Mining Initiative for Ground Support - Workpackage 5

Overview of Test Methods for Ground Support

Masterarbeit

von

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„I declare in lieu of oath that this thesis is entirely my own work except where otherwise indicated. The presence of quoted or paraphrased material has been clearly signalled and all sources have been referred. The thesis has not been submitted for a degree at any other institution and has not been published yet."

Angelika Haindl

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This thesis is dedicated to Sebastian and Bartl, whose love and support gave wind to my sail in times of need.

Executive Summary

This report comprises a collection of testing methods for ground support. The results of the report shall be used for further investigations and evaluation on testing methods for support systems. Canada, Australia, South Africa, Sweden, Germany, Austria and USA are in focus of view.

In order to obtain a uniform structure, the testing methods were separated into specification and performance tests. According to Wagner (2010) "*the objective of specification testing is to determine whether a support meets the performance that is pre-defined in the support specification*". In contrast to that performance testing is used to test the support performance under static or dynamic loading conditions or to test the functionality of the support.
The specification and performance tests are divided into tests on material, components, support unit, support system and support system including rock mass. The latter chapter is differentiated into static and dynamic tests.

Although rock properties are very important to evaluate the rock support system, this report does not include tests to determine these rock properties.
The listed support systems can be used either in mining or in civil engineering.
This report focuses on roadway support. Powered support as well as face support and shaft support were left unconsidered.

The literature review resulted in a list of many different testing methods to determine the performance of support units, systems and support systems including rock mass. These tests have two main objectives. On the one hand there are tests and experiments that shall help to understand the mechanism of the support system. On the other hand, tests are run to determine the capability or effectiveness of systems. The latter ones can be used to quantify the support systems.
Therefore the objective of the tests is from interest.

The report presents the first phase of the Mining Initiative on Ground Support Work package 5. It comprises a literature review, collection of data and development of a sufficient structure or data evaluation. An ongoing project will be the evaluation of the collected data.

By means of the collected data on testing methods for ground support and after developing a sufficient structure for data evaluation, the following conclusion can be drawn: There are a lot of standards for testing the materials and also for testing components for ground support systems. However, there is a lack of standards for testing the support units and support systems.

TABLE OF CONTENTS

Enclosures

ENCL	TITLE – DESCRIPTION	VERSION/DATE
1	SKETCH	26.05.2010
2	STANDARDS	05.07.2010
3	LIST OF TESTS	05.07.2010

Glossary and definitions

Units

Some of the standards mentioned in this report do not use SI- units. To make the contents comparable, this units have been converted with the factors shown in Table 0-1.

Table 0-1 Conversion factors

Unit	Symbol	SI-Unit	Symbol
1	in	2.540	cm
1	psi	6894.757	Pa
1	lb	453.600	g
1	lbf	4.448	N
1	in-lb	0.113	Nm

Vocabulary

Wagner stated in his "Comments on Test Methods" the following definitions, which are also used in this report.

> *"Support element: component of a support unit (bolt, expansion shell, face plate, etc)*
> *Support unit: comprises of one or several support elements which together form a support unit, i.e. rock bolt assembly.*
> *Support system: comprises of a number of support units which, when installed, form an integral support system. A combination of different support units into a support system is quite common, i.e. rock bolts and wire mesh or rock bolts, wire mesh and shotcrete.*
> *Yield load: load at which permanent deformation of support unit occurs. Note in the case of hydraulic support the yield load is usually determined by the fluid pressure at which the hydraulic valve opens.*
> *Failure load: Load at which support unit looses its support capabilities. The loss in support capability can be sudden or slow*
> *Static conditions: Loading rate is very slow typically in the region of 1mm per minute or less*
> *Dynamic conditions: Relate to strain- or rock burst conditions. Loading rate is typically in excess of 100 mm/s. Often ground vibrations are associated with dynamic loading conditions.*
> *Support tendon: General term for a support unit that is subjected to tension, i.e. rock bolts, rock studs, reinforcement bars (re-bars), rope anchors."*

(Wagner, 2010)
The flow sheet on the following page shall outline the definitions. Also a graphical realisation is enclosed (Enclosure 1).

Although several researcher distinguish between the terms roof bolt, rock bolt, dowel, bar, bolt, tendon, stud and anchor, these terms are used as synonyms within this report.
Shotcrete is short for sprayed concrete.
Precast concrete products are also known as tubbing, crib or curb.

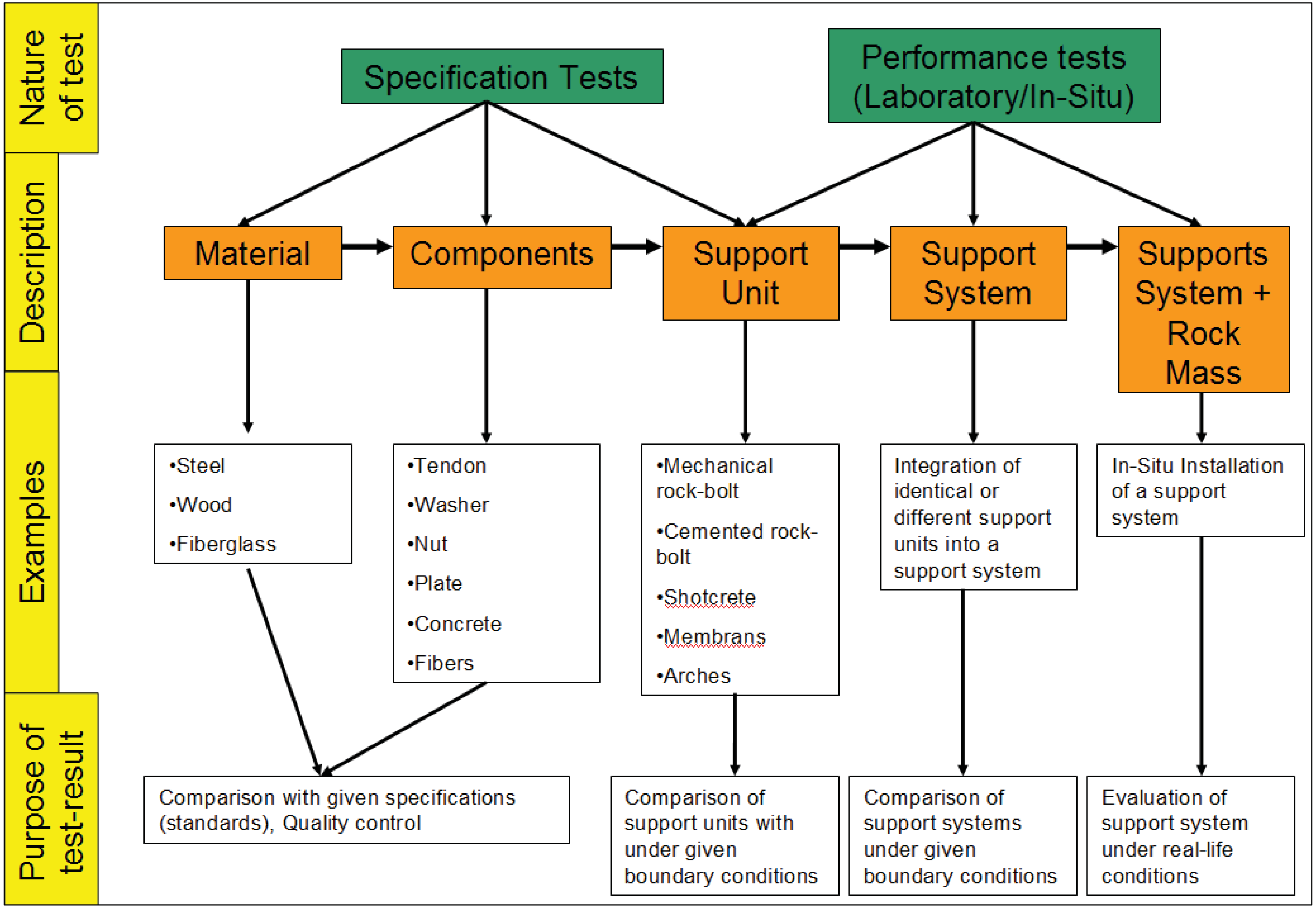

Figure 0-1 Flow Sheet of support definitions

Special definitions

The DIN standards draw a distinction between five types of test. To be comparable with the other standards, the focus in this report is on the testing methods disregarding the various types of tests.
There are tests of construction method, principle, adequacy, acceptance and tests after a certain time period.

Minimum ultimate load (MUL):
"*The minimum load, in kilonewton at which the assembly, complete with, accessories, shall not fail*" (SABS 1408[1])
"The load level in pounds through which bolt/plug thread failure must not occur"
(ASTM F 432-08)

Minimum non-seizure load (MNSL):
"*The load level in pounds through which bolt/plug thread seizure must not occur*"
(ASTM F 432-08)

Thin Spray-on Liner (TSL):
A thin (less than 10 mm thick) continuous, non-structural membrane applied to strata by spraying as surface reinforcement. (cf. EFNARC)

Proof stress

> *"<non-proportional elongation> the nominal stress that produces a non-proportional elongation equal to a specified percentage of the extensometer gauge length, as deduced from a load-extension diagram or a stress-strain diagram" (SABS 920)*
> (see Figure 0-2)

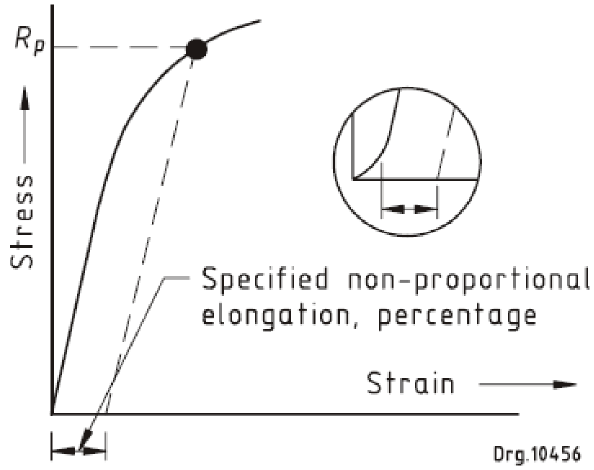

Figure 0-2 Determination of proof stress (SABS 920)

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[1] The specific edition of the cited standards can be seen in the references.

1 Introduction

1.1 Task

This report comprises a collection of testing methods for ground support. It was suggested to start a literature review for obtaining an overview of worldwide used testing methods on ground support. The results of the report shall be used for further investigations and evaluation on testing methods for support systems. Therefore this report concentrates on the collection of the literature available and not on the conclusions and evaluation of the data comprised.

1.2 Approach

Canada, Australia, South Africa, Sweden, Germany, Austria and USA are in focus of view.
The first step was to search among the national standards, which were suspected to deliver data about material specifications. It was not estimated to find much information about support system or support system and rock mass performance tests in the standards.
A second step comprised the research in literature available, mostly articles in conference papers or similar publications.
In the end the contact to several companies and institutions was made to get additional information about testing methods in use, either in praxis or in research.

In order to obtain a uniform structure, the testing methods were separated into specification and performance tests. Further there is a partition in material, components, support unit, support system and support system including rock mass. The latter chapter is differentiated into static and dynamic tests.

There is no differentiation between the three main steps for measuring: primary support, short-term, long-term measuring, for it is not point of view when or where the specific support system or element is to be used, but how it can be classified.
Timber support is not part of the report, since there is no standardisation for it and the use in today's underground mines has decreased.
Furthermore there are no tests concerning only the rock mass. The so gained rock parameters are essential for the underground support design, but not discussed here.
In addition to all described tests there should be in-situ observations and trial and error analyses for each specific location. These methods are not described here.
Although rock properties are very important to evaluate the rock support system, this report does not include tests to determine these rock properties.
The listed support systems can be used either in mining or in civil engineering.
This report focuses on roadway support. Powered support as well as face support and shaft support were left unconsidered.
Only literature in English and German could be used.

2 Specification Tests

2.1 Material

To avoid confusion this chapter is organized as follows: For each material a short overview in general about the found standards is given. A list of names of the standards belonging to the materials shall help to find the detailed description in Enclosure 2.

2.1.1 Steel (and iron)

All in all two types of national standards dealing with steel and underground support were found. The first group discusses steel used for the reinforcement of concrete, whereas the second group contains specifications for mining support units, mainly for tendons and their accessories.
One DIN-Standard was found that comprises material specifications for arch support.
To test the steel, most standards require a tensile test, shear and bending tests as well as measurements of the proper dimensions and the determination of the chemical composition.

The documents belonging to this chapter are:
ÖNORM B 4200-7:1968 Concrete reinforcement
ÖNORM EN 1537:2000: Execution of special geotechnical work - Ground anchors.
DIN 21530-3:2003 Mine support - Part 3: Requirements
DIN 21531-1:1990 and -2 Arch supports
DIN 488:1996 Reinforcing steels
ASTM F 432-08 Standard Specification for Roof and Rock Bolts and Accessories
CAN/CSA-M430-90 Roof and Rock Bolts, and Accessories
BS 7861-1:2007 Strata reinforcement support system components used in coal mines
SABS 1408:2002 Mechanical components for tendon based rock support systems
SANS 920:2005 Steel bars for concrete reinforcement

2.1.2 Concrete (including Shotcrete)

The number of standards discussing the issue of concrete and sprayed-on concrete, so-called shotcrete, is very large. The reason therefore is that concrete is not only used for mining purposes but also for civil construction work. The material itself remains the same, only the requirements differ slightly. Therefore the standards can be also used for ground support material, eventually some modifications may be decided in the contract between supplier and client.
The main principles of testing methods are similar in the different countries. Parameters tested are the ultimate compressive strength and the ductility, to name but the most common ones.

In contrast to steel, concrete is a mixture of different materials, namely water, cement, aggregates and various additives. Therefore every component has its own specifications. Tests on cement and aggregates may be very similar in each country, with varying threshold requirements. However, they are not in view of this paper, and therefore only referenced in the detailed description (Enclosure 2).

Concrete can be tested either wet or hardened. For testing hardened concrete a core is drilled and then tested in the laboratory or penetration needles are used to test the concrete in-situ.

What is of interest are the guidelines by EFNARC on shotcrete. These documents are essential, for they are valid in all Europe and deal with shotcrete, which is widely used underground.

The documents belonging to this chapter are:

Austrian Guidelines: Sprayed Concrete August 2006 from Austrian Society for Concrete- and Construction Technology
ÖNORM B 3303:2002 Testing of Concrete
ÖNORM B 3313:1980 Blast furnace slags; general aspects
EN 206-1:2005 Concrete - Part 1: Specification, performance, production and conformity
EN 12504-1:2009 Testing concrete in structures
EN 13791:2007 Assessment of in-situ compressive strength in stuctures and precast concrete components
EFNARC European Specification for Sprayed Concrete,1996
ASTM C39-09 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens
ASTM C42/C42M-04 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C78-09 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C143-10 - Standard Test Method for Slump of Hydraulic-Cement Concrete
ASTM C192-07 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
ASTM C231-09 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C 403-08 Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
ASTM C805-08 Standard Test Method for Rebound Number of Hardened Concrete
ASTM C 1550-05 Flexural Toughness of fibre reinforced concrete (using centrally loaded round panel)
CSA A23.1/A23.2-09 Concrete materials and methods of concrete construction/Test methods and standard practices for concrete
BS 1881-124:1988 Testing concrete - Part 124: Methods for analysis of hardened concrete
SANS 5861:2006 Concrete tests - Mixing fresh concrete in the laboratory
SANS 5862:2006 Concrete tests - Consistence of freshly mixed concrete
SANS 5863:2006 Concrete tests - Compressive strength of hardened concrete
SANS 5864:2006 Concrete tests - Flexural strength of hardened concrete

SANS 5865:1994 Concrete tests - The drilling, preparation, and testing for compressive strength of cores taken from hardened concrete
SANS 6085:2006 Concrete tests - Initial drying shrinkage and wetting expansion of concrete
SANS 6250:2006 Concrete tests - Density of compacted freshly mixed concrete and
SANS 6251:2006 Concrete tests - Density of hardened concrete

2.1.3 Resin

Only four standards were found, dealing with material specifications of resin for grouted bolts.
What is important to test on resin is on the one hand the age and on the other hand the setting time. Furthermore strength tests are done on resin and the South African standard also comprises specified testing methods for the resin capsules.

The documents belonging to this chapter are:
ÖNORM EN 1537:2000: Execution of special geotechnical work - Ground anchors.
see US standards for grout
BS 7861-1:2007 Strata reinforcement support system components used in coal mines
SABS 1534:2004 Resin capsules for use with tendon based support systems

2.1.4 Grout

Compressive strength and setting time are the two parameters that are of main interest, when testing grout for tendons. The German standard refers to special standards, available for each type of grout.
Most standards also deal with dimension requirements for the cartridges.

The documents belonging to this chapter are:
DIN 21521-2:1993 Rock bolts for mining and tunnel support; general specifications for steel-bolts; tests, testing methods
EN 445-2008 Grout for prestressing tendons - Test methods
ASTM F 432-08 Standard Specification for Roof and Rock Bolts and Accessories
BS 7861-1:2007 Strata reinforcement support system components used in coal mines
SABS 1745:2003 Cementitious grouting capsules for use with tendon-based support systems

2.2 Components

The comparison of specifications for components was a very difficult task. It was tried to give an general overview of the procedure, although each standard comprises very different testing methods. A table summarising the important parameters for each group of components, such as tested parameters, thresholds, load rate and equipment, is used to try to give a clear view on the component tests.

Short comments at the end of each chapter shall point out the main differences or remarkable similarities.

Documents found deal with tendons, bearing plates, expansion shells and plugs, nuts, tubbings, mesh, straps, lacing and Thin Spray-on Liners (short TSL). Shotcrete is not mentioned in this chapter, for it is already discussed in the previous one.

2.2.1 Tendons

Procedure in general:
Most nations comprise standards that include a test method to determine the tensile strength of the tendon.
With an appropriate machine a tensile force is applied on the bar until a distinct value or failure of the bolt. In most cases the yield strength is determined. Furthermore the elongation is measured.
Often there is no specification of the monitoring systems.
The following diagram shall give a clear definition of the tested parameters, see Figure 2-1.

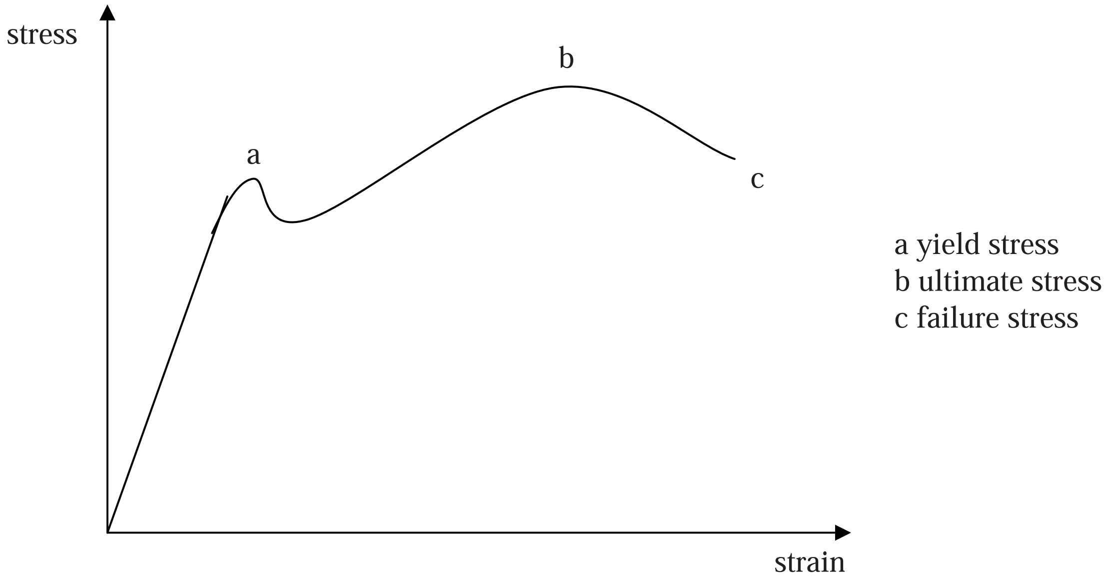

Figure 2-1 Sketch of tested parameters for tendons

Values:

Table 2-1 Overview of standards for component 'tendon'

Country	Standard	Parameters Tested	Thresholds for Parameters	Load rate, stress rate	Required equipment	References	Remarks
United Kingdom	BS 7861-1:2007	Minimum yield strength	Min. 640 MPa	stress rate not exceeding 10 (MPa)/s prior to the yield point	Tensile test machine, Extensometer	BS EN 10002-1:2001 BS EN ISO 7500-1:2004 BS EN ISO 9513:2002	
		tensile strength (on the actual cross-section area, based on equivalent diameter)	Min. 20 % greater than the yield strength				Also specified for GRP
		elongation [%] after fracture over a gauge length of 100 mm	min. 18 %				
		elongation at maximum force	min. 8 %				
		Resistance to brittle fracture	Max. 2 values < 27 J Average value ≥ 27 J Max. 1 value < 19 J	*See reference*	Charpy impact test machine	BS EN 10045-1:1990 BS EN ISO 7500-1:2004	
Canada	CAN/CSA-M430-90	yield point	min. 205 MPa (in table[2])	*See reference*	*See reference*	ASTM A370-09 ASTM F606-10	Depends on nominal diameter
		tensile strength	min. 415 MPa (in table)				
		Elongation in 200 mm	min. 17 % (in table)				

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[2] See *Comments* at the end of the table

Country	Standard	Parameters Tested	Thresholds for Parameters	Load rate, stress rate	Required equipment	References	Remarks
South Africa	SABS 1408:2002	Minimum ultimate tensile strength	570 MPa (Type B: 600 MPa)	2.0 kN/s until fracture, gradually applied	Testing machine, two square flat bearing plates, one or two nuts		Also Charpy impact test
		0.2 % yield proof stress	360 MPa (Type B: 450 MPa),				
		minimum elongation after fracture in L_0	22 % (Type B: 14 %)				L_0 has to be calculated after a special equation.[3]
United States	ASTM F 432-08 ASTM D 4435-08 ASTM D 4436-08 ASTM D 7401-08	Min. Yield point	276 MPa	*See reference*	*See reference*	ASTM F 606-10 ASTM A 370-09	Values depend on nominal diameter.
		Min. Tensile strength	483 MPa				Values here for nominal diameter of 19-38 mm.
		Elongation in 200 mm Minimum	12 %				

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[3] See *Comments* at the end of the table

Country	Standard	Parameters Tested	Thresholds for Parameters	Load rate, stress rate	Required equipment	References	Remarks
Germany	DIN 21521-2:1993	Yield point	Distinct values given in referred documents.	*See reference*	*See reference*	DIN EN 10002-1,5:1992 DIN 488-1,3:1996 DIN 50115:1975	Parameters Tested by: Tensile test and Notched bar impact test.
		Tensile strength					
		Reaction force					
		Elongation after fracture					
		Percentage reduction of area after fracture					
		Variation of free length					
		Elongation (testing area of the specimen is ten times the diameter long)					

Comments:
The values for the minimum elongation cannot be compared directly, for there are different geometric requirements and diameters of the bars tested.

The *ASTM* defines minimum yield point, minimum tensile strength and elongation in 200 mm for five grades (40, 55, 60, 75 and 100) for steel bars for the manufacture of bolts. Steel bolts, threaded bars, threaded deformed bars, and threaded slotted bars shall meet given yield and ultimate tensile loads for the required grade.
Furthermore the *ASTM* contains surface configurations on formable anchor bars and dimensions of formable anchor tubes.
Special feature of the *ASTM* (and *CSA*): For plain bolts to be used with grout there shall be a design feature to provide interlocking between the steel and the grout.
Slotted bolts produced by methods involving metal removal have to meet requirements with lower values.
The *ASTM* includes a test of friction stabilizers. The friction stabilizer device is inserted by means of a plug (to be able to grip the stabilizer) into the testing machine. This machine has two test plates as shown in Figure 2-2. The stabilizers are loaded until their minimum ultimate load with no failure of the head end.

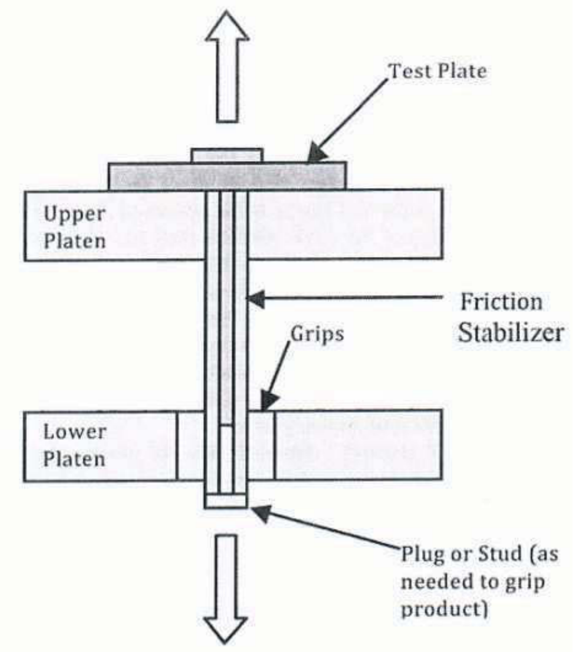


Figure 2-2 Friction Stabilizer Generalized Test Apparatus (ASTM F432)

In case of the bolt being too long for the testing machine *ASTM* and *CSA* suggest to

> *"cut the head with a portion of the body in the case of bolts, and the thread with a portion of the body, from the bolt or threaded bar and test each separately. Test the section containing the threads for yield point and breaking load by using the nut intended for use on the threaded portion and by gripping the bolt body. Failure may not occur by stripping of threads. Test the section containing the bolt head with a 10° wedge under the head and by gripping the body." (ASTM F432)*

ASTM and *CSA* contain figures with the required dimensions of the bolts and bars.
ASTM and *CSA* suggest, that threaded slotted bars from which no material has been removed during the slotting procedure need not be tested on the slotted end. Threaded

slotted bars from which material has been removed shall be tested by tack welding the two ends together at the end of the bar. Then gripping both ends and leave 2.54 cm of slot in the tested part in between.
ASTM and *CSA* include a bend test for notched bendable bolts. After a successful bend test, the bolts shall be tension tested. Reference: *ASTM A615-09*.

The *CSA* contains minimum yield point, minimum tensile strength and elongation in 200 mm for four different grades (30, 55, 60 and 75). Furthermore the standards differ between steel bars and rock bolts, threaded bars and threaded slotted bars.

In addition to the testing method for the tendon the *BS 7861* includes definitions for profile, diameter, tensile properties and resistance to brittle fracture. It also defines the manufacture of proximal and distal end as of length. For corrosion protection it refers to *BS EN ISO 1461.*
For GRP (Glass fibre reinforced plastic rock bolts) the standard defines profile, diameter, straightness, electrical resistance (*BS EN 13463-1*), fire resistance, torsion strength, tensile strength (see *BS EN ISO 527-1*) and flexural strength.

The *SABS* elongation is determined for a gauge length L_0 in metres. It is calculated after the following equation.

$$L_0 = \sqrt{\frac{K}{0.00785 \cdot L}}$$

K stands for the mass of the bar (in kilograms) and L for the length of the bar (with at least 0.5 m), in metres.
This standard contemplates a Charpy V-notch impact resistance test for rock bolts and studs.

The tensile test described in *DIN 21521* is used to determine maximum tensile strength, maximum yield strength, elongation after fracture, elongation without necking, percentage reduction of area after fracture and the variation of the free length of the bar between the gripping devices.
The notched bar-impact test is performed according to *DIN 50115* on DVM-specimens. In case it is not possible to make a proper test specimen (i.e. **cable bolts**) a substitute testing method has to be agreed on.
When yielding elements are to be used, the characteristic curve of the bolt shall be determined for the hole yielding space.

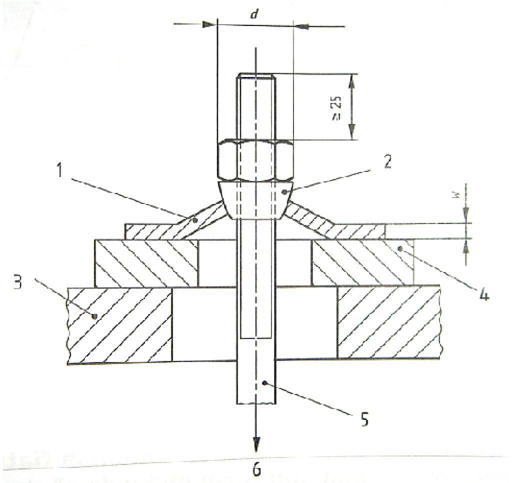
The special topic **cable bolts** is handled in *DIN* as follows. Cables of cable bolts shall be tested separately. If the bolt has several different diameters, the tensile tests shall be made at least on the diameter which is the most important for the tensile strength.
The *ASTM F432* refers to *ASTM A416-88b* and *ASTM A416-90b*, the *CSA* to *CSA G279-1975* and *CSA 6279-m1985*

Rod and nut for **rebar bolts** are special handled in the *CSA M430* by referring to *CSA G30.18-M92 Carbon steel bars for concrete reinforcement.*

Content*:* The document covers the requirements for two different types of hot-rolled deformed steel bars (regular and weld able, differences in the chemical composition) and plain bars. The standard differences between two minimum yield strength levels, namely 400 MPa und 500 MPa.
Refers to: CSA W186 for requirements for welding of reinforcing bars

2.2.2 Bearing and header plates

Procedure in general:
In general, testing the plates is done by positioning the specimen on a steel test plate with a hole in the centre. For the procedure a testing machine with at least two support devices is needed. This can be the same machine as used to test the bolts. Furthermore a rock bolt and some fixture are used for the test, with only analysing the bearing plate or washer.
The common test is to apply a tensile force on the bolt and so loading the specimen, as shown in Figure 2-3. After the test, the plate is examined and the axial movement is measured. Nut and spherical seat must not be pulled through the plate.
In contrast to the bolt tests the specimen is only loaded until a distinct value, not until failure.



1 Steel domed washer plate
2 Conical seat
3 Testing machine platen
4 Backing plate
5 Rockbolt
6 Applied load

Figure 2-3 Testing of bearing plates (BS 7861)

Plate test by van Sint Jan and Palape, 2007
The plates are either tested by pushing onto them or by applying a load due to pulling on a bolt and nut assembly, resting on the centre of the plate, as illustrated in Figure 2-4. The test is run until the plates fold. The deformation observed during the tests closely resembled the deformation seen in the field.

Figure 2-4 Sketch for plate testing (van Sint Jan and Palape, 2007)

Values:

Table 2-2 Overview of standards for component 'bearing or header plate'

Country	Standard	Parameters Tested	Thresholds for Parameters	Load rate, stress rate	Required equipment	References	Remarks
United Kingdom	*BS 7861*	pull through loads	No distinct values given. A graph shall be plotted.	*See reference*	Tensile test machine	BS EN ISO 7500-1:2004	Due to a tensile test.
		flattening					Performance requirements are assembly load and alignment.
Canada	*CSA-430-90*	Maximum deflection	6.35 mm	*From 26.7 kN pre-load to 66.7 kN maximum*	*See Comments*	For the hardness test the document refers to ASTM F606-10.	Also the monitoring systems are defined.
							The standard requires a measuring device accurate to 0.03 mm for measuring the axial movement.
							There is no specific test method described for spherical washers. They shall successfully perform the intended use.

Country	Standard	Parameters Tested	Thresholds for Parameters	Load rate, stress rate	Required equipment	References	Remarks
South Africa	*SABS 1408*	withstand a force	equal to the 0.2 % proof stress	No distinct value given.	testing machine, a test block that has a 50 mm ± 0.5 mm diameter hole through the middle, flat bearing plates, nuts and two rock bolts or studs		without anything pulled through the hole of the bearing plate
		deformation	15 mm maximum				There is no specification of the monitoring systems.
		Charpy impact test	*See reference*	*See reference*		SABS ISO 148:2007	
United States	*ASTM F432-08*	Maximum deflection	6.35 mm	From pre-load 26.7 kN to 66.7 kN maximum load	*See comments*		two types to test header and bearing plates.
		Hardness test	*See reference*			The hardness test after Rockwell has to be in accordance with *ASTM F606*.	There are no specific requirements for bevelled washers or spherical washers.
Germany	*DIN 21521*	Suggests to test the plates by testing the hole anchor head. Therefore the test is described later on in this report in chapter support unit. *DIN 21522:1972* specifies dimensions of plates.					

Comments:
DIN 21522 and DIN 21521-2
The German standard requires a 15 degrees inclined testing plate and defines the most unfavourable position of the plate to be tested. The plate is shown in Figure 2-5.

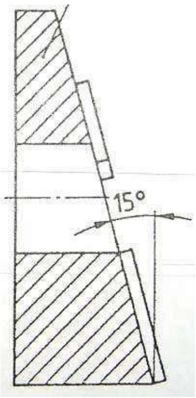


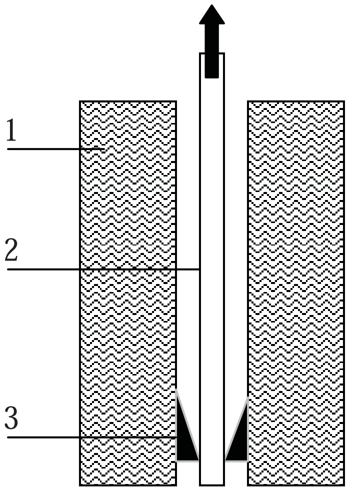
Figure 2-5 Testing plate for bearing plates (DIN 21521)

ASTM F432 refers to *ASTM F436* for testing hardened flat washers.
CSA M430 is very similar to *ASTM F432.* It specifies, that plates, which are strengthened by quenching and tempering shall have a maximum hardness of 45 HRC (Rockwell). Hardened washers shall have a hardness range form 35 to 45 HRC. The testing procedure of hardness tests shall be in accordance with *ASTM F606.*

ASTM F432 describes two types of tests.
For the first type of test a bolt is inserted into the washer and the hole assembly is positioned in a testing machine. Then a pulling force is applied on the bolt to test the washer. For the other test method a testing machine with a punch is needed. This punch shall load the washer until a certain value. (see Figure 2-4)

2.2.3 Expansion shells and plugs

Procedure in general:
For the test of the expansion shells (and threaded tapered plugs) a special test block is needed. Then the specimen and a test bolt are installed into the artificial bore hole. By applying a force onto the bolt, the expansion shell is loaded and examined afterwards. A sketch of the testing process is shown in Figure 2-6.



1 artificial rock mass comprising a borehole
2 rock bolt with applied force
3 specimen to be tested

Figure 2-6 Testing of expansion shells.

In general the expansion shells and plugs have to be of the same or a higher grade as the bolts, with which they are intended to be used.
A table would not be the proper way to compare these tests, therefore a short description of the procedure in each standard is given.

Procedure described in the standards:
DIN 21521-2
The test requires an artificial rock mass, realised by a cylindrical steel tube, filled with concrete able to bear the ultimate tensile strength of the bolt. In the centre of the concrete block there is a bore hole. The expansion shell and a test bolt shall be positioned in the hole according to the installation instruction. During the test a tensile force is applied on the bar, ten times until 0.9 times the yield strength of the bolt and one time until fracture.

The standard CSA M430 suggests a test for threaded tapered plugs for expansion shells, although this test should only be performed when the strength and performance of the component have become important. The testing procedure covers installation of bolt, expansion shell and threaded tapered plug in a straight hole, tightening the assembly and then loading it to the ultimate tensile strength. The force can be an axial load or a torque load. Neither stripping of the threads nor rupturing of the plug may occur.
Testing tensile nuts is similar to the procedure described above.
Threaded tapered plugs must be capable of withstanding the ultimate tensile load capacity of the bolt, even though this is no routine test.

ASTM F432 describes a non-routine test, where bolt, expansion shell and threaded tapered plug are positioned in a test cylinder or block. The assembly is loaded (axial or rotating) to the minimum non-seizure load (depending on the grade of the plug) and later on to the minimum ultimate load. Afterwards the components shall be examined. The threads must not be stripped.

The *SABS 1408* also includes a strength test for expanding shells. For the test a testing machine, like the one necessary for the bolt tests, is needed. Also a special steel test block including a hardened ring, shown in Figure 2-7, is required. The testing assembly consists of the expanding shell, a rock bolt, a square flat bearing plate and hexagon nuts. The expanding shell is tested by applying a tensile force on the rock bolt until fracture.

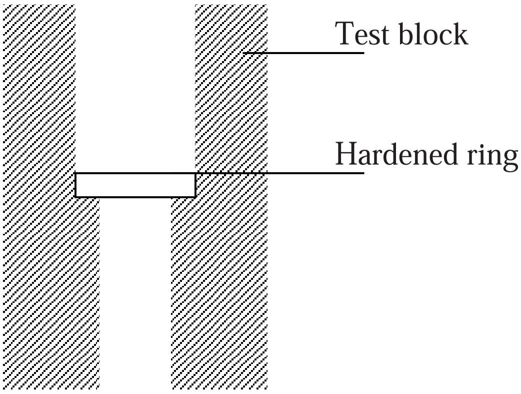


Figure 2-7 Steel test block and hardened ring for testing expanding shells

2.2.4 Nuts

Procedure in general:
Most standards refer to external standards for the requirements for nuts. There is no unique standard testing method. It can be said, that the nut has to provide at least the same material requirements as the bolt.

Procedure described in the standards:
ASTM F432 and *CSA M430* refer for the nuts dimensions to *ANSI B18.2.2*. The nuts shall be tested in accordance with the supplied specification and they must withstand the required mechanical properties of the highest grade bolt with which they are to be used. Tension nuts testing is no routine test.

BS 7861 refers to *BS EN ISO 4034* for the manufacturing requirements of nuts. A breakout type test shall be made. Therefore the nut is screwed onto a bolt and inserted into a test machine gripping device. A torque meter is attached to the nut and the bolt now is rotated with 75 rpm. The torque at which the nut fails is recorded.
Nuts used with GRP shall also be tested for breakout facility. The test is similar to the steel nut testing procedure, but the load is applied manually with a torque wrench.

SABS 1408 refers for plain nuts to *SABS 1700-5-2, SABS 1700-5-4 and SABS 1700-5-15.* The nuts shall withstand the breaking load requirements of the bolt and be treated in a way preventing seizure during installation.

DIN 21521 requires a test of the hole rock bolt head. For the nut is part of the head it is tested with it. See chapter Support Unit for the test method.

2.2.5 Tubbings

Procedure in general:
Only a few standards were found, concerning tubbings. They, however, do not have much in common. Therefore it is not possible to give a general description of a common procedure.
They all test a kind of strength parameter of the concrete products.

Values:

Table 2-3 Overview of standards for component 'tubbing'

Country	Standard	Parameters Tested	Thresholds for Parameters	Load rate, stress rate	Required equipment	References	Remarks
Austria	*ÖNORM B 2203-2 "Underground works - Works contract - Part 2: Continuous driving"*	only refers to the progress report 'Tubbings' by the *Austrian Society for Concrete- and Construction Technology*.					
Europe	*EN 13369:2008 Common rules for precast concrete products (consolidated version)*	compressive strength	*See reference*	*See reference*	*See reference*	EN 1990:2006, Eurocode 0 EN 1992-1-1:2004, Eurocode 2 EN 206-1: 2000 EN 933-1:2006 EN 934-2:2009 EN 1008:2002 EN 1097-6:2006 EN 12390-2:2009 EN 12390-3:2009 EN 12390-7:2009	Compressive strength test specimen are cubes or cylinders. It is also not appropriate for reinforced precast concrete products made of light-weight concrete.
		water absorption	*See reference*	*See reference*	Oven, flat box		
		oven-dry density	*See reference*	*See reference*	*See reference*		
		dimensions	*See reference*	*See reference*	*See reference*		
		surface condition	*See reference*	*See reference*	*See reference*		
		masses	*See reference*	*See reference*	*See reference*		

Country	**Standard**	**Parameters Tested**	**Thresholds for Parameters**	**Load rate, stress rate**	**Required equipment**	**References**	**Remarks**
Japan	*JIS A 5363:2004 Precast concrete products - General rules for methods of performance test*	cracking load	There are no distinct values given in the standard.	*See reference*	*See reference*	JIS A 0203 Concrete terminology JIS B 7505 Bourdon tube pressure gauges JIS B 7721 Verification and calibration of the force measuring system of the tension/compression testing machines	The parameters are archived by means of a bending test method and a shear test method for simple beams.
		crack width					
		residual crack width					
		Breaking load					
		displacement					
		curvature					

Comments:

A European as well as a Japanese standard was found, dealing with testing methods for tubbings. The Austrian standard only refers to special guidelines. There is a main difference between the first two documents. The Japanese one focuses on destructive testing, as bending and shear tests, whereas the European standard also comprises tests of surface condition and dimensions.
Both, however, have in common, that they test a kind of strength parameter. The testing methods are not very similar.
A remarkable point is that the Japanese standard discusses the testing procedure and comprises formulas to calculate the strength parameters, but it does not contain any threshold values.

