Study on Feasibility of Columnar jointed basalt as a high-arch dam foundation

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ABSTRACT: Columnar jointed basalt is a fractured rock, with a lot of small spacing structural planes and poor integrity of the rock mass. On the basis of the comprehensive study of the columnar shape of Columnar joints, rugosity of the fracture surface and the chemical composition of basalt, columnar joints of Bai hetan dam area were formed as a result of the cooling and shrinkage effect of magma. Columnar joints basalt are mainly chlorite, kaolinite, epidote, tremolite chemical reactions and the content of columnar joints are mainly chlorite by slice identification and chemical analysis. Columnar joints basalt showed high uniaxial tension test, low coefficient of friction and high cohesion by indoor physical and mechanical test. Columnar joints rock mass showed high strength and large deformation by field shear test and deformation test. Columnar joints basalt can be used directly as a foundation of dam as long as we follow the rules and reduce disturbance strictly.

1 INSTRUCTIONS

The Proposed Baihetan Hydropower Station which located on the lower part of Jinsha River from Panzhihua to Yibin is another K W hydropower station to be built following the Three Gorges,Xi luodu. The impounded level was planed to be 825m ,and it was a hydropower station with a total installed capacity of 12600MW.Concrete double curvature arch dam with height to 284m and high flood discharge, and high seismic intensity, this project’s reconnaissance and design work for selection of dam-site is under way. Columnar jointed basalt was found In dam area, Fig.1.

Figure.1 Columnar jointed basalt in Baihetan dam site

Columnar jointed basalt is a fractured rock, owing to small spacing structural planes and poor integrity of the rock mass; it is not directly adopted for rock mass of dam foundation in hydropower project. In view of relatively little recognition and direct adoption and research of fractured rock, the present research concentrates on project treatment.

In China, Fan guosong and etc. have conducted research on Baise hydro-junction whose main dam were built on Huaxi period diabase vein with fractures grew, rock mass fractured, and the cataclastic texture～mosaic cataclastic texture mainly exists here.The deformation modulus of the light weathered diabase is about 5.8GPa, after anchor grouting of the light weathered rock mass on engineering, the rock mass was used as dam foundation [3].A chemical composition diffraction analysis and analysis through scanning electronic microscope of composition and microstructure property of discrete structure surrounding rock mass at the right abutment of a hydropower engineering in a city of Northwest China by Hu xiasong, Zhao fasuo, etc. probed into the characteristics and patterns of deformation and failure of surrounding rockmass of underground excavation.A research on sspage resistanceseepage resistance.

Homas Dalmalm，Thomas Janson, etc.from abroad have conducted experimental research on indoor grouting of cataclastic rock mass,making a set of achievements such as grouting material,grouting pressure.

However, on the study of cataclastic texture rock mass, scholars home and abroad put their focus mainly on technology of project treatment cataclastic rock mass ,fewer studies were made for formation mechanism of cataclastic texture rock mass and if it could be put to direct use with a few or without project treatments which is the study mainly contain contained in this report.

2 THE CAUSE OF COLUMNAR JOINTED BASALT

2.1 The research status of The Cause of Columnar Joint

The formation of Columnar jointed structure of volcanic rock is a very complicated problem which, for over a century, were believed by petrologists as Iddings(1886), James(1920)that this structure can only developed in basic extrusive rock mass with SiO2 content between 45~52%, low viscosity and large fluidity.However,recent studies show that the formation of columnar Jointed Basalt was not the result of restriction (such as viscosity)by a single factor, but the product of extensional breakage and deformation caused by stress action pattern after comprehensive influence of some internal and external factors during lava cooling contraction,these factors include homogeneity of lava substances ,the texture and structure of rock, the viscosity of magma,the cooling temperature and change of magma, the cooling speed and cooling uniformityof magma, the occurrence of rock mass, ancient landform, paleoclimate condition,flat condensing surface and enough depth of rock flow, etc.

Since 1980, scholars home and abroad have started studying self-organization phenomena by non-equilibrium statistical theory, having a new understanding of the Cause of Columnar Joint, especially the determination of cooling centre. Various kinds of formation theory have appeared.

