Rock mass quality comparison during selection of sites for underground storage of crude oils

SHI YONGYUE[1] SHANG YANJUN[1] GUO SHUTAI[2] & CHEN SHANLING[2]

[1] *Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029*
[2] *Superway Engineering Investigation Co., Ltd, CNPC, Langfang 065000*

Abstract: According to requirements of sitting crude oil storage caves, this paper briefly reviews the common methods used on rock mass quality indices and classifications. By means of field investigation, in-site measurement of discontinuities, and polar projection of joints, the rock mass quality was assessed for rating rocks in sites for potential storage of crude oils. At the stage of site selection, the rock mass quality index respectively specified in Chinese National Standards and in the Department of Hydrology, and Q values were computed as one of surveying results at 21 exposed points. As a result, it is found that the results from these three approaches are very similar. The mosaic texture as layer quartz was rated as III. The integrative and massive gneiss and diorite were rated as II. So the gneiss and diorite can be mostly selected as favourable rocks crude oil caves. And the three sites were compared with focus on their rock mass qualities in selection of underground caverns for storage of crude oils.

Résumé: Selon des conditions de reposer des cavernes de stockage de pétrole brut, cet article passe en revue brièvement les méthodes communes employées sur des index et des classifications de qualité de la masse de roche. Au moyen de recherche de champ, mesure d'dans-emplacement des discontinuités, et projection polaire des joints, la qualité de la masse de roche a été évaluée pour des roches d'estimation dans les emplacements pour le stockage potentiel de pétroles bruts. À l'étape du choix d'emplacement, l'index de qualité de la masse de roche respectivement indiqué dans des normes nationales chinoises et dans le département des valeurs d'hydrologie, et de Q ont été calculés en tant qu'un de résultats examinants à 21 points exposés. En conséquence, on le constate que les résultats de ces trois approches sont très semblables. La texture de mosaïque comme quartz de couche a été évaluée pendant que le gneiss d'III?the et le diorite intégrateurs et massifs étaient évalués en tant qu'II. Ainsi le gneiss et le diorite peuvent être la plupart du temps choisis en tant que cavernes favorables de pétrole brut de roches. Et les trois emplacements ont été comparés au foyer sur leurs qualités de la masse de roche dans le choix des cavernes souterraines pour le stockage de pétroles bruts.

Keywords: Rock mass quality, classification, site selection, crude oil storage cave.

INTRODUCTION

To meet the strategic demands of China for the state security and stabilization in oil supply, and to suit with the increasing contradiction between supply and demand in international energy sources market and the integrative current of global economy, it is necessary for the national economy and the people's livelihood of our country to set up a long-term and steady underground storage of strategic petroleum reserve in feasible places.

According to the technology demand of underground oil storage, rock mass quality should be graded I~II. However, in nature, rock mass is a very complicated geologic material which has deformed and broken, built and rebuilt by geologic tectonic movement. Whatever research conducted in rock mass (mechanical experiment of rock samples in laboratory, large-scale in-situ field testing of rock mass mechanical parameter) is difficult to understand the specific mechanical character (strength and deformation module etc.) of rock mass completely in engineering area (Chen Zongji. 1982). So the reductionism method is used to evaluate the stability of rock mass and analyze and forecast the reliability of rock mass, and it is also necessary when the parameters are not available at the stage of sitting cave. Therefore, according to the feature and the demand of underground oil storage, classifying rock mass summarily based on some characters (stability of engineering rock mass commonly) is named wall rock classification. Wall rock classification is an evaluation of wall rock through engineering analogue, and is also a base to provide reference for engineering design and construction (Wang Sijing et al. 1984; Li Shihui, 1991). The basic request of wall rock classification is that the class is specific to use, and it should embody possessed engineering experience and knowledge.

