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भाग 2 भूमिगत द्वारों में आधार-दाब के निर्धारण के लिए शैल-संहति गुणता

Indian Standard

QUANTITATIVE CLASSIFICATION SYSTEMS OF ROCK MASS — GUIDELINES

PART 2 ROCK MASS QUALITY FOR PREDICTION OF SUPPORT PRESSURE IN UNDERGROUND OPENINGS

UDC 624·12·001·3

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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Price Group 4

Rock Mechanics Sectional Committee, CED 48

FOREWORD

This Indian Standard (Part 2) was adopted by the Bureau of Indian Standards, after the draft finalized by the Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

Quantitative classification of rock masses have many advantages. Past experience with field tests and monitoring has provided fairly good correlations with quantitative classifications and these may be used to predict engineering behaviour of rock masses with reasonable accuracy. This is the reason why quantitative classifications have become very popular all over the world.

Guidelines for quantitative classification system of rock mass has been covered in the following two parts:

Part 1 For predicting engineering properties (RMR Method), and

Part 2 For prediction of support pressure in underground openings.

This part covers classification of rock mass for prediction of support pressure in underground openings. In the formulation of this standard due weightage has been given to the work of Nick Barton who developed this classification after studying 200 case histories, as well as to the experience gathered abroad and within this country.

For the purpose of eliminating the bias of an individual user, the rating for different parameters should be given a range in preference to a single value.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a measurement, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

QUANTITATIVE CLASSIFICATION SYSTEMS OF ROCK MASS — GUIDELINES

PART 2 ROCK MASS QUALITY FOR PREDICTION OF SUPPORT PRESSURE IN UNDERGROUND OPENINGS

1 SCOPE

1.1 This standard covers the procedures for obtaining the value of rock mass quality (Q) and correlation for predicting the support pressure for both small and large underground openings.

2 REFERENCE

2.1 The Indian Standard IS 11315 (Part 11) : 1985 'Method of quantitative description of discontinuities in rock mass: Part 11 Core recovery and rock quality' is necessary adjunct to this standard.

3 PROCEDURE

3.1 Determination of the Rock Mass Quality (Q)

The rock mass quality (Q) shall be defined by the following equation:

Rock Mass Quality (Q) = $(RQD/J_n) . (J_r/J_a) . (J_w/SRF)$ ....(1)

where

RQD = Deere's Rock Quality Designation,

J_n = Joint set number,

J_r = Joint roughness number,

J_a = Joint alteration number,

J_w = Joint water reduction factor, and

SRF = Stress reduction factor.

NOTE — The rock mass quality in Equation 1 is related with the ultimate support pressure requirements.

3.1.1 *Rock Quality Designation (RQD)* [*see* IS 11315 (Part 11) : 1985]

RQD shall be defined as the sum of core pieces with lengths greater or equal to 10 cms expressed as percentage of length of the borehole. In the absence of a borehole, RQD may be estimated from the number of joints per unit volume of the rock mass, in which the number of joints per meter for each joint set are added. Thus, RQD for clay free rock masses shall approximately be given by the following formula:

$$RQD = 115 - 3.3 J_v \qquad \text{...........(2)}$$

where

J_v = Total number of joints per cubic metre called volumetric joint count.

If RQD is less than 10 percent, a nominal value of 10 is used to evaluate rock mass quality (Q), (*see* Table 1).

Table 1 Rock Quality Designation (RQD)

Classification	Designation	RQD
A	Very poor	0-25
B	Poor	25-50
C	Fair	50-75
D	Good	75-90
E	Excellent	90-100

NOTES

1 Where RQD is reported or measured as ≤ 10 (including 0) a nominal value of 10 is used to evaluate Q in equation 1.

2 RQD intervals of 5, that is, 100, 95, 90, etc, are sufficiently accurate.

3.1.2 *Joint Set Number* (J_n)

The parameter (J_n) representing the number of joint sets shall often be affected by foliations, schistocity, slaty cleavages or beddings, etc. If strongly developed, these parallel discontinuities should be counted as a complete joint set. If there are few joints visible or only occasional breaks in rock core due to these features, then it should be counted as 'random joints' while evaluating J_n from Table 2.