2.1.1 Cooling Contraction Theory

It was believed by many scholars that the ideal generative pattern of Columnar Joint in basalt have always taken two condensing surface as its developing bases. One of the two condensing surface is top condensing surface,namely the contact interface between the top lava flow and atmosphere, and another one is bottom condensing surface,namely the interface between the bottom lava flow and lower bedrock. Traditional theory of cooling contraction effort is the analogy of the cause of mud crack, which is a trustworthy evidence, but Kantha，Dergaff(1987) believed that mud crack only have lower aspect ratio whose width is usually exceeds depth, and the aspect ratio basically can not exceeds 1,but basalt pile array have a very high aspect ratio, even above 100,so this simple analogy of cause may have defects which prevent people from further consideration of any other cause patterns.

Gerhard Muller(1998) as a representative scholar, proved anew of the raditional theory of cooling contraction with experimental method .They mixed flour with water in different proportion and anhydrated them under certain condition for observing a series of similar appearance of strip form of basalt bifid spine which have similar effort of morphology controling factors,for example, water content factors in flour,like temperature factors in basalt, all of them follow diffusion law,that is: water content decreasing equal to temperature dissipating and shrinkage stress depends on action time and the depth of cylinder,etc. Experimental result shows that Cooling Contraction Theory of Columnar jointed basalt is a possibility.

2.1.2 Study on the Cause of Columnar Joint by Benard Convection Model

Wang jianghai, etc. have explained the Cause of Columnar Joint by Benard Convection Model,they believe that Columnar Joint was the result of self-organization magma during condensation process,when lava rayleigh number above critical value（657.51）during condensation process,there will be the Benard convection which formed convective cellulars with hexagonal structure grid type. The energy of java itself cannot overcome viscous force within java when java was kept on cooling, so the convection stopped, then, densities of every part within each convective ring of lava have obvious differences, central density of hexagonal convective cellular is low and it increases successively along normal line,therefore,once the convective stopped, density equalization is performed on lava and a cold shrinkage centre is formed, the location of cold shrinkage is anastomosed with original convective centre, an inevitable tensional fracture will take place at every six angle of convective pattern, and tensile stress takes place at connecting line of two adjacent convective centre.

Columnar jointing is formed by three sets of joints of intersecting 120° and regular distribution and layer by layer solidification contraction from top to the bottom. if magma composition and condensing rate do not have homogeneity,they will form polygonal columnar joints of non hexagonal grid.

2.1.3 The theory of double diffusion convection effects

Kantha has put forward his different view on traditional Cooling Contraction Theory which explains the cause of columnar joint by means of analogy of the cause of mud crack.he believes that mud crack only has lower aspect ratio, its width usually exceeds depth, so its aspect ratio seldom exceed 1.But columnar joint has higher aspect ratio which can reach to 100.therefore,it is difficult to conceive a continuous homogeneity within such a large depth range when fracture extends from bottom or top to inner rock body,unless there exists spreading path within melting magma.thus,Once the magma consolidateds, fracture will spread into internal along intrinsic, pre-established paths,therefore, the rock mass which were cut by original fracture lead to forming the very regular columnar structure in Columnar joint.

2.2 Formation types of Columnar jointed basalt in dam site

Basalt in this area is basalt of potassic series weak alkaline, Basalt in Baihetan is continental rift condition and the product of magma outpouring by koe major fracture of western edge of yangtze plate.

According to the outdoor statistics of columnar joint length and diameter of column, see Fig. 2 for the aspect ratio of columnar joint (aspect ratio= column length/ column width).It can be seen from Fig.1 that aspect ratio of columnar joint is mainly in 2~10,and the most dense areas is in 2~5.

Spot investigation found that columnar joint in Baihetan dam site has these characteristics as follows: columnar joint in Baihetan dam site is mostly irregular, column of aspect ratio is not high, sections are mainly pentagon,see Fig.2. Columnar joints are mainly developed in grayish-black crypto-crystal basalts, the changed value of chemical composition gradient of upper and lower column is relatively small, see table 1. Columnar joint appears fluctuating, rough surface and partial bending.

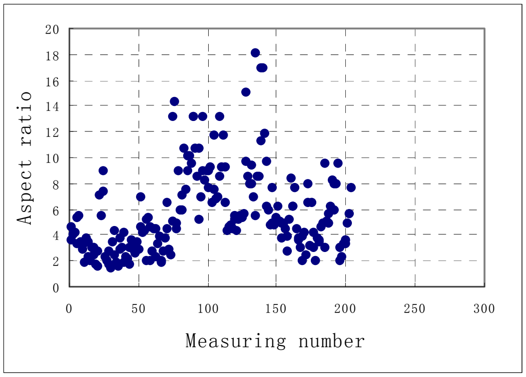

Figure 2 Statistics of aspect ratio columnar joint in dam site

Table 1 Chemical composition of columnar joint basalt in dam site of Baihetan Hydropower Station

