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British Mountaineering Council

TECHNICAL NOTE TCN 01/11

BMC ANCHOR TESTING REPORT

SUMMARY

In 2007 the BMC set up an anchor testing facility at Horseshoe Quarry in the Peak District. The aim was to compare the performance and longevity of different anchor systems placed in natural stone, and also to investigate methods of sustainable bolting.

The findings of this interim report are that staples are the poorest performing anchors in the test. The best performing are those manufactured by Bolt Products, and Fixe anchors when used with a glue capsule. Neither repeated loading nor 1 year's exposure to the weather noticeably weakened any test anchors. Future test results should indicate whether longer exposure to the elements has any significant effect.

A practical method of sustainable bolting has yet to be devised.

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1 INTRODUCTION

Following meetings of the BMC Bolts Working Group (BWG) and the decision to purchase a number of anchors for donation to local Bolts Funds in 2007, it was felt worthwhile that the BMC set up an anchor testing facility at Horseshoe Quarry in the Peak District.

The aim of the project was to compare the performance of different systems when placed in natural stone, and to evaluate the longevity of each system. A secondary objective was to explore the possibility of sustainable bolting – that is, systems which enable weakened anchors to be removed and the original hole to be re-used.

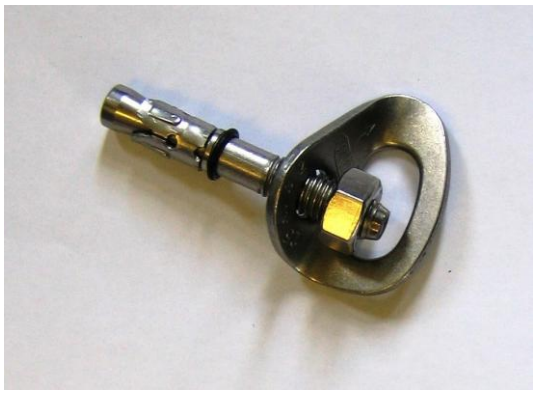
2 METHOD

A flat solid area of limestone was located at the quarry, and permission was granted to place anchors in agreement with Natural England. Three criteria were used in selecting the location: good, solid rock quality; avoiding fossil features; out of the way of the main path to reduce the tripping hazard. Anchors were placed vertically in the quarry floor at the designated site.

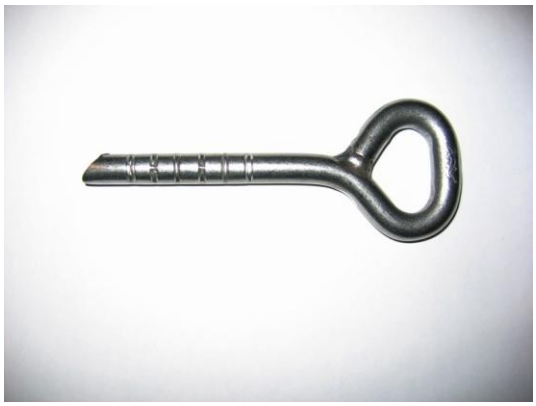
Horseshoe Quarry test site.

A realistic and achievable testing programme was chosen, based around the testing equipment available. Axial or pullout testing up to 20kN load gives a quick and easy indication of whether a system is likely to achieve the equivalent to the minimum standard required for EN and UIAA certification. The systems selected for the full test programme are outlined below:

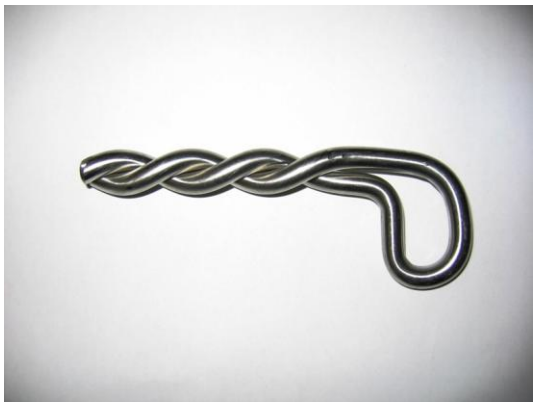
Expansion bolts		
M2	Petzl 12mm x 67mm A4 SS	
Resin anchors		
G1	Fixe AISI304	Hilti HIT HY 150 resin
G2	Fixe AISI304	Masonmate epoxyacrylate hammer-in capsule
S	Staple AISI316	Epoxyacrylate cartridge resin
P1	BP 8mm x 100mm AISI304	Polyester cartridge resin



