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INTERNATIONAL SOCIETY FOR ROCK MECHANICS

COMMISSION ON TESTING METHODS

WORKING GROUP ON FLEXIBLE DILATOMETERS

SUGGESTED METHODS FOR DEFORMABILITY DETERMINATION USING A FLEXIBLE DILATOMETER

Co-ordinator
B. Ladanyi (*Canada*)

INTRODUCTION

Background to the Suggested Methods

The ISRM Commission on Testing Methods, formerly the Commission on Standardization of Laboratory and Field Tests, was established in 1967. Its main task has been the drafting of "Suggested Methods" for rock testing, and its aim has been to achieve some measure of standardization without inhibiting the development and improvement of techniques.

The present document on use of flexible dilatometers falls into the category "Field Design Tests" and augments others in the family of *in situ* deformability measuring methods, such as the plate loading and radial jacking tests. These were published in the Pergamon Press (1981) book of Suggested Methods. A parallel Suggested Method covering rigid dilatometer techniques is in preparation.

The document has been prepared by a Working Group of the Commission, through several years of correspondence and review of drafts. The following Working Group members are acknowledged as having made major contributions:

B. Ladanyi (Working Group Co-ordinator, *Canada*); J. Bourbonnais and J. A. Franklin (*Canada*); K. Drozd (*Czechoslovakia*); A. Pahl and W. Wittke (*F.R. Germany*); J. L. Pinto and J. G. Charrua-Graça (*Portugal*); O. Stephansson (*Sweden*); J. Szlavin (*U.K.*); R. K. Atkinson and L. A. Panek (*U.S.A.*).

Feedback from users is essential if the continuing process of updating the Suggested Methods is to work effectively. Those who can suggest improvements are encouraged to do so by sending full details of their proposals to the Secretary General, ISRM, Labóratorio Nacional de Engenharia Civil, Avenida do Brasil, P-1799 Lisboa Codex, Portugal.

Suggested Methods for Deformability Determination Using a Flexible Dilatometer

Technical Introduction

A dilatometer for soil deformability determination was first described in the German literature of the 1930s. The method came to be used as routine only in the late 1950s, following developments of apparatus and test procedure by Menard in 1956. In rock mechanics, the first successful applications of high-capacity flexible dilatometers were reported in 1964 by Panek *et al.* [1] at the United States Bureau of Mines, and in 1966 by Rocha *et al.* [1] at the National Civil Engineering Laboratory (LNEC) in Portugal. Through the years, the drillhole dilatometer systems have undergone further developments and have found broader applications as noted below.

The two Suggested Methods given here relate to two types of dilatometer. The first measures drillhole volume change from which radial displacements must be calculated, whereas the second measures radial displacements directly using displacement transducers. Only the direct measuring type can be used to determine anisotropy of deformability as a function of radial direction within the drillhole; volume change types give an average value for the deformability modulus.

Both types are "flexible" in that they apply a uniformly distributed pressure to the drillhole wall through a flexible membrane, and in this, they differ from "rigid dilatometers" such as the Goodman Jack which has semi-cylindrical loading platens of steel, and therefore directional pressure application (see: ISRM Suggested Method for Deformability Determination using a Rigid Dilatometer, in preparation).

Clearly, all types of dilatometers can be used to produce a log of deformability variations with depth. In this they are superior to the flatjack method, for example, which is designed only for near-surface application. Dilatometers are particularly valuable for the rapid index logging of drillholes in fragile, clayey or closely jointed rocks that yield poor core recovery and inadequate specimens for laboratory testing. The deformability values obtained by dilatometer logging give a very useful record of variations in rock quality and a useful comparison of relative deformabilities in adjacent rock strata.

The volume of rock stressed by a dilatometer is quite small, usually less than one third of a cubic metre and often too small for direct application of the results to design problems. Correlation of the dilatometer modulus with that obtained, for example, by plate loading, radial jacking or flatjack methods, or still better, by back-calculation from direct observations made on real rock structures, allows an extrapolation of the dilatometer test results to the large scale [3]. Adjustments are also needed to take into account the fact that a dilatometer test carried out in a vertical hole gives information on horizontal deformability, whereas it is vertical deformability that is often more relevant, for example to foundations.

The present Suggested Methods are limited to describing the measurement of rock mass deformability, which is the principal use of the dilatometer. A more complete catalogue of applications for this versatile instrument, details of which are given in papers listed in the accompanying bibliography, is attempted as follows:

Field determination of elastic modulus of deformability of the rock mass by applying loads within the elastic or pseudoelastic range, and measuring the resulting dilations. Solutions are presented in these Suggested Methods for both unfractured rock (or rock with widely spaced joints), and fractured rock that is assumed to have no tension in a directional tangential to the drillhole. Amadei [4] has published a solution for anisotropic fractured rock.

Field determination of *in situ* stress and tensile strength by using a high capacity dilatometer to fracture hard rocks (the radial fracturing method, [5]).

Laboratory determination of tensile strength and modulus of elasticity in tension by using a dilatometer to internally pressurize intact rock cylinders [6]. Such measurements can assist in rock stress measurement by overcoring methods.

Field determination of creep properties by using a relatively high capacity dilatometer in a weak or plastic rock, such as oil shale, potash or rock salt. In these cases, either stage-loaded creep tests, or step-strained relaxation tests can be carried out in the drillhole [7, 8].

