LUIS I. GONZALEZ DE VALLEJO
Empresa Nacional Adaro de Investigaciones Mineras, Dr. Esquerdo 138, Madrid
Facultad de Ciencias Geológicas, Universidad Complutense.

TUNNELLING EVALUATION USING THE SURFACE ROCK MASS CLASSIFICATION SYSTEM (SRC)

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ABSTRACT:

The Surface Rock Mass Classification System (SRC) is described as a method to evaluate engineering geological conditions for tunneling where the main source of information comes from surface data. This Classification is based on the RMR Geomechanical Classification, however in SRC new indices and correction factors are included to assess extrapolation of data from surface to tunnel depth, state of natural stresses, and the influence of construction conditions. The procedure to apply SRC is explained and the results from 80 tunnels and 2 mines are discussed.

1.- INTRODUCTION

Empirical methods for tunnel design has been widely used during the last decades due to the succesful development of the Rock Mass Classification Systems (RMCS). Particulary the RMR System described by Bieniawski (1973) and the Q System decribed by Barton et al 1974. This methods are efficient when appropiate and representative geomechanical data are use. However during the early stages of tunnel design most of the engineering geological information are based on reconnaisance surveys. Limited number of deep site investigations are generally carried out, e.g. borehole drilling and geophysics, and few of this investigations reach the tunnel depth. Under this circumstances the application of RMCS are subjected to a high degree of geological uncertainties, depending on the geological complexity, the thickness of the overburden materials and the topographical relief.

To investigate the use of RMCS when most of data are obtained from surface investigations have been carried out in 80 tunnels and 2 mines in Spain. Rock mass quality indices were measured on surface and inside excavations, as well as the rock behaviour during construction.

2.- THE SRC GEOMECHANICAL CLASSIFICATION

The Surface Rock Mass Classification System (SRC) is based on the RMR System (Bieniawski 1973, 1979), and can be considered as a modification of this system to account extrapolation of surface data to tunnel depth. However new indices are included such as the state of stresses, which is assessed from geological factors, and the influence of construction methods on rock mass quality. The indices considered in SRC are:

- Intact rock strength
- Spacing of discontinuities or RQD
- Conditions of discontinuities
- Water inflow into excavations
- State of stresses
- Construction methods

The procedure to evaluate these indices has been previously described (González de Vallejo 1983 and 1984). Nevertheless a brief description is given to explain the criteria to define the state of stresses and construction methods.

2.1.- State of Stresses

Natural stresses are highly dependent on tectonic and geomorphological processes, including paleotectonic, neotectonic, lithogenesis, lifting, subsidence, erosion, sedimentation, isostatic changes and topographic effects.

To assess high potential horizontal stresses due to these geological processes the following factors have been considered:

- Competence Factor (CF), included in the Q System, and defined as the ratio of the uniaxial compressive strength of the rock and the maximum vertical stress due to the overburden thickness.

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TABLE 1. SRC GEOMECHANICS CLASSIFICATION

ROCK QUALITY INDICES	RANGE OF VALUES				
1. INTACT ROCK STRENGTH					
Point Load Test (MPa)	> 8	8 – 4	4 – 2	2 – 1	Not applicable
Uniaxial Compressive Strength (MPa)	> 250	250 – 100	100 – 50	50 – 25	25–5 5–1 < 1
Rating	20	15	7	4	2 1 0
2. SPACING or R Q D					
Spacing (m)	> 2	2 – 0.6	0.6 – 0.2	0.2 – 0.06	< 0.06
R Q D (%)	100 – 90	90 – 75	75 – 50	50 – 25	< 25
Rating	20	17	13	8	5
3. CONDITIONS OF DISCONTINUITIES					
Conditions	Very rough surfaces Not continous joints No separation Hard joint walls rock	Slightly rough surfaces No continous joints Separation < 1 mm Hard joint wall rock	Slight rough surfaces Not continous joints Separation 1 mm Soft or weathered joint walls	Slickensides surfaces Continous joints Doints open 1-5 mm Gouge materials	Slickensides surfaces Continous joints Joints open > 5 mm Gouge materials > 5 mm thick
Rating	30	25	20	10	0
4. GROUND WATER					
Inflow per 10 m tunnel length (litre/min)	None	< 10	10 – 25	15 – 125	> 125
General conditions	Dry	Slightly moist	Occasional seepages	Frequent seepages	Abundant seepages
Rating	15	10	7	4	0
5. STATE OF STRESSES					
Competence Factor (see table 2)	> 10	10 – 5	5 – 3	< 3	–
Rating	10	5	– 5	– 10	–
Tectonic Activity Rating	Zones near Faults/thrusts of Regional importance – 5		Compression Stresses – 2		Tension Stresses 0
Stress Relief Factor (see table 2)	> 200	200 – 80	80 – 10	< 10	Slopes and Valley Side areas 200 – 80 80 – 10 < 10
Rating	0	– 5	– 8	– 10	– 10 – 13 – 15
Neotectonic Activity Rating	Noner or Unknown 0		Assumed – 5		Confirmed – 10
6. ROCK MASS CLASSES					
Class Number	I	II	III	IV	V
Rock Quality	Very Good	Good	Fair	Poor	Very Poor
Rating	100 – 81	80 – 61	60 – 41	40 – 21	< 20