M2: Petzl 12mm



G1/G2: Fixe AISI304



P1: BP 8mm

The following tests were planned, with the objective to test 3 samples of each system per test:

Test	
T1	Tensile test, approx. 1 week after placement
T2	Tensile test, approx. 1 year after placement
T3	Tensile test, approx. 5 years after placement
T4	Tensile test, approx. 10 years after placement
T5	Tensile test, approx 1 year after placement, after 20 x 8kN proof loadings

For each test, the following possible failure modes were identified and recorded along with the maximum load recorded during the test:

Failure modes	
A	No failure, exceeded tester capacity of 20kN
B	Pullout, Anchor-resin bond failure (resin left in hole)
C	Pullout, Resin-rock bond failure (resin attached to anchor)
D	Pullout of expansion bolt (local rock failure)
E	Anchor material failure (breakage of bolt itself)
F	Rock cone fracture (large rock failure)

In addition, the following were tested on an ad hoc basis as a result of being placed as part of various bolting workshops:

Expansion bolts		
M1	Petzl 10mm x 58mm A4 SS	
M3	Masonmate 10mm x 80mm SS	
M4	Screwfix 10mm x 100mm Zinc coated	
Resin bolts		
E	DMM Eco anchor, 18mm x 100mm AISI316	Hilti HIT HY 150 resin
P2	BP 6mm x 80mm AISI304	Polyester cartridge resin

When placing the anchors, a decision was made to place these based on normal practice employed by established bolters, rather than strictly adhering to manufacturer's advice. In the case of expansion bolts, this meant tightening the nut until they "felt" correct rather than using a spanner set to the recommended torque. Although this may not produce the best results, it does reflect common practice.

The procedure for placing these anchors was to blow the dust out of the hole, then to hammer in the anchor with the nut and hanger in place. The nut was tightened by feel, and then the hanger and nut removed. For testing, a standard industrial eyebolt was screwed onto the exposed stud.

For resin bonded anchors, it is well known that the cleanliness of the hole is critical to the anchor strength [1]. The cleaning procedure was to blow debris from the hole using a blow pump, and then brush the inside using a wire hole cleaning brush. This procedure was completed at least 3 times for each hole.

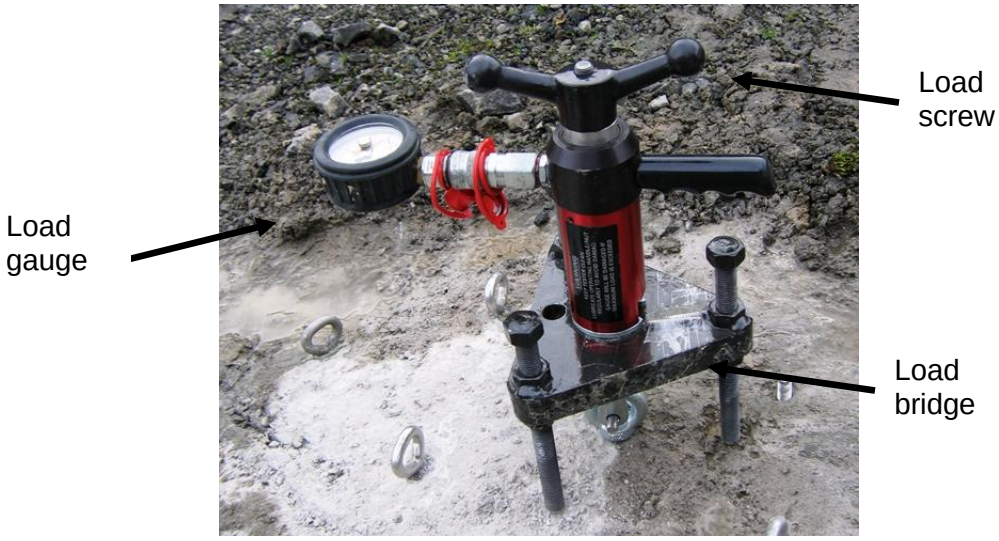
Anchors placed using cartridge resin had a sample of resin taken to ensure it had mixed and cured correctly. The first part of each resin application was discarded as per the manufacturer's advice.

