New SRF Values for Moderately Jointed Rocks

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ABSTRACT

Stress reduction Factor (SRF) is probably the most contentious parameter in estimation of Q-value. On application of the Q-system at the headrace tunnel (HRT) of Nathpa Jhakri Project, it was found that 431 tunnel sections fell in categories L, M and N of' competent rock, rock stress problems' condition for the selection of SRF (Barton et al., 1974 and Grimstad and Barton, 1993). SRF-values selected in these sections are 9, 15 and 20 respectively. But in all these sections, rocks are jointed moderately and not massive, and two or more joint sets are present in all of them. It has therefore been apprehended that in these sections Q-values might be erroneous and further estimation of pressures and design of support systems would consequently be incorrect. Therefore, an attempt has been made in this paper to suggest a suitable solution of the problem concerning selection of SRF in moderately jointed rocks experiencing high stresses.

Keywords: SRF value, moderately jointed rock, massive rock, rock burst, pressure.

1. INTRODUCTION

The complexities and uncertainties inherent in the tunnel design compel the engineers to adopt empirical methods for design of tunnel supports. Engineering rock mass classification is the best-known empirical approach for assessing the stability of underground openings in rock. Such classification methods enable the designer to relate the experience on rock conditions and support requirements gained on other sites to the conditions anticipated on his own site. This approach has got enormous potential and forms the backbone of present day rock engineering. As a matter of fact, almost all the modern underground constructions are utilizing rock mass classification approach due to its simplicity. The Q-system proposed by Barton et al. (1974) is based on a numerical assessment of the rock mass quality using six different parameters: (a) RQD, (b) number of joint sets J_n, (c) roughness of critically oriented joint set J_r, (d) degree of alteration or filling along critically oriented joint set J_a, (e) water inflow J_w and (f) SRF. These six parameters are grouped into three quotients to give the overall rock mass quality Q as follows:

$$Q = \frac{RQD}{J_n} \cdot \frac{J_r}{J_a} \cdot \frac{J_w}{SRF} \qquad (1)$$

Although rock mass classifications are being used more widely throughout the world, they are still in developmental phase, and there is no single accepted system. The real advances in empirical design methods will have to wait for a greater measure of consensus on an improved, integrated classification approach. The existing rock mass classifications are useful when used under the conditions for which they were designed and for which their proponents agree that they are suitable.

Ram and Jethwa (1986) on the basis of studies conducted on the Maneri-Bhali Hydroelectric Project Stage-II located in Himalaya, concluded that the feasibility of rock mass classification systems in Himalayan formations has to be studied in the various works in Himalaya. They felt the need for modification in at least one of the existing systems, which holds good for the Himalayan region.

On application of the Q-system at the HRT of Nathpa Jhakri Project, it was found that 431 tunnel sections fell in categories L M and N of 'competent rock, rock stress problems' condition for the selection of SRF (Barton et al., 1974 and Grimstad and Barton, 1993). SRF-values selected in these sections are 9, 15 and 20 respectively. But in all these sections, rocks are jointed moderately and not massive; and two or more joint sets are present in all of them. It has therefore been apprehended that in these sections Q-values might be erroneous and further estimation of pressures and design of support systems would consequently be incorrect. Therefore, an attempt has been made in this paper to suggest a suitable solution of the problem concerning selection of SRF in moderately jointed rocks experiencing high stresses.

2. NATHPA JHAKRI PROJECT

Nathpa Jhakri Project, located in the state of Himachal Pradesh in India, is a run-of-the river scheme on river Satluj, which is the principal tributary of river Indus, originates near lake Mansarovar at an altitude of 4570 m. The project utilizes a drop of 488 m between Nathpa, the dam site and Jhakri, the powerhouse site. The Powerhouse has an installed capacity of 1500 MW (6 x 250 MW). The head race tunnel (HRT) is 27.4 km long having a diameter of 10.15 m. It is the longest power tunnel in the world being constructed in Higher Himalaya. Excavation of this long tunnel has imposed many challenges to the field engineers. These include problems related to geothermic, heavy inflow of groundwater, excessive rock covers, flowing, slabbing and squeezing ground conditions. The plan and longitudinal section of the HRT are shown in Figs. 1 and 2 respectively.