TABLE 2. CORRECTIONS FACTORS

INTACT ROCK STRENGTH

Strength index = I R S x D C F
D C F < 30 % = 0.6
D C F ≥ 30 < 50 = 0.7
D C F ≥ 50 < 80 = 0.8
D C F ≥ 80 % = 1.0

NOTES

I R S = Intact Rock Strength
D C F = Durability Correction Factor using Slake Durability Test
T H C F = Tectonic History Correction Factor
W C F = Weathering Correction Factor

SPACING or R Q D

Spacing index = Spacing or R Q D x T H C F x W C F
T H C F – Compressive fractures = 1.25
T H C F – Tension fractures = 0.8
T H C F – For depths < 50 m = 1.0

W C F – Weathering Grade ≥ IV = 0.7
W C F – Weathering Grade III = 0.8
W C F – Weathering Grade I or II = 1.0

CONDITIONS OF DISCONTINUITIES

The rating results obtained in Table I for this index adjust to orientation, according with Bieniawski (1979)

Strike perpendicular to tunnel axis				Strike parallel to tunnel axis		Dip 0º – 20º irrespective of Strike
Drive with dip		Drive against dip				
Dip 45º – 90º	Dip 20º – 45º	Dip 45º – 90º	Dip 20º – 45º	Dip 45º – 90º	Dip 20º – 45º	
Very favourable 0	Favourable – 2	Fair – 5	Unfavourable – 10	Very Unfavourable – 12	Fair – 5	Unfavourable – 10

GROUND WATER

The rating obtained adjust it for

T H C F – Compressive fractures + 4 points
T H C F – Tension fractures cero points
T H C F – For depths < 50 m not applicable

TABLE 3. RATING ADJUSTMENT FOR CONSTRUCTION CONDITIONS

The Total Rating from Table 1 and 2 must be adjusted for the following factors:	
CONSTRUCTION FACTORS	POINTS
Excavation Methods	
– Tunnelling Boring Machines, Continous Miner, Cutter Machines, Mechanical Precort, etc.	+ 5
– Controlled Blasting, Presplitting, Soft Blasting, etc.	0
– Uncontrolled Blasting, or Bad Quality Blasting	– 10
Support methods (See Note 1)	
Class I	0
Class II < 10 days > 10 days < 20 days > 20 days	 + 5 – 5 – 20
Class III < 2 days > 2 days < 5 days > 5 days < 10 days > 10 days	 + 5 0 – 5 – 20
Class IV and V < 8 hours > 8 hours < 24 hours > 24 hours	 0 – 10 – 20
Distance to adjacent excavations (See Note 2)	
A E F < 2.5	– 20
2.5 < A E F < 10	– 10
A E F > 10	0
Portals, Accesses, and areas with small overburden thickness (See Note 3)	
P F < 5	– 20
5 < P F < 10	– 10
P F > 10	0

NOTES

(1) Based on Bieniawski (1979) graphic representation of the stand–up–time and the unsupported span the rating are applied in relation with the maximum time that must be applied the appropiate support.

