Use of concrete screws in caving

Rolf Siegenthaler (SGH Bern), Florian Hof (SCVJ)
Translation by Derek Bristol

Introduction

At the top of the shaft which is to be derigged, the caver discovers a hexagonal bolt. So a wrench is produced and unscrew ... unscrew, unscrew. The thing is weirdly long ... and much thinner than normal! What should be done now? And what load does this thin piece of metal hold?

This is probably something like what went through the minds of some who first encountered a «concrete screw» in a cave. For a few years these screws have been used in various caves. Opinions differ, but well-founded information has been missing so far. We have done research and testing to close this knowledge gap.

The Idea

The most appropriate name is «concrete screw». Some manufacturers have alternative names, such as «screw anchors». These screws are simply screwed into a predrilled hole in the rock. The necessary thread is automatically milled by the specially designed screw tip as it's screwed into the rock, in principle the same as a wood screw. After removal nothing remains but a small hole, and the screw can be used again.

In the following article, the scope and limits of this product are shown. This article presents theoretical information from trusted sources and the results of our self-executed static and dynamic stress tests as well as our experiences in the cave. The findings should serve as a guide for those who rig caves.

Theoretical Values

The manufacturers of course provide theoretical values for the strength of their product. These values apply to concrete that is normalized in contrast to our cave rock. Some manufacturers also sell expansion anchors (heavy load anchors), which allows a direct comparison (Hilti 2016).
In order for this information to be interpreted correctly, some technical terms have to be explained:

Tensile force / shear force
The direction of the forces acting on the anchor is given. An anchor in the ceiling is typically loaded «in tensile» – i.e. in the longitudinal axis. When anchored to a vertical wall, on the other hand, a shear force is generally more likely to act transverse to the longitudinal axis.

Working load / breaking load
Here we come to the potential misunderstanding between the world of industry and those of climbing and caving. The safe working load corresponds to the force that can occur in everyday life and under repetition (Wikipedia 2018). The breaking load is the force that is just acceptable during one or more incidents. The typical stainless steel 7 mm maillon rapide, with a designated 4000 kg / 40 kN breaking load, has a working load of only 800 kg (Peguet 2014).

Cracked / Unbroken concrete
Here we only consider the values in unbroken concrete, which corresponds to normal limestone. Clearly, «cracked concrete» is not a concrete whose strength suffers from cracks, but a concrete used under such circumstances (tensile zone, for example a concrete pavement) in which microcracks may occur (Bati 2014).
Hilti's documentation states that concrete screws are more resistant to shear than to tensile. The thin diameter of 6 mm screws does not adversely affect maximum shear loads when compared to an expansion anchor of 8 mm. The tensile force acting on a screw is distributed over the entire length of the thread, and

Figure 1: Various concrete screws surrounded by some heavy-duty anchors.

Figure 2: Typical application on a construction site.

Figure 3: The screws may be used near edges, but not on an abrupt overhang.

the theoretical strength is surprisingly small. Compared with expansion anchors, the screws need more length to be equally strong in tensile. The endurance of a working load of 3 kN is enough for a fixed device in good concrete. We estimate that good limestone is harder and more resistant than concrete. With regard to impact forces, none of the manufacturers considered certified their bolts (Hilti 2016; Heco 2016), whereas Hilti claims that this is an expansion anchor.
A concrete screw does not develop expansion forces in the drill hole and can therefore be placed very close to another screw, at a rock edge or a break, except for an abrupt overhang. Our intuition tells us that such situations are dangerous, but Hilti specifies a minimum distance of only 35 mm for the 6 mm screws. This is a big difference compared to expansion anchors and self-drilling anchors (Spits), as they develop a permanent expansion force in the rock.
There are also reservations regarding the reusability of the screws. The two manufacturers considered here offer test data, but only from a screw diameter of 10 mm (Heco 2016). The 6 mm screws receive little attention from industrial users. The reusability of the holes is not considered in any technical documentation.
Another practical aspect is that the holes to be drilled are smaller than with the most common caving anchors, 8 mm for expansion anchors or 12 mm for spits. Compared to spits, the drill hole volume is 4 times less, as is the required torque. This allows the use of compact drills. The larger drilling depth on the other hand plays a minor role in the amount of energy used. In a practice trial in Jurakalk limestone we were able to drill 60 % more 6 mm holes than 8 mm holes with the same equipment and energy. Without a drill, using an SDS bit + hand drill, it takes about the same amount of time as spits.

