ROCKBOLT TENSILE LOADING ACROSS A JOINT

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1. INTRODUCTION

In recent years the range of applications for rockbolts has widened throughout the world as an alternative to more traditional forms of rock support. Furthermore, the development of new rockbolt concepts has led to the use of rockbolts in non-traditional applications.
The engineer who must design rock reinforcement systems today is faced with an increasing demand to optimize his design with respect to both safety and economic considerations. The principal objective in the design of a support system is to help the rock mass to support itself. This applies to rock reinforcement systems, e.g., where the rockbolts actually form part of the rock mass. The rockbolt reinforces and mobilizes the inherent strength of the rock mass by constraining the movements of individual blocks of rock. Block movements are constrained principally by rockbolts intersecting the joints between blocks.

Traditionally, standard pull-out tests are used by engineers to obtain guidance on the load bearing capacity and the load-deformation characteristics of installed rockbolts. There are however, depending on the type of rockbolt tested, a number of disadvantages in using standard pull-out tests as a means of testing and comparing different rockbolt types. One obvious deficiency being that a standard pull-out test simply does not provide the load-deformation characteristics of a rockbolt subjected to loading across a joint in the rock, a situation for which rockbolts are designed. Below the concept of the ideal rockbolt, subjected to load across a single joint, is presented and discussed in terms of load-displacement characteristics.

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.

Reported is the test results, employing the developed test arrangement, of the most commonly used types of rockbolts. Further, the test results are discussed and compared with the characteristics of the ideal rockbolt.

2. THE CONCEPT OF THE IDEAL ROCKBOLT

Here it is interesting to consider the ideal load-displacement characteristics of an installed rockbolt acting across a single joint in tension. A relationship that can be given independent of available ground conditions, from swelling/-squeezing rock to extremely hard and brittle rock, in low or high stress conditions.

The ideal bolt system, should initially act infinitely stiff in order to attract load and by doing so help to maintain the integrity of the rock mass as much as possible. However, as the load on the bolt gets near its ultimate tensile strength the bolt should have the ability to accommodate large rock deformation, not fail or drop in its load bearing capacity. The bolt behaviour should be rigid/perfectly-plastic.
This ideal load-displacement characteristics of an installed rockbolt is schematically illustrated in Fig. 1.

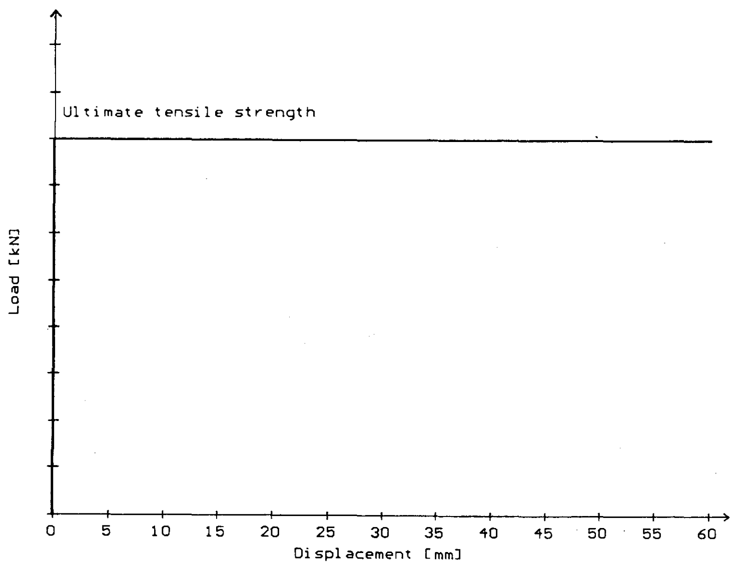

Fig. 1 The ideal load-displacement characteristics of an installed rockbolt, independent on ground conditions.

3. REVIEW OF ROCKBOLTS TESTED

A number of different types of rockbolts are now used worldwide. One soon realizes in planning for a comparative test program, the impossibility of testing all the different types. Many rockbolt types show however, only minor differences in their design and are basically varieties of the same concept. It is therefore possible to arrange the different types of rockbolts in groups and test representatives from each group, particularly since the prime interest of the study was to compare the general characteristics of different types of rockbolts.
Classification of the different types of rockbolts are made on the basis of their anchoring mechanism.

The following groups of bolts are considered:

- Mechanically anchored rockbolts
- Grouted rockbolts
- Friction anchored rockbolts

In order to limit the content of this paper results are presented only on a limited number of the types of rockbolts tested, the complete report, Stillborg (1992) include all different rockbolts and cablebolts tested.

