Quantitative evaluation of the classification of the unloading zone of a rock mass slope

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Abstract: In research of water-conservancy and hydroelectric projects rock mass unloading and the classification of unloading zones are very important. At the same time it is a main factor that affects the choice of the bearing surface for a dam's foundation. On the base of previous research results this paper presents quantitative indexes (fissure aperture, fissure amount, longitudinal wave velocity and coefficient of permeability) into the classification of the unloading zone. Using these indexes the unloading zones can be determined and checked with qualitative in situ investigations. These indexes offer a reference to aid in the classification of the unloading zone for rock mass slope engineering.

Résumé: La décharge et la bande de décharge de la roche est le contenu principal de la recherche géologique des travaux hydrauliques et hydroélectriques. Elle est un des facteurs principaux influençant la choix de la surface de la fondation du barrage. Basé sur les résultats de recherche nationale et internationale de la bande de décharge de roche, le texte a proposé l'indice quantitatif utilisant l'ouverture de la fissure, le nombre de la fissure, la viteese de l'onde verticale et le coeficient de perméabilité pour distinquer la bande de la décharge de roche. On a utilisé pratiquablement l'ouverture de la fissure, le nombre de la fissure et la vitesse de l'onde verticale pour déterminer la bande de la décharge de la roche du tunnel horizontal des travaux. Le résultat est fondamentalement conforme à la limitation de la bande de décharge sur place. Cet indice quantitatif donne la référence de la détermination de la bande de décharge de roche des travaux.

Keywords: rock mass, classification, weathering, joints, unloading zone , index

INTRODUCTION

The rock mass unloading and classification of unloading zone are the important contents in the engineering geology researches on hydroelectric projects. The slope's rock mass unloading can be defined as such: the freeing surface which caused by the river valley's erosion or manual excavation destroy the rock mass' original stress state, make the rock mass stress redistribute. The superficial rock mass relax to the freeing surface direction, the stress concentration happen in the deeper part of the slope. During this process, the stress reducing in the superficial part to certain depth of rock mass will make the relaxation of the rock mass structure and the original structural fissure's expansion or strain-slip, even create a new fissure system. All these provide a passage-way for the weathering agent ,underground water and other exogenic process speed up the rock mass weathering and stress decreasing lower, promote the rock mass deforming and destroying worse the rock mass completeness. In present stage, many researches have been done on the deforming process of the rock mass unloading zones (Runqiu Huang, 2000; Xiufa Zhang, 1993), the engineering characters of the unloading rock mass (Qiulin Ha, 2001; Jianlin Li, 2001); the unloading of engineering rock mass and failure characters (Gang Wu, 2001) etc. These researches have got lots of achievements. However, the unified standards of the classification of the unloading zones have not been come to decision. The traditional way is that the geologists use the slope rock mass structure characters, fissure aperture, the characters of the filler and the distribution of the underground water to make site statement, so there are many inaccuracy and artificial factors in the classifying process. It will bring many troubles in the engineering rock mass' statement especially in the chosen of the high dam' s foundation plane. In this paper, basing on the research findings and data from engineering projects, several quantitative indexes which can be used in unloading zones classification of rock mass are studied. It provides theories for the classification of rock mass unloading zones in engineering experience.

THE CHOICE OF THE QUANTITATIVE INDEX FOR CLASSIFICATION OF THE UNLOADING ZONES

The researches indicate that, the slope rock mass unloading will induce the relaxation of rock mass, which located superficial part, pulling cracks on the original structural surface and creating new secondary fissures. This unloading process will increase the quantity of the fissures in rock mass, worsen the integrity and the structure of the rock mass (Dexin Nie, 2002). Fissure density (fissure amount) and fissure aperture are both showing a tendency, which is decreasing along with the increase of the depth which calculated from the slope surface, and then tend to stay in a

stable stage in certain depth. The fissure amount, fissure departure's changing process is induced by the rock mass weathering and unloading during the period of the slope deformation. The process, in which the fissure amount decreasing with the increase of the depth and then tends to be stable while the fissure is closing, indicates that the weathering and unloading have little effect on the rock mass to certain depth. The rock mass unloading will induce the formation of a new fissure system and the relaxation of the original structural surface, then destroy the rock mass' integrity, and enhance its water transmitting ability at the same time. So the changing process of the rock mass completeness, fissure amount, fissure departure and the fissure filler or other secondary filler's thickness can properly disclosure the unloading degree of the rock mass, and it can also provide some evidence to classify the rock mass unloading zones. According to the above analysis, the quantitative index of unloading zones classification can be selected as follow: fissure amount, fissure aperture, longitudinal wave velocity in rock mass, coefficient of permeability, etc.

