Top: The anchor puller in use while suspended on a slope; the white labels mark the anchors waiting to be extracted Photo: Gethin Thomas

Cavers are used to finding anchors in limestone and much is known about how best to place them and the forces involved. Yet, what of other rocks? How much research has been conducted into the performance of anchors in different substrates which are then used in a life-critical situation? Mindful of the many trips undertaken in old mines, Bob Mehew and Gethin Thomas report on a project to test anchors in slate.

TESTING ANCHORS IN SLATE

IN 2012 a project involving several regular cavers in North Wales started to look at the strength of various types of anchors placed in slate. Our work was limited by only having access to a pulling device which could achieve a 20kN axial pull – that is, straight out along the axis of the shaft of the anchor as a means of testing the reliability of the placement. The choice of anchors was wide-ranging, based on the variety we had seen and used in a number of slate mines. Notably, several 10mm rock screws failed below 20kN, but the rest of the anchors frustratingly – because our aim was to test these to the point of failure – sustained a 20kN force (though usually with some degree of damage).

In 2013 we returned with the BCA anchor puller and tested the remaining anchors. The results produced some surprises, for example when several anchors failed after the hangar plate had lifted off the rock. An analysis of the forces indicates that the force on the shaft magnifies when the hanger plate lifts off due to the location of the fulcrum moving, perhaps by a factor of two. However, the sturdy favourites such as the Collinox anchor withstood over 30kN at peak force before being extracted. It was therefore clear that slate could be a usable rock for the careful placement of anchors.

These results whetted an appetite for more work and BCA's Equipment & Techniques Committee was approached to support a bigger program. The committee agreed to fund the purchase of a number of Collinox resin anchors together with Goujon expansion anchors combined with Coeur hanger plates. It also provided some Bolt Products (BP) anchors as used elsewhere in the UK, and Simon Wilson donated some IC resin anchors.

WORKING A CHAMBER IN SLATE

A representation of a chamber in slate showing cleavage planes and pillaring planes (adapted from *Candles to Caplamps. The story of Gloddfa Ganol* and reproduced by permission of the author, Graham Isherwood).

The quarrymen extracted slate by leaving a block of slate (1) with a free end (2) and side (3) so that when it was cracked along a cleavage plane and pillaring line (the quarrymen at (4) and (5) respectively are drilling holes to place explosives for this purpose) the block would break at weak joints (6) and slide to the foot of the chamber where it was split into small segments for transport. The quarryman at (7) is channelling to create a free end at the foot of the slope, ready for the next extraction.