3.1 Mechanically Anchored Rockbolts

The expansion shell anchored rockbolt, of standard or bail type, is the most common form of mechanically anchored rockbolt. The expansion shell anchor operates basically in the same manner whether it is of standard or bail type. A wedge attached to the bolt shank is pulled into a conical expansion shell as the nut on the bolt is rotated. This forces the shell to expand against and into the wall of the borehole. The nut is rotated until a preset torque is reached, resulting in the desired bolt tension.

The effectiveness of an expansion shell anchored rockbolt strongly depends basically on two "points", the grip of the shell against the borehole wall and the contact between the rock and the face plate.

The two mechanisms by which the shell is anchored against the borehole wall are; friction and interlock. The second of the two is the most significant in order for the rockbolt to provide optimum support action.

For application in permanent reinforcement systems, the void between the bolt shank and the borehole must be postgrouted.

Figure 2 illustrates the mechanically anchored rockbolt tested, including some technical data on the rockbolt and conditions at the tests.

3.2 Grouted Rockbolts

The most commonly used grouted rockbolt is the fully grouted rebar or threaded bar made of steel. Cement or resin are used as grouting agents. The rebar or the threaded bar used with resin creates a system for tensioned rockbolts. More common is however the rebar or the threaded bar used as untensioned bolts with cement or resin as grouting agents. Both systems are used for temporary as well as permanent support under various rock conditions. The threaded rockbolt is mainly used in particular civil engineering applications for permanent installation.
The grouted rockbolts are confined inside the borehole by means of cement or resin grout. Anchoring, (bond) between the bolt and the rock is provided along the whole length of the reinforcing element by means of three mechanisms; chemical adhesion, friction and interlock. The second and third mechanisms are by far the most significant. The bond due to chemical adhesion may often, therefore, be disregarded.

Figures 3 and 4 illustrate the two different systems of rebar rockbolts tested, including some technical data on the rockbolts and conditions at the tests.

A more recent development compared with the rebar is the fibreglass rockbolt. Resin, commonly in the form of resin cartridges, is exclusively used as the grouting agent, very much similar to the resin grouted rebar. The high tensile strength coupled with a low unit weight is the principal advantage over the rebar, not considering special applications where steel bars can not be used. Bond between the bolt and the rock is provided along the whole length of the rockbolt however principally by two mechanisms; chemical adhesion and friction. Interlock do not play an active role in the anchoring of the fibreglass rockbolt since the bolt shank generally is not supplied in the form of a "rebar".

Figure 5 illustrates the type of fibreglass rockbolt tested, including some technical data on the rockbolt and conditions at the tests.

The effectiveness of a grouted rockbolt strongly depends on two factors; the quality of the grout and the quality of the grouting. Both factors are equally important however difficult to control.

3.3 Friction Anchored Rockbolts

Friction anchored rockbolts represent the most recent development in rock reinforcement techniques. Two friction anchored rockbolt types are available, the Split Set and the Swellex. For both types of rockbolt system, the frictional resistance to sliding, (for the Swellex combined with interlocking) is generated by a radial force against the borehole wall over the whole length of the bolt. The Split

Set rockbolt is forced into a borehole slightly smaller than the bolt whereas the Swellex is expanded inside the borehole into the irregularities of the borehole wall by means of a high pressure water pump.
Although the two systems are presented under a common heading, they display some major differences. These are related to the anchoring mechanism and their support action, as well as their installation procedure.

The anchoring mechanism of the Split Set will prevent the bolt from sliding up to a load of approximately half the ultimate tensile strength of the bolt, when the bolt will slide.

The anchoring mechanism of the EXL Swellex will prevent the rockbolt from sliding. However, as the load approaches the ultimate tensile strength of the bolt the bolt slide. This property of the EXL Swellex rockbolts implies that the full strength of the bolt is utilized.

Friction anchored rockbolts are the only type of bolts where the load of the rock is transferred to the reinforcing element directly without any necessary auxiliaries such as mechanical locking devices or grouting agents.

Coated Swellex is required for permanent installations and Split Set can only be used in temporary reinforcement.

Figures 6 and 7 illustrate the two different types of friction anchored rockbolts tested, including some technical data on the rockbolts and conditions at the tests.