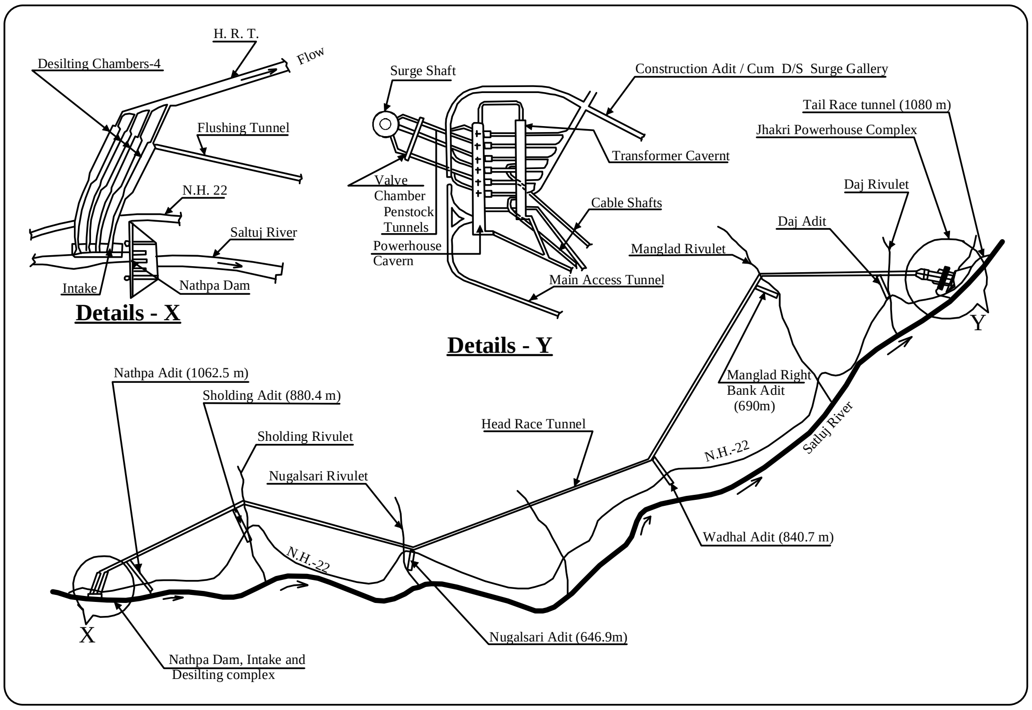

Fig. 1 – Layout plan of Nathpa Jhakri Power Project

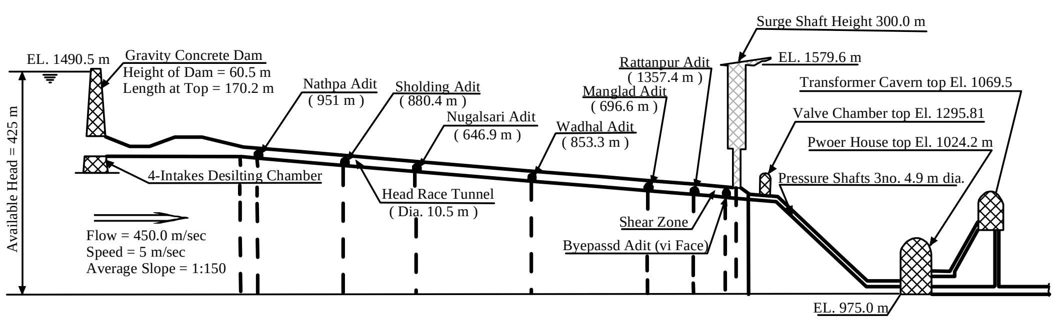

Fig. 2 – Longitudinal section of HRT of Nathpa Jhakri Power Project

3. GEOLOGY ALONG TUNNEL ALIGNMENT

Nathpa Jhakri Project area is located in the outer crystalline unit of the Higher Himalaya, which is characterized by very rugged topography with lofty hills. The general altitude of the area is above EL 1000 m. Rock types in the project area encompassed by the project comprises a variety of metamorphic rocks belonging to Jeori-Wangtu-Gneissic Complex of Precambrian age.

