

Geotechnical Core Characterisation for the UK Radioactive Waste Repository Design

Geotechnische Kernmaterial Beschreibung für den Entwurf von Lagern für radioaktiven Abfall in Grossbritannien

Description de carottes géotechniques pour le dimensionnement d'aires de stockage enfouis et permanent pour déchets radioactifs

by

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The NGI methods of characterising joints (using JRC, JCS and ϕ_r) and characterising rock masses (using the Q-system) are being utilised extensively in a current geotechnical consultancy project for UK Nirex Ltd. Present geotechnical characterisation activities include the logging of six kilometres of 100mm drill core from cored drill holes of up to 1,960m depth.

Preliminary rock reinforcement designs (systematic bolting and unreinforced or fibre-reinforced shotcrete) are derived from the Q-system statistics, which are logged in parallel with JRC, JCS and ϕ_r . The UDEC-BB modelling provides a check on the performance of the proposed excavations with Q-system reinforcement, giving predicted bolt loads and rock deformations, together with joint shearing and hydraulic apertures to better define the disturbed zones.

NGI's Methoden der Trennflächenbeschreibung (unter Gebrauch der Q-Methode) sind wesentliche Bestandteile des gegenwärtigen geotechnischen Consultingprojektes für UK Nirex Ltd. Die geotechnischen charakterisierenden Aktivitäten beinhalten die Beschreibung von 6 km, 100 mm Kernmaterial aus einer Tiefe bis zu 1960 m.

Das vorläufige Sicherungskonzept (systematisches Ankern und unverstärkter oder fiberverstärkter Spritzbeton) beruht auf einer statistischen Q-system Analyse. Diese wird parallel mit der Registrierung von JRC, JCS und ϕ_r durchgeführt. Die UDEC-BB Simulationen erlauben eine Überprüfung des Verhaltens der geplanten und Q-System gesicherten Kavernen. Berechnungen der Ankerlasten, Felsdeformationen, und Scherdeformationen entlang der Trennflächen und der hydraulischen Klüftöffnungen erlauben eine verbesserte Beschreibung der Auflockerungszone.

Les méthodes NGI pour caractériser les joints (utilisant JRC, JCS et ϕ_r) et les massifs rocheux (utilisant le système Q) sont utilisées à grande échelle dans un project de consultation géotechnique pour UK Nirex Ltd. Les activités de description en cours incluent l'enregistrement de 6 kilomètres de carottes de 100 mm extraites de trous de forages d'une profondeur jusqu'à 1950 m.

Les dimensionnements d'armement du rocher (ancrages systématiques et béton projeté non-armé ou armé de fibres) sont dérivés des statistiques du système Q, enregistrées en parallèle avec les paramètres JRC, JCS, et ϕ_r . Les modèles analytiques UDEC-BB permettent de vérifier le comportement de l'armement basé sur le système Q, et donnent forces d'ancrages, déformations du rocher, cisaillement du joint, et ouvertures hydrauliques afin de mieux définir les zones remaniées.

INTRODUCTION

The NGI methods of characterising joints (using JRC, JCS and ϕ_r) and characterising rock masses (using the Q-system) are being utilised extensively in a current geotechnical consultancy project for UK Nirex Ltd. This organisation is responsible for the safe disposal of low and intermediate level radioactive waste in the UK. Present planning and site investigation is now focused at Sellafield in NW England where extensive deep drilling, downhole testing, geological and geophysical investigations are being progressed.

The NGI/WS Atkins/Taywood Engineering work as Geotechnical Consultants to UK Nirex Ltd has included field mapping and core logging, using newly developed geotechnical logging charts which combine Q-system parameter histograms with more detailed joint and rock mass descriptions suitable for use in the distinct element

code UDEC-BB. Extensive numerical analyses of access tunnel and cavern excavation response are being carried out to investigate rock reinforcement requirements and the extent of the disturbed zones.

GEOTECHNICAL LOGGING CHART

As a first step in the rock mechanics design process, data of relevance to cavern and tunnel design studies are collected from field mapping and from current logging of some 6 km of orientated drill core. The chart used in the field mapping is illustrated in Fig. 1.

