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Testing Procedure

Recommendations for test procedure
for NC-Bolt and PC-Bolt





Mounting of M20 NC-Bolt.

Introduction

Pretec is manufacturing and marketing steel bolts for rock support, with the functional target of satisfying load requirements for immediate support, as well as offering load parameters and durability acceptable for permanent support. Dual purpose bolts of this kind are often referred to as Combination Bolts.

The two combination bolt types being discussed in this report are named NC-Bolt and PC-Bolt and this report is giving recommendations regarding on Site testing of these bolts to verify satisfactory load capacity after installation. Since these bolts are first installed for immediate support and are shortly after grouted by cement mortar, load capacity testing should ideally be executed for both these situations.

Pretec has issued detailed recommendations regarding installation, tensioning, grout properties and grouting equipment and procedures. This Report is presuming that all these recommendations have been carefully implemented, so that load testing and evaluation may reasonably assume correct bolt installation and overall properties. Refer to the brochure "Grouting – Recommendations for cementitious grout for NC-Bolt and PC-Bolt".

The main difference between the NC-Bolt and PC-Bolt is:

NC-Bolt:

It is made from a solid rebar surrounded by a full-length plastic sleeve, where grout enters between bolt and plastic sleeve and then returns from the inner end of the bolt to the bearing plate between sleeve and borehole rock wall. The bolt is therefore protected by 2 layers of mortar with a plastic sheet in the middle.

Pc-Bolt:

It is made from a hollow steel bar forming a thick-walled steel pipe. Grout is pumped through the bolt central hole, until it returns from the inner end between the bolt and the borehole rock wall to appear at the bearing plate. The bolt is after grouting fully embedded in one thick layer of mortar.

For both these bolt types, Pretec has specified the borehole diameter to be between $\text{Ø}45$ and $\text{Ø}48\text{mm}$ (or $\text{Ø}64$ - $\text{Ø}68$ mm for the heavier M33 NC-Bolts).



NC-Bolt

PC-Bolt™

Testing of immediate support load capacity

2.1 GENERAL

These considerations are valid both for the NC-Bolt and the Pc-Bolt, since they both are using the same expansion shell to give immediately effective end-point anchoring before later time grouting.

The immediate anchorage is provided by the bail type expansion shell (see Figure 1) at the inner end of the bolt. Make sure to remove the black plastic ring transport protection and open the bail enough that the shell leaves will slightly push against rock during insertion of the bolt. When the bolt has been fully pushed into the borehole and the free-end nut is tightened against the angle washer, the wedge-formed plug inside the expansion shell is pulled toward the borehole opening while the not moving shell leaves are jammed against the borehole rock wall.

The specified torque applied on the nut will tension the bolt to between 40 and 60 kN (for metric threads). (Ref. PC-Bolt and NC-Bolt brochures / product data sheets)

The design engineer must decide on how to define the 'load capacity' that needs verification by testing. The minimum yield and failure loads of the bolt rod itself are parameters known from quality testing of the steel and should not be the purpose of load capacity testing of installed bolts.

However, the expansion shell properties under local ground conditions may need to be verified as satisfactory. The expansion shell has a limited range of acceptable expansion, before the wedge-formed plug in rare cases would pull through the shell and lose all load capacity. In very poor ground, the shell may slide during bolt tensio-

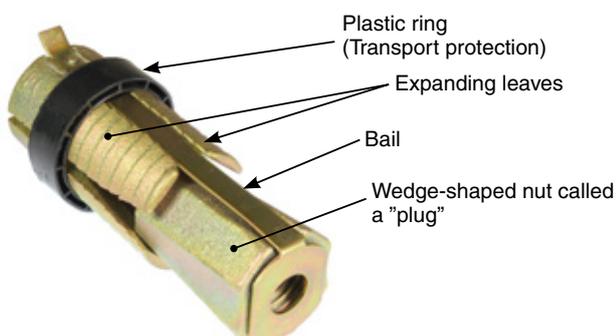


Figure 1. Bail type expansion shell

ning and not reach the targeted load before running out of threads at the end of the bolt, but typically, the expansion shell will still get jammed to provide full bolt load.

