Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 29, No. 5, pp. 525–533, 1992
Printed in Great Britain

0148-9062/92 $5.00 + 0.00
Pergamon Press Ltd

Technical Note

An Experimental Procedure for the *In Situ* Testing of Cable Bolts

W. F. BAWDEN†
A. J. HYETT†
P. LAUSCH†

INTRODUCTION

Although, it has been 10 yr since the ISRM outlined a Suggested Method for rock bolt testing [1], no standard test procedure exists for the field testing of cable bolts. Consequently, the majority of researchers have conducted tests on cable bolts in much the same manner as if they were testing rock bolts. This typically involves grouting a short section (usually 250 mm) of cable into a borehole, approx. 1–3 m away from the collar, and pulling on that portion of the cable that projects from the collar using a barrel and wedge grip. By necessity, a section of free cable exists, the length of which depends on the distance between the test section and the borehole collar. Standard 7-strand cable has a relatively low torsional rigidity (compared to a rock bolt), and therefore, the short embedment length test section is able to fail by a simple "unscrewing" mechanism. As a result, unrealistically low failure strengths are recorded, due to failure by a mechanism which has little relevance to any mining application (Fig. 1). The pull out response when rotation of the pulling set-up allows unscrewing and when it is prevented are compared in Fig. 2. In the former case, the response is almost perfectly plastic as would be expected for slip between the steel cable and cement in the absence of dilatation. However, in the latter case strain hardening is observed up to relatively high displacments (30–50 mm), due to an additional frictional component related to the mobilization of "geometric mismatch" (analogous to roughness for a rock joint) between the cable and cement as displacement proceeds [2].

The objective of this Technical Note is to describe a proven experimental procedure designed to eliminate rotation during cable pull tests. It has been successfully used for tests involving both standard 7-strand cable and modified cable geometries such as "birdcage" cable and "nutcase" cable. For the 7-strand cable this has allowed a correlation to be demonstrated between laboratory tests, using the standard split-pipe test described by Fuller and Cox [3] and *in situ* field tests [2]. This could be a precursor to an ISRM Suggested Method and so the authors would appreciate receiving any comments on the procedure described here.

SITE SELECTION

In situ cable pull tests are designed to measure the short-term strength of a short section of cable bolt installed under representative field conditions. For underground tests, site selection can be the most critical aspect of the entire test programme. Selection should be based on the following criteria:

(i) The test programme should be conducted in a rock mass which is representative of that in which the cable bolts are installed in normal operational practice. This may require tests at several different locations so as to access different rock types or rock masses of different quality. If the rock displays bedding or a foliation, test holes should be drilled at the same relative angle as operational cable bolt holes.
(ii) If a "mine-by" experiment is proposed it is important that the test hole locations and orientations are such as to be subjected to representative mining-induced stress changes.
(iii) Tests are most conveniently conducted in dry holes.
(iv) An area with limited access is preferable as long as the rock mass is representative of that expected for operational cable bolting.

It is recommended that, if possible, test holes should be drilled in the excavation walls at angles steeper than 30°. Borehole deviation can be a factor, especially in poor-quality ground, and as a precaution holes should be kept shorter than 5 m. Test hole size should be the same as the operation's cable bolt holes (usually 57–64 mm), although sometimes it is convenient to work in slightly oversize holes. Figure 3 shows results for comparable tests conducted for 57 and 76 mm holes. As a general

†Department of Mining Engineering, Queen's University, Kingston, Ontario, Canada K7L 3N6.