NOTE — Multiply J_n by factors 2 and 3 for portals and intersections respectively.

Table 2 Joint Set Number

	Classification	J_n
A	Massive, no or few joints	0.5-1.0
B	One joint set	2
C	One joint set plus random	3
D	Two joint sets	4
E	Two joint sets plus random	6
F	Three joint sets	9
G	Three joint sets plus random	12
H	Four or more joint sets, random, heavily jointed, 'sugar cube', etc	15
J	Crushed rock, earthlike	20

NOTES

1 For intersections use ($3.0 \times J_n$).

2 For portals use ($2.0 \times J_n$).

3.1.3 *Joint Roughness Number and Joint Alteration Number* (J_r *and* J_a)

The parameters J_r and J_a, given in Tables 3 and 4 represent roughness and degree of alteration of joint walls or filling materials respectively. The parameters J_r and J_a should be relevant to the weakest significant joint-set or clay filled discontinuity in a given zone. If the joint set of discontinuity with the minimum value of (J_r/J_a) is favourably oriented for stability, then a second less favourably oriented joint set or discontinuity may be of greater significance, and its higher value of (J_r/J_a) should be used when evaluating Q from Equation 1.

Table 3 Joint Roughness Number (J_r)

	Classification	J_r
	For Rock Wall Contact and Rock Wall Contact before 10 cm Shear	
A	Discontinuous joints	4
B	Rough or irregular, undulating	3
C	Smooth, undulating	2
D	Slickensided, undulating	1·5
E	Rough or irregular, planar	1·5
F	Smooth, planar	1·0
G	Slickensided, planar	0·5
	For No Rock Wall Contact When Sheared	
H	Zone containing clay minerals thick enough to prevent rock wall contact	1·0 (nominal)
J	Sandy, gravelly or crushed zone thick enough to prevent rock wall contact	1·0 (nominal)

NOTES

1 Add 1·0 if the mean spacing of the relevant joint set is greater than 3 m.

2 J_r = 0·5 may be used for planar slickensided joints having lineations, provided the lineations are favourably orientated.

3.1.4 *Joint Water Reduction Factor* (J_w)

The parameter J_w (*see* Table 5) is a measure of water pressure, which has an adverse effect on the shear strength of joints. This is due to reduction in the effective normal stress across joints. Water may in addition cause softening and possible outwash in the case of clayfilled joints.

3.1.5 *Stress Reduction Factor* (SRF)

The parameter SRF (*see* Table 6) is a measure of the following:

a) loosening pressure in the case of an excavation through shear zones and clay bearing rock masses,

b) rock stress q_c/σ_1 in a competent rock mass where q_c is uniaxial compressive strength of rock mass and σ_1 is the major principal stress before excavation, and

c) squeezing or swelling pressures in incompetent rock masses. SRF can also be regarded as a total stress parameter.

NOTE — SRF ratings for squeezing rock conditions are not found reliable for predicting support pressures as these depend upon tunnel wall displacements.

3.2 As seen from Equation 1 the rock mass quality (Q) may be considered a function of only three parameters which are crude measures of the following:

a) Block size (RQD/J_n) : It represents overall structure of rock mass

b) Inter block shear strength (J_r/J_a) : It has been found that the $\tan^{-1}$ (J_r/J_a) is a fair approximation to the actual peak sliding angle of friction along the joint

c) Active stress (J_w/SRF) : It is an empirical factor describing the active stress