The resin capsules are designed to be used with threaded anchor rod, which is spun in using a power tool and attachment. Using a one piece eyebolt as the anchor makes this impractical without manufacturing a special adapter. Placement therefore followed the practice used by the main employers of this system for climbing anchors in the UK.

The procedure was to place the capsule in the hole and then hammer the anchor in on top of it, turning the anchor between blows. The anchor was then fully rotated at least 10 times, and moved in and out to try and ensure both good mixing of the resin and to encourage the resin to key into the notches in the anchor leg.

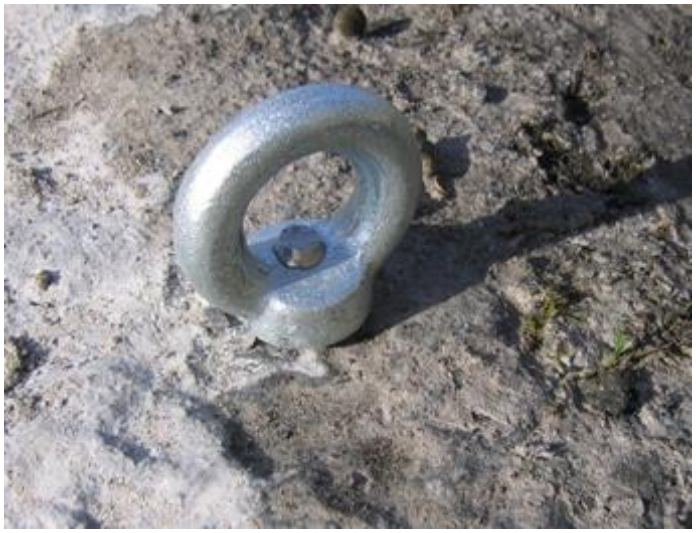
The only anchors which were not placed by the author were the home-made staples, which were placed by an experienced user and manufacturer of this anchor type. These were produced and installed using typical methods and techniques for this anchor.

Anchors were subjected to an axial (pullout) load using a Hilti 2000 Anchor Tester and a custom built load spreading bridge. The maximum load capacity of the tester was 20kN. The load spreading bridge was custom designed to allow rock or substrate cone failure by not constraining the substrate. Standard load spreading bridges supplied with the tester are not strong enough for the job, especially when used on rough rock surfaces. The custom built bridge allows the load to be lined up in the correct direction despite irregular angles on the surface of the rock.



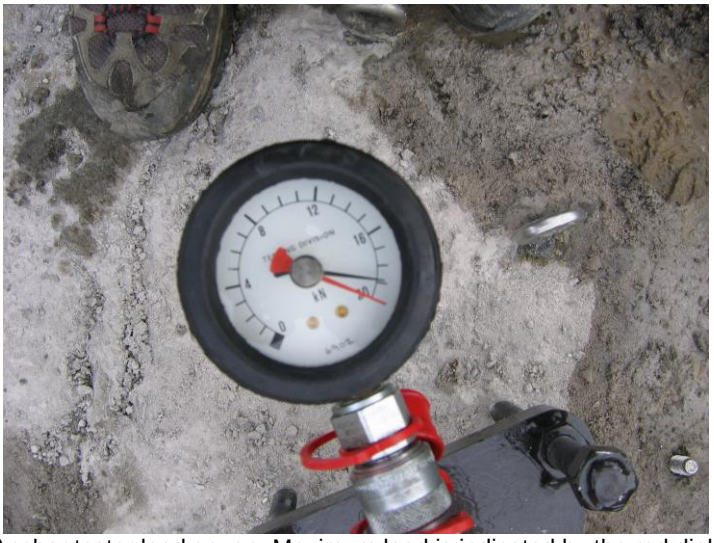
Hilti 2000 Anchor Tester.

Eyebolt type anchors (Eco anchors and Fixe glue-ins) were directly loaded using the shackle pin and arm supplied with the tester. Expansion bolts were tested with a standard 12mm or 10mm eyebolt threaded onto the exposed stud. This allowed us to test the anchor, instead of the hanger.