(2) A E F is the Adjacent Excavation Factor defined as the ratio between the distance to an adjacent excavation, in metres, with respect to the main excavation under design, and the section of that adjacent excavation, in metres.

(3) P F in the Portal Factor defined as the ratio between the thickness of overburden and the section of the excavation, both in metres.

- Stress Relief Factor (SRF) defined as the ratio between the age (in years $\times 10^{-3}$) of the last main tectonic deformation, and the absolute difference in level (in metres) between the present elevation of the tunnel and the level at which the rock could be sited during lithogenetic process. This data can be estimated with regional geological information, usually included in published geological maps.

- Tectonic Activity, is assessed considering the tectonic accidents and the predominant type of regional tectonic stresses, that can induced anisotropies in the stress fields directions and its magnitudes.

- Neotectonic Activity in terms of recent tectonic deformation and seismicity can also introduce horizontal stresses. This factor is evaluated on regional seismotectonic information.

2.2.- Construction Methods

The rock mass quality during tunnelling can be very much affected by the excavation and construction methods. The following factors can modify significantly the distribution and the amount of the induced stresses around excavations:

- Escavation methods
- Support systems
- Influence of portals, intersections and areas with small thickness of overburden.

Influence of excavation methods are evaluated as a function of the damage introduced in the rock mass. Support methods are estimated as a funtion of the Rock Mass Class and their related time to apply appropiate support measures, according with the span-up-time concept described by Bieniawski, 1979. The other factors are defined as functions of geometrical parameters, described in Table 3.

3.- APPLICATION OF THE SRC SYSTEM

SRC System procedure is showed in Tables 1, 2 and 3. Practical guidelines could be as follows:

- Step 1. Divide the tunnel trace in similar lithological zones.

- Step 2. Suddivide these zones in those which show similar structural or fracturing features.

- Step 3. Identify "critical points" along the tunnel trace.

- Step 4. Indicate the length and location of each zone in the geological cross section through the tunnel trace.

- Step 5. Apply geomechanical field data to rock mass quality indices, Table 1.

- Step 6. Apply correction factors, Table 2.

- Step 7. Obtain Classes of Rock for conditions before excavation, Table 1.

TABLE 4. SUPPORT ASSESSMENT

ROCK MASS CLASS	SUPPORT
Very Good Rock Class I SRC = 100–81	Generally No support required
Good Rock Class II SRC = 80–61	Locally Bolts or Shotcrete in crown, Ocassionally bolting and shotcrete
Fair Rock Class III SRC = 60–41	Systematic bolting or shotcrete. Occasionally systematic bolting and Shotcrete in Crown and Sidewalls
Poor Rock Class IV SRC = 40–21	Systematic bolting with wire mesh. Shotcrete in crown and sidewalls Occasionally light steel ribs
Very Poor Rock Class V SRC ≤ 20	Full Face systematic bolting, shotcrete and wire mesh and steel ribs. Occasionally close invert required

TABLE 6. AVERAGE VALUES OF RMR, Q AND SRC MEASURED EN SURFACE AND UNDERGROUND

LITHOLOGY	RMR (s)	Q* (s)	SRC	RMR (u)	LOCATION
SHALES	57	48	33	31	Peñarroya (1)
	20	31	32	27	Pajares (2)
	25	40	40	37	Pajares (2)
	37	48	48	42	Pajares (2)
SHALES + SANDSTONES	20	26	40	45	Pajares (2)
	38	42	53	52	Pajares (2)
	53	61	65	60	Pajares (2)
	38	—	42	40	Toledo (5)
SANDSTONES + MARLS	37	31	25	27	Andorra (1)
SANDSTONES + CONGLOM.	40	59	59	50	Pajares (2)
	58	65	65	68	Pajares (3)
SANDSTONES + QUARCITES	52	—	63	70	Toledo (5)
LIMESTONES	38	54	55	52	Pajares (3)
	45	65	65	56	Pajares (2)
	55	75	75	64	Pajares (2)
QUARCITES	33	42	49	53	Pajares (2)
	45	56	63	62	Pajares (2)
	56	70	78	72	Pajares (2)
SCHISTS	63	34	48	55	Granada (4)
	55	37	47	50	Granada (4)
	42	31	46	38	Granada (4)
SCHISTS + QUARC.	59	35	61	61	Granada (4)
	73	46	68	70	Granada (4)
	69	51	61	60	Granada (4)

Q * = Related with RMR:
– Pajares: RMR = 53,3 + 9,14 LQ
– Other: RMR = 9 LnQ + 44

(s) = Surface data
(u) = Underground data

(1)–Coal Mine; (2)–Motorway Tunnel; (3)–Railwai Tunnel; (4)–Hydroelectric Tunnel; (5)–Underground Storage.

