*38.7*	*4.9*	13	2.08	28.5
BP / Fischer resin Penwyllt quarry flooded holes	12	35.6	5.4	15.0	2.4	22.4

excluded metal failure results
& excluded wet hole results