Static Tests

Static forces put a strain on our anchors, especially with techniques used in cave rescue (pulley block, highline, etc.). What are the limits of concrete screws in this respect compared to our classic anchors (SSS 2005) with expansion bolts (21 kN tension, 20 kN shear force) and spits (18 kN tension, 16 kN shear force)?

Produit Produkt	Ø [mm]	P/T [mm]	Mat		Charge de travail Nutzlast [kN]	Charge de rupture Bruchlast 1kN ≡ 100kg [kN]
Hilti HUS3-H 6	6		g			
		55		—→	3.6	9.0
		55		—↓	6.0	12.5
Hilti HUS-HR 6	6		A4			
		55		—→	3.1	9.0
		55		—↓	8.1	17.0
Hilti HUS-HR 8	8		A4			
		50		—→	3.6	9.0
		50		—↓	11.2	23.6
		80		—→	6.3	16.0
		80		—↓	12.4	26.0
Hilti HST3 M8	8		g			
		47		—→	5.7	12.0
		47		—↓	7.9	13.8
Hilti HST3-R M8	8		A4			
		47		—→	5.7	12.0
		47		—↓	9.0	15.7
Peguet maillon rapide						
Zicral, 49g	10		alu	↕	5.0	25.0
Inox, 52g	7		A4	↕	8.0	40.0

Hilti HUS…	Vis à béton	Betonschraube
Hilti HST…	Cheville à expansion	Expansionsanker
	maillon rapide	Schraubglied
⌀	diamètre	Durchmesser
P/T	profondeur d'ancrage	Verankerungstiefe
Mat	matériel	Material
g	galvanizé / zingué	galvanisch verzinkt
A4	acier inoxidable	nichtrostender Stahl
alu	Zicral	Zicral
—→	traction	Zug
—↓	cisaillement	Quer
↕	traction	Zug

Table 1: Theoretical values.

We investigated the behavior of various concrete screws with continuously increasing shear force in compact Gemmenalp limestone. We used a Rock Exotica Enforcer with 2 % measurement tolerance (not self-calibrated) as a measuring device, and to apply a force we used a simple Habegger (model HIT 16) manually operated hoist. In a total of 13 trials we have varied many factors.
We have found that the stainless steel (inox) screws are clearly superior to the non-inox. Inox breaks around 20 kN, while non-inox can break at 10 kN. The factor of material type (inox or non-inox) is even more significant than the screw length. We compared 6 mm and 6.35 mm (¼ inch) drill holes and found no significant difference in shear force. We were interested in this aspect because the screws are easier to screw in when the hole is drilled a little bit larger. At about 8 kN, the screws begin to deform – then they are difficult or impossible to reuse and must be discarded – which is good.
We have only performed two experiments in tensile: in brittle sandstone, the anchor pulled out a piece of rock at about 15 kN, which of course shows that even for screws the rock must be tested well. Then we selected a perfectly compact Schrattenkalk (Upper SK) limestone for an exit test, with the result that we had to end the test at 20 kN because we could not build up more power. The inox hanger had bent, but the screw was completely undeformed. Additional tests did not seem necessary to us.

Figure 4: Comparison of 6 mm vs. 8 mm holes with the same small battery.

Figure 6: The stainless-steel screws deform spectacularly.