Key to geotechnical logging charts

Q-value (Barton, Lien and Lunde 1974)

The Q-value is a measure of the stability of excavations in a rock mass. The Q-value is

The numbers vary from 0.75 for healed joints to 20 for discontinuities with thick fillings of swelling clay. The J_a -numbers depend generally on the thickness and mineralogy (frictional properties) of the fillings. J_r together with J_a give an approximate indication of the friction angle along the joints or filled discontinuities. Other parameters which are supplementary to this are: JRC, JCS, ϕ_r .

9. *JRC = joint roughness coefficient*

The numbers describing the joint roughness may vary from 0 for smooth, planar joints, up to 20 for very rough joints. The numbers may be measured in the laboratory by means of tilt tests or by profile gauges.

JRC may also be calculated in the field by measuring the amplitude of the irregularities in relation to their length (a/L).

10. *a/L = roughness amplitude of asperities per unit length (mm/m)*

The amplitude of asperities in millimetres are measured for two reference lengths along the joint plane: 0.1 m and 1.0 m. Measurement along the two most prominent joint sets are usually carried out in the dip direction - the presumed direction of any sliding failure. (The 1.0m measurement is performed in field mapping.)

11. *JCS = joint wall compressive strength*

This value is given in MPa and is measured by a Schmidt-hammer on the saturated joint surface. In the field JCS is based on the best 10 results of 20 Schmidt hammer readings on each joint set at the natural moisture content conditions prevailing at that time.

12. *ϕ_r = residual friction angle*

This value may be calculated by using tilt tests on smooth planar surfaces of the rock (ϕ_b) and Schmidt-hammer rebound tests on natural (r) and unweathered (R) surfaces. A simple formula relates these parameters; (Barton and Choubey, 1977).

13. *J_w = joint water reduction factor*

This parameter varies from 1.0 for dry rock masses to 0.05 for rock masses with very high inflow, as recorded or expected at the proposed tunnelling depth.

14. *SRF = stress reduction factor*

For the case of competent rock, the SRF-value is based on the ratio between rock strength (σ_c) and principal stress (σ_1) at tunnelling depth. Special cases are swelling and squeezing rocks and fault zones. The factor may vary from 1 for hard rocks with moderate stress to 20 or more for rocks with extremely high stress, or for cases of extreme squeezing or swelling. J_w together with SRF gives a description of the effective stress situation in the rock mass at tunnelling depth.

15. *K = rock mass permeability (m/s)*

Values of K seldom lie outside the range 10^{-3} to 10^{-14} m/s. Hydraulic measurements in the boreholes provide this information. Note the approximate conversion to Lugeons. (Data from other Nirex contractors.)

16. *σ_c = compressive strength*

Measurements of the compressive strength of the rocks are carried out on cylindrical samples prepared from the cores. (Data from other Nirex contractors, i.e., British Geological Survey.)

17. *σ_1 = major principal stress*

The magnitude of the major principal stress for the particular depth of interest is plotted, so that the ratio σ_c/σ_1 can be evaluated for purposes of choosing SRF in the Q-system. (σ_1 data from other Nirex contractors, i.e., Sir Alexander Gibb in association with Geoscience and J. Arthur and Associates.)

18. *w = weathering*

The diagram contains 6 classes of weathering where Class I means fresh rock and Class VI means weathered to a soil-like material (ISRM, 1981).

19. *α/β = dip/dip direction*

In the lower right hand side of the charts, poles of the different joints are plotted in a stereo diagram. The lower hemisphere of the Schmidt net is used here. The joint orientation is given as dip (0 to 90°) and dip direction (0 to 360°) related to Magnetic North (5½° west of Grid North). (Field data from NGI/WSA mapping; core orientation data from other Nirex contractors, i.e., BGS.)

JOINT CHARACTERISATION AT SELLAFIELD

Present geotechnical characterisation activities are focused on the logging of six kilometres of nominally 100mm diameter drill core. Core orientation is performed by the British Geological Survey (BGS), as described in a companion article in this conference (Horseman et al. 1992). See also Ireland (1992).

