Rock mass classification methods for deep buried tunnels

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Abstract: The existing rock mass classification methods are only appropriate for conditions of low or moderate field stress and low water pressures. These methods are not appropriate for conditions of high field stress and high water pressures. In general, if the major principal stress is greater than 20 MPa, then the field stress is called high field stress. High water pressure is defined as the water pressure which is much greater than 1 MPa. In this paper, two new methods called HHQ-system and HHRMR method are proposed, which can be appropriate to the conditions of high field stress and high water pressure. The HHQ-system is based on the famous Q-system of Nick Barton. The HHRMR method is based on the famous RMR method of Bieniawski. The two methods were both derived from a deep buried tunnel in China which has 20 to 42 MPa field stress and 1 to 10 MPa water pressure. In addition, a new method, which is called the normalization method and used to analyse the compatibility of classification results coming from different classification methods, is proposed also. The classification results show that the applicability and compatibility of the two methods in this deep buried tunnel are very good. More important, these methods can be popularized to similar projects.

Résumé: La méthode existante de classification de roc adjacent formation est seulement approprié au bas effort dans la croûte central, le bas revenu supplémentaire pressurisez la condition, sous l'effort dans la croûte élevé, les frais supplémentaires élevés l'utilité d'état de pression de revenu est mauvaise. Cru généralement cela, le plus grand effort principal est plus grand que 20 MPa pour appartenir à l'effort dans la croûte élevé, la pression de revenue supplémentaire loin est plus grand que 1 MPa est la pression élevée de revenu supplémentaire. Cet article proposé dessous deux genre de nouveaux efforts dans la croûte élevés, la pression élevée de revenu supplémentaire conditionnez les méthodes adjacentes de classification de formation, à savoir le HHQ système et la classification de HHRMR, elles sont respectivement dans le système du Q de Barton célèbre, base de classification établissent compare à Nepali intimide dans la base RMR, son prototype géologique que tout est a effort haut dans la croûte de MPa du 20 ~ 40, pression élevée de revenu supplémentaire de MPa du 1 ~ 10 la profondeur enterre le tunnel. Le résultat de classification de roc adjacent formation indiqué cela, méthode adjacente de classification de cesdeux formations enterre l'utilité de tunnel dans cette profondeur pour être bon, et peut favorisez l'utilisation. D'ailleurs, dans l'article également proposé entre un genre de résultat différent de classification de méthode de classification de recherches la nouvelle méthode uniforme, à savoir méthode normale.

Keywords: rock mechanics, engineering geology, rock description, tunnels, underground mining, rock burst

1 PREFACE

With the development of economy, the depth of underground cavern is increased rapidly. The maximum depth of hydropower tunnel in JIN PING Hydroelectric Station in China will be added to 2525 m. In general, if the major principal stress is greater than 20 MPa, then the field stress is called high field stress. And the high external water pressure is defined as the water pressure which is much greater than 1 MPa. With the increasing of depth of tunnel, the field stress and water pressure are increased also. In the condition of high field stress, soft rock will produce plastic deformation and hard rock will probably produce rock burst or structural rheology. In the condition of high external water pressure, the shear strength of rock mass will be depressed and the hydro-splitting crack will be happened. Thus, the stability of surrounding rock mass will be depressed. To find surrounding rock mass classification methods which are appropriate for the conditions of high field stress and high external water pressure is necessary for the hydroelectric surrounding rock mass classification. In this paper, two new methods called HHQ-system and HHRMR method are proposed, which can be appropriate for the conditions of high field stress and high external water pressure. The HHQ-system is based on the famous Q-system of Nick Barton. The HHRMR method is based on the famous RMR method of Bieniawski. The two methods are both come from a deep buried tunnel in China which has 20 to 42 MPa field stress and 1 to 10 MPa water pressure.

2 THE INTRODUCTION OF A DEEP BURIED TUNNEL

There is a deep buried tunnel in China which has a horseshoe-shaped section. The height of upper arc is 0.4 m, the height of lower square is 3 m. The total length of the tunnel is about 4 kilometres. The buried depth in most areas is greater than 1200 m ,and the maximum buried depth of the tunnel is 2525 m. The strata that the tunnel crosses is mainly marble and argillaceous limestone, et al.