There are two basic reasons that may cause this kind of poor performance:

1. The borehole diameter could by mistake be too large. The maximum specified borehole diameter (Ø48mm or Ø68mm) should take care of preventing this from happening (in 'normal' rock mass quality).
2. Weak and soft rock material may appear locally in some of the boreholes, coinciding with where a given expansion shell happens to get located, which may produce a locally enlarged borehole diameter due to flushing action during drilling. Even with the correct borehole diameter after drilling, the expansion shell may get so much transversally extended that the wedge-plug pulls through the shell. This may happen if the surrounding material is too soft and deformable. The more likely effect of such conditions is that the expansion shell will provide full bolt load, but only after more than normal movement in the borehole.

When testing tensile load capacity there are four possible outcomes:

1. The bolt outward movement is larger than acceptable at or before the specified acceptable test load (non-destructive testing, which in such a case would be a failed test).
2. The wedge-plug pulls through the expansion shell at a load less than the specified acceptable test load (non-destructive testing, which in such a case would be a failed test).
3. Load gets increased until bolt yield is taking place and the test is stopped (destructive testing, which would normally be approved).
4. The bolt is pulled to failure (destructive testing, normally approved).

The design engineer will in most cases decide on a non-destructive routine testing, that will be applied to a specified percentage of installed bolts. All tests must be successfully pulled to a given percentage of the bolt minimum yield load, normally within the range 50% to 90%. Using 90% for the most common NC-Bolts, the numbers would be:

- M20x2.5 HRB500E: 90% of min yield load = 111 kN
- M22x2.5 HTRB630: 90% of min yield load = 172 kN.
- M33x3.5 HRB500E: 90% of min yield load = 312 kN
- M33x3.5 HRB600E: 90% of min yield load = 374 kN

For Pc-Bolt calculated the same way:

- M27/15: 90% of min yield load = 141 kN
- R27/15: 90% of min yield load = 143 kN
- R27/12: 90% of min yield load = 227 kN

Refer to Product data sheets – www.pretec.no

For special cases of poor rock quality, raising concern that 'soft' rock may cause expansion shell failure at less than bolt rod steel failure, destructive testing (pulling to failure) may be requested to verify that the expansion shell is not the limiting factor.

When installing the bolts and applying the recommended tensioning to between 40 and 60 kN (valid for M-threads and as given in the PC-bolt brochure for R-threads), the bolt rod will move outward until the wedge plug stops within the expansion shell and the bearing plate has crushed point contacts at the rock surface. This deformation is normal and necessary. However, the design engineer will typically specify the maximum acceptable additional bolt-end movement for the non-destructive test load. Even if the test load is successfully reached, deformation larger than the limit may indicate unacceptable rock mass quality where the expansion shell is located and the necessary mitigation must be described by the design engineer.

2.2 Pull test execution

2.2.1 Equipment

First, a suitable set of equipment for the pull test execution must be selected. The necessary main elements of such a set must include minimum the following items: (See example in Figure 2)

- A pull-rod to be attached to the free length of threads sticking out of the bolt end nut using a connecting sleeve
- The pull-rod tensile load capacity must be higher than the bolt failure load. The bolt to be tested must also show enough length of free threads to sustain the maximum potential test load from the pull-rod. Of course, threads must match, or an adapter must be inserted.
- A cylindrical hollow hydraulic jack with maximum pull capacity larger than the maximum test load (as well as cylinder stroke length larger than the maximum potentially necessary recording of pull deformation).