Consider the test series from other publications: first by Olivier Gola (Gola 2007). The galvanized 6 mm Hilti screws failed with a shear force between 7 and 14 kN. Unfortunately, that is less than in our own tests. However, we suspect that this is due to the fact that an older screw model was tested, namely the HUS-S 6 versus HUS3-H 6 with us. When pulling, at Gola, the screws broke between 11 and 14 kN, which corresponds to our own observations. These are better values than shearing force, contrary to the values postulated by Hilti, which we mentioned earlier. The tensile force tests performed by Simon Wilson are only on galvanized screws (Wilson 2018). The screws he tested: Multi-Monti MMS 7.5x60 for
6 mm holes, held 24 kN. With Fischer FBS II 8 x 70 20/5 US screws in 8 mm holes, he gets a tensile strength of 50 kN, which is 60 % better than the similar FBS 8 x? / 5 US from Gola's study. Additional screw models will be investigated in a further study.

Various anchor holes were drilled vertically and horizontally into the rock wall, as if we were rigging a cave normally. In the tests we limited ourselves to 6 mm concrete screws, which we then tested with either a tensile or shear impact force. With more than 5 drops being held per screw and hole, we ended the testing, as we certainly do not see the use of screws in an application where such repeated shock forces can occur, such as in sport climbing.

It turned out that the rock quality is a decisive criterion. We had two cases where the screw pulled out on the first shock. In the first case, the drill hole was drilled vertically in the ceiling and the thread already pre-milled by a screw of another brand. In the second case, the rock was deliberately chosen as being poor quality and the hole «reused». A non-inox screw was broken on the second shock with a shear load. In general, it can also be said that the rock breaks with dynamic shock forces unlike with slowly built up static forces.

Dynamic Tests

In these tests, we want to find out how anchors react to shock loads, including single and multiple peak loads. Such as, in a practical caving example, falling on a traverse rope.

As a test site, we selected a location that has limestone that is as typical as possible for our research region. The simulated fall has a fall factor of 1, the fall distance is about 2 m, and the mass of the rock used to generate the shock load has a weight is 88 kg.

Table 2: Static tests.

	Produit Produkt	Ø [mm]	P T [mm]	Mat			Remarque Bemerkung	Charge de rupture Bruchlast 1kN ≡ 100kg [kN]
1	Hilti HUS3-H 6	6	40	g	—⬇			11.0
2	Hilti HUS3-H 6	6	40	g	—⬇			13.0
3	Hilti HUS-HR 6	6	45	A4	—⬇			25.0
4	Hilti HUS-HR 6	6	70	A4	—⬇		vis abîmée beschädigte Schraube	10.0
5	Hilti HUS-HR 6	6	70	A4	—⬇			23.0
6	HECO MMS A4 7.5x50	6	50	A4	—⬇			16.0
7	HECO MMS A4 7.5x50	6	50	A4	—⬇	✓	vis déjà utilisée gebrauchte Schraube	20.0
8	MUNGO MCSr-S 6x60	6	60	A4	—⬇			20.0
9	Hilti HUS3-H 6	6	40	g	—⬇	✓	avec Dyneema mit Dyneema	9.0
10	Hilti HUS-HR 6	6.35	70	A4	—⬇	✓		20.0
11	HECO MMS A4 7.5x50	6.35	50	A4	—⬇		même trou qu'au 10 gleiches Loch wie 10	>10.0
12	HECO MMS A4 7.5x50	6.35	50	A4	—⬇		vissé & dévissé 5x 5x ein- & ausgeschraubt	17.0
13	Hilti HUS3-H 6	6	60	g	—⬇			14.0

Ø	diamètre du trou	Bohrloch
P/T	profondeur d'ancrage	Verankerungstiefe
Mat	matériel	Material
g	galvanizé / zingué	galvanisch verzinkt
A4	acier inoxidable	nichtrostender Stahl
—⬇	cisaillement	Quer
✓	la vis a tenu	Schraube hat gehalten

Figure 5: Setting up a test.