Field determination of short-term strength properties of weak rocks, from the non-linear pressure–volume curve obtained by using a high capacity dilatometer to load the rocks beyond their elastic limit. The methods are similar to those used for interpreting Menard pressuremeter test results in stiff soils [9–11].

Suggested Method for Deformability Determination Using a Flexible Dilatometer With Volume Change Measurements

SCOPE

1. (a) This test uses an expanding probe (dilatometer) to exert pressure on the walls of a drillhole. The resulting diametral hole expansion (dilation) is determined from measurements of the volumetric expansion of the probe. Deformability characteristics of the rock mass at the dilatometer location may be calculated from the relation between pressure and dilation.[1]*

(b) Various such dilatometers are commercially available. This Suggested Method is based mainly on the Colorado School of Mines (CSM) cell[2] [12, 13], which is a modified version of the Cylindrical Pressure Cell (CPC) originally developed by Panek [1] and still in use.

(c) The results of dilatometer tests are used for rock quality evaluation and design of structures such as foundations, dams, tunnels and caverns. The test is particularly valuable for the rapid index logging of drillholes in fragile, clayey or closely jointed rocks that yield poor core recovery and inadequate specimens for laboratory testing.

(d) The volume of rock stressed by a dilatometer is generally small in comparison with that loaded by alternative tests such as plate loading or radial jacking, although greater than that of a joint-free laboratory specimen. As a result, the deformability values measured by dilatometer may require adjustment to take into account scale and the effects of jointing [3, 4].

APPARATUS

Equipment for drilling and preparing the test hole, including

2. (a) A drill or boring machine to produce a test hole of the required diameter to the required maximum depth of investigation. Rotary diamond coring is usually needed to give a smooth walled drillhole.

(b) Casing as necessary to support the wall of the hole outside its test sections.

(c) Equipment and materials for grouting and re-drilling the test sections within the hole [when required, see paragraph 8(c)].

(d) A diameter gauge (e.g. a cylinder of the same size as the probe) to check that the hole is clear for insertion of the dilatometer.

3. *Calibration equipment*—One or more calibration cylinders of known elastic properties, with internal diameter equal to that of the test hole, and with length similar to the active length of probe.[3]

The dilatometer probe (e.g. Figs 1 and 3)

4. (a) A dilatometer probe or "cell" which includes a high pressure flexible membrane mounted on a core, such that the membrane can be inflated to press against the drillhole wall. The membrane must be strong enough not to be damaged when inserted into and withdrawn from the drillhole, yet flexible enough to transmit not less than 90% of the applied hydraulic pressure.

(b) A means of inserting, raising and lowering the probe in the hole and of measuring its position to within ±5 cm. Drill rods, special installing rods or cables may be used.

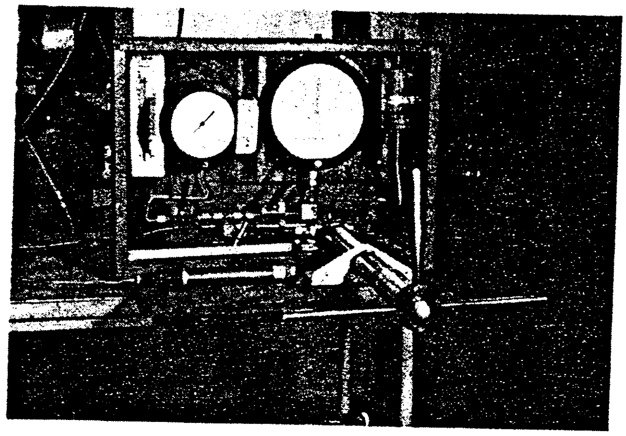

Fig. 1. A flexible dilatometer of CSM type.

A hydraulic system to pressurize the probe (e.g. Fig. 2)

5. (a) A pump and tubing system capable of filling, inflating and deflating the probe and of applying and maintaining the required range of pressures.[4]

(b) A hand-operated screw pump (or "pressure generator") is usually employed because it serves the 2-fold purpose of applying pressure and measuring volume displacements of the fluid. Piston movement is actuated by turning the wheel of the pump.

(c) If volume measurements are made outside the drillhole, the hydraulic system must be of rigid construction to minimize errors in determining dilation and to facilitate cyclic loading and stress relaxation testing.[4] Alternatively, the expansion of hydraulic lines is immaterial and can be ignored if volumetric expansion is monitored directly within the probe, as when using a dilatometer such as described by Bourbonnais [15].

(d) Testing in large drillholes using a large diameter probe may call for the use of two pumps, a high-displacement one for filling the system and applying initial pressure, in addition to the screw pump for pressurization.

Measuring systems as follows

6. (a) A volume measuring system, accurate to ±1% of the cell volume, to determine the amount of hydraulic fluid injected into or extracted from the cell. Volume is usually measured as the number of turns or part-turns of the screw-pump. A greater accuracy, typically in the order of ±0.2%, can be achieved using down-hole electrical measurements of probe expansion [15].

(b) A pressure measuring system such as a Bourdon gauge or electric transducer, with range as required and

* Superscript numbers refer to Notes at the end of the text.