Expansion Shell Anchored Rockbolt*

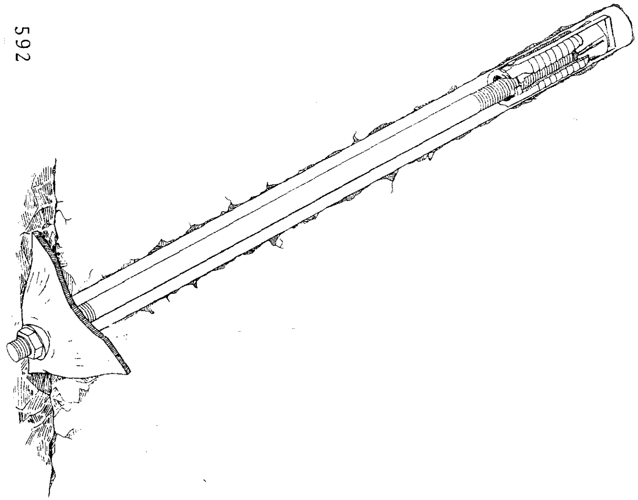

Fig. 2

Technical data and conditions at the tests

Steel diameter: 17.28 mm.
Ultimate tensile strength of bolt shank, (smooth steel bar): Approx. 127 kN (12.7 tons).
Type of expansion shell anchor: Bail type.
Type of face plate: Triangular bell plate, nut with hemi-spherical seating.
Bolt pre-tensioning applied: 22.5 kN, (2.25 tons).
Bolt length: 3 meter.
Borehole diameter[1]: 34 mm.

1) Recommended borehole diameter: 33-35 mm.
GIA Expander bult of GIA industri ab, Sweden.

Cement Grouted Rockbolt - Rebar

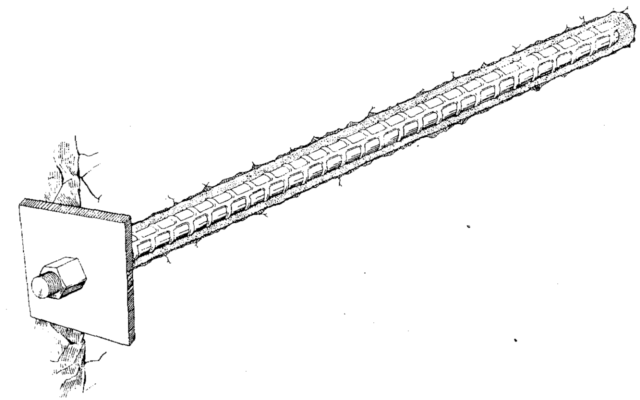

Fig. 3

Technical data and conditions at the tests

Steel diameter: 20 mm.
Ultimate tensile strength of bolt: 180 kN, (18 tons).
Type of face plate: Flat plate.
Bolt length: 3 meter.
Borehole diameter[1]: 32 mm.
Cement grout: w/c-ratio 0.35, curing time 11 days[2].

1) Recommended borehole diameter: 30-40 mm.
2) The cement grout was injected through a grout inlet tube at the bottom of the borehole and the grout injection was discontinued as the borehole was full of grout. The rock-bolt was subsequently inserted into the borehole.

Resin Grouted Rockbolt - Rebar

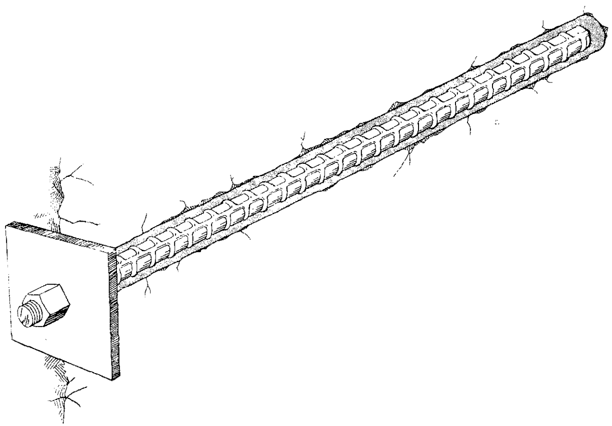

Fig. 4

Technical data and conditions at the tests

Steel diameter: 20 mm.
Ultimate tensile strength of bolt: 180 kN, (18 tons).
Type of face plate: Flat plate.
Bolt length: 3 meter.
Borehole diameter[1)]: 32 mm.
Resin grout: Five 580 mm long, 27 mm diameter polyester resin cartridges, curing time 60 min[2)].

1) Recommended borehole diameter: 30-40 mm.
2) The mixing of the resin took place when the bolt was rotated through the cartridges in the borehole.

Resin Grouted Rockbolt - Fiberglass rod*

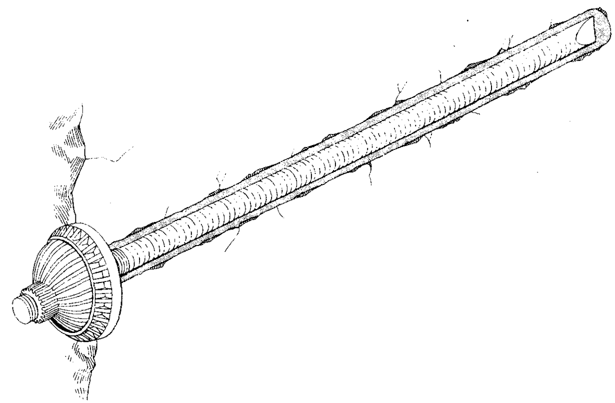

Fig. 5

Technical data and conditions at the tests

Fiberglass rod diameter: 22 mm.
Ultimate tensile strength of bolt: 350 kN, (35 tons).
Type of face plate: Special design for the bolt.
Bolt length: 3 meter.
Borehole diameter[1)]: 32 mm.
Resin grout: Five 580 mm long, 27 mm diameter polyester resin cartridges, curing time 60 min[2)].