2.2.6 Shotcrete

See chapter Material under Concrete.

2.2.7 Meshes, straps, lacing

Both, *ASTM F432* and *CSA M430*, demand a test of truss brackets. Truss brackets for primary support shall be tested like the bearing or header plates. Otherwise they are tested on a steel fixture similar to the position in which they are intended to be used. Loads are applied on the bolt, while the horizontal element is held and on the horizontal element while the bolt is held stationary. The bracket shall be tested to failure and withstand the lowest failure load of the tested components.

Meshes can be also tested at WASM, with a special testing rig.
Static testing of high-tensile mesh is conducted with the facility shown in Figure 2-8 (at WASM). Results are force-displacement diagrams. (Coates et al., 2009)

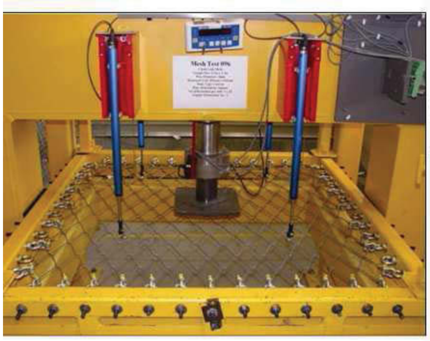


Figure 2-8 Mesh testing (Coates et al., 2009)

For dynamic testing the mesh panel is installed in a loading frame in which a weight (bag with steel balls) can be dropped onto the mesh from different heights (WASM momentum transfer concept).

The rebound of the loading gram is stopped by buffers while the loading mass impacts the mesh sample without being separated from it. (Coates et al., 2009)

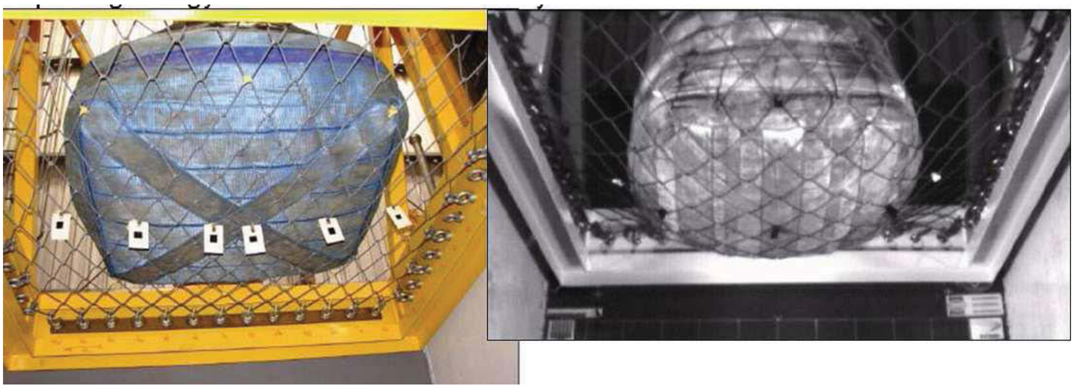


Figure 2-9 Dynamic testing of mesh (Coates et al., 2009)

2.2.8 Thin Spray-on Liners - TSL

See chapter Performance Tests under Support unit.

2.2.9 Arch support components

The testing of components for arch support are described in the chapter 'Arch support' under performance tests on the support unit, for there is a German standard.

3 Performance tests

The literature review resulted in a list of many different testing methods to determine the performance of support units, systems and support systems including rock mass.
These tests have two main objectives. On the one hand there are tests and experiments that shall help to understand the mechanism of the support system. On the other hand, tests are run to determine the capability or effectiveness of systems. The latter ones can be used to quantify the support systems.
Therefore the objective of the tests is from interest.

Each test is unique and it is impossible to find a general, common testing procedure.
In order to try to organize the amount of tests the chapter is divided into several main groups. In each group the corresponding testing approaches are discussed in detail, including sketches to assist the discussion. A first general description shall give an overview of the group.

For tests employing an artificial rock mass, the strength of the concrete blocks used may be from interest.

In Enclosure 3 all the tests described here are summed up in a table.

In contrast to the previous chapter for the specification tests, the chapter for performance tests is organized as follows. Rather than referring to standards and guidelines, equipment and testing procedures of individual testing methods are shown and described in detail.

3.1 Support unit

3.1.1 Static

3.1.1.1 Rock bolts

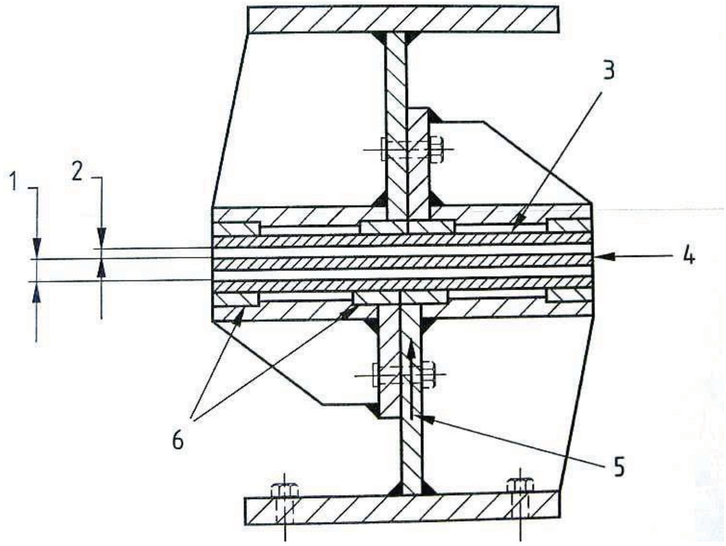
Shear tests

In general
In literature a variety of shear tests on rock bolts can be found. They differ by means of their object and the testing facilities. Most use self-made shear frames. They are therefore very difficult to compare. The next section contains a list of experiments, covering the main objective and data on the testing facility. There are two main types of shear tests: the ones using one joint, the others investigate the rock bolt behaviour when sheared on two joint zones.

The testing facilities comprise one or more artificial joints between blocks of concrete or rock.
For small scale-tests also cylinder can be used, otherwise special apparatuses are needed. (Li, 2008)
Some researchers developed testing facilities that can perform shear tests as well as pull-out tests on rock bolts.

Shear tests to determine strength and deformation behaviour

BS 7861
The *BS 7861* comprises several tests for support units containing steel rock bolts as well as for GRP bolts.
To determine the ultimate shear strength of a rock bolt and resin system a special shear test has to be carried out. The equipment needed is a single (guillotine) shear frame (shown in Figure 3-1), a tensile test machine, and three test assemblies as well as a displacement transducer. The rock bolt is pushed into the tube, filled with slow-set resin, by hand in a rotating manner. After preparation and curing the assembly is positioned in the test machine and loaded with a stress rate of 10 N/mm² maximum until maximum load. The latter and the displacement are recorded. The shear strength can be calculated by means of the maximum load and the cross-sectional area.



1 internal tube diameter 5 mm grater than nominal bolt diameter
2 wall thickness at least 50 % of bolt nominal diameter
3 double embedment assembly containing steel rock bolt resin
4 bolt
5 load applied to lower section of shear frame only, upper section remains static
6 hardened steel bushes interchangeable to accommodate different tube sizes

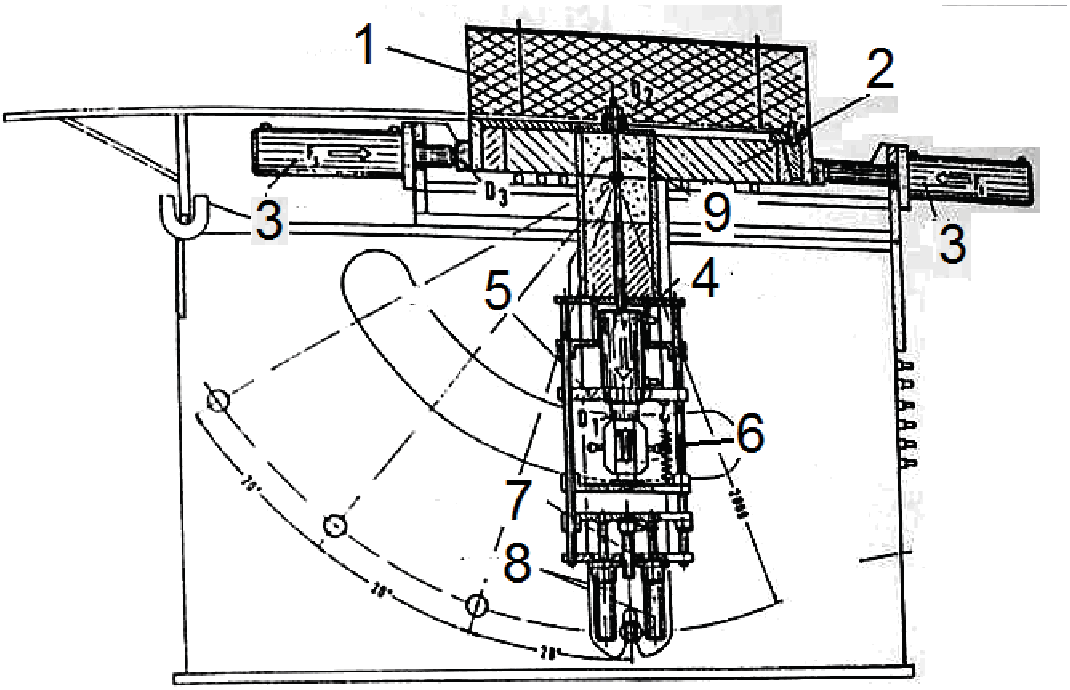
Figure 3-1 Shear frame (BS 7861)

Bartels and Pappas, 1985

In their report ‘Comparative Laboratory Evaluation of Resin-Grouted Roof Bolt Elements’ they stated, that

> *“The testing procedure for the shear tests consisted of shimming the bolt host rock into a loading frame incorporating a [...] 30.48 t actuating ram locate as close to the interface of the two block halves as possible. An LVDT was placed on the side of the top clock opposite the ram. Tensioned and point anchors bolts were torqued to approximately[203.37 Nm]. Displacement and pressure readings were taken until failure” (c.f. Bartels and Pappas, 1985; as cited in Whitaker, 2001)*

Wittenberg, 1995



1 cover
2 shear box
3 shear cylinder
4 hollow piston cylinder
5 lever
6 grip head
7 disengaging cylinder
8 hydraulic jack
9 test specimen

Figure 3-2 Test facility (Wittenberg, 1995)

Hexagonal concrete block simulate the rock mass, so several inclinations (33, 55, 78 and 100^{g}) between shear zone and rock bolt axis can be chosen. The resin grouted rock bolts used are pre-tensioned due to a hollow piston cylinder, mounted on the extruding bolt end.

Shear forces are created by either the right or the left hydraulic cylinder. The concrete blocks are coated to avoid cleavage fracture due to pressure on the face of a hole.
Shear force, displacement and tensile force are recorded.

Deangeli, Ferrero and Pelizza, 1995

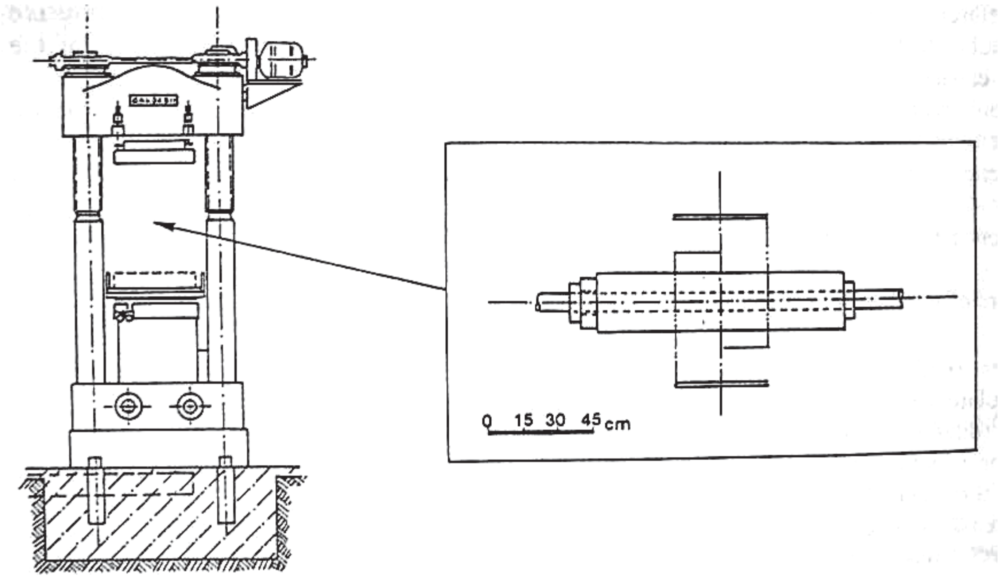
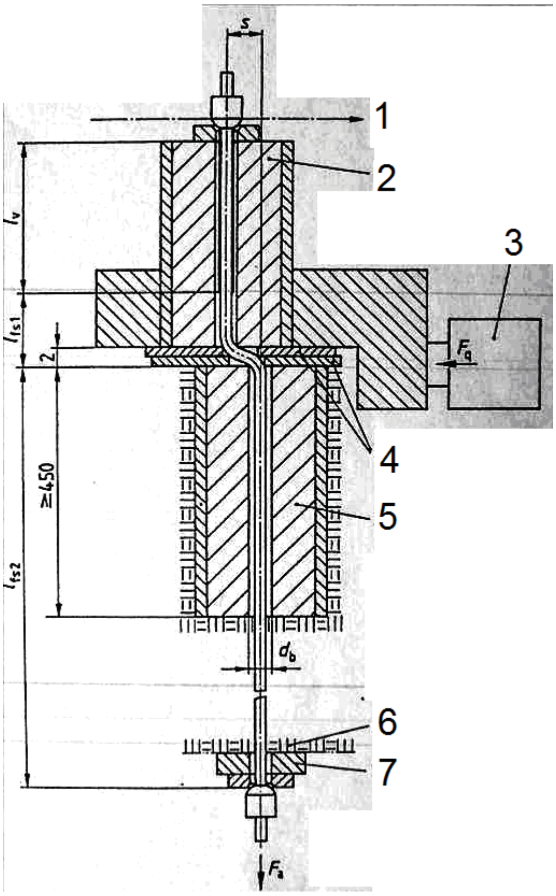


Figure 3-3 Testing facility (Deangeli, Ferrero and Pelizza, 1995)

Deangeli performed shear tests on specimens of different materials, reinforced by different types of fully grouted bolts (steel bar and tubes, prestressed and non-prestressed). The reinforcement element is installed perpendicular to the artificial joint plane. The shear plane is smooth and flat. Test samples have dimensions of 0.3x0.3x0.8 m. The testing facility allowed a shear displacement of about 150 mm. The grout used was fast setting mortar. The testing device is shown in Figure 3-3. The shear box has two sides, one able to move and one fixed, and is positioned between the plates of a conventional press. This assembly allows the application of a transverse load. The load is applied incrementally in constant steps. The steel sides of the box are separated by frictionless contact and lateral displacement is not allowed.

DIN 21521



1 plane of symmetry
2 Shear block B
3 hydraulic jack
4 lubricated plate
5 Shear block A
6 bearing
7 force transducer

Figure 3-4 Test facility (DIN 21521)

DIN 21521 contemplates a shear test for rock bolts, either as single or double joint test, to determine the yielding strength. Concrete bocks as shown in Figure 3-4 are used to simulate the rock mass. The test procedure contains the installation of the rock bolt, pre-tensioning it and then loading the assembly until failure. Force-displacement diagrams and tensile force are the gained results. For a double joint test, the single joint testing arrangement is completed symmetrically.

The following tests comprise two shear zones

Grasselli, Kharchafi and Egger, 1999

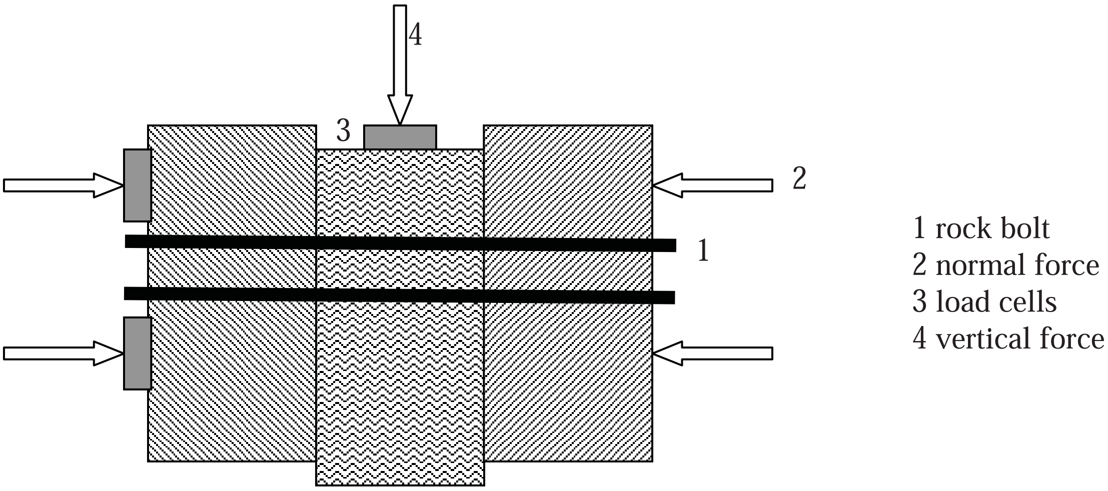
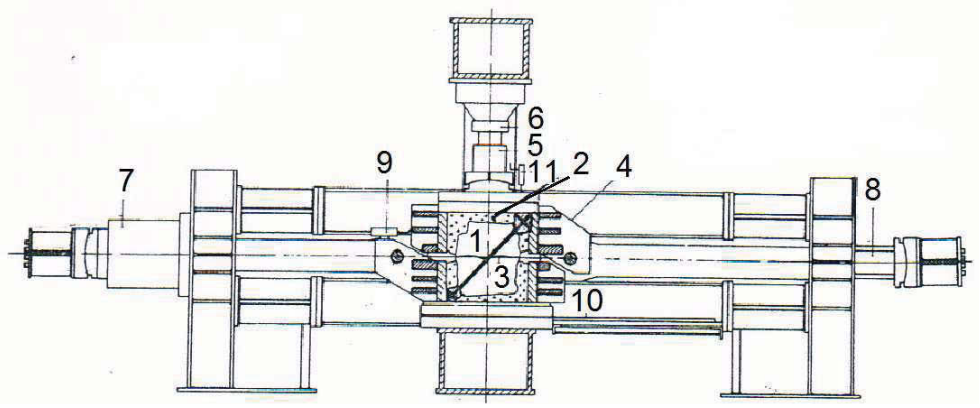


Figure 3-5 Testing facility (Grasselli, Kharchafi and Egger, 1999)

The testing facility comprises three blocks (0.1x0.6x0.6 m) - and therefore two shear zones - that are jointed with one or two rock bolts.
During the test the block in the middle is pressed downwards with up to 1000 kN. Load cells record the loading force and the normal pressure. A linear displacement sensor records the vertical displacement. The rock bolts are instrumented with strain gauges.

Shear tests to determine mode of action of the support unit

Bjurström, 1974



1 sample
2 mortar
3 joint to be tested
4 shearbox of steel
5 load cell
6 150 t hydraulic jack
7 300 t hydraulic jack
8 load cell
9 LVDT (horizontal)
10 tefloncovered sliding plane
11 LVDT (vertical)

Figure 3-6 Testing facility (Bjurström, 1974)

The testing facility is shown in Figure 3-6.
The object of the test is to determine differences in the shear behaviour between bolted and unbolted rock samples.
Therefore a rock block (0.25x0.40 m) comprising a smooth, horizontal shear zone is displaced by a constant normal force and a velocity of 0.15 mm/min. The two hydraulic jacks have a capacity of 150 t and 300 t, respectively.
LVDT record relative displacement and dilatation between the shear zones, load cells measure normal force and shear resistance and strain gauges determine tensile forces in the bolt.

Haas, 1981

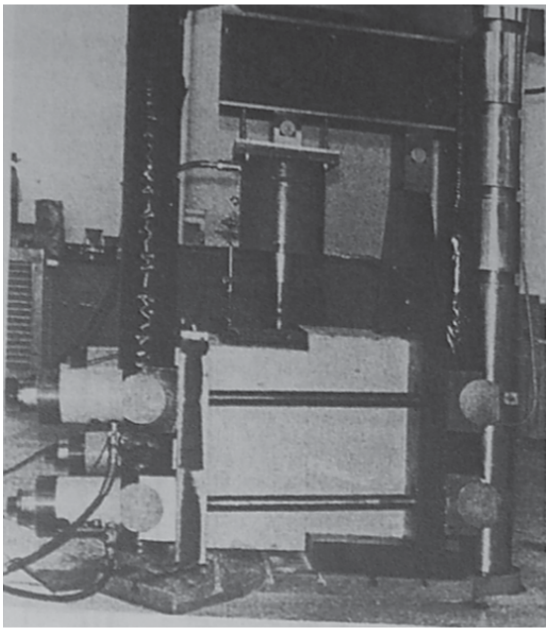


Figure 3-7 Testing facility (Haas, 1981)

The system shown in Figure 3-7 is loaded with 172 kN/m² or 1720 kN/m². The tests are conducted in three different inclinations of the anchor to the horizontal (-45°, 0° and 45°).Shear force, displacement of the blocks and of the anchor as well as of the anchor head are recorded. Displacement of the anchor is recorded by strain gauges in the shear zone. Deformation of the anchor head is also recorded.

Ludvig, 1983

The shear tests performed by Ludvig are suitable for Swellex and Split set bolts, fully grouted steel bolts as well as for resin grouted fibre glass bolts. Aim of the test is the estimation of the joint shear strength, reinforced with a bolt, by a direct shear test, see Figure 3-8.

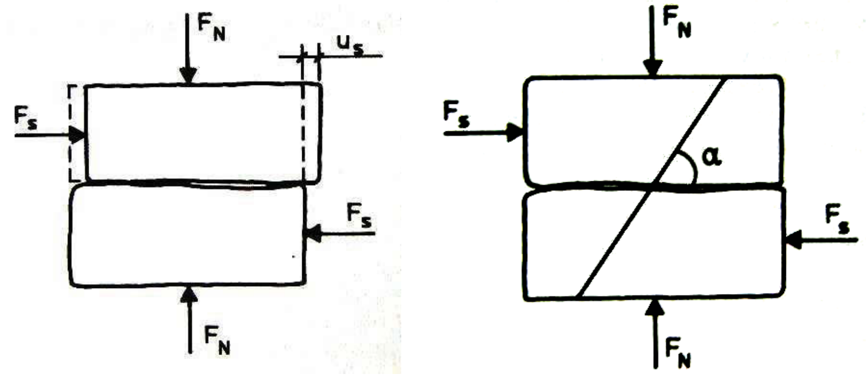


Figure 3-8 Direct shear test of bolted and unbolted rock joint (Ludvig, 1983)

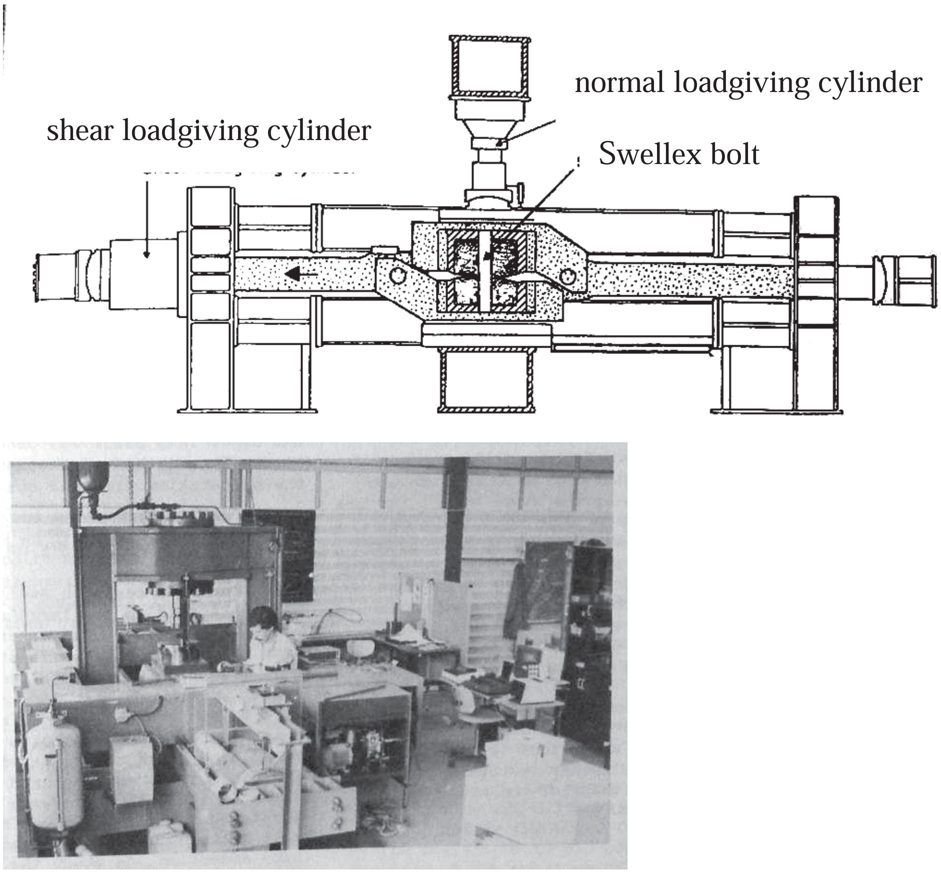


Figure 3-9 Testing facility (Ludvig, 1983)

Therefore some equipment is needed, consisting of two steel boxes. Then a bolt is installed in a block of jointed rock. The lower section of this block is inserted into the lower steel box. The top box is positioned onto the upper section of the rock. The steel boxes are connected and the lower section is sheared to the left side by a hydraulic cylinder. Load cells, placed between the cross bar and the frame of the shear rig, record the shear force.

For full scale rock bolt displacement, two LVDT are used to determine lateral displacement (relative to the upper box), normal loading and normal displacements. For determination of the displacement in the joint, an internal

deformation gauge (containing two LVDT gages, moving along the two oppositely inclined surfaces) is mounted vertically in a hole across the joint.
One method of sample preparation involves the casting of a reinforced concrete block, with the maximum size for the shear rig. It is set that the blocks of rock are too small and also have irregular shape. Therefore the have to be casted into concrete. The blocks are inserted parallel to top and bottom of the boxes, as shown in Figure 3-10.

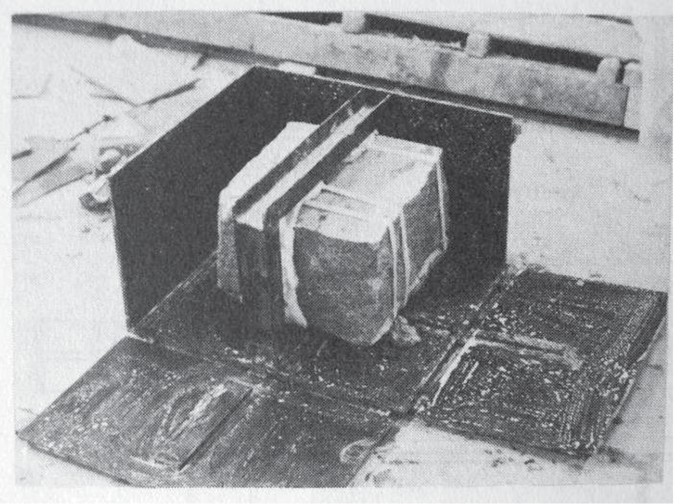
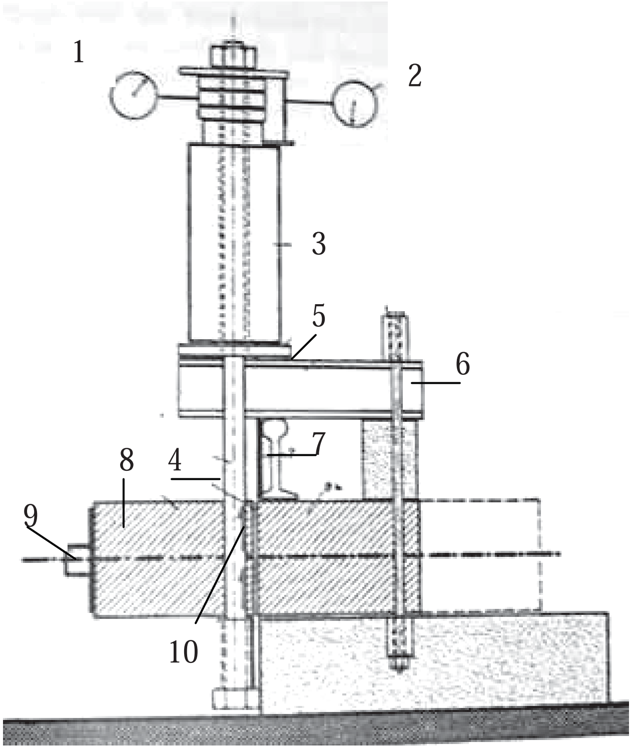


Figure 3-10 Casting of irregular blocks of rock (Ludvig, 1983)

On both sides of the joint, rock is left free from concrete, in order to part the concrete.
Another method of sample preparation is to simply cut one block with a joint out of rock, meeting the same dimensions as the steel boxes.
After preparation a bore hole is drilled and the bolt is installed.
The block can be used several times.

Schubert, 1984

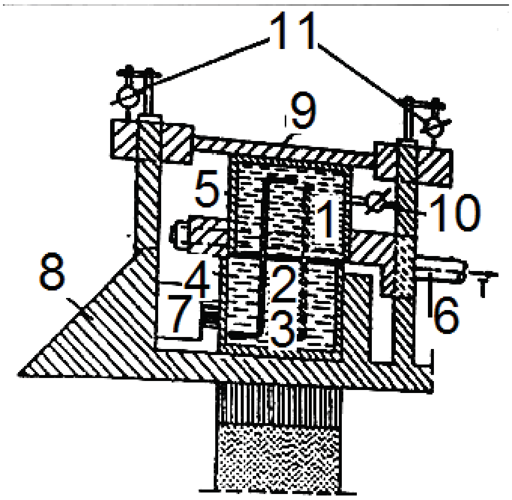


1 force measuring
2 displacement measuring
3 hydraulic jacks
4 tendon
5 steel plate
6 I-frame
7 steel platen with Teflon
8 test sample
9 rock bolt head
10 shear zone with Teflon

Figure 3-11 Test facility (Schubert, 1984)

The testing facility consists of a concrete or rock (limestone, granite) block, surrounded by a steel frame (see Figure 3-11). This frame is supposed to adjust the side pressures reacting on the rock bolt. The normal force is created in the bolt, there is no external shear force reacting on the shear zone. Therefore also the shear resistance measured is only due to the effect of the bolt.
The specimen is fixed by a steel plate to simulate an embedment length, long enough, to avoid pull-out.
The left block is slid up with two hydraulic rams. In order to reduce friction Teflon coated plates are located in the shear zone.
Force and displacement are measured by load cells and micrometer gauges, respectively.

Egger and Zabuski, 1991



1 specimen
2 shear zone
3 rock bolt
4 lower sample
5 upper sample
6 lever to apply shear force
7 hydraulic press to fix the lower sample
8 steel frame
9 upper plate with roller bearing
10 and 11 gauges for measuring horizontal and vertical displacement

Figure 3-12 Test facility (Egger and Zabuski, 1991)

The test facility is employed with a press with 0.7 MN maximum. The lower hydraulic ram loads a normal force on the shear zone of 2 MN.
The testing assembly is shown in Figure 3-12.
Test blocks are made due to moulding the concrete straight into the shear box. A plastic form is used to fabricate a uniform shear zone. The ends of the installed rock bolts are bended to avoid pull-out.
The testing procedure is to cast the concrete with the rock bolt perpendicular to the shear zone into the lower shear box. After curing of the concrete, the upper box is positioned and filled with concrete. As soon as the concrete has set, the boxes are slightly slid to create a shear zone.
When the concrete has cured, the upper block is slid with 0,05 to 0,1 mm/min until failure of the bolt
The force is measured.

Ferrero, 1994

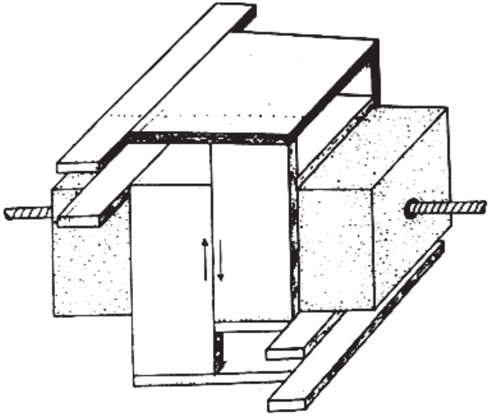


Figure 3-13 Testing facility (Ferrero, 1994)

Two blocks (0.3x0.4x0.8 m) are jointed by pre-tensioned, fully grouted anchors, perpendicular to the shear zone. The blocks have very smooth surfaces, due to their manufacturing process (sawing).
The test is performed as illustrated in Figure 3-13.
Shear force, displacement in shear direction, axial (to the rockbolt) force and deformation of the rock bolts at several points is measured.
Steel quality, rock mass and diameter of the rock bolts have been exchanged.

Stjern, 1995

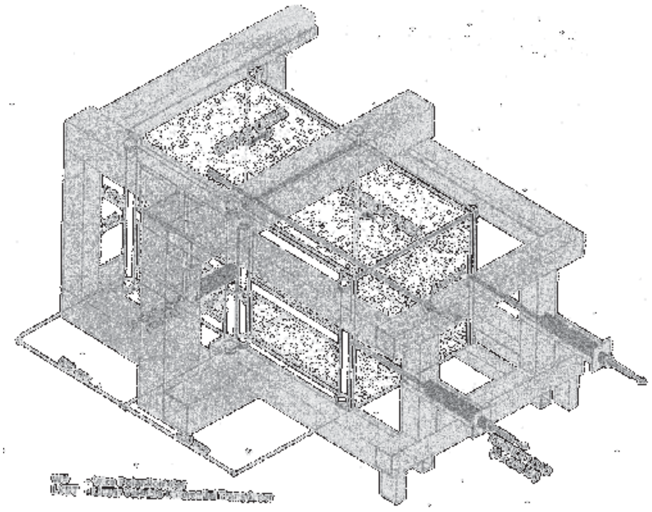


Figure 3-14 Test facility (Stjern, 1995)

The testing facility comprises concrete blocks (0.95x0.95x0.95 m) that can be moved either in direction of the shear zone or normal to it. Therefore real-life sized rock bolts can be tested by means of tensile or shear tests.
Hydraulic rams and hydraulic hollow jacks can create up to 500 kN for shear tests and 300 kN for tensile tests. The 45 mm boreholes in the blocks are arranged in a way that allows to use one block several times, by rotating it.
Load cells and displacement probes are part of the general instrumentation. Depending on the demand of the specific tests, the facility can be rigged with special load cells and LVDT. The load cells measure the tension in the collar, the LVDT absolute displacements of the anchorage and washers, as well as the movement of the blocks. In some tests also strain gauges are mounted on the rock bolts, that have to be calibrated previously.
All parameters are transferred to a special computer program.

The following tests comprise two shear zones

Jalalifar, Aziz and Hadi, 2004

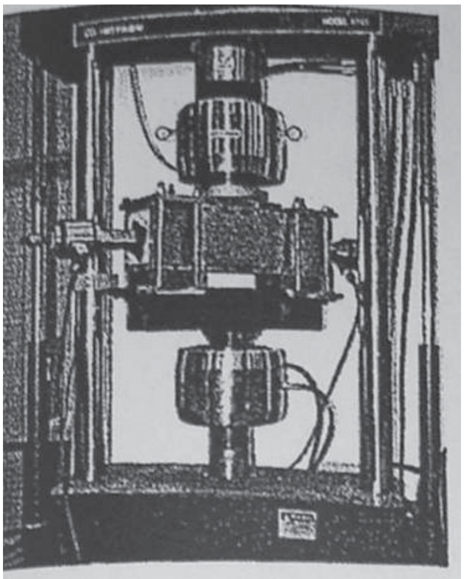
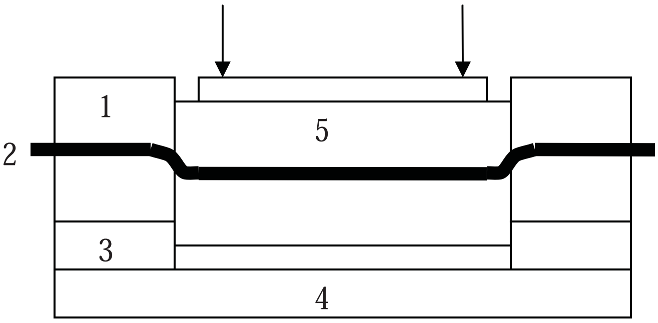


Figure 3-15 Testing machine (Jalalifar, Aziz and Hadi, 2004)



1 Block (150 mm)
2 Bolt
3 Steel plate
4 Base plate
5 Concrete block (300 mm)

Figure 3-16 Model of the testing facility

Three concrete blocks, all together 0.6x0.15x0.15 m, are used. To create this special block, the formwork is split with plates into one middle piece of 0.30 m and two marginal parts of 0.15 m each.
A plastic tube of 24 mm diameter creates a borehole.
A fully grouted rock bolt (22 mm diameter) is installed and pre-tensioned with 20, 50 or 80 kN.
For testing the marginal blocks are supported by steel plates, whereas the block in the middle is jointed by means of the rock bolt and pressed downwards with up to 500 kN.
Load cells record the vertical force. Vertical displacement of the block in the middle and force at the end of the rock bolt are determined.

Pull tests

In general

A common test method for rock bolts is a laboratory pull test to obtain the ultimate load. There are various slightly different ways to run these tests, which follow the same basic principle. A rock bolt is installed in an artificial borehole and loaded with a tensile force until a distinct value or failure. Load and deformation are measured. The artificial borehole can be drilled in two steel cylinders or concrete blocks, which then are pulled apart. The basic principle is illustrated in Figure 3-17.

Pull tests are easier to perform than the shear tests, since no lateral load has to be applied.

In case of grouted bolts, the length of the steel tube has an influence on the result. "*Short steel tubes (1 -2 dm) test the pull out resistance of the grout, longer tubes can be used to study the behaviour of the bolt*". (Marklund, 2010)

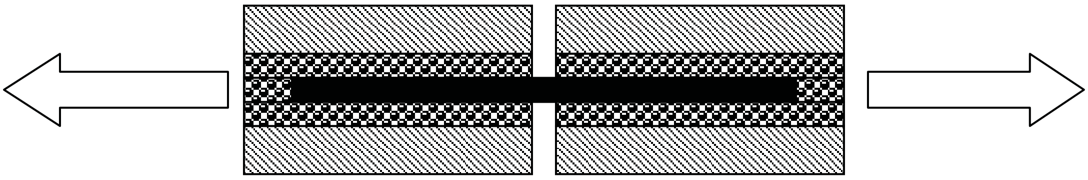


Figure 3-17 Basic principle of a pull test

Performance of pull test is also a service of many laboratories in the world. (Li, 2008a)

Since there are not for all types of tendons chucks available, a special technique shown in Figure 3-18 may be used. (Hassani and Khan, 1993)

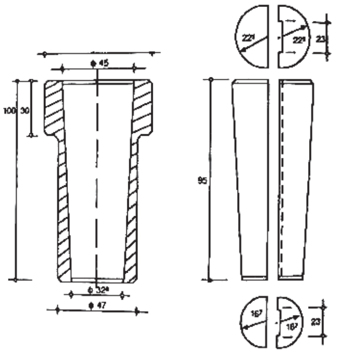


Figure 3-18 Special anchoring device (Hassani and Khan, 1993)

Pull tests can also be carried out in-situ, as quality control of the grouting or for determining the load capacity, see Figure 3-19.