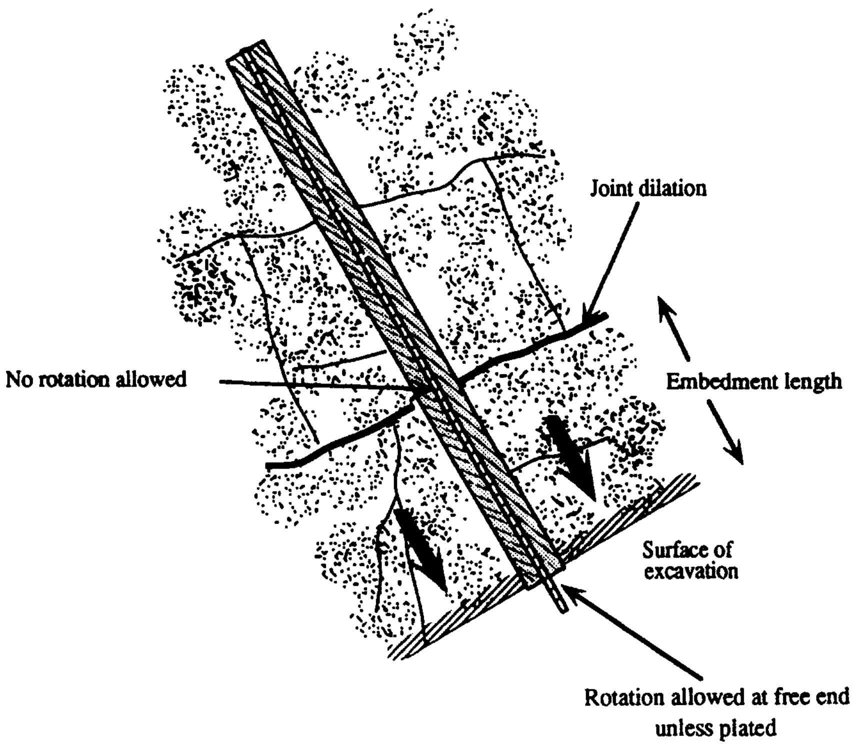


Fig. 1. Failure of cable bolt in mining practice. The fracture at which dilation occurs and which defines the embedment length may be either natural or stress induced. No rotation or twisting of the cable is allowed across this interface. However, at the exposed end of the cable rotation/twisting is allowed: it can be prevented by the addition of plates.

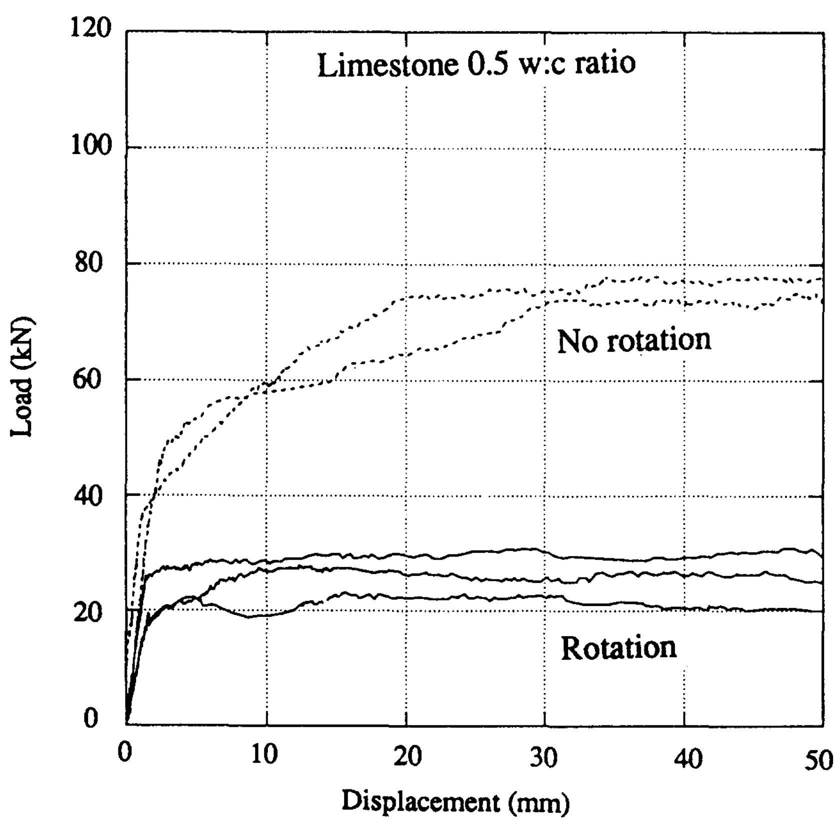


Fig. 2. Pull out response for cases in which rotation of the pulling system is allowed and prevented. Tests were conducted in limestone with a 0.5 water:cement ratio grout.