3.3 Collection of Field Data

The length of core or an exposed excavation to be used for evaluating the first four parameters (RQD, J_n, J_r and J_a) shall depend on the uniformity of the rock mass. If there is little variation, a core or wall length of 5-10 m should be sufficient. However, in a few meters wide closely jointed shear zone with alternate sound rock, it shall be necessary to evaluate these parameters separately, if it is considered likely that the closely jointed shear zones are wide enough to justify special treatment (that is, additional shotcrete) compared to only systematic bolting in the remainder of the excavation. If on the other hand the shear zones are narrow than 1-2 metres and occur frequently, then an overall reduced value of Q may be most appropriate since increased support is likely to be applied uniformly along the entire length of such variable ones. In such cases a core or wall length of 10-50 m may be needed to obtain an overall picture of the reduced rock mass quality.

NOTES

1 Values of the rock mass quality Q should be obtained separately for the roof, floor and the two walls, particularly when the geological description of the rock mass is not uniform around the periphery of an underground opening.

2 Mean value of rock mass quality should be taken as root mean square value of its maximum and minimum values.

3 In case of power tunnels, the value of J_w for calculation of ultimate support pressures should be reduced assuming that seepage water pressure in Table 6 is equal to the internal water pressure.

3.4 Classification of the Rock Mass

On the basis of the Q-value, the rock masses may be classified into the following nine categories:

Q	*Group*	*Classification*
010·000-0 040·00	1	Good
040·000-0 100·00		Very good
100·000-0 400·00		Extremely good
400·000-1 000·00		Exceptionally good
000·100-0 001·00	2	Very poor
001·000-0 004·00		Poor
004·000-0 010·00		Fair
000·001-0 000·01	3	Exceptionally poor
000·010-0 000·10		Extremely poor

Table 4 Joint Alteration Number

(*Clause* 3.1.3)

	Classification	J_a	ϕ_r (approx)
	Rock Wall Contact		
A	Tightly healed, hard, non-softening, impermeable filling	0·75	(--)
B	Unaltered joint walls, surface staining only	1·0	(25°-35°)
C	Slightly altered joint walls, non-softening mineral coatings, sandy particles, clay-free disintegrated rock, etc	2·0	(25°-30°)
D	Silty or sandy-clay coatings, small clay-fraction (non-softening)	3·0	(20°-25°)
E	Softening or low friction clay mineral coatings, that is, kaolinite, mica. Also chloride, talc, gypsum and graphite, etc, and small quantities of swelling clays (Discontinuous coatings, 1-2 mm or less in thickness)	4·0	(8°-16°)
	Rock Wall Contact Before 10 cm Shear		
F	Sandy particles, clay-free disintegrated rock, etc	4·0	(25°-30°)
G	Strongly over-consolidated, non-softening clay mineral fillings (continuous, < 5 mm in thickness)	6-0	(16°-24°)
H	Medium or low over-consolidation, softening, clay mineral fillings (continuous, < 5 mm in thickness)	8·0	(12°-16°)
J	Swelling clay fillings, that is, montmorillonite (continuous, < 5 mm in thickness). Value of Ja depends on percent of swelling clay-size particles, and access to water, etc	8·0-12·0	(6°-12°)
	No Rock Wall Contact When Sheared		
K, L, and M	Zones or bands or disintegrated or crushed rock and clay (*see* G, H, J)	6·0-8·0 8·0-12·0	(6°-24°)
N	Zones or bands of silty or sandy clay, small clay fraction (non-softening)	5·0	
O, P, R	Thick, continuous zones or bands of clay (*see* G, H, J)	10·0-13·0 13·0-20·0	(6°-24°)

NOTE

Values of (ϕ_r) are intended as an approximate guide to the mineralogical properties of the alteration products, if present.