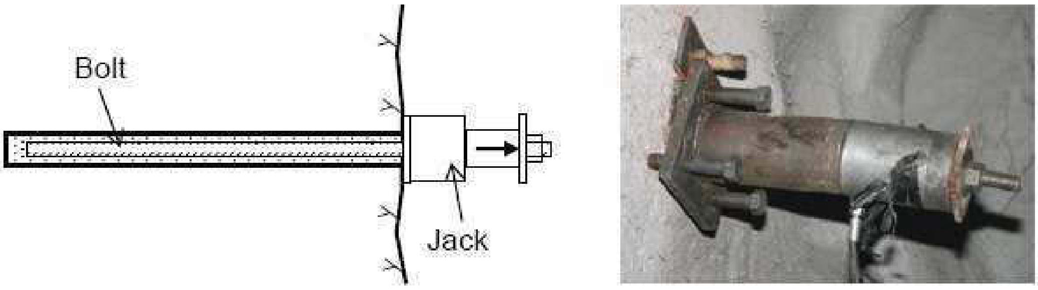


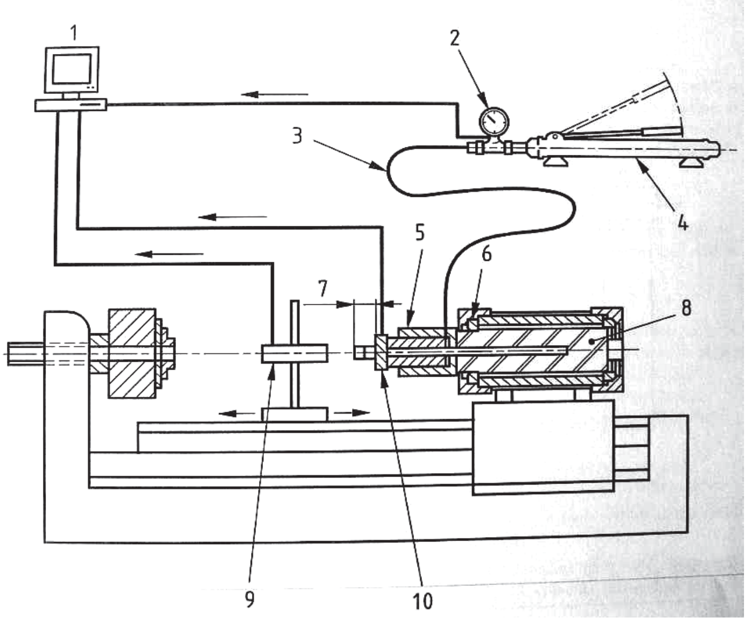
Figure 3-19 Pull test of bolt in-situ, (Li, 2008a)

Therefore the bolt is loaded by a pull load, commonly around 80 % of the strength of the bolt. Due to laboratory tests it is assumed that these pull-out tests only examine the external 0.3 to 0.5 m long part of the bolt. (Li, 2008a)

Pull tests to determine strength and deformation behaviour

BS 7861

The *BS 7861* comprised for examining the bond strength and system stiffness a laboratory short encapsulation pull test. It is performed on a resin grouted rock bolt installed in a rock core. Therefore a lathe-based testing apparatus, autographical recording facility and pull test equipment (Figure 3-20) are needed.



1 data collection
2 pressure gauge
3 hydraulic hose
4hydraulic pump
5 30 t hydraulic jack
6 bearing plate
7 100 mm thread
8 rock core
9 LVDT
10 load cell

Figure 3-20 Hydraulic pull test apparatus (BS 7861)

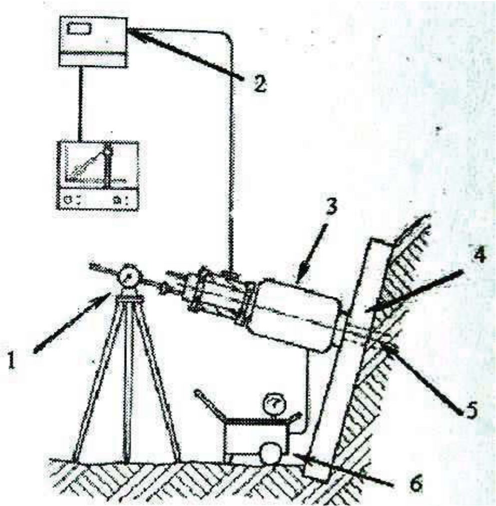
The *BS 7861* comprises several tests for support units containing steel rock bolts as well as for GRP bolts.
For determining the tensile strength the tensile test of threaded end of the rock bolt demands a tensile test machine and an assembly containing a backing plate with clearance hole and a rock bolt. Then a tensile load of 10 N/mm² maximum until failure is applied on the bar.

DIN 21521

German standard *DIN 21521* comprises a testing of the internal bond of grouted anchors. Therefore the rock bolt is positioned after installation information in a steel cylinder, filled with concrete containing an artificial bore hole. After a defined hardening time a tensile force is applied on the bolt and increased continuously until failure. An important issue is the length of the bond.

ÖNORM EN ISO 22477-5

The draft ÖNORM EN ISO 22477-5 discusses three different testing methods.
Cyclic tensile test with displacement measurement by maximum testing load. equipment, shown in Figure 3-21.



1 displacement measurement
2 load measurement
3 tension machine
4 bearing
5 bolt
6 hydraulic system

Figure 3-21 Test facility (ÖNORM EN ISO 22477-5)

An axial force is applied incrementally in 5-6 cycles on the bolt until the testing load is reached. The force shall cause failure in the zone between the bottom and the grout. When the maximum load of each cycle is reached, the force is held constant for a certain time.
The displacement of the bolt head applied as well as of the heads of the bearing elements are measured.
Cyclic tensile test with drop in force measurement by maximum testing load.
An axial force is applied on the bolt in increments in 3, 4 or 7 cycles until the testing load is reached. The object can be to determine the capability of ground/grout interaction or control of quality and safety of the design.
At the highest load rate the displacement of anchor head and ground is held constant.
The decrease of stress over a certain time span is measured. This test method can also be used for assessing the adequacy of a distinct rock bolt type for given ground conditions.
Tensile test with gradually constant testing load.
This test is similar to the cyclic tensile test with displacement measurement by maximum testing load.

ASTM D 4435 – 08 Standard Test Method for Rock Bolt Anchor Pull Test.

Object of the testing method described in the document is to measure working and ultimate capacities of rock bolt anchors. The tests shall measure the anchor performance and not the rock bolt itself. The test site shall be representative, and a sufficient number of tests shall be performed.

A rock bolt is installed in the same manner and in the same material as its intended support use. The load on the bolt is monitored over a period of time, usually several weeks.

The apparatus needed consists of the following components:

A loading system (hollow-centre hydraulic ram and mounting/reaction frame with a capacity to fail the anchor and a force that deviates by no more than 5° from the long axis of the bolt during the test), load transducer (electronic load cell, a pressure gauge or an electronic transducer), displacement transducer (dial gauge, shall be mounted in the axis of the rock bolt within 5°), displacement transducer support (the transducer shall be supported from a point no closer than 0.9 m to the reaction frame; the support shall be sufficiently rigid to avoid deflection or instability during testing), anchor systems (shall be from the manufacturer's standard production stock; shall be inspected of correct size for the hole diameter and the anchorage size should be known; grout or resin shall be fresh and obtained from unopened containers; ensure resin cartridge sizes are compatible with hole diameter, rock bolt bar diameter and length of anchorage required), rock bolt and accessories (shall be of sufficient diameter and strength; standard bearing plates and washers may be used as required) drilling equipment (the same that will be used for installing rock bolts during construction, as far as possible) torque wrench (for setting expandable shell mechanical anchors; capacity at least 20 % greater than the manufacturer's recommended anchor-setting torque), borehole diameter measuring gauge and thermometer (temperature in the borehole, if resin or cement grout anchorages are being tested).

The test setup is shown in Figure 3-22.

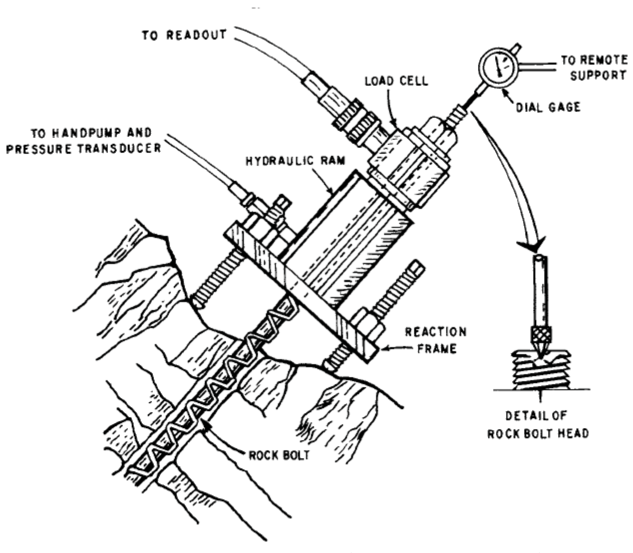


Figure 3-22 Test facility (ASTM D4435)

The testing procedure is to drill and measure the boreholes as usual.

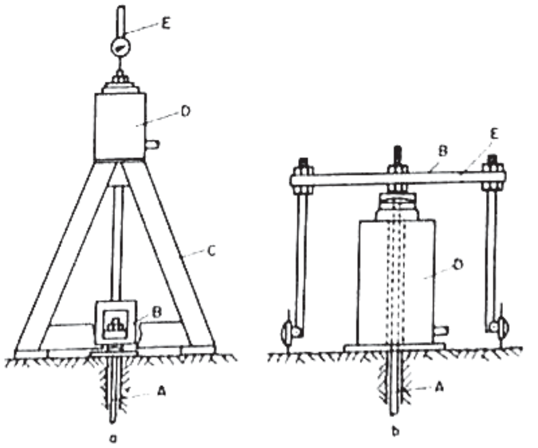
> *"If mechanical anchors are used, lightly lubricate the downhole end of the rock bolt and screw on the anchor. When in position, torque the bolt to the manufacturer's recommended level to set the anchor. A pair of jam-nuts on the upper end of the rod may be used to apply torque without producing axial load in the bolt. If the manufacturer's torque cannot be achieved because of anchor rotational slippage due to shear failure in the rock, note the maximum torque reading and install subsequent anchors to 80 % of this value. Do not test anchors where rotation occurs between the rock surface and the anchor. [...]*
>
> *Install cement grout or resin anchors according to the manufacturer's recommendations.*
>
> *Test Method:*
>
> *All tests are performed on untensioned bolts. Record the temperature in the borehole within the anchor zone; the temperature of the resin or grout at the time of injection and the ambient air temperature. Ideally the test anchorages should be installed under the same temperature conditions as expected during construction. The time required for resin or grout anchorages to reach their design strengths is temperature dependent and may vary significantly. Consult the resin or grout manufacturer's literature for recommended curing times under various temperature conditions. Curing times may be varied between 1 to 5 days under similar temperature conditions to assess the effects of curing time on strength. To evaluate the influence of grouted bond length on anchor strength, several anchorage lengths should be tested, ideally under similar temperature conditions and curing times.*
>
> *On at least half of the tests, perform three loading and unloading cycles to check for pre-failure anchor movements. Apply the load with the hydraulic ram in cycles to ¼, ½, and ¾ of the estimated failure load. Load the bolt in ten equal increments and unload it in ten equal decrements.*
>
> *Apply the load smoothly and rapidly.*
>
> *After the third cycle, pull the bolt in the same increments as used during the last cycle or in 2.2 kN increments, whichever is less, until the anchor system fails or the limit of the loading system is reached.*
>
> *Test non-cycled bolts to failure in 20 equal load increments or increments of 2.2 kN, whichever is less.*
>
> *Read and record displacement and load after each pressure increment or decrement.*
>
> *Failure is the peak load sustained by the bolt or a total deflection of 1.25 cm.*
>
> *Pull the bolt 12.5 mm beyond the failure displacement. Record the load every 1 mm."*

All relevant data shall be recorded and used in calculations.

ISRM - suggested method for determining the strength of a rock bolt anchor (pull test) (ISRM, 2007a)

This destructive test helps determining the strength of a rock bolt anchor.

Three different types of equipment are needed, for installing the test anchors (drilling, inspection of bore hole, rock bolt assembly), for applying the load (Figure 3-23, plus spherical seating, bevelled washers, wedges) and for measuring load and displacement (i.e. load cell).



A Anchored rockbolt
B Coupling and spherical seat
C Reaction frame
D Hydraulic jack, pump and pressure gauge
E Dual gauge assembly

Figure 3-23 Rockbolt testing equipment (ISRM, 2007a)

The testing procedure covers the site preparation (choosing a representative site with a firm surface, making holes perpendicular to face, inspect materials) and the testing. For the latter an axial pulling force is applied on the bolt, with no interference between components and measuring equipment. The equipment shall be placed firmly on the rock. The initial load is 5 kN maximum, increased with 5-10 kN/min until the displacement is greater than 40 mm respectively until fracture or yielding of the bolt. The load-displacement shall be recorded.
Results are illustrated graphically and used for calculations.

ISRM - suggested method of determining rock bolt tension using a torque wrench (ISRM, 2007b)

The procedure can be used to install a bolt, or to test previously installed bolts or test the anchor strength.
Equipment used therefore is a torque wrench plus sockets for nuts or anchor heads, a torque wrench calibration equipment (rigid bolt head, weights) as is an equipment to determine relationship between tension and torque (rock bolt assembly plus hydraulic ram or rock bolt load cell).
The Procedure runs as follows. By means of a calibration of the torque wrench (every six months) a correction factor R can be calculated. The measure ratio C of tension to torque is examined by applying a torque force incrementally on the rock bolt and measuring torque as tension (with the hydraulic jack). Doing this with 5 pairs a graph can be plotted. To determinate the bolt tension using a torque wrench a force is applied incrementally (if wrench applies preset torque) or steadily (if wrench has maximum applied torque indicator). Recording this force and using the factors C and R the tension can be calculated. (ISRM, 2007b)

Franklin and Woodfield, 1971

The scope of the pullout test is the evaluation of the strength, of the slippage of the bolt before full-load mobilization and of the loss of resistance when overloading the bolt.

Details of factors, like type of anchor, method of drilling or roughness of the hole, have to be reported, for they influence the testing results.
Equipment for drilling and measuring the bore hole as well as equipment for installing the bolt is required.
The testing equipment (Figure 3-92) covers a centre-hole jack (with chains to secured it), a hand pump and pressure hose. Furthermore a pressure gauge with a maximum-pressure indicator (to measure pressure in the jack), a base-plate and wedges (to adjust the jack and tighten it), a spherical seating (to take up bolt misalignment to ensure that the bolt is tensioned with minimum bending) and locating washers (to centre the jack and spherical seating on the bolt are needed. A firmly fixed rigid steel measuring beam, micrometer dial gauges and clamps to fix the gauges (adjustable to position the gauges parallel to the bolt and equidistant form the axis, as shown in Figure 3-92) shall be used.

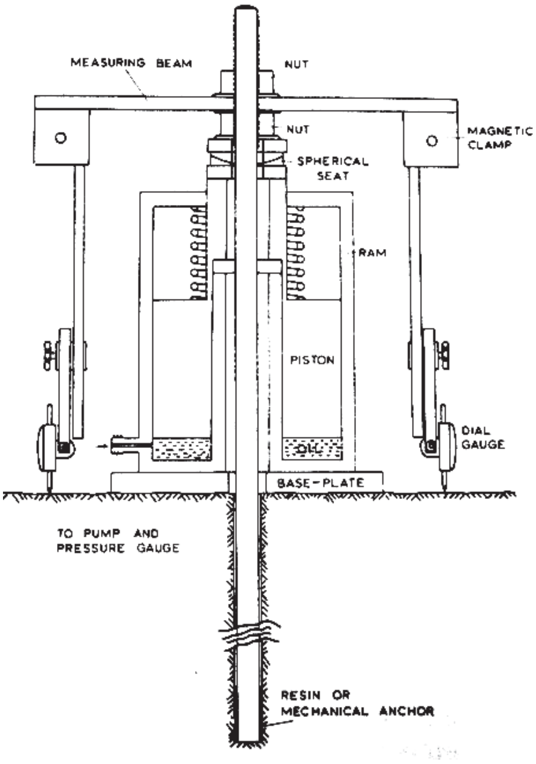


Figure 3-24 Test facility (Frankling and Woodfield, 1971)

In the case of soft or rough rock, small, flat plates of hard material should be used at the measuring points to prevent sideways slip of the dial gauge.
Preliminary to testing, yield strength, ultimate strength, young's modulus of the bolt steel, rock strength and fracture spacing indices shall be gained due to laboratory tests.
After drilling, the holes shall be flushed with air or water. At least the average diameter, straightness and roughness of each hole shall be recorded.
Now the bolt shall be installed following the installation manual.
The equipment described above (base-plate, jack, spherical seating, locating washers, fixing nut, measuring beam, clamps, dial gauges and small bearing plates) is installed over the bolt. The gauges are checked and the untensioned length of the bolt at the jack is determined.

For testing a small load is applied to tighten the assembly. Then the jack pressure is incrementally increased, reading the dial gauges at each stage. In case the pressure rises then fall off after stopping to pump, both values should be recorded. Test until failure, yielding or after the anchor has travelled 30 mm.
What the authors state is that the rock strength is also a very important factor.

Ballivy and Martin, 1983
Laboratory tests on small cylindrical and cubic samples as well as on concrete and granite blocks were performed. The material used consisted of steel rods and seal grout, see Figure 3-25.

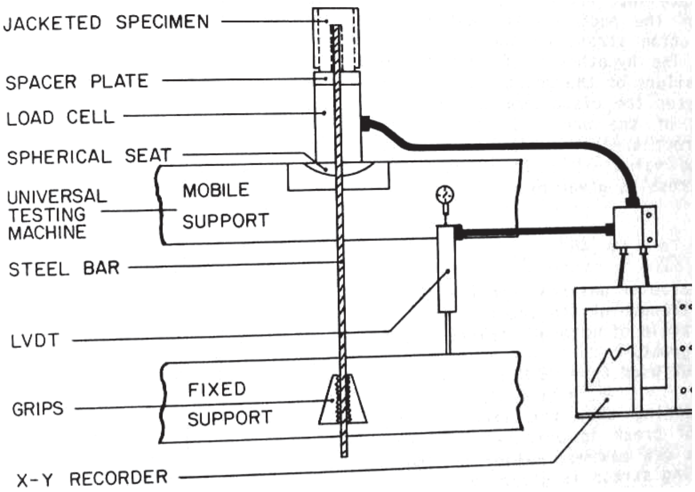


Figure 3-25 Test facility (Ballivy and Martin, 1983)

Field tests were conducted to verify the lab results. Therefore short rods were loaded until failure to determine the rod-grout adhesion limit. A hollow ram jack and a manual pump were used for testing. The procedure was in accordance with ISRM rock bolt testing (loading speed approximately 45 kN/min).

Bartels and Pappas, 1985

> *"Four bolting types using resin grouted bolts were tested: full column, point anchor, tensioned, debondable, and several modifications to the full column system. [...]*
> *The axial tension test procedure was initiated by placing a hollow 20 [...]t hydraulic ram and donut-shaped bearing plates around the exposed portion of the installed roof bolt. The roof bolt was attached to a Strainsert bolt to obtain exact tension readings.[...]*
> *Tensioned and point anchor bolts were then torqued until the Strainsert bolt indicated [...] 2.72 t of tension. Bolts are loaded with the hydraulic ram and displacement readings taken from two LVDT's placed on either side of the bolt bearing plate."*

All readings are taken until failure.

> *"Failure is considered to be either when the bolt breaks or when the bolt-resin-rock system could no longer support the applied load without appreciable displacement."*
> *(c.f. Bartels and Pappas, 1985;as cited in Whitaker, 2001)*

Pettibone, 1988

> *"[For preliminary tests] resin [grouted] bolts were inserted in concrete blocks [0.61 m] by [0.61 m] in cross section and [1.73 m] long-block testing method. The blocks were installed on a steel frame where they could be drilled with a mast type roof bolter. The bolts were tested in the same frame. The bolter was mounted on a small frame that could be moved with a hand-operated hydraulic pallet lifter. Power was supplied to the roof bolter by a [...] hydraulic pump. The bolter was equipped with adjustable needle valves, so that the maximum thrust, torque, and speed could be set to the desired levels"*

The maximum values measured are about 1.63 t of thrust, 101.7 Nm of torque, and a speed of 500 rpm.

Then the real pull tests were performed.

> *"The hydraulic centre pull jack, pull rod, crows foot, and the A-frame were installed on the pull collar about 5 minutes after the bolt had been installed. [...] Movement of the head of the bolt was measured with a linear-position transducer mounted on an adjustable photographic monopod. The hydraulic pressure was monitored with a pressure transducer. Signals from both transducers were fed to an X-Y plotter that produced load deflection curves for each bolt tested. The load was applied with a hand pump until failure occurred or until the limit of the equipment was reached."*

(c.f. Pettibone, 1988; as cited in Whitaker, 2001)

Goris, 1991

The test is a laboratory test of cable supports.

> *"The pull test apparatus [...] consists of two [6.65 cm] diameter steel pipes through which the cable runs. The portion of the cable embedded in the [30.48 cm] (bottom) pipe is the segment actually being tested. To prevent slippage of the cable embedded in the [50.8 cm] (upper) pipe, a [4.45 cm] dia by [3.81 cm] long barrel-and-wedge steel anchor was attached to the end of the cable and a load of [11.34] tonnes applied to set the anchor prior to making the pull-test sample. The purpose of using pipe apparatus was to confine both ends of the cable to prevent rotation during testing.*
>
> *Pull tests on the cable supports samples were conducted on a hydraulic test machine with a [181.44 t capacity]. When the test was in progress, the upper head of the test machine would move away form the lower head, causing the two pipes of the pull-test sample to separate. Because the end for the cable in the larger pipe was secured in place with a barrel-and wedge anchor, as a displacement of the pipes occurred, the end of the cable in the shorter pipe deboned from the grout and shearing took place along the cable grout interface. Loading was continued until the total displacement was about [15.25 cm]. The important information collected was the amount of uniaxial load applied to the sample, which forces the cable to slip, and the displacement or degree of slippage taking place. For every sample tested, shear failure occurred between the cable and the grout. No detectable slippage took place between the grout and the pipe interface." (c.f. Goris, 1991; as cited in Whitaker, 2001)*

Bawden, Hyett and Lausch, 1992

They stated in the article 'An Experimental procedure of the in situ testing of cable bolts' the following.

There is no testing standard for cable bolts. Test for normal rock anchors deliver no realistic results, therefore a proven experimental procedure is needed, comprising no rotation during tests.

To measure short-term strength of a short section of cable bolts, the cable is grouted in a pulling pipe with grooves. The pull-out equipment is shown in Figure 3-26. The pulling rate is 0.215-0.3 mm/s. Force and displacement are recorded.

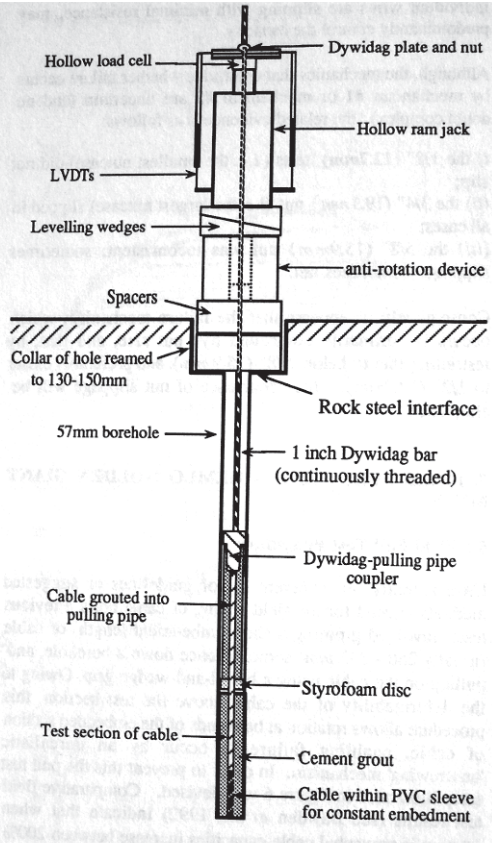


Figure 3-26 Testing facility (Bawden, Hyett and Lausch, 1992)

Hassani and Khan, 1993

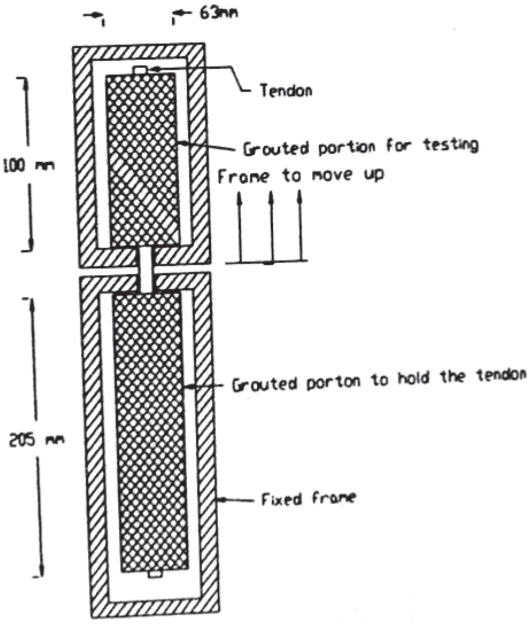


Figure 3-27 Test facility (Hassani and Khan, 1993)

One problem, which is common for all non-metallic tendons, is the incompatible holding of anchoring devices. Conventional steel devices destroy the test specimen.
For testing ARAPREE a special anchoring device is used (Figure 3-18). The cable is grouted in a steel pipe and placed in a R.D.P. Howden servo-controlled stiff testing machine (for compression and tension). The tests are run in a constant displacement control mode, with 1 mm/min maximum.

Hyett et al., 1993

Laboratory pull-out tests are performed using a modified Hoek cell, shown in Figure 3-28. Two different failure mechanisms can be observed. On the one hand a pullout of the nutcase structure, on the other hand slipping and twisting of the cable through the nutcase structure (cable was pulled, nut remained) lead to failure, see Figure 3-28.

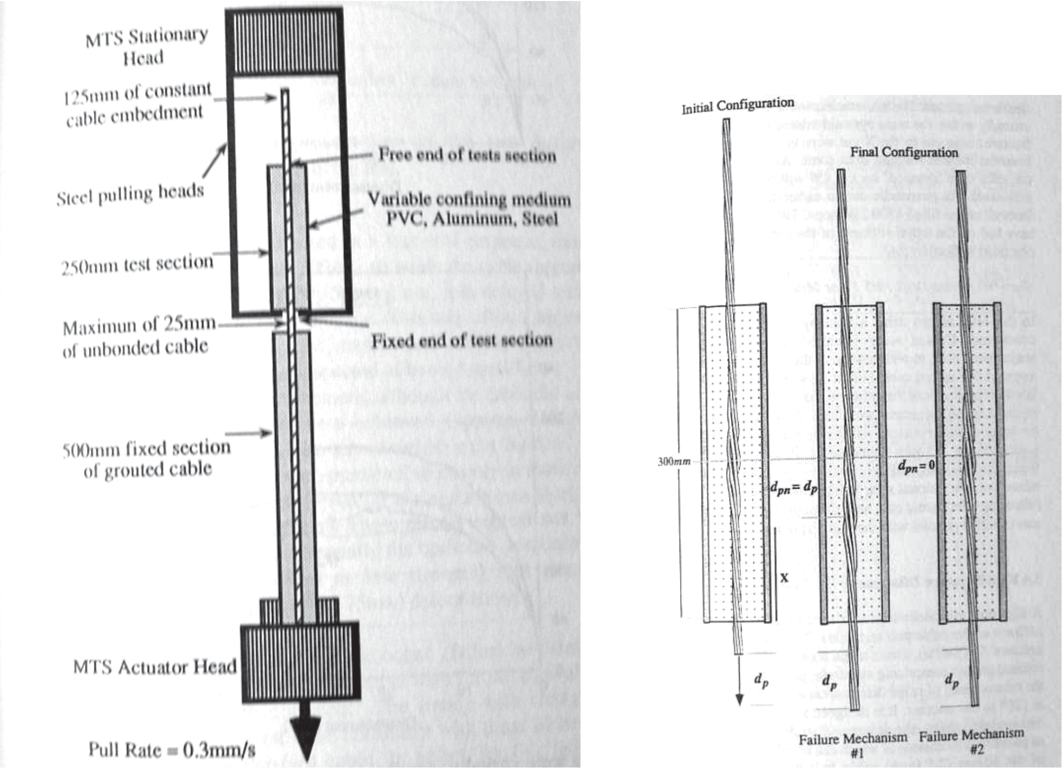


Figure 3-28 Testing facility and failure mechanisms(Hyett et al., 1993).

Stjern, 1995

A hollow steel cylinder with an anchor positioned in the centre is filled with mortar, as shown in Figure 3-29. Then a load is induced with 30 kN/min until failure. The maximal breaking force is recorded.

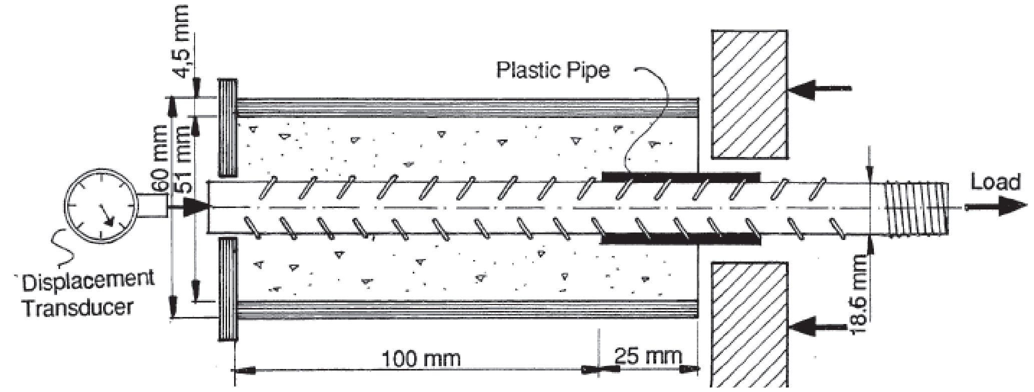
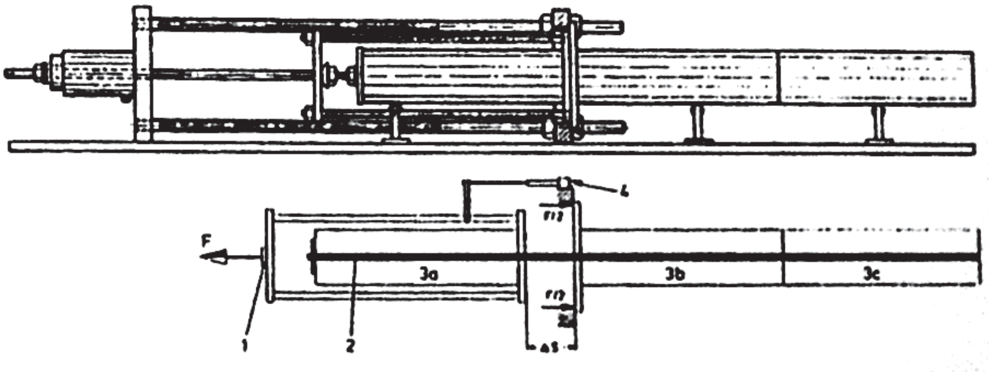


Figure 3-29 Test facility Sjern, 1995.

Wittenberg, 1995

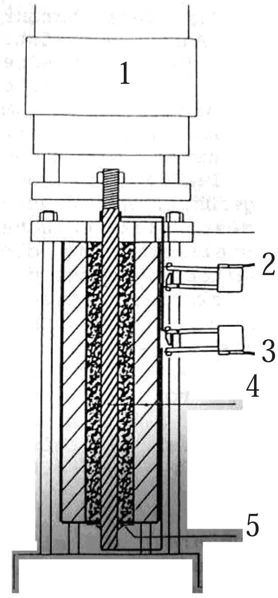


1 force transducer
2 bolt
3 mountain-pipes
4 displacement tranducer

Figure 3-30 Test facility (Wittenberg, 1995)

Two so-called "mountain-pipes", shown in Figure 3-30 simulate the artificial rock mass. The position of the joint is variable with the length of the pipes.
These mountain-pipes comprise two pipes of steel, filled with anhydrite mortar, and contain a drill hole.
Grouting is done either with resin cartridges or with mineral mortar.
Between the pipes there are two steel plates, with different diameter, each welded to one of the pipes.
In order to test, the two plates are connected. The bigger one is supported by the frame, whereas the smaller one comprises a contact point for the hydraulic-hollow-cylinder. The pipes are moved apart and tension and displacement are measured and plotted as a diagram.

Röck, Schwab and Blümel, 1995



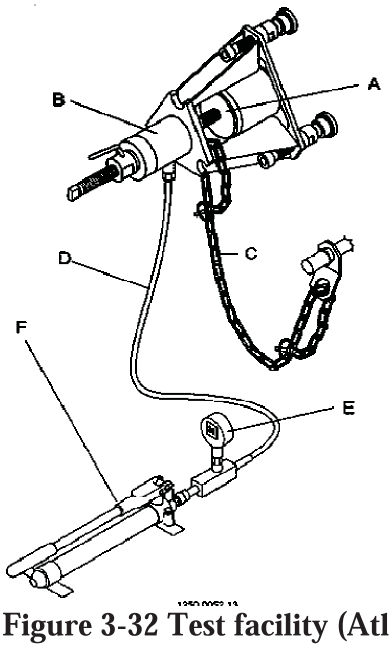
1 force transducer
2 displacement transducer (bolt head – pipe)
3 displacement transducer (bolt head – end)
4 bolt, grout, concrete, steel pipe
5 lip seal

Figure 3-31 Test facility Röck, Schwab and Blümel 1995

The testing apparatus consists of a steel pipe, filled with concrete and a hole in the centre. A lip seal is attached at the end of the pipe. The rock bolt is installed, like shown in Figure 3-31. Two electronic displacement transducers are installed to measure the deformation anchor head/pipe respectively anchor head/anchor end. The pull-out velocity is 0.012 mm/min.

Atlas Copco, 1998

Figure 3-32 shows the main components of the testing facility.

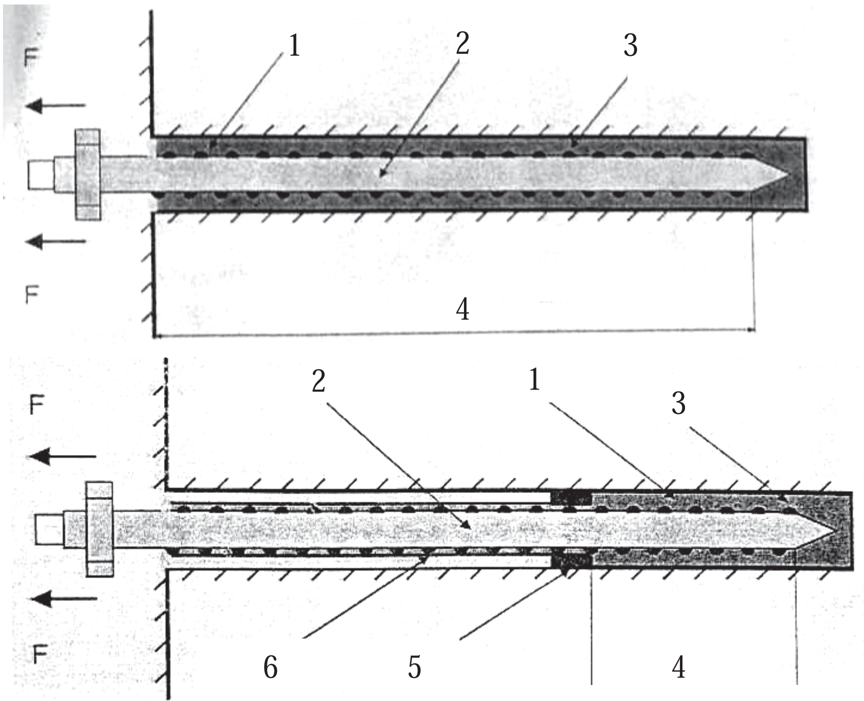


A Extractor unit
B Cylinder
C Safety chain with fastener
D Hose
E Digital Pressure gauge
F Hand pump

Figure 3-32 Test facility (Atlas Copco, 1998)

The manual discusses three types of pull tests: destructive, non-destructive and pull-out resistance tests. Destructive pull-tests are performed to determine the tensile strength (breaking strain) of an installed bolt. They are carried out on the full length of a bolt, expanded inside the borehole.
Non-destructive pull-tests to determine the anchoring effect of an installed bolt are performed after a period of time. The bolt is not permitted to fail. These tests shall check that the bolt is correctly anchored in the rock mass with a certain force.
The pull-out resistance test is used to determine pull-out force per unit of an installed bolt, when only a part of the bolt has been expanded inside the hole.

Wittenberg, 1999
Wittenberg states, that there is no adequate simple underground testing method to determine the external bond.
In the United Kingdom a testing procedure by enlarging a borehole is used, although there is only one cartridge in the hole and therefore the method is not really representative.
Wittenberg suggests a pull-out test with a special pipe, shown in Figure 3-33 and manufactured by DMT, to test the external bond.



1 grout
2 rock bolt
3 profiling of tendon
4 external bond length
5 sealing
6 special pipe

Figure 3-33 Normal testing facility (upper) and modified testing facility (lower) (Wittenberg, 1999)

Moosavi, Bawden and Hyett, 2002

A modified Hoek cell is used for testing cable bolts, shown in Figure 3-34. This testing device consist of a conventional Hoek cell, used for triaxial rock test, that has been modified.
Shear tests on grout are conducted to specify the observations during pull-out test.

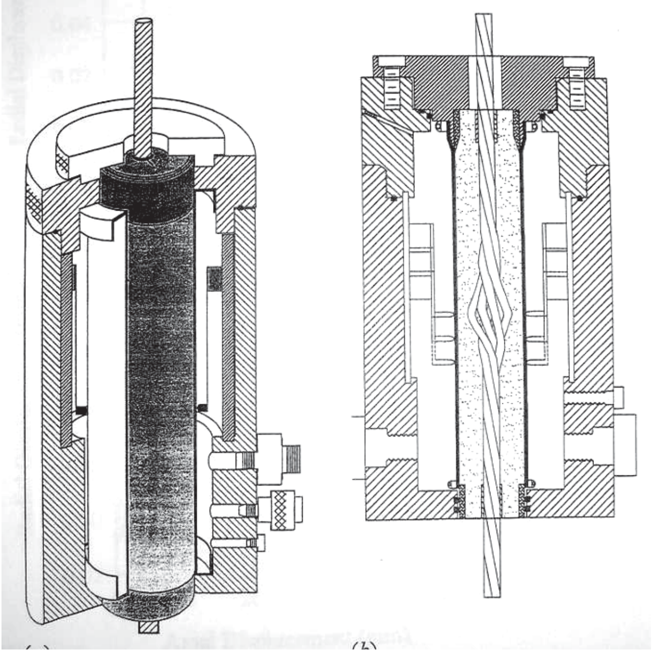


Figure 3-34 The new modified Hoek cell (Moosavi, Bawden and Hyett, 2002)

Kilic, Yasar and Atis, 2003

A big rock block made of basalt is used (for several anchors). The length of the drilling hole has to be neither too short nor too long. In the first case failure would occur by shearing of the bond mortar-rock, in the second case failure of the anchor steel would be the breaking mechanism.
The rock bolts are cement grouted. Load is enhanced in 8-kN steps.
Measuring comprises the determination of the displacement with flow meters and due to oil pressure to plot a diagram.
The test is run until failure of the rockbolt and the maximum failure strength as mean of three tests is determined.

CANMET Pull Test

Artificial boreholes are simulated by steel tubes with an roughed internal surface (approximately over the last meter) on the top of the tube. These holes are drilled completely through the cylinder. A so-called 'split-tube' configuration is used for testing, where the tube holding the bolt has two sections and the impact is not on the bolt but on the tube.
Plugs are installed in the tube to control bolt insertion and resin flow. The cylinder is inserted into a jig aligned with the installation drill (see Figure 3-35), the cartridges are inserted into the tube and the bolt (with nuts) is positioned into the chuck.