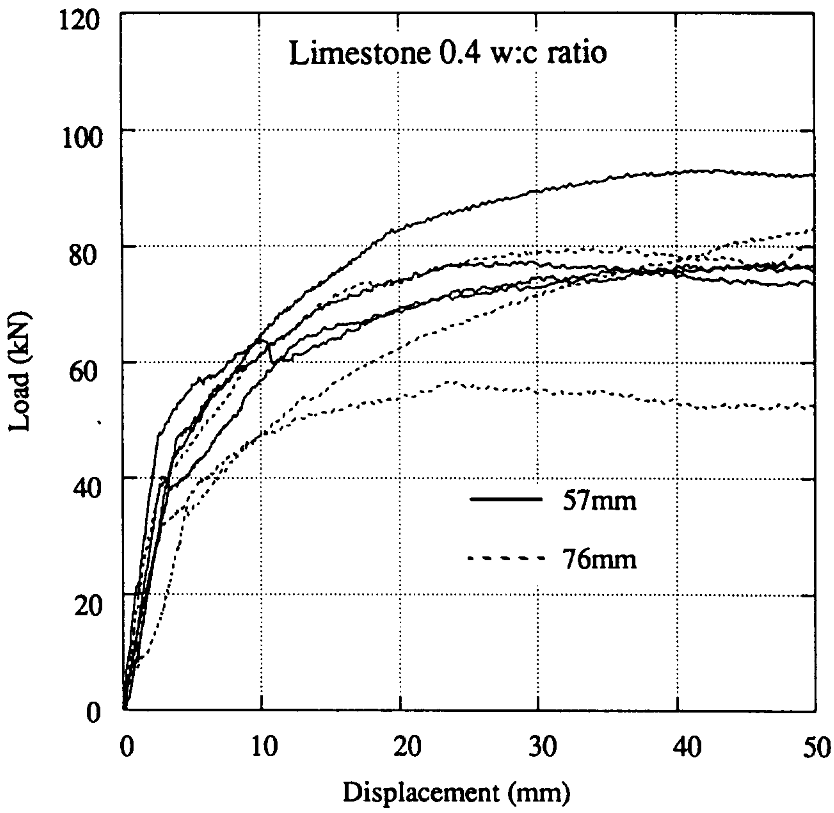


Fig. 3. The effect of hole size on pull out response. Tests were conducted in a limestone with a 0.4 water:cement ratio grout.

rule the use of oversize holes will result in lower pull out loads owing to the increase in thickness of the relatively deformable grout annulus.

The collars of the holes should be reamed to diameter of 130–150 mm, to provide a bearing surface during pulling.

TEST EQUIPMENT

The test equipment required can be divided into two categories:

(i) installation equipment; and
(ii) pull out equipment.

Installation equipment

The cable specimens themselves comprise the main component of the installation equipment. Each specimen weighs about 6 kg. A typical example is shown in Fig. 4. The thick walled pulling pipe was selected with a wall thickness sufficient to support 35 tonnes after internal threading (5 threads/in.). The internal thread must be left-handed to counteract the torque generated during cable bolt failure (see comments below), and should be coarse enough to operate in the advent of light corrosion. Prior to grouting of the cable into the pulling pipe, a series of grooves were machined on the inside of the pipe, in order to prevent slippage at the steel pipe–grout contact. Provision must be made to centre the pipe in the hole: in the example shown PVC centralizing "fins" were used. It is recommended that tests be conducted at constant embedment length rather than decreasing embedment length (see Fig. 5 for an explanation). Figure 6 shows comparative test results for each.

The cement pump used for regular cable bolting will generally be used. The water:cement ratio of the cement can be estimated either by accurate batch mixing in the pump or from a measurement of the wet density (see Hyett *et al.* [4] for appropriate relations). A grout in the range 0.3–0.4 water:cement ratio is recommended. Equipment, typically a tray of cylinders, must be available for the collection of "control" grout samples for later uniaxial compressive strength (UCS) testing.

Pull out equipment and instrumentation

The pulling equipment is illustrated in Fig. 7. The components are:

(i) 5 m of a 25 mm dia. Dywidag (continuously threaded) bar threaded into a pulling head coupler. All threads must either be left-handed or have locking devices;
(ii) spacers for the collar of the hole;
(iii) levelling wedges;
(iv) the anti-rotation device;
(v) a 150 mm (6 in.) stroke, 30 tonne hollow ram jack;
(vi) a load cell;
(vii) a threaded Dywidag nut and plate; and
(viii) displacement measuring devices (LVDTs).

The anti-rotation device comprises a hexagonal nut, fitted with Teflon inserts to minimize friction, which can