The surrounding rock mass of this tunnel has some properties as follows:①The strata belongs to hard rock, it's uniaxial compressive strength is 50~100 MPa. The hard surrounding rock and the much hard surrounding rock appears alternately. The occurrence of the strata is about erect. The strike of the tunnel is almost vertical to the strike of the strata. ②The structure of rock mass is mainly massive structure, some areas have the beded structure and fissuration structure. ③The major principal stress is the gravity, it is about 42 MPa according to the test results. The tunnel in 0~520 m areas belongs to low or moderate field stress, and the tunnel in 520~4165 m areas belongs to high field stress.④High field stress areas can be divided into rock burst areas and non rock burst areas. Rock burst appears from the point of 520 m, it exists in high field stress areas discontinuously. The grade of rock burst intensity is mainly grade Ⅰ and grade Ⅱ.⑤There are more than ten points which have 1～10 MPa external water pressure. The observation results show that the maximum external water pressure is about 10 MPa.

According to the qualitative description of rock mass quality, the following features of this deep buried tunnel can be found. Almost 95％ of rock mass quality belong to grade I and grade III, the others belong to grade I and grade IV. The rocks of grade I and grade II exist in the integrated rock mass or the areas that the slight rock burst happened. The rocks of grade III exist in the areas that the moderate rock burst happened or the areas where have many cracks or have big water pressure. The rocks of grade IV mainly exist in the areas that the fault passes and have very big water pressure.

3 NORMALIZATION METHOD AND SOME CONCEPTS

3.1 The normalization method and the compatibility of classification results

Here the normalization method is used to compare compatibility of classification results that come from different classification methods. The normalization method is based on the thought that the total values of the rock mass quality of each classification methods are in the rang of 0 to 1.

When the total values of the rock mass quality of each classification methods are dealt with the normalization method, they will be called the normalization values and expressed by the small letter of the total values. For example, Q and RMR value are usually used to express the total value of Q-system and RMR method separately. The small letters q and rmr are used to express the normalization values of Q and RMR separately. The normalization method of Q-system is that q =(LgQ+3)/6. The normalization method of RMR method is that rmr = RMR/100.The q and rmr can be used to compare the relative magnitude. The grade of surrounding rock mass is divided by Table 1.

Table 1. Grade of surrounding rock mass

	V	Ⅳ	III	II	I
Q	0.001～0.01	0.01～0.1	0.1～4	4～100	100～1000
q	0～0.17	0.17～0.33	0.33～0.6	0.6～0.83	0.83～1
RMR	0～20	20～40	40～60	60～80	80～100
rmr	0～0.2	0～0.4	0.4～0.6	0.6～0.8	0.8～1

The surrounding rock mass of Q-system is divided into 9 grades, here it is divided into 5 grades. From the table 1 we can see that the grade of Q-system and RMR method determined by the normalization values is approximately even. So the rock mass qualities coming from different classification methods can be compared. The grade of compatibility is regulated as table 2.

Table 2. Grade of compatibility

good		moderate			bad
$0 \le \alpha_0 \le 0.1$		$0.1 < \alpha_0 \le 0.2$			$\alpha_0 > 0.2$
$0 < \Gamma \le 0.05$	$0.05 < \Gamma \le 0.1$	$\Gamma \le 0.1$	$0.1 < \Gamma \le 0.15$	$0.15 < \Gamma \le 0.20$	
very good	good	moderate to good	moderate	moderate to bad	

Notes: It is supposed that two methods are used to value the quality of surrounding rock mass, and at least 80 percentage of absolute values of margin of normalization values are less than α_0 ($0 \le \alpha_0 \le 1$).The α_0q-rmr is used to express the α_0 which is appropriate for the above conditions drawn from q and rmr. The Γq-rmr is used to express the average of absolute values of q-rmr.

3.2 The correlation of classification results

The correlation of classification results means to the correlation among total values coming from different classification methods. It is divided according to table 3.

Table 3. Grade of correlation

correlation coefficient	<0.2	0.2~0.4	0.4~0.6	0.6~0.8	>0.8
correlation	bad	moderate to bad	moderate	good	Very good

3.3 The applicability of classification results

The applicability of classification results is pointed to the difference between classification results and qualitative description. The smaller is the difference, the better applicability is. The applicability is divided as table 4.