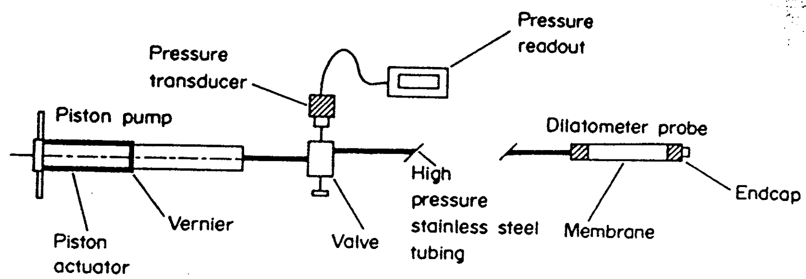

Fig. 2. Components of CSM-type dilatometer system [13, 14].

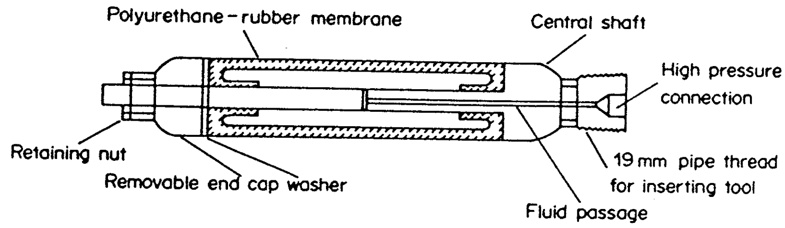

Fig. 3. Cross-section of CSM-type dilatometer system [13, 14].

with reading sensitivity better than ±2% of the range employed in the test.

PROCEDURE

Selection of test locations

7. (a) Drillhole locations and depths are to be selected taking into account the anticipated rock quality variations and depths of weathering, and the requirements of the designs or structures for which the test data are to be used.

(b) Within each drillhole, the tests may be spaced either at equal intervals or at specified locations in pre-selected geological formations or beds. Generally, a continuous log of deformability should be taken along the length of test hole pertinent to design. For example, a 1, 2 or 5 m test interval may be specified depending on test hole lengths and required resolution.

Drilling and preparation

8. (a) Test holes are to be drilled with the utmost care to preserve their stability, bearing in mind that rock fragments inadvertently wedged between the probe and the drillhole wall can trap the dilatometer permanently.

(b) The hole diameter is to be 0.5–3.0 mm larger than the deflated diameter of the probe.[5]

(c) Checking of the drillhole with a TV camera is recommended to avoid damage to the flexible membrane that might be caused by open fissures or voids. When the drillhole requires support, this may be achieved by casing down to the uppermost test section and/or by cementing.[6]

(d) Drill cores are to be fully logged to record recovery and the characteristics of the rock and jointing. Rock cores are to be available on site for inspection by the testing crew if they are not present during drilling.

Calibration [1, 12, 13]

9. (a) The purpose of calibration is to determine the "system stiffness M_s", the value of which is required to allow calculation of the volume change of the test section from the measured volume change of the probe and hydraulic system combined.

(b) The complete dilatometer equipment is to be thoroughly checked and calibrated before each test series, also at least weekly during a testing program and after major repairs such as membrane replacement. Ambient air temperature at the time of calibration is to be recorded and the calibration repeated if this changes by more than 5°C.

(c) The probe, pump and hydraulic system to be used in field testing are to be connected and filled with hydraulic fluid, checking for leaks and thoroughly bleeding to remove any entrapped air.

(d) With the probe in the calibration cylinder, pressure is to be increased incrementally through the range to be used in testing, taking at least five readings of pressure (MPa) and corresponding volume (pump turns). A pressure–volume curve is to be plotted and its slope M_m (MPa per turn), the overall stiffness of the system plus calibration cylinder, measured. M_s is to be calculated from M_m as described in paragraph 11(c).

(e) The probe is to be inflated in air (without confinement) to determine the membrane rigidity correction factor m (MPa/turn), obtained as the slope of the unconfined pressure–dilation curve.

Testing

10. (a) Having checked clearance of the hole using the diameter gauge, the probe is to be inserted and lowered or raised to the required test location. This location is to be measured with an accuracy ±5 cm and recorded.

(b) The probe is to be expanded under a pressure just enough to ensure permanent contact with no sliding. This seating pressure is to be the minimum pressure throughout the test.

(c) Pressure is to be increased in not less than five approximately equal increments to the maximum value, which is to be as high as possible but no greater than the

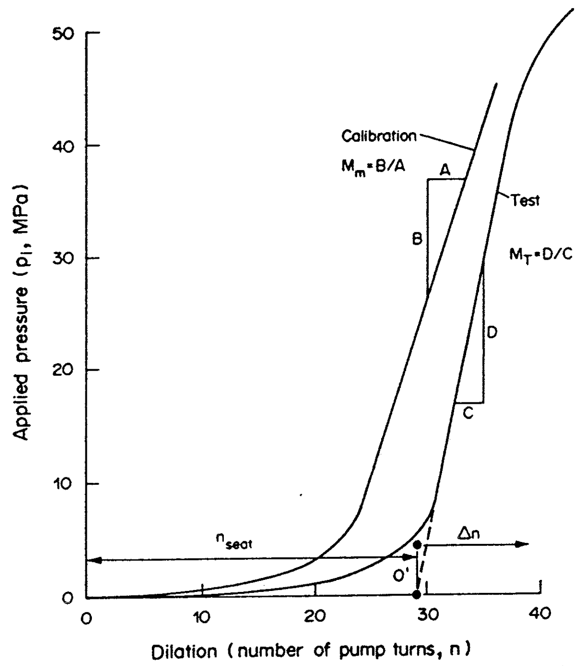

Fig. 4. Pressure–dilation graphs from a CSM dilatometer test.

safe operating pressure of the test equipment, taking into consideration the smoothness and diameter of drillhole at the test depth.[5]

(d) At each increment the pressure is to be maintained constant while taking readings of pressure (MPa) and corresponding volume (pump turns). Dilation (if any) is to be recorded versus time to give an indication of whether the rock behaviour is time-dependent. Alternatively, the same can be achieved by maintaining the volume of the probe constant (without pumping), and recording the drop in pressure with time.[7]

(e) At a maximum test pressure, the applied pressure is to be maintained constant during at least 10 min, longer if specified. Readings of dilation versus time at constant pressure are again to be tabulated to determine creep rates.