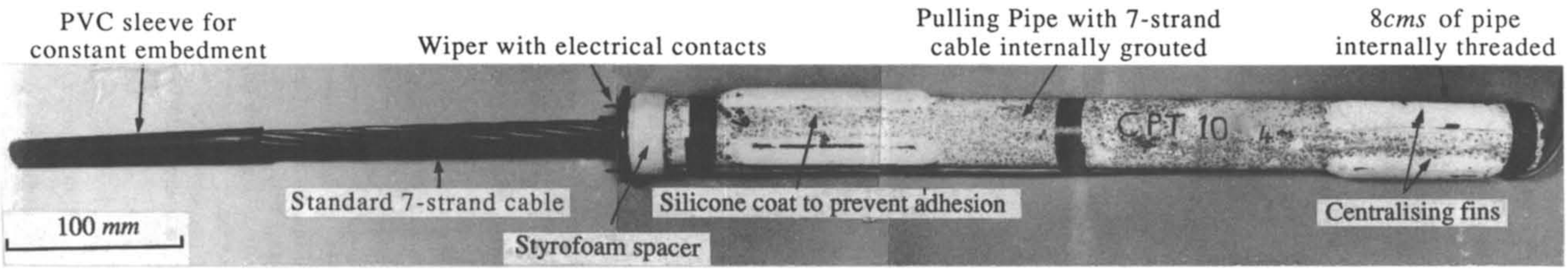
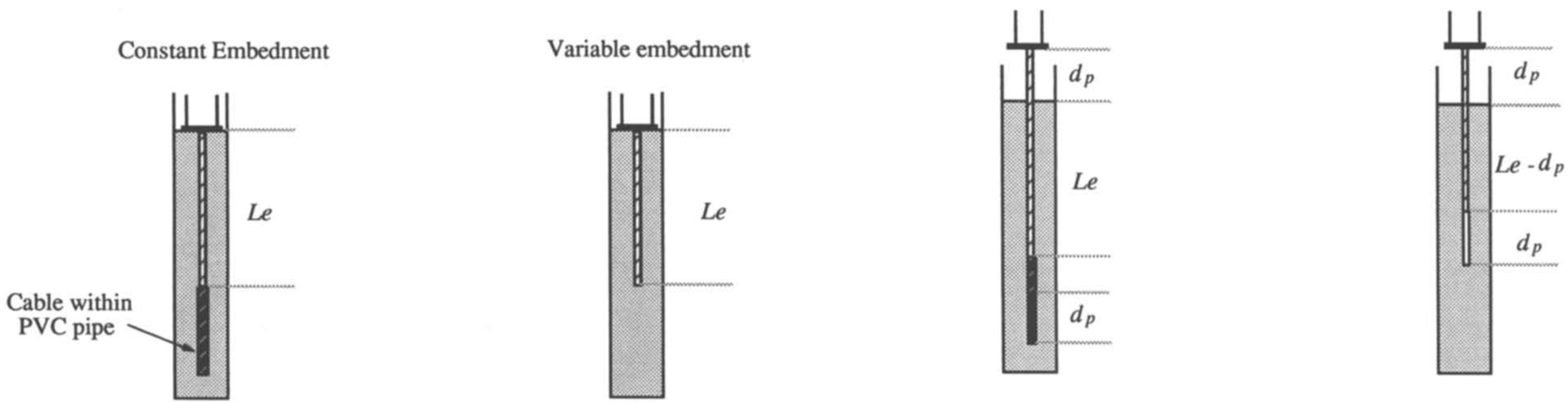


Fig. 4. A typical test specimen. The cable has been grouted into the pulling pipe except for the right-hand 8 cm which is internally threaded.



a. $d_p = 0$.

b. $d_p = 100mm$.

Fig. 5. As the name suggests, for constant embedment length tests the active embedment length (Le) is maintained during a test, whereas for variable embedment length tests it is allowed to decrease in compliment to the cable displacement (d_p).