Table 5 Joint Water Reduction Factor

(*Clause* 3.1.4)

	Classification	(J_w)	Approx Water Pressure (kg/cm²)
A	Dry excavations or minor inflow, that is, 5 l/min locally	1·0	< 1
B	Medium inflow or pressure occasional outwash of joint fillings	0·66	1·0-2·5
C	Large inflow or high pressure in competent rock with unfilled joints	0·5	2·5-10·0
D	Large inflow or high pressure, considerable outwash of joint filling	0·33	2·5-10·0
E	Exceptionally high inflow or water pressure at blasting, decaying with time	0·2-0·1	> 10·0
F	Exceptionally high inflow or water pressure continuing without noticeable decay	0·1-0·05	> 10·0

NOTES

1 Factors C to F are crude estimates. Increase J_w if drainage measures are installed.

2 Special problems caused by ice information are not considered.

Table 6 Stress Reduction Factor

(*Clause* 3.1.5)

	Weakness Zones Intersecting or Influencing Excavation, which may Cause Loosening of Rock Mass When Tunnel is Excavated			
	Classification			**SRF**
A	Multiple occurrences of weakness zones containing clay or chemically disintegrated rock, very loose surrounding rock (any depth)			10·0
B	Single weakness zones containing clay, or chemically disintegrated rock (depth of excavation ⩽ 50 m)			5·0
C	Single weakness zones containing clay, or chemically disintegrated rock (depth of excavation > 50 m)			2·5
D	Multiple shear zones in competent rock (clay free), loose surrounding rock (any depth)			7·5
E	Single shear zones in competent rock (clay free) (depth of excavation ⩽50 m)			5·0
F	Single shear zones in competent rock (clay free) (depth of excavation >50 m)			2·5
G	Loose open joints, heavily jointed or 'sugar cube', etc (any depth)			5·0
	Competent Rock, Rock Stress Problems			
		σ_c/σ_1	σ_r/σ_1	
H	Low stress, near surface	> 200	> 13	2·5
J	Medium stress	200-10	13-3·66	1·0
K	High stress, very light structure (usually favourable to stability may be unfavourable to wall stability)	10-5	0·66-0·33	0·5-2·0
L	Mild rock burst (massive rock)	5-2·5	0·33-0·16	5-10
M	Heavy rock burst (massive rock)	<2·5	<0·16	10-20
	Squeezing Rock, Plastic Flow of Incompetent Rock Under the Influence of High Rock Pressures			
N	Mild squeezing rock pressure			5-10
O	Heavy squeezing rock pressure			10-20
	Swelling Rock : Chemical Swelling Activity Depending on Presence of Water			
P	Mild swelling rock pressure			5-10
R	Heavy swelling rock pressure			10-15

NOTES

1 Reduce these values of SRF by 25-50 percent if the relevant shear zones only influence but do not intersect the excavation.

2 For strongly anisotropic stress field (if measured):
when $5 \leqslant \sigma_1/\sigma_3 \leqslant 10$, reduce σ_c and σ_t to 0·8 σ_c and 0·8σ_t;
when $\sigma_1/\sigma_3 > 10$, reduce σ_c and σ_t to 0·6 σ_c and 0·6 σ_t;
where: σ_c = unconfined compression strength,
σ_t = tensile strength (point load), and
σ_1 and σ_3 = major and minor principal stresses.

3 Few case records available where depth of crown below surface is less than span width. Suggest SRF increase from 2·5 to 5 for such cases (*see* H)

3.5 Estimating Support Pressures

All methods of tunnel excavation and support systems presently used, allow some degree of deformation of the surrounding rock mass. In most of the poorer qualities of rock masses (excluding squeezing and swelling conditions), the final support pressures tend to be somewhat greater if the temporary support is excessively flexible (that is steel ribs and wooden blocking) or if the installation of support is delayed. Use of immediate shotcrete and/or rock bolt as temporary supports tends to minimize the final pressures as compared to steel rib support. This is because the latter allows just sufficient deformation for arching to develop but prevents loosening of the rock mass within this arch.

It may be mentioned that Q referred to in the following correlation is actually the post excavation quality of a rock mass. In tunnels, the geology of the rock mass is usually studied after blasting and on the spot decision is taken on support density of spacing of steel ribs, etc.