Joints recovered in the drill core are subjected to index tests to determine JRC (tilt tests, profiling), JCS (Schmidt hammer tests), ϕ_r (tilt, Schmidt). This index testing is performed in the NGI/WSA laboratory kindly provided by BGS at Keyworth. The NGI methods of tilt testing and Schmidt hammer testing of joints have been described in detail by Barton and Choubey (1977) and by Barton and Bandis (1990) and will not be elaborated upon here.

Examples of a set of data for JRC, JCS and ϕ_r obtained from a section of one of the Sellafield boreholes is shown in Fig. 2. The mean values of JRC, JCS and ϕ_r of approximately 5, 110 MPa and 23° can be used directly as input data in UDEC-BB models of excavations.

The extensive core logging performed in this project for UK Nirex Ltd is providing significant data concerning the statistical variation of joint parameters and the potential variation of data from joint set to joint set.

The statistically representative data set

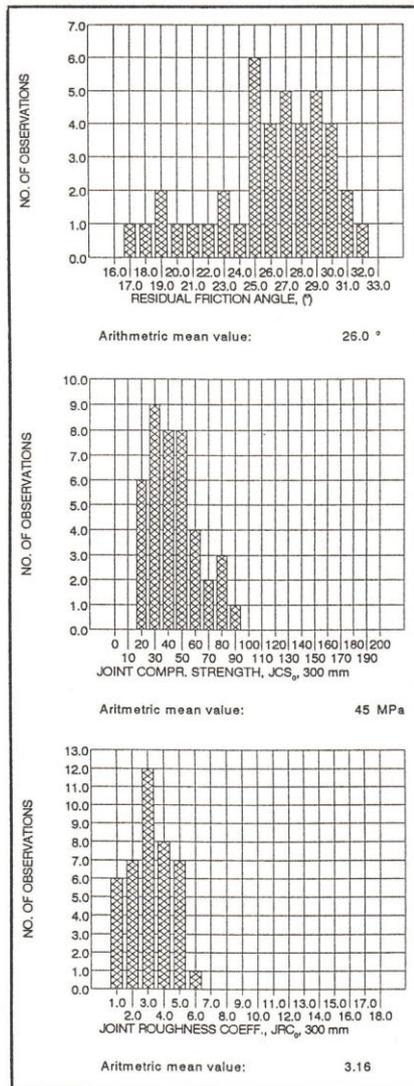


Fig 2 Examples of Sellafield index testing results using JRC, JCS and ϕ_r to characterise the joints

obtained from many hundreds of joint samples that undergo tilt testing and Schmidt hammer testing is complemented by a lesser but significant number of laboratory tests. Direct Shear Testing (DST) and Coupled Shear Flow Testing (CSFT) performed in NGI's laboratories indicate satisfactory agreement between prediction and practice.

The large amount of data generated in this characterisation programme has necessitated

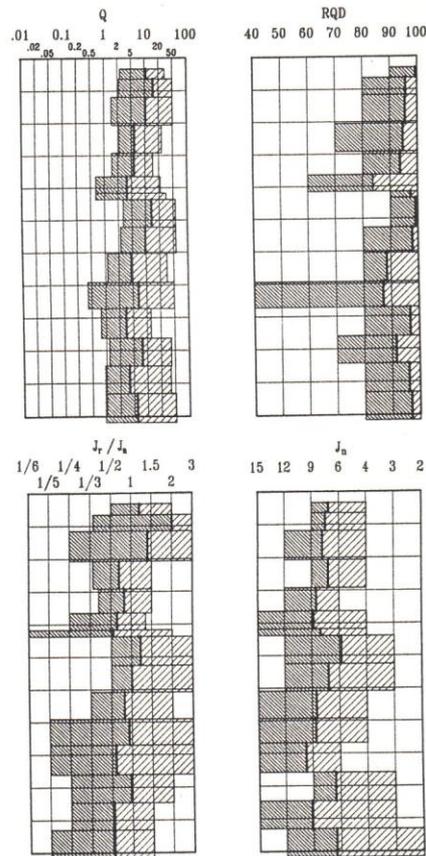


Fig. 3 Examples of depth logs for key Q-system parameters from a section of a Sellafield borehole.

computerised data handling. All the geotechnical joint logging performed on core at BGS by the NGI/WSA team is therefore recorded on a PC.