> *"Whereas for drop test experiments, two holes are drilled in the top half of the test tube.*
> *The top set of holes facilitates the support of the tube in the drop test rig, while the lower set allows access to the end of the bolt after its installation inside the tube."*

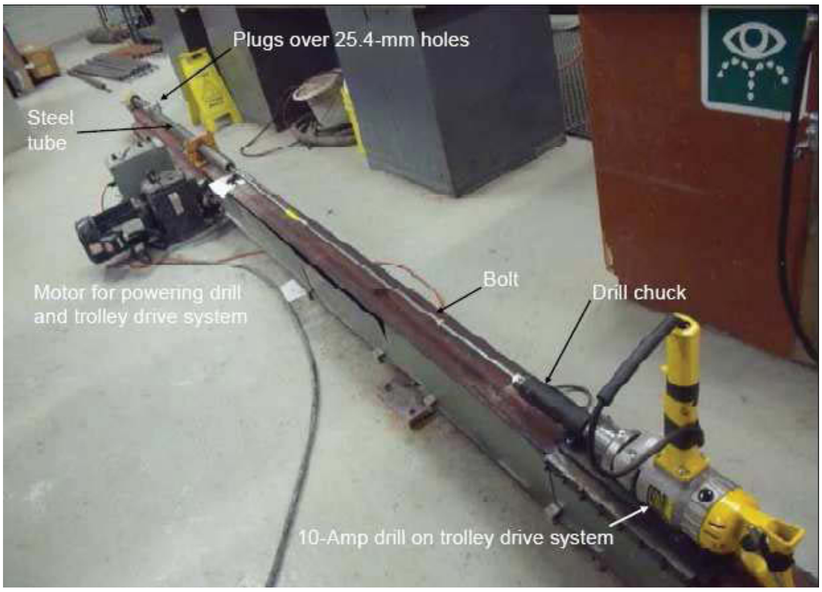


Figure 3-35 Test facility for pull out tests at CANMET (Doucet, 2010)

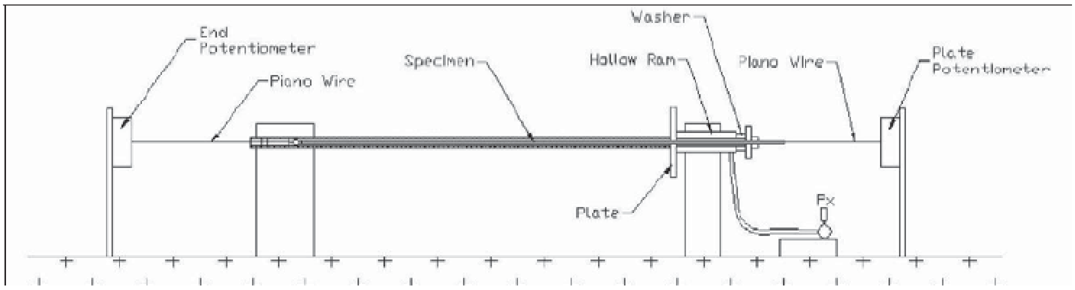


Figure 3-36 Sketch of the test facility at CANMET (Doucet, 2010)

> *"All equipment and procedures were developed to meet or exceeds the [...] ASTM D 4405 – 08 Standard Test Method for Rock Bolt Anchor Pull Test. A hollow hydraulic ram with a minimum load capacity of 325 kN and total displacement of either 150 or 250 mm is used for this test. Operation of the ram is accomplished using either a hand operated pump or an electric pump. A hand pump is used during the initial loading phase, until the bolt reaches its yield point and starts sliding or stretching. An electric pump [...] is then used until the specimen fails, or the ram reaches its stroke capacity (displacement of either 150 or 250 mm)."*

Figure 3-36 shows a typical set-up for static pull tests.

> *"The pressure of the hydraulic ram is measured using an electronic pressure transducer. Two 508-mm stroke potentiometers with a resolution of 0.6 mm are used to measure displacements. These are measured at both ends of the test specimen, i.e. plate and top end, during the test [...]. All measuring instruments are connected to an automatic data acquisition system and zeroed at the beginning of each test."*

(Doucet, 2010)

Pull tests to determine mode of action of the support unit

Pells, 1974

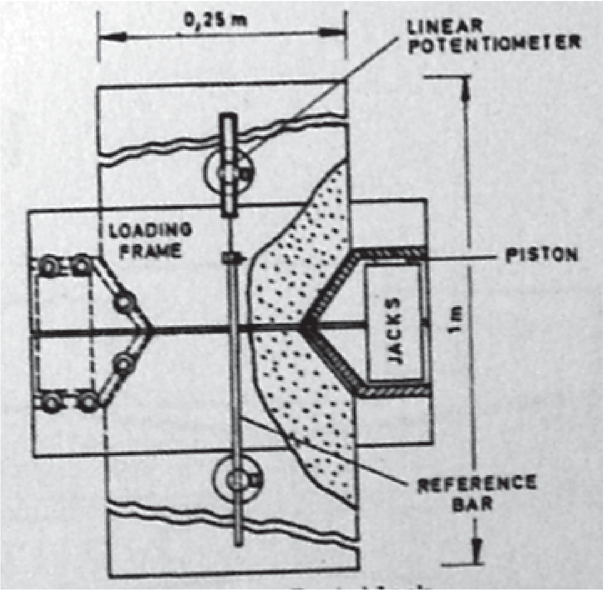


Figure 3-37 Test facility (Pells, 1974)

To test fully grouted anchors a special testing facility (two blocks of rock, with rockbolt connected) is required.
A borehole is drilled into two rockblocks (sandstone and norit) and filled with epoxy resin or left empty. The rock bolt is installed, so that it connects the two blocks (see Figure 3-37).
Presses are used to simulate an opening joint by pulling the blocks apart. The elongation of the bolt is measured and plotted in a displacement-force diagram.

Serbousek and Signer, 1987

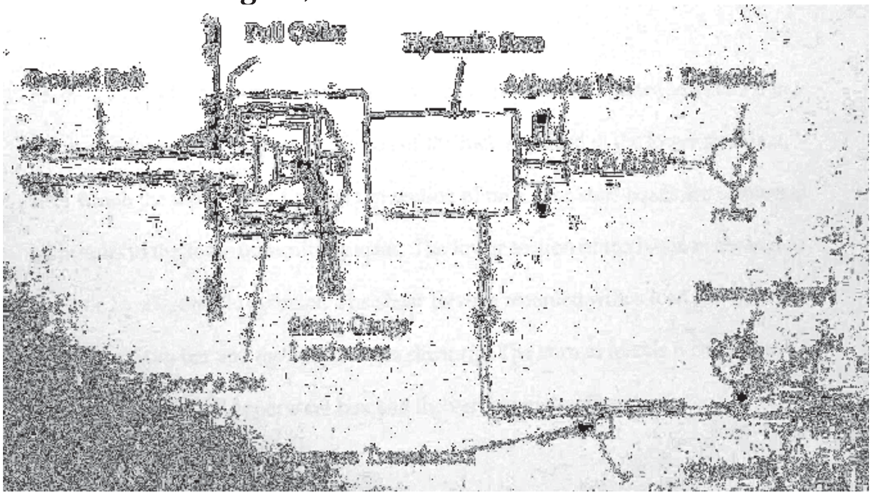


Figure 3-38 Test facility (Serbousek and Signer, 1987)

> *"This study used a pull test to study the transfer of load from the bolt to the rock. The rate at which load was transferred out of the bolt and into the rock was measured. [...]*
> *The bolts used in this experiment were instrumented with strain gauges [...]. The bolts were installed in 0.61x0.61x1.37 m concrete blocks, which were used to simulate roof rock. Bolts are installed in concrete blocks, which simulate the roof rock. [...]*
> *The pull gear consist of a collar placed on at the bolt head. Over this collar, the crow's foot is attached. It, in turn, is connected to a threaded rod. The force is applied to the head of the bolt by a hydraulic ram. A hand pump supplies the hydraulic pressure. The applied force is monitored with a pressure gauge and a pressure transducer.*
> *Several tests were conducted to determine the amount of measured deflection due to the pull gear. At least squares regression analysis was performed on the data, and a load deflection relationship of the pull gear was determined." (c.f. Serbousek and Signer, 1987; as cited in Whitaker, 2001)*

Signer, 1990

The topic was the field verification of load transfer mechanics of grouted bolts. A pull test gear arrangement is used.

> *"The pull test gear consists of a pull collar placed at the bolt head. Over this collar a crow's foot is attached, which in turn, is connected to a threaded rod. Force is applied to the head of the bolt by a hydraulic ram that is activated by a hand pump. The applied force is monitored with a pressure gauge and a pressure transducer. [...]*
> *The defections [of the bolt head] are measure at the end of the pull gear by a dial gauge [...]. Force was applied to the bolt head in increments of [0.83 t], beginning at [0.42 t] and ending at [5.8 t, (approximately 80 % of the yield of the bolt)]. The applied force at the bolthead was maintained at each level for 5 min. so the system could stabilise before readings were taken. Three loading cycles are conducted for each test.[...]*
> *The [strain] gauges were positioned in pairs on each side of the bolt to account for any bending effects and to provide redundancy. [They] were calibrate in an uniaxial tension machine to correlate voltage change directly with load. This technique eliminated [several problems (gauge location, localised inconsistencies in the bolt)] and produced [tests results having good repeatability]." (c.f. Signer, 1990; as cited in Whitaker, 2001)*

Fabjanczyk and Tarrant, 1992

> *"A length (70 mm) of rebar is encapsulated into a metal cylinder that has an internal (threaded) surface that prevents premature failure on the cylinder/resin interface. The rebar is pushed through the resin under stain control and the full load/displacement history is recorded.*
> *Further confinement measurements were taken by attaching four strain gauges to the outside of the cylinder. The gauges were spaced evenly around the cylinder and orientated tangentially. Two gauges were positioned opposite the deformation ribs."*

(c.f. Fabjanczyk and Tarrant, 1992; as cited in Whitaker, 2001)

Hyett et al., 1993

Previous to testing a short length of the cable was grouted some distance down a borehole. During testing a pull force was applied to the cable using a barrel-and-wedge grip. This allows rotation at both ends of the embedded section of the cable, enabling failure to occur by an unrealistic 'unscrewing' mechanism. The pull test setup is shown in Figure 3-26.

Stillborg, 1993

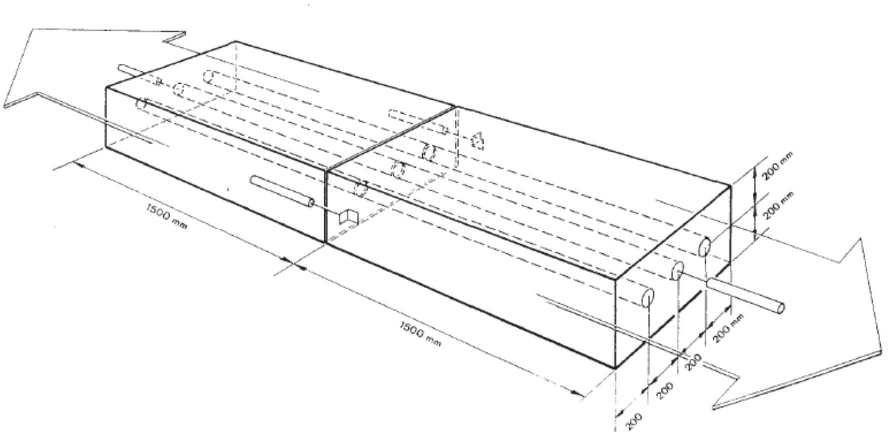


Figure 3-39 Schemata of the test facility (Stillborg, 1993)

In the report 'Rockbolt tensile loading across a joint' is discussed, that

> *"In order to obtain the load-deformation characteristics of rockbolts which realistically resemble the characteristics of the installed rockbolt, and to be able to compare, the general load-deformation characteristics of different types of rockbolts, a laboratory test arrangement was developed.*
>
> *The test arrangement is designed to, under strictly controlled conditions, simulate the load-deformation characteristics of rockbolts subjected to tensile loading across a joint which opens normal to the joint plane. The test arrangement is schematically illustrated in [Figure 3-39].*
>
> *High strength reinforced concrete with a compressive strength of 60 MPa was used for the two 1,5 m concrete blocks simulating two 1.5 m blocks of rock separated by a joint. The boreholes for the rockbolts where all drilled using a percussive technique in order to create borehole surfaces with a roughness comparable to those obtained in metamorphic and igneous rock types. The length of the boreholes and the subsequently installed rockbolts were 3 m. The borehole diameter was carefully measured to meet the requirements set by the rockbolt manufacturer. The two blocks were separated, simulating joint opening, at a rate of 3.6 mm/min.*
>
> *Friction between the concrete blocks and the foundation on which the blocks rested was to a large extent eliminated by placing the blocks on low friction rollers. Fiction that could not be eliminated in the test set-up was measured and compensated for in the final evaluation of the test results.*
>
> *The joint opening was measured by two LVDT measuring gauges, one on each side of the meated blocks. This arrangement facilitates compensation of any rotational movement that may occur between the two blocks. At the free ends of the two blocks, any rockbolt displacement, (sliding) was also measured by LVDT measuring gauges, all four gauges with a measuring accuracy of +/- 0.125 mm. the servo-hydraulic load actuator and the LVDT gauges, were connected to a host computer that provided real time graphical output of the rockbolt load-deformation relationship as well as any rockbolt sliding that occurred.*
>
> *One advantage in using concrete blocks in a comparative test program as oppose to blocks of rock is the consistency in the properties or the concrete blocks that can be obtained."*

Ohtsu, Shigeishi and Chahrour, 1995

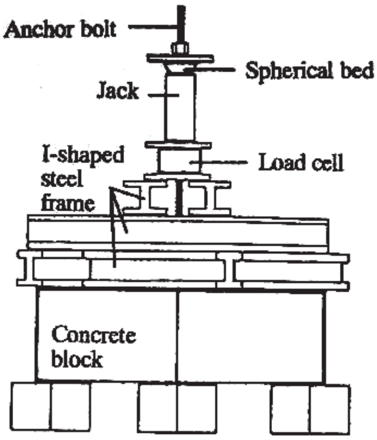


Figure 3-40 Test facility Ohtsu, Shigeishi and Chahrour 1995)

For studying the fracture zone, acoustic emission during a pull-out test can be used. Figure 3-40 shows the testing facility. A 1m x 1m x 0.3 m concrete block is used. The testing assembly covers a washer fastened by a nut and a prestressed steel bar, embedded 5 cm deep. For minimizing friction between the concrete and the steel bar, the rod is muffled in a polyethylene sheet.

Benmokrane, Chekired and Xu, 1995

To determine the long-term performance of cement grouted anchors, surface-mounted vibrating wire strain gauges can be micro-welded on the surface of a bar. Due to the gauges load, head displacement and load distribution can be observed. Laboratory pull-out tests comprises concrete cylinders cast in a steel barrel, with a borehole to insert the bolt and injected the cement.

In field tests a hollow hydraulic jack is used to apply the load on the anchor. The applied load is measured with a hollow load cell, mounted at the anchor head. The test facility is shown in Figure 3-41.

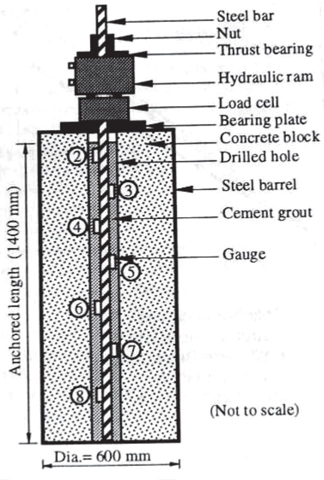


Figure 3-41 Test facility (Benmokrane et al., 1995)

VandeKraats and Watson, 1996
In their report 'Direct laboratory tensile testing of select yielding rock bolt systems', they describe the following.
For testing a Baldwin test machine with 530 kN capacity used.

> *"Tests were in-line, direct tensile tests controlled by displacement. Load and displacement data were collected each second. The data were displayed as a load versus displacement plot in real time and also recorded by the PC based data acquisition system for later analysis. [...]*
> *Tests were limited by the approximate 0.2 m [...] stroke of the machine and testing was interrupted as required to reset the test machine. In the case of some of the Yielding Cable Bolts, three resets were necessary to pull the system through the 0.51 m [...] yield range. Rigging: The Load Indicators and Yielding Collars were tested using threaded bars as the bolt system. The anchor ends of the cables on the Slip Nut and Yielding Cable Bolt systems were fitted with a swaged nut. In all tests, both ends of the systems tested were installed next to rigid, flat bearing plates. While the anchor end remained fixed, the platen with the yielding component was displaced which loaded the system*
> *Test Sequence: After rigging was completed and the bolts were installed in the test machine, testing commenced."*

Galvin et al., 2001

The testing rig (at the University of New South Wales) is shown in Figure 3-42. It can apply 1 to 7.5 MPa/mm.

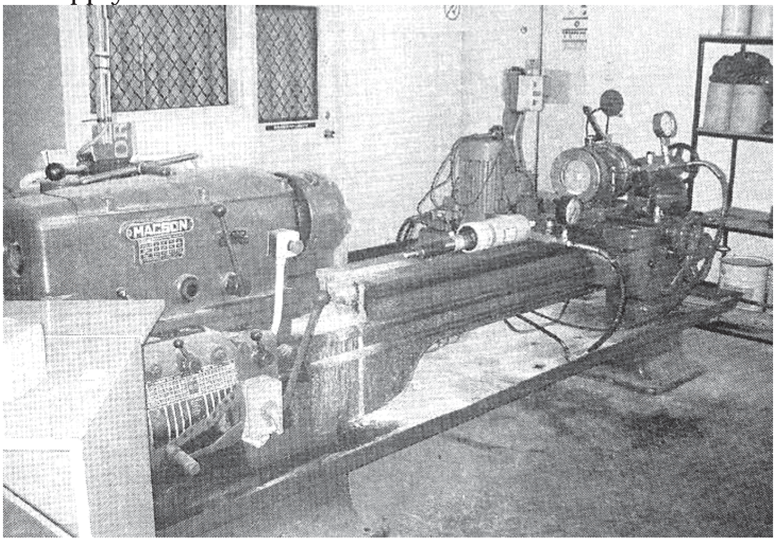


Figure 3-42 Testing facility (Galvin, et al. 2001)

The testing rig consists of a lathe, able to drill and install the bolt. A biaxial cell (metal cylinder with membrane) is installed on the lathe to fix the specimen during drilling, installation of the bolt and pull-out test. A hollow core jack, mounted to an electric pump is used for the tests.
A schema of the pull out test equipment is shown in Figure 3-43.

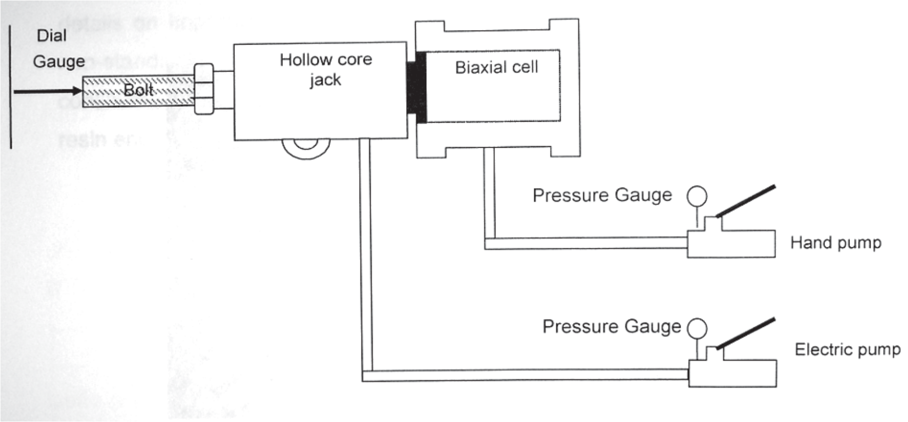


Figure 3-43 Schemata of test facility (Galvin, et al., 2001)

> *"Once the resin was set, a hollow ram jack was placed over the free end of the bolt. It was held against the sample by the self centering faceplate arrangement to ensure that load was applied axially. A dial indicator used to measure displacement [...] was placed on the lathe and positioned so that displacement was measured from the free end of the bolt. The hollow ram jack was then loaded in intervals of approximately 2.5 MPa. A reading was taken from the dial indicator at each of these points." (Galvin, et al., 2001)*

Hagan, 2004

The test shall simulate a non-linear loading of the embedded anchor length. This is achieved by clamping the artificial rock mass to the frame.
The test specimen consists of concrete, set in a biaxial cell. This sample is then drilled. An instrumented rock bolt (strain gauges) is grouted with resin. Loading of the rock bolt is done incrementally. Load and displacement are recorded.
In a second test the bearing is uncoupled due to a stiff frame. It is a modification of the test described above, but this time the loading is linear. To achieve that, the rock is not collaterally clamped and able to deform with the bolt simultaneously.

Satola, 2007

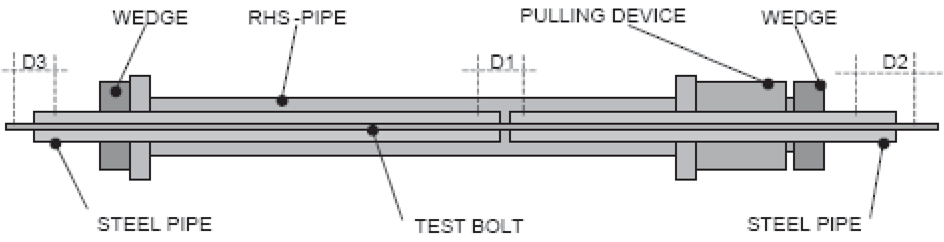


Figure 3-44 Double pipe test system (Satola, 2007)

The loading of an anchor over an opening joint is simulated. Two steel pipes simulate the borehole. They comprise a small gap between, as sort of an artificial joint. Each pipe is fixed to a flange, which are pulled apart by a hydraulic press. This loads the bolt-grout bond. The test machine has a maximum capacity of 350 kN. Pressure as well as displacement are measured.

Simser et al. 2007
The tests were carried out at NTC. The equipment comprised two steel tubes, simulating the borehole and a pneumatic stoper (for mixing and installing the conebolt).
Further tests comprised a real-time observation, which showed how the cone ploughed through the resin under static and dynamic loading. Since the pull test ram had less stroke than the bolt is able to displace, a cyclic loading was used. The bolts were statically tested until failure, by inserting a steel collar between the loading cycles.

Overcoring technique

In general

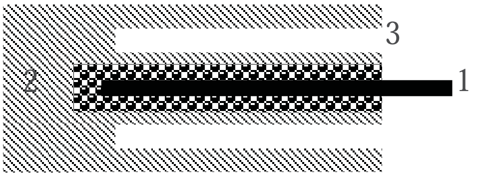


Figure 3-45 Basic principle of the overcoring technique

To examine cable bolts, several researchers do not want to use pull-out tests, for they think, that these do not comprise reliable results. So they use a special overcoring technique to examine bond strength of grouted bolts.
Information gained from such cores are encapsulation of the bolt, distribution and migration of resin and gloving.
Furthermore this technique can help to assess the in-situ corrosion (Hassell and Villaescusa, 2005).
The overcored samples can be cut and tested in the laboratory, i.e. with push tests.(Varden and Villaescusa, 2005).

Special
Another possibility for examination of the bond length of rock bolts is to drill the bolt out in a lager diameter and cut the shaft up in sections. (Jirovec, 1995)

Varden and Villaescusa, 2005
In their report 'A methodology for selection of resin grouted bolts' they stated the following.

> *"A 300 mm long section of rock core with 100 mm of cleaned protruding bolt were prepared. [...] The protruding length of bolt was used for the 'seating arrangement' required to allow push testing. Prior to testing, the resin annulus was measured to give an indication of 'centralisation' within the hole."*
> *"An Avery 50 t test machine was used for testing of the samples [see Figure 3-46]. The sample is confined within a steel jacket during the push test. The jacket consists of two halves that are bolted together. The bolts were tensioned with a torque wrench to 60 kN. The jacket was lined with a piece of thin rubber and the sample placed in a*

PVC sleeve. This allowed the sample to be firmly camped. A cap was placed on top of the protruding bolt. The inside of the cap was domed to allow the bolt to align with the platen when the machine applied load. Data was collected electronically with a load-displacement plot displayed on the computer screen during a test."

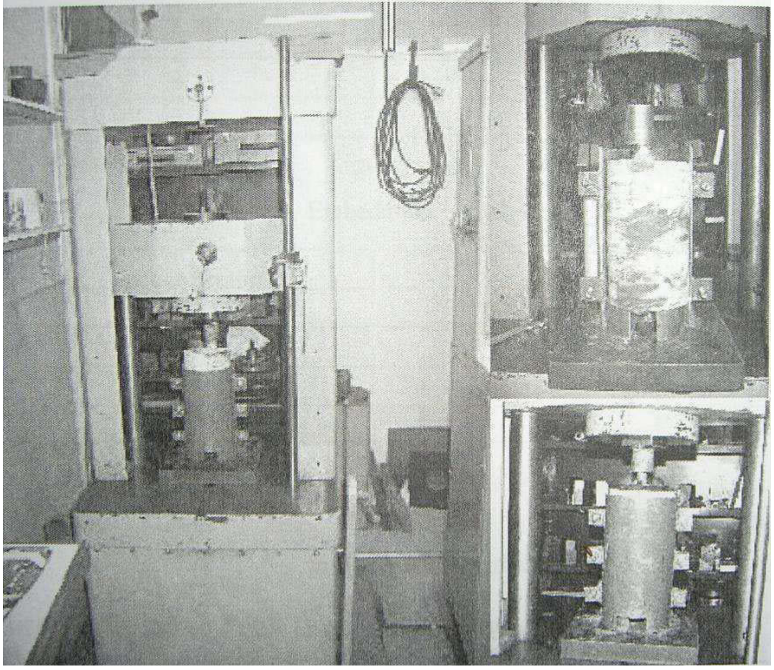


Figure 3-46 Test facility (Varden and Villaescusa, 2005)

Villaescusa, Varden and Hassell, 2008

The document 'Quantifying the performance of resin anchored rock bolts in the Australian underground hard rock mining industry' contains the following. WASM researches delivered a versatile overcoring system for lengths of 3 m, collar heights of 5-7 m and diameters of 140 mm (see Figure 3-47).

Figure 3-47 WASM bolting overcoring facility (Villaescusa, Varden and Hassell, 2008)

The so gained cores shall give a clear view of rock bolt system/rock mass interaction. Further information comprised is location, geological discontinuities, rock mass condition, bolt encapsulation, load transfer along axis, corrosion effects and borehole overdrilling. The overcored bolts are tested in the laboratory by a testing machine, as described above.

Monitoring and non-destructive testing

In general

There are some approaches to test the support units in-situ without destroying them.

One way is to instrument the bolts in use with for example strain gauges or similar measuring devices. Another way is the usage of ultrasonic or flexural elastic waves. Testing devices, basing on this principle are either not in use any more, still in development or have never been used in praxis.

Special

ASTM D4436 Long-term load retention test

This test shall determine the time over which a rock bolt tension decreases from the installed to a certain minimal value.

It can be used for all systems, which are not fully encapsulated. The rock bolts shall be installed in the same manner and material as they are intended to use.

The load on the bolt is monitored over a period of time (i.e. weeks). The test holes shall be representative.

Equipment needed are: Load cells (mechanical, photoelastic, hydraulic, rubber compression pad, or electronic type), anchor systems, rock bolt and accessories (plus a spherical bearing is desirable on very uneven surfaces; rock bolts used with grout or resin anchors shall have identical ungrouted bolt lengths), drilling equipment, torque wrench (shall also be used to load the bolts), hydraulic pulling system, borehole diameter measuring gauge and a thermometer as described in D4435.

The testing procedure is to drill and measure a test hole (as usual). Maybe a preparation of the rock bolt is required. The setting and loading of the bolt is done as follows.

> *"If mechanical anchors are used, lightly lubricate the downhole end of the rock bolt and screw on the anchor. When in position, torque the bolt to the manufacturer's recommendations to set the anchor. A pair of jam-nuts on the upper end of the rod may be used to apply torque without producing axial load in the bolt. If the manufacturer's torque cannot be achieved because of anchor slippage due to shear failure in the rock, note the maximum torque reading and install subsequent anchors to 80 % of this value. Do not test anchors where rotation occurs between rock bore hole surface and anchor. [...]*
>
> *Install grout or resin anchors according to the manufacturer's recommendations. Record the temperature in the borehole within the anchor zone; the temperature of the resin or grout at the time of injection and the ambient air temperature. Ideally the test anchorages should be installed under the same temperature conditions as expected during construction. The time required for resin or grout anchorages to reach their design strengths is temperature dependent and may vary significantly. Consult the resin or grout manufacturer's literature for recommended curing times*

> *under various temperature conditions. Curing times may be varied between 1 to 5 days under similar temperature conditions to assess the effects of curing time on strength. To evaluate the influence of grouted bond length on anchor strength, several anchorage lengths should be tested, ideally under similar temperature conditions and curing times.*
> *Loading the Bolt:*
> *The torque wrench is recommended for tensioning the bolt. Alternatively, the hydraulic pulling system may be used to apply load. In this case, attach a pulling rod to the rock bolt above the nut. Apply the load hydraulically, then tighten the nut. As the nut is tightened, the hydraulic pressure decreases because the load is transferred from the ram to the nut.*
> *Tension the bolt until the load cell indicates that the installation load has been achieved."*

Reading of the measuring devices is done as required. The document also gives information about calculations and reporting.

A non-destructive method to control the quality of the grout is the so-called "Boltometer". This device transmits flexural elastic waves into the rock bolt. At the end of the bolt this waves are reflected. The Boltometer records the received echoes by means of an echo diagram. The so gained diagram gives information about the state of the grouted bolt (Malmgren, 2010).
The Boltometer can measure bolt length and quality of grouting under favourable condititons. It is, however, unable to measure shepherd's crooks and has a reduced performance in the presence of mesh, lace and washers. (Kelly and Jager, 1996)

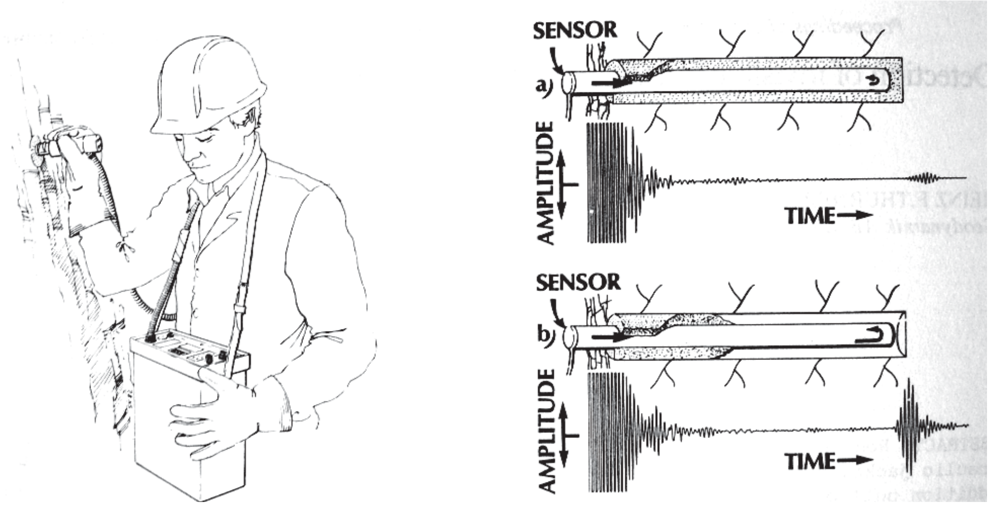


Figure 3-48 Boltometer and example of registrations (Thurner, 1983)

This instrument can also be used to detect invisible faults in rock bolts as suggested by Thurner, 1983.
The Boltometer is not commercially available any more. An other, quite similar measuring device is the GRANIT (GRound ANchor Integrity Testing) system, shown in Figure 3-49. This instrument uses an impactor to create a signal and determine load, length and quality of a rock bolt. (Bäckblom, 2009)

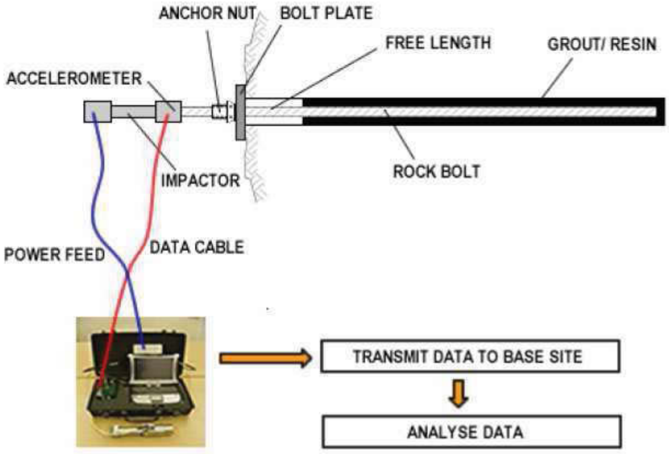


Figure 3-49 GRANIT system (Bäckblom, 2009)

Two monitoring devices are the dilatometer, and the instrumented bolt. The latter comprises a rod and an indicator plate. The rod is resin-embedded and the plate is fixed to the wall by two small bolts. (Ferrier and Roux, 1980)

There is also an US patent for a “Method and apparatus for testing installation quality in a grouted anchor system”. The testing principle is to apply acoustic signals and detecting the response.

> *"In summary, there is known technology to develop that likely could provide information whether the bolt installation is correct (length, grout quality): It is also possible that the bolt evolution (broken bolts, corrosion) could be tracked, but no technology is commercially available, likely to weak demands or that the instruments were not useful." (Bäckblom, 2009)*

Two further monitoring devices are slit nuts, which close under loading, or indicators, mounted between the face plate and the nut, with a spalling rate of an enamel covering. (Reuther and Heime, 1990)

Calibrated end-plates and the tension of wire mesh can conclude on the forces action on a rock bolt. (Dejean and Raffoux, 1980)

Bigby, 1997

A routine monitoring system, called "Dual Height Telltale" (shown in Figure 3-50), uses two indicators (upper one for movements within rockbolted height, lower one for movement above) and a software ("Telltale for Windows").

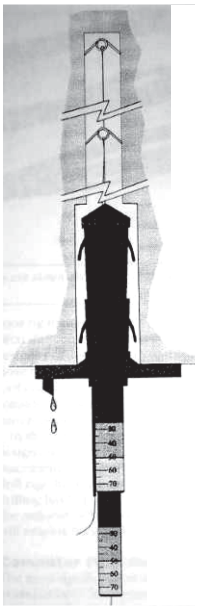
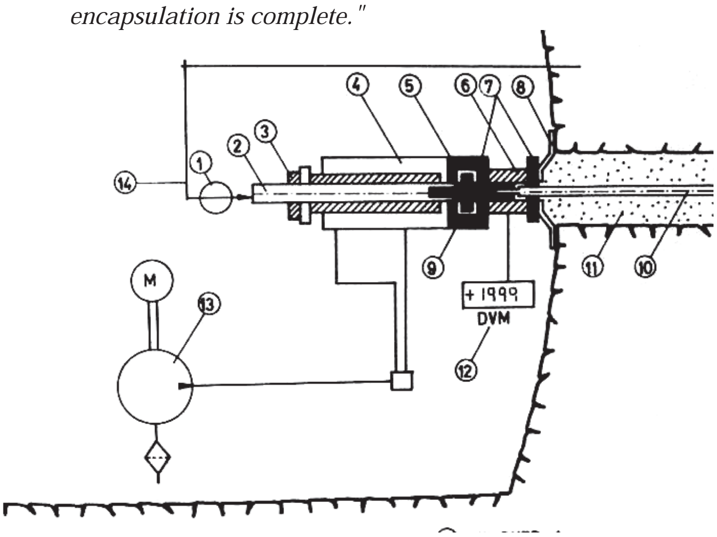


Figure 3-50 Dual Height Telltale (Bigby, 1997)

Beard and Lowe, 2003

The object of the research was to develop a portable non-destructive testing instrument for evaluating the condition of rock bolts

> *"The proposed inspection technique is an ultrasonic pulse echo test, carried out from the free end of the rock bolt. An ultrasonic transducer is clamped onto the end of the bolt and connected to a pulse-echo instrument. A short duration toneburst is used to excite a guided wave in the rock bolt, which is then reflected from the bolt end and from any major defects. Accurate knowledge of the wave velocity dispersion curves allows the position of defects or the bolt length to be calculated from the reflection arrival time. The use of a toneburst signal allows the excitation frequency bandwidth to be tightly controlled. The maximum test range is limited by the amount of attenuation that the wave experiences as it propagates. [...] It is envisaged that the technique could be used to detect failure by determining the residual bolt length. In addition, defects such as necking, severe corrosion, or loss of encapsulation could be identified by additional reflections. The test could also be used as a form of quality control, to determine that the correct length bolts have been installed, and that the encapsulation is complete."*



1 Displacement gauge
2 bolt
3 nut
4 hydraulic jack
5 bracket
6 force transducer
7 washer
8 washer
9 nut
10 rock bolt
11 grouting mass
12 digital display
13 hydraulic motor pump
14 displacement gauge holder

Figure 3-51 Test facility (Jasarevic et al., 1984)

Jasarevic et al., 1984
The equipment cannot only be used for pull out tests, but for long-term control of displacements in rock bolts. Therefore the hydraulic jack has to be taken out (4) and the lock-unit has to be fixed (9) on the bearing plate.

SMART
For direct ground support instrumentation SMART cable bolts, SMART contractometers, micro seismic monitoring system, multiple position borehole extensometers and stress cells can be used. (Bawden et al., 2007)
Mine Design Technologies comprises the SMART Cable bolt, shown in Figure 3-52.

Figure 3-52 SMART Cable bolt (http://www.mdt.ca/index.cfm?page=products&s=SMART_cable_bolt; 19.05.2010)

> *"By combining the support capabilities of a standard 7-strand cable bolt with a miniature 6-wire extensometer, the SMART (Stretch Measurement to Assess Reinforcement Tension) Cable was born.*
> *The stretch in the cable is determined via the integrated six-point extensometer, allowing the strain between the anchor points to be calculated. Because we know the properties of the cable-rock-grout interface, the loading profile along the cable can be inferred."*

The SMART bolts dimensions are a length up to 30 m and a diameter of the head of 33 mm, needing a borehole diameter of 50 mm minimum. (http://www.mdt.ca/index.cfm?page=products&s=SMART_cable_bolt; 19.05.2010)

To monitor roof bolts installed in roadways several equipment can be used, i.e. sonic-type extensometers (side or roof extensometers) and vibrating wire strain gauges or strain gauged roofbolts for load measurement
(Daws, 1992)

The roof-bolt bond tester is a non-destructive device, based on energy transfer measurements. It measures the loss of intensity of ultrasonic energy, send through a roof bolt. The instrument is small and can be manually positioned to the head of a rock bolt, like shown in Figure 3-53. There are three different results, related to colours. Red stands for bonds, less than one-half, yellow signals that one-half to three-quarter are bonded and green means that more than three quarter of the bolt are bonded. (Bolstad, Hill and Karhnak, 1983)

Figure 3-53 Roof-bolt grout bond tester (Bolstad, Hill and Karhnak, 1983)

Wang and Wang, 2001

Their report 'Nondestructive testing of grouted bolts system' contains the following.

The technique is based on acoustic frequency stress wave (AFSW). They wanted to find a relationship between the reflective character phase and grouted condition and the wave energetic attenuation and anchored length.

They mentioned a non-destructive pull-out test (NDPT).

> *"The propagation and attenuation of AFSW: AFSW at the bolthead excited and propagates in bolt grouted medium and rock mass"*
>
> *"Our research result have shown that the phase characteristic is closely bounded up with the anchoring state and the distribution of side resistance. Reflects totally at bottom end interface, multiple reflection appears clearly in the bolt of bad anchoring state*
>
> *Non-destructive measurement of anchoring fore:*
>
> *Many field pullout tests have shown, that the pullout curve and the pullout factor defined as pulloutforce to produce unit deformation displacement demonstrate some relations with the increment of pullout force applied. Especially it obviously fluctuates when the GBS approaches the failure. The afterbody of pullout drive increases in a near linear relation when the anchoring force is more than the ultimate strength of steel bolt and the pullout factor increases sharply fig.1a. whereas when the anchoring force is less than the ultimate strength of steel bolt, the curve afterbody rises slowly and the growth rate tend to decrease. So the variation law can be utilized to judge whether the GBS approaches to the failure. The value of anchoring force is determined through the interaction value of two secant lines, plotted on both sides of inflection point of curve drawn automatically by the testing system. Likewise, the proper value of ultimate pullout-coefficient is designed to autotrack the curve before stopping the pullout tests and then the method is capable of measuring accurately the anchoring force without disturbing the anchorage capacity of bolt." (Wang and Wang, 2001)*

ISRM - suggested method for monitoring rock bolt tension using load cells, (ISRM, 2007c)

The method deals with the measuring of tension changes in a rock bolt.

Equipment needed consist of load cells (for 1 out of ten rock bolts; can be mechanical, photo elastic, hydraulic, electric or rubber compression pad type.) They have to resist blasting, water and dust for a long time.

Procedure: First the load cells have to be calibrated. After installation, the instrumented bolts shall be recorded. Immediately after installation the tension shall be noted, then read in intervals.
The data can be used for calculations, defined in the standard.

DIN 21521
For testing bond (between rock bolt and rock mass), anchoring force, free length and yield strength a tensile test shall be performed. Therefore a hydraulic press is used to apply a tensile force on the anchor head. The test is performed with approximately 30 kN/min or 200 kN/min maximum, in case of the anchor does not creep or set. There are two different types of testing:
(1) The press is placed on a (simulated) rock mass, surrounding the borehole mouth. The bearing of the press shall have a distance to the borehole mouth of at least one time the borehole diameter. Then the required pre-tension force is applied. Several times increasing forces are applied by unloading the bolt each time. Force and displacement are measured. This test can also be performed as creep test, by holding the testing load constant.
(2) The press is mounted without removing the head of the bolt. The applied force is increased, decreased and increased again. Then the load is held constant for five minutes. The bolt has to withstand this load. There is no displacement measuring.

3.1.1.2 Testing of Thin-Spray on liners (TSL)

In general
Since TSL are a 'new' support unit, various tests are performed to understand their mechanism and to compare different types of TSL. Until now there are no specific standards available. However, researchers have collected several existing standards on polymers that can be adopted for testing TSL.