(f) Dilation and pressure readings may then be taken during unloading if specified. Three cycles of loading and unloading are required in most applications.[8]

(g) A pressure–volume curve is to be plotted and its slope M_t (MPa per turn), the overall stiffness of the system plus rock, determined (e.g. Fig. 4).

(h) Pressure is then to be released and the probe relocated for the next test.

CALCULATIONS

Calculation of calibration constants

11. (a) The shear modulus G_c of a calibration cylinder material having Young's Modulus E_c and Poisson's Ratio ν_c is given by:

$$G_c = \frac{E_c}{2(1+\nu_c)} \text{ (MPa).}$$

(b) The stiffness M_c of the calibration cylinder is calculated as:

$$M_c = \frac{\alpha G_c}{\pi L a^2 \left[\dfrac{1 + B_c(1-2\nu_c)}{1 - B_c}\right]} \text{ (MPa/turn)}$$

where

α = pump constant (fluid volume displaced per turn of pump wheel),
L = length of cell membrane, (m)
a = the inside radius and b the outside radius of the calibration cylinder (in metres), and
$B_c = (a/b)^2$.

(c) The stiffness M_s of the hydraulic system is calculated as:

$$M_s = \frac{M_c M_m}{M_c - M_m} \text{ (MPa/turn)}$$

where M_m is the stiffness of the system plus calibration cylinder, measured as described in paragraph 9(c).

Corrections for pressure and volume losses

12. (a) *Pressure losses*—Observed pressures p_i (those read on the pressure gauge or transducer) are only equal to those acting on the rock if the membrane is very flexible or the dilations very small. Usually the observed pressures will require correcting for membrane rigidity as follows:

$$p_{i,corr} = p_i - nm \text{ (MPa)}$$

where $p_{i,corr}$ is the corrected pressure, n is the total number of turns needed to attain p_i, and m (MPa/turn) is the membrane rigidity correction factor [paragraph 9(e)].

(b) *Volume losses*—These occur as a result of probe seating and inflation of the loading system. Using measurements defined in Fig. 4, the net corrected number of turns Δn_{corr} is calculated from:

$$\Delta n_{corr} = n - n_{seat} - p_i/M_s \text{ (turns).}$$

Calculation of linear elastic parameters of rock

13. (a) The stiffness M_R for the test section in rock is calculated as:

$$M_R = \frac{M_s M_T}{M_s - M_T} \text{ (MPa/turn).}$$

(b) The dilatometric shear modulus G_d for a drillhole test section is calculated as:

$$G_d = M_R \frac{\pi L a^2}{\alpha} \text{ (MPa)}$$

Where L and a are the length and diameter of drillhole test section and α is the pump constant [see paragraph 11(b)].

(c) The dilatometric shear modulus G_d for a dilatometer test in a rock cylinder is calculated as:

$$G_d = M_R \frac{\Pi L a^2}{\alpha}\left[\frac{1 + B_c(1 - 2\nu_R)}{1 - B_c}\right] \text{(MPa)}$$

with notation as before, but with B_c referring to the tested rock cylinder.

(d) The dilatometric modulus of elasticity E_d for a test in either a drillhole or rock cylinder can then be found from:

$$E_d = 2(1 + \nu_R)G_d \text{ (MPa)}$$

where Poisson's ratio ν_R for the rock is either known or estimated.

Calculations for non-linear behaviour

14. (a) If the drillhole is located in closely jointed rock, the measured pressure–volume relation may become non-linear when the applied pressure exceeds about twice the average ground stress. In that case and assuming zero tensile strength for the rock mass [16], G_d can be calculated from:

$$G_d = p_{i,corr} \frac{\pi L a^2}{\alpha \Delta n_{corr}}\left[(1 - \nu_R)\ln\left(\frac{p_{i,corr}}{2p_0}\right) + 1\right] \text{(MPa)}$$

where $p_{i,corr}$ and Δn_{corr} are the corrected values for applied pressure and number of turns (paragraph 12), and p_0 is the average ground stress around the drillhole (MPa), to be estimated or measured independently.

(b) Alternatively one can obtain a pressure versus dilation curve (Fig. 4) by plotting $p_{i,corr}$ on the ordinate and V_m on the abscissa, where

$$V_m = \alpha(n - p_i/M_s)\,(\text{m}^3).$$

The curve can be used subsequently in the same manner as in a Menard pressuremeter test [9–11, 17].

REPORTING OF RESULTS

15. The following are to be reported for the site as a whole:

(a) Details of the drilling program including the drilling company, method and equipment used.

(b) A map of drillhole locations and a tabulation of hole lengths, diameters, inclinations and directions.

(c) Geotechnical logs of the drill core, showing locations of cased and cemented sections if any; groundwater levels, rock types and characteristics; locations of test sections.