In principle, the Q-system data logged in the left hand side of the chart (see parameters RQD, J_n , J_r , J_a , J_w , SRF) is used to make preliminary designs for rock reinforcement for tunnels or waste storage caverns. The recommended rock reinforcement (i.e., bolts of specific length, diameter and spacing) is subsequently modelled discretely (Cundall, 1980) in the UDEC-BB models of the specific excavations, to check on the adequacy and predicted performance of the excavation both with and without reinforcement.

VARIATION OF PARAMETERS AS A FUNCTION OF DEPTH

Both lateral and depth variation in properties is typical for rock masses, and Sellafield is no exception.

A selection of some of the depth-related data is shown in Fig. 3. The central black line

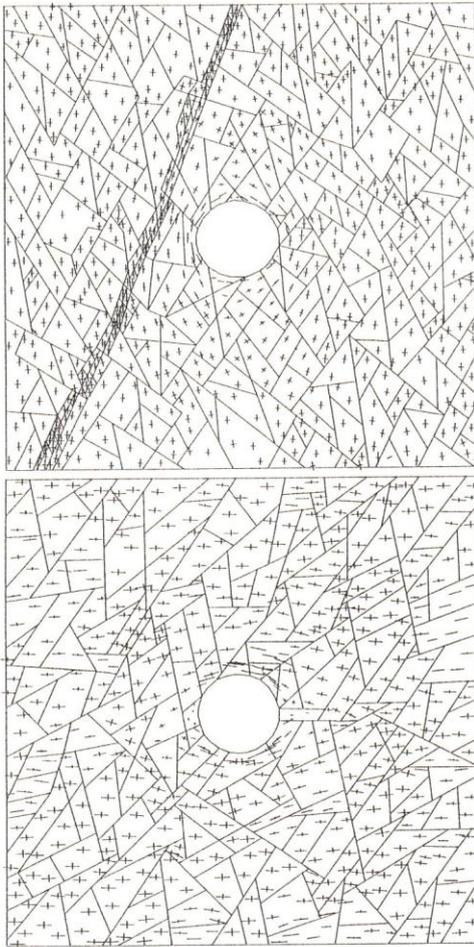


Fig. 4 Sections of TBM tunnel at two locations and depths around the planned access spiral. UDEC-BB results showing principal stresses. Bolted cases.

represents the mean value of the parameter at the particular depth. To the left, the dark, shaded area is plotted as far as the typical worst quality, while the lighter, shaded area is plotted to the right as far as the typical best quality. The parameter in question usually varies normally between these typical (but not extreme) limits. The data is obtained from histograms such as those illustrated in Fig. 1.

NUMERICAL MODELLING OF TBM ACCESS TUNNELS

A present concept for access to the repository depth, which will probably be in the region of 800m, is by inclined spiral tunnels which may be driven by hard rock TBM of about 8m diameter. Some preliminary studies of tun-