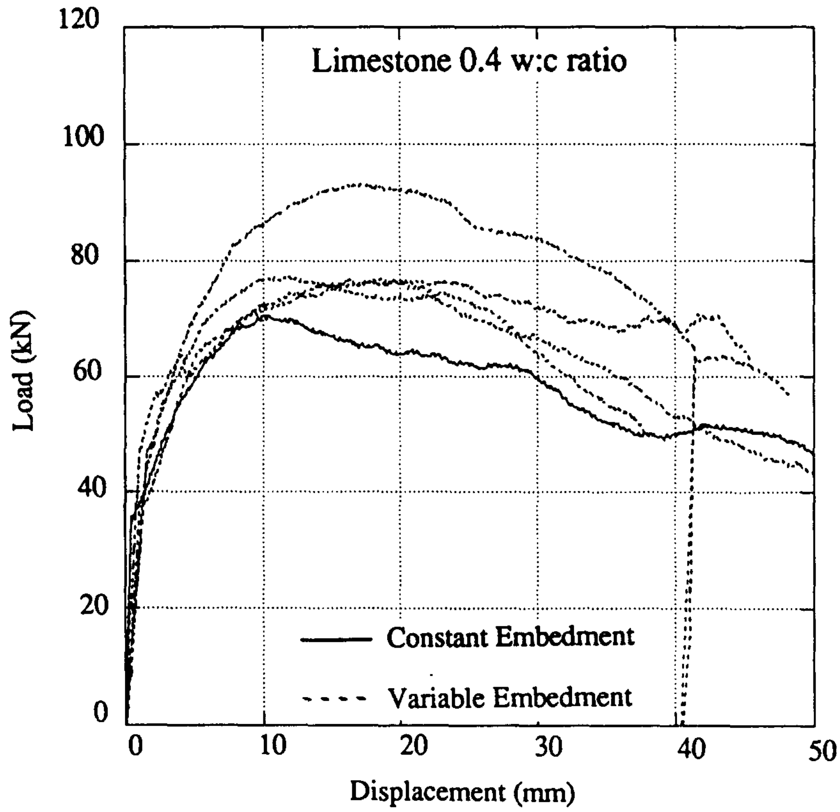


Fig. 6. Comparative test results for constant and variable embedment length tests.

be clamped onto the Dywidag bar, and will ride within a high-strength steel hexagonal sleeve during the test (Fig. 8).

PROCEDURE

Installation procedure

If wet, the holes should be pumped or blown dry. If this is impossible, perhaps because of drill tailings at the bottom of the hole, add sufficient coarse aggregate in order to raise the test section above the water level. Pump an appropriate amount of grout to the bottom of the hole and install the specimen. Two methods are used to indicate when the specimen is fully embedded:

(i) a physical resistance will be felt as the wiper (Fig. 4) contacts the grout; and
(ii) because the grout is relatively conductive, the resistance across the pair of electrical contacts built into the wiper, approx. 50 mm apart, will reduce dramatically.

The former works quite well in relatively short vertical holes, but it is not as suitable for inclined holes. Care must be taken to ensure that alignment is coaxial with the borehole axis. The specimens are then left to cure for 28 days.

Pull out procedure

A pulling rate of about 0.25–0.3 mm/sec is comparable to that used by previous workers [5]. The pulling force F_p and the cable bolt displacement (d) should be recorded at least every 0.1 sec. Deformations induced in the pull out system (in this case 39.2 tonnes/mm) should be subtracted from the cable bolt displacements. The only deformation not accounted for is that occurring at the rock–steel interface (see Fig. 7).

A series of tests were conducted to determine whether confinement at the collar of the hole has any effect on the measured cable bolt capacity. A comparison of tests using the procedure outlined in this Note, with one for which the bearing surface during pulling was at least 0.75 m away from the collar of the hole, is shown in Fig. 9.

The control UCS cement samples should be tested. Their 28-day density can be used to provide a further confirmation of water:cement ratio (again see Hyett *et al.* [4]).

PRESENTATION OF RESULTS

Results are most commonly presented as load vs displacement plots. Results of a test programme conducted at Hemlo Golden Giant Mine are presented (Fig. 10) as typical of the results that can be obtained. A typical data sheet which summarized the potentially important details of each test is presented in Table 1. It includes:

(i) information on the location;
(ii) information on the rock type, and rock mass properties, and especially any information relevant to the radial stiffness of the test hole walls (see Hyett *et al.* [2]);