ROCK MASS TEXTURE AND ENGINEERING GEOLOGIC ROCK GROUP

In terms of structural plane classification and rock mass structure classification (Gu Dezhen, 1979; Huang Dingcheng, 1987), firstly, geological structure, hill body structure and rock mass texture should be classified. Considering long-term security and economic rationality of underground oil storage, the site of storage should avoid Grade I~II structural plane (viz. fault which is more than several kilometre long and whose zone of fracture is more than several meter wide). In fact, it is unavoidable to meet the structural planes, which are not bigger than Grade III (length less than several kilometre and the breadth of the zone of fracture less than several meters). Most structural planes through on-the-spot observation and statistic are Grade IV (viz. extending length less than 100 meters and breadth of zone of fracture several centimetres).

Observation of structural plane comprises following aspects: occurrence (strike, dip & dip angle), dimension (length & breadth), density (spacing) ect. These are the most essential datum for the assessment of rock mass quality. Different lithologies can lead to different physical and mechanical character of rock block. And it influence the density and dimension of joint which is the basic factor of rock mass texture. It is the structural plane and rock block of different rock mass that influence the mechanical character of rock mass differently. When researching character of rock mass, we should pay attention to their natural character firstly, namely genetic type, mass component, structural character which is primary and had been rebuilt later (secondary or tectonic), so we use the concept of engineering geologic rock group (Xu Bin, et al., 1985) to classify the texture and character of rock mass macroscopically; and then, we evaluate rock mass quality by different indexes. Considering hard rock controlling factor is structural character, spatial distribution, dimensions and character of structural plane. When classifying engineering geologic rock group and evaluating rock mass quality, we should classify structural type, observe and count joints on-the-spot.

CLASSIFICATION OF ROCK MASSES

In general, the classification includes rock mass classification and rock block classification. From engineering view, and according to the character of rock mass and block, sorts of the same or similar engineering character are classified, the qualitative and quantitative evaluations are carried out based on the engineering adaptability of all kinds of rock mass and block. Thus rock mass classification is always one of the basic research tasks of engineering geology and rock mass mechanics. In 17th century, rock had been classified according to its rigidity for underground mining. From 1960s, there have been more than 30 kinds of classification of rock mass and block in the world, and more than half of these classifications adapt to the underground engineering classification of wall rock.

Tab.1 shows common classifications of rock mass and block, and classifications of RQD, Q and RMR indices are widely used. In China, BQ (basic index of rock mass quality) in Standard for Engineering Classification of Rock Mass (1995) and primary and detailed classification of wall rock in Code for Investigation of Water Conservancy and Hydroelectric Power (1991) are applied widely in fact engineering.

At the stage of selecting sitting, there are not actual physical and mechanical indices of rock mass on-the-spot, and drilling do not start. Based on outdoor investigation and collecting dada, it is find that BQ index, Q index and wall rock quality can be applied. The five aspects of strength of rock, integrity of rock mass texture, state of structural plane, underground water and earth stress were considered in classification. The precondition of classification is that axes of caverns intersects main structural plan with a large angle, and earth stress is got through the analysing of data.

In practical work, we adopt the combined method of analysing data, surveying joints and stereographic method, and gather and analyse the data of rock mass texture.

ROCK GROUP CLASSIFICATION OF FIELD ENGINEERING GEOLOGIC AND CHARACTER OF ROCK MASS TEXTURE

According to the four sites' earth stress data that we have collected, orientation of tectonic stress is approximate horizontality, and the difference between the maximal principal stress and the middle principal stress is small. The maximal principal stress is not more than 10MPa within 100m-deep, so the axes of caverns can intersects main structural plan with a large angle. Nowadays, smooth blasting has been used in the construction of underground engineering to reduce the disturbance of wall rock and increase the successful rate of opening cavern.

Through preliminary contrast and research, we find that, according to the relation between grade of joint density and rock mass texture, migmatite is integral structure (Figure 1); gneiss is block structure (Figure 2), and quartzite is mosaic structure Figure 3), but not cataclastic structure. So three engineering geologic rock groups can be classified: quartzite group, gneiss group and migmatite group. These three rock masses are located in different areas, and they have different structural character and physical and mechanical behaviours.