- Step 8. Adjust ratings for construction conditions, Table 3, and obtain Classes of Rock during excavation, Table 1.
- Step 9. Assess design criteria from RMR - correlations Table 4 and 5.

Critical points referred in Step 3 are those geological or geomechanical factors that could have a very unfavourable influence on tunneling. Some of the most important are:

- Tectonic accidents.
- Contacts between rocks of different geomechanical behaviour.
- Zones of large water leakage.
- Portal areas, access and zones of shallow overburden.
- Zones of potential plastification.
- Expansive, agressive and abrassive terrains.

A practical example is following described to evaluate the state of stresses index.

3.1.- Case of Salto del Duque Tunnel

- Lithology: micaschists.
- Rock density 2.3 Mg/m3.
- Uniaxial Compressive strength 25 MPa (2,500 Tn/m2).
- Overburden thickness = 150 m.
- Competence Factor = 2,500/(2.3 x 150) = 7.2, Score from Table 1 = 5
- Tectonic Activity: last main tectonic deformation Alpine, around 12 mill. of years. Predominant stress field: compression, Regional faults present in the area. Score from Table 1: - 5.
- Stress Relief Factor (SRF): metamorphic rocks of low grade of metamorphism. Possible rock forming depth ranging from 5 to 10 km Tunnel elevation ±1,500 m. Tunnel located in valley side.

  $$SRF = (12,000,000 \times 10^{-3})/(10,000 + 1,500) = 1.0$$

  Alternatively,

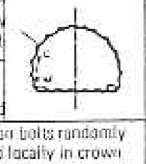
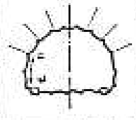
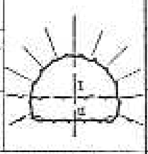
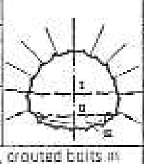
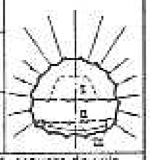
  $$SRF = (12,000,000 \times 10^{-3})/(5,000 + 1,500) = 1.8$$

  In both cases the score from Table 1 = -15
- Neotectonic Activity: Although the tunnel is in a region of moderate seismicity, no major fault of recent age is near the area. Score from Table 1 = 0.
- Total Rating for the State of Stresses Index = - 15.

3.2.- Design Criteria

Design criteria (Step 9) in terms of support, stability and construction methods can be - assessed using the RMCS, Bieniawski 1984. As the SRC and the RMR System have the same Class ratings direct correspondance can be stablished by substitution the SRC for a $RMR_{(s)}$ corrected value for surface data. Table 4 shows guide lines for support measures, while Table 5 presents a correlation for support, stability and excavation sequences when the New Austrian Tunneling Method (NATM) is recommended.

TABLE 5. NATM ROCK MASS CLASSIFICATION AND SUPPORT (MUSSGER 1981) RELATED TO SRC (Sections higher than 40 m^2)