1) Recommended borehole diameter: maximum 32 mm.
2) The mixing of the resin took place when the bolt was rotated through the cartridges in the borehole.

* Weidmann Fiberglass Rockbolt of H. Weidmann AG, Switzerland.

Friction Anchored Rockbolt - Split Set, type SS 39*

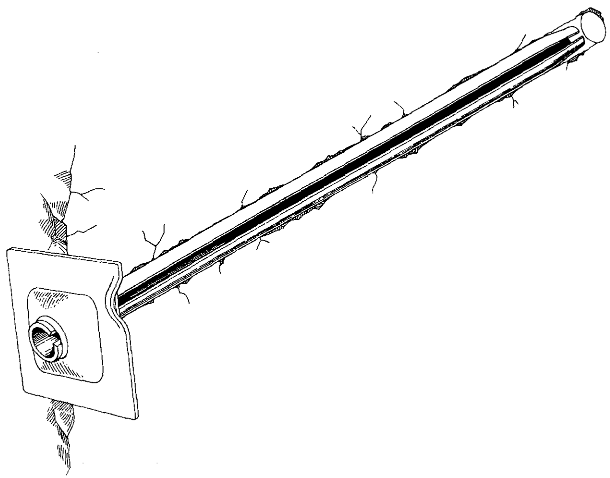

Fig. 6

Technical data and conditions at the tests

Tube diameter: 39 mm.
Ultimate tensile strength of steel tube: 110 kN, (11 tons).
Type of face plate: Special design by the manufacturer.
Bolt length: 3 meter.
Borehole diameter[1]: 37 mm.

1) Recommended borehole diameter: 35-38 mm.
* Split Set of Ingersoll-Rand Company, USA.

Friction Anchored Rockbolt - EXL Swellex*

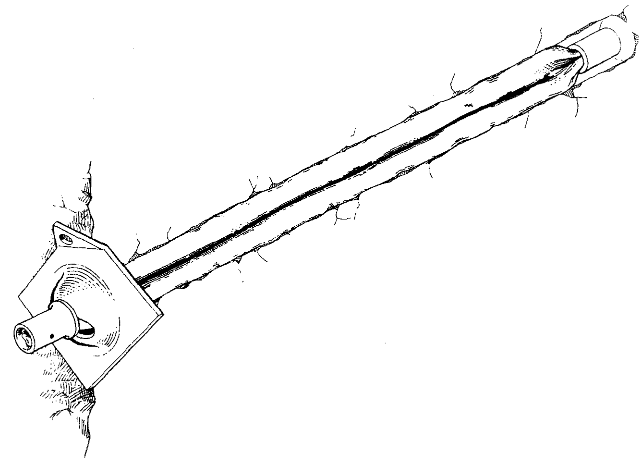

Fig. 7

Technical data and conditions at the tests

Tube diameter, before expansion: 26 mm.
Ultimate tensile strength of steel tube, before expansion: 110 kN, (11 tons).
Type of face plate: Domed plate.
Bolt length: 3 meter.
Borehole diameter[1]: 37 mm.
Pump pressure for expansion of bolt: 300 bar.

1) Recommended borehole diameter: 32-39 mm.
* Swellex of Atlas Copco AB, Sweden.

4. TEST ARRANGEMENT

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 8.

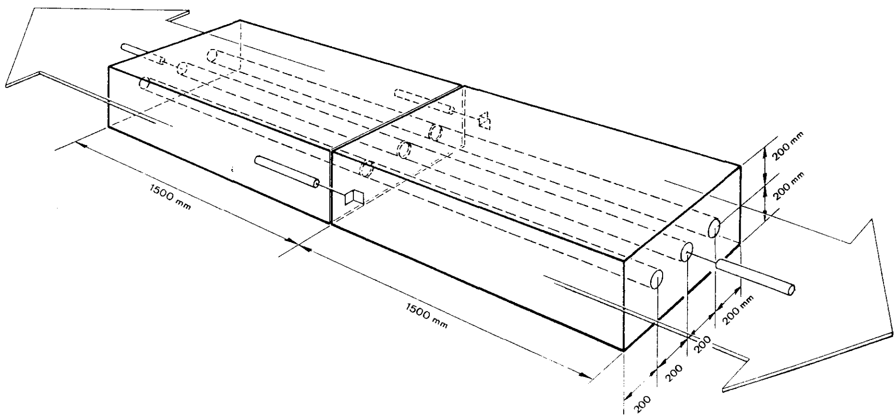

Fig. 8 Schematic illustration of the test arrangement for rockbolt tensile loading across a joint. Note, for practical purpose three bolts, one at the time, can be tested in the same test set-up.