Nathpa - Sholding section is represented mainly by medium to coarse-grained gneisses and augen gneisses with quartz mica schist and amphibolites. Rocks are structurally disposed in a broad anticline. A number of shear seams of 5 cm to 1 m thickness are present in this area. Rocks of Sholding downstream area lie on the western limb of the anticlinal fold mentioned in Nathpa - Sholding section. Rocks encountered in both Nigulsari upstream and downstream are amphibolite, mica rich gneisses and quartz mica schist. Amphibolite was hard but heavily jointed. Nigulsari downstream passes through a maximum cover of 1430 m. A number of closely spaced anticlines and synclines are also present in certain areas.

Wadhal upstream encounters quartz mica schist and gneisses with thin bands of amphibolite. Rocks encountered in Wadhal - Manglad section are quartz mica schist, quartzite and amphibolite. Structurally, rocks form an open anticlinal fold with local flexures. Numerous cross folds are also present in this section. Manglad - Rattanpur and Rattanpur- Jhakri sections are represented mainly by quartz mica schist with bands of amphibolite. Rattanpur - Jhakri section encounters Daj Khad and Daj shear zone where tunnelling conditions were very difficult.

4. PROPOSED SRF VALUES FOR MODERATELY JOINTED ROCK

Bieniawski (1976) regards the Q-system as an excellent approach for initial support in tunnels but considers it to be complex to be easily applied to wide ranging geological conditions. According to him some analyses suggest that the basic ratings suggested in the Q-system are highly sensitive to most difficult parameters to evaluate and this makes the choice of rating quite critical.

SRF is one such difficult parameter to evaluate for estimating Q-value. Singh et al. (1997) have also opined that estimating a correct value of SRF is difficult and incorrect selection of SRF-values may lead to an unreliable prediction. Nevertheless, the present paper tries to resolve this issue a little bit.

Barton et al. (1974) and Grimstad and Barton (1993) have considered four broad conditions of rock masses for which ranges of SRF-values have been recommended. In the second rock condition i.e. 'competent rock, rock stress problems', further categories have been indicated based on ratios of q_c/σ_1 and σ_θ/q_c and corresponding SRF-values have been recommended. Here, q_c represents uniaxial compressive strength of intact rock, σ_1 major principal stress and σ_θ the tangential stress. In these categories of rock conditions, first three i.e. H, J and K (low stress, medium stress and high stress respectively) are understood to be applicable for both massive as well as moderately jointed rock masses. On the other hand in rest of other three conditions named L, M and N (moderate slabbing, slabbing and rock burst and heavy rock burst respectively), it has been clearly mentioned that these pertain to massive rock only which should really be the case since slabbing, rock burst etc. are associated with competent and massive rocks only. But what about if rock is not massive but moderately jointed? Therefore, in a condition in which ratios q_c/σ_1 and q_c/σ_0 lie in ranges corresponding to conditions L, M or N and rock is jointed moderately, Barton's table do not suggest SRF-values to be considered. If SRF-values are selected purely on the basis of q_c/σ_1 and σ_θ/q_c which is really the only option left for the user of the Q-system, unmindful of the fact whether rock mass is massive or moderately jointed, results for massive rock might be correct but for moderately jointed rock masses these are bound to be incorrect.

High value of J_r/J_a leads to high angle of internal friction along joints. Consequently, the intermediate principal stress (σ_2) which is the in situ stress along tunnel axis increases the rock mass strength enormously where overburden is more than 1000m. The net effect is that the rock burst condition is not serious as anticipated from Barton's et al. (1974) and Grimstad and Barton (1993). In other words the effect of σ_2 on rock mass strength is similar to enormous reduction in SRF values.

In the present rock mass classification following the Q-system, for tunnel section falling in categories L, M and N, SRF-values selected are 9, 15 and 20 respectively. But in all these sections, rocks are jointed moderately and not massive; and two or more joint sets are present in all of them. It has therefore been apprehended that in these sections, Q-values might be erroneous and further estimation of pressures and design of support systems would consequently be incorrect.