ROCK MASS TYPES		1 STABLE ROCK		2 SLIGHTLY UNSTABLE ROCK		3 MODERATELY FRIABLE ROCK		4 FRIABLE OR MODERATE PRESSURE EXERTING ROCK		5 HEAVY PRESSURE EXERTING ROCK	
ROCK MASS PROPERTIES AND BEHAVIOR	STRUCTURAL FEATURES	Massive, few or no joints		Few joints, indistinct stratification		Stronger fracturing due to joints, foliation or stratification, some clayey gouge		Heavy fracturing due multiple joint, strong tectonic movements, large mylonitic		Extremely fractured up total loss of rock mass strength, mylonitic zones loosening to pasty consistance	
	CHEMICAL	Unweathered		Unweathered to slightly weathered		Slightly weathered		Significant clay content in rock		Chemical disintegrated by weathering	
	WATER	Without effect		Without effect		Minor effect		Moist, dripping		May affect rock mass strength	
	ROCK MECHANICS	Uniaxial compressive strength of rock mass does not exceed tangential stress. Local support in crown, where tensile strength of rock mass is exceeded				Rock mass strength around tunnel circumference may be exceeded, support by creation of reinforced rock arch is required				(1)	
EXCAVATION	EXCAVATION SECTION	Full face		Full face		Top heading/ bench		Top heading/ bench		Top heading/ bench	
	LENGTH OF ROUND	Theoretically unrestricted		3.0 meters		2.5 meters in crown		1.5 to 2.5 meters in crown		Maximum 1.0 meter in crown	
	STAND UP TIME	C: several months W: unlimited		C: several weeks W: several months		C: several days W: several weeks		C: several hours W: several days		C: up to 1 hour W: several hours	
SUPPORT	ANCHORS	Expansion bolts randomly installed locally in crown prestressed, 3.0 meters long.		Patterned, grouted bolts in crown prestressed, 3.0 meters long.		Patterned grouted bolts in crown and walls prestressed, 4.0 meters long		Patterned, grouted bolts in crown and walls prestressed 4.0 to 6.0 meters long		Patterned, grouter dowels in crown and walls, non-prestressed, 6.0 meters long	
	SHOTCRETE	Local scaling		Crown: 10 cm Walls: 5 cm		Crown: 10 cm Walls: 10 cm		Crown: 15–20 cm Walls: 15–20 cm		Crown: 20–25 cm Walls: 20–25 cm	
	STEEL ARCHES	———		Crown: welded wire fabric		Crown and walls: welded wire fabric Crown: rib arches, if required		Crown and walls: welded wire fabric Crown: light steel ribs, forepiling sheets, if required		Crown and walls: welded wire fabric steel ribs Crown: forpilingsheets, if required	
	FACE	———		———		———		———		Shotcrete sealing, support core	
	INVERT	———		———		———		Invert arch		Invert arch	
	GROUTING	———		———		———		———		———	
	TIME OF INSTALLATION	Outside of working face		After two rounds		Crown: immediately after excavation Walls: after two rounds		Immediately after excavation invert arch within 20 days		Immediately after excavation invert arch within 20 days	
INSTRUMENTATION		Convergency measurements				Convergency measurements Extensometers, shotcrete, pressure cells					
S R C		> 75 (I–II)		74–50 (II)		50–25 (III–IV)		< 25 (IV–V)		Critical Points	

(1) Stresses in tunnel vicinity exceed rock mass strenghth, plastic zones exert pressure at lining, moderate lateral pressures and invert up-lift must be taken by completely closed reinforced rock arch.