- Supporting frame for the pull reaction forces. Such a frame may be for example a tripod or a tubular frame with an inner diameter large enough to clear the bolt and pull-rod assembly. A tripod will typically be seated against rock or sprayed concrete surface outside of the rock bolt bearing plate. It is important that the pulling force is centered on the rock bolt and pulling in the extended direction of the rock bolt. If the rock bolt bearing plate has an angle washer between itself and the bolt end-nut, it is sometimes possible to set the supporting frame against the angle washer to ensure centric pull. The reaction forces would go through the angle washer and rock bolt bearing plate onto sprayed concrete and/or rock. With a tripod or any other configuration transferring load outside of the bearing plate, the supporting frame must be adjusted by shims, wedges or by any other solid means to ensure correct axial pull on the rock bolt. Reaction forces would transfer directly to surrounding sprayed concrete/rock.
- A hydraulic pump with hoses and couplings to power the hydraulic jack for necessary pull force.

Options

- Device for recording and logging of applied load and resulting deformation together with bolt ID for subsequent identification.
- Equipment for measuring deformation during pull test. This will typically include a micrometer that has an independent stable basis and can be set to zero before starting the pull test and should give deformation read-out and recording of deformation with time.



Figure 2: Pull test equipment.

Rock support – R27/12 PC-Bolt
Contractor: Implenia
Project: Slussen SN91 – Stockholm, Sweden



2.2.2 Testing procedure

Details of the actual testing procedure will depend on the requirements specified by the design engineer for the specific project at hand. This procedure must include the detailed description of the selected testing equipment, how to set it up correctly, as well as describing the test execution necessary to provide the results asked for by the design engineer. The results must be classified as either approved satisfactory, or if not, what specific action must be taken regarding any additional testing or changes/limitations of bolt usage, or supplemental use of a different bolt type.



NC-Bolt M20 cut 1500mm from protruding end.
Orange plastic sleeve surrounds the bolt.

3 Testing of load capacity after grouting

3.1 GENERAL

The NC-Bolt and Pc-Bolt types are fully grouted by cement mortar, typically within 50 m of the tunnel face, so within relatively short time (a week or two) after installation for immediate support. Because of the corrosion protection applied on the bolts (PC-Coat – HDG, zinc manganese phosphating and epoxy powder coating), this time span before being fully grouted is of no concern for load capacity or durability, even if occasionally the time period until grouting becomes quite a bit longer.

Provided that the clear recommendations and procedures regarding grouting are properly implemented, the bolts will be completely and fully grouted by high quality cementitious mortar and the targeted load capacity and durability for approval as permanent support should be satisfied.

The question then becomes how to test and verify that the installed bolts do satisfy specified load requirements. It has been found that reliable and practically useful test methods for such bolts are generally missing.

3.2 Applicable functional principles

These bolts comprise 3 functional elements after grouting has been done:

1. The area around the expansion shell.
2. The fully grouted length of steel rod between expansion shell and borehole mouth.
3. End of bolt with bearing plate and nut.



PC-Bolt M27/15 cut 500mm from each end.

All test bolts have been grouted vertically.

In terms of overall load bearing capacity, item 1 is of negligible importance for the general performance of the bolt (after grouting), but the expansion shell can be expected to show even better anchorage in the grout than item 1.

Item 2 is the most important part of the bolt, because many rock discontinuities will typically cross the bolt and represent preferred locations for any rock dilation and rock movement. The bolts are normally placed to mitigate such risk of movement and thereby maintain stability.

Item 3 will in most cases include rock surface reinforcement by sprayed concrete between the rock surface and the bolt bearing plate. The bearing plate is therefore a supplementary device to prevent the immediate rock surface (to a depth of say 2 dm) from cracking up and falling down as a result of general or local radial convergence. For the functionality of the item 2 part, the item 3 is of marginal importance, while the function of item 3 depends on item 2 working as expected.