Petzl 12mm expansion anchor with eyebolt attached for testing.

Anchors were subjected to an axial load, i.e. we attempted to pull them straight out. The maximum load as shown on the test gauge was recorded. If the upper limit of the test equipment was reached, a result of 20kN was recorded and the test was stopped.



Anchor tester load gauge. Maximum load is indicated by the red dial.

For the T5 tests, each anchor tested had a load of 8kN repeatedly applied. This was done by turning the test rig load screw steadily up to 8kN, then immediately reversing down to 0kN. This was repeated without pause until the anchor had been loaded 20 times.

3 RESULTS

Not all tests have been completed at the time of writing this report, with the 5 and 10 year results still outstanding. The available test results are as follows:

M2: Petzl 12mm expansion bolts

T1: 1 week

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	M2	T1	18/10/2007	20	A
10/10/2007	M2	T1	18/10/2007	20	A
10/10/2007	M2	T1	18/10/2007	20	A

T2: 1 year

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	M2	T2	18/03/2009	20	A
10/10/2007	M2	T2	18/03/2009	20	A
10/10/2007	M2	T2	18/03/2009	20	A

T5: 1 year, 20 x 8kN

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	M2	T5	18/03/2009	20	A
10/10/2007	M2	T5	18/03/2009	20	A
10/10/2007	M2	T5	18/03/2009	18	D

G1: Fixe / Hilti cartridge

T1: 1 week

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	G1	T1	18/10/2007	20	A
10/10/2007	G1	T1	18/10/2007	19	B
10/10/2007	G1	T1	18/10/2007	20	A

T2: 1 year

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	G1	T2	18/03/2009	20	A
10/10/2007	G1	T2	18/03/2009	20	A
10/10/2007	G1	T2	18/03/2009	20	A

T5: 1 year, 20 x 8kN

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	G1	T5	18/03/2009	16	F
10/10/2007	G1	T5	18/03/2009	19	B
10/10/2007	G1	T5	18/03/2009	16	B

G2: Fixe / Masonmate capsule

T1: 1 week

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	G2	T1	18/10/2007	20	A
10/10/2007	G2	T1	18/10/2007	20	A
10/10/2007	G2	T1	18/10/2007	20	A

T2: 1 year

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	G2	T2	18/03/2009	20	A
10/10/2007	G2	T2	18/03/2009	20	A
10/10/2007	G2	T2	18/03/2009	20	A

T5: 1 year, 20 x 8kN

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	G2	T5	18/03/2009	20	A
10/10/2007	G2	T5	18/03/2009	20	A
10/10/2007	G2	T5	18/03/2009	20	A

S: Staple / epoxyacrylate cartridge resin

T1: 1 week

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
15/12/2007	S	T1	26/01/2008	16.5	B
15/12/2007	S	T1	26/01/2008	13.5	B
15/12/2007	S	T1	26/01/2008	13.5	B

T2: 1 year

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
15/12/2007	S	T2	18/03/2009	20	A
15/12/2007	S	T2	18/03/2009	20	A
15/12/2007	S	T2	18/03/2009	20	A

T5: 1 year, 20 x 8kN

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
15/12/2007	G4	T5	18/03/2009	17.5	B
15/12/2007	G4	T5	18/03/2009	20	A
15/12/2007	G4	T5	18/03/2009	20	A

P1: Bolt Products 8mm / polyester cartridge resin

T1: 1 week

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
03/10/2008	P1	T1	15/10/2008	20	A
03/10/2008	P1	T1	15/10/2008	20	A
03/10/2008	P1	T1	15/10/2008	20	A

T2: 1 year

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
23/01/2008	P1	T2	18/03/2009	20	A
03/10/2008	P1	T2	18/03/2009	20	A
03/10/2008	P1	T2	18/03/2009	20	A

T5: 1 year, 20 x 8kN

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
03/10/2008	P1	T5	18/03/2009	20	A
03/10/2008	P1	T5	18/03/2009	20	A
03/10/2008	P1	T5	18/03/2009	20	A