Therefore to find a suitable solution of the problem concerning selection of SRF in moderately Jointed rock masses experiencing high stresses, it has been considered appropriate to utilize rock mass number (N) proposed by Goel et al. (1995). Reasons for selecting N in this regard are as follows:

(i) N has been derived from Q with the only difference being that in N, SRF has been considered equal to 1. Therefore, uncertainties involved in selection of proper SRF have been removed.

(ii) The empirical correlation developed for estimating support pressure using N is based on measured support pressures and other related parameters from several Indian tunnels. Detailed field studies were carried out for eight tunnelling, projects located in Himalaya and the Peninsular India. Therefore, correlations using N applies to the HRT of Nathpa Jhakri Project also as it lies in Himalayan region only.

Comparison has been made between pressures estimated from N and Q for categories L, M and N separately. Number of tunnel sections falling in L, M and N are 158, 132 and 141 respectively. The following Eqs. 2 and 3 have been used for estimation of pressure (p_v) from N (Goel et al., 1995) and Q (Barton et al., 1974) respectively :

$$p_v = \frac{0.12\,H^{0.1}.a^{0.1}}{N^{0.33}} - 0.038 \quad \text{MPa} \tag{2}$$

$$p_v = \frac{0.2}{J_r}.\frac{\sqrt{J_n}}{3}.Q^{-1/3} \quad \text{MPa} \tag{3}$$

where H is depth of overburden in m, and radius of tunnel in m.

Figures 3, 4 and 5 show comparison between roof pressures estimated from N and Q for categories L, M and N respectively. From these figures, it is clear that Q overestimates pressure compared to that from N. Therefore, SRF-values have been lowered from current 9, 15 and 20 for L, M and N respectively so that the pressure estimated from Q is reduced and comes closer to that estimated from N. The lowered SRF-values considered for comparison have got ranges 1.0-4.5, 1.5-5.0 and 1.5-4.0 for categories L, M and N respectively.

The results of this study have been presented in Table 1 in which an estimate has been shown regarding number of sections lying in each group of inequality i.e. $P_N < P_Q$, $P_N = P_Q$ and $P_N > P_Q$. Here, P_N and P_Q are defined as support pressures estimated from N (Eq. 2) and Q (Eq. 3) respectively. Numerical values in parenthesis show maximum deviation of pressure. Standard deviation and correlation have also been indicated in this table. The coefficient of correlation is represented by r.

Considering standard deviation, maximum deviation, correlation and number of sections, SRF-values proposed for overstressed and moderately jointed rock mass may be as follows:

(a) Category L : 1.5-2.0
(b) Category M : 2.0-2.5
(c) Category N : 2.5-3.0

Barton's table (Barton et al., 1974 and Grimstad and Barton, 1993) may therefore be modified slightly by incorporating SRF-values for overstressed and moderately jointed rock comprising two or more joint sets typical in Himalaya. The modified version of Barton's table has been presented as Table 2 in which proposed new SRF-values for moderately jointed rock have been shown in the boldface.

5. CORRELATION FOR SRF FOR MODERATELY JOINTED ROCK

As mentioned earlier the Q-system has been applied in the HRT of Nathpa Jhakri Project. Out of a total length of 27.4 km of the HRT, rock mass classification for more than 22 km length has been performed. For 592 tunnel sections falling in 'competent rock, rock stress problem' of Barton's table, SRF has been computed by equating Eqs. 2 and 3 as follows:

$$SRF = \frac{3375\, J_r^3}{J_n^{3/2}} . (0.12\, H^{0.1}\, a^{0.1} - 0.038\, N^{0.33})^3 \qquad (4)$$

SRF obtained from Eq. 4 is then correlated from the present study as :

$$SRF = 5.84 \left(\frac{q_c}{H}\right)^{0.001} . \frac{J_r^3}{J_n} + 2.58 \qquad (5)$$

where, q_c is in MPa and H in m. Coefficient of correlation of Eq. 5 is 0.90.