Table 4. Grade of applicability

the difference between classification results and qualitative description	in half grade	in one grade	Greater than one grade
Applicability	Good	Moderate	Bad

Note: The rock quality can be divided to 5 Grades from good to bad, i.e. grade I, II, III, IV, V.

4 HHQ-SYSTEM

The Q-system was proposed in 1974 by Nick Barton of Norway. Having being updated in 1993 and 2002,the Q-system becomes more perfect[1],[2]. Being based on the Q—system, the HHQ—system is established in this paper. The parameters of HHQ—system are almost same to the Q—system's except the parameters SRF and Jw which are given in table 5 to table 7.In these tables, other than the boldface contents which are new-made by authors on the base of Q-system, the other contents are all come from Q-system. The HQ value which is defined as the total value of HHQ-system is calculated as follows:

$$HQ = \left(\frac{RQD}{J_n}\right) \times \left(\frac{J_r}{J_a}\right) \times \left(\frac{J_w}{SRF}\right)$$

Other than the SRF and Jw are changed, the other four parameters are all the same to the Q-system's.

Table 5. Stress reduction factor *SRF* of HHQ-system

The stress reduction factor			SRF
（a）Weakness zones intersecting excavation, which may cause loosening of rock mass when tunnel is excavated			
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 excavation50 m)			5.0
C. Single weakness zones containing clay or chemically disintegrated rock (depth of excavation >50m)			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 >50m)			2.5
G. Loose, open joints, heavily jointed or ‘sugar cube’, etc. (any depth)			5.0
（b）Competent rock, rock stress problems			
	σ_c/σ_1	或σ_θ/σ_c	*SRF*
H. Low stress, near surface, open joints	>200	<0.01	2.5
J. Medium stress, favourable stress condition	**200～10**	**0.01～0.2**	**1.0**
K. High stress, very tight structure. Usually favourable to stability	**10～1**	**0.2～1**	**1～2.5**
L. **Grade Ⅰ rock burst areas**	**4～1**	**0.2～0.7**	5～50
M. **Grade Ⅱ rock burst areas**	**2～1**	**0.7～0.85**	50～200
N. **Grade Ⅲ or Ⅳ rock burst areas**	**<1**	**>0.85**	200 ～400
（c）Squeezing rock: plastic flow of incompetent rock under the influence of high rock pressure		σ_θ/σ_c	*SRF*
O. Mild squeezing rock pressure		1～5	5～10
P. Heavy squeezing rock pressure		>5	10～20
（d）Swelling rock: chemical swelling activity depending on presence of water			
R. Mild swelling rock pressure			5～10
S. Heavy swelling rock pressure			10～15

Notes: ①~⑥ are same to the primary[1],[2]. ⑦In the rock burst areas, σ_c is instead of σ_R, where σ_c is the wet uniaxial compression strength (MPa);σ_R is the dry uniaxial compression strength (MPa); σ_θ is the maximum tangential stress (estimated from elastic theory); σ_1 is the major principal stress. The grade of rock burst intensity can be determined by compositive method which includes rock property, field stress, geometrical shape of excavation boundary,etc. Table 6 gives the dividing standard of rock burst intensity.

Table 6. Grade of rock burst intensity

Grade of rock burst intensity	**description**	**Type of rock burst**	**Scope**	**Depth of rock burst pit**
I	**weak**	**peel off, loose**	**few, all to pieces, continuous**	**<0.1m**
II	**moderate**	**Peel off, loose,eject**	**few, all to pieces, continuous**	**0.1~1m**
III	**Strong**	**strongly eject**	**all to pieces, continuous**	**>1.0m**
IV	**violent**	**Tempestuously eject ,launch**	**all to pieces, continuous**	**>1.0m**

Table 7. Joint water reduction factor *Jw u*pdated by high water pressure

	Approx. water pres. Pw(Mpa)	*Jw*
A. Dry excavations or minor infl.ow, i.e., <5 l/min locally	<0.1	1.0
B. Medium inflow or pressure, occasional out wash of joint fillings	0.1~0.25	0.66
C. Large inflow or high pressure in competent rock with unfilled joints	0.25~1	0.5
D. Large inflow or high pressure, considerable out wash of joint fillings	0.25~1	0.33
E. Exceptionally high inflow or water pressure at blasting, decaying with time	**1<Pw < Pc**	0.2~0.1
F. Exceptionally high inflow or water pressure continuing without noticeable decay	**1<Pw < Pc**	0.1~0.05
G. high external water pressure	**Pc <Pw<10**	**0.05~0.005**

Note: Pw is external water pressure, Pc is the critical water pressure resulting in hydro-splitting. Here Pc=2 MPa[8].