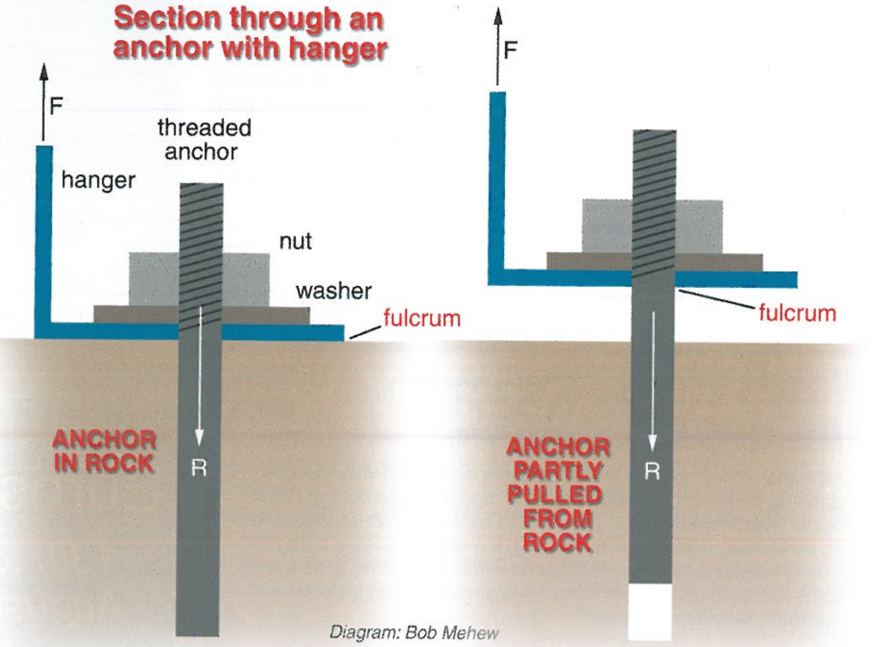
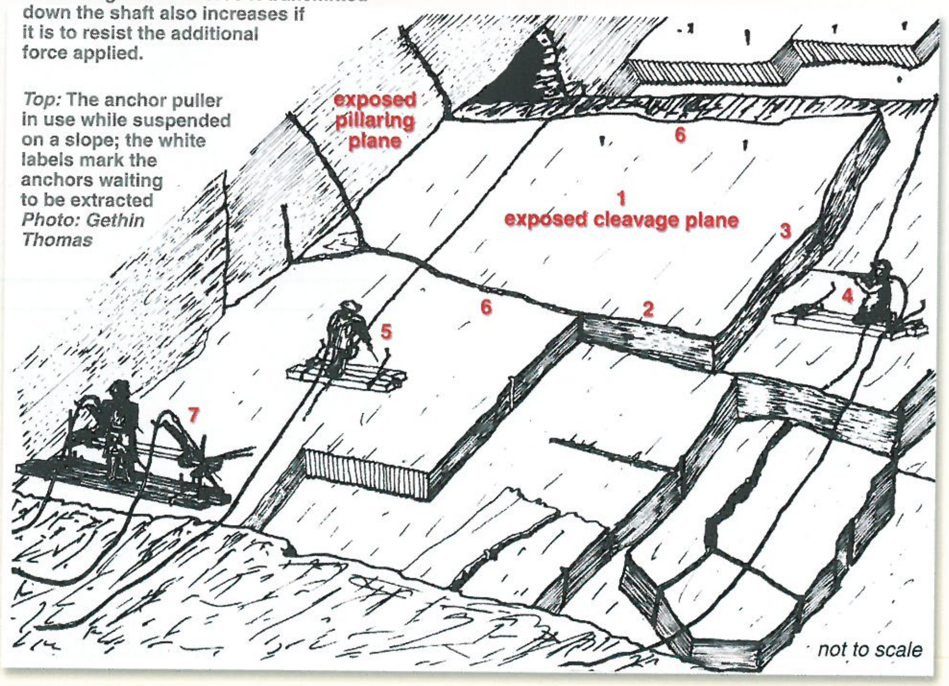


Diagram: Bob Mehew

When the hanger is flush with the rock face and force F (a caver on rope) is applied, this is resisted by force R (the anchor shaft fixed into the rock), while the fulcrum is at the opposite edge of the hanger. However, if the hanger lifts off the rock face the fulcrum moves to the edge of the hanger shaft, thus increasing force F. Force R transmitted down the shaft also increases if it is to resist the additional force applied.



Limestone is a sedimentary rock, but slate is a metamorphosed rock formed by the alteration of mudstone and shale through low-grade regional metamorphism (ie. under relatively low temperatures and pressure). The combination of heat and pressure causes the transformation and relocation of minerals such as chlorites and micas to regrow in planes of least resistance at right angles to the pressure. As metamorphosis usually occurs several times with different orientations of pressure, so different orientations of these planes can build up in the slate.

Slate can be split along these planes, the predominant plane being called the cleavage. In addition, slate can be split at an angle to the cleavage plane, commonly referred to as the pillaring plane (probably from the term used by quarrymen for the supporting pillars between worked-out chambers). These two planes of rock are often exposed where explorers wish to place anchors.

The quality of slates produced, be they roofing slates from good quality rock or slabs and blocks from poorer quality rock, relate to the regional metamorphism, so testing was conducted at four different sites to reflect the variations in quality across North Wales as well as accessible cleavage and pillaring planes. The locations were: the Back Vein and the Stripey Vein in Cwmorthin Slate Mine near Blaenau Ffestiniog, Cambrian Slate Mine near Llangollen and Braich Goch Slate Mine near Corris (with thanks to Go Below for the use of Cwmorthin and Corris Mine Explorers for Corris). In addition, another major variable was included by placing the anchors at right angles to either the cleavage plane or the pillaring plane.

In total, 76 anchors were placed in drilled holes that were cleaned by blowing and brushing (dry cleaning) or by washing and brushing (wet cleaning). In early 2014 the British Mountaineering Council reported that an expansion anchor had become loose in slate and suggested that: 'With heavy use, the softness of slate appears to allow degradation of the rock leading to movement and weakening of the bolt because it no longer securely fits into the drilled hole.' In addition, therefore, prior to extraction a selection of anchors were exercised by a 6kN force repeated some six times to reflect the extremes of normal usage. Then, in a flurry of work over a two-week period, the 76 anchors were extracted using the BCA puller and the force required recorded – the raw data is summarised in the graph.