Figure 1. block structure gneiss

Figure 2. integral structure migmatite

Figure 3. mosaic structure quartzite

THE RESULT OF ROCK MASS ASSESSMENT

Corresponding borehole was not performed about the project, and the corresponding data of velocity survey and rock characteristics are not available either, so the rough experience data is employed. RQD is the quality of the core used as a basis for estimating the quality of a rock mass, for there no drill core, RQD value is only obtained based on joint average spacing (Deere's RQD, 1964), but the result is not dependable perfectly.

Rock mass classification is conducted through Q system, Total Rating of Wall-rock and [BQ], and the result is showed by histogram. It is find that the rock mass quality of 21 geological observation spots can divided into two groups: the one is gneiss belonging to II class; the other is quartzite belonging to III class basically, the results of three methods are similar (Figure 4, Figure 5 and Figure 6).

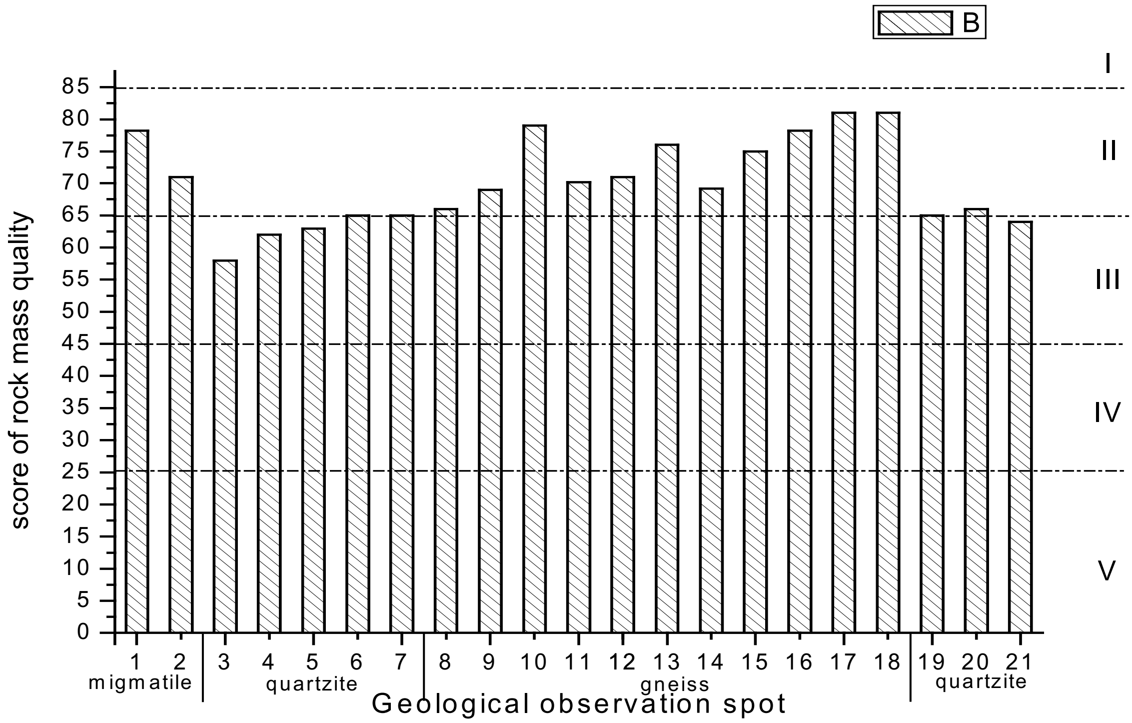

Figure 4. Score of The Total Rating of Wall-rock for different geological observation spot.