High strength reinforced concrete with a compressive strength of σ_c = 60 MPa was used for the two 1.5 meter concrete blocks simulating two 1.5 meter 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 meters. 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. Friction 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 mated 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.

Three rockbolts of each type were tested. Based on the three test results a graph was constructed that represents the mean value of the three tests. The monitoring system further facilitated data processing and final presentation of the results as it appears in the next section of this paper.

Altogether sixty blocks of concrete were used in the test program. One advantage in using concrete blocks in a comparative test program as oppose to blocks of rock is the consistency in the properties of the concrete blocks that can be obtained.

A general overview of the test arrangement and the measurement system is shown in Figure 9.

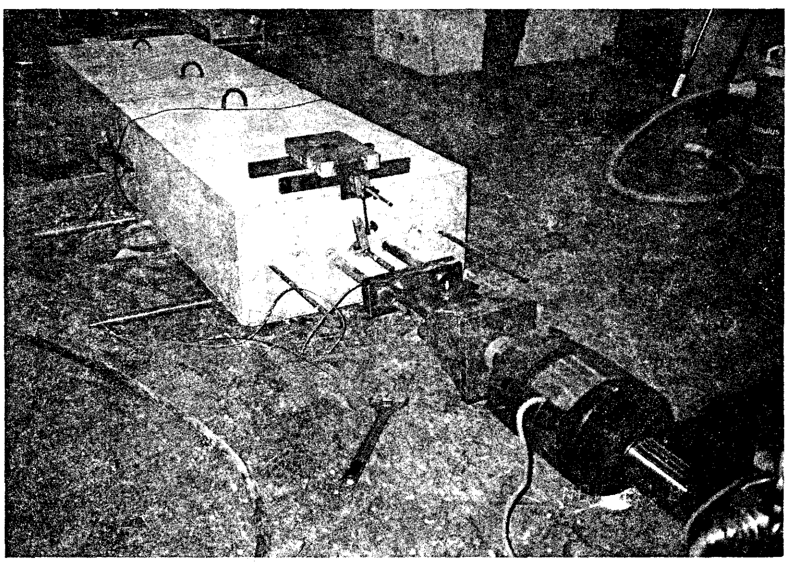

Fig. 9 General overview of the test arrangement. Part of the load actuator and the measurement set-up for registration of bolt sliding can be seen in the foreground. To the left side of the blocks is one of the joint opening measurement LVDT set-up.

5. RESULTS WITH COMMENTS

The test results, (mean value of three tests) are presented graphically and comments are given with reference to each type of bolt tested. In order to facilitate comparison of results between different types of bolts, the axis of the diagrams are given in the same scale whenever practical. As stated in the previous section, the test arrangement with associated measurements allowed for monitoring of joint opening, as well as any rockbolt deformation/displacement as a function of applied load.
Without lend oneself to any mathematical developments it is important to distinguish between rockbolt deformation and rockbolt displacement. Rockbolt deformation is a change of size and shape of the rockbolt that occurs as a result of loading. This change may be also defined as strain. Rockbolt displacement occurs when the inner and/or the outer end of the rockbolt moves relative to the rock as a result of loading. This movement is also defined as general bond failure, sliding of the bolt. Practically, for rockbolt displacement, one is principally concerned only with the inner end that moves since the outer end is prevented to move by the face plate.
One of the two, deformation or displacement, can theoretically occur independent of the other, however, in practice rockbolt displacement will always be associated with rockbolt deformation. Consequently in the diagrams, when no bolt sliding occurred, load has been plotted against deformation but when sliding was present load has been plotted against displacement.

5.1 Mechanically Anchored Rockbolts

Expansion Shell Anchored Rockbolt, Fig. 10.

Before the bolt load reaches the level of pre-tensioning 22.5 kN, no rockbolt deformation occurs. At 22.5 kN, the face plate starts to deform. At a load of 30 kN the face plate is deformed 4.5 mm and at the load of 40 kN the deformation of the face plate is 9.5 mm. The bolt shank has deformed an additional 3.5 mm at a load of 40 kN. This gives a total rockbolt deformation of approx. 13 mm at the load of 40 kN.
At the load of 40 kN the triangular bell plate is completely flat and only the bolt shank deforms. At a load of approx. 80 kN and 25 mm of rockbolt deformation, the expansion shell anchor fails progressively when the wedge, attached to the bolt shank, is pulled through the conical anchor shell. The rockbolt fails completely at a load of approx. 70 kN.
The bolt accommodate a total displacement of approx. 35 mm, combined face plate deformation, bolt shank deformation and "anchor slippage", under an increasing load bearing capacity up to approx. 90 kN.