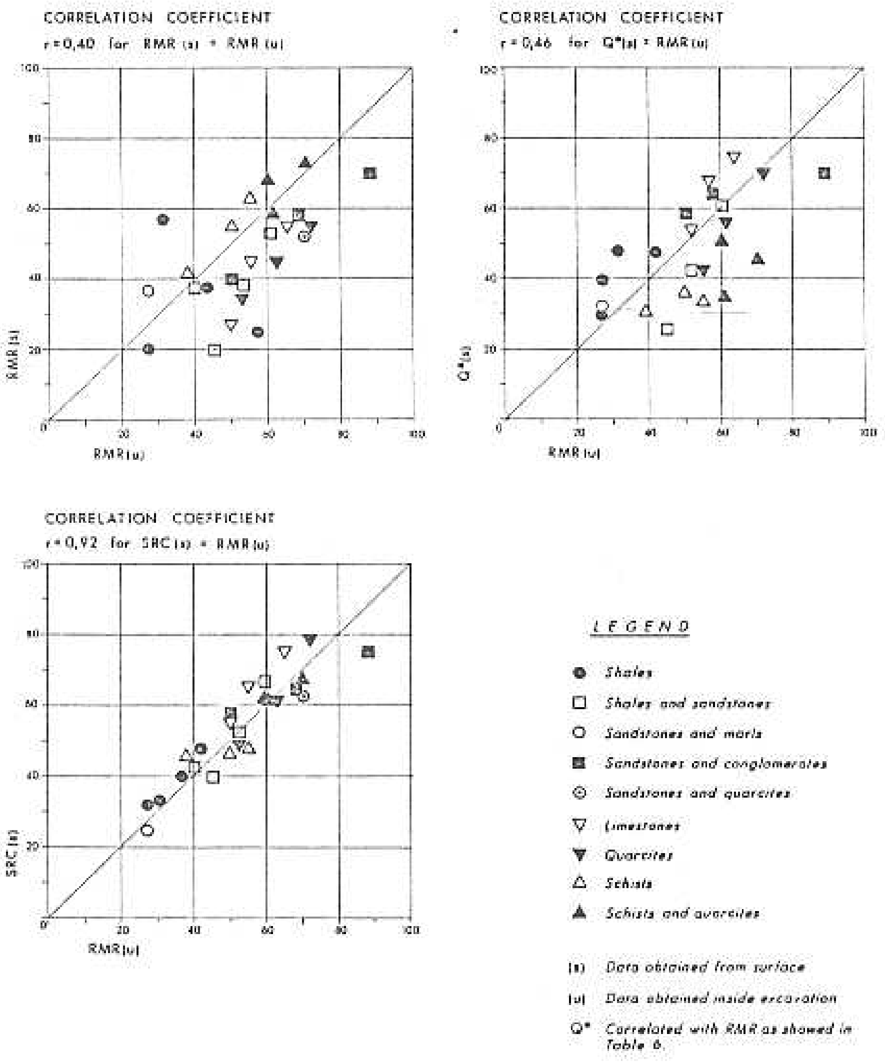
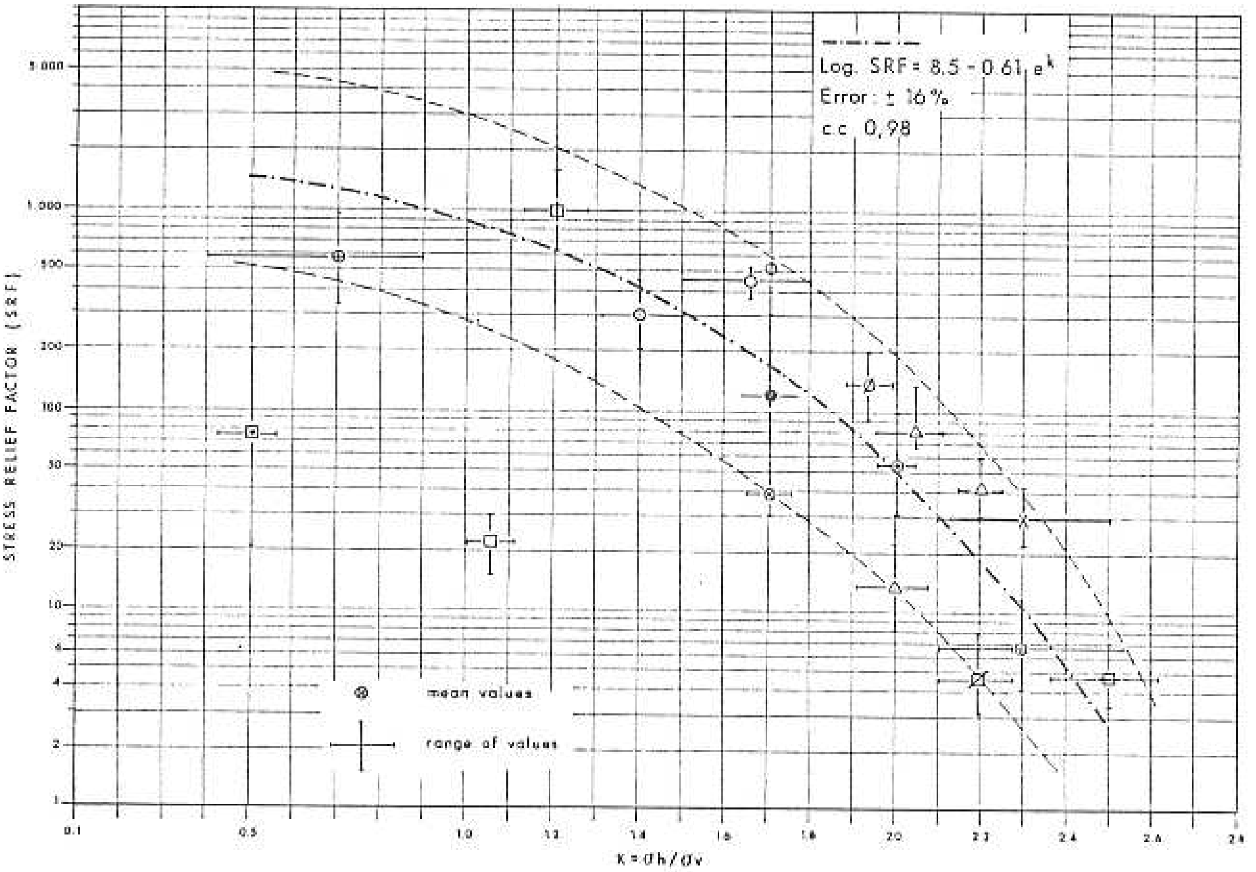