Compared to Q-system, HHQ-system mainly has following characteristics: ①The values of SRF in the non-rock burst areas was increased. ②Instead of the description of items L,M,N, the rock burst intensity is introduced into surrounding rock mass classification. Thus, the compositive method in determining rock burst intensity is strengthened. ③In the rock burst areas, σ_c is instead of σ_R .The values of σ_R /σ_1, σ_θ/σ_R is given according to the deep buried tunnel. ④The high external water pressure is considered in the surrounding rock mass classification. ⑤The grade of surrounding rock mass is divided into 5 grades. It is easily to communicate with the other classification methods. In the Q-system, the grade of surrounding rock mass was divided into 9 grades.

It is supposed that hq = (LgHQ+3)/6,where hq is the normalization value of HQ. The hq of this tunnel is showed in Figure 1.

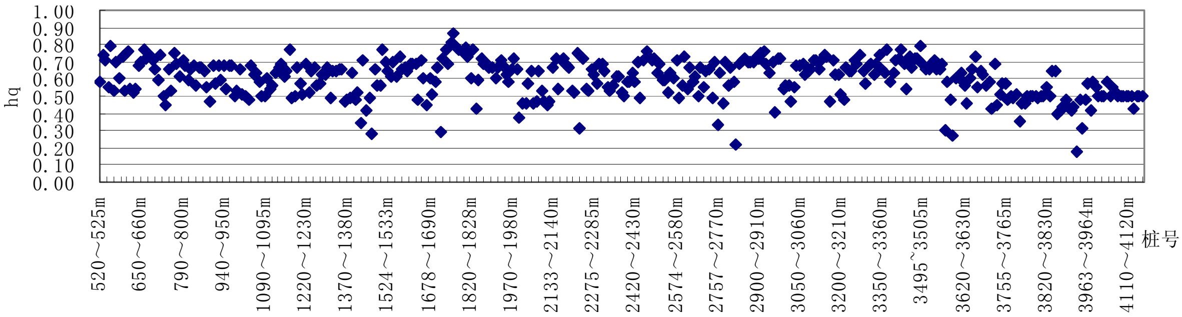

Figure 1. hq of the tunnel

From Figure 1 we can draw followed conclusions. Most of hq are between 0.8 to 0.4. Most surrounding rock mass in this tunnel belong to grade I and III. According to statistic results, the grade II and III surrounding rock mass are about 97.6%.The grade I and IV surrounding rock mass are about 2.4%.These results show that HHQ-system has a good applicability in this deep buried tunnel.

5 HHRMR METHOD

Here the correlation and compatibility between RMR method and HHQ-system will be analysed. It's aim is to find the drawbacks of RMR method. The RMR method is "Rock mass ratio" method, also called Geodynamic Method. It was proposed by Bieniawski in 1973.It's main problem is that it did not consider the influence of high field stress to the rock mass quality.

5.1 The correlation between HQ and RMR

The correlations between HQ and RMR in this tunnel are showed in Table 8.

Table 8. Statistics of correlations between HQ,RMR and HRMR

	HQ~RMR		HQ~HRMR	
	Correlation equation	Correlation coefficient	Correlation equation	Correlation coefficient
Whole tunnel	RMR=3.1451Ln(HQ)+55.68	0.36	HRMR=5.0421Ln(HQ)+48.657	0.74
Low and moderate field stress areas(0~520 m)	RMR=5.5454Ln(HQ)+45.28	0.85	HRMR=5.5454Ln(HQ)+45.28	0.85
High field stress areas(520~4165 m)	RMR=3.217Ln(HQ)+56.315	0.37	HRMR=5.1319Ln(HQ)+48.823	0.74
Non rock burst areas in high field stress areas	RMR=5.6404Ln(HQ)+45.726	0.82	HRMR=5.6404Ln(HQ)+45.726	0.82
Rock burst areas in high field stress areas	RMR=3.4396Ln(HQ)+70.906	0.54	HRMR=5.9014Ln(HQ)+53.237	0.76
Grade • rock burst areas	RMR=4.2353Ln(HQ)+67.23	0.63	HRMR=4.2353Ln(HQ)+ 57.23	0.63
Grade • rock burst areas	RMR=7.3328Ln(HQ)+72.054	0.67	HRMR=7.3328Ln(HQ)+52.054	0.67