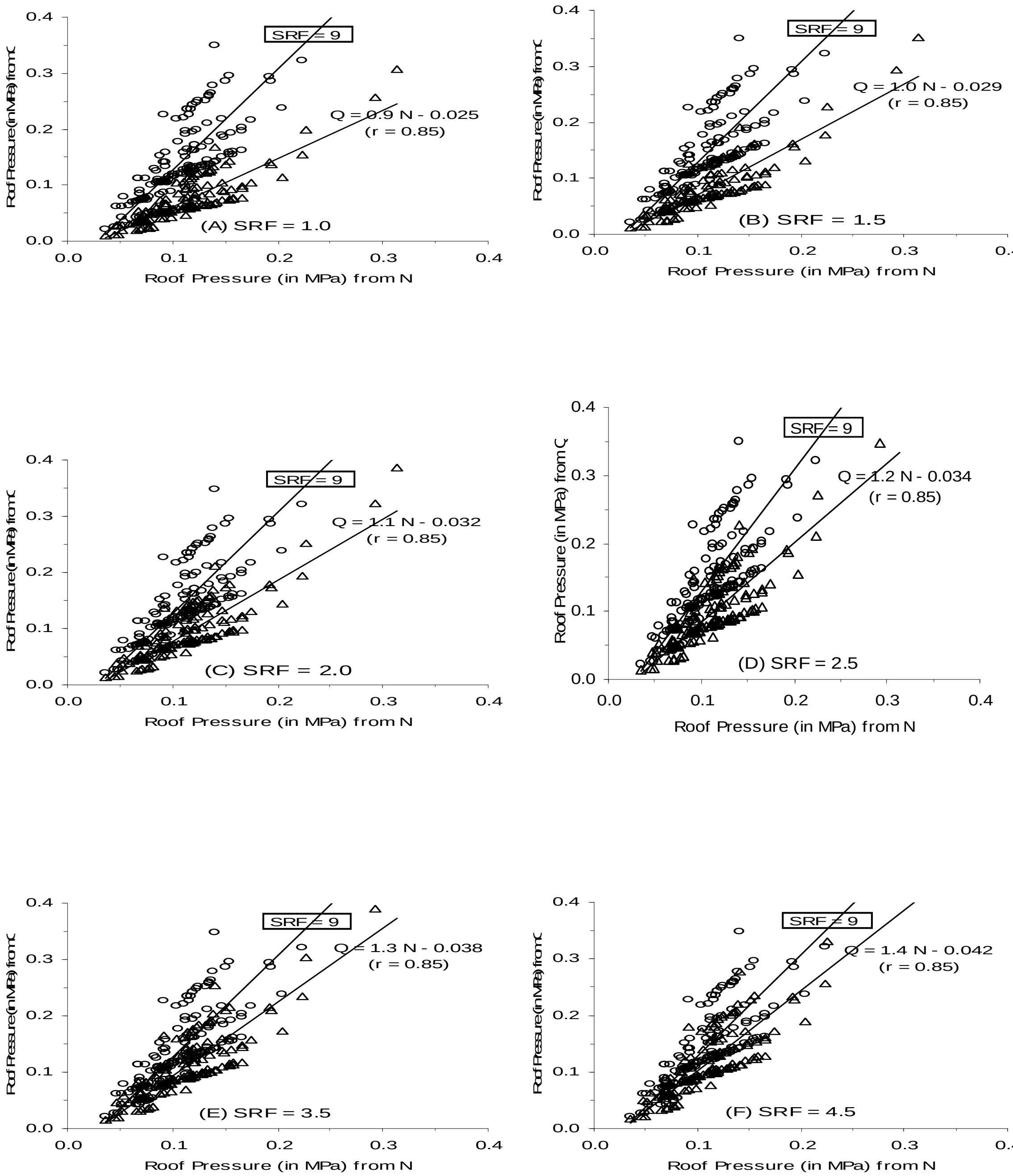

Fig. 3 – Comparison of Roof Pressure Estimated from N and Q for Category L

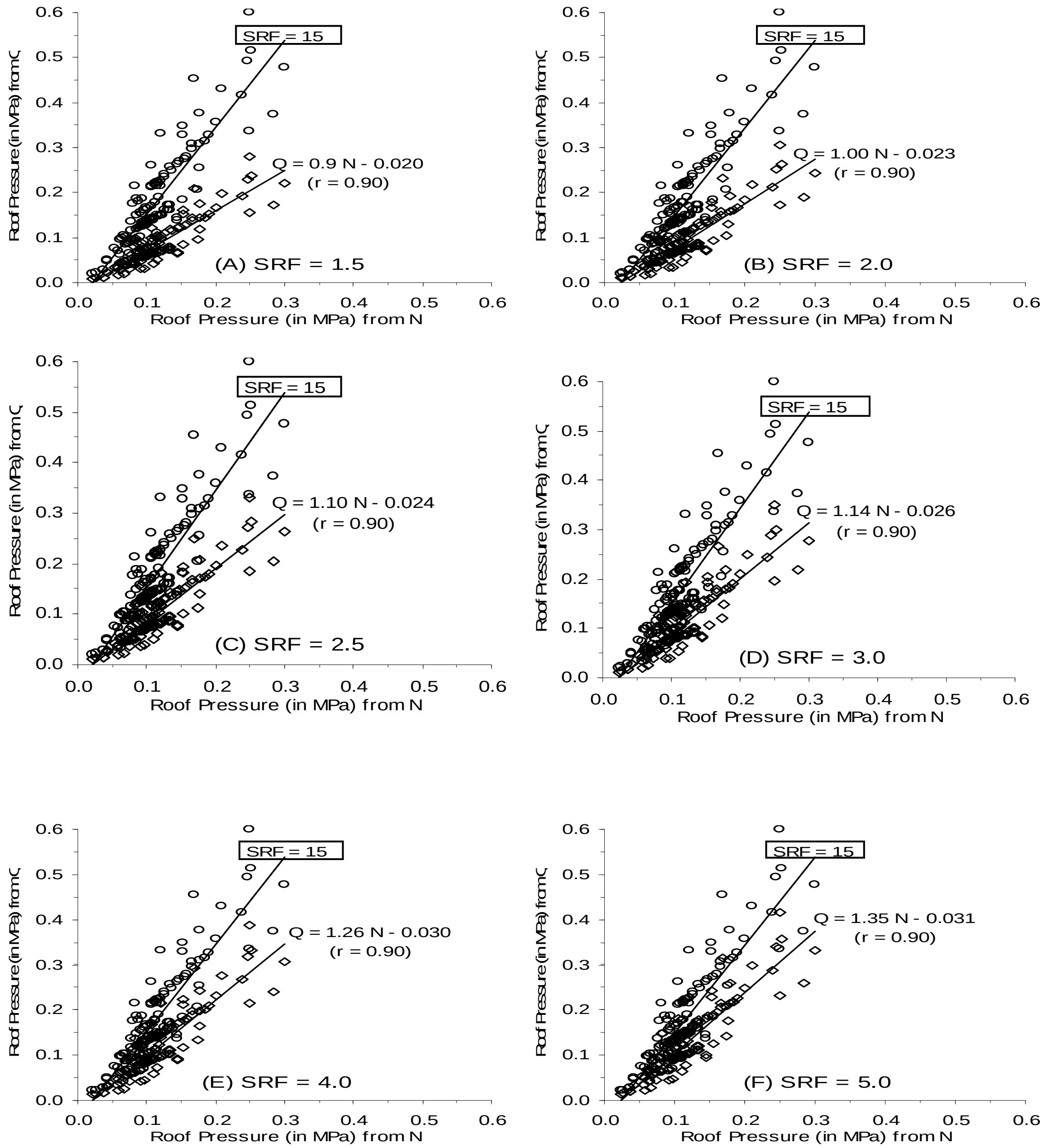

Fig. 4 – Comparison of Roof Pressure Estimated from N and Q for Category M

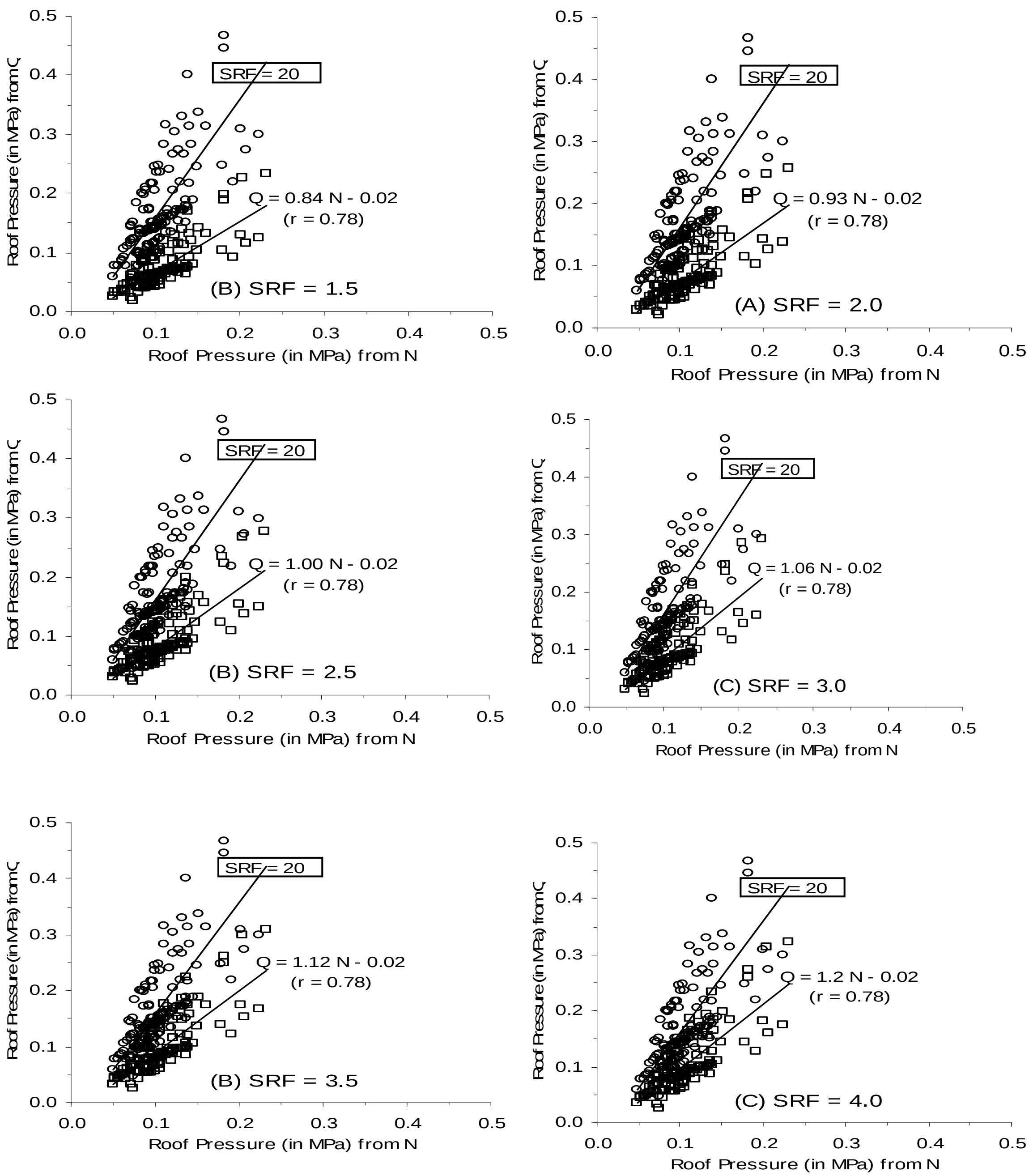

Fig. 5 – Comparison of Roof Pressure Estimated from N and Q for Category N

Table 1 - Comparison of Roof Pressure Estimated from N and Q

Category	SRF	Number of Sections (in percent)			Standard Deviation	Correlation
		$P_N < P_Q$	$P_N = P_Q$	$P_N > P_Q$		
1	1.0	1 (0.03)	15 (± 0.015)	84 (0.09)	0.045	$P_Q = 0.9\ P_N - 0.025$ (r = 0.85)
	1.5	2 (0.05)	23 (± 0.015)	75 (0.08)	0.038	$P_Q = 1.0\ P_N - 0.029$ (r = 0.85)
	2.0	15 (0.07)	15 (± 0.015)	70 (0.07)	0.035	$P_Q = 1.1\ P_N - 0.032$ (r = 0.85)
	2.5	16 (0.10)	22 (± 0.015)	62 (0.06)	0.033	$P_Q = 1.2\ P_N - 0.034$ (r = 0.85)
	3.5	21 (0.15)	32 (± 0.015)	47 (0.05)	0.035	$P_Q = 1.3\ P_N - 0.038$ (r = 0.85)