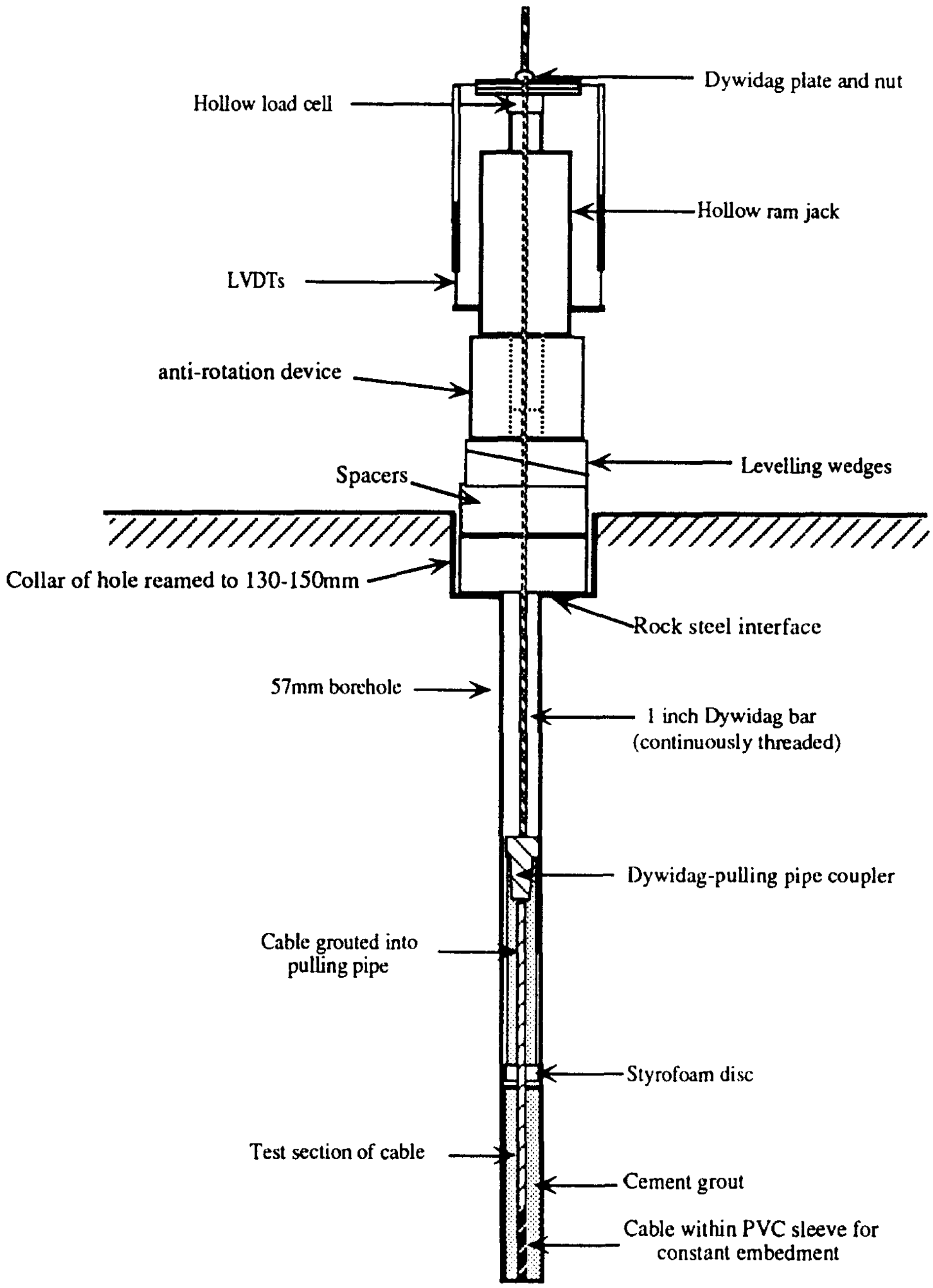


Fig. 7. Experimental set-up for *in situ* pull out test. It works equally well in the walls or floors of underground excavations.

Fig. 8. The anti-rotation device. During a pull test the hexagonal nut (lower-right) will ride inside the hexagonal sleeve. To minimize friction the sleeve is manufactured in high-strength steel and the nut is fitted with Teflon inserts (T).

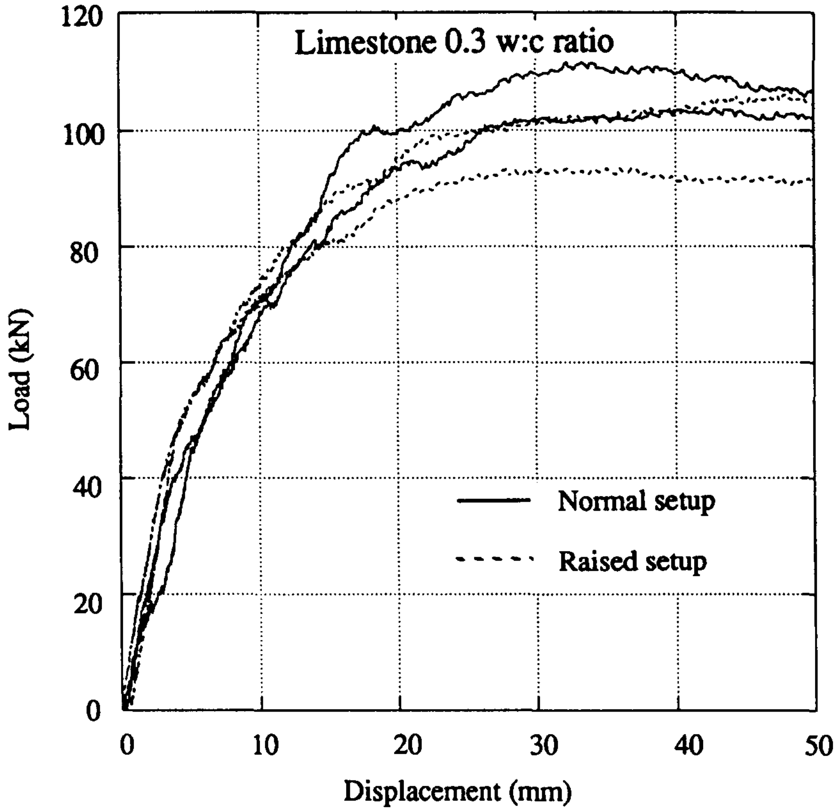


Fig. 9. Comparative test results for a normal set-up (Fig. 7) and "raised" set-up.