Table 1. The popular classification systems of rock block and rock mass

Type	name	formula	numbers of classifa-cion	good to bad					propo-sed
rock block engineering classification	double index classification method	(σ_c)uniaxial compressive strength and modulus ratio(E_t/σ_c)	rock block five classes and modulus ratio three classes	A H	B M	C L	D	E	Deere & Miller, 1966
	rock block coefficient(S) classification method	$S=(\sigma_{cw}\times E_w)/(\sigma_{cs}\times E_s)$ σ_{cw} :saturated uniaxial compressive strength σ_{cs}:saturated uniaxial compressive strength of prescriptive softr E_w :saturated elastic modulus E_s : saturated elastic modulus of prescriptive softrock	five classes	exce-llent	good	fair	bad	very poor	hydro-electric ministry 1978 China
rock mass engeneering classifica-tion	RQD	RQD(%)=100× Lp×Lt Lp is the total length of all pieces exceeding 100mm, Lt is the total length of borehole, RQD is originally introduced for use with NX-size core(54.7mm).	Five classes	very good (I)90-100%	good (II) 75-90%	fair (III) 50-75%	poor (IV) 25-50%	very poor(V) <25%	Deere 1964 USA
	rock mass structure classfication	six classes: block structure, mosaic structure,cataclastic texture,layared structure,layered-cataclastic structure,spall structure							Institute of geology, CAS 1972 China
	CSIR(RMR)	The five basic classification parameters are: 1. Strength of intact rock material, 2. Rock Quality Designation(RQD), 3.Spacing of joints, 4.Condition of joints, 5.Ground water conditions.	Five classes	very good (I) 100-81	good (II) 80-61	fair (III) 60-21	poor (IV) 40-20	very poor (V) ≤20	Bieniawski (1973,1974,1976,1979,1989) South Africal

rock mass engeneering classifica-tion	NGI(Q)	Q=(RQD/Jn)×(Jr/Ja)×(Jw/SRF) RQD is Deere's Rock Quality Designation J_n is the joint set number, J_r is the joint roughness, J_a is the joint alteration number, J_w is the joint water reduction factor, SRF is a stress reduction factor.	Five classes	very good (I)>40	good (II) 40-10	fair (III) 10-1	poor(IV) 1-0.1	very poor (V) 0.1	Barton, Lien and Lunde 1974 Norway
	Standard of engineering cclassification of rock mass	[BQ]=90+3Rc+250Kv-100(K1+K2+K3) Rc:saturated uniaxial compressive strength Kv:intactness index of rock mass K1:correct index of groundwater effect K2:correct index of dominated discontinuty K3:correct index of initial stress state	Five classes	very good (I)> 550	good (II) 550-451	fair (III)450-351	poor (IV) 350-251	very poor (V) 250	National Standard 1994 China
	hydroelectric engineering rock mass classification	particular wall-rock classification(grade):rock strength,intactness of rock mass,discontinuty state, groundwater and occurrence of dominated discontinuty	Five classes	very good (I)100-85	good(II) 84-65	fair (III)64-45	poor(IV)44-25	very poor(V) <250	Minister of water resources 1991 China
	classification of storage oil in rock caverns	QM=Vpn×RQD×[R]×Kd QM:qulity index of wall-rock,Vpb:elastic velocity of rock mass,RQD:Deere's Rock Quality Designation,[R]:compressive strength of rock mass,Kd:softening coefficient of rock	Four classes	A >2000	B 2000-700	C 700-130	D <130		Minister of Petroleum 1983 China