(d) Characteristics of all discontinuities within each test section and 0.5 m above and below. ISRM Suggested Methods for Quantitative Description of Discontinuities in Rock Masses are to be employed.

(e) Details of the method and equipment for calibration and testing. Reference may be made to this Suggested Method, stating only departures from the procedures given here.

(f) Full results of calibrations.

16. The following are to be reported for each test:

(a) Tabulated test readings including both raw and corrected values with depths of measurement and graphs as in Fig. 4.

(b) Derived values of deformability parameters, together with details of methods and assumptions used in their derivation. Deformability parameters should be tabulated and shown graphically as a function of applied pressure.

(c) Logs of deformability variation as a function of depth (or distance from the drillhole collar in the case of a non-vertical hole).

Suggested Method for Deformability Determination Using a Flexible Dilatometer With Radial Displacement Measurements

SCOPE

1. (a) This test uses an expanding probe (dilatometer) to exert pressure on the walls of a drillhole. The resulting hole expansion (dilation) is measured directly by a displacement transducer in the probe. Deformability characteristics of the rock mass at the dilatometer location may be calculated from the relation between pressure and dilation.[1] Anisotropy of deformability in the plane perpendicular to the drillhole may also be determined.

(b) This Suggested Method is based mainly on the original LNEC dilatometer method developed in Portugal. Various other dilatometers of a similar type are available [2, 12, 15, 18–22] which may also fulfil the test requirements.

(c) The results of dilatometer tests are typically used in exploratory investigations for foundations, dams, tunnels, caverns, etc. The tests are particularly valuable for rapid index logging of drillholes in fragile, clayey or closely jointed rocks that yield poor core recovery and inadequate specimens for laboratory testing.

(d) The volume of rock stressed by a dilatometer is generally small in comparison with that stressed by alternatives such as plate loading or radial jacking tests, although greater than the volume of a joint-free laboratory specimen. As a result, the deformability values measured by dilatometer may require adjustment to take into account scale and the effects of jointing.

APPARATUS

Equipment for drilling and preparing the test hole

2. (a) A drill or boring machine to produce a test hole of the required diameter to the required maximum depth of investigation.

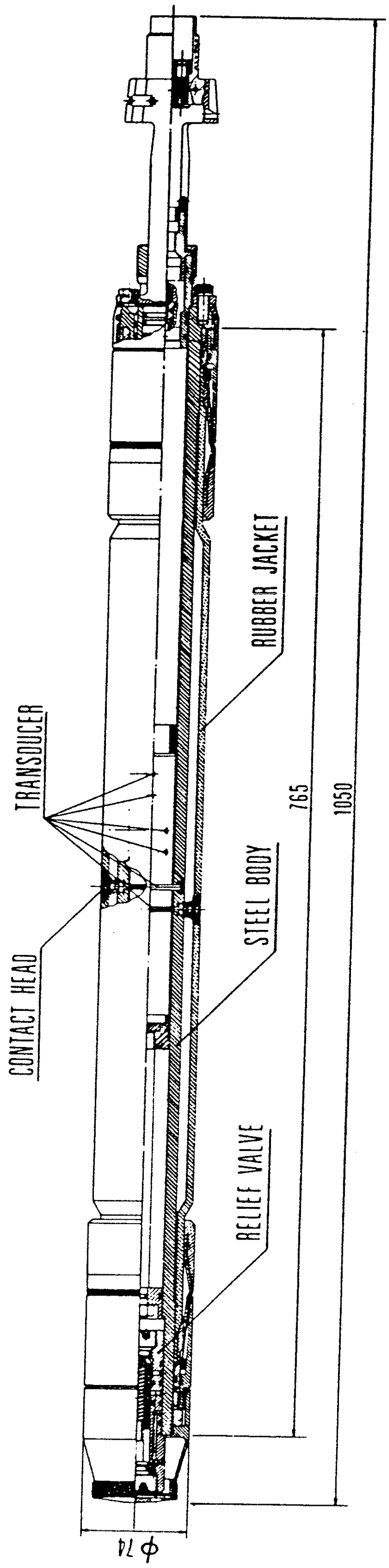

Fig. 5. LNEC-type dilatometer [2].

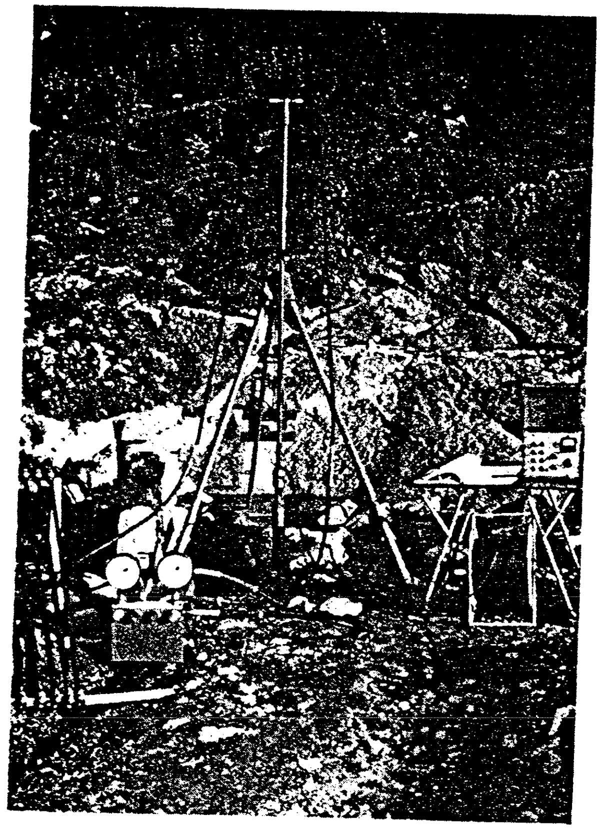

Fig. 6. LNEC-type dilatometer with probe, pump, installing and readout equipment [20].