Rock support – M20 NC-Bolt
Contractor: MossIA (Joint Venture Implenía Norge AS and Acciona Construction)
Project: Railway tunnel, double track Sandbukta – Moss - Såstad, Norway

Any testing method for load capacity of the fully grouted bolt, must therefore produce reliable information about item 2, the fully grouted length of steel rod between expansion shell and borehole mouth.

If item 2 is of primary interest for testing of bolt load capacity and functionality, then it is obvious that any version of pull testing as described above for the end-anchored bolt will be of no value at all. It is well known that in a normal hard rock and using a good quality grout, the NC- and Pc-Bolt rods will need a very limited mortar fixation length to be pulled to failure (like 2-3 dm). It means that even if pull testing (like described above) a fully grouted bolt to failure at minor deformation, the bolt at depth beyond 2-3 dm inside the rock surface, has not been subjected to any load at all. Every effect of such a test happens within the first 30 cm of the steel rod and tells nothing about capacity along the rest of the bolt.

It also means that a bolt embedded in proper quality mortar, that is crossed by an opening discontinuity located at depth, will reach bolt yield load at minor deformation, since just a dm or two on each side of the joint will be loaded.

Any conceivable direct testing of load capacity for a fully grouted NC-Bolt or Pc-Bolt will have to include drill out of the whole bolt by over-coring. It is a slow as well as costly and not so easy exercise and a test method for the extracted column of rock and bolt must be designed to provide the test results that have priority from a design viewpoint. This is considered a task outside of the scope of this Report.

There are indirect test methods, like ultrasound measurements to indicate completeness of grout filling, but reliability is questionable, especially for long bolts. There is also the CaviMeter device from Rock Safety Systems that may be considered.

3.3 Recommendation

There is hardly any doubt that when using a good quality grout and recommended mixing and pumping equipment with proper procedures for execution of the grouting, that the bolts will be completely embedded, well protected and provide a complete load transfer between the surrounding rock and the steel bolt. In situations of significant rock movements within the rock mass volume held together by the bolts, the maximum

load capacity of the bolts will be fully utilized. The load capacity of each bolt type and production batch is documented in the Inspection Certificate according to EN10204, 3.1.

Since really good testing methods for fully grouted bolts are unavailable, it is considered more relevant and productive to execute pre-construction testing to ensure correct bolt installation and grouting, along with pre-selection of grout mix design that will reliably produce top quality bolt encapsulation.

During the production stage, there should be routine checks at specified intervals of all necessary and relevant items of bolt grout execution. Bottom line is that if the grout has the right quality parameters and especially the proper rheological properties, the complete mortar filling along the full length of the bolt will be ensured, as can be directly observed during execution of grouting of every single bolt. The resulting bolt quality may consequently be considered beyond question. This is where the focus should be, not on unreliable indirect testing methods. It should also be mentioned that with such an approach and the right equipment in place (including quality control supervision), there would be no motivation for the operators to take shortcuts of any practical nature. To do it right, is no more complicated or demanding than being sloppy.

Fully grouted rock bolts should be considered reinforcement of the rock mass working the same way as rebars placed in reinforced concrete. Individual rebars in concrete structures are not routinely tested for load capacity, they are simply considered (in design) to be well embedded in the concrete and reliably offering expected load transfer. The way this is ensured is by materials testing both for steel and concrete combined with work execution requirements like how to pour the concrete, details about concrete vibration, requirements on formwork etc. With proper work execution and supervision, the result will be satisfactory as per design, based on experience. The same quality assurance principles and load verification approach must be valid also in case of fully grouted rock bolts.

4 Conclusion

Combination rock bolts like NC-Bolt and Pc-Bolt from Pretec cover the two purposes of immediate and permanent rock support. Immediate effect is achieved by the expansion shell anchorage, while permanent durability is provided by the pre-treatment and coating of all steel parts, plus the full-length embedment in high quality cement mortar.