EFNARC Specification and Guidelines on Thin Spray-on Liners for Mining and Tunnelling
The guideline defines performance requirements and refers for testing methods to European standards. Parameters to be testes and corresponding standards are listed in Table 3-1.

Table 3-1 Tested Parameters and corresponding standards for TSL (EFNARC, 2008).

Tested Parameter	Standard(s)
Tensile strength	DIN 53504 Type S2 or ASTM D638
Rate of strength development: (Time to reach a Tensile Strength of 2 MPa at 50±5% rh and 80±5% rh at 23℃)	DIN 53504 Type S2 or ASTM D638
Linear load resistance	TSL Linear Block Support Test
Tensile E-modulus	Stress/strain on DIN 53504 Type S2 or ASTM D638 specimens
Elongation at break	DIN 53504 Type S2 or ASTM D638

Shear strength	EN 1373 or ASTM D732 on sawn granite.
Ultimate bond strength	EN 1542 to EN 1766 (type MC 0.40) concrete grit blasted to SA 2½
Fire classification	EN 13823 under conditions of EN 13501-1:2002
Flammability	ASTM E84 (surface spread of flame and smoke index development)
Products of combustion	NES 713
Crack bridging	DIN EN 1062-7
Tear strength @ 28 days	DIN ISO 34-1, DIN 53515
Water tightness	EN 1928 or DIN 1048
Freeze thaw resistance	e.g. SN 73 1326 or SS 13 72 44
Permeability to water vapour, methane, radon etc	DIN 52615, DIN 16726 or SN 021582
Surface Electrical resistance	DIN 22107 Part 6
Electrostatic charge transfer	EN 13463 Part 1

These tests shall be performed by the manufacturer.
In-situ testing on TSL shall be done in an appropriate time after spraying. Tested parameters may be applied thickness (with tyre tread gauge), adhesion to substrate (qualitative peel test) and ultimate shore A hardness.
The document also gives details of the so-called 'TSL Linear Block Support Test'. This test shall qualify the bearing capacity of a TSL. For testing until failure a load of 16 mm/min is applied on the assembly shown in Figure 3-54.

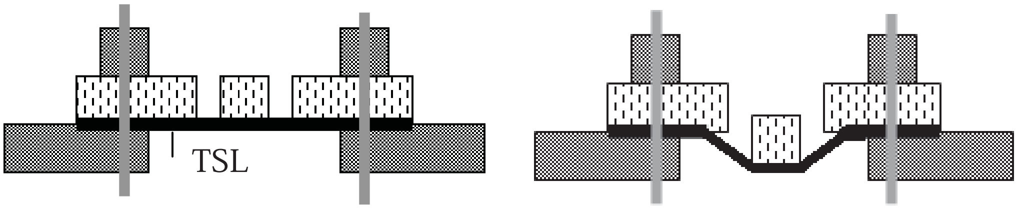


Figure 3-54 TSL Linear Block Support Test after EFNARC

Furthermore a gap shear load test is required, in case of the TSL partially debonding (see Figure 3-55).

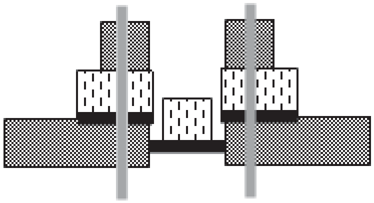


Figure 3-55 Gap shear load test of TSL

The guideline describes precisely the equipment needed for the tests.

The document 'Proposed procedures of the testing of TSL properties' (Toper et al. 2003) referred to Potvin (2002), who categorised TSL tests, as shown in Figure 3-56.

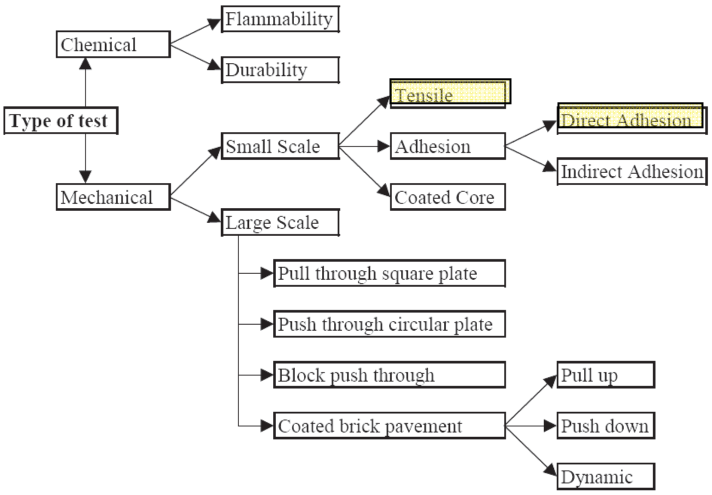


Figure 3-56 TSL tests (Toper et al., 2003)

They also state, that only two tests are generally accepted by researchers. These tests are highlighted in figure.

Large-scale tests were found to provide interesting results but were also found to be difficult to interpret in term of TSL properties and behaviour. (Toper et al., 2003)

The following chapter contains test performed on TSL, no matter which loading mechanism is used (shear, tensile, compression, etc.)

Special

Yilmaz, Saydam and Toper, 2003
They state in their report 'Emerging Support Concept: Thin Spray-on Liners' that currently it is not possible to evaluate the quality and performance capabilities of TSL products. There is no reliable correlation between laboratory results and field results whether on surface nor underground.
Testing could be performed to address TSL material itself or both the TSL material and the substrate.
The two most important factors influencing the testing results are temperature and humidity.
They state that only two tests have met the acceptance of the researchers. This are the tensile and the direct adhesion tests. Large-scale tests provide interesting results but are also difficult to interpret.

Adhesion tests

> *"The adhesion test measures the adhesion or bonding strength of a TSL attached to a rock substrate. Two types of bond strength needs to be considered: tensile and shear. Failure may occur due to the low tensile adhesion strength between TSL and rock*

> *surface. Adhesion strength on different rock types and the factors influencing the adhesion are important test considerations."*

Core adhesion test

> *"The direct adhesion test consists of two pieces of core bonded together by TSL as shown in [see* Figure 3-57*]. The top and bottom halves are subjected to a uniaxial pull until failure takes place at the TSL rock interface. The core adhesion test has the potential to become the main testing method in determining the bonding strength of TSL due to its simplicity. Sample preparation is an important issue in that both halves should lie along the same axis and in the direction of pull to prevent eccentric loading and premature failure."*

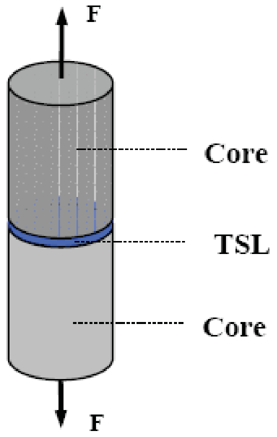


Figure 3-57 Core adhesion test (Yilmaz, Saydam and Toper, 2003)

Plate-pull testing

> *"This test consists of pulling on a test dolly embedded within TSL. A test dolly can be made from varying diameters and thicknesses of perforated steel discs that are applied to thin rock slabs [see* Figure 3-58*]. Tannant et al. (1999) showed that high humidity or wet rock surfaces may significantly degrade the adhesive bond between the TSL and the rock. The TSLs bond to the rock normally increases with time, provided that the rock is firm, clean and dry. Adhesion to smooth, wet and soft rock is generally poor. Difficulty persists in being able to produce consistently repeatable results between tests using rock slab bonding surfaces. Archibald (1992) showed that bond adhesion varies on irregular rock surfaces due to differences in substrate strength, surface roughness, porosity and degree of alteration characteristics. Therefore, he used a paving stone product that exhibits uniform strength and surface properties.*

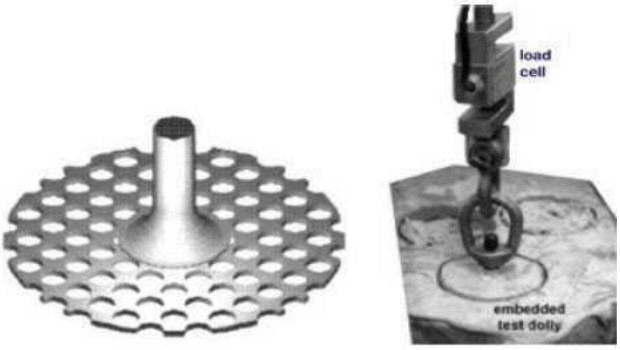


Figure 3-58 Generic view of a test dolly and typical test setup in the laboratory (Yilmaz, Saydam and Toper, 2003).

Specimen preparation and testing procedures can be summarised as following.

- *A test product is sprayed onto a flat surface of a cut concrete or rock surface.*
- *A test dolly is immediately placed on the fresh, uncured coating. TSL is still in its initial liquid state and permitted to seep through the numerous perforation holes of the test dolly.*
- *Immediately following the initial curing, TSL forms an adhesion bond with the test surface and produces an embedment bond about the pull plate.*
- *A second coating is sprayed over the test dolly to fully embed it within the TSL.*
- *After the test product has cured the embedded test dolly and coating are overcored to isolate the test area from the rest of the TSL. (Overcoring of the pull plate is conducted to insure that only the bond adhesion associated with the area immediately beneath the pull plate is actually measured during pull testing.)*
- *After 2 days of curing for the last layer of TSL, the test dolly is pulled normal to the substrate surface*
- *Test is continued until full release or loss of adhesion contact between the pull plate assembly and the substrate.*
- *The adhesive strength is determined from the peak stress.*

The test process is designed to be carried to ultimate bond failure; therefore, no residual adhesion bond strength is quantifiable. The location of the failure should be determined and, if it is in the bond plane, the amount of the applied material remaining should be assessed. Underground adhesion testing of TSLs, similar to laboratory plate-pull testing, on rock and shotcrete was also performed with a range of cure times and for various moisture levels (Espley et al. 2001). The surface substrates were cleaned prior to liner application and pull plates were embedded in the liner for the testing. After the liner had cured, each test dolly was overcored and pulled as the loads were measured. The results indicate a correlation between surface moisture and adhesive strength – that is, the adhesion strength is decreased as the surface moisture increases."

Baggage capacity test

"The baggage capacity test measures loose rock supporting capacity of a deformable TSL (Swan & Henderson, 1999). An open-ended steel frame, of dimension 1.1m x 1.1 m x 0.3 m, is used and loaded with actual slabs of unwashed –100mm rock debris. A liner is sprayed on the "loose" rock debris surface [see Figure 3-59*]. Since the surface is discontinuous some penetration occurs between the rock fragments. After curing for the required time the frame is inverted and placed in a loading machine. A distributed compressive load is applied to the "loose" rock, thereby deforming the liner, which eventually ruptures. Repeatability of this test is questionable since the distribution of rock debris varies for each test. Preparation for a test appears to be difficult and time consuming due to the size involved."*

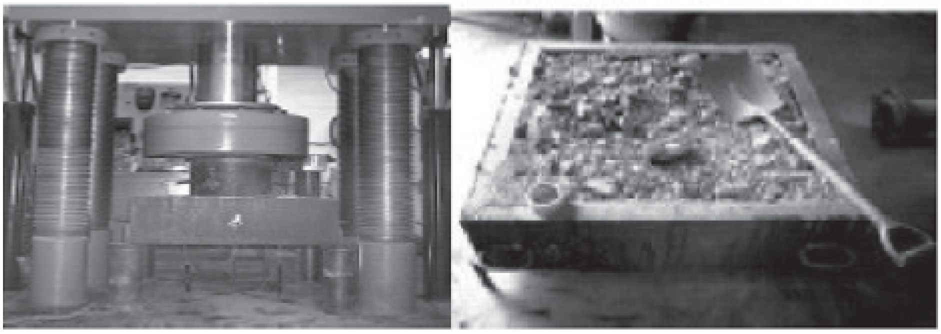


Figure 3-59 Baggage load test frame and set-up (Yilmaz, Saydam and Toper, 2003)

Tensile strength and elongation tests

"Standard testing method on "dog-bone" shaped pieces of plastics (ASTM D638, 1998) has been selected by most of the researchers [see Figure 3-60*] (Tannant et al., 1999; Archibald, 2001; Spearing & Gelson, 2002) to assess tensile properties,*

initial stiffness (modulus) and elongation capacity of TSL material at failure. TSLs have different rigidity properties and therefore their dimensions should have the ability to deal with rigid, semi rigid and non-rigid products. Thicknesses between 3 mm to 14 mm can be accommodated with dog-bone testing. Multiple tests need to be performed in order to obtain reliable measurements of the tensile strength. The test specimen is clamped at each end in a tensile testing machine and then pulled. The specimen should break into two pieces on the narrow section for a valid test. The clamping can be achieved in a number of ways; gluing, screw clamping and fixed gripping platens are some of the methods.

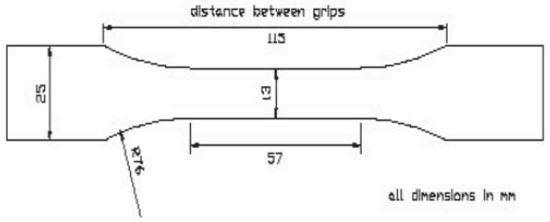


Figure 3-60 Test specimen after ASTM D638 (Yilmaz, Saydam and Toper, 2003)

Material tensile strengths were determined either at break or yield positions along the measured load deformation curves. The load is divided by original minimum specimen cross-sectional area at the specimen centre span to obtain the nominal tensile strength."

Pull strength determination

"The plate pull test simulates the loads generated in a supporting liner when a loose block of rock moves relative to the surrounding rock [see Figure 3-61 *]. The test consists of placing a solid circular plate of steel on either a concrete block or rock surface and then spraying the test material over the plate and the substrate surrounding the plate with a uniformly thick and continuous TSL. No TSL is permitted to be placed between the substrate and plate as it is not the aim of this test to measure the direct bonding strength of TSL [see* Figure 3-62*]*

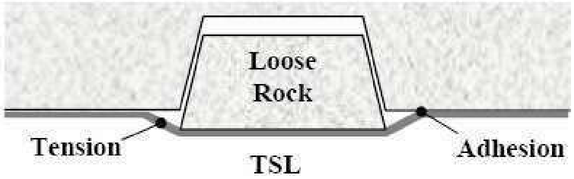


Figure 3-61 TSL supporting a loose rock (Yilmaz, Saydam and Toper, 2003)

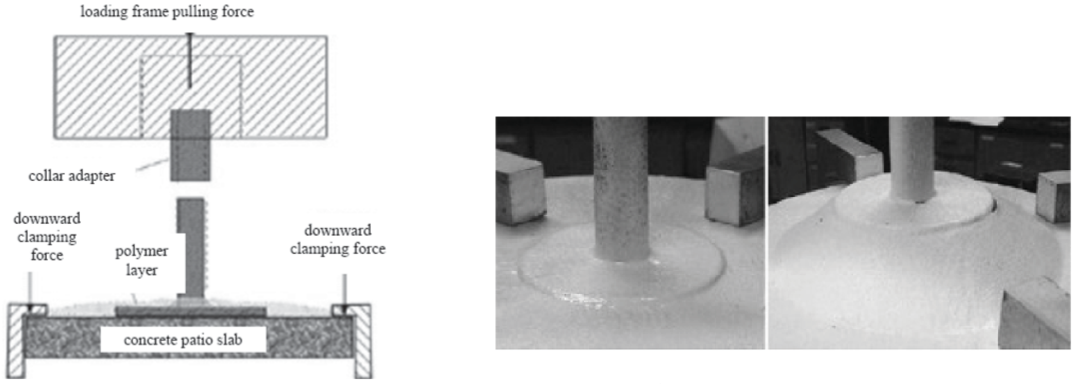


Figure 3-62 Pull test assembly sketch and photo (Yilmaz, Saydam and Toper, 2003)

The plate pull test procedure can be summarised as follow (Tannant et al. 1999):

- *Place the pull plate on a concrete or rock surface which has a diameter greater than the pull plate.*
- *Coat the pull plate and the area surrounding the plate with TSL.*
- *Slowly pull the plate perpendicular and away from the substrate after the required curing time.*

The test is completed when the load begins to drop or when the plate is pulled free of the substrate. A combination of adhesion loss and tensile rupture is the expected and desired ultimate failure mode and not that of shear rupture through the TSL."

Large scale pull test

*"Espley et al. (1999) assessed the load carrying capacity of a TSL by coating an interlocking series of 50 mm thick hexagonal concrete paving blocks. The TSL is applied to the concrete blocks from above and left to cure. A pull-type loading is applied by a 300 mm square steel plate located in the centre and underneath the assembled paving blocks until the TSL has failed as illustrated in [*Figure 3-63*]. Espley et al. (1999) observed that the TSL is able to enhance the interaction between the loose blocks and thus a significant portion of the supporting function arises from block-to-block interaction."*

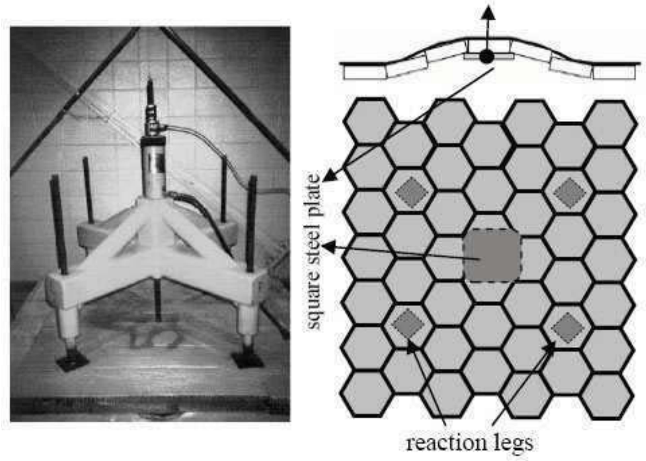


Figure 3-63 Test setup from large-scale pull test (Yilmaz, Saydam and Toper, 2003)

Punch test

"Spearing et al. (2001) performed the so called MBT Method (Membrane Displacement Test) where the TSL is punched by a plunger at the end of a hole in a concrete slab as illustrated in [Figure 3-64]. This test is very similar to the plate pull test in terms of the movement of the TSL i.e. punching or pulling affectively results in the same TSL behaviour."

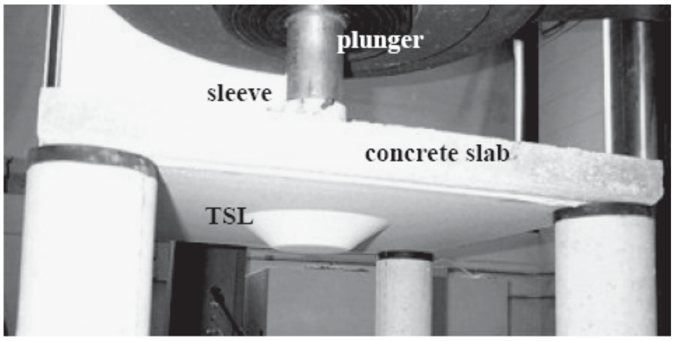


Figure 3-64 Punch testing setup (Yilmaz, Saydam and Toper, 2003)

Compression Failure Tests on Coated Samples

> *"TSL coated cylinders of concrete and rock were tested by various researchers (Espley et al. 1999; Archibald & DeGagne, 2000) to demonstrate TSL's ability to contain and reduce the damage resulting from potential pillar-bursts. Tests were done under uniaxial loading conditions and the results demonstrated significant positive benefits at the laboratory scale in terms of non-violent post-peak failure response, and the liner's ability to absorb some of the stored strain energy. A compression failure test may not be relevant in deriving physical properties of TSLs; however it is useful to demonstrate the liner's ability to accommodate large strain ranges."*

Toper et al., 2003

The document 'Proposed procedures for the testing of TSL properties' contains a list of testing standards that could be adapted to TSLs either directly or by appropriate modifications (marked with * in Table 3-2). However, changes may affect the test results.

No matter which testing method is adopted, the two most important factors, temperature and moisture, need to be recorded.

Table 3-2 Relevant standards for testing of TSL (Toper et al., 2003)

Test type	**Standard**
Tensile Strength and Elongation	ASTM D638
	ASTM D1708-84
Tear Strength	ASTM D1004-90 *
	ASTM D1922-89 *
	ASTM D5884-99 *
	BS 903-A3-3.2: 1997, ISO 34-2: 1996
	BS 903-A3:1995, ISO 34-1: 1994
Shear Strength	ASTM D732-90
Adhesion Strength	ASTM D4541
Toxicity	ASTM E1619-95
Flammability	ASTM E162
	ASTM D568-74
	ASTM E84
	IEC 707
	CAN/UCL S102-M88
Water Absorption	ASTM C827
	ASTM D570
Abrasion	ASTM D4060
	ASTM D1242

Yilmaz, Saydam and Henderson, 2003

The paper 'Torque Testing of Thin Spray-on Liner Coated Cores' contains the following.

The author states that this test, satisfying most of the requirements mentioned earlier, has a great potential to be accepted as a standard testing method.

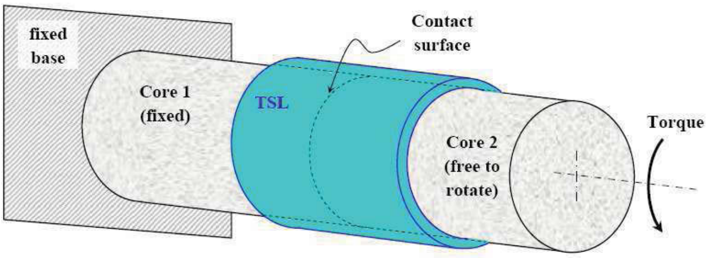


Figure 3-65 Test principle (Yilmaz, Saydam and Henderson, 2003)

End effects should be avoided. Therefore, the proposed test method takes into account the continuous nature of TSL on the applied rock surface.
Continuity is introduced by applying a jacket of TSL around cylindrical cores.
Opening of discontinuities during any type of movements and filling of open cracks by TSL are also not represented by the torque testing method.
The load cell shall be capable of measuring in Newtons.
Two pieces of 53 mm diameter and 130 mm length diamond cored samples of granite were used as substrate for TSL application.
TSL components are taken according to manufacturer's mixing ratios and then hand drill-mixer was used.
The cores are pressed together along the same axis by a custom made clamp during TSL coating in order to prevent any shifting of the core axis. TSL mixture is placed inside the moulds and manually applied by compressing the moulds against the core surface.
No TSL is allowed to penetrate into this area, see Figure 3-66.

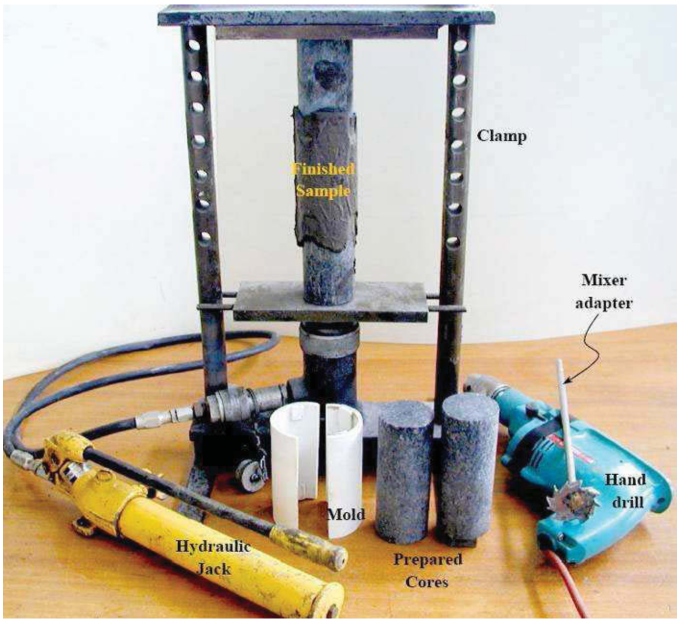


Figure 3-66 Testing arrangement (Yilmaz, Saydam and Henderson, 2003)

The clamp, roller bearing and specimen centres of axis should all coincide to prevent eccentricity and premature failure due to bending action against which the TSL material is weaker. The test set-up does not contain any thrust load along the axis of rotation but only tangential load due to the weight applied on the loading wheel. Therefore the only resistance existing and measured would be the one offered by the TSL in the system.

Post failure behaviour could not be measured. Figure 3-67 shows the testing setup.

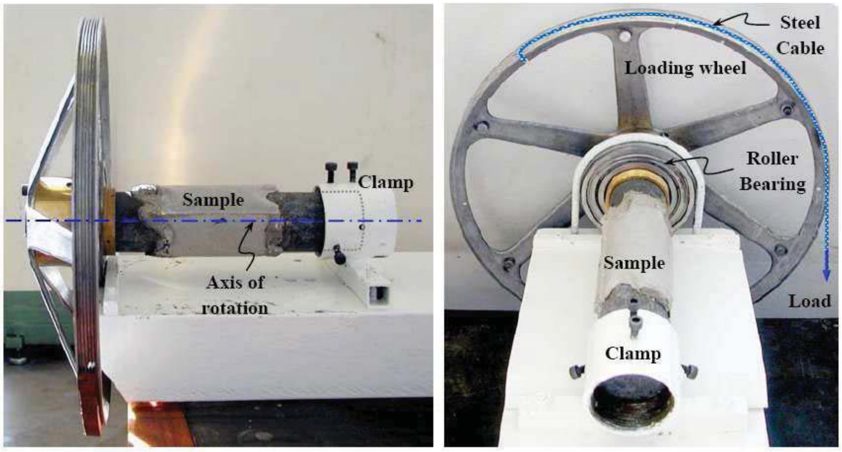


Figure 3-67 Testing facility (Yilmaz, Saydam and Henderson, 2003)

Saydam, Yilmaz and Stacey, 2003

In their report 'A New Testing Approach for Thin Spray-on Liners: Double-Sided Shear Strength (DSS) Test' is described the following.

The proposed Double-Sided Shear Strength (DSS) test determines shear bond, tensile bond and tensile adhesion characteristics within fractured zones of the TSL.

It has been developed in the School of Mining Engineering Rock Mechanics Laboratory at the University of the Witswatersrand.

The *MTS Model 815 Rock and Concrete Mechanics Testing System* was used as a loading system and data acquisition system.

The test requires the use of three granite blocks where the adjoining surfaces are glued together by TSL as seen in [Figure 3-68].

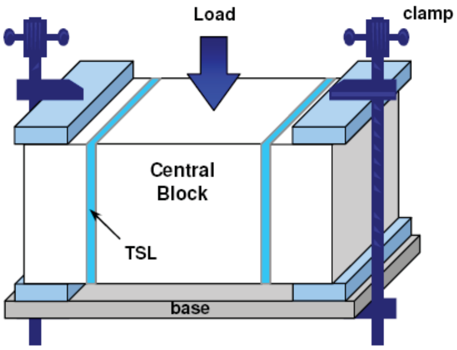


Figure 3-68 DSS test (Saydam, Yilmaz and Stacey, 2003)

The mixing of TSL is done by a hand held drill with a specially designed mixer attachment for small scale laboratory tests. TSL components are taken according to manufacturer's mixing ratio and then mixed until a uniform, well mixed paste of TSL was obtained.

TSL mixing should be immediately followed by pouring of TSL between the block contacts due to hardening and bonding difficulties with the passage of time.

Pouring of TSL ensures that the three granite blocks, which have got same surface area, were glued to each other.

All prepared samples should be kept in an environment where the variations in temperature and moisture are minimal. The samples should be placed on a plastic sheet to prevent TSL from sticking to the floor surface.

The contact area between the TSL and rock block provides an input value for the strength calculations. At the beginning of the test, the test specimen was placed onto the MTS machine’s loading piston where they are clamped rigidly. And then the load was applied onto the middle block.

As results peak strength-deformation curves are plotted. The energy absorption could be calculated.

Archibald, 2001

In his report 'Advances in the Use of Thin, Spray-on Liner Systems' two further tests are described.

The object is the

> *"side-by-side evaluation of various physical characteristics of the range of proposed lining agents using standardized testing procedures. Material tests have and will concentrate on determination of physical characteristics of lining materials which are thought to best quantify a material's expected support performance behaviour and capabilities to mitigate potential health and safety hazards associated with flame exposure, gas inflow, water inflow, loose retention and dynamic rock movement."*

Support and operational performance

> *"Typical views of tested samples, both pre- and post-failure, are shown to illustrate the positive structural reinforcement effects that can be achieved by applying polymer liner coatings onto specimens prior to failure testing [Figure 3-69]."*

Figure 3-69 Concrete and rock samples before and after compression failure (Archibald, 2001)

> *"Though the physical characteristics and support capacities of a wide variety of TSL materials have been studied by manufacturers and researchers, the validity of these assessment procedures and results is often questioned. Laboratory testing procedures do not accurately reflect conditions of use to which lining materials may be set in the field. Alternately, mine operators who may contemplate use of spray-on polymer materials often utilize assessment procedures which are not in accordance with those of other potential users. Current industry efforts for material testing are unlikely to yield comprehensive, quantifiable and comparable evaluations for all candidate materials available. Certain tests can only be performed within specialized laboratory sites, due to the complex nature of the testing process, machinery and costs involved. Because no consistent testing procedures have been established,*

> *confusion often develops when representing and comparing the physical properties of different candidate TSL materials which may be adopted for mine support use. [...] Neither quantitative measurements of the relative support performance of the variety of available TSL materials nor standardized testing procedures for these materials currently exist. [...]"*

Material Flammability Assessment

> *"Acceptable and safe application of any technology in underground workplaces must also include assessment of the flammability characteristics of this technology. The assessment of the surface burning characteristics of construction materials has been established as a National Standard of Canada. The method of test for building materials (designated the "tunnel test") is designed to determine the comparative burning characteristics of any material or test assembly by evaluating flame spread over its surface when exposed to a standardized flame source (CAN/ULCS102- M88, 1988)."*

Spearing and Champa, 2000

They did some research on ground support membranes for use in underground mines. They found that no compressive strength can be readily tested on thin membranes.

For testing, they referred to various standards for small-scale laboratory testing, namely ASTM D624-98 for tear strength, ASTM D412 for tensile strength and elongation, ASTM D4541 can be used for adhesion, ASTM E1619-95 for toxicity, ASTM E84-99 and IEC 707 for flammability, ASTM 162 for flame spread, NES 713 for smoke toxicity, ASTM C 827 for water absorption and ASTM D3045 for accelerated ageing.

The MBT Membrane Displacement Test

The test facility is shown in Figure 3-70. The test shall measure load and displacement of the performance of a support membrane. Before measuring the thickness and testing, the membrane is applied to the surface of the concrete patio slab, except for the corner where the support cylinders are placed. The result is a load-deflection graph.

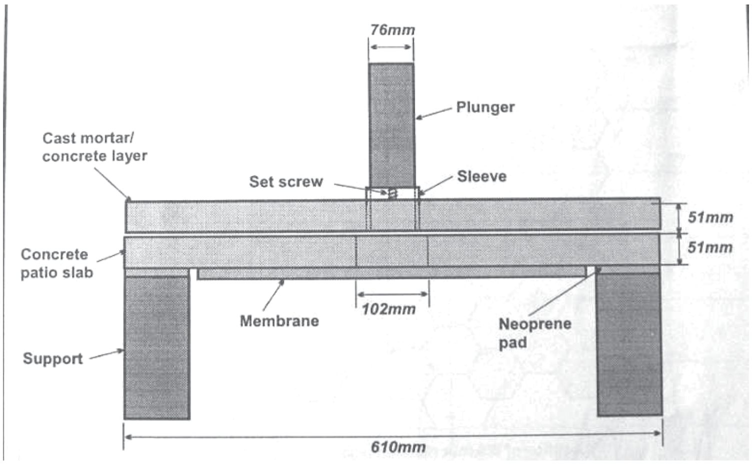


Figure 3-70 MBT Membrane Displacement Test facility (Spearing and Champa, 2000)

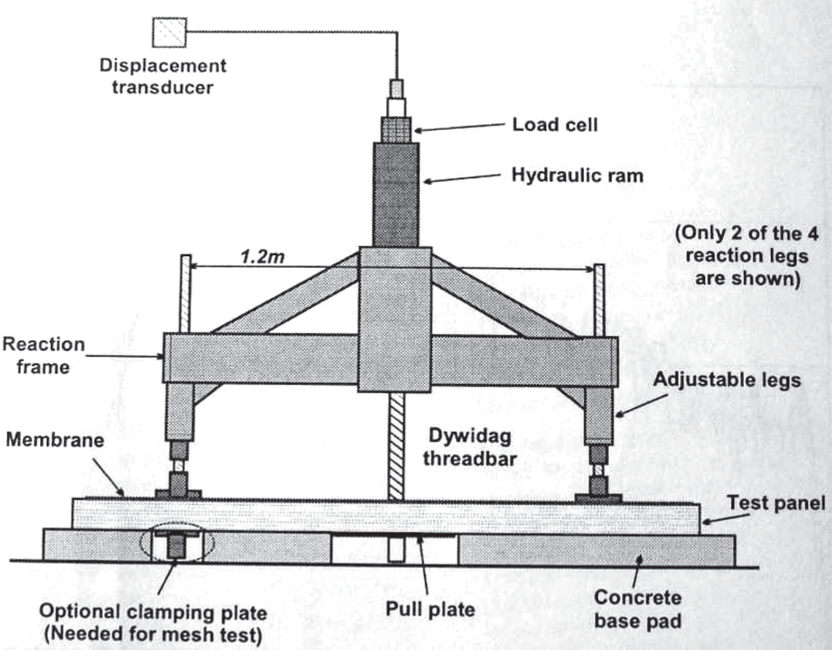


Figure 3-71 MBT pull test frame (Spearing and Champa, 2000)

The INCO/GRC Membrane Test Method

The test facility is shown in Figure 3-72. Aim of this test procedure is it to gain the load - deformation behaviour of the support device. There is also a dynamic test arrangement, as can be seen in the chapter 'Dynamic - Drop facilities'.

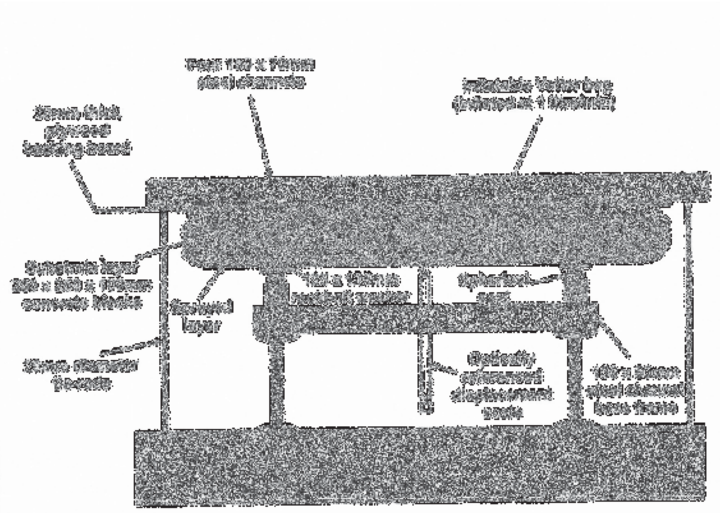


Figure 3-72 Quasi-static test arrangement of INCO (Spearing and Champa, 2000)

The CANMET Membrane Test

During this test a box is filled in three layers with specific aggregates, made of stone or paving blocks. Over the compacted aggregate the membrane is positioned.

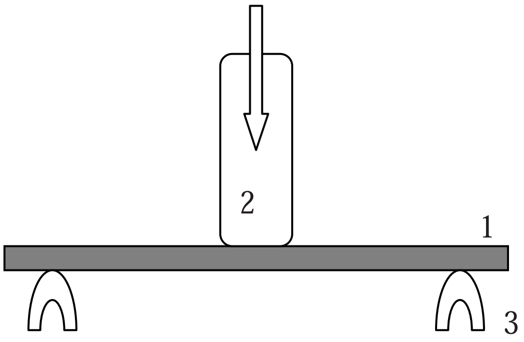
Then the box is inverted, inserted into a compression machine and loaded until failure. A load-displacement graph is the result.

3.1.1.3 Arch support

In general
Only a German standard could be found, dealing with arch support for mining purposes.

Specific

DIN 21530-4 Arch support - sliding roadway arch (open or closed)
DIN 21530-4 gives specific instructions where the samples are to take from. The standard also demands mechanical analyses for the arch support. Several tests shall be performed. These tests are, however, not described in this standard, but in referred ones. A tensile test (according to DIN EN 10002-1), beam impact test (DIN 50115, hardness test (DIN EN ISO 6506-1) and a surface hardness test (DIN EN ISO 6507-1) are suggested in the standard.
To determine the bending strength a bending test is described. The basic principle is shown in Figure 3-73.



1 test sample
2 testing die
3 bearing

Figure 3-73 Sketch of profile testing (DIN 21530-4)

The standard differs between various types of profiles and positions of testing.

The connecting elements shall be tested by a bending test (Figure 3-74) and of insertion resistance (Figure 3-74).

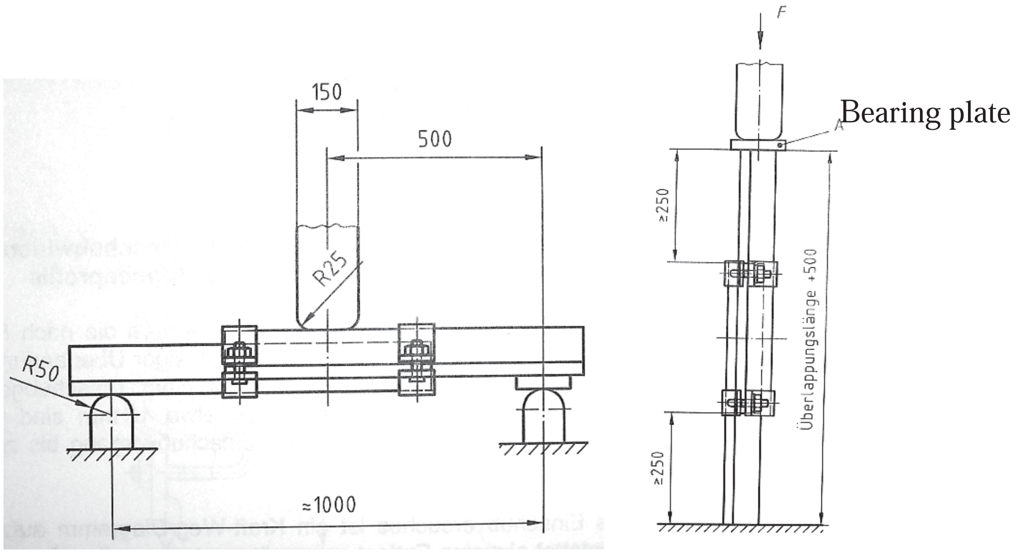


Figure 3-74 Testing of connecting elements (DIN 21530-4)

The bolting has to succeed a tensile test (Figure 3-75) and a compression test (Figure 3-75).

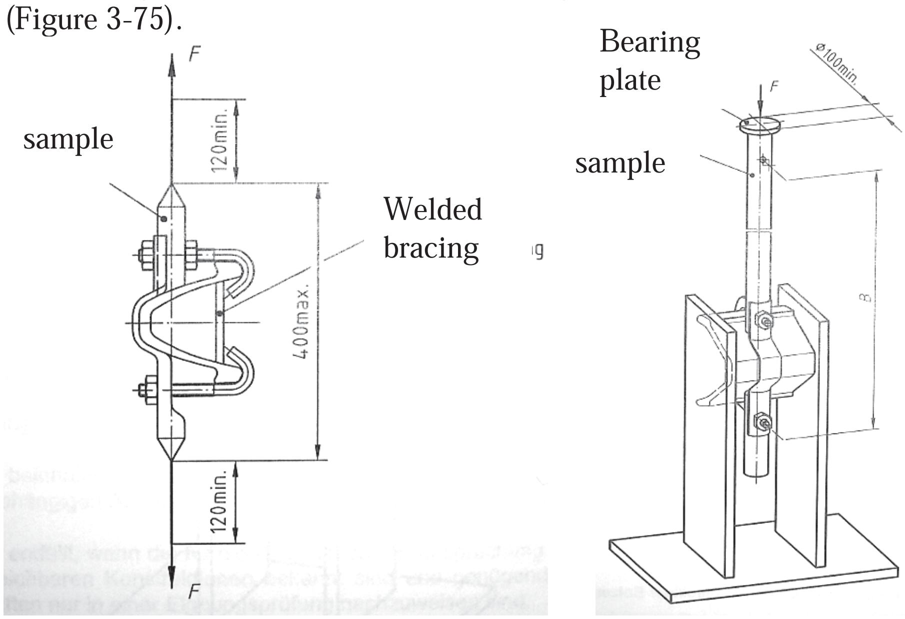


Figure 3-75 Tests of bolting (DIN 21530-4)

The test is performed to determine mechanical specific values of open or closed sliding roadway arches under external loading.

The arch is installed according to the manufacturer's recommendations. A displacement, as it is supposed to occur during usage of the support, is impressed onto the arch. Boundary conditions shall ensure a realistic simulation of the in-situ loading situation.