(b) Casing as necessary to support the wall of the hole outside its test sections.

(c) Equipment and materials for grouting and re-drilling the test sections within the hole [when required, see paragraph 8(c)].

(d) A diameter gauge (e.g. a cylinder of the same size as the probe) to check that the hole is clear for insertion of the dilatometer.

Calibration equipment

3. (a) A calibration cylinder of known elastic properties, with internal diameter equal to that of the test hole, and with length similar to the active length of probe.[3]

(b) A micrometer gauge to measure the outside diameter of the probe, with an accuracy of ±0.02 mm or better.

The dilatometer probe (e.g. Figs 5 and 6)

4. (a) A dilatometer probe, which includes a high pressure flexible membrane mounted on a core, such that the membrane can be inflated to press against the drillhole wall. The membrane is to be strong enough not to be damaged when inserted into and withdrawn from the drillhole, yet flexible enough to transmit not less than 90% of the applied hydraulic pressure. Typical dilatometer probes have a diameter of 76–116 mm and effective lengths of 5–15 times their diameter.

(b) A means of inserting, raising and lowering the probe in the hole and of measuring its position to within ±5 cm and its orientation to ±5 deg. Drill rods, special installing rods or cables may be used.

A hydraulic system to pressurize the probe (e.g. Fig. 6)

5. (a) A pump and tubing system capable of filling, inflating and deflating the probe and of applying and maintaining the required range of pressures.[4]

(b) The pump is usually electrically operated with a pressure controller to maintain loads or apply a constant loading rate.

(c) Testing in a large drillhole using a large diameter probe may require the use of two pumps, or at least a two speed pump with one pumping rate for filling the system and applying initial pressure, and another for pressurization.

Measuring systems as follows

6. (a) One or more displacement measuring system, to determine drillhole diameter with an accuracy of ± 0.02 mm or better. For example, three electric displacement transducers of LVDT (linear variable differential transformer) type may be mounted to measure along diameters inclined at 120 degrees to each other. The transducers are connected by electric cables to a readout unit at surface.

(b) A pressure measuring system such as a Bourdon gauge or an electric pressure transducer, with range as required and with reading sensitivity better than $\pm 2\%$ of the range to be employed in any one test.

PROCEDURE

Selection of test locations

7. (a) Drillhole locations and depths are to be selected taking into account the anticipated rock quality variations and depths of weathering, and the nature of the design calculations for which the test data are needed.

(b) Within each drillhole, the tests may be spaced either at equal intervals or at specified locations in pre-selected geological formations or beds. Generally, a continuous log of deformability should be taken along the length of test hole pertinent to design. For example, a 1, 2 or 5 m test interval may be specified depending on test hole lengths and required resolution.

Drilling and preparation

8. (a) Test holes are to be drilled with the utmost care to preserve their stability, bearing in mind that rock fragments inadvertently wedged between the probe and the drillhole wall can trap the dilatometer permanently.

(b) The hole diameter is to be 0.5–3.0 mm larger than the deflated diameter of the probe.[5]

(c) Checking of the drillhole with a TV camera is recommended to avoid damage to the flexible membrane that might be caused by open fissures or voids. When the drillhole requires support, this may be achieved by casing down to the uppermost test section and/or by cementing.[6]

(d) Drill cores are to be fully logged to record core recovery, fracture frequency, rock characteristics, weathering, and structural features such as schistosity, foliation, bedding and joints. Rock cores are to be available on site for inspection by the testing crew if they are not present during drilling.

Calibration

9. (a) The complete dilatometer equipment is to be thoroughly checked and calibrated before each test series, also at least weekly during a testing program and after major repairs such as membrane replacement.

(b) With the probe inserted in the calibration cylinder, the full test pressure is to be applied and a check made for pressure maintenance and leakage.

(c) Pressure is then to be released and increased incrementally through the range to be used in actual testing, taking at least five readings of pressure (MPa) and corresponding dilation. If the cell contains more than one displacement transducer, the readings are to be compared and then averaged. A pressure versus average dilation curve is to be plotted and its slope M_m (MPa per mm) compared with theoretical cylinder expansion obtained from elastic theory.[9]

(d) The probe is to be inflated in air (without confinement) to determine the membrane rigidity correction factor m (MPa/mm), obtained as the slope of the unconfined pressure–dilation curve.

(e) The displacement measuring system should also be independently checked using a micrometer, preferably one spanning directly between the measuring pads of the probe. Within the measurement range, the overall sensitivity of the equipment should be constant, e.g. one dial division of the readout voltmeter per millimetre of dilation.

Testing

10. (a) Having checked clearance of the hole using the diameter gauge, the probe is to be inserted and lowered or raised to the required test location. This location is to be measured with an accuracy ± 5 cm and recorded.

(b) The probe is to be expanded under a pressure just enough to ensure permanent contact with no sliding. This seating pressure is to be the minimum pressure throughout the test.