4.1 Immediate support verification

Verification of immediate support load capacity (depends on the function of the expansion shell), will typically be done by non-destructive pull test that will be deemed satisfactory if reaching a pre-defined percentage of the minimum yield load of the bolt. In addition to this requirement, there may also be a specified maximum allowed deformation. The design engineer will typically specify the relevant numbers for individual tunnel projects.

Destructive testing may be specified by the design engineer to be optionally executed if some not satisfactory non-destructive load tests are identified, for further evaluation of potential action to be taken. Such testing may also include a fixed routine test to be done per a higher number of installed bolts, or in case geological mapping shows a less than acceptable rock mass quality.

4.2 Permanent support verification

Regarding verification of load capacity after grouting (for the permanent support), the same principles being used for rebars in reinforced concrete are considered valid.

There is no direct test procedure available to test the load capacity of the bolt rod between expansion shell and the bearing plate, which is the reason why 'verification' should be based on ensuring required materials parameters for steel and mortar, as well as proper supervised execution of grouting. When all aspects of grouting are correct, any later movement of cracks and joints crossing the bolt will transfer load to the steel which will quickly reach yield load at relatively small deformations. Ultimate capacity will be determined by the steel rod properties and not be limited by mortar quality or incomplete grout embedment caused by poor execution of grouting.

*This presentation have been made by K. Garshol
Rock Engineering Ltd*

INSPECTION CERTIFICATE
In accordance with EN 10204: 3.1

Customer: PRETEC AS
Purchasing order No: EX2019216/200634
Order Quantity: 30000pcs
Part Name: M20 NC-Bolt L=4000
Material: Rebar Bolt: HRB500E acc. to GB 1499.2-2018
Grouting head: 20; Steel tube: Q235B
Nut: CK35
Finishing: Pc-Coat
Article No: 5060003
Drawing No: PTC-173 of Jan.23.2019; PTC-173-1 of Jun.18.2015
PTC-173-3-1 of Nov.23.2016; PTC-173-4 of Jan.23.2019

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Certificate No: 24111
Date: 2020-03-24

Chemical composition analysis for material, ref certificate from mill: 191226C00334							
Batch No.	B31912050002						
Requirements (Before processing)	Max	C	Si	Mn	P	S	CEV
	Min	0.25	0.80	1.60	0.045	0.045	0.55
Test Report		0.23	0.46	1.48	0.025	0.015	0.50

Mechanical tests for material, ref certificate from mill: 191226C00334				
Batch No.	B31912050002			
Requirements (Before processing)	Min	Yield ReH(MPa)	Tensile Rm(MPa)	Agt %
	Max	500	630	9
Test Report		545	720	13.0
		550	715	13.5

Chemical composition analysis for grouting head material, ref certificate from mill: 2017-2-12						
Batch No.						
Requirements	Max	C	Si	Mn	P	S
	Min	0.20	0.35	1.40	0.045	0.045
Test Report		0.15	0.30	0.55	0.045	0.045

Mechanical tests for grouting head material, ref certificate from mill: 2017-2-12				
Batch No.				
Requirements	Min	Yield Rp0.2(MPa)	Tensile Rm(MPa)	Elongation (EL)%
	Max	235	375	9
Test Report		235	410	31

Chemical composition analysis for steel tube material, ref certificate from mill: TS2510G668-2020						
Batch No.						
Requirements	Max	C	Si	Mn	P	S
	Min	0.24	0.37	0.62	0.035	0.035
Test Report		0.17	0.17	0.35	0.018	0.006
		0.20	0.23	0.47	0.018	0.006

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NTN

NORWEGIAN TUNNELLING NETWORK

Norwegian Tunnelling Network (NTN) has issued a "Best Practice / the Norwegian way" document regarding installation of rock bolts:
www.norwegiantunnelling.com

Look under "Elements of Norwegian tunneling" and "Temporary and permanent rock bolts".



Factory in Haining, Zhejiang, China

Total area: 22000 m²

Content: Mechanical production, hot dip galvanizing and powder coating



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Rev. 12/2020