The testing facility comprises an uniform deformation of the support, parallel and normal to the stratification.

The forces are applied via load application elements of 200 mm width, mounted radial respectively vertical to the tangent of the support.

Number and position of these elements are depending on the circumference and weight of the arch as well as of the in-situ way of packed bed.
Load application elements are divided into active and passive ones. Active elements simulate movements of the roof and the side wall as well as the floor (when testing closed arches.)
Passive elements simulate the touch of the arch on rock mass or back-filling. They adjust reaction forces, acting on the surrounding rock.

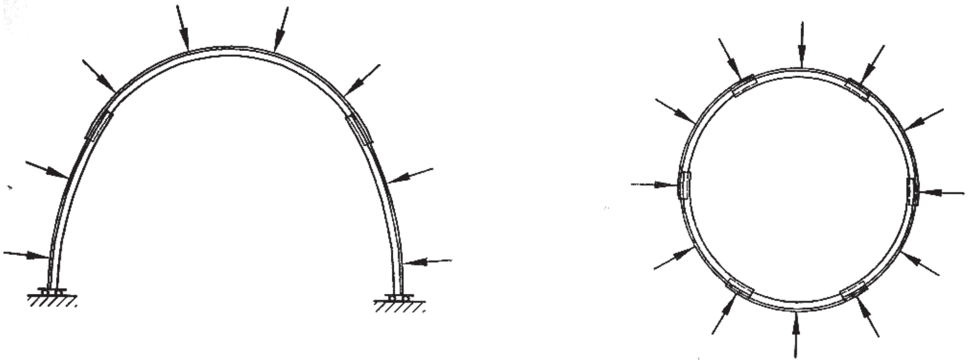


Figure 3-76 Testing arrangement for open (left) and closed (right) arch (DIN 21530-4)

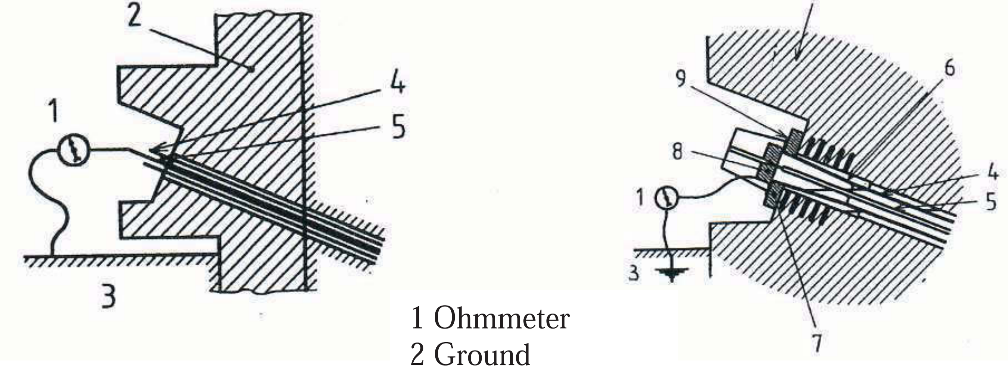
When testing opened arches, rolls on the ends of the support are used as bearings.
The testing procedure runs as follows. The arch is installed including the necessary measuring devices. Before the test starts, the arch is measured (form, position of the load application elements and overlapping). Pre-tension forces in the connecting screws are also measured.
For testing active load application elements are loaded controlled by displacement.
The test is run until failure of the arch (incorrect plastic deformation or breaking) or until end of the insertion.
Forces at load application elements, bearing forces, screw forces, roof height, floor width, floor lift as well as length of overlapping and its change are recorded.

3.1.1.4 Other

In general
Some tests are so specific and unique, that they could not be summed up into one of the previous groups. This group now contains all these tests.

Specific
Corrosion
There are several standards that deal with corrosion protection, i.e. ÖNORM EN 1537, DIN 4125, BS 8081, SIA 191, PTI Recommendations for Prestressed Rock and Soil Anchors, FIP: Recommendations for the Design and Construction of Prestressed Ground Anchorages (Institution of Structural Engineers).
The test conducted by Grimm is based on Electrical-Resistance-Measurement (ERM). (Grimm, 1995)

To test the corrosion protection the ÖNORM EN 1537 suggests electrical resistance measurements. Two types of tests are described, one to test the isolation of the anchor from the ground, the other to measure the isolation of the anchor head from the ground. The basic test assembly is shown in.



1 Ohmmeter
2 Ground
3 Earth
4 Duct
5 Tension member
6 Anchor fantail
7 Washer plate
8 Anchor head
9 Isolation platen

Figure 3-77 Electrical resistance measurements (ÖNORM EN 1537)

Grout penetration, cable bolts

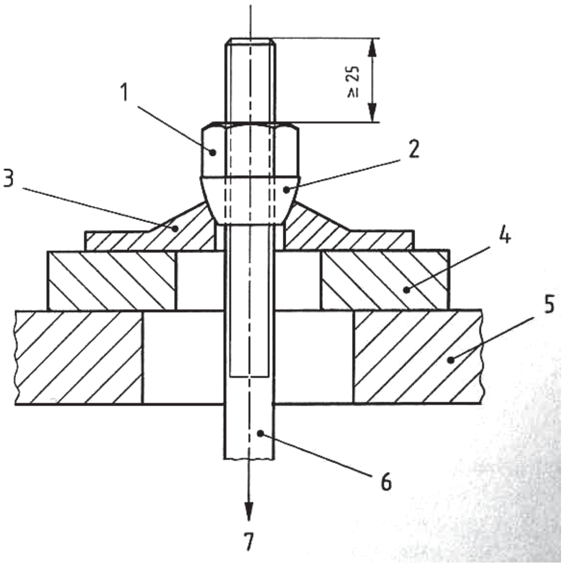
Hyett et al. performed grout penetration tests to obtain the optimal water to cement ratio for cable bolts. Low ratios mean strong grouts and higher bond capacities, but lower flowability. (Hyett et al., 1993)

Tests on support units according to BS 7861-1

The British *BS 7861-1* comprises three testing procedures concerning support units.

During the breakout facility torque test the steel rock bolt and nut assembly is tested by gripping the bolt, attaching a torque meter and rotating the rock bolt with 75 rpm. For GRP rock bolts a uniform load is applied until the nut breaks out in stead of rotating the bolt.

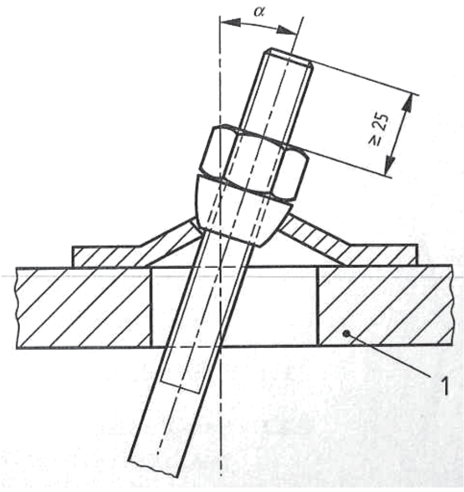
The determination of the failure load of a GRP rock bolt assembly runs by applying an increasing load on the components (as shown in Figure 3-78) and recording the extension.



1 GRP torque nut
2 Conical seat
3 Domed washer plate
4 Backing plate
5 Testing machine platen
6 GRP bolt
7 Applied load

Figure 3-78 Testing of failure load of GRP bolt assembly (BS 7861)

For examining the alignment of conical seat and domed washer plate the maximum misalignment tolerance of the assembly (Figure 3-79) is measured with an inclinometer.



1 support plate

Figure 3-79 Alignment test (BS 7861)

3.1.1.5 Shotcrete

In his doctoral thesis, Lars Malmgren sums up several documents, dealing with shotcrete. Objective of the thesis was to study the interaction between shotcrete and rock. Therefore a number of laboratory and field tests were performed. These comprised tests on strength, toughness and stiffness of fibre reinforced shotcrete, laboratory tests on shotcrete-Rock Joints in Direct Shear, Tension and Compression, tests of Adhesion strength and shrinkage of shotcrete and a study of the Behaviour of shotcrete supported rock wedges subjected to blast-induced vibrations. (Malmgren, 2005)

3.1.2 Dynamic

3.1.2.1 Drop facilities

In general

Support units can be tested as well as support systems under dynamic loading. This tests are performed in laboratories, needing special design drop facilities. Some of this facilities may be used for different support types. They are very unique. A drop facility consists of some kind of steel frame, comprising a drop weight, that causes an impact on the installed support. Another possibility to load the specimen is to install it in a mass and drop the hole unit down.

The different facilities are described in the following section including sketches or photos.

Specific

ASTM D7401

This standard suggests a drop and a pull test.

> *"A rock anchor is installed in a steel pipe instead of a borehole the same manner and in the same material as its intended use. In the Pull test, the rock anchor is hydraulically pulled horizontally and the displacement of the bolt head is measured concurrently. The bolt is pulled until the anchor system fails (or to the ultimate stroke of the ram). The ultimate and working capacity of the rock anchor is calculated from the plot of load versus displacement. In the Drop test, a known mass is released vertically impacting on a plate at a preset distance that is in turn affixed to the end of a rock anchor. The maximum energy is expressed in kJ."*

Momentum transfer concept

Player, Villaescusa and Thompson (2004) presented in their report 'Dynamic testing of rock reinforcement using the momentum transfer concept' a dynamic testing facility for reinforcement systems. The schematic test arrangement is shown in Figure 3-80.

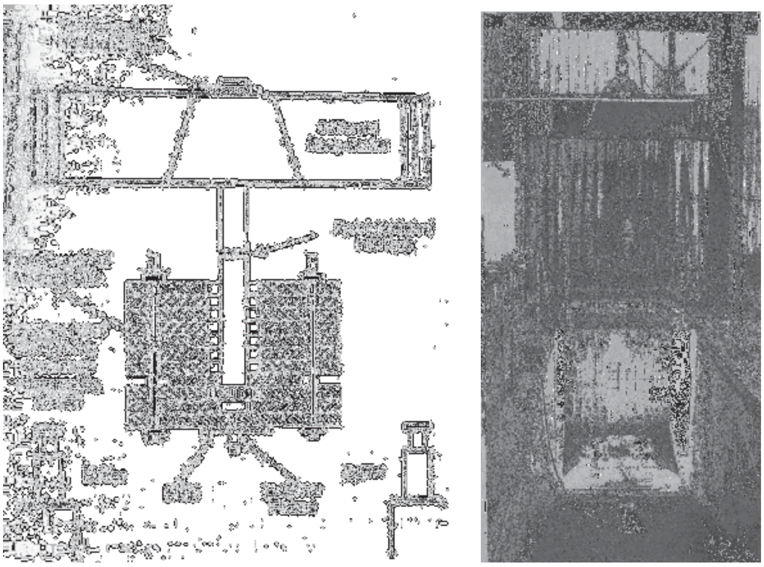


Figure 3-80 Test facility (Player, Villaescusa and Thompson, 2004)

To achieve an equal velocity of all components they are dropped as one unit.

> *"Tests have a high level of instrumentation to measure forces and displacements combined with digital video recording. Analysis of these data allow the calculation of energy absorbed form the force displacement curves of the tested system and the impact point in the facility."*

Thompson, Player and Villaescusa (2004) stated in a further document 'Simulation and analysis of dynamically loaded reinforcement systems'. The test facility for support systems is shown in Figure 3-80.

The three major components are reinforcement system, collar zone and anchor zone.

In the field, the latter two components correspond to a detached block of rock and stable rock, respectively. The test facility attempts to simulate the loading on the reinforcement within and between these two zones.

> *"All reinforcement systems are contained within two abutting steel pipes. The lower, collar pipe simulates the collar zone of the reinforcement system and the upper, anchor pipe simulates the anchor zone."*
>
> *"The collar zone consists of the collar pipe and a welded steel flange to which the loading mass (comprising a number of separate steel plates) is clamped. The reinforcement system plate is clamped between the loading mass and the external fixture."*
>
> *"The anchor zone comprises a deep, stiffened steel beam to which the anchor pipe is connected. The reinforcement system transfers load from the collar pipe to the anchor pipe. The anchor zone behaviour is directly affected by the beam impact surface. Initially, commercially available hydraulic buffers were selected to protect the concrete foundations during commissioning of the test facility. [...] It is also possible to replace the buffers with other devices that have different responses to impact."*
>
> *"A test involves dropping the beam, reinforcement system and loading mass from a known height to impact on the buffers. After the initial impact, the combined beam and buffers comprise the anchor zone."*
>
> *"In order to quantify the behaviour of the complete testing facility, and in particular the reinforcement response, measurements are made at various locations on the components of the testing facility."*

Forces are recorded by electronic load cells, displacements by motion sensor and post processing of a high speed digital video camera, accelerations by accelerometers and strains by strain gauges.

Ortlepp and Stacy, 1998

Ortlepp developed this testing facility on basis, that rock bolts due to a rockburst were loaded on a distinct length with high kinetic energy. To gain a higher velocity than other dynamic testing rigs, this facility has a drop mass and a swivel bracket. For full grouted bolts the borehole is simulated by two steel cylinders, for friction bolts two half-pipes, that are clamped together, are used. For friction purposes a fine and hard cement is put into the pipes.

The fall mass (1048 or 2706 kg) is dropped on a beam, to load a distinct value of energy on the lower borehole.

To measure the velocity, a special 'gravity-driven cylindrical chart recorder' and a speed probe are used.

Gaudreau, Aubertin and Simon, 2004

Scope of the research was to evaluate tendon support performance in impact loading for the modified cone bolt (MCB).

Preliminary to the drop tests, pull-out tests were conducted.

The testing rig comprises a cyclic drop mass of 1 ton, falling from 2 m. When released, the mass hits a absorption plate, connected to the installed bolt.

Two load cells, one on top of the bolt and the other under the absorption plate, as well as a deformation sensor constitute the measuring instruments.

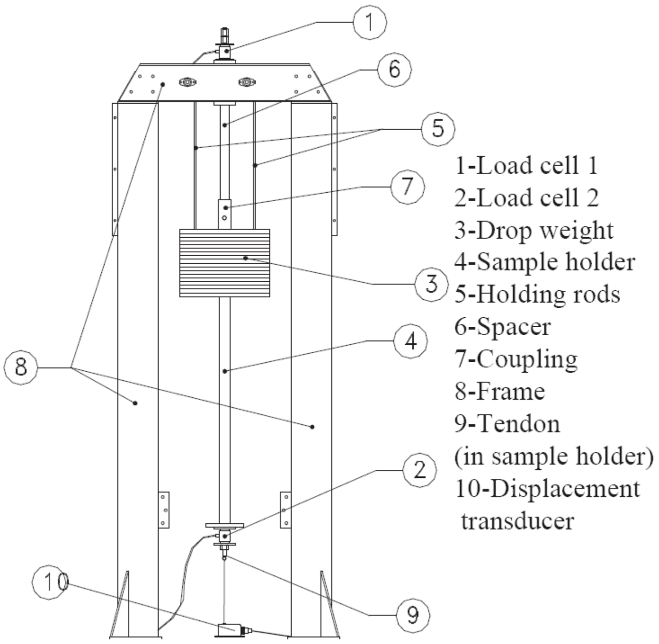


Figure 3-81 NTC Impact Testing rig schemata (Gaudreau, Aubertin and Simon, 2004)

Ansell, 2005

Ansell created dynamic loading by dropping the hole specimen of a distinct high. The specimen consists of a steel rock bolt, inserted into a cardboard pipe. This pipe is filled with concrete, simulating grouting.

The rock bolt is pulled up and by releasing a pneumatic hook, the hole system falls free. Two steel beams catch the specimen and so load the energy through the head of the rock bolt into the rock bolt-cement bond.

Before the testing, the bolt is marked in distinct spacing, to evaluate the deformation afterwards.

SRK

The testing facility from SRK uses a drop-weight to simulate a rockburst. The test section is life-sized and loaded by dropping the weight onto a load distribution pyramid, that also simulates the surrounding rock mass.

This imparts a damping effect, due to the surrounding fractured rock

> "*between the exposed surface of the tunnel walls and an interface or inter-zone of stable rock mass beyond the fractured rock, which would not become part of the intensely damaged region.*
>
> *It attempts to provide 'boundary conditions' (edge restraints) to the cladding or containment that recognises that the test portion is part of a surface that extends for some distance beyond in all directions in the plane of the containment support. In other words, it is a surface that possesses in-plane continuity parallel to, and transverse to, the axis of the tunnel.*
>
> *It allows variability in spacing, lengths, stiffnesses and mobility of the tendons supporting the mesh, and close simulation of the connection arrangements (e.g. washer plates, strapping) between retention elements and containing elements.*
>
> *[...]*
>
> *[The facility comprises] load cells an accelerometers and [a] test panel, [...] supported by four or six yielding bolts depending on the configuration of lacing of strapping elements that is to be used. [...] The edges of the test panel were constrained to move only vertically. the boundary condition that is represented was thus one where in-plane tensile forces generated by the stay ropes represented the in-plane strength continuity of the stronger elements of the containment support such as the lacing or straps, if such were used, plus the relatively low strength of the mesh itself. it can thus be reasonably argued that the tested panel was representative of any portion of the system supporting any section of the tunnel roof (or sidewall).*
>
> *However, there is no way that a similar claim may be made that the impulsive loading imposed on the test section represented a damage mechanism that was uniformly active over a relatively large area. Even though considerable thought was given to the construction of the load-distribution pyramid, it was soon apparent that is was quite impracticable to obtain a uniformly distributed impulsive load using a single drip-weight.*"

(Ortlepp and Swart, 2007)

Terratek

The facility comprises a hydraulic system to pull the collar of a shortened bolt or push the top end of a prop.

Rockbolts are loaded through tension or shear, to assess the performance of the reinforcing unit or the anchor mechanism of the system. The facility is able to apply loads with 30 mm/min.

Displacement, piston velocity and force are measured.

This facility, however, cannot test reinforcement systems. (Hadjigeorgiou and Potvin, 2007)

The Dynamic Membrane Test (SRK)

The test facility is shown in Figure 3-71. This testing facility covers a dynamic and a quasi-static arrangement. The testing procedure is similar to the INCO/GRC Membrane Test Method (described above).
(c.f. Spearing and Champa, 2000)

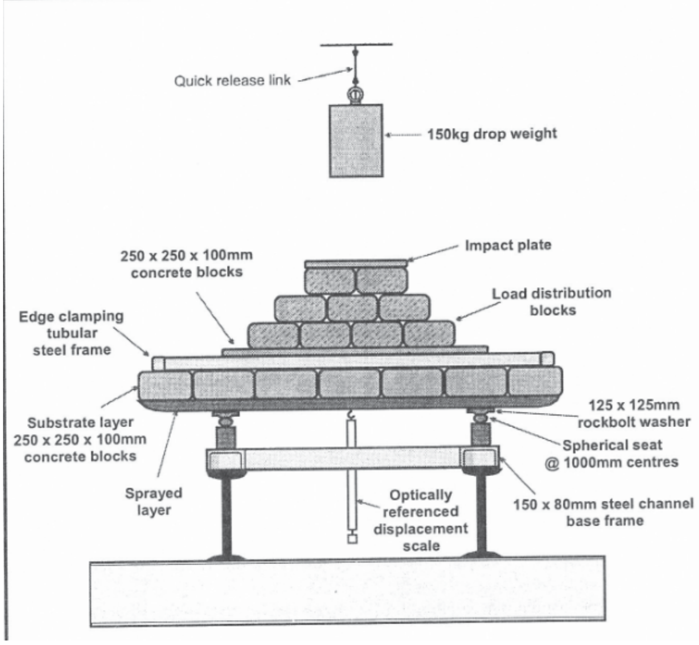


Figure 3-82 Dynamic test arrangement of INCO (Spearing and Champa, 2000)

The WASM dynamic testing rig

The maximum energy and testing velocity is 36 kJ or 6 m/s, respectively. The facility comprises two steel cylinders in which the rock bolt to be tested is installed. In contrast to the CANMET testing rig, the fall mass target is the lower cylinder. This procedure is more similar to the loading of a in-situ rock bolt. (The rig is shown in Figure 3-80) (Li, 2008)

Dynamic Impact Drop Test Procedure at CANMET

> *"Each test consists of dropping a known mass from a known height onto a plate connected to a bolt specimen grouted inside an installation steel tube. The energy input in the system is controlled by the drop mass and height used during the test. The drop height can vary from 0.0 to 2.1 m (2.4 m if removing the bottom load cell from the testing set-up). The testing rig in its actual configuration has a rated capacity of 3 tons from a height of 2 meters, for a maximum energy of 58.8 kJ.[**Figure 3-83**]"*

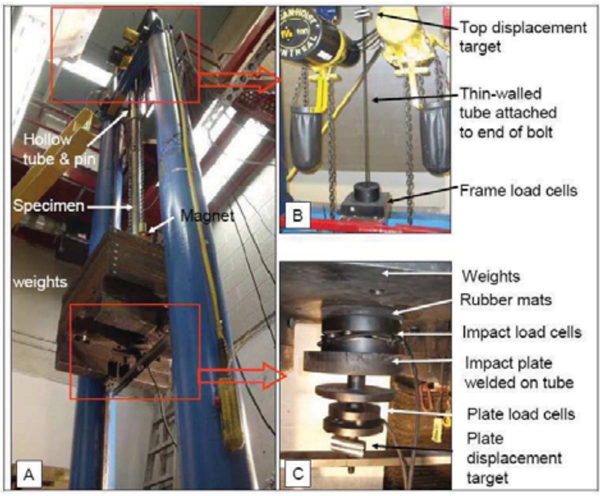


Figure 3-83 Details of the dynamic testing rig including instrumentation: General view (A), Top view (B), and Bottom view (C)

> *"For this test program, a minimum weight and height of 2452 kg and 1.3 m, respectively, will be used to generate an impact of 30 kJ with a velocity of 5 m/s. It may be needed to increase these parameters in order to determine the ultimate capacity of the bolt, if required by the client. The weight is lifted with an electromagnet, which in turn is lifted by two cranes mounted in parallel on the top of the testing rig [...]. By turning off the power of the magnet, the weight falls freely onto the test specimen. The selected weight is composed of a series of individual steel plates bolted together to reach the predetermined weight specified for the test. The installation tube bearing the test specimen is inserted through the center of the magnet and steel plates [...]. The top end of the installation tube is inserted into a larger tube fixed to the top of the testing rig (transverse-beam). A 25.4 mm pin locks the installation tube into the bigger (holding) tube, through holes drilled in both tubes to allow the connection. The magnet is then lowered down on top of the weight. The weight is attached directly to the cranes to allow its handling and lifting. Once the weight is in holding position, a load cell with a 12 mm-thick impact plate, a rock bolt steel plate, a dome washer and a thread nut are installed on the lower end of the bolt (threaded end) [...]. A target for measuring the displacement of the lower plate assembly is installed at the end of the bolt, on the remaining threaded section. Displacements are measured using linescan cameras. Displacements are also measured at the upper end of the bolt, or test specimen. A rod (thin-wall tube) is passed through the holding tube and the connecting pin (through a small hole drilled in the pin), across the top of the testing rig. The rod is connected to the upper end of the bolt test specimen. A second target is fixed at the top of the rod, between the cranes, to measure the displacement of the upper end of the bolt [...]. System lights are turned on to provide sufficient lighting for linescan cameras (for lower and upper targets). Cameras are calibrated against known targets (black and white layered plates with a fixed distance between layers). Following the calibration, the weight and resting magnet are lowered down onto the impact plate. Crane chains are moved from the weight to the magnet. The data acquisition system is started. The weight is lifted to the predetermined test height (measured with a potentiometer similar to those used for static tests, but with a longer stroke). Once all instrumentation is set in place, and both weight and data acquisition system have stabilized, the operator turns off the magnet switch to release (drop) the weight. Instrumentation Overall instrumentation consists of lower plate and upper end targets installed on the bolt test specimen, and linescan cameras to measure displacements, and load cells inserted within the test system to measure loads at both ends of the bolt specimen, and/or at an intermediate distance along the specimen if needed. A linear*

> *potentiometer is attached to the weight, to adjust the drop height. All instruments are verified at the beginning of each test, and re-calibrated if required."*

(Doucet, 2010)

MIRARCO impact test

The object is to conduct impact tests on full size screens.

> *"A large circular mass (up to 565 kg) with a diameter of 600 mm is dropped, using an electro-magnetic release mechanism, from heights of 0.25 to 3 metres onto full-size mesh panels. Load distribution is through the use of hexagonal concrete blocks onto the mesh in the impact area. Load cells at each of the four interior columns record the resulting impact and the downward deflection of the mesh at its centre is monitored using a displacement measuring rotary potentiometer (in retraction mode). The movement of the drop weight is measured using a velocity transducer."*

(Hadjigeorgiou and Potvin, 2007)

Rock bolts testing under dynamic conditions at **CANMET-MMSL**

Plouffe, Anderson and Judge (2008) state in their report the following.

> *"A high-strength concrete holding tube was developed to simulate the rock mass while testing friction bolts, where steel tubes were clearly not appropriate.[...]*
> *Since its move to CANMET-MMSL, the dynamic testing rig was greatly modified. The height of drop of the mass can reach up to 2.1 m. The drop test rig has a present capacity of 3 Tons from a height of 2 m. Thus, the maximum energy available and the maximum impact velocity that each drop can reach are 62 kJ and 6.5 m/s, respectively. Thus, with these latest modifications, CANMET-MMSL possess a world-class dynamic testing facility [Figure 3-84] and are continually investing in, developing and expanding the capabilities of the facility."*

Figure 3-84 CANMET-MMSL testing rig (Plouffe, Anderson and Judge, 2008)

> *"The latest changes were related to the instrumentation used to measure the loads and the displacements. These parameters are usually measured at the plate and at the*

end of the simulated borehole. The displacements are measured using Dalsa SP-14-02K40 linescan cameras. The cameras are sampled at 10,000 lines per second to match the sampling of the analog signals. The lines are amalgamated to form an image of distance vs. time. The location of black and white targets, attached to the plate nut or to the bolt end, is detected within the image. The loads are measured using arrays of four PCB 205C/FCS-5 ICP piezoelectric force sensors, sandwiched between two platen rings [Figure 3-85].

Manual measurements of the displacements are recorded before and after the test to verify the electronic data."

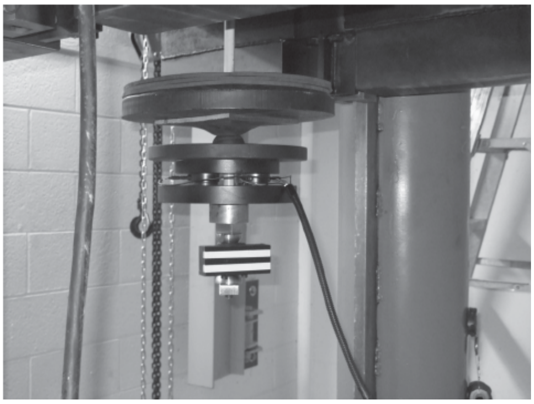
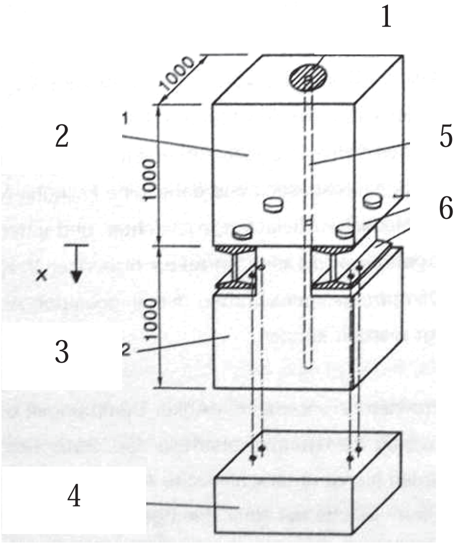


Figure 3-85 Displacement target and load cells at the plate (Plouffe, Anderson and Judge, 2008)

Dynamic testing at DMT



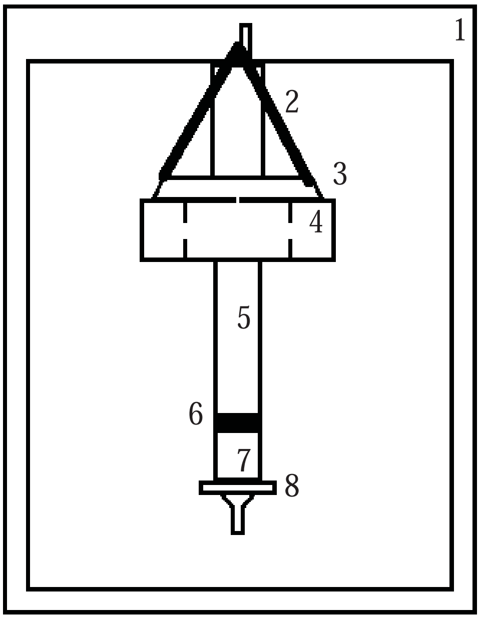
1 bolt head and bearing plate
2 upper concrete block
3 lower concrete block
4 additional load
5 fully grouted anchor
6 load cells

Figure 3-86 Schematic test arrangement of DMT

The testing rig, shown in Figure 3-86, shall test real-size, fully grouted bolt under rockbursts. The upper half of the concrete block simulates a stable rock mass. The lower half is loaded with extra masses, but blocked in the beginning. Starting the test means to loosen the clogging of the lower concrete half. Due to that a sudden additional loading bears the bolt.

Monitoring equipment comprises four load cells and a special designed strain gauge. (Witthaus and Müller, 1995)

Charette, 2007



1 Frame of the testing machine
2 Steel cable sling and hook to move weight to desired height
3 Electro-magnet for holding and releasing the weight
4 Moving weight for impact
5 Top pipe anchored on frame at top
6 Separation plane
7 Bottom pipe on which impacting plate is welded
8 Impacting plate

Figure 3-87 Testing arrangement for impact loading of Swellex rockbolts (cf. Charette, 2007)

The testing rig, shown in Figure 3-87 is used to simulate the action of seismic events.

The test used two steel pipes, one holding the bolt, the other generating friction above the plate assembly to damp the impact.

This configuration was decided due to field observations and should create a load caused by friction additional to the bushing capacity. However, the friction obtained could not create failure to the bolt.

The basic principle of the testing procedure is to lift and drop the falling mass over the bolt by turning on and off a electromagnet. This activity is repeated until failure or sliding of the bolt inside the tube.

(Charette, 2007)

GRC weight drop test

The apparatus was build to test small steel rods with cushions, using scaled down bolts.

The object was to demonstrate the influence of multiple impact loading.

(Hadjigeorgiou and Potvin, 2007)

3.1.2.2 Laboratory tests on core

In general
Hadjgeorgiou and Potvin (2007) stated that there are three types of dynamic tests for support systems. Drop facilities have been discussed in the previous chapter and simulated rockbursts will be described in the last chapter.
The last type of dynamic tests are laboratory tests on cores. They rely on acoustic emission record during failure and can be used to study liners. The advantages of these tests are that the environment is controlled and the set-up is rather inexpensive. The disadvantages are, however, that the loading mechanism is questionable, the scale is not representative and only one unit component can be tested.

3.2 Support system

3.2.1 Static

Modelling and field verification of roof-bolt systems
The load frame shown in Figure 3-88 is used for laboratory tests to verify FEM analysis. Roof plates or pillars and polyethylene layers in between (for a determined coefficient of friction), cement grout to simulate shale. A structural steel reaction frame surrounds the concrete and supports a servo controlled hydraulic loading system. The hydraulic cylinders apply a load, that is spread over the surface by means of rubber-faced steel loading pads.
Several parameters are measured, namely strain (in bolts), total load on plates and pillars, slip between the plates, temperature, moment of the model and entry closure. (Bolstad, Hill and Karhnak, 1983)

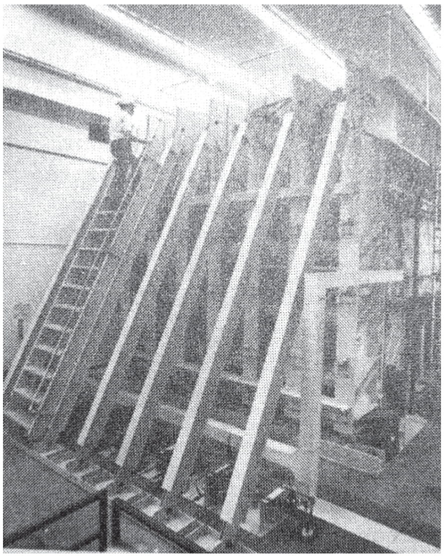


Figure 3-88 Full-scale load frame surrounding model (Bolstad, Hill and Karhnak, 1983)

Despite tensile and shear test, also compressive test can give valuable information about the performance of the support unit. They, however, seem to be not used very often. The following two test descriptions deal with those compressive tests.

Tinceling and Sinou, 1980

Specimens are loaded with a compressive force, without binding stress. Samples, that fractured, but remained in their state, are assembled with bolts. Figure 3-89 shows an example. Thereafter the specimen are conducted a further compression test.

There is a relation between the elongation of the steel and the elongation of the bolt.

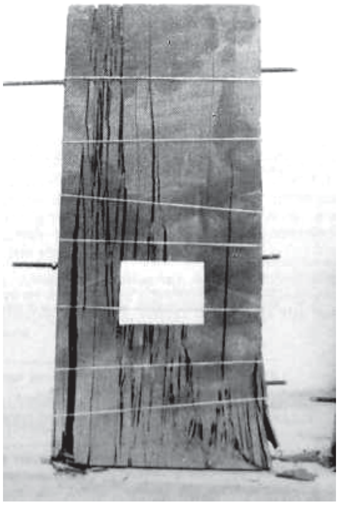


Figure 3-89 Compressed and bolted rock sample (Tinceling and Sinou, 1980)

Wullschläger and Natau, 1983

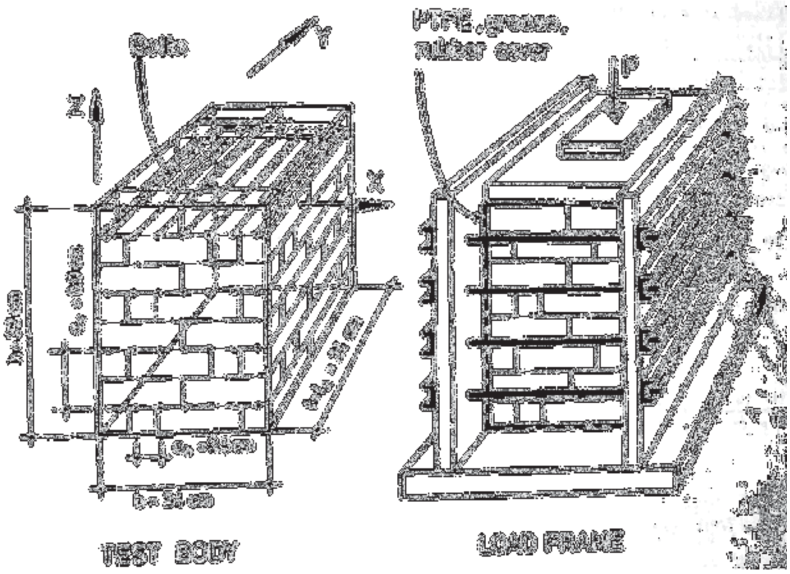


Figure 3-90 Test facility (Wullschläger and Natau, 1983)

They did some studies concerning the support system of rock mass and non-pre-stressed rock bolts. For their experiments they used a special test frame for uniaxial compression tests shown in Figure 3-90. Due to this testing rig the influence of bolt density can be approved.

ISRM - Suggested Methods for Rock Anchorage testing (ISRM; 2007d)

Two methods described are the co-axial loading, when surrounded rock mass is not allowed to fail, and the remote loading to evaluate strength of anchorage plus surrounding rock.

For the co-axial loading method the surrounding rock is used as bearing surface, therefore rock movement or failure cannot be tested.

For the remote loading method rock mass failure is possible. The reaction loads are applied via beam or grillage to the ground surface; the distance between the reaction points allow rock mass failure, if the rock is weaker than the tendon or the bond. Surcharge by overburden - if necessary - should not be ignored.

Equipment: tools and material for surface preparation, loading and load measuring equipment (hydraulic jack, bearing plates, wedges, shims, spherical seating), hydraulic pumps, hydraulic gauges (or load cells), measuring anchorage movement (equipment that will permit measurement of movement of the anchor head in a direction co-axial with the tendon with reference to a stable datum, such as rock remote from the anchor head, load cells, steel rule for jack ram extension measurement)

Procedure: calibration, test surface preparation, setting up the extension measuring system, testing, graph plotting, calculations

A general test procedure is suggested, modification may be made if required for a particular site.

The document gives advices how to apply, hold and record load. It differs between design test (are undertaken before the installation of working anchorages; provide criteria to substantiate the design parameters used and to define acceptable performance of service anchorages during proof testing) and proof test (carried out on all working anchorages, can employ procedure similar to design tests, but are generally abbreviated and much simpler).

> *"Check-lifting. Check-lifting is the technique of using the stressing jack straddling over the stressing head to lift it clear of its distribution plate to record the tendon load with the jack pressure gauge or load cell. The distance the anchor head is raised, normally 1mm, although this may be as low as 0.1 mm, should be fixed and the method of measurement should ensure that all sides of the stressing head are clear of the distribution plate.*
>
> *When a stressing operation is the start point for future time-related measurements, the stressing operation should be conclude with a check-lift load measurement, following the exact procedure to be used for subsequent check-lifts in order to minimize operational error.*
>
> *Unit stressing. The procedure for stressing multiunit tendons using a number of hydraulically synchronized monojacks or individual monojacks, should allow for the fact that, when stressing is carried out using an individual monojack ,the possible change in load in adjacent tendon units should be appreciated. Such load changes generally result form frictional forced between adjacent units in the free length and from the permanent displacement of the fixed anchor grout during loading. These effects can be reduce by application of small load increments and can generally be eliminated by repeat application of lead, unless permanent displacement is*

> *continuous. At any time, the load in each individual tendon unit can be measured by a lift-off check.*
>
> *For anchorages that have failed a proof load criterion, some additional tendon unit stressing may help to ascertain location of failure, e.g. for a temporary anchorage, pull-out of individual rents on units may indicate deboning at the grout/tendon interface; whereas, if all tension units hold their individual proof loads, attention is directed towards failure of the fixed anchor at the ground/grout interface."*

Khair, 1983

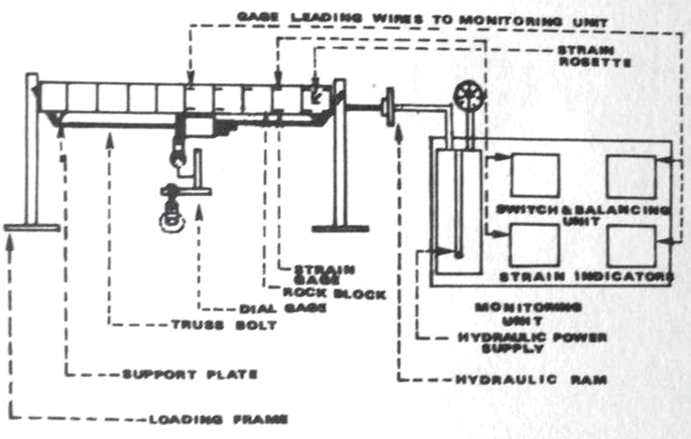


Figure 3-91 Schemata of the physical model (Khair, 1983)

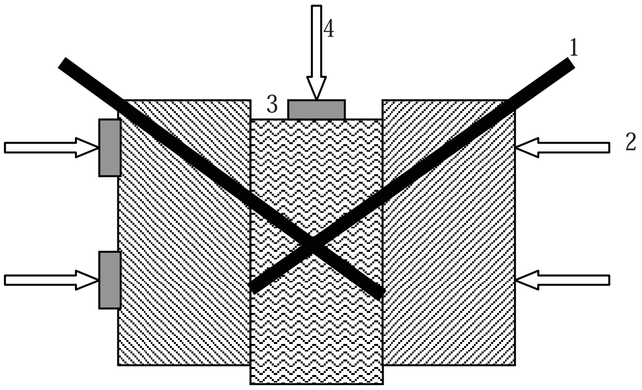
Figure 3-92 Photo of the model (Khair, 1983)

A discrete model of ten blocks shall simulate fractured roof. It is loaded in a loading frame, shown in Figure 3-91 and Figure 3-92. Some of the installed bolts are instrumented with resistance type strain gages at the corner of the blocks. The end of the block was instrumented with a strain gage rosette at centre. The truss bolt is instrumented with the same gauges at three locations on each end to measure strains and tension in the bolt. The pressure on the truss bolt support plate is recorded by a pressure cell, inserted between the support plate and rock block. Two different types of tests were conducted. After lowering of the blocks and balancing of the gauges, the load was applied incrementally. At each loading stage the output of the strain gages and the divergence of the centre of the beam are recorded

Witthaus, 1995
Through the convergence of the rock mass an interference to the deformation of the rock bolts can be made.