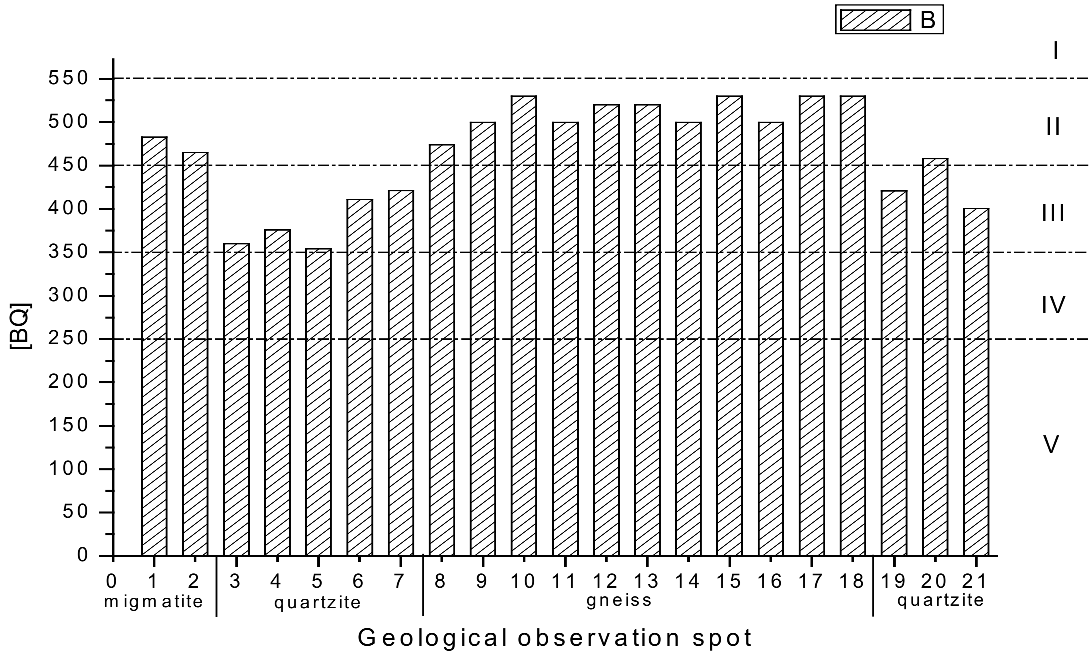

Figure 5. Score of [BQ] for different geological observation spot

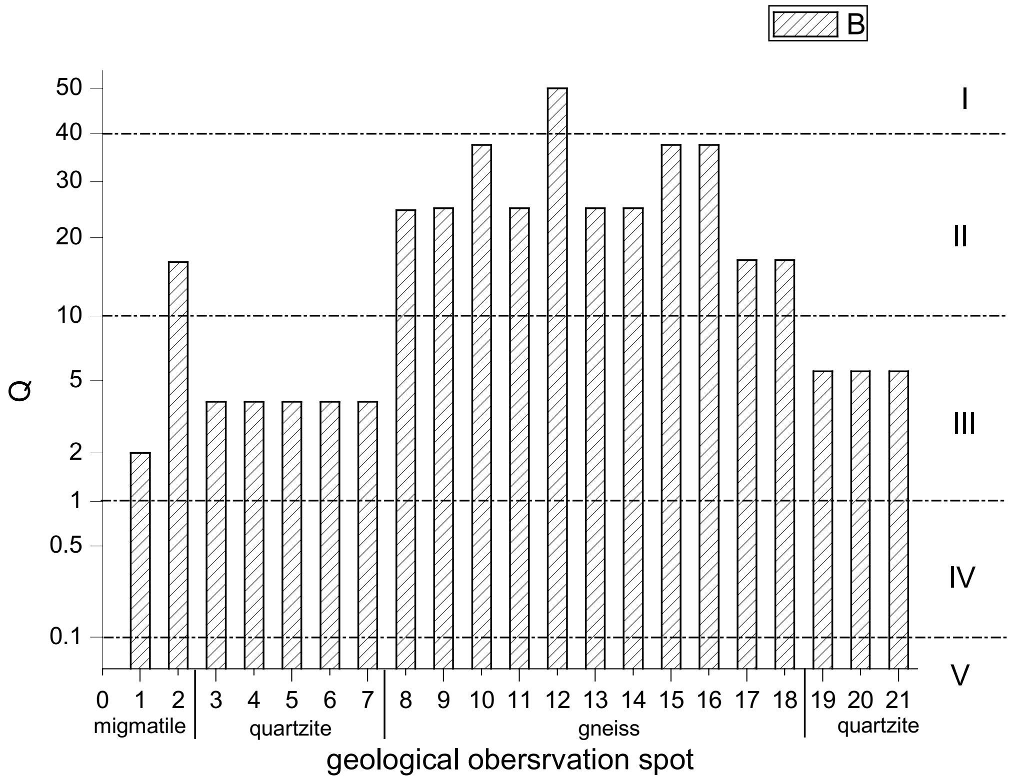

Figure 6. Score of Q for different geological observation spot

CONCLUSIONS

During the stage of sitting crude oil storage caves, firstly the petrofabric partition should be carried out, for it is general basic analysis work based on structure, lithology and texture. The classification and grade of discontinuity is the basis of assessing rock mass quality. Project petrofabric and stage ought to be considered when using different rock mass classifications. The analysis was performed on 21 geological observation spots with quartzite and gneiss etc using the rock mass classification methods of Q, [BQ] and the total rating of wall-rock, it is found that the result of three methods is sameness completely.

REFERENCES

CHEN ZONGJI. 1982. Foreword to a Periodical of Chinese Journal of Rock Mechanics and Engineering. *Chinese Journal of Rock Mechanics and Engineering* 1 (1), 4.

WANG SIJING, YANG ZHIFA & LIU ZHUHUA. 1984. Stability Analysis of Rock Mass for Underground Engineering. Beijing: Science Press. pp.25-47.

LI SHIHUI. 1991. *Systems Analysis Tunnel Rock Stability*. Beijing: China Railway Press. 119 - 128.

MINISTRY OF WATER RECOURCES, P. R. CHINA. 1995. *Standard for engineering classification of rock masses*. GB50218-94. Beijing: China Planning Press.

MINISTRY OF OIL INDUSTRY, P. R. CHINA. 1983. Code for Investigation of Engineering geology for Underground oil storage. SYJ52-83. Standard of Oil Industry.

MINISTRY OF WATER RECOURCES, P. R. CHINA. 1991. Code for Investigation of Water Conservancy and Hydroelectric Power. Standard of Water Recources.

GU DEZHEN. 1979. *Engineering Geomechanics Base of Rock Mass*. Beijing: Science Press. 198 - 241.