3.5.1 *Non-squeezing Ground* ($H < 350\ Q^{1/3}$)

3.5.1.1 *Ultimate roof support pressure*

a) *Vertical support pressure*

The ultimate roof support pressure is related to ultimate roof rock mass quality (Q_{ru}) by the following empirical correlation:

$$P_{ru} = \frac{(2.0)}{J_r} . (Q_{ru})^{-1/3} .f \qquad \ldots\ldots(3)$$

where

P_{ru} = ultimate roof support pressure in kg/cm²

J = joint roughness number

Q_{ru} = ultimate rock mass quality = Q

f = correction factor for overburden
= 1 + (H−320)/800 ....(4)
> 1

H = overburden above crown or tunnel depth below ground level in metres.

b) *Ultimate wall support pressure*

In view of the more favourable position of walls as compared to roofs, the following hypothetically increased value of wall rock quality (Q_{wu}) may be used to find out ultimate wall support (horizontal support) pressure on the walls:

i) In good to exceptionally good qualities of rock masses of group 1 ($Q_u > 10$)

$$Q_{wu} = 5\ Q_u \qquad \ldots\ldots(5)$$

ii) In very poor to fair qualities of rock masses of Group 2 ($Q_u < 10$)

$$Q_{wu} = 2.5\ Q_u \qquad \ldots\ldots(6)$$

iii) In extremely poor and exceptionally poor qualities of rock masses of Group 3 ($Q_u < 0.1$)

$$Q_{wu} = Q_u \qquad \ldots\ldots(7)$$

The ultimate wall support pressure (P_{wu}) is given by the following correlation in kg/cm²:

$$P_{wu} = \frac{2.0}{J_r} . (Q_{wu})^{-1/3} .f \qquad \ldots\ldots(8)$$

where

Q_{wu} = ultimate wall rock quality.

NOTE — The ratio of ultimate to short-term support pressures may increase from $5^{1/3}$ as assumed in **3.5.1.1** (a.b) to as high as 6 in cases of rock mass with soluble and erodible joint fillings and seepage problems. Concrete lining should be designed for high net ultimate support pressures in the roof in such rock masses.

3.5.1.2 *Short-term support pressure*

Temporary supports should be designed for short-term support pressure only. These supports may be strengthened later on by shotcreting or lining to take care of ultimate support pressures.

a) *Short-term roof support pressure*

The short-term roof support pressure is related with the so called short-term roof rock quality (Q_{ri}) by the following correlation:

$$P_{ri} = \frac{(2.0)}{J_r} . (Q_{ri})^{-1/3} .f \qquad \ldots\ldots(9)$$

where

P_{ri} = short-term vertical roof support pressure in kg/cm²

$Q_{ri} = 5Q_{ru}$ = short-term roof rock quality = 5Q

Field observations of the support pressures are close to those estimated from Equation 9 for non-squeezing rock conditions.

b) *Short-term wall support pressure*

The short-term wall support pressure (P_{wi}) is similarly given by the following equation in kg/cm²:

$$P_{wi} = \frac{(2.0)}{J_r} . (Q_{wi})^{-1/3} .f \qquad \ldots\ldots(10)$$

where

Q_{wi} = short-term wall rock quality

The short-term wall rock quality Q_{wi} is obtained after multiplying Q by a factor which depends on the magnitude of Q as given below:

i) $Q > 10$: $Q_{wi} = 5.0\ Q_{ri} = 25\ Q$

ii) $0.1 < Q < 10$: $Q_{wi} = 2.5\ Q_{ri} = 12.5\ Q$

iii) $Q < 0.1$: $Q_{wi} = 1.0\ Q_{ri} = 5Q$

For rock mass quality (Q) used in Equations 1 to 10, the corresponding support pressure may also be obtained from the chart given in Fig. 1. The shaded envelope is the estimate of range of support pressures to be expected in practice.