Ad hoc test results

M1: Petzl 10mm expansion bolts

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
26/01/2008	M1	T1	26/01/2008	20	A
26/01/2008	M1	T1	26/01/2008	20	A
26/01/2008	M1	T1	26/01/2008	19	D

M3/4: assorted zinc-coated expansion bolts

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
26/01/2008	M3	T1	26/01/2008	20	A
26/01/2008	M4	T1	26/01/2008	20	A
26/01/2008	M4	T1	26/01/2008	20	A
26/01/2008	M4	T1	26/01/2008	20	A

P2: Bolt Products 6mm x 80mm / polyester cartridge resin

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
23/01/2008	P2	T1	26/01/2008	20	A
23/01/2008	P2	T1	26/01/2008	20	A
23/01/2008	P2	T1	26/01/2008	20	A
15/12/2007	P2	T1	26/01/2008	20	A

E: DMM Eco-anchor

Date Installed	Bolt Type	Test	Date Tested	kN	Failure Mode
10/10/2007	E	T1	18/10/2007	20	A

4 DISCUSSION

The inability of the test device to achieve pullout forces in excess of 20kN meant that in most cases it wasn't possible to extract the anchors. As a result we weren't able to confirm a mean pullout load and hence directly compare the strength of different anchor systems. What this did enable us to do, however, was to benchmark each systems performance in our tests against the pullout test requirements for the UIAA 123 and EN 959 standards.

Anchor test performance compared to EN959 and UIAA 123

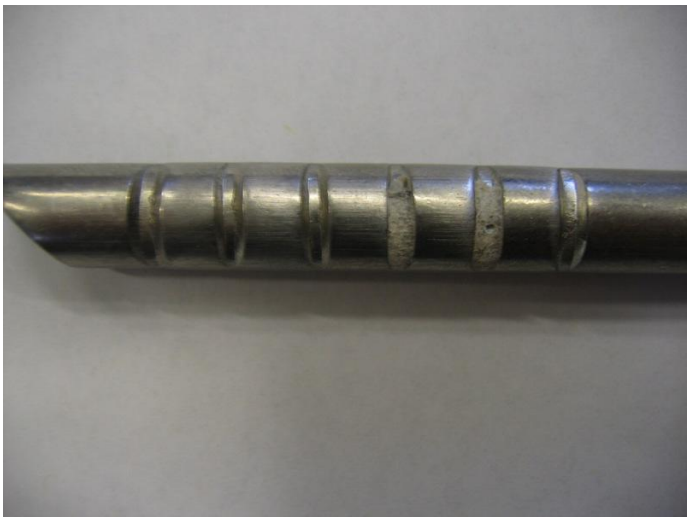
Anchor	**EN 959** 15kN				**UIAA 123** 20kN			
	Certified	T1	T2	T5	Certified	T1	T2	T5
Petzl 12 mm	Y	Y	Y	Y	N	Y	Y	N
Fixe/Hilti	Y	Y	Y	Y	Y	N	Y	N
Fixe/MM	Y	Y	Y	Y	Y	Y	Y	Y
Staples	N	N	Y	Y	N	N	Y	N
BP 8mm	Y	Y	Y	Y	N	Y	Y	Y

Petzl 12mm

The baseline test results (T1) all reached 20kN, as did the T2 test series. One anchor failed at 18kN from the T5 test series. Does this mean that repeated loading weakens these anchors? Possibly, but as this was only one result from three this isn't proven. In addition, the manufacturer's documentation states that the strength of these anchors is 18kN axially [2], so it may be that this is just a result at the lower end of the normal distribution.