Fig. 1.- Mean values of RMR, Q and SRC obtained from surface (s) and inside excavation (u). Data from 80 tunnels and 2 mines with sections ranging from 10 to 100 m^2

FIG. 2.- EMPIRICAL RELATIONSHIPS OF SRF AND $\sigma h/\sigma v$



REFERENCES AND LOCATIONS OF DATA PLOTTED
IN FIG. 2

⊕ GAY (1975) South Africa, Precambrian quarcites.
⊞ HERGET (1973) Canada, Precambrian volcanic rocks.
▢ HAST (1968) Sweden, Precambrian granites.
○ LNEC–Lisbon (1982), Spain, Hercynian shales.
ϕ EISBACHER (1971), Canada, Precambrian quarcites.
Φ BENSON (1970), Canada, Precambrian gneiss.
⊗ WOROTNICKI (1976), Australia, Precambrian and Hercynian shales.
Ø MYRVANG (1976) Norway, Precambrian schists and gneiss.
⊛ LNEC–Lisbon (1984), Spain, Hercynian shales and quarcites.
△ PINE (1983) United Kingdom, Hercynian and Alpine granites.
△ DOUGLAS (1983), United Kingdom, Hercynian slates.
X CHAPPEL (1984) Australia, Hercynian sandstones.
◎ ZOBACK (1980) USA–Calif. Alpine volcanic rocks.
⊠ HAIMSON (1979), Canada, Precambrian granites.
⊟ LEE (1978) USA, Hercynian dolomites.
▣ NAVALON (1979) Spain, Alpine limestones and marls.
□ HAIMSON (1981) USA, Alpine sandstones.

4.- DISCUSSION AND CONCLUSIONS

RMR, Q and SRC Systems have been analysed in 80 tunnels and 2 coal mines in Spain. In all cases the indices were measured on surface and inside excavation. A detailed description of these cases have been presented elsewhere, (Gonzalez de Vallejo 1984). Fig. 1 and Table 6 show a summary of these results and the obtained correlation coefficients. As it can be seen from that figure the best correlation between rock mass classifications from surface data and tunnelling behaviour is obtained from SRC System.

Empirical investigations on the state of stresses index used in the SRC, particulary the stress relief factor (SRF), suggest a possible relation between this factor and the natural stresses $\sigma h/\sigma v$. Fig. 2 shows selected data from a wide range of geological situations where this relation can be observed. Further investigations on tectonic stresses and engineering implications are undertaken (Gonzalez de Vallejo and Capote 1985).

The previous discussed results from tunnels and mines located in different geological and engineering situations indicate that tunneling conditions can be better evaluated by the SRC System, when the main source of information comes from surface data. The procedure to apply the SRC Systen needs regional geological information, geological mapping of the tunnel trace, geomechanical data from outcrops, and limited deep site investigations. This kind of information can be very useful for preliminary tunnelling design. However, in areas of high mountain relief or difficult access to the tunnel trace, this kind of information could be the only one available before construction.

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