5.2 Grouted Rockbolts

Cement Grouted Rockbolt - Rebar, Fig. 11.

The rockbolt does not slide but is loaded up to failure which occurs between the blocks, in the joint, at approx. 180 kN, (18 tons) and 30 mm of rockbolt deformation.
The sudden drop in load which can be seen in the graph at approx. 150 kN reflects the typical characteristics of the hot rolled rebar steel subjected to tensile loading.

Resin Grouted Rockbolt - Rebar, Fig. 12.

The rockbolt does not slide but is loaded up to failure which occurs between the blocks, in the joint, at approx. 180 kN, (18 tons) and 20 mm of rockbolt deformation. The resin is stiffer than the cement and local fracturing as well as bond failure in and near the joint is limited, resulting in comparatively smaller rockbolt deformation. The loading of the rockbolt is concentrated over a short section of the rockbolt.

Resin Grouted Rockbolt - Fibreglass rod, Fig. 13.

Initially no deformation occurs in the rockbolt up to a load of approx. 15 kN. At 15 kN, the bolt starts to deform locally between the two blocks, in the joint. At the same time bond failure, failure of the chemical bond and over-come of the friction, at the rockbolt-resin interface, starts to progress along the bolt, initiated at the position of the joint. As bond failure progress the bolt deforms over a progressively longer "free" length.
General bond failure is reached at load of approx. 260 kN (26 tons). This corresponds to a rockbolt deformation of approx. 25 mm. As general bond failure occurs the bolt starts to slide and can take no more load.
It is a general observation that the bond strength between the rockbolt and the polyester resin, the chemical bond including the relatively low frictional resistance of the fibreglass rod, determines the ultimate load bearing capacity of the rockbolt.
The bolt accommodate a total rockbolt deformation of approx. 25 mm under an increasing load bearing capacity up to approx. 260 kN, when the rockbolt starts to slide and can take no more load.

5.3 Friction Anchored Rockbolts

Friction Anchored Rockbolt - Split Set, type SS 39, Fig. 14.

The frictional resistance is overcome and the bolt starts to slide, at approx. 50 kN, (5 tons). The sliding of the bolt is preceded by no measurable rockbolt deformation. The rockbolt maintains however, a constant load bearing capacity for at least the duration of the test which was 150 mm of joint opening.

Friction Anchored Rockbolt - Swellex, type EXL, Fig. 15.

Initially no deformation occurs in the rockbolt up to a load of approx. 50 kN, (5 tons). At 50 kN, the bolt starts to deform locally between the two blocks, in the joint. At the same time "bond failure" occurs near the joint, (some of the frictional and interlock resistance are overcome, partly due to lateral contraction of the bolt). As the load increases the "bond failure" progress and the bolt deforms over a progressively longer "free" length. General "bond failure" reaches the far end of the bolt at approx. 115 kN, (11.5 tons). This corresponds to a rockbolt deformation of approx. 10 mm. At general "bond failure" the bolt starts to slide. The rockbolt maintains however, a constant to increasing load bearing capacity for at least the duration of the test which was 150 mm of joint opening, divided into initially 10 mm of rockbolt deformation followed by approx. 140 mm of sliding.

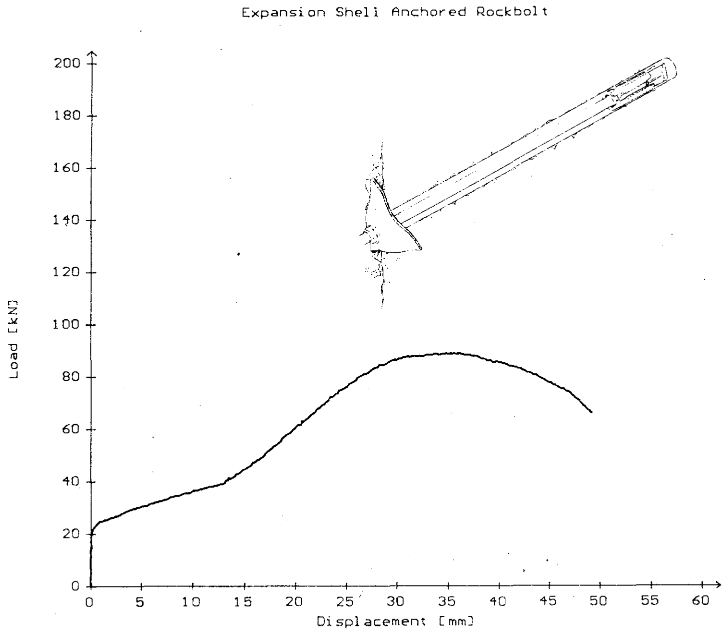

Fig. 10 Expansion shell anchored rockbolt, tensile loading across a joint.