UNLOADING ZONES CLASSIFICATION USING QUANTITATIVE INDEX

The general introduction of project

The project is located in the valley of Longyang valley, Huanghe River's upper course. The river valley is very narrow, the bench section is shaped V, and the riverbanks turn out to be symmetry. The depth of the valley is 600~700m. The average angle of slope is between 40°~65°, composed of the Mesozoic era Indo-Chinese epoch granite with high strength, high modulus and strong resistance to weathering. The rock mass is developing three groups faults with high dip angle which are in NNW, NNE, NE strike and one group of low dip angle which is in NWW. The joint's developing law is almost the same as the faults, which is dominated by high dip angle(approximately 92~95%),and 80% of theses joints are in the compaction state, the type of the underground water is fissure phreatic water, it is mainly from the atmospheric water and drainage to Huanghe River. The underground water is buried deeply. The ground stress in this region is high, according to the three-dimensional stress testing, the maximum principal stress (σ_1) is 8.8~29.7MPa, with strike NE10°, NE9° and its dip angle is 19° to 55°, mostly round 40°. The minimum principal stress (σ_3) is 2.2~13.1MPa.

The settlement on the boundary values of the quantitative index for unloading zones classification

In present stage, according to the research findings both from home and abroad, the unloading zone is divided into three parts: intensely unloading zone, moderate unloading zone, slightly unloading zone. Because of the rock mass which in the slightly unloading zone is corresponding to the slightly weathering zone, it can be used as the high dam foundation directly. So, the depth of intensely unloading zone and moderate unloading zone should be researched in detail. Here are some examples: Xiaowan hydropower-project(under construction , located in the Lancang River, the height of the dam is 292m) and Xiluodu hydropower-project (under construction , located in the JinSha River, the height of the dam is 273m), two of those quantitative index (**l**ongitudinal wave velocity; fissure departure) are chosen to carry out the unloading zones classification in dam abutment rock mass, the boundary value of the quantitative index for unloading zones classification are recorded in the Table 1. Zhibing Hou (2000) studied the changing characters of unloading joints density and aperture along with adit depth in sand-shale rock mass of Dongzhuan water conservation project. He found that fissures in the intensely unloading zone are generally open 0.5~1.5cm wide in general and filled with the secondary clay, fissures in the moderate unloading zone most are 1mm wide (maximum with up to several mm), filled with calcareous and argillaceous.

Table 1. The unloading characters of rock mass for some large arch dams

Hydroelectric station	Unloading zone	Vp(m/s)	aperture	Unloading characters	Lithologic character
Xiaowan	intensely	<3000	>2cm	Developing the moderate steep and low-angle structural surface, the width of the fissure is large in general, filled with debris , block and argillaceous. Unloading structural surface's bilateral rock mass displace obviously, the rock mass in the intensely unloading zone is relaxing obviously, the developing depth does not surpass the intensely weathering zone.	gneiss
	moderate	3000~ 4500	0.2~2cm	Unloading fissure with small width, no argillaceous filler, and the developing depth is corresponding to the boundary of the moderate weathering zone.	
Xiluodu	intensely	<2500	>2cm	Rock mass is relaxing, fissures open in general, rust, filler is debris mostly	$P_2\beta$ basalt
	moderate	<4100	Aperture slightly	moderate relaxation ,fissure open slightly, <1mm in general, the rust is serious on the big fissure's surface	
	Original	>4800	closed	The structure of the rock mass is tight, the fissure's surface is fresh.	

The research disclosures that the unloading will induce the relaxation of the rock mass, destroy the rock mass' integrity, enhance the rock mass water transmitting ability at the same time. Therefore, the coefficient of permeability which is obtained from the water-pressure test can reflect the unloading degree of rock mass, the fissure departure, so it can be used to classify the unloading zones. In the code for investigation of hydropower engineering geology (GB50287-99) there is a detailed statement on the classification of the rock mass permeability in appendix J (Table 2). It indicates that the rock mass permeability and fissure departure have intimate relationship. Hong Lu (1995) provided a conclusion that the rock mass permeability in intensely weathering zone and intensely unloading zone are mostly >100 Lugeon unit while 1~100 Lugeon unit in moderate weathering zone and outer part of slightly weathering zone .

Comprehensive consideration on these characteristic index and the project's experiences, the following index are chosen to classify the rock mass unloading zone: the fissure amount, fissure aperture, rock mass longitudinal wave velocity, coefficient of permeability. The standard is listed in the Table 3.