However, the observed short-term wall support pressure is not significant in non-squeezing rock conditions. It is, therefore, recommended that these may be neglected in the case of tunnels in rock masses of good quality of group 1 ($Q > 10$).

NOTE — Although the bottom support pressure is negligible in non-squeezing ground conditions, invert support may be used when the estimated wall support pressure requires the use of wall support in exceptionally poor rock conditions and squeezing ground conditions.

3.5.2 *Squeezing Ground* ($H > 350\ Q^{1/3}$)

3.5.2.1 *Ultimate support pressure*

a) *Roof support pressure*

The ultimate roof support pressure (P_{ru}) is related to ultimate roof rock quality (Q_{ru}) by the following empirical correlation:

$$P_{ru} = \frac{(2{\cdot}0)}{J_r} (Q_{ru})^{-1/3} .f.f' \quad ......(11)$$

where

f = correction factor for overburden (Equation 4), and

f′ = correction factor for tunnel closure (Table 7 and Fig. 2).

Values of correction factors for tunnel closure (f′) may be obtained from Table 7 the basis of design value of tunnel closure.

NOTES

1 Tunnel closures more than 6 percent of tunnel span should not be allowed otherwise support pressures are likely to build up rapidly due to loosening of rock mass. In such cases, additional rock anchors should be installed immediately to arrest the tunnel closure within limiting value. Otherwise the ratio of ultimate to short-term support pressure may rise to 2 to 3.

2 Steel ribs with struts may not absorb more than 2 percent tunnel closure.

3 Tunnels in highly squeezing ground should be less than 6 m in span to ensure better rate of tunnelling with less construction problems. Tunnel instrumentation is recommended.

4 In case of very good and hard rocks, rockburst may occur in place of squeezing when overstressed ($H > 350\ Q^{1/3}$ m).

5 In case of parallel tunnels, the wall support pressure shall be much higher than roof support pressure if clear spacing between tunnels is less than sum of the span of openings.

b) *Wall support pressure*

The ultimate wall support pressure (P_{wu}) is obtained by the following empirical correlation:

$$P_{wu} = \frac{(2{\cdot}0)}{J_r} (Q_{wu})^{-1/3} .f.f' \quad ......(12)$$

where

Q_{wu} should be used as per **3.5.1**(b).

3.5.2.2 *Short-term support pressure* (*corrected*)

a) *Short-term roof support pressure*

The short-term roof support pressure is related with the short-term rock mass quality (Q_{ri}) by the following correlation:

$$P_{ri} = \frac{(2{\cdot}0)}{J_r} (Q_{ri})^{-1/3} .f.f' \quad ......(13)$$

$Q_{ri} = 5Q$ = immediate or short-term rock mass quality

b) *Short-term wall support pressure*

The short-term wall support pressure (P_{wi}) is similarly given by the following equation:

$$P_{wi} = \frac{(2{\cdot}0)}{J_r} . (Q_{wi})^{-1/3} .f.f' \quad .....(14)$$

where

Q_{wi} = short-term wall rock quality [*see* **3.5.1.2**(b)].

3.6 Unsupported Span

The equivalent dimensions (D_e) of self supporting of unsupported tunnel is given below:

$$D_e = 2{\cdot}0\ (Q^{0{\cdot}4}) \quad ......(15)$$

in which

D_e = limiting value of $\frac{\text{(span, diameter or height in meters)}}{\text{ESR}}$

Q = rock mass quality, and

ESR = equivalent support ratio.