	4.5	27 (0.20)	43 (± 0.015)	30 (0.04)	0.040	$P_Q = 1.4\ P_N - 0.042$ (r = 0.85)
M	1.5	3 (0.04)	16 (± 0.015)	81 (0.08)	0.039	$P_Q = 0.90\ P_N - 0.020$ (r = 0.90)
	2.0	5 (0.06)	29 (± 0.015)	66 (0.08)	0.033	$P_Q = 1.00\ P_N - 0.023$ (r = 0.90)
	1.5	2 (0.05)	23 (± 0.015)	75 (0.08)	0.038	$P_Q = 1.0\ P_N - 0.029$ (r = 0.85)
	2.5	10 (0.08)	36 (± 0.015)	54 (0.08)	0.031	$P_Q = 1.10\ P_N - 0.024$ (r = 0.90)
	3.0	14 (0.10)	33 (± 0.015)	53 (0.07)	0.030	$P_Q = 1.14\ P_N - 0.026$ (r = 0.90)
	4.0	29 (0.15)	35 (± 0.015)	36 (0.06)	0.033	$P_Q = 1.26\ P_N - 0.030$ (r = 0.90)
	5.0	34 (0.20)	46 (± 0.015)	20 (0.05)	0.038	$P_Q = 1.35\ P_N - 0.031$ (r = 0.90)
N	1.5	2 (0.03)	20 (± 0.015)	78 (0.10)	0.040	$P_Q = 0.84\ P_N - 0.02$ (r = 0.78)
	2.0	6 (0.05)	21 (± 0.015)	73 (0.09)	0.036	$P_Q = 0.93\ P_N - 0.02$ (r = 0.78)
	2.5	11 (0.06)	23 (± 0.015)	66 (0.08)	0.033	$P_Q = 1.00\ P_N - 0.02$ (r = 0.78)