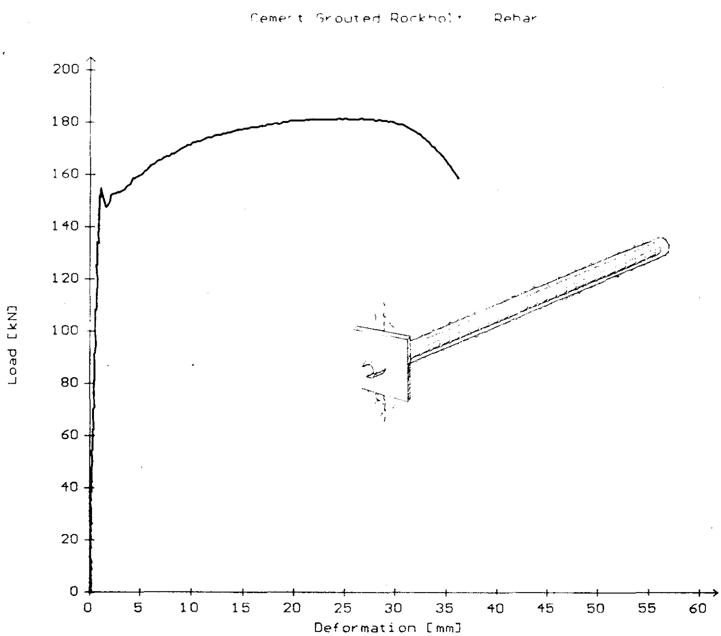

Fig. 11 Cement grouted rockbolt - rebar, tensile loading across a joint.

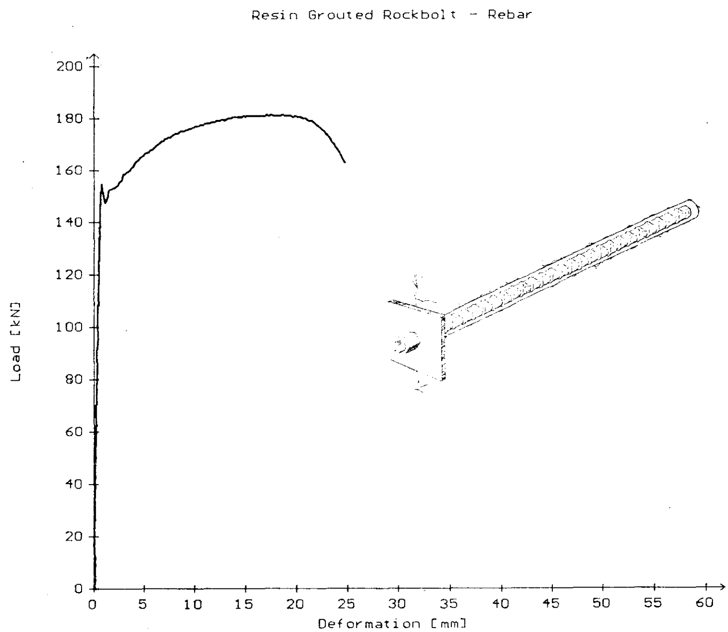

Fig. 12 Resin grouted rockbolt - rebar, tensile loading across a joint.

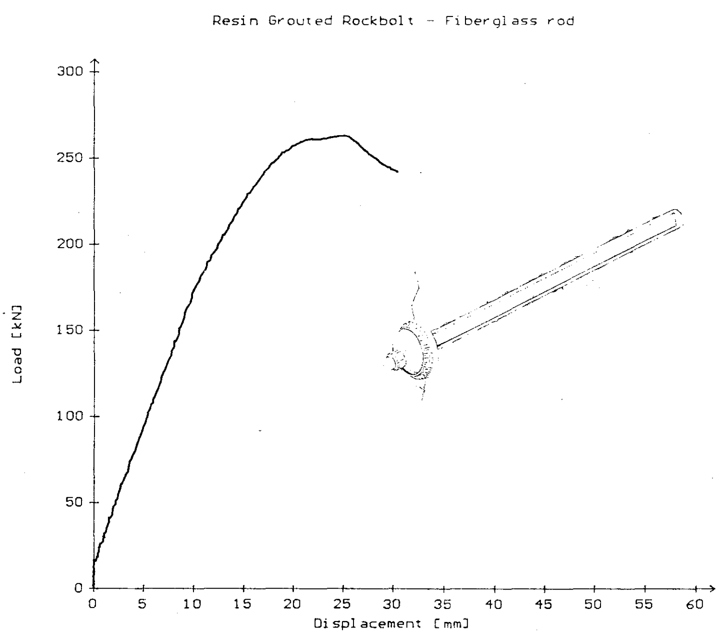

Fig. 13 Resin grouted rockbolt - fibreglass rod, tensile loading across a joint.