The international standard for mountain anchors (EN 959:2007) requires an anchor to sustain an axial pull of 15kN. The UIAA standard 123, from which the EN standard was drawn, was updated in 2014 and now requires the anchor to sustain an axial pull of 20kN. BCA's Equipment & Techniques Committee has adopted a slight modification to these values, requiring that the results from a set of anchors shall have a normal distribution and that the 5% fractile value of the set shall exceed 15kN. This approach mimics standard engineering practice where, instead of using a mean, the requirement is that 95% of the sample exceeds the given value. (Strangely, the EN standard makes no comment about how many anchors are required to be tested – the advice we received was only one!)

The data is presented in three tables. Table 1 shows that all anchors meet both the European Standard and UIAA criteria. From the statistical calculations only the BP anchor meets BCA's E&T criteria (though it is likely that testing more anchors would cause the results to become normally distributed, thus meeting E&T's criteria). Data for types of slate appears in Table 2: there is little difference in the results between different types of slate, though the Cambrian slate results show a larger standard deviation and thus range of results than the others.

The results were subject to intensive work correlating the written records with photographs and videos (a useful arbiter of disagreements on recorded values). A number of samples were excluded from more detailed analysis on the grounds that the extraction of a previous

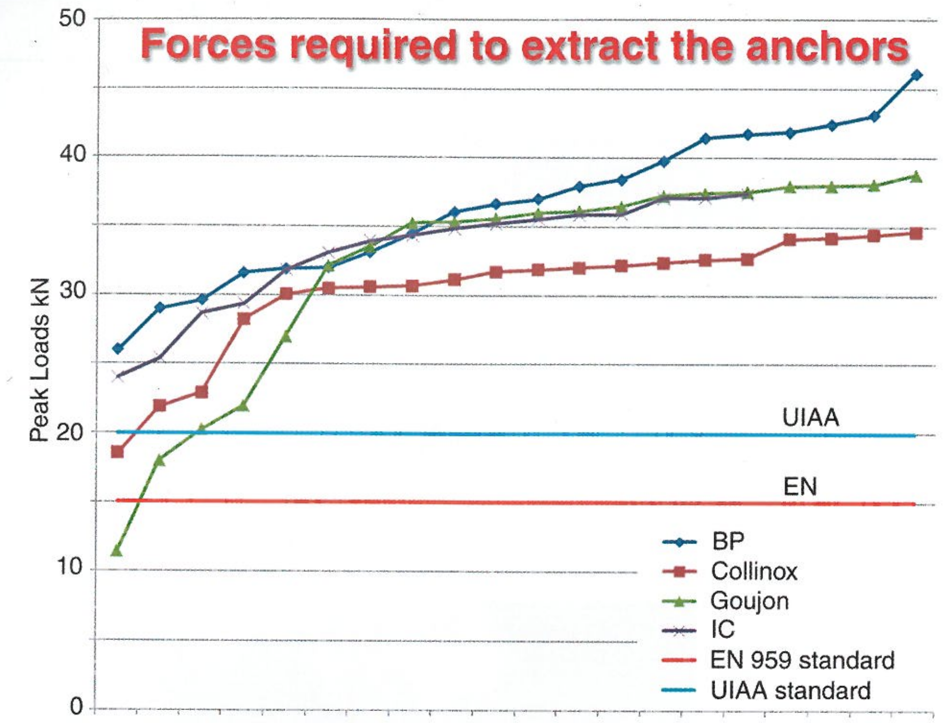


Table 1: Data by anchor type

Anchor type	No. placed	Mean (kN)	SD (kN)	5% (kN)
BP	20	37	5.4	24
IC	16	33	4.2	24
Goujon	20	32	8.0	15
Collinox	20	30	4.4	21

Table notes
Mean: Mean force required to extract anchor
SD: Standard deviation
5%: 5% fractile

Table 2: Data by slate type

Slate type	No. placed	Mean (kN)	SD (kN)	5% (kN)
Cwmorthin Back Vein	21	31	4.8	20
Cwmorthin Stripey Vein	20	36	3.8	28
Cambrian	20	31	8.2	13
Braich Goch	15	34	4.8	23

Table 3: Anchor forces and dimensions

Anchor	Mean (kN)	SD (kN)	Length (mm)	Dia. (mm)
BP	37	5.4	96	16
IC	33	4.2	70	10
Goujon	32	8.0	60	12
Collinox	30	4.4	82	12

Length = Anchor shank length
Dia. = Drilled hole diameter

A wheelbarrow was the simplest way to shift the heavy anchor puller and quantity of gear required Photo: Gethin Thomas