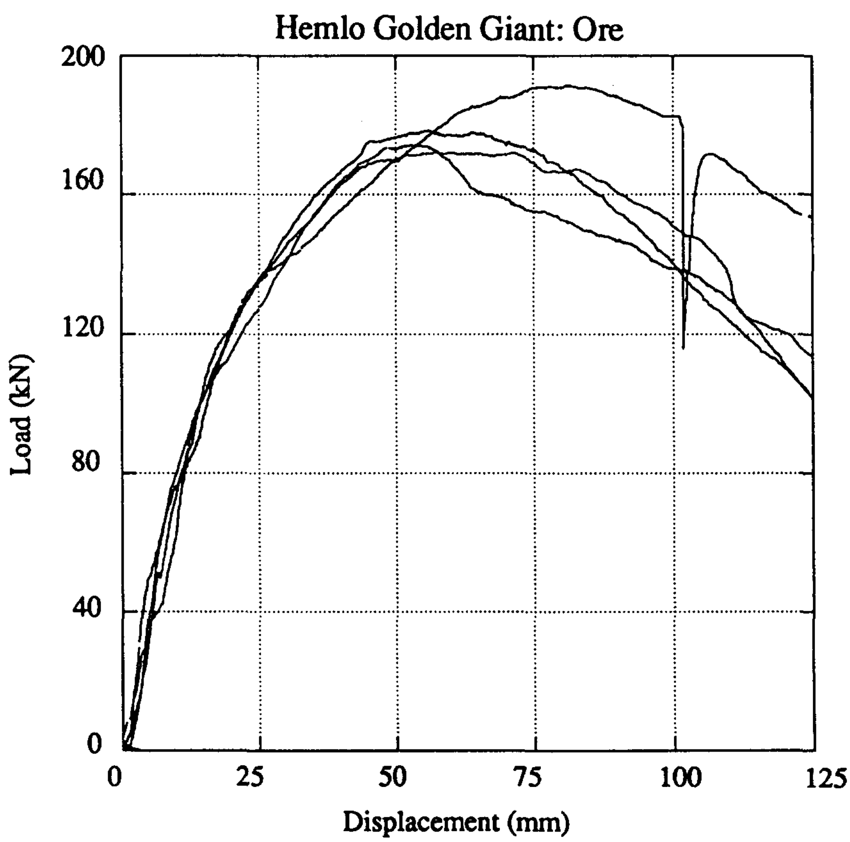


Fig. 10a. Cable pull tests conducted at Hemlo Golden Giant Mine in ore.