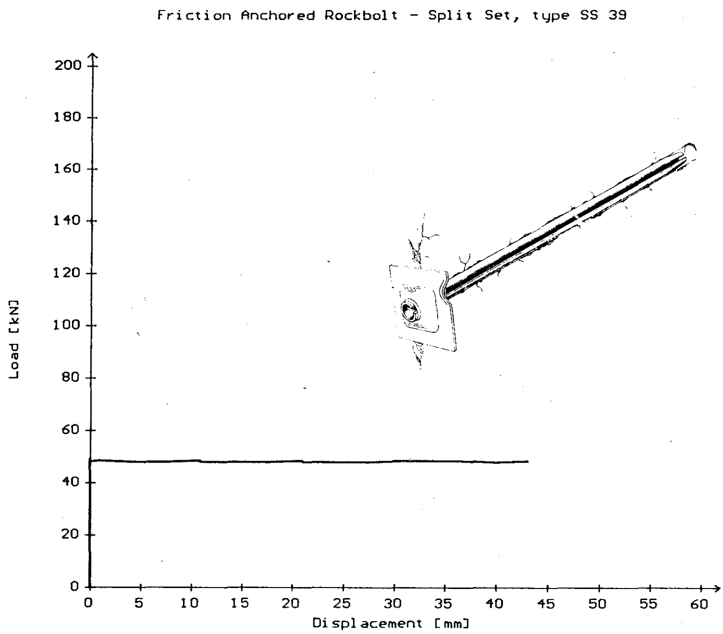

Fig. 14 Friction anchored rockbolt - Split Set, type SS 39, tensile loading across a joint.

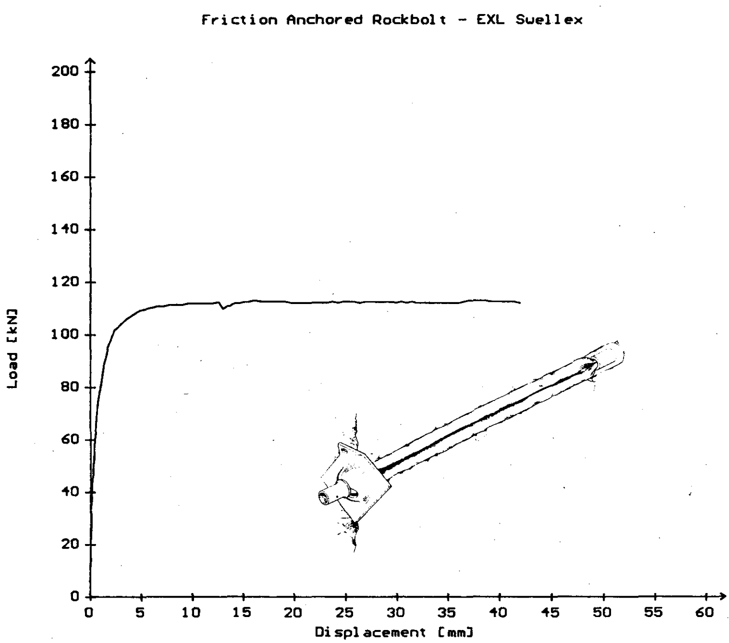

Fig. 15 Friction anchored rockbolt - Swellex, type EXL, tensile loading across a joint.

6. DISCUSSION

It is clear from the test results given in figures 10 to 15 matched with the technical specifications for the respective bolts tested that some bolts better than others resemble the ideal load-displacement characteristics of an installed rockbolt, as given in Fig. 1. The information should serve most valuable in the choice of rockbolt system.
The results reported above must however, not lead one to believe that this information alone is the key to a successful rockbolt design. Apart from the load-displacement characteristics of the rockbolt it is important to consider the following rockbolt system (rockbolt and installation equipment) properties;

- versatile, can be used in any excavation geometry,

- installation procedure must be simple and reliable such that the rockbolt can be installed with a high rate of success,

- the rockbolt should give immediate support action after installation and should be able to install in water-filled boreholes,

- the system should be relatively inexpensive,

- sometimes the shear strength of the rockbolt has to be considered.

7. ACKNOWLEDGMENT

The tests have been carried out by James Askew Associates, (JAA AB), Sweden and the Dept. of Rock Mechanics at the University of Technology in Luleå, Sweden in co-operation, as part of ongoing work which aim at improving methods for the design of rockbolt reinforcement. The testing has been conducted at and in close co-operation with the Division of Structural Engineering at the University of Technology in Luleå. The financial support provided by the different rockbolt manufacturers is greatly appreciated.

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