Fixe / Hilti cartridge

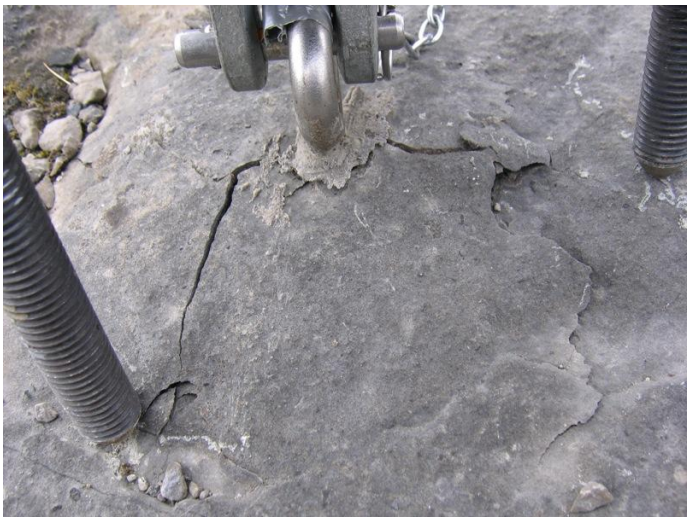
The T1 test series of Fixe / Hilti cartridge resin reached 20kN with one exception, which recorded 19kN during extraction. This was unexpected, given that these anchors are rated at 35kN by the manufacturer [3]. Inspection of the extracted anchor indicated that not all the notched areas of the anchor leg had been filled with resin.



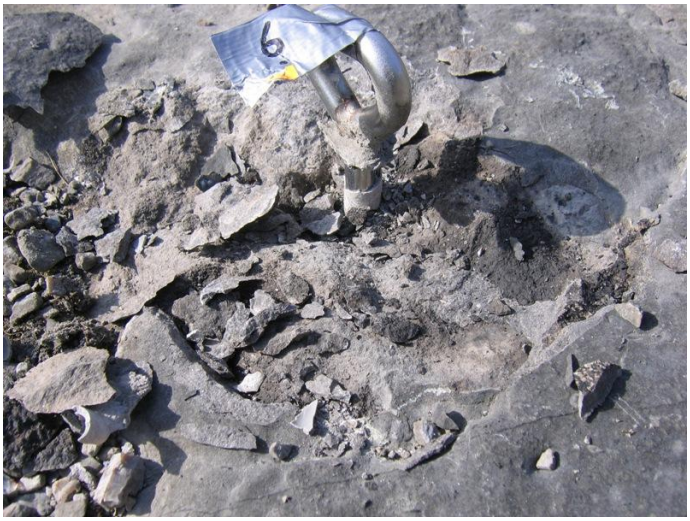
Fixe / Hilti cartridge. Resin missing from extracted anchor notches.

One can conclude that the resin had failed to mechanically key into all of the notches in the anchor during installation, leading to a reduction in the pullout strength.

Whilst the T2 test results all reached the maximum, all 3 of the T5 results were lower. In one the cause was rock failure. The rock surface cracked during the test, followed by an area breaking off.



Fixe / Hilti cartridge. Start of rock fracture.



Fixe / Hilti cartridge. End of test, anchor easily removed.

Inspection of the other two T5 test anchors found similarities to the low T1 test – incomplete filling of the notches with resin. If the resin had been weakened by the repeated loading, it would be expected to still be present in the notches, but to have broken off during extraction. As this was not the case, it is likely that the missing resin was again due to incomplete keying during installation, and that this lead to the reduction in strength.

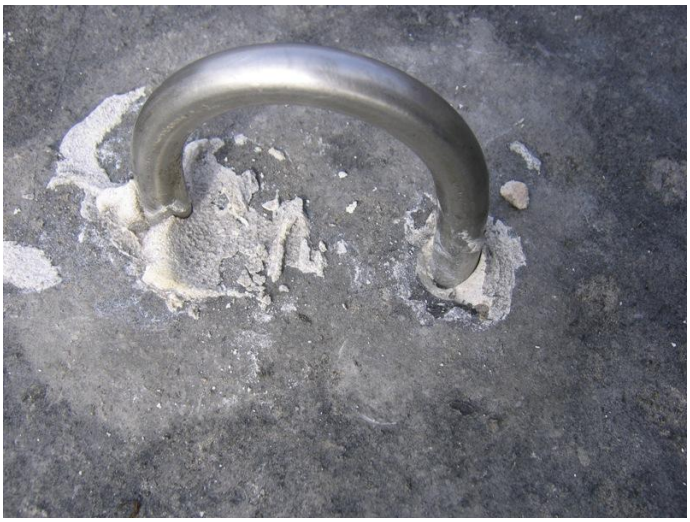
There are a number of reasons why the resin did not fill the notches completely. The problem could be with the resin – as the resin begins to harden, if the anchor is not installed rapidly enough, then the resin may not be viscous enough to flow into the notches. In the authors opinion, the fact that the notches are neither particularly deep, nor cut in a spiral to encourage filling during turning, may contribute to this problem.