HUANG DINGCHENG. 1987. Problems of Level of Geologic Body's Structure in Estimation of Engineering Geology. *Problems of Engineering Geomechanics of Rock Mass*. Beijing: Science Press. 15 - 24.

XU BIN. Li yurui. Zhang ruyuan. 1985. Engineering Geomechanics Research on Slope Stability of Strip Mine in Jinchuan. *Problems of Engineering Geomechanics of Rock Mass*. Beijing: Science Press. 1 - 106.

PAN BIETONG. 1990. *Rock Mass mechanics. Staff Room of Engineering Geology*, China University of Geosciences (Wuhan) (mimeograph).

V.U.NGUYEN,E.ASHWORTH.1985. Rock mass classification by fuzzy sets. *Proceedings of the 26th US Symposium on Rock Mechanics*, 937-945.

GOEL, R. K., JETHWA, J. L. AND PALHANKAR, A. G. 1996.Correlation between Barton's Q and Bieniawski's RMR – A new approach. *Sci and Geomech* 33, 179 - 181.

ALI EL-NAPA.2001. Application of RMR and geomechanical classification systems along the proposed Mujib Tunnel rounte, central Jordan. *Bulletin Engineering Geology and the Environment*, 257 - 269.

ALI YASSAGHIA, HOSSEIN SALARI-RADB, HOSSEIN KANANI-MOGHADAM.2005. Geomechanical evaluations of Karaj tuffs for rock tunneling in Tehran–Shomal Freeway, Iran. *Engineering Geology* 77, 83 – 98.

TUGˇRUL, A. 1998. The application of rock mass classification systems to underground excavation in weak limestone, Atatu¨rk dam, Turkey. *Engineering Geology*. 50, 337 - 345.

C.T. CHANG , P.C. HOU, M.C. LEE, Y.T. LEE, P.H. CHANG. 2004 Extension of RMR and Q-system in Taiwan. *Tunnelling and Underground Space Technology* 19, 430 – 431.

J.E.UDD,H.WANG. 1985.A comparison of some approaches to the classification of rock masses for geotechnical purposes. *Proceedings of the 26th US Symposium on Rock Mechanics*. 26 - 28.