Wittenberg, 1998
To monitor the underground rock bolt support, convergence measurements, by means of extensometers (tell-tales) and borehole endoscopes were used, during design tests.

Grasselli, 2005



1 rock bolt
2 normal force
3 load cells
4 vertical force

Figure 3-93 Test facility (Grasselli, 2005)

A test to determine the shear behaviour of differently inclined, bolted joints is performed. Two rock bolts are installed symmetrically into the test block (1x0.6x0.6 m), that consists of three concrete blocks with smooth shear zones, to reduce friction and dilatation.
Rock bolts can be installed with 0, 15, 30 or 45° inclination to the horizontal. Normal stress on the testing system by means of a pre-tensioned steel frame shall comprise constant normal stiffness of the system.
The block in the middle is loaded with a vertical load to create a shear force. Shear force, normal force, vertical displacement and deformation of the rock bolt is recorded. All rock bolt types, but Swellex, are instrumented with five strain gauges.

Bäckblom, 2009
Field observations suggest, that a bolt plate can "*indicate load on the bolt as load is transferred to the plate when the opening deforms.*" This can be achieved by using load cells. There have been discussions [...] to develop an integrated bolt plate sensor for testing semi-static and dynamic load measurements.

3.2.2 Dynamic

In general

There are several dynamic testing facilities with the same basic principle for bolt testing, located in Canada, Australia and South Africa.

The dynamic loading is simulated by dropping a weight onto a support tendon installed in an artificial borehole, usually drilled in thick wall steel cylinders. The weight either hits on the lower cylinder or in the washer of the bolt.

Special

Buckling Plate tests

This test aims to evaluate large deformations, particular for TSL and shotcrete, in form of blast simulations.

The test suggested, that it is not possible to achieve rock displacement, only caused by shock energy, not by the gas development from the blast. Due to this a laboratory-scale failure test was developed. The testing arrangement consists of thin plates of rock, predestined to buckling failure, shown in Figure 3-94. Load and deformation are recorded.

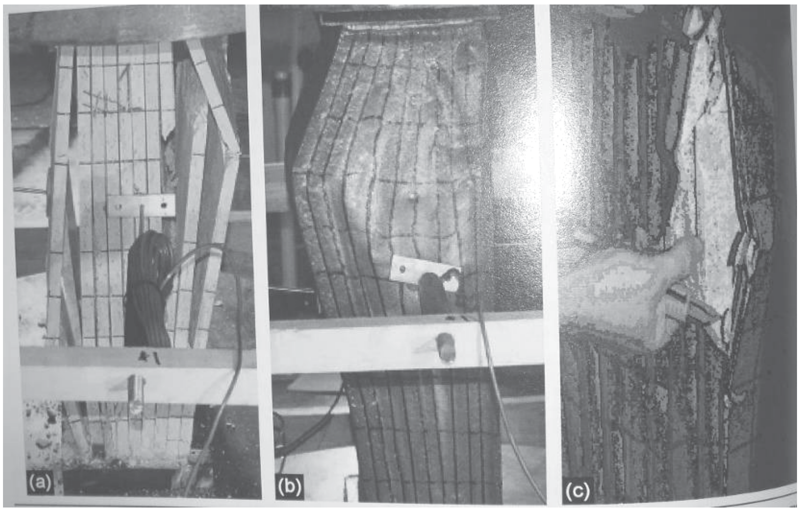
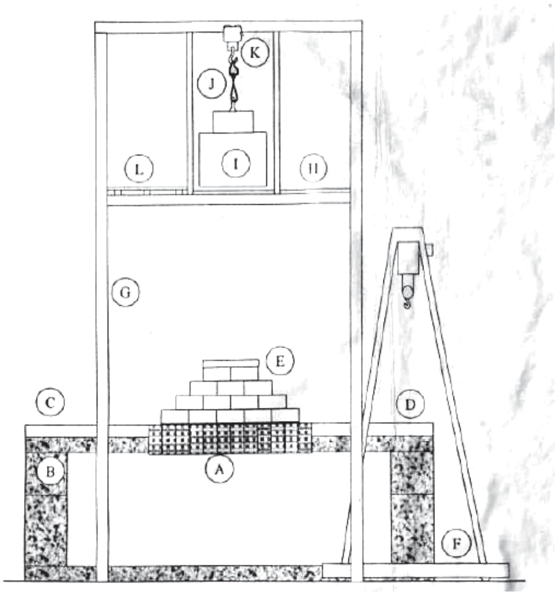


Figure 3-94 Buckling Plate tests

(Swan et al., 2007)

The SIMRAC dynamic testing rig



A Collapsible roof
B Corner column
C Deck
D Slide beam
E Load distribution pyramid
F Portal crane
G Main support column
H Floor
I Drop weight
J Quick release shackle
K 10 t hoist
L Berthing platform for drop weight

Figure 3-95 The SIMRAC dynamic testing rig (Li, 2008)

The testing rig is able to perform tests on bolts and on surface support systems, like shotcrete panels or props.

Figure 3-96 SIMRAC dynamic testing rig (Li, 2008)

The testing rig comprises a simulated fractured hanging wall and a fall mass to cause a dynamic impact. The load is distributed by a load distribution pyramid onto the simulated underground area.
The facility is able to create a kinetic energy impulse of 294 kJ with an impact velocity of 7.67 m/s. The measuring devices cover a dumpy level survey instrumented reference target, for observing the vertical displacement by means of tapes.
(Human and Ortlepp, 2007)

Ortlepp and Stacy, 1998

They stated in their document 'Dynamic testing of tunnel support' the following.

> *"A combination of rockbolts, wire mesh and shotcrete is commonly used for the support of underground excavations. The capacity of these elements to contain the rock, particularly under dynamic loading, is not well known. A research program shall test the capacity of various types of containment support under simulated rockbursts loading. The following types of support will be tested: welded wire mesh, chain link wire mesh, Various types of wire mesh with wire rope lacing, and Wire mesh reinforced shotcrete and fibre reinforced shotcrete.*
> *The dynamic loading is imposed by means of a free fall drop weight. Impact velocities of up to 8 m/s and input energies of up to 80 kJ are used in the testing.*
> *Test facility*
> *A 2x2 m^2 area of wire mesh was used, supported by four rockbolts spaced 1m apart. The central 1 m^2 area would effectively be subjected to the dynamic loading*
> *The mesh was attached to a flexible steel frame, and the effective area of the mesh was extended by holding the frame back to remote points using appropriately tensioned wire ropes.*
> *The rock mass was simulated with three layers of packed concrete blocks in direct contact with the mesh*
> *The load distribution system consisted of a thick steel impact plate and a three layer pyramid of steel-encased concrete blocks, and*
> *The rockbolt support system allowed for yield"*

The constructed test facility is shown in Figure 3-97.

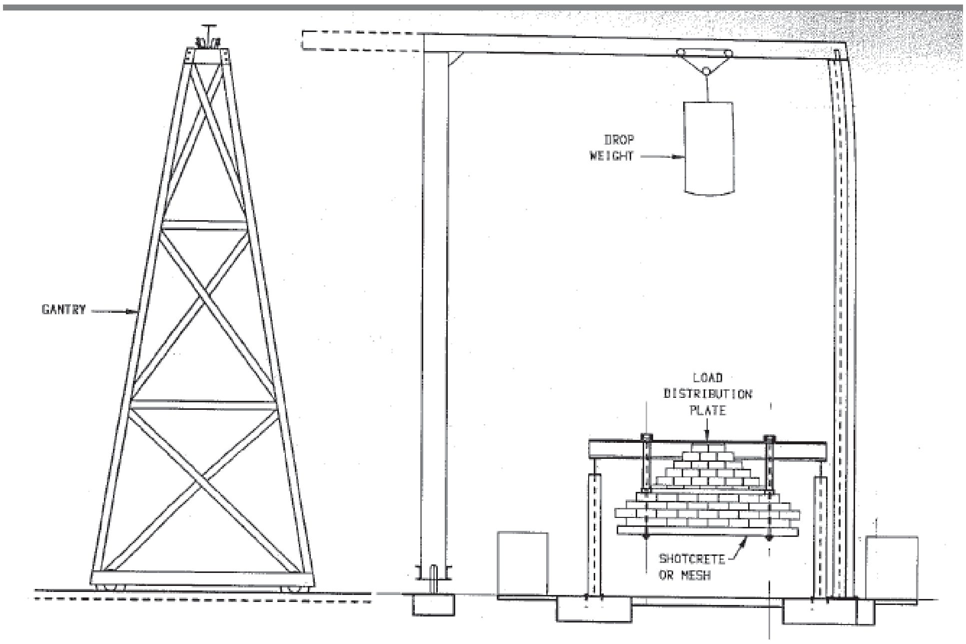


Figure 3-97 the test facility (Ortlepp and Stacey, 1998)

> *"The facility has the following features:*
> *The "sample" is hung from support beams by four rockbolts.*
> *Anchors grouted into the ground surface provide points of attachment for wire ropes which provide effective extension of the boundary conditions of the test.*
> *Dynamic loading is provided by a drop weight. Three drop weights, with masses of 650kg 1050 kg and 2700 kg respectively were available.*
> *The maximum impact velocity of 8.10 m/s is possible, corresponding with a drop height of 3.3 m and a maximum energy input of 21.5 kJ/m^2 is possible with the drop weight used in the tests."*

SRK drop weight test facility

The object is to determine the performance characteristics of surface support systems (like wire mesh, lacing, shotcrete) under dynamic loading.

The loading energy is 70 kJ, with 8 m/s impact velocity. That is supposed to be representative for severe rockbursts.

Two configurations can be used. The facility is shown in Figure 3-97.

The drop weight, comprising 1048 or 2706 kg, is dropped onto the load-distribution system-which then loads the surface support systems.

> *"In practice, a load distribution pyramid of steel-enclosed concrete blocks was applied on a "simulated rockmass". The upper layers and lowest layer of blocks are restrained to preventing spreading. This is to maintain load transfer to the lower block and support element. This rock mass consists of concrete blocks that are in contact with the support. The support sample is hung form support beams using 22 mm diameter cone bolts. The choice of cone bolts was made in order to ensure that failure of bolts did not occur during tests. This was necessary given the objective to determine the performance of containment support systems. The drop weight test facility could test "panels" of 1.6 x 1.6 m. The test facility was designed to be capable of input energies up to 70kJ and with impact loading velocities up to 8 m/s. Instrumentation was limited to direct tape measurements in elevation, still photographs (before/after) and video recordings" (Hadjigeorgiou and Potvin, 2007)*

Ortlepp and Stacy made several modifications of the facility.

SRK/Duraset wedge-block loading device

The facility employs a 30 kJ drop weight in the SIMRAC stope support test facility.

The test is performed for testing long cables.

> *"The wedge-block loading device consists of two guided thrust blocks with inclined faces, with a wedge driving them apart. The wedge converts vertical displacement into horizontal displacement. As the test-piece is supported in the horizontal position it is possible to test bolts longer than 5 m. The hollow bar from which the specimen holder is made has an outside diameter of 80 mm and an inside diameter of 50 mm. This is considered to adequately represent the compressibility of the partly-relaxed rock surrounding a hard rock excavation. The mass of the drop weight is 10000 kg. The height of the drop can be varied between 0.4 to 4 m. maximum energy available is about 390 kJ when the weight falls from a height of 4 m to generate an impact velocity of 8.9 m/s. Electronic monitoring devices record the very rapid loads and displacements on the bolts providing for measure of the energy consumed during the test or at breakpoint" (Hadjigeorgiou and Potvin, 2007)*

GRC Support element test facility

The facility comprises a drop test to test shotcrete (bolt/mesh reinforced) under impact loads performed as direct impact onto the support element.

> *"A series of concrete columns was set up to support mesh and shotcrete panels to be tested, using a drop weight operated by a hoist and release mechanism. The panels rested on support plates anchored to the columns and these could be tensioned from above. Load cells were installed between the columns and the lower support plates. The impact of the load was monitored with accelerometers, the load cells, and displacement measuring instruments. The rig had a maximum drop height of 4 m that would imply a potential velocity of 8.8 m/s, with a kinetic energy of 21.9 kJ." (Hadjigeorgiou and Potvin, 2007)*

Ortlepp, 2000

> *"The development project GAP 611 comprised essentially four phases: design, construction, proof testing and a brief programme of testing of actual supports.*
> *The project was driven by the perception that existing support testing equipment could provide only a quality control function. To stimulate development of innovative types of support and support accessories that would overcome some of the limitations of existing systems, required the development and construction of a completely different type of facility. The two most important differences compared with conventional testing procedures would be the provision of a discontinuous roof surface which would be subjected to dynamic loading. [...]*
> *The performance parameters were set at providing an energy impulse of 300kJ with displacement rates of several metres per second.*
> *The impulsive energy would be generated by dropping a mass of 10 000kg from a height of 3 metres to impact at a velocity of 7.7 m/s upon the target 'rock mass'.*
> *The target mass was represented by a discontinuous but compact arrangement of steel-clad concrete blocks which would transmit and disperse the concentrated impact load downward on to a collapsible roof. Carefully designed, shaped concrete blocks would represent the fractured hangingwall layer of the stope, the stability of which would be determined largely by the support system under test. The other determinants of stability would be the energy of the impulse and the initial boundary conditions. The boundary conditions could be varied to some degree. Depending on these conditions and on the areal effectiveness of the support system, the hangingwall layer would have the potential to collapse between support units. [...]*
> *The three full tests on hydraulic props, timber elongates and linked timber elongate systems demonstrated that such testing can provide vital understanding of the behaviour of the support units under dynamic loading. The video-cam monitoring gives unique visual insight into the detailed response of support units to the dynamic forces that operate for a very brief period of time. This is obviously something that would be quite impossible to do in a real underground situation.*
> *The linking of the elongates in the final test gave a most encouraging indication of how the facility can be used as a ' testing ground' for innovative developments. In particular, techniques for preventing collapses between support units and over the work area between the front line of support and the stope face can be explored. [...]"*

Figure 3-98 Testing rig, showing the stope with the drop weight temporarily berthed at the centre of the stope floor (Ortlepp, 2000)

Ortlepp and Swart, 2002

In the GAP 818, the testing facility from the GAP 611 project was upgraded, as can be seen in Figure 3-99.

In order to achieve a more-efficient distribution of the load impulse the load distribution pyramid was made two-dimensional (Figure 3-100).

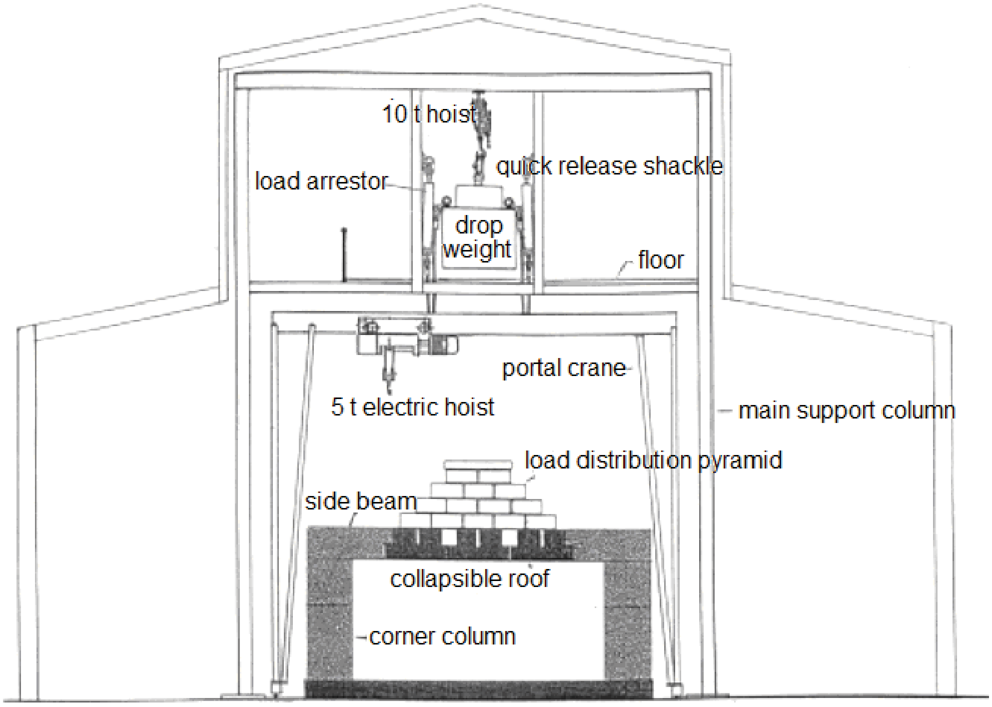
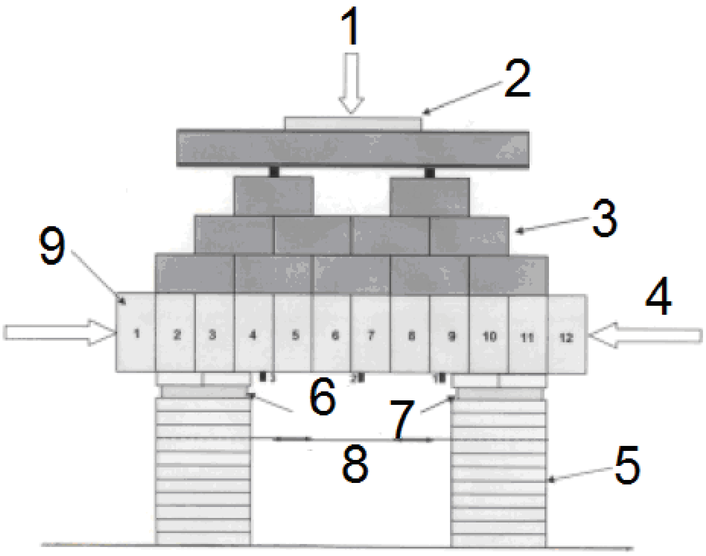


Figure 3-99 Testing rig (cf. Ortlepp and Swart, 2002)



1 Impulse load
2 Strike platen
3 load distribution blocks
4 Chlamping force
5 650 mm* 650mm pack
6 Accelerometers
7 Pre-stressing unit
8 Arrestor device
9 Hangingwall beam

Figure 3-100 Two dimensional pyramid (Ortlepp and Swart, 2002)

3.3 Support system and rock mass

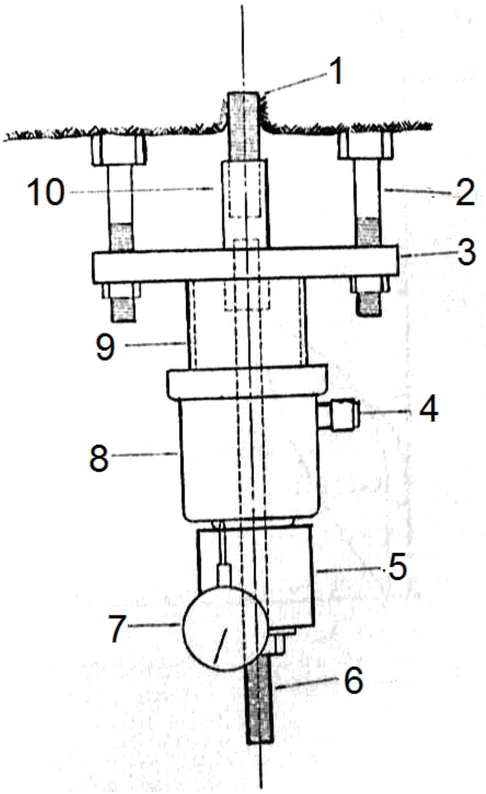
3.3.1 Static

In general
This chapter briefly sums up some in-situ testing methods for support systems and rock masses that are not done by simulated rockbursts.
In-situ pull-out tests investigate the support unit including the rock mass.

Pull-out tests on rock bolts can also be carried out in-situ. These tests than can be used to evaluate rock bolts and rock bolt systems including the rock mass. However, they will not be repeated here, for most of them have been discussed in the chapter 3.1.1.1 Rock bolts.

Special
Instrumented bolts
Another approach to measure and observe a rock bolt is to fix several strain gauges, fibre-optical sensors or vibrating wires on it. Although shear strains can merely be measured with this method. (Bäckblom, 2009)

Singh and Buddery, 1983



1 Rockbolt
2 25 mm dia footbolts
3 25 mm steel plate
4 hose connection to hydraulic pump
5 dial gauge mounting
6 extension rod
7 dial gauge
8 16 t hydraulic jack
9 circular jack seating
10 adoption collar

Figure 3-101 Test facility (Singh and Buddery, 1983)

To test the rock bolts in a relatively controlled environment, a special test drive is developed. The tests are performed in order to investigate two different parameters. The one is to measure the mechanical performance of individual anchorages, the other to determine the efficiency of several bolt-anchorage combinations.
The first series of tests were performed like pull-out tests. The testing apparatus contains special foot screws to enable an axial loading on bolts, not exactly perpendicular to the wall, and applying the load outside the borehole collar. For testing the friction rock stabilizers, special collars are needed. The load-displacement tests consisted of loading and unloading the bolts step by step, in three cycles. Dial gauges were used in order to measure the movement.
Breaking of the grout or rock collar, can be partially prevented by preloading the system. For future research, however, a collar of cement of suitable strength might be considered.

Tannant, 1995
Tannant describes pull-out tests at INCO Ltd's Creighton mine over several years.

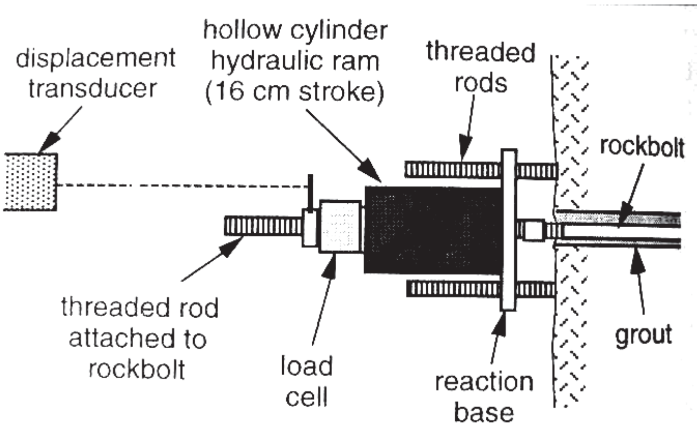


Figure 3-102 Test facility Tannant, 1995

The tests are conducted with a hydraulic hand pump assembled to a hollow cylinder hydraulic ram (300 kN capacity). The measuring devices cover a hollow cylinder, load cells and a rotary potentiometer (to measure the displacements).

It is possible to conclude on the effect of bolting by measuring the -to-floor convergence. (Myrvang and Hanssen, 1983)

3.3.2 Dynamic

3.3.2.1 Simulated rockbursts

In general
There is only one proven way to test support systems and the rock mass under dynamic loadings.

To test the in-situ performance of ground support under dynamic conditions in field, a seismic event is needed. Since rockbursts are unpredictable, they are simulated by controlled blasting. One or several carefully designed blasts cause a strong ground motion. The test sites are instrumented, to gain the desired data. The object of this tests are mainly to assess the in-situ performance of ground support. There are some differences between real rockbursts and blasts, concerning gases and seismic waves. The alternative is passive monitoring while real rockbursts. The alternative to blasting is, however, passive monitoring of real rockbursts, and this is rather time consuming and uncontrolled. (Hadjgeorgiou and Potvin, 2007) However, some research has been focused on the attempt to forecast seismic events. (deBeer, 2000)

Specific

Bajzeli, Likar and Zigman, 1995

A measuring anchor (long cable bolt with strain gauges and deformation sensors) Blasts are used to test the dynamic behaviour of the bolts.

Hagan et al. 2001

> *"A simulated rockburst experiment was conducted underground at a deep level gold mine. This was done by means of a large explosion detonated in solid rock close to a tunnel sidewall. The resultant shake-out damage is typical of that associated with a small seismic event in close proximity to a tunnel that is subjected to the estimated field stress, as in this case, of 50 MPa.*
> *The experiment involved:*
> *• the design of a blast to mimic a seismic source*
> *• seismic monitoring using a dense seismic array*
> *• high speed video filming*
> *• a study of rock mass conditions (fractures, joints, rock strength etc.) before and after the simulation using mapping and ground penetrating radar*
> *• special investigations to evaluate the mechanism and the magnitude of the damage*
> *• a study of support behaviour under excessive dynamic loading."*
>
> *"The existing support system of the tunnel consisted of rock bolt reinforcement units and mesh and lacing fabric support. The fabric support system used to contain the rock was not active at the site. Therefore, without significantly disturbing the integrity of the support system, the mesh and lace was removed from the sidewall, before the simulated rockburst experiment, to allow ejection of the rock blocks. The behaviour of the rock bolts during the simulated rockburst experiment indicated a limited interaction between the rock bolt and the rock mass at the boundary of the excavation."*

Haile and LeBron, 2001

> *"Detailed monitoring of the response of the rock mass between rock bolt reinforcement units subjected to a simulated seismic source has been successfully conducted. This work has shown the increase in amplification of the Peak Particle Velocity (PPV) with distance from a rock bolt unit, and, a minimum PPV for rockburst damage for the given site characteristics. This understanding, at this site, will allow the design of a suitable rock bolt spacing to prevent unravelling of the rock mass between the rock bolt units for a given level of seismicity. Or, alternatively, an*

> *estimation of the requirement for a suitable fabric support system, for the anticipated level of seismicity, can be made."*

Player, Morton, Thompson and Villaescusa, 2008

They stated in their report 'Static and dynamic testing of steel wire mesh for mining applications of rock surface support' the following.

> *"The dynamic test facility has been described in detail by Player et al. (2004) [...]. A frame, to support the mesh, is bolted to the drop beam. The mesh is held in place using threaded bar, shackles and eye bolts in the same configuration as the standard static test arrangement. A loading mass is placed into the centre of the restrained mesh. The loading mass consists of a pyramid shaped bag filled with a known mass of steel balls (0.5 or 1 tonne). The loading area of the bag is 650 mm x 650 mm. A wooden prop is placed between the loading mass and the drop beam to prevent the mass "floating" during the initial free fall period. The drop beam and attached mesh frame assembly are dropped from a specific height to generate dynamic loading on the mesh sample. Computer software, advanced instrumentation and a high speed video camera are used to record the test data. [...] Data processing is undertaken after the test to determine the dynamic performance of the test sample."*

The WASM static test facility has been described already in the previous chapters.

Heal and Potvin, 2007

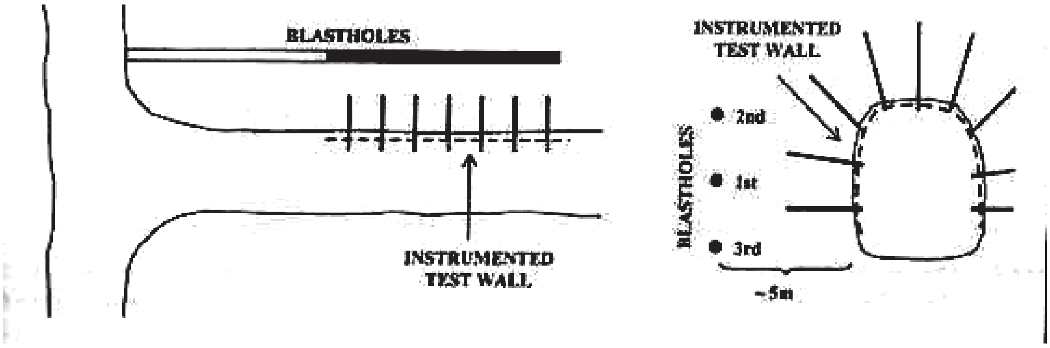


Figure 3-103 Plan and cross-sectional view of the test side (Heal and Potvin, 2007)

Simulated rockbursts are performed by blasts near by the walls of disused excavations. As shown in Figure 3-103, three blast holes are drilled. Each hole is separately charged with emulsions and detonated, to get a lager dynamic loading. The blasts should simulate an actual seismic event as closely as possible. The ground motion was observed with geophones (that were over damped), installed at the test wall. The bore holes were inspected before testing with a borehole camera.

GRC CANMET Laboratory

Instruments used are: three strain gauges on shank of three mechanical rock bolts and six geophones.

Dynamic loads are produces by mining a drift adjacent to the instrumented area. The test objective was to measure and find a correlation between PPV and strain in the bolt. This, however, was not really reached. (Hadjigeorgiou and Potvin, 2007)

GRC Bousquet #2

Eight blastholes are blast one at a time, behind a with shotcrete and bolts supported wall.

Nine geophones per test site, strain gauges, "home-made" velocity probes and a high speed video camera are used as measuring devices.

The object is to establish a comparison of the performance of shotcrete and mesh and fibre reinforced shotcrete.

This simulation of rockbursts is stated as a poor one, because of the gases. (Hadjigeorgiou and Potvin, 2007)

CSIR Kopanag Test

A single blast (five blastholes) is performed 6m away from the testing area, to reduce the effect of gas.

The testing site consisted of a 30 m well-instrumented drift. The measuring devices are two accelerometers, a microseismic system (GMM), triaxial and uniaxial geophones, borehole camera, extensometers and a high speed video camera.

The three objectives are to measure the influence of the reinforcement on the reaction of the rock mass to dynamic loading, secondly to gain data to calibrate seismic wave propagation simulation programs and at last to study the rock mass fracturing process. (Hadjigeorgiou and Potvin, 2007)

INCO

Five cross-cuts supported by TSL and shotcrete are affected by parallel blastholes. Parallel blasting shall reduce gases and provide high velocity and density. The test site is instrumented with a painted grid, eight velocity sensors (also on bolts) and a laser scanner.

The object is to assess the in-situ resistance of different surface support types. However, these experiments are time consuming and costly. (Hadjigeorgiou and Potvin, 2007)

Queen's University

The limestone test site is subdivided in 4x5 m² panels. In each panel a blasthole is drilled and crater blast.

Instruments are blast monitors and a high speed video camera.

The object is to compare capabilities of different support systems (rock bolt, shotcrete, fibrecrete, TSL). (Hadjigeorgiou and Potvin, 2007)

University of Western Australia (WASM)

The testing facility allows a direct comparison of different support systems. Rockbursts are simulated by a parallel blast. Therefore three separate blasts are done with 0.5 m/s, 1.5 m/s and 5 m/s. So a high impact and a low gas generation shall be reached. The measuring devices comprise a borehole camera, geophones, impulse microseismic monitoring, ground motion monitor (GMM) and a digital video camera.

The object was to gauge the performance of support systems in-situ when subjected to strong ground motion.

Heal (2005) produced several graphs, relating the energy sustained by individual support system and the damage scale. This may lead to reliable guidelines on resistance of support system to dynamic loading. (Hadjigeorgiou and Potvin, 2007)

Falconbridge

The object was the comparison of existing dynamic resistance support systems and data to calibrate a numerical model.

Three different support system types have been measured. The first consisted of a weld-mesh screen, rebar mesh straps and conebolts, the second of fibre reinforced shotcrete and rebars and the third of TSL and conebolts.

One blasthole, inclined 30° from the supported and instrumented face was blast.

The instruments used were a seismic system, triaxial geophone, uniaxial accelerometer, a high speed camera and instrumented rockbolts. (Hadjigeorgiou and Potvin, 2007)

4 Discussion and conclusion

The task of this report is to give an overview of the testing methods. The previous chapters contained detailed descriptions of tests available.
Testing methods for support materials are to be found in national standards. This standards mostly are not only concerning mining applications. Therefore it can be stated that national standards can be rather easily adopted for mining purposes, with or without modification. That, however, needs some investigations before, to ensure the adequacy of the specific standard for mining purposes.
Tests for support components are also included in standards. A table summarising the important parameters for each group of components is used to try to give a clear view on the component tests.
All performance tests are listed in a table in Enclosure 3. It sums up the most important information and shall therefore comprise a compact overview of the tests discussed. The two most important facts are which support unit is tested and what object was intended.
The tests have two main objectives. On the one hand there are tests and experiments that shall help to understand the mechanism of the support system. On the other hand, tests are run to determine the capability or effectiveness of systems. The latter one can be used to quantify the support systems.

By means of the collected data on testing methods for ground support and after developing a sufficient structure for data evaluation, the following conclusion can be drawn: There are a lot of standards for testing the materials and also for testing components for ground support systems. However, there is a lack of standards for testing the support units and support systems.

It is possible to modify the test methods and testing rigs. The described forces and rates for the testing rigs may change in the future.
Also simple test configurations can be changed to evaluate the behaviour of a specific component rather than testing the hole support unit. This means, that for example a test method for a rock bolt and accessories assembly can be modified by substitution of the required nut and tendon with higher grade ones in order to only test the washer plate.
Some testing equipments used in the laboratory can also be used in-situ (i.e. pull-out tests).

It can be seen that a large number of the performance tests concern rock bolts. This may be so because of the importance of the rock bolts, and the long time, they have been used until now.
Also, the age and the importance of rock bolts result in standard test methods. Concrete tests are also a main part in national standards. This may be so because concrete is not only used for ground support purposes.
It can be also seen, that a 'new' invented material or support system, i.e. TSL, is of main interest for researchers. Tests have to be performed to understand the support mechanism and quantify and compare the system with the 'old' ones.

Almost every test comprises a chapter that evaluates the performed method and points out pros and contras. Also other authors compare tests and evaluate them. For it is not the task of this report to evaluate the tests, this comments have been left unconsidered.

Articles with the object to give an overview of testing methods always include a discussion and comparison of strengths and weaknesses of the different testing methods.

Swan et al., 2007 state, that these tests are limited in attempts to simulate the reality and

> *"perhaps the only realistic alternative is to find cheap and effective ways of installing the various candidate support system components in the filed that monitor themselves in the event of a rockburst, somewhat similar to a black box on an aeroplane."*

One of the problems encountered is that a proper classification system had to be found. However, there may be several other ways to classify the testing methods. The one seeming to fit the best was selected. There are still some tests, that can not be clearly attached to one class.

Despite the problem of comparing different tests and standards there are some further handicaps. A difficult task was the search for standards in different countries. Although most of them were available in English language, there are still differences in used technical terms. So it was very hard, to find the right standards. The next problem encountered was the availability of the standards. This is a very time consuming and costly task.

It was very difficult to make a list of standards used for underground support systems. By their nature the documents refer endlessly to other standards and due to time, money and clearness a clear limit had to be drawn.

To sum up, the report contains the available standards and procedures on the static and dynamic testing of support material, components, support units and systems. Based on this acquired information, a detailed evaluation and comparison of the testing methods will be conducted. This will be part of the next phase of the MIGS-WP5 project.

Abbreviations

AFSW	acoustic frequency stress wave
ANSI	American National Standards Institute, standard
ARAPREE	A cuttable cable-bolt support system, of Twaron fibres in epoxy resin.
ASTM	American Society for Testing and Materials, standard
BS	British Standard
CANMET	Canada Centre for Mineral and Energy Technology
-MMSL	Mining and Mineral Sciences Laboratories
CSA	Canadian Standards Association, standard
CSIR	Council for Scientific and Industrial Research
DIN	Deutsches Institut für Normung, Norm (German Institute for Standardization; standard)
DMT	Deutsche Montan Technologie (German montane technology)
DSS	Double-Sided Shear Strength Test
EFNARC	European Federation of National Associations Representing procedures and applicators of specialist building products for Concrete
EN	European Standards
ERM	Electrical-Resistance-Measurement
FEM	Finite Elements Methods
FIP	Paper by the Institution of Structural Engineers
GBS	Grouted bolt system
GMM	Ground Motion Monitor
GRANIT	GRound ANchor Integrity Testing
GRC	Geomechanics Research Centre; Laurentian University
GRP	Glass fibre Reinforced Plastic (rockbolts or components)
IEC	International Electrotechnical commission, standard
INCO	International Nickel Company; Vale Inco
ISO	International Organization for Standardization, standard
ISRM	International Society for Rock Mechanics
LVDT	Linear Voltage Displacement Transducers
MCB	Modified Cone Bolt
MIRARCO	Mining Innovation Rehabilitation and Applied Research Corporation
MNSL	Minimum non-seizure load
MUL	Minimum ultimate load
NDPT	Non-Destructive Pull-out Test
NTC	Noranda Technology Centre
ÖNORM	Österreichische Norm (Austrian standard)
PPV	Peak Particle Velocity
PTI	Post-Tensioning Institute
rpm	rounds per minute
SABS	South African Bureau of Standards, standard
SANS	South African National Standard
SIMRAC	Safety in Mines Research Advisory Council; South Africa

SMART	Stretch Measurement to Assess Reinforcement Tension
SRK	Steffen Robertson and Kirsten consultants
TSL	Thin Spray-on Liner
WASM	Western Australian School of Mines

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ASTM C 1436-08: Standard Specification for Materials for Shotcrete1.

ASTM F 432-08: Standard Specification for Roof and Rock bolts and Accessories.

ASTM D 4435-08: Standard Test Method for Rock Bolt Anchor Pull Test.

ASTM D 4436-08: Standard Test Method for Rock Bolt Long-Term Load Retention Test.

ASTM D 7401-08: Standard Test Methods for Laboratory Determination of Rock Anchor Capacities by Pull and Drop Tests.

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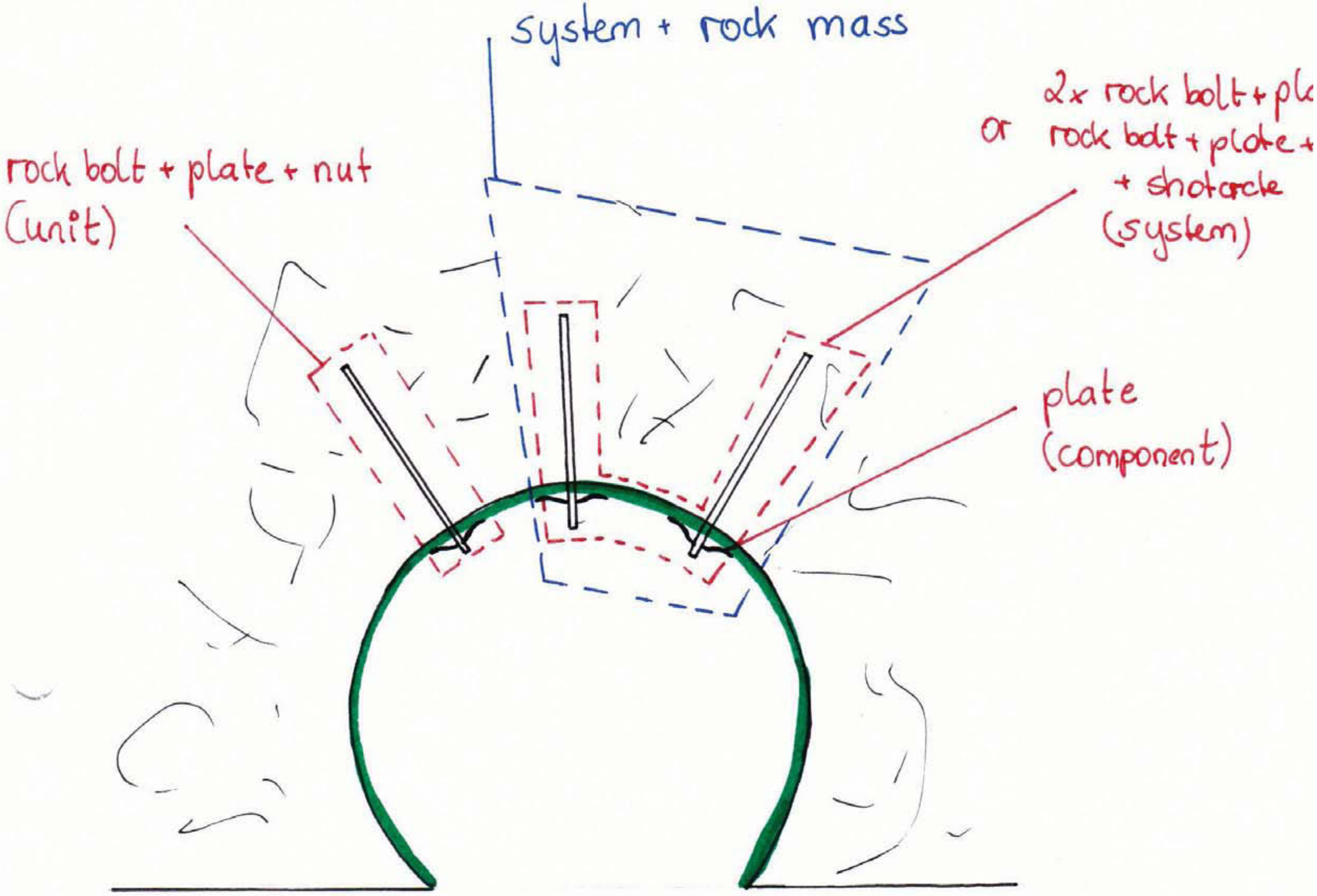
Index of Tables

Index of Figures

Enclosure 1 - Sketch for Ground Support Definitions



Enclosure 2 - Standards for Support Material

Steel

Austrian standards

ÖNORM B 4200-7:1968 Concrete reinforcement

Content: This standard comprises the field of application, types and designations of reinforcement, form of delivery, requirements, tests and control, procedure of tests and shape of specimen and defects and claim. The testing methods include tests of diameter or cross-section, gauging of elements of bond, tensile test, rebending test, bending test on welded joints, shear test and bending test on welded knots, dynamic fatigue test and bond test.