From table 8,we can see that RMR is the logarithm function of HQ. In the whole tunnel, correlation coefficient is 0.36;in the moderate and low field stress areas, it is 0.85;in the high field stress areas, it is 0.37.These data told us that the lower correlation coefficient in the whole tunnel is ascribed to the lower correlation coefficient in the high field stress areas. Well and truly, it should be ascribed to the lower correlation coefficient in the rock burst areas. Actually, HHQ-system considered the influence of high field stress, but RMR method did not. Thus, the data in the table 8 reflected the difference between RMR method and HHQ-system.

5.2 Compatibility between hq and rmr

The Γ and α_0 are showed in Table 9. From table 9,we can draw the following conclusions. The compatibility of hq and rmr in the rock burst areas is bad, this resulted in the moderate compatibility of hq and rmr in the whole tunnel. The classification results will be analysed particularly as follows.

Table 9. Statistics of Γ, α_0

		Whole tunnel	Low and moderate field stress areas	High field stress areas	Non rock burst areas	Non rock burst areas in high field stress areas	rock burst areas	Grade I rock burst areas	Grade II rock burst areas
hq-rmr	Γ	0.11	0.09	0.11	0.08	0.08	0.18	0.12	0.22
	α_0	0.17	0.14	0.18	0.14	0.13	>0.2	0.19	>0.2

In the grade I rock burst areas ,the rmr is often higher than hq, hq-rmr = -0.3~+0.05.According to the statistical results, Γhq-rmr =0.12, $\alpha_0$hq-rmr=0.19.So the compatibility of rmr and hq is moderate. Because that the RMR method doesn’t consider the high field stress, the classification results drawn from RMR method are often higher. If the RMR value is decreased 10 points by introducing field stress factor k, the rmr will have a good compatibility to hq.

The hq-rmr of grade II rock burst areas is showed as Figure 2.

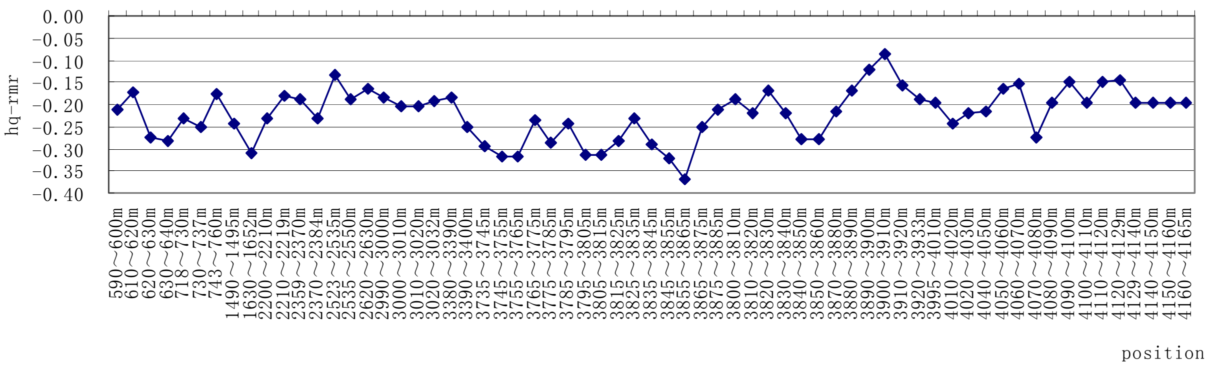

Figure 2. hq -rmr of grade II rock burst areas

From this table we can draw followed conclusions. In the grade II rock burst areas, the rmr is often higher than hq, hq-rmr = -0.4~-0.05. According to the statistical results, Γhq-rmr =0.22, $\alpha_0$hq-rmr>0.2.So the compatibility of rmr and hq is bad. Because that RMR method doesn’t consider the high field stress , the classification results drawn from RMR method are often higher. If the RMR value is decreased 20 points by introducing field stress factor k, the rmr will have a good compatibility to hq.