Figure 7: The material after the shear force tests.

Figure 8: Our installation for the impact tests.

Normally, the screws were sufficiently solid for our application. Ideally, a Multi-Monti screw survived 5 falls in shear, and another on direct pull. This means that an inox screw remains reliable even after sustaining a fall. It is also worth mentioning that the two concrete screws, with which we had fixed our test weight, held all 29 test laps!
In summary, it can be said that the following factors adversely affect anchor quality:

- Bad rock (weakened, brittle zones or soft rocks)
- A «reused» hole, especially in combination with another detrimental factor.

We have found no existing publications that have tested shock loading of concrete screws.

Experience

We have been using concrete screws for 7 years on our cave trips. This allowed us to check the practicality and identify the sensitive issues.
Some models require a stronger contact force at the beginning, so that the screw tip engages in the rock. With an arm extended overhead (as with aid climbing), the application becomes too cumbersome. It must be said that it is quite boring to screw in a long screw. A ratcheting wrench is highly recommended because it is much more efficient than a normal wrench. A manufacturer advocates for a special drill for placing their screw, which we did not want to test.
In any case, there is a risk of tilting the screw until it is fully set. In such a case, you must not apply excessive force, otherwise there is a danger of bending the screw and thus rendering it useless, something that has happened to us several times. In such a case, instead of using force (Attention: with a 13 mm wrench, a screw can easily be sheared off by hand!) simply unscrew and re-attach.

Figure 9: After a shock load, cracks develop in the rock.

	Produit Produkt	Ø [mm]	P/T [mm]	Mat			Résultat Resultat	Remarque Bemerkung
1	HECO MMS A4 7.5x50	6	50	A4	—⬇	✓		
2	HECO MMS A4 7.5x50	6	50	A4	—⬇	✓		
3	HECO MMS A4 7.5x50	6	50	A4	—⬇	✓		
4	HECO MMS A4 7.5x50	6	50	A4	—⬇	✓		
5	HECO MMS A4 7.5x50	6	50	A4	—⬇	✓		
6	HECO MMS A4 7.5x50	6	50	A4	—➡	✓		
7	HECO MMS A4 7.5x50	6	50	A4	—➡	!	mauvais rocher	schlechter Fels
8	HECO MMS A4 7.5x50	6	50	A4	—➡	✓	a fissuré le rocher	danach Riss im Fels
9	HECO MMS A4 7.5x50	6	50	A4	—➡	✓		
10	HECO MMS A4 7.5x50	6	50	A4	—➡	✓		
11	HECO MMS A4 7.5x50	6	50	A4	—➡	✓		
12	HECO MMS A4 7.5x50	6	50	A4	—➡	✓		
13	Hilti HUS-HR 6	6	70	A4	—➡	✓		
14	Hilti HUS-HR 6	6	70	A4	—➡	✓		
15	Hilti HUS-HR 6	6	45	A4	—➡	✓	dans ancien trou	im alten Loch
16	Hilti HUS-HR 6	6	45	A4	—➡	✓		
17	Hilti HUS-HR 6	6	45	A4	—➡	✓		
18	MUNGO MCSr-S 6x60	6	60	A4	—➡	✓		
19	MUNGO MCSr-S 6x60	6	60	A4	—➡	✓		
20	Hilti HUS3-H 6	6	40	g	—⬇	✓		
21	Hilti HUS3-H 6	6	40	g	—⬇	✓		
22	Hilti HUS3-H 6	6	40	g	—⬇	✓		
23	HECO MMS A4 7.5x50	6	50	A4	—➡	!	dans ancien trou	im alten Loch
24	Hilti HUS3-H 6	6	40	g	—⬇	✓	trou utilisé 2x	Loch 2x benutzt
25	Hilti HUS3-H 6	6	40	g	—⬇	!		
26	Hilti HUS-HR 6	6	45	A4	—⬇	!	ancien trou, mauv. Roch.	altes Loch, schl. Fels
27	Hilti HUS-HR 6	6	45	A4	—⬇	✓		
28	Hilti HUS-HR 6	6	45	A4	—⬇	✓		
29	Hilti HUS-HR 6	6	45	A4	—⬇	✓		