(c) Pressure is to be increased in not less than five approximately equal increments to the maximum value, which is to be as high as possible but no greater than the safe operating pressure of the test equipment, taking into consideration the smoothness and diameter of drillhole at the test depth.

(d) Each pressure increment is to be maintained constant while taking readings of pressure (MPa) and corresponding hole dilation (mm). If the probe contains more than one displacement transducer, individual diameter readings are to be recorded in order to compute modulus values as a function of direction. Dilation (if any) is to be recorded versus time to give an indication of whether the rock behaviour is time-dependent. Alternatively, the same can be achieved by maintaining the diameter of the probe constant and recording the drop in pressure with time.[7]

(e) At the maximum test pressure, the applied pressure is to be maintained constant during at least 10 min,

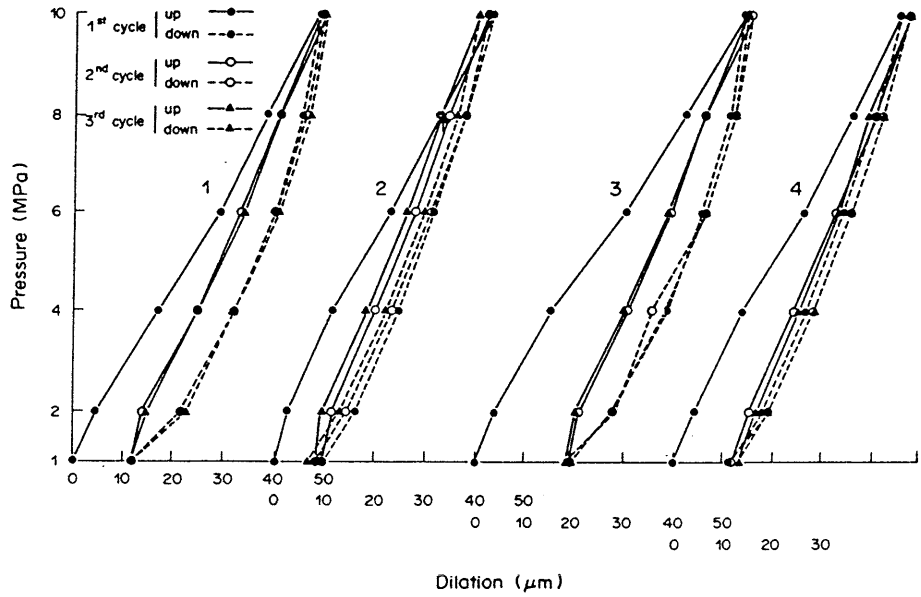

Fig. 7. Pressure–dilation curves, showing separate curves for each of four dilation-measuring transducers mounted in the same probe (LNEC dilatometer, [2, 20]).

longer if specified. Readings of dilation versus time at constant pressure are again to be tabulated to determine creep rates.

(f) Dilation and pressure readings may then be taken during unloading if specified. Three cycles of loading and unloading are required in most applications.[8]

(g) During the test cycling, a pressure–dilation curve is to be plotted such as shown in Fig. 7.

(h) Pressure is released. If the probe has just one displacement measuring direction it may then be rotated at the same depth in the hole, and the test repeated to measure deformability in another direction. The probe is then relocated for the next test.

CALCULATIONS

Calculation of calibration constants

11. (a) The shear modulus G_c of a calibration cylinder material having Young's Modulus E_c and Poisson's Ratio ν_c is given by:

$$G_c = \frac{E_c}{2(1+\nu_c)} \text{ (MPa)}.$$

Calculation of deformability parameters of rock

12. (a) For any segment of the pressure displacement diagram (e.g. Fig. 7) and in rock with widely spaced joints [see 12(b) below], the corresponding secant dilatometric modulus E_d may be calculated as follows:

$$E_d = (1+\nu_R) D \frac{\Delta p_i}{\Delta D} \text{ (MPa)}$$

where:

Δp_i = pressure increment within the considered segment (MPa);
ΔD = corresponding average change in drillhole diameter D (m);
ν_R = Poisson's ratio of the rock mass.

(b) If the test is performed in cracked rock, and if p_i exceeds about twice the average ground pressure p_0 around the drillhole, all existing radial cracks will open, and the equation of paragraph 12(a) is to be replaced by:

$$E_d = D \frac{p_i}{\Delta D}(1+\nu_R)\left[(1-\nu_R)\ln\left(\frac{p_i}{2p_0}\right)+1\right] \text{ (MPa)}$$

where:

p_i = applied pressure (MPa), and
ΔD = average increase of drillhole diameter (m), when pressure increases from zero to p_i.

Note that the equations of paragraphs 12(a) and (b) are strictly valid only for a linear-elastic, homogeneous and isotropic rock mass.

(c) When the cell contains several diametral displacement transducers or when a single transducer cell has been rotated to measure anisotropy of deformability, the measured dilations for several directions of measurement are to be plotted as shown in Fig. 8 [19]. Deformability values are then to be calculated for each direction of measurement. Further details of test interpretation in jointed and anisotropic rock are given in [3, 4, 6, 21, 22].

(d) From the pressure–dilation diagram, both short-term and time-dependent response of the rock mass can be determined.

REPORTING OF RESULTS

13. The following are to be reported for the site as a whole:

(a) Details of the drilling program including the drilling company, method and equipment used.