Fixe / Masonmate capsule

The Fixe anchor performed well when combined with the Masonmate capsule. This was despite the capsules being used outside of their manufacturer's method statement. Results from all series reached the 20kN maximum test force.

Staples / epoxyacrylate

T1 test results for the home-made staple design showed several interesting features. In each test, one leg started pulling out first.



Staple, showing R leg failure

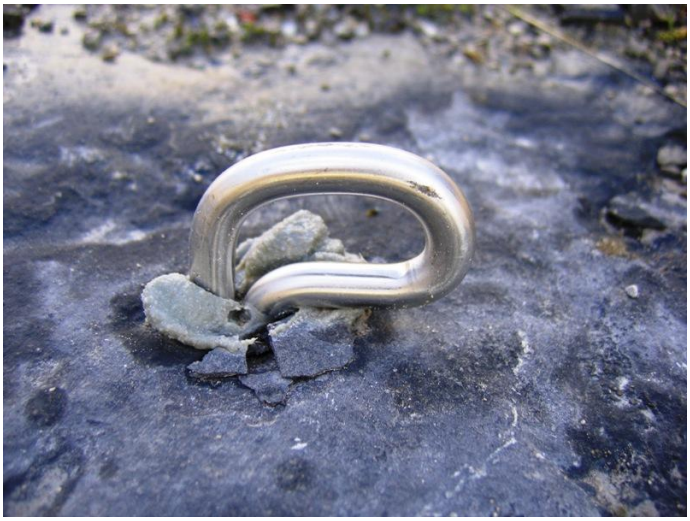
A common feature was a leg audibly popping with the load on the gauge suddenly dropping away, followed by requiring a similar or greater force to extract the anchor any further. The results of this series were the lowest of all anchors tested.

In contrast, the T2 series all reached the 20kN maximum, whilst one of the T5 series failed, this at 17.5kN. These variable results were felt to be down to 2 factors. First, the anchors are home-made and therefore are likely to inconsistent in the position and depth of the notches cut into the legs. The roughly cut end of the legs may help key the legs in, and these cut ends again may be quite variable. Secondly, the staple cannot be turned during installation, so the viscosity of the resin becomes a major factor in respect to whether the notches become filled.

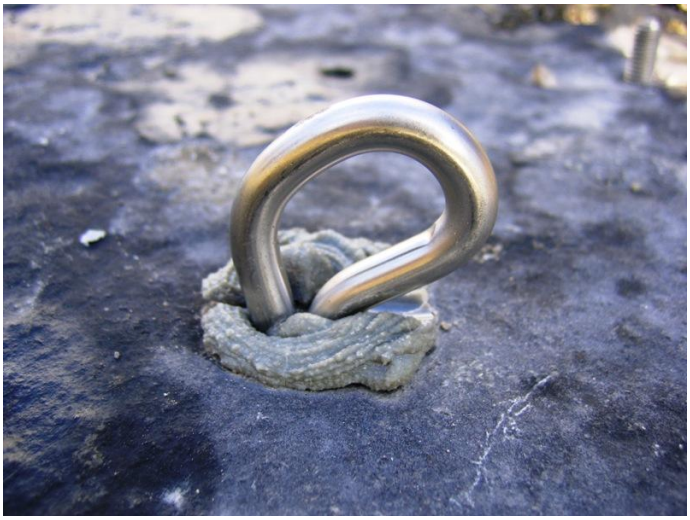
Bolt Products 8mm / polyester cartridge

All test series reached the 20kN limit with no visible evidence of extraction. This made this the most consistent performer of the resin bonded anchor types tested.

It became quickly evident that at loads above approximately 8kN, the eye of the anchor was beginning to deform. After testing to 20kN, this deformation was readily visible. In theory, it is possible to generate forces in a fall which might be great enough to distort the eye [4]. Typically though, forces would be expected to remain somewhat lower than 8kN and therefore not lead to permanent deformation of the anchor. In any case, the same limitations apply to the plate hangers used with expansion anchors.