	3.0	18 (0.08)	21 (± 0.015)	61 (0.07)	0.032	$P_Q = 1.06\ P_N - 0.02$ (r = 0.78)
	3.5	20 (0.10)	25 (± 0.015)	55 (0.07)	0.032	$P_Q = 1.12\ P_N - 0.02$ (r = 0.78)
	4.0	22 (0.10)	28 (± 0.015)	50 (0.06)	0.032	$P_Q = 1.20\ P_N - 0.02$ (r = 0.78)

Table 2 Stress Reduction Factor for Jointed Rock for Categories L, M and N

Category	Rock Stress Problem		q_c/σ_1	σ_θ/q_c	SRF (Old)	SRF (New)
H	Low stress, near surface open joints		>200	<0.01	2.5	2.5
J	Medium stress, favourable stress condition		200-10	0.01-0.3	0.5-2.0	1.0
K	High stress, very tight structure (usually favourable to stability, may be unfavourable to wall stability)		10-5	0.3-0.4	0.5-2.0	0.2-2.0
L	Moderately slabbing after > 1hr in	Massive rock	5-3	0.5-0.65	5-9	5-50
		Moderalety jointed rock			-	**1.5-2.0**
M	Slabbing and rock burst after a few minutes in	Massive rock	3 - 2	0.65-1.0	9-15	50-200
		Moderalety jointed rock			-	**2.0-2.5**
L	Heavy rock burst (strain burst) and immediate deformations in	Massive rock	< 2	< 1	15-20	200-400
		Moderalety jointed rock			-	**2.5-3.0**

Therefore, for moderately jointed rocks falling in 'competent rock, rock stress problem' of Barton's table, SRF may be also obtained from Eq. 5 to be used in computing Q-value. The pressure estimated from Eq. 3 using Q then would be almost same as estimated from Eq. 2 using N.

6. CONCLUSION

In the Q-system, the recommendations given by Barton et al. (1974) and Grimstad and Barton (1993) do not suggest SRF-values for 'competent rock, rock stress problems' category for moderately jointed rocks in categories L, M and N. On the basis of present work, new SRF-values have been proposed for moderately jointed rocks. A new correlation has also been developed for this purpose.

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