Ø	diamètre du trou	Bohrloch
P/T	profondeur d'ancrage	Verankerungstiefe
Mat	matériel	Material
g	galvanizé / zingué	galvanisch verzinkt
A4	acier inoxidable	nichtrostender Stahl
—➡	traction	Zug
—⬇	cisaillement	Quer
✓	la vis a tenu	Schraube hat gehalten
!	vis cassée ou sortie	Schraube raus o. kaputt

Table 3: Dynamic tests.

Figure 10: A ratchet wrench is highly recommended to speed up screwing.

It often happens that the screw begins to drill its own hole. In such a case, it is easy enough to simply tighten the screw again. If the problem gets worse, you should look for better rock, take a better screw or consider doubling the anchor.
The drill hole must be drilled deep enough, i.e. it must be slightly longer than the screw because of the rock dust that occurs when tapping. Drilling a bit deeper than absolutely necessary is not a disadvantage.
When derigging, we sometimes collected curved screws. We discarded them because they were not reusable.
In terms of safety, we never once had a screw failure. Nevertheless, it is appropriate to respect the rock as «fallible» and to take the same precautions as with expansion anchors.

Summary

Concrete screws offer many advantages in caving. They are reusable several times, and they can also be connected to a hanger for immediate use. The required hole is small, which means that even small drills can often be taken without a replacement battery. Battery capacity is no longer a bottleneck! On the ecological side, it is gratifying that after derigging, no foreign matter remains in the rock. The small holes are as good as invisible.
The biggest disadvantage is the time required for screw installation. A small consolation is that the person doing the rigging stays warmer for at least one to two minutes. The setting of the screw and the choice of the location for the hole require careful work. Like other «light» techniques, concrete screws are not necessarily suitable

Figure 12: It is simply impossible to reuse this bent screw.

Figure 11: At the moment of the break.

for everyone. Their relative novelty is a psychological factor not to be underestimated.
The strength, however, is even sufficient with 6 mm diameter for our purposes. We are not interested in using larger diameters because they are a) not necessary and b) incompatible with existing equipment (wrenches, hangers). The gain in strength through a larger screw diameter (Wilson 2018) would be pointless for our main applications. Also, the types of uses would not really be extended, because even then the anchor is not suitable for long-term use (establishment of well-traveled routes), because our experience shows that it can be weakened by repeated load movements. We clearly prefer stainless steel screws to others that they rate as «expensive and rare» (Eon 2016). The reason for this is that inox is less brittle and has a greater safety margin from when the screw first deforms (around 8 kN) until it breaks (beyond 20 kN). Inox screws can stay in place for a long time without corroding. It is noted that depending on the publication, the strength differs from what we measured.

What principles should be considered?

Do not place screws in bad, cracked rock and especially soft rock. The screws are not suitable for setting up classic, busy routes in caves with thousands of transitions. They would loosen themselves too fast. Reusing existing holes brings some random results. Particular care should be taken when applying a load in tension (typically for anchors in ceiling sections) – this requires long screws (at least 60 mm). The worst-case is applying a shock force onto non-inox screws.

When to remove a screw?

If a set screw repeatedly loosens itself or has too large a bend, it is advisable to replace the existing anchor. The existing hole should not be used for a new screw. Likewise, after a big impact or another event that brings into question the quality of the whole anchor or parts of it. If you notice a bent screw when screwing in, it is better to not use it. Such cases are always immediately obvious.

What are the ideal applications?