Refers to: ÖNORM B 3304:1981
ÖNORM B 3310:1995
ÖNORM B 4200-10:1996

ÖNORM EN 1537:2000: Execution of special geotechnical work - Ground anchors.

Content: The document refers to several European standards for steel used for the tension member, the anchor head and the coupling element.

Refers to: EN 1993-1-1:2006
EN 1992-1-1:2009
EN 10138:2000

German standards

DIN 21530-3:2003 Mine support - Part 3: Requirements

Content: Material specifications for steel used for arch support. Chemical composition, mechanical properties and delivery condition have to meet the values given in tables.

Refers to: DIN EN 10025:1993 Hot rolled products of structural steels

DIN 21531-1:1990 and -2 Arch supports

Content: Dimensions and material of structural steel.

Refers to: DIN 21544 Steel for underground support (remark: has been substituted by DIN 21530:2003).

DIN 488:1996; Reinforcing steels (Part 1: Grades, properties, marking; 2: Reinforcing steel bars; 3: Reinforcing steel in coils, steel wire; 4: Welded fabric; 5: Lattice girders; 7: verification of weldability of reinforcing steel bars, test procedure and evaluation)

Content: The first part classifies the steel grades, deals with the requirements, manufacturing, dimensions and properties. The second and third part discuss the determination of the properties by means of tensile test, dynamic fatigue test, flexibility, surface property, deviation form the nominal cross-section surface and the weldability. In the fourth part requirements, manufacturing, manufacturing of welded reinforcing steel fabrics, properties (and their determination by means of tensile test, shear strength of welded connections, dynamic fatigue test, flexibility and bending test at welding point) and geometric properties are defined. The following part contains details about requirements, manufacturing, material, manufacturing for lattice girders, design, properties (and their determination by means of tensile test and shear strength of welded connections), form and dimensions for lattice girders. The seventh part is about the weldability.

US standards

ASTM F 432-08 Standard Specification for Roof and Rock Bolts and Accessories
Content: Specifications for material for bolts, extensions, and threaded or threaded slotted bars including a table with chemical requirements and a lot of references for the various components. There are also two tables containing specific mechanical properties for various size friction stabilizers.

Refers to: for plain bars: ASTM A29/A29M-05
for plain or deformed bars: ASTM A615/A615M-09
for tapered wedges: ASTM A47/A47M-99(2009), ASTM A220/A220M-99(2009)
for expansion shells: ASTM A47/A47M
for spherical or bevelled washers: ASTM A47/A47M, ASTM A220/A220M
for nuts: ASTM A194/A194M-10 or A563-07.
for bolts and threaded bars for use in grouted systems: ASTM A615/A615M
for friction stabilizers: ASTM A1011/A1011M-10
for formable anchors: ASTM D 1248-05
for chemical analyses of steel: ASTM A751-08

Canadian standards
CAN/CSA-M430-90 Roof and Rock Bolts, and Accessories
Content: Requirements for the manufacturing process, the chemical composition, the mechanical properties, dimensions, mass and permissible variations.
Chemical requirements for steel are part of the restrictions for the manufacturing process.

Refers to: ASTM A29 for plain bars
ASTM A615 for plain or deformed bars
ASTM A47 for malleable iron castings
ASTM A220
ASTM A536
ASTM A194 or A563 for nuts (for manufacturing process)
ASTM A751 for chemical analysis

British standards
BS 7861-1:2007 Strata reinforcement support system components used in coal mines
Content: The standard specifies the composition of steel used for rock bolt bars. For nut, conical seat and domed washer plate material properties are contemplated (electrical resistance, fire resistance for domed washer plate, form, breakout facility for nut).

Refers to: BS EN ISO 4034
BS EN 13463-1

South African standards
SABS 1408:2002 Mechanical components for tendon based rock support systems
Content: There are no specific compositions or properties which the steel of rock bolts, rock studs, nuts, bearing plates or washers must meet listed in the standard. The only requirements are a homogenous microstructure and a uniform hardness.
Spherical seats, plugs and leaves (for expanding shells) can be made of steel or malleable or spheroid graphite iron. They shall withstand 200 Nm (respectively the minimum ultimate load of expansion shells for leaves) when the bolt or expansion shell is tensioned.

Refers to: SABS 920:2005 Steel bars for concrete reinforcement
SABS 1700-5-2:1996 Fasteners – Part 5: General requirements and mechanical properties – Section 2: Nuts with specified proof load values – Coarse thread
SABS 1700-5-4:1996 Fasteners – Part 5: General requirements and mechanical properties – Section 4: Nuts with specified proof load values – Fine pitch thread

SABS 1700-5-15:2008 Fasteners – Part 5: General requirements and mechanical properties – Section 15: Bolts, screws, studs and nuts

SANS 920:2005 Steel bars for concrete reinforcement
Content: This standard gives mechanical and physical requirements for carbon steel bars which are to be used as reinforcement of concrete. It specifies testing methods for dimensions and mass, tensile test, bending test, rebending test, test for deformed bars and pull-out test by describing apparatus, test specimens and procedure of the method.
Refers to: SANS 282:2004, Bending dimensions and scheduling of steel reinforcement for concrete.
SANS 540-1:2009 (SABS 540-1), Fibreboard products – Part 1: Uncoated fibreboard.
SANS 540-2:2009 (SABS 540-2), Fibreboard products – Part 2: Coated fibreboard.
SANS 1200 G:1982 (SABS 1200 G), Standardized specification for civil engineering construction – Section G: Concrete (structural).
SANS 5863:2006 (SABS SM 863), Concrete tests – Compressive strength of hardened concrete.
SANS ISO 6892:1998, Metallic materials – Tensile testing at ambient temperature.
SANS ISO 9001:2008, Quality management systems – Requirements.
SANS 10100-1:2000 (SABS 0100-1), The structural use of concrete – Part 1: Design.
SANS 10100-2:1992 (SABS 0100-2), The structural use of concrete – Part 2: Materials and execution of work.
SANS 10144:1995 (SABS 0144), Detailing of steel reinforcement for concrete.

Concrete and Shotcrete

Austrian standards

Austrian Guidelines: Sprayed Concrete August 2006 from Austrian Society for Concrete- and Construction Technology

Content: The standard specifies materials, requirements and procedures for mixing and applying sprayed concrete. At the rear of the document testing and testing procedures for constituent materials, mix and sprayed concrete are described. Parameters tested are temperature, early strength class, compressive strength (7 and 28 days), sprayed concrete thickness, modulus of elasticity and tensile adhesive strength to name but the most important.

The described testing procedures cover a variety of tests for the constituent materials (i.e. bleeding of cement, setting, strength development and loss of strength or volume stability), the mix and base concrete without accelerator (i.e. assessment of workability time of moist mix, testing of extended workability time of wet mix or early shrinkage cracking), the young sprayed concrete (penetration needle method and bolt-driving method) and the sprayed concrete (i.e. testing of compressive strength, tensile splitting strength, for water impermeability, determination of equivalent flexural strength and toughness, panel test or leaching of sprayed concrete).

Refers to: ÖNORM B 2203-1:2001
ÖNORM B 2203-2:2005
ÖNORM B 3131:2010
ÖNORM B 3303:2002
ÖNORM B 3309: 2010

ÖNORM B 3327:2001
ÖNORM B 4710-1:2007
EN 149:2009
EN 196 (Part 1, 2, 3, 7 and 27)
EN 197-1: 2008
EN 450: 2005 and 2009
EN 459-2:2002
EN 480 (Part 1, 2, 6, 8, 10 and 12)
EN 932-1:1997
EN 933-1:2006
EN 934-2:2009 and -5:2008
EN 1008:2002
EN 1097-3:1998
EN 1542:1999
EN 12350-5:2009
EN 12390-3:2009
EN 12504-1: 2009
EN 12620:2008
EN 13263:2009
EN 14488-1:2005
ASTM C 227-81
ASTM C 289-97
ASTM C 403-95
DIN 51302-1:2000
ISO 758:1976
ISO 1158:1998
ISO 4316:1977

ÖNORM B 3303:2002 Testing of Concrete
Content: The standard discusses the different types of tests, geometry and manufacturing of the specimen, testing of fresh and hardened concrete and a test report. There are five types of specimen: cubes, cylinder, beams, plates and prisms. The following tests determined on fresh concrete: consistency; flow diameter; compaction; weight; contents of water; aggregates and cement and air content. Weight, compressive strength, bending tensile strength, splitting tensile strength, wear, elasticity modulus, frost resistance and water permeability are tested on hardened concrete.
Refers to: ÖNORM B 3220:2000

ÖNORM B 3313:1980 Blast furnace slags; general aspects
Content: Discussing terminology, properties (chemical and physical), production and application, the standard also deals with testing methods. This tests are about volume stability, frost-resistance, grain size distribution, grain shape, bulk density, moulded density and water absorption.
Refers to: ÖNORM B 3314:1980
ÖNORM B 3315:1980
ÖNORM B 3316:1955
ÖNORM B 3317:1980
ÖNORM B 3318:1980

European standards
EN 206-1:2005 Concrete - Part 1: Specification, performance, production and conformity

Content: The standard comprises the field of application, terminology, classification, concrete requirements and verification, transport, production and conformity control. The latter includes controlling properties, compressive strength and splitting tensile strength. A more detailed description of initial testing and identity verification for compressive strength can be found in the appendix of this European standard.

Refers to: EN 1008:2002
prEN 12390-3:2009
prEN 12620:2008
EN 13055:2004
prEN 13263:2009
prEN 13577:2007
prEN 13791:2007
ISO 2859-1:1999
ISO 3951:2005
ISO 4316:1977
ISO 7150-1:1984
ISO 7980:1986
DIN 4030-2:2008
ASTM C 173-09
OIML R 117
90/384/EWG

EN 934-2:2009 Admixtures for concrete, mortar and grout - Part 2: concrete admixtures - Definitions, requirements, conformity, marking and labelling

Content: The standard is organized as follows: field of application, terminology, requirements, sampling, control of conformity, evaluation of conformity and marking and labelling. The part 'requirements' covers general and specific requirements and disposal of hazardous substances.

Refers to: EN 934-1:2008, -3:2009, -4:2009, -5:2008, -6:2006
EN 480:2005

EN 934-5:2008 Admixtures for concrete, mortar and grout - Part 2: concrete admixtures - Definitions, requirements, conformity, marking and labelling

Content: The documents comprises the field of application, general and specific terminology, general and specific requirements, sampling, control and evaluation of conformity and marking and labelling. Testing methods discussed in this standard are testing of reference concrete (cement content, grains, consistence, compressive strength) and testing of adhesive tensile strength).

Refers to: EN 934-1, -2, -3, -4, -6
EN 480

EN 12504-1:2009 Testing concrete in structures

Content: This standard is organized in four parts. Part 1 covers cored specimens, part 2 non-destructive testing, part 3 determination of pull-out strength and part 4 determination of ultrasonic velocity. The first part discusses taking and examine cored specimens and testin in compression.

EN 13791:2007 Assessment of in-situ compressive strength in stuctures and precast concrete components

Content: As suggested by the title, this standard deals with testing method for determining the compressive strength of concrete in structures or precast concrete products.

EFNARC

European Specification for Sprayed Concrete,1996

Content: In addition to definitions, constituent materials, requirements for concrete composition, requirements for durability, mix composition, execution of spraying, requirement for final product, quality control and health and safety this standard deals with test methods and test procedures. The test methods cover testing of compressive strength and density, testing of flexural strength and residual strength (third-point loading), determination of energy absorption class (plate test), modulus of elasticity, bond strength (by means of a core pull and direct tension testing), permeability, frost resistance and determination of the fibre content of sprayed concrete.

The document also includes test procedures for determination of setting time, compressive strength and tensile bond strength between layers and at interface with substrate.

Refers to: EN 197-1:2008 Cement; Composition, specifications and conformity criteria
EN 206-1:2005 Concrete - Performance, production, placing and compliance criteria
EN 450-1:2009 Fly ash for concrete - Definitions, requirements and quality control
EN 934-2, -5 and -6 Admixtures for concrete, mortars and grouts (Part 2: Concrete admixtures - definition, specification and conformity criteria; Part 5: Sprayed concrete admixtures - definition, specification and conformity criteria; Part 6: Sampling, quality control, evaluation of conformity and marking and labelling)
EN 1008:2002 Mixing water for concrete
EN 1504 Products and systems for the protection and repair of concrete structures
EN 1542:1999 Products and systems for the protection and repair of concrete structures - Test methods - Measurement of bond strength by pull-off
EN 4012:2005 Testing concrete - Determination of compressive strength of test specimens
EN 6275 Testing concrete - Determination of density of hardened concrete
EN 6784:1982 Testing concrete - Determination of static modulus of elasticity in compression
EN 7031 Testing concrete - Determination of the depth of penetration of water under pressure
EN 7034 Testing concrete - Cored specimens - Taking, examining and testing in compression
EN 10080:2005 Steels for Reinforcement of Concrete. Weldable, ribbed reinforcing steel B 500. Technically delivery conditions for bars, coils and welded fabric
EN 10138:2000 Pre-Stressing steel, Part 1 - Part 5
ASTM C 666-03 Test Method for Resistance of Concrete to Rapid Freezing and Thawing
ASTM C 672-03 Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals
ASTM A 820-06 Specification for Steel Fibres for Fibres-Reinforced Concrete
SS 137244 Betongprovning - Hårdnad betong - Frostresistens

US standards

ASTM C39-09 Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

Content: The test method suggests to apply a compressive axial load to special specimen (moulded cylinders or cores) at a distinct rate until fracture. Then the compressive strength of the specimen can be calculated.

Refers to: ASTM C 31-09
ASTM C 42-04
ASTM C 192-07
ASTM C 617-09
ASTM C 873-04
ASTM E 4-09
ASTM E 74-06

ASTM C42/C42M-04 Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

Content: The standard states that a core drill is needed to obtain specimen for testing the compressive strength and a saw for the preparation of beams to test the flexural strength. The testing procedure is described elsewhere (ASTM C 39 for compressive strength and ASTM 469 for flexural strength).

Refers to: ASTM C 39-09
ASTM C 78-09
ASTM C 116-90
ASTM C 174-06
ASTM C 192-07
ASTM C 496-04
ASTM C 617-09

ASTM C78-09 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

Content: The standard describes the test apparatus (Figure 0-1), test specimen, testing procedure and calculations.

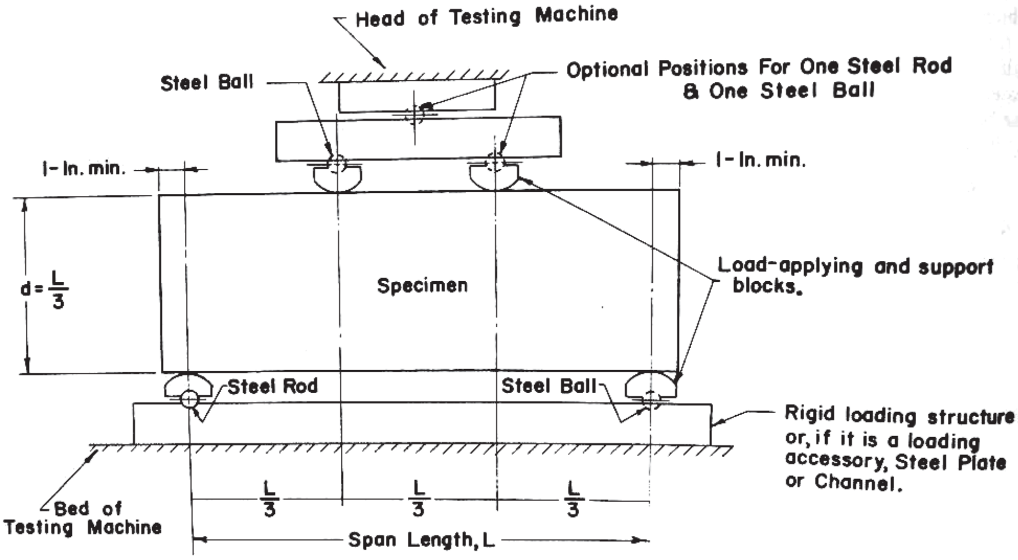


Figure 0-1 Testing the flexural strength (ASTM C78-09)

Refers to: ASTM C 31-09
ASTM C 192-07
ASTM E 4-09

ASTM C143-10 - Standard Test Method for Slump of Hydraulic-Cement Concrete

Content: The described procedure can be used in laboratory as in-situ. For the procedure a special mould is needed. These mould shall be placed on a flat surface and filled in layers with the concrete to be tested. Each layer shall be rodded. After removing the mould the vertical displacement of the centre of the top surface of the specimen shall be measured.
Refers to: ASTM C 172-08

ASTM C192-07 Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory
Content: The document comprises equipment, shapes and sizes of specimen, preparation of materials and procedures to create and cure the specimen.
Refers to: ASTM C31-09
ASTM C33-08
ASTM C70-06
ASTM C125-09
ASTM C127-07
ASTM C128-07
ASTM C138-09
ASTM C143-10
ASTM C172-08
ASTM C173-09
ASTM C231-09
ASTM C330-09
ASTM C470-09
ASTM C511-09
ASTM C566-97
ASTM C567-05
ASTM C617-09
ASTM D448-08

ASTM C231-09 Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method
Content: The standard describes the equipment needed (air meters, as shown in Figure, and accessories), the act of calibration, determination of aggregate correction factor, preparation of the concrete test samples and the procedure for determining the air content of the concrete. Thereby the testing procedure consists of measuring the change in volume of the concrete with a change in pressure.
Refers to ASTM C138-09
ASTM C143-10
ASTM C172-08
ASTM C173-09
ASTM C192-07

ASTM C 403-08 Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance
Content: The method suggests to obtain a mortar sample by sieving and positioning fresh concrete in a box. After storage the resistance of the mortar to penetration by standard needles is observed in distinct intervals. From the resistance-time plot the initial and final setting time can be calculated.
Refers to: ASTM C143-10
ASTM C172-08
ASTM C173-09
ASTM C231-09

ASTM C670-03
ASTM E1-07
ASTM E11-09

ASTM C805-08 Standard Test Method for Rebound Number of Hardened Concrete
Content: The standard deals with the apparatus (rebound hammer), the test area (selection and preparation of the test surface), the testing procedure and the calculation.
Refers to: ASTM E177-08

ASTM C 1550-05 Flexural Toughness of fibre reinforced concrete (using centrally loaded round panel)
Content: "*Molded round panels of cast fiber-reinforced concrete or fiber-reinforced shotcrete are subjected to a central point load while supported on three symmetrically arranged pivots. The load is applied through a hemispherical-ended steel piston advanced at a prescribed rate of displacement. Load and deflection are recorded simultaneously up to a specified central deflection. The energy absorbed by the panel up to a specified central deflection is representative of the flexural toughness of the fiber-reinforced concrete panel.*" (ASTM C 1150)
Refers to: ASTM C31/C 31M-09
ASTM C125-09
ASTM C670-03

Canadian standards
CSA A23.1/A23.2-09 Concrete materials and methods of concrete construction/Test methods and standard practices for concrete
Content: The combined standards cover on the one hand requirements for materials and methods of construction cast-in-place, residential and precast concrete in the field, including conventionally reinforced elements and on the other hand basic test methods for hardened, freshly mixed concrete and concrete materials. The testing methods include testing methods for aggregates, concrete and dimensions.
Refers to: CAN/CSA A23.2-09
CSA A23.4-09 for prestressed, post-tensioning products and precast concrete used in segmental construction.

British standards
BS 1881-124:1988 Testing concrete - Part 124: Methods for analysis of hardened concrete
Content: The standard describes the assembling procedures, treatment of samples, and analytical methods to be used on a sample of concrete to determine the cement content, aggregate content, aggregate grading, original water content, type of cement, type of aggregate, chloride content, sulphate content, and alkali content.
The procedures apply to concretes made with Portland cements and, in favourable circumstances, containing ground granulated blast-furnace slag.

South African standards
SANS 5861:2006 Concrete tests - Mixing fresh concrete in the laboratory
Content: The SANS 5861-series consists of three parts. Part one deals with mixing of fresh concrete in the laboratory, part two with sampling of freshly mixed concrete and the third part with making and curing of test specimens. The first part discusses basic methods of batching prepared materials and mixing fresh concrete in the laboratory. The second part describes test procedures for sampling freshly mixed concrete, delivered in measurable quantities to a site or mixed in laboratory. The third part covers making and curing of test specimen. They can be in shape of cubes, cylinders or prisms.

Refers to: SANS 5862-1:2006 Concrete tests - Consistence of freshly mixed concrete - Slump test
SANS 195:2006 Sampling of aggregates

SANS 5862:2006 Concrete tests - Consistence of freshly mixed concrete
Content: The SANS 5862-series holds four parts. Every part describes a particular test to determine the consistence of freshly mixed concrete either in the laboratory or on site. The first two parts deal with test methods for determining the slump (part one) or flow (part 2) of freshly mixed concrete. The third part specifies the Vebe test. This test is meant to measure the consistence of concrete of low workability. Thereby the settling time of concrete, shaped like a frustum, in a container is measured, when a standard vibration is applied. The fourth part discusses two methods to determine the degree of compactibility. Therefore the compacting factor and the compaction index are measured.
Refers to: SANS 5861-1:2006
SANS 5861-2:2006

SANS 5863:2006 Concrete tests - Compressive strength of hardened concrete
Content: As suggested by the title, this standard comprises test methods and procedures to determine the compressive strength of specimen of hardened concrete.
Refers to: SANS 5861-2:2006
SANS 5861-3:2006

SANS 5864:2006 Concrete tests - Flexural strength of hardened concrete
Content: For determining the flexural strength, two different procedures are described in this standard: The two-point loading method, where a constant bending moment is applied along the centre of the test specimen, and the centre-point loading method.
Refers to: SANS 5861-1:2006
SANS 5861-2:2006
SANS 5861-3:2006
SANS 5863:2006

SANS 5865:1994 Concrete tests - The drilling, preparation, and testing for compressive strength of cores taken from hardened concrete
Content: This standard adheres to a test procedure for taking cores from hardened concrete, preparing this samples for testing and determining the compressive strength.
Refers to: SANS 10100-2:1992 The structural use of concrete Part 2: Materials and execution of work

SANS 6085:2006 Concrete tests - Initial drying shrinkage and wetting expansion of concrete
Content: The document covers a test to determine the initial drying shrinkage and wetting expansion of specimens, taken from freshly cast concrete. This standard is not valid for precast concrete products, hardened or matured concrete or for concrete with expansion-inducing agents.
Refers to: SANS 5860:2006
SANS 5861-1:2006
SANS 5861-2:2006

SANS 6250:2006 Concrete tests - Density of compacted freshly mixed concrete and SANS 6251:2006 Concrete tests - Density of hardened concrete
Content: This standards describe a test method for determining the density of compacted freshly mixed concrete (SANS 6250) respectively of hardened concrete (SANS 6251).

Refers to: SANS 5861-1:2006
SANS 5861-3:2006

Resin

Austrian standards
ÖNORM EN 1537:2000: Execution of special geotechnical work - Ground anchors.
Content: The standard states, that resins can be used for ground anchors when there is a proper system testing to prove their applicability. However, laboratory and in-situ tests have to be conducted to test their mixture, setting time and behaviour.

US standards
see US standards for grout

British standards
BS 7861-1:2007 Strata reinforcement support system components used in coal mines
Content: Specifies the capsule material and size. The standards discusses the shelf live of resins and gel and setting times of mixed resin. It includes tests for determining the mechanical performance like uniaxial compressive strength, elastic modulus and resistance to creep.
Refers to: BS EN ISO 7500-1:2004
BS 6319-1, 2:1983

South African standards
SABS 1534:2004 Resin capsules for use with tendon based support systems
Content: This standard specifies the capsule dimensions and types. The capsules shall be tested in accordance to this standard. The tested parameters are rigidity, pull test, shear strength, set time, flash point, viscosity, resin mastic content of capsules and storage stability. Testing the length is done from clip to clip with a metal ruler, the diameter is measured with a GO-NO-GO gauge and the freedom from leakage with a special apparatus. Latter has to have a flat surface, where the capsules are laid on. On the capsules aluminium plates and mass pieces are positioned. After a certain time the specimen are inspected - no leakage of resin mastic or catalyst must occur. The rigidity test is done by inserting the capsule in a steel tubing at 45 degrees and checking if the sheath does not kink. For the shear strength test specimens are prepared by means of washers. A special apparatus (with a punch, a loading device and a die) is needed. The resin is mixed, cooled and tested to fracture within 15 s to 45 s by applying a constantly increasing force on it. The maximum force of six specimen is recorded and used to calculate the shear strength.
The set time is determined by filling a plastic cup with resin mastic and catalyst, separated by a film, then mixing the two components and measuring the time until setting occurs. The flash point test is based on modificated IP method 303. The pull test needs a concrete block with a bore hole (down with rotary hammer drill) in the centre. The hole is filled with water and then dried with compressed air. The test bar must not be pulled out more than 11 mm when a load of 100 kN is applied for 5 minutes. Determining the viscosity is done in a plastic syringe with a pipeline viscometer. The resin mastic content of a capsule is designated by weighting the resin mastic, the catalyst and the remaining film of the capsule and calculating the content.
Refers to: IP method 303
BS 5080-1:1993

Grout

German standards

DIN 21521-2:1993 Rock bolts for mining and tunnel support; general specifications for steel-bolts; tests, testing methods

Content: The components of the grout have to be content of the installation instruction. Grout has to meet the requirements given in the proper standard for the specific grout.

European standards

EN 445-2008 Grout for prestressing tendons - Test methods

Content: The document is organized as follows. Field of application, terminology, testing of grout for prestressing tendons, sieving test, determination of flowability, settling test in inclined pipe, settling test in vertical pipe, determination of compressive strength and determination of density.

Refers to: EN 13670:2010
EN 1992:2009
EN 446:2008
EN 447:2008

US standards

ASTM F 432-08 Standard Specification for Roof and Rock Bolts and Accessories

Content: The ASTM describes laboratory tests for determining the strength index for chemical grouting materials and for determining the speed index. Furthermore the cartridge equivalent length requirements are discussed.

British standards

BS 7861-1:2007 Strata reinforcement support system components used in coal mines

Content: The standard specifies requirements for grout, such as shelf life, gel and setting times, UCS, elastic modulus and resistance to creep. Tests for the last three parameters are described very detailed in the annexes. Furthermore material, size and packaging of the capsules are defined.

Refers to: BS 6319-1:1983
BS 6319-2:1983
BS EN ISO 7500-1:2004

South African standards

SABS 1745:2003 Cementitious grouting capsules for use with tendon-based support systems

Content: This standard contains several test methods. Furthermore it defines cement and additives and the sheath, which shall be made of water-permeable material, using ISO 3781 for testing. The test parameters are dimensions (length and diameter), wetted volume yield, initial setting time (pot life) and final setting time, pull-out strength, grout mix volume expansion, compressive strength, long-term soundness, formulations and storage stability. The dimensions are determined using a metal ruler for measuring length and circumference of an empty sheath slice for calculating the diameter. To define the mixing of grout a measuring cylinder, a mass meter and a Hobart-type planetary mixer are used. The wetted volume yield is designated by determining the yield per capsule by mixing the grout, pouring it into a measuring cylinder and measuring the volume. The grout mix volume expansion is measured according to ASTM C 827. To determine the pull-out strength a steel tube is filled with grout and a threaded bar is inserted centrally with the threaded end out of the grout. The assembly is positioned in a hydraulic ram and a specific load is applied on the bar to pull at it. If so required by the purchaser, the test is continued until failure. The compressive strength is determined according to SANS 5863.

<u>Refers to</u>: SANS 50197-1:2000
BS 915-2:1972
SANS 1491-1:2005, -2:2005, -3:2006
SANS 5863:2006
ISO 3781:1983
SANS 4788:2009
SANS 50196-1:2006
ASTM C 827-01

Enclosure 3 - List of Performance Tests

Name, Year	Tested unit	Object	Capacity or rate	Page in Main Report	Remark
Rock bolts					
Shear tests to determine strength and deformation behaviour					
BS 7861	grouted bolt	Standardisation	10 N/mm²	29	steel frame
Bartels and Pappas, 1985	grouted bolt	Evaluation of roof bolt	203.37 Nm	30	Rock block
Wittenberg, 1995	grouted bolt	Bolt behaviour		30	Hexagonal blocks, several inclinations
Deangeli, Ferrero and Pelizza, 1995	grouted bolt	Comparison of different rock/bolt types		31	0.3*0.3*0.8 m, several materials
DIN 21521	mechanical anchor	Standardisation		32	Concrete blocks
Grasselli, Kharchafi, Egger, 1999	grouted bolt and friction bolts	Bolt behaviour	1000 kN	33	0.1*0.6*0.6 m concrete blocks
Shear tests to determine mode of action of the support unit					
Bjurström, 1974	grouted bolt	Determine shear behaviour of bolted and unbolted rock	0.15 mm/min.	33	Block: Rock, 0.25*0.4 m
Haas, 1981	grouted bolt	evaluate effectiveness of various bolt types in resisting shear under verious conditions		34	
Ludvig, 1983	grouted bolt and friction bolts	Bolt's influence on joint shear strength		34	Rock blocks
Schubert, 1984	grouted bolt	Bolt behaviour		37	Concrete or rock blocks
Egger and Zabuski, 1991	mechanical anchor	Bolt behaviour	0.7-2 MN	38	Concrete blocks
Ferrero, 1994	grouted bolt	Bolt behaviour		38	0.3*0.4*0.8 m blocks
Stjern, 1995	all types	Bolt behaviour	500 or 300 kN	39	0.95*0.95*0.95 m concrete blocks
Jalalifar, Aziz and Hadi, 2004	grouted bolt	Bolt behaviour	500 kN	40	0.6*0.15*0.15 m concrete blocks
Pull tests to determine strength and deformation behaviour					
BS 7861	grouted bolt	Standardisation		42	specific apparatus
DIN 21521	grouted bolt	Internal bond		43	steel cylinder
ÖNORM EN ISO 22477-5	grouted bolt	Standardisation		43	3 different methods
ASTM D 4435	all types	Measure ultimate capacities	2.2 kN increments	44	in situ
ISRM 2007a	all types	Determine strength	5-10 kN/min	45	in situ
ISRM 2007b	all types	Determine tension		46	non-destructive

Name, Year	Tested unit	Object	Capacity or rate	Page in Main Report	Remark
Franklin and Woodfield, 1971	all types	Evaluate strength, slippage and loss of resistance		46	rock, in-situ
Ballivy and Martin, 1983	grouted bolt	Bolt behaviour	45 kN/min (in field)	48	Lab and field; cylindrical and cubic samples
Bartels and Pappas, 1985	grouted bolt	Evaluation of bolt elements	20 t	48	with bearing plates
Pettibone, 1988	grouted bolt	Bolt behaviour	1.63 t	49	concrete blocks and in situ
Goris, 1991	cable bolt	Bolt behaviour	181.44 t	49	Cable bolt
Bawden, Hyett and Lausch, 1992	cable bolt	Bolt behaviour	0.215-0.3 mm/s	49	For cable bolts; special pulling pipe
Hassani and Khan, 1993	cable bolt	Bolt behaviour	1 mm/min	50	Cable bolt
Hyett et al., 1993	cable bolt	Failure mechanisms		51	Modified Hoek cell
Stjern, 1995	grouted bolt	Bolt behaviour	30 kN/min	51	hollow steel cylinder
Wittenberg, 1995	grouted bolt	Bolt behaviour		52	Used special mountain-pipes
Röck, Schwab and Blümel	grouted bolt	Bolt behaviour	0.012 mm/min	53	steel pipe
Atlas Copco, 1998	Bolt	Bolt behaviour		53	Different types of tests
Wittenberg, 1999	grouted bolt	Test external bond		54	Uses special pipe
Moosavi, Bawden and Hyett, 2002	cable bolt	Bolt behaviour		55	Modified Hoek cell
Kilic, Yasar and Aziz, 2003	grouted bolt	Bolt behaviour	8-kN steps	55	rock block
CANMET Pull Test	grouted bolt	Bolt behaviour	325 kN	55	steel tubes
Pull tests to determine mode of action of the support unit					
Pells, 1974	grouted bolt	Bolt behaviour		57	rock blocks
Serbousek and Signer, 1987	grouted bolt	Bolt behaviour		57	concrete blocks
Signer, 1990	grouted bolt	Load transfer mechanics	5.8 t	58	in situ
Fabjanczyk and Tarrant, 1992	grouted bolt	Bolt behaviour		58	In metal cylinder
Hyett et al., 1993	Cable bolt	Bolt behaviour		58	for cable bolts
Stillborg, 1993	all types	Load-deformation characteristics	3.6 mm/min	59	also for several bolts
Ohtsu, Shigeishi and Chahrour, 1995		Study fracture zone		60	concrete blocks

Name, Year	Tested unit	Object	Capacity or rate	Page in Main Report	Remark
Benmokrane, Chekired and Xu, 1995	grouted bolt	Long-term performance		60	Surface mounted gauges
VandeKraats and Watson, 1996	cable bolt	Bolt behaviour	530 kN	61	
Galvin et al., 2001	grouted bolt	Bolt behaviour	1-7.5 MPa/mm	61	special lathe
Hagan, 2004	grouted bolt	Test loading of embedded anchor length		62	concrete in biaxial cell
Satola, 2007	grouted bolt	Bolt behaviour	350 kN	62	double pipe system
Simser et al., 2007	grouted bolt	Bolt behaviour		63	Ploughing of cone observed
Overcoring technique					
Jirovec, 1995	Bolt	Bond		63	
Varden and Villaescusa, 2005	Bolt	Bond	60 kN (lab)	63	
Villaescusa, Varden and Hassell, 2008	Bolt	Performance of grouted bolts		64	
Monitoring and non-destructive testing					
ASTM D4436	Bolt	Lon-term load evaluation		65	
Thurner, 1983	Bolt	Bond		66	Boltometer
Bäckblom, 2009	Bolt	Bond		66	GRANIT system
Reuther and Heime, 1990	Bolt	Evaluate condition		67	Slit nuts
Dejean and Raffoux, 1980	Bolt	Evaluate condition		67	Calibrated end-plates
Bigby, 1997	Bolt	Evaluate condition		67	Dual Height Telltale
Beard and Lowe, 1980	Bolt	Evaluate condition		68	
Jasarevic et al., 1984	Bolt	Long-term control		69	Also as pull out test
SMART	Bolt	Long-term control		69	Cable bolt
Daws, 1992	Bolt	Long-term control		69	
Bolstad, Hill and Karhnak, 1983	Bolt	Bond		69	Roof bolt grout bond tester
Wang and Wang, 2001	Bolt	Evaluate condition		70	
ISRM	Bolt	Measure load		70	
DIN 21521	Bolt	Bond and strength		71	several methods
TSL					
EFNARC	TSL	Standardisation of properties		71	Block Support Test
Yilmaz, Sydam and Toper, 2003	TSL	Standardisation of properties		73	Adhesion, pull, baggage capacity, punsh and compression test

Name, Year	Tested unit	Object	Capacity or rate	Page in Main Report	Remark
Toper et al., 2003	TSL	Standardisation of properties		78	Link to standards
Yilmaz, Saydam and Henderson, 2003	TSL	Standardisation of properties		78	Torque test
Saydam, Yilmaz and Stacey, 2003	TSL	Standardisation of properties		80	Double sided shear strength test
Archibald, 2001	TSL	Standardisation of properties		81	Compression test, flammability test
Spearing and Champa, 2000	TSL	Standardisation of properties		82	Referred to standards
MBT Membrane Displacement Test	TSL	TSL behaviour		82	
INCO/GRC Membrane Test	TSL	TSL behaviour		83	
CANMET Membrane Test	TSL	TSL capacity		83	
Arch support					
DIN 21530-4	Arch	Standardisation		84	Test arch and connections (separately)
Other					
Grimm, 1995	Bolt	Test corrosion		86	electric
ÖNORM EN 1537	Bolt	Test corrosion		87	electric
Hyett et al., 1993	Bolt/grout	Penetration of grout		87	Cable bolt
BS 7861	Bolt and accessories	Behaviour		87	
Shotcrete					
Malmgren, 2005	Shotcrete	Study interaction shotcrete/rock		88	
Drop facilities					
ASTM D 7401	Bolt			89	auch pull test
Player, Villaescusa and Thomposn, 2004	Support unit	Capacity under dynamic loading		89	Momentum transfer concept
Thompson, Player and Villaescusa, 2004	Support unit	Capacity under dynamic loading		90	
Ortlepp and Stacy, 1998	Bolt	Capacity under dynamic loading	1048 or 2706 kg drop mass	91	
Gaudreau, Aubertin and Simon, 2004	Bolt	Capacity under dynamic loading	1 t from 2 m	91	

Name, Year	Tested unit	Object	Capacity or rate	Page in Main Report	Remark
Ansell, 2005	Support unit	Capacity under dynamic loading		92	
SRK	Support unit	Capacity under dynamic loading		92	
Terratek	Bolt or prop	Capacity under dynamic loading	30 mm/min.	92	
INCO/GRC Membrane Test	TSL	TSL behaviour		93	dynamic testing arrangement
WASM	Bolt	Capacity under dynamic loading	36 kJ	93	steel cylinders
CANMET	Bolt	Capacity under dynamic loading	58.8 kJ	93	
MIRARCO	Screen	Evaluate behaviour	565 kg, 3 m	95	for mesh
CANMET-MMSL	Bolt	Capacity under dynamic loading	6.5 m/s	95	
DMT	Bolt	Capacity under dynamic loading		96	
Charette, 2007	Bolt	Capacity under dynamic loading		97	
GRC	Bolt	Demonstrate influence of multiple impact loading		97	
Static support system testing					
Bolstad, Hill and Karhnak, 1983	Roof-bolt system	Verify FEM analysis		98	
Tinceling and Sinou, 1980	Bolt/Rock	Effect of bolting on specimen		99	compressive test
Wullschläger and Natau, 1983	Bolt/Rock	Influence of bolt density		99	compressive test
ISRM	Rock anchorage	Evaluate capacity		100	
Khair, 1983	Bolts	Evaluate behaviour		101	Truss bolt
Witthaus, 1995	Bolt	Deformation rock - bolt behaviour		102	in situ
Wittenberg, 1998	Bolt	Deformation rock - bolt behaviour		102	in situ
Grasselli, 2005	all types	Relation inclination and shear behaviour		102	1*0.6*0.6 m concrete blocks

Name, Year	Tested unit	Object	Capacity or rate	Page in Main Report	Remark
Bäckblom, 2009	Bolt	Load on bolt		102	Observe plate
Dynamic support system testing					
Buckling plate test	TSL, Shotcrete	Evaluate behaviour		103	surface support
SIMRAC	Support system	Evaluate behaviour	7.67 m/s	104	
Ortlepp and Stacey, 1998	Support system	Capacity under dynamic loading	8 m/s	105	
SRK drop weight	Support system	Determine performance	8 m/s	106	Can also be used with wedge-block
GRC	Support system	Capacity under dynamic loading	8.8 m/s	106	
Ortlepp, 2000	Support system	Capacity under dynamic loading	7.7 m/s	107	
Ortlepp and Swart, 2002	Support system	Capacity under dynamic loading	7.7 m/s	108	Upgraded rig from Ortlepp, 2000 2-dim pyramid
Static testing of support system and rock mass					
Instrumented bolts	Bolt	Long-term behaviour		109	
Singh and Buddery, 1983	Bolt	Mechanical performance and efficiency of anchorage combos		109	in special test drive pullout tests
Tannant, 1995	Bolt	Bolt behaviour	300 kN	110	Over several years
Simulated rockbursts					
Bajzeli, Likar and Zigman, 1995	Bolts	Dynamic bolt behaviour		111	
Hagan et al., 2001	mesh and lacing	Dynamic behaviour of support	50 MPa	111	
Haile and LeBron, 2001	bolts	relation to PPV		111	
Player, Morton, Thompson and Villaescusa, 2008	Mesh	Dynamic behaviour of mesh	0.5-1 t	112	
Heal and Potvin, 2007	Support system/Rock mass	Dynamic behaviour		112	
GRC CANMET Lab	Support system/Rock mass	correlation between PPV and strain in bolt		112	
GRC Bousquet #2	Support system/Rock mass	Compare performance of different systems		113	

Name, Year	Tested unit	Object	Capacity or rate	Page in Main Report	Remark
CSIR Kopanag Test	Support system/Rock mass	Influence of suppport on rock, calibrate programs, study fracturing process		113	
INCO	TSL, shotcrete/rock mass	Compare different systems		113	
Queen's University	Support system/Rock mass	Compare capabilities of different systems		113	
University of Western Australia	Support system/Rock mass	Direct comparison of different systems		113	
Falconbridge	Support system/Rock mass	Compare different systems and calibrate numerical model		114	