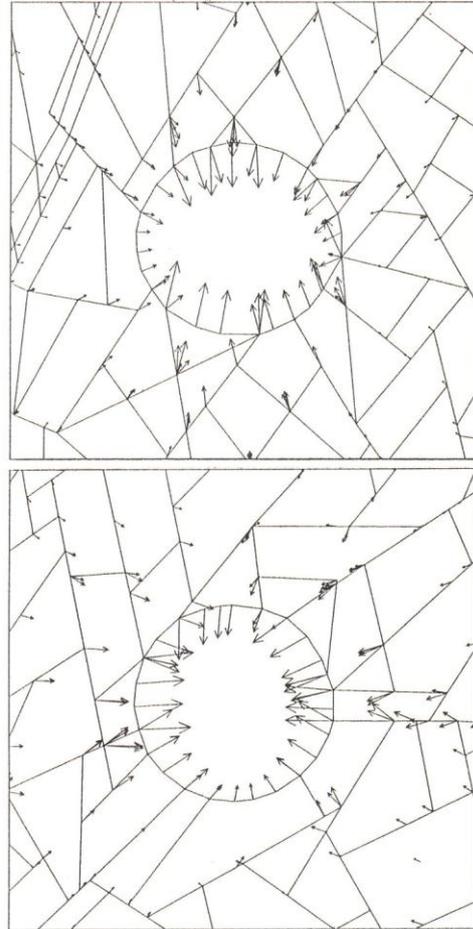


Fig. 5 UDEC-BB results showing displacement vectors for the two cases shown in Fig. 5. Both models are bolted according to Q-system logging results.

nel stability which demonstrate the use of the core logging data in discrete element (UDEC-BB) models are shown in Figs 4 and 5.

The lower horizontal rock stress around one side of the spiral (Fig. 4, top) contrasts with the higher horizontal rock stress around the side of the spiral at right angles to the principal stress (Fig. 4, bottom). The contrasting influence on displacement vectors is shown in Fig. 5, where vertical deformations dominate in the first case (max. 10.6mm, top) and where horizontal deformations dominate in the second case (max. 7.5mm, bottom).

On occasion, the UDEC-BB verification of the Q-system reinforcement design shows the need for minor adjustments to bolt spacing or bolt diameter. This is an important aspect of qual-

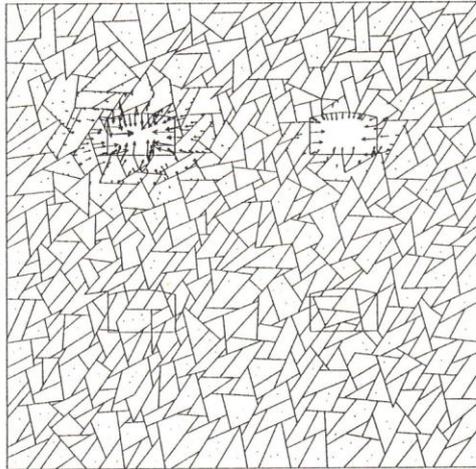


Fig. 6 UDEC-BB model of LLW caverns showing displacement vectors after excavating two caverns (unbolted case).

ity control which is followed systematically. A further check on the performance of the UDEC-BB models with the Q-designed reinforcement is to compare the wall and arch displacements with Q-system case records of measured deformations in excavations of equivalent size and Q-value. The "normalised" plot of Q/span or Q/height versus measured deformation given by Barton et al. (1980) forms the data base for this verification exercise.

NUMERICAL MODELLING OF LLW CAVERNS

Low level waste caverns are presently planned as 25m span by 15m high excavations on two levels in the repository. NGI is performing scoping studies with UDEC-BB to investigate the effects on various pillar widths and crown pillar thicknesses of the disturbed zones surrounding each cavern. Different cavern orientations are also being investigated, in order to minimise construction difficulty, cost and disturbed zone development.

An example of one of the LLW scoping studies is shown in Fig. 6. In the figure, the displacement vectors caused by excavating the first two caverns without any rock reinforcement are shown. Maximum inwards displacement is of the order of 14mm, a very reasonable figure which compares well with comparable case records. The stress relieving influence of the first cavern is significant. Studies with systematic bolting demonstrate that influences from adjacent cavern excavation can be engineered to be negligible.

CONCLUSIONS

1. A systematic method of recording relevant geotechnical data during field mapping and core logging has been described. The method serves as a check list of important parameters, and allows the all important variability of rock masses to be recorded and taken account of in design.

2. The integrated use of Q-system rock mass parameters and the more detailed joint descriptors JRC, JCS, and ϕ_r have been demonstrated.

3. UDEC-BB discrete element models of TEM driven access tunnels and low level waste caverns demonstrate the capability for realistic modelling of excavations in jointed rock.

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