5.3 HHRMR method

From the above analyses we can know that the compatibility of rmr and hq in the non rock burst areas of high field stress is moderate to good. However the compatibility of rmr and hq in the rock burst areas of high field stress is bad. So the total value RMR should be modified. Here, the modified RMR method is called HHRMR method.

HHRMR method is based on the RMR method. The field strsss factor k is introduced. The total value of HHRMR method can be calculated from the followed formula. HRMR= RMR’–100 k. RMR’ is the total value of RMR method when the underground water factor R_5 chooses the updated value as table 10 showed. The field strsss factor k can be drawn from table 11.In the table 10 and 11,the overstriking letters are new-made contents. It is obvious that the HHRMR method considers the high field stress and high external water pressure.

Table 10. Updated underground water factor R_5

Inflow per 10 m tunnels（L/min）	ratio of joint water pressure to major principal stress	**Pw (MPa)**	state	R_5
0	0		dry	15
<10	<0.1		wet	10
<25	0.1～0.2		wettest	7
25～125	0.2～0.5		Moderate water pressure	4
125～250	0.5～1.0	**1<Pw <Pc**	**Have serious underground water pressure problems**	**0**
>250	**>1.0**	**Pc <Pw <10**	**Have serious underground water pressure problems**	**-2 ～ -10**

Notes: Pw is external water pressure, Pc is the critical water pressure resulting in hydro-splitting. Here Pc=2 MPa[8].When Pw >Pc,if the Pw adds 1 MPa, then R_5 will increased –1.

Table 11. Stress reduction factor k

	Grade I rock burst areas	Grade II rock burst areas	Grade III rock burst areas
σ_θ/σ_R	0.2~0.7	0.7~0.85	>0.85
k	0.05~0.15	0.15~0.22	0.22~

Note: Grade of rock burst intensity can be divided as table 6.

6 THE ANALYSE OF CLASSIFICATION RESULTS COMING FROM HHRMR METHOD AND HHQ-SYSTEM

The classification results of HHRMR method and HHQ-system will be analysed, and the compatibility of HHRMR method in this tunnel will be summarised as follows.

6.1 The correlations

The correlations between HQ and HRMR in this tunnel are shown in Table 8.From table 8 we can draw followed conclutions. Compared to the correlation coefficient between HQ and RMR, the correlation coefficient between HQ and HRMR was increased greatly. These results show that the update to RMR method is correct.

6.2 The compatibility of classification results

The hq-rmr and hq-hrmr in this tunnel are given in Figure 3.It shows us that the quantities of the points which have a big hq-rmr are excessive, especially in the rock burst areas such as in the 3600•3900 m. However, most of the points of hq-hrmr are near zero. Obviously, compared to the compatibility between hq and rmr, the compatibility between hq and hrmr is better. So the update of the RMR method in the rock burst areas are correct.

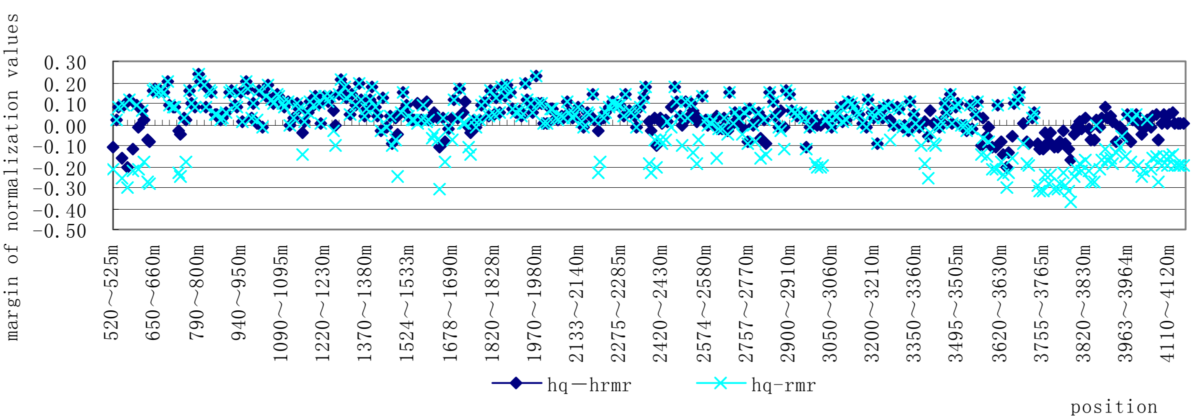

Figure 3. hq -rmr and hq-hrmr of high field stress areas

The Γ and α_0 of hq-rmr and hq-hrmr in this tunnel are shown in the table 12.