Table 2. Classification scheme of permeability for rock mass

Permeability grade	coefficient of permeability K(cm/s)	rate of perviousness q/(Lu)	rock mass character
Most slight	$K<10^{-6}$	q<0.1	Integrity,the rock mass with fissure of <0.025mm width
slight	$10^{-6}<K<10^{-5}$	0.1≤q<1	the rock mass with fissure of 0.025-0.05mm width
minor	$10^{-5}<K<10^{-4}$	1≤q<10	the rock mass with fissure of 0.05-0.01mm width
middle	$10^{-4}<K<10^{-2}$	10≤q<100	the rock mass with fissure of 0.01mm-0.5mm width
strong	$10^{-2}<K<10^{0}$	q≥100	the rock mass with fissure of 0.5mm-2.5mm width
Most strong	$K\geq10^{0}$		include the connectivitv hole or the rock mass with fissure of >2.5mm width

Table 3. Quantitative indexes of classification for unloading zones on rock mass

Classification of the unloading zone	Fissure aperture (mm)	Fissure amount in 5m of the cave	Longitudinal wave velocity (m/s)	Lugeon unit (Lu)	Permeability ωL/min.m.m
moderate unloading zone lower limit	1	18	4000	<10	0.1
intensely unloading zone lower limit	10	36	2500	≥100	1

Classification of unloading zone

The fissure aperture in the quantitative index mentioned above is the most direct quantitative index that used to reflect the rock mass unloading characters, but it is very difficult to measure efficiently especially in moderate and slightly unloading zones. Fissure amount in rock mass also reflects the degree of unloading, so it is list in Table 3.

Generally speaking, the quantity of the developing fissures in the slope rock mass is decreased as the increasing of the distance to slope surface. When reaching a certain depth, the quantity of fissures in the rock mass stabilize on a certain level, and it is relatively correspondent to the weathering and the unloading degree. From the valley slope's surface to its deeper layer and the riverbed's surface to its deeper rock mass, the weathering of the rock mass generally passes through surface completely weathering → intensely weathering → moderate weathering → slightly weathering → fresh rock mass of deeper layer, the rock mass unloading usually proceeds from surface intensely unloading → moderate unloading → slightly unloading → original rock mass of deeper layer. The changes of weathering and unloading degree of rock mass are graded and asymptotic, and the number of the corresponding structural surface decreases gradually, the spacing length of the joints also gets longer gradually and the rock mass' structure becomes better. They all present mutually corresponding asymptotic changing characteristics. The increase of rock mass' fissure results from the weathering and unloading of rock mass. Therefore, the research of the fissure's change from slope surface to its deeper layer can disclose the weathering and unloading degree of the rock mass. Here we make the division of the lower limit of unloading zones in rock mass according to the number of fissure in the 5m section. But the cite investigation of fissure emphasize on the ones which are longer than 50cm, thus there is a difference between the number of fissures obtained from actual investigation and the real number of growing fissures along the opening of the adit. Therefore the number of fissures is mainly used to determine the lower limit of moderate unloading zone.

As the index obtained from exploration adit in the bank slope are mainly fissure aperture, number of fissures and rock mass' wave speed, therefore in the following we will mainly classify the unloading zones with fissure aperture, number of fissures and rock mass' wave speed and compare the classification result with the qualitative judgment on the spot (Table 4).

As is shown in Table 4, by applying various quantized index, the result of classification of unloading zone of the rock mass basically corresponds to the result of the classification by experienced geological engineers. Thus the fissure aperture, number of fissures and rock mass' wave speed can be taken as the quantized index on the Classification of slope unloading zones.

Table 4. Classification result of unloading zones for rock mass in some adit

Adit NO.	Lower limit of intensely unloading zone (m)			Lower limit of moderate unloading zone (m)			
	Fissure aperture	longitudinal wave velocity	Site investigation	Fissure aperture	Fissure amount	longitudinal wave velocity	Site investigation
PD7-2	10	20		35	40	40	40
PD35		10	10		20	20	20
PD35-1	10	10		15	35	20	28
PD5-3	10	5		30	30	30	
PD28	10	42		40	55	57	48
PD8-3	30	20	25	35	25	30	36
PD26		20		10	15	30	15
PD32	5	0		37	25	35	37

CONCLUSIONS

From the preceding results, it can be concluded as that:

(1)The rock mass unloading causes new fissures formation, the looseness and opening of the original structural planes, thus destroy the integrity of the rock mass and increase its water transmitting ability.

(2)The indexes which reflect the rock mass integrity, number of fissure, fissure aperture or character of fissure filling disclose the degree of unloading.

(3) After a comprehensive consideration on the actual measurement data, the fissure amount, fissure aperture, rock mass longitudinal wave velocity, coefficient of permeability are selected to carry out unloading zones classification .The classification results of unloading zones in some adits are consistent with the results given by those experienced geological engineers. Those quantitative index provide scientific evidence for the of rock mass unloading zones in engineering experience.

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