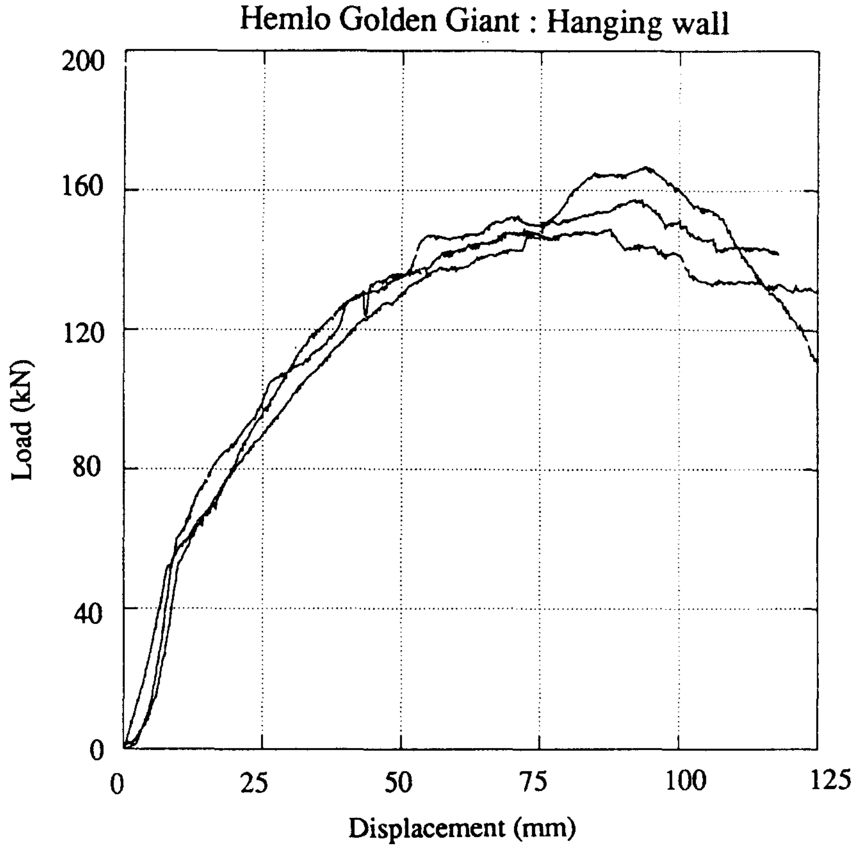


Fig. 10b. Cable pull tests conducted at Hemlo Golden Giant Mine in bulk hanging wall.

Table 1. Data sheet for the Hemlo Golden Giant test programme

Cable pull test	Result sheet	Test No: PTHEM.hw1
Date of installation: 27/7/91 Mine: Hemlo Golden Giant	Date of test: 25/8/91 Location of test: 4775 level	Depth: 546.5 m

Rock mass properties:
Rock type: bulk hanging wall
Rock mass quality (Q' or RMR): $Q' = 9.12$
Intact rock properties (if available): UCS = 82.2 MPa, Intact E = 22.31 GPa
In situ stress/stress change information: No information. No mine induced stress change.

Installation/grout data:
Hole size: 63.5 mm Hole length: 2.5 m Inclination: 40° Drill type: Percussion
Cement type (type 10/type 30): type 10
Grout pumping system used: Spidel
Grout w:c ratio: 0.34 Grout UCS: 61 MPa
pH of water: 7.0

Pull test procedure:
Type of cable (standard, birdcage etc.): 5/8" standard 7-strand. Strength: 28 tonnes
Embedment length: 250 mm Constant/variable embedment: constant
Pull rate: 0.3 mm/sec

Test characteristics:
Maximum pull force: 154 kN
Maximum displacement during test: 128 mm
Failure mechanism: Shearing of grout flutes. No rotation during test.

Condition of retrieved sample: Cable relatively undeformed. Minor unravelling at free end. Grout flutes present around cable.

Tested by: A. J. Hyett and P. Lausch

(iii) information on the grout used (particularly water:cement ratio and UCS) and the curing period;
(iv) information on the pull out test procedure: cable type; pull rate; constant or variable embedment etc.
(v) test characteristics and condition of the retrieved cable.

Hyett *et al.* [2] have demonstrated that the procedure for the field testing of cable bolts outlined above has enabled a definite correlation to be established between laboratory test results, based on the standard split-pipe experiment [3] and *in situ* field tests.

Acknowledgements—Research funding was provided by the Mining Research Directorate (MRD) under the research contract "Support of Underground Excavations in Hard Rock". Randy Reichert, Adam Coulson, Delbert Adams, Doug Milne, Yves Potvin and Alain Gendron provided helpful ideas on various aspects of the experimental design; Delbert Adams manufactured the equipment often at short notice. Jim Paynter supported the work at Hemlo Golden Giant Mine, where Donna Cortolezzis organized the test programme and Alistair Mathias helped install the test samples. Dywidag Inc. provided bars and accessories.

Accepted for publication 8 January 1992.

REFERENCES

1. ISRM Suggested Method for rockbolt testing (Franklin, Coordinator). In *Rock Characterization, Testing and Monitoring* (Brown E. T., Ed.). Pergamon Press, Oxford (1973).
2. Hyett A. J., Bawden W. F. and Reichert R. D. Effect of rock mass confinement on the bond strength of fully grouted cable bolts. *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr* **29**, 503–524 (1992).
3. Fuller P. G. and Cox R. H. T. Mechanics of load transfer from steel tendons to cement based grout. *Proc. 5th Aust. Conf. on the Mechanics of Structures and Materials*, Melbourne, pp. 189–203 (1975).
4. Hyett A. J., Bawden W. F. and Coulson A. L. Physical and mechanical properties of type 10 portland cement for underground support systems. In prep. (1992).
5. Goris J. M., Laboratory evaluation of cable bolt supports. *92nd Annual General Meeting of the CIM*, Ottawa (1990).