Table 7 Correction Factor for Tunnel Closure
(*Clause* 3.5.2.1)

Sl No.	Rock Condition	Support System	Tunnel Closure u/a (percent)	f′
1	Non-squeezing ($H < 350\ Q^{1/3}$)			1·1
2	Squeezing ($H > 350\ Q^{1/3}$)	Very stiff	< 2	> 1·8
3	Squeezing ($H > 350\ Q^{1/3}$)	Stiff	2-4	0·85
4	Squeezing ($H > 350\ Q^{1/3}$)	Flexible	4-6	0·70
5	Squeezing ($H > 350\ Q^{1/3}$)	Very flexible	6-8	1·15
6	Squeezing ($H > 350\ Q^{1/3}$)	Extremely flexible	> 8	1·8

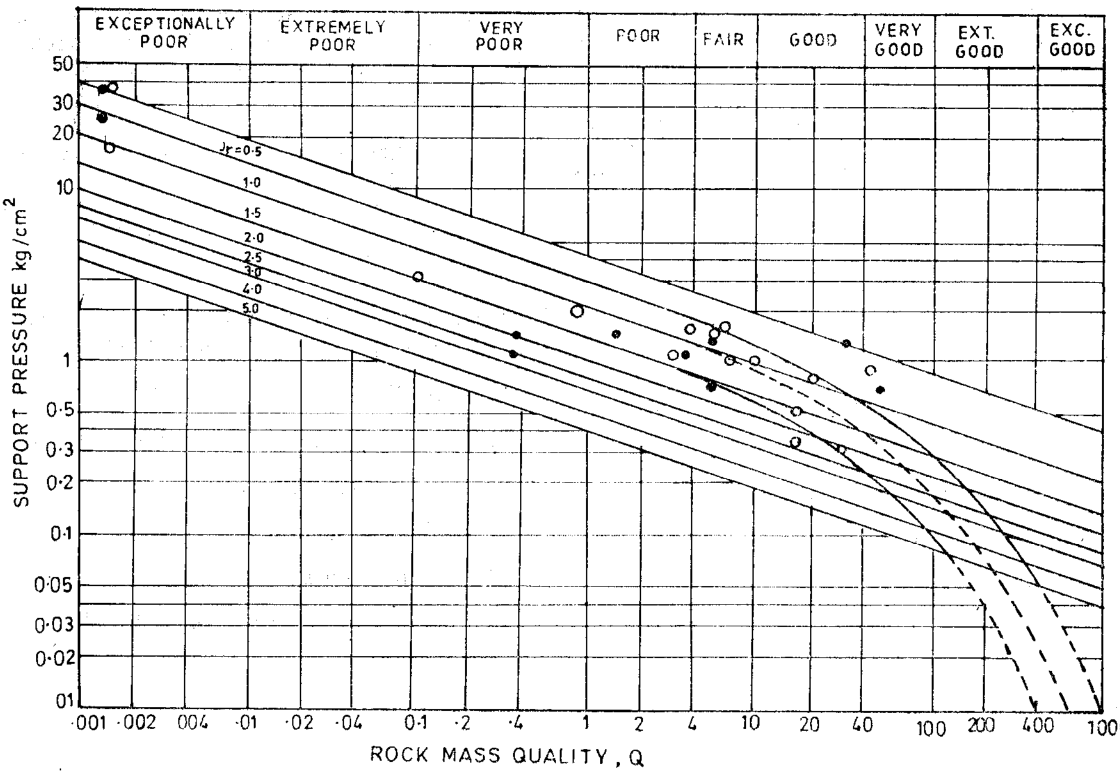

FIG. 1 RELATIONSHIP BETWEEN Q AND SUPPORT PRESSURE

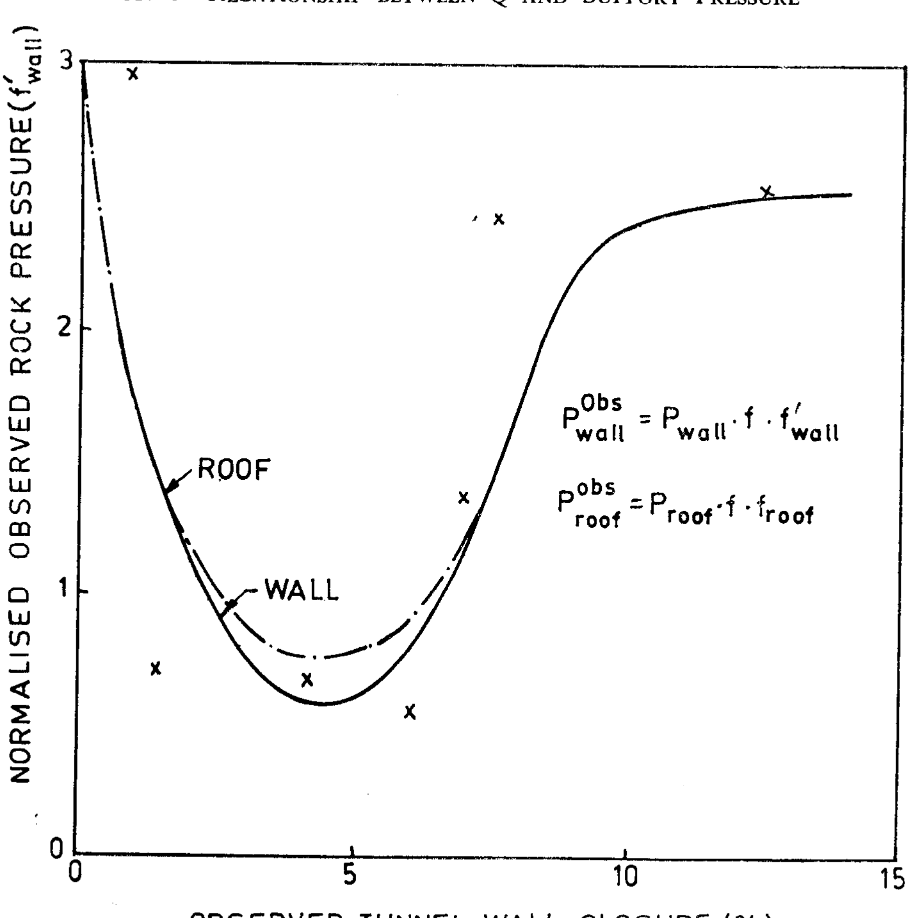

FIG. 2 CORRECTION FACTORS FOR TUNNEL WALL CLOSURE UNDER SQUEEZING GROUND CONDITION ($H > 350\ Q^{1/3}$ m)

In equivalent dimension, the span or diameter is used when analyzing the roof support, and the diameter or height for the wall support.

Excavation support ratio (ESR) appropriate to a variety of underground excavations is listed in Table 8 increasing order of importance or degree of safety.

Table 8 Values of Excavation Support Ratio (ESR)

Type of Excavation	ESR
i) Permanent mine openings, water tunnels for hydro power (excluding high pressure penstocks), pilot tunnels, drift and headings for large excavations and oil storage caverns, etc	1·6
ii) Storage rooms, water treatment plants, minor road and railway tunnels, surge chambers, access tunnels, etc	1·3
iii) Power stations, major road and railway tunnels, civil defence chambers, portals, intersections, etc	1·0

For working out the temporary support requirements, ESR values mentioned above should be multiplied by a factor 1·5 and Q should be increased to 5Q.

General requirements for permanently unsupported openings are:

a) $J_n < 9$, $J_r > 1·0$, $J_a < 1·0$, $J_w = 1·0$ SRF $< 2·5$

Further, conditional requirements for permanently unsupported openings shall be as follows:

b) If RQD < 40, need $J_n < 2$

c) If $J_n = 9$, need $J_r > 1·5$ and RQD > 90

d) If $J_r = 1·0$, need $J_w < 4$

e) If SRF > 1, need $J_r > 1·5$

f) If span > 10 m, need $J_n < 9$

g) If span > 20 m, need $J_n < 4$ and SRF < 1

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