Concrete screws are ideal for exploration into new territory. They are lightweight, require little energy (drill battery), can be reused multiple times, and the anchors endure hundreds of passages.
For the same reasons they are perfect for artificial aid climbing. No material is consumed at all and nothing remains in the rock. Only for the impatient is the increased labor of screwing a disadvantage.
Although the screws are not particularly suitable for permanent rigging, the screws can be used to first explore the best route. Once the best route is established, the 6 mm holes may be drilled-out to 8 mm and then a permanent expansion bolt can be set.

Application in cave rescue?

We are of the opinion that concrete screws are also suitable for rope anchors used in cave rescue. With rescue rigging techniques, only static tensile forces are applied. The strength of 6 mm concrete screws is sufficient, even if we ignore that in rescue systems the load is distributed on three anchor points. In the case of large cave rescue operations, drill battery capacity is chronically scarce so screws can be used to drill considerably more holes.

Outlook

On the one hand, based on recent findings, it becomes clear that the concrete screws deserve much more attention than before. On the other hand, we are still looking for the «ideal screw», which would combine all the advantages of all tested screw models. The ideal screw is made of inox material, with a diameter of 6 mm, has a hexagonal head of 13 mm with a support plate, and it has a specially hardened tip with fine saw teeth, which easily and instantly grabs when screwing. This screw would allow the use of our normal hangers and wrenches.

Thanks

Several people helped us with this testing with time, material, muscle power and / or brain fat. Special thanks to: Nicolas Boisard, Raphaël Lachat, Alex Hof, Michael Höttl and the Spéléo-Secours Switzerland. We congratulate those who take the trouble to explore these new possibilities for themselves.

Bibliographie

Bati (2014): Les goujons Ancrage. – Bati 27, Oct. 2014. https://www.baselopresse.fr/batidistribution/produits/fixation/les-goujons-d-ancrage

Eon, T. (2016): Choix des ancrages en canyon. – http://storage.canalblog.com/02/08/841534/115024509.pdf

Salvatori, F. (2007): Multi Monti: Una rivoluzione nell'ancoraggio in grotta e in montagna. – http://www.heco.it/files/download/catalogo/HECO-MULTI-MONTI/Sito%20web%20-%20gennaio%202007.pdf

Gola, O. (2007): 637 tests de résistance d'ancrages mécaniques. – Memento équipement des canyons, 12/12, http://cnc-ffcam.fr/wp-content/uploads/2016/04/cahier12.pdf

Gola, O. (2009): Comportement des amarrages. – Memento équipement des canyons, 5/12, http://cnc-ffcam.fr/wp-content/uploads/2016/06/cahier-N%C2%B05.pdf

Heco-Schrauben GmbH & Co.KG (2016): Produktkatalog 07/2016. – https://www.heco-schrauben.de/downloadcenter/downloadcenter/de/Prospekte/DE_HECO-Produktkatalog_72016.pdf

Hilti AG (2016): Technisches Handbuch der Befestigungstechnik für Hoch- und Ingenieurbau, Ausgabe 01/2016. https://www.hilti.ch/medias/sys_master/documents/h31/9188891197470/Technisches_Handbuch_der_Befestigungstechnik_DE_Technische_Information_ASSET_DOC_LOC_2584401.pdf

Hof, F. & Siegenthaler, R. (2018): Einsatz von Betonschrauben in der Höhlenforschung. – Stalactite 68 (2), 47-55.

Peguet SA (2014): Catalogue Peguet 2014. – http://www.peguet.fr/maillons-rapides-auto-certifies

Spéléo-Secours Schweiz (2005): Handbuch für Höhlenretter.

Wikipedia (2018): Working Load Limit. – https://de.wikipedia.org/w/index.php?title=Working_Load_Limit&oldid=178989905

Wilson, S. (2018): Self-tapping concrete screws: their selection, testing and use. – https://cncc.org.uk/doc/1182

Figure 13: An ideal application for concrete screws.