Table 12. Statistics of Γ and α_0

	hq-rmr		hq-hrmr	
	Γ	α_0	Γ	α_0
Whole tunnel	0.11	0.17	0.07	0.12
Low and moderate field stress areas(0~520 m)	0.09	0.14	0.09	0.14
High field stress areas(520~4165 m)	0.11	0.18	0.07	0.11
Non rock burst areas in whole tunnel	0.08	0.14	0.08	0.14
Non rock burst areas in high field stress areas	0.08	0.13	0.08	0.13
rock burst areas in high field stress areas	0.18	>0.2	0.05	0.09
Grade • rock burst areas	0.12	0.19	0.06	0.10
Grade • rock burst areas	0.22	>0.2	0.05	0.08

From this table we can draw the following conclusions. Compared to the compatibility between hq and rmr, the compatibility between hq and hrmr becomes better in the whole tunnel and high field stress areas. Especially, in the rock grade II burst areas, the compatibility becomes from bad to good.

HHQ-system has a good applicability in this deep buried tunnel. Meanwhile, HHRMR method has a good correlation and compatibility with HHQ-system. So HHRMR method has a good applicability in this deep buried tunnel also.

According to the rock property and rock mass structure, this tunnel was divided into 433 segments. Here the classification results and parameters of some typical segments are showed in table 13.

From the table 13 we can see the following conclusions. The RMR method has a higher classification results in the rock burst areas and high external water pressure areas. The HHQ-system and HHRMR method have a good applicability in this deep buried tunnel.

Table 13. Some surrounding rock mass classification results and classification parameters

position		description and value	rock property	HHQ-system before high external water pressure updated			HHQ-system			RMR method		HHRMR method		qualitative grade	note
				Jw	HQ	Grade	Jw	HQ	Grade	RMR	Grade	HRMR	Grade		
1132~1137 m	top	description	argillaceous limestone(T_{2v}^{6})	drip			drip							II	Normal areas
		value		1	14.035	II	1	14.035	II	62	II	62	II		
	wall	description		drip			drip								
		value		1	14.035	II	1	14.035	II	62	II	62	II		
1137~1154 m	top	description	argillaceous limestone(T_{2v}^{6})	dry			dry							II	Grade I rock burst areas
		value		1	5.067	II	1	5.067	II	76	II	66	II		
	wall	description		dry			dry								
		value		1	5.067	II	1	5.067	II	76	II	66	II		
1630~1652 m	top	description	marble(T_{2v}^{5})	dry			dry							III	Grade rock burst areas
		value		1	0.741	III	1	0.741	III	79	II	59	III		
	wall	description		dry			dry								
		value		1	0.741	III	1	0.741	III	79	II	59	III		
3945~3950 m	top	description	marble(T_{2v}^{5})	gush(12.3l/s)			gush(12.3l/s)							IV	high water pressure areas
		value		0.1	0.200	III	0.039	0.078	IV	37	IV	34	IV		
	wall	description		gush(12.3l/s)			gush(12.3l/s)								
		value		0.1	0.200	III	0.039	0.078	IV	37	IV	34	IV		

7 CONCLUSIONS AND ADVICE

The HHQ-system and HHRMR method have a good applicability in this deep buried tunnel. The two methods have some common characteristics. ①The high field stress was considered. The rock burst intensity was introduced into the surrounding rock mass classification. The compositive method that determines the grade of rock burst intensity was strengthened. ②The high external water pressure was considered.

The influence of high field stress to surrounding rock quality can be embodied by introducing field stress factor SRF or k into classification. In the condition of high field stress, the probably rock deformation phenomena are rock burst, plastic deformation of engineering soft rock and structural rheology of hard rock. In this deep buried tunnel, rock burst is seen, but the other deformation phenomena were not found. Actually, the above deformation phenomena all can be embodied by introducing field stress factor SRF or k into classification. From this sense, we think that the two methods can be popularised into other deep buried tunnels.

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