Before testing



After testing to 20kN

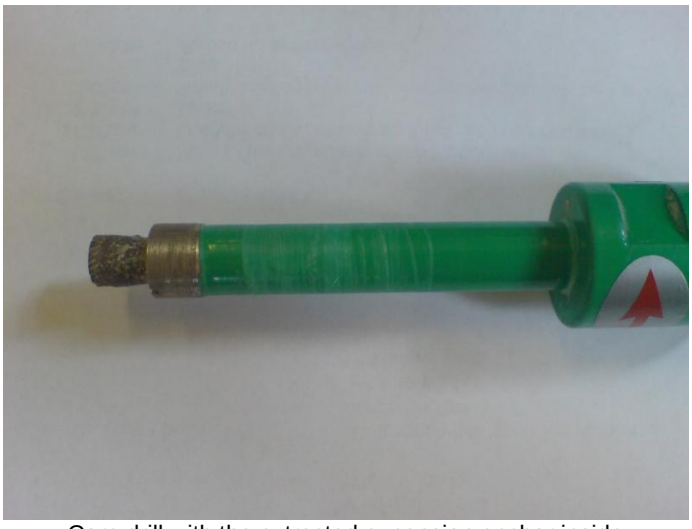
In an ad hoc T1 test, the 10mm Petzl anchors reached 20kN with one exception at 19kN. Again this anchor is rated to 18kN by the manufacturer, so these results were as expected.

Most surprisingly, the cheap galvanised bolts bought from a hardware supplier were unexpectedly strong. The four tested all reached 20kN. Time will tell how these fare when exposed to the elements; this type of anchor if used with stainless steel hangers has proven to corrode very badly. Using these anchors cannot be recommended for climbing, despite these good results. There is no guarantee of the necessary Q/A procedures to ensure consistent performance, as these anchors are not certified for use in safety critical applications.

Sustainable bolting

Attempts were made to remove some anchors to test the idea of sustainable bolting. A specialist diamond core drill was used to extract expansion anchors, leaving a hole which could be re-drilled and used with a resin anchor such as the Bolt Products anchor. This was found to be messy as the drill must be water cooled, and slow going. In addition the core drills are expensive, easily damaged, and wear out quickly.

This method was felt to only be worthwhile for situations where placement position is critical, or where it is felt that leaving old studs is unacceptable. The easiest solution to this at the moment still appears to be to drill holes for expansion anchors too deep, and then tap them in at the end of their lifetime. The hole can then be filled with resin and rock dust, leaving little evidence behind.



Core drill with the extracted expansion anchor inside

The manufacturer of the Bolt Products anchors gives guidance on how to remove their anchors to enable the holes to be reused. This involves breaking up the resin by hammering the anchor in, and then rotating the anchor out of the hole.

In practice, this wasn't found to be very successful. Either the anchor eye broke off, or simply could not be removed. More work on this area is required before recommending this approach, as any problems with removal would no doubt be increased when attempting this hanging from a rope.

5 CONCLUSIONS

- Staples were the only system which did not reach 15kN in all test series and were the worst performing system in test
- The best performing anchors across all series were the Fixe/Capsule combination, and the Bolt Products anchors, which reached the 20kN maximum test force in all cases.
- Although repeated loading appeared to weaken one of the Petzl 12mm anchors and all 3 of the Fixe/Hilti resin anchors, in both cases other factors may have been the cause.
- For resin anchors, mechanical keying of the resin into any notches or grooves is a key performance aspect. Those anchors which failed all exhibited poor keying, and more work investigating why this occurs would be useful.
- No significant reduction in performance over a 1 year timescale was noted in any of the anchor systems.
- A practical sustainable bolting system has yet to be proven. Current the best advice is to install anchors with the longest possible lifespan.

References

[1] Bolt Products: Bolting information
http://www.bolt-products.com/Glue-inBoltDesign.htm

[2] Petzl Technical Notice: Anchors, Coeur Goujon P32/33
http://www.petzl.com/files/all/technical-notice/Sport/P32%20AMARRAGES%20P32500-C.pdf

[3] Fixe Anchor Instructions
http://www.fixeclimbing.com/pdf/Libro%20tecnica.pdf

[4] BMC Technical Conference 2006: Presentation by Michel Beal
http://www.thebmc.co.uk/Download.aspx?id=446

BOLT LAYOUT MAP