(b) A map of drillhole locations and a tabulation of hole lengths, diameters, inclinations and directions.

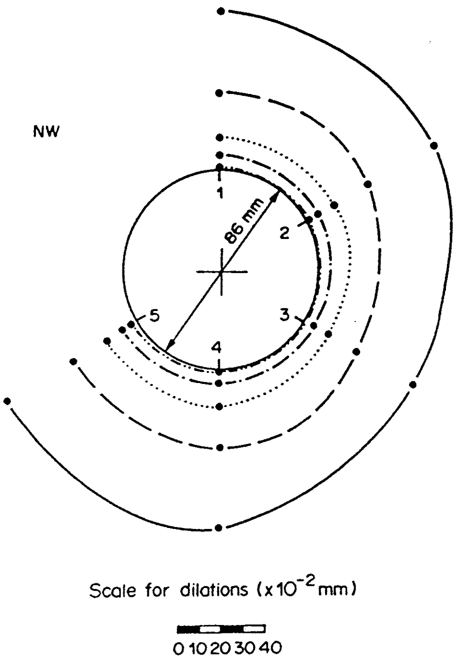

Fig. 8. Dilations of a drillhole wall, measured by a dilatometer with three displacements transducers, at pressures of 1, 2, 5, 10, 20 and 40 MPa [19].

(c) Geotechnical logs of the drill core, showing locations of cased and cemented sections if any; groundwater levels, rock types and characteristics; locations of test sections.

(d) Characteristics of all discontinuities within each test section and 0.5 m above and below. ISRM Suggested Methods for Quantitative Description of Discontinuities in Rock Masses should be employed.

(e) Details of the method and equipment for calibration and testing. Reference may be made to this Suggested Method, stating only departures from the procedures given here.

(f) Full results of calibrations.

14. The following are to be reported for each test:

(a) Tabulated test readings, including both raw and corrected values with depths and directions of measurement and graphs as in Fig. 7.

(b) Derived values of deformability parameters, together with details of methods and assumptions used in their derivation. Deformability parameters should be tabulated and shown graphically as a function of applied pressure.

(c) Logs of deformability variation as a function of depth (or distance from the drillhole collar in the case of a non-vertical hole).

(d) Graphs in the plane perpendicular to the drillhole, showing anisotropy of the measured dilations and deformability values.

NOTES

1. Only the elastic parameters can be calculated if the maximum applied pressure is less than needed for the rock to yield or fail around the drillhole. When, however, a high capacity dilatometer is used in a weak or plastic rock like shale or potash, the short-term strength and creep properties of the rock may also be inferred from the shape of the force–displacement–time curves. Similarly, when a high capacity dilatometer is used to produce radial fracturing in a hard rock like granite, conclusions on the tensile strength and state of stress in the rock can be made.

2. In the CSM system the probe or "cell" consists of a polyurethane-rubber membrane mounted on a steel shaft. The probe (Fig. 3) is 37.5 mm dia and 165 mm long. It is pressurized with a manually operated screw pump having a 30 cm^3 reservoir capacity and an operating range of up to 100 MPa. Stainless steel tubing 3.2 mm o.d., 1.0 mm i.d. is used. Injection of 30 cm^3 of fluid results in a 7.8% increase in probe diameter.

In the original and still-employed alternative design (CPC), the membrane is 0.6 mm thick copper. Different commercially available flexible dilatometers, although based on the same principle, differ in size, capacity, construction and control systems. Menard-type soil pressuremeters, which are dilatometers but designed to operate at lower pressures, are sometimes used for deformability determination of soft rocks such as those whose Modulus of Deformability is less than 500 MPa [9, 10].

3. Although one calibration cylinder may be sufficient, two or more of different stiffnesses are often employed to improve the precision of determination. There are no special requirements regarding the material or outer diameter of the calibration cylinders, although they should have stiffnesses similar to that of the rock mass and should allow calibration over the full range of pressures to be employed in the drillhole.

4. For measurements in hard rocks a pressure range of at least 20 MPa is recommended. Pressurizing fluids that have been used include glycerin, ethylene glycol, water or hydraulic oil.

For testing in very stiff rocks, a high stiffness pressurizing system is usually essential [2]. Rubber hose is to be avoided and steel tubing must be used unless downhole monitoring of cell volume is employed [15].

5. An irregular or over-sized drillhole will necessitate a much reduced measuring range, with a maximum test pressure much lower than the nominal maximum working pressure of the dilatometer. High quality drilling is essential to avoid membrane damage and to permit the highest possible test pressure.

6. The head of fluid grout is at no time to exceed 3 m, so as to preclude pressure grouting of the rock mass to be tested. The cemented hole is to be redrilled to the tolerances specified. The cement lining is to be thinner than 1 mm. Cementing, if used, is to be fully documented and its effects evaluated in the report.

7. In a Menard pressuremeter test such as commonly carried out in soils, the pressure is usually increased in steps and kept constant at each level for a selected length of time, during which the increase in volume of the drillhole is recorded.

8. The maximum test pressure should be as high as possible, so as to involve the largest possible volume of rock mass in the test. In a multi-cycle test, the maximum pressure of each successive cycle should be progressively increased so that useful information is obtained in early cycles even if the membrane is damaged later.

9. Some probes measure dilation against the internal wall of the membrane rather than directly against the rock, and require a calibration to determine the change in membrane thickness as a function of internal pressure.

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