horizon	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	MnO	Na_2O	K_2O	P_2O_5	H_2O	sum
$P_2\beta_2$	49.77	3.39	13.84	4.46	8.81	4.01	9.14	0.17	2.34	0.92	0.34	2.19	100.4
$P_2\beta_3$	47.8	4.14	13.88	5.81	8.39	4.14	8.19	0.16	2.46	1.32	0.44	2.56	99.89
$P_2\beta_4$	49.26	3.74	13.21	6.87	7.93	3.97	9.04	0.14	1.48	1.15	0.46	2.76	100.6
$P_2\beta_5$	50.95	4.06	12.73	5.58	8.31	3.74	8.25	0.21	2.19	1.5	0.34	1.66	99.48

Basalt in Emeishan dam site is continental rift condition, and the product of the product of magma outpouring by koe major fracture of western edge of yangtze plate with comparatively large thickness of lava ejected from terminal magma and similar chemical composition , the cooling temperature and homogeneity of magma are necessary for the development of columnar joint.

It can be seen from the above-mentioned analysis on columnar external form,the roughness of fracture surface chemical composition of basalt that the formation of columnar joint in Baihetan dam site does not conform to the formation of double-diffusive convection,but the formation mechanism of cooling contraction effort of magma. This area has the characteristic of comparatively flat ancient landform, comparatively large thickness of lava ejected from terminal magma, similar chemical composition, the cooling temperature and homogeneity of magma are necessary for the development of columnar join.

3 THE WEATHERING CHARACTERISTICS OF COLUMNAR JOINTED BASALT

3.1 The Appearance and Microscopic Characteristics

Emeishan basalt in project area can be divided into two large classes as slightly weathered rock mass and weakly weathered rock mass by surface color,hammering sound and filler in tectonic zone; Weakly weathered rock mass can be divided into two subclasses as upper segment of weakly weathered rock mass and lower upper segment of weakly weathered rock mass. See Fig.3, Fig.4, Fig.5.

As the weathering degree aggravates. Emeishan basalt joint surface ranged from steel-gray(grayish-black) fresh rock to partial filemot lower upper segment of weakly weathered rock mass to Filemot upper segment of weakly weathered rock mass.

The rock fracture ranged from grayish-black (steel-gray) slightly weathered rock mass to small amount of filemot lower upper segment of weakly weathered rock mass to large part of upper segment of weakly weathered rock mass.

The fractured rock which filled in Interformational, intrastratal Disturbed belt and fracture zone ranged from steel-gray slightly weathered rock mass ,grayish-yellow non secondary allochthonous soil to weakly weathered zone of yellow secondary allochthonous soil.

Fig.3 The Appearance of slightly weathering of ColumnarJointed Basalt (the 36th adit in Baihetan dam site)

Fig.4 The Appearance of lower segment of weak weathering of Columnar Jointed Basalt(the 68th adit in Baihetan dam site)

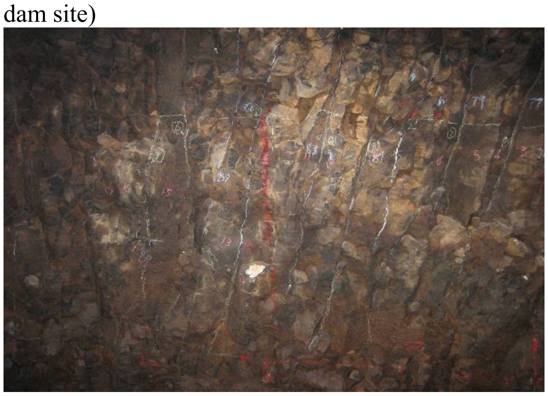

Fig.5 The Appearance of upper segment of weak weathering of Columnar Jointed Basalt(the 68th adit in Baihetan dam site)

Columnar jointed basalt produce micro flat microfracture, micro implicit microfracture and flat implicit joint is in accordance with flat microfracture on origin, but it was believe that tectonism is related to the formation of flat microfracture, see Fig.6, Fig.7. Flat microfracture exist filling dike and non filling dike. Filling dike fracture formed generally from tectonism, filling dike are mainly quartz and parts of filling dike exist tremolite dike which are typical altered minerals and product of altered pyroxene ,existing in igneous rocks of some contact metamorphic zone. The emergence of tremolite dike suggests that fault contact zone exist here, rock mass quality is poor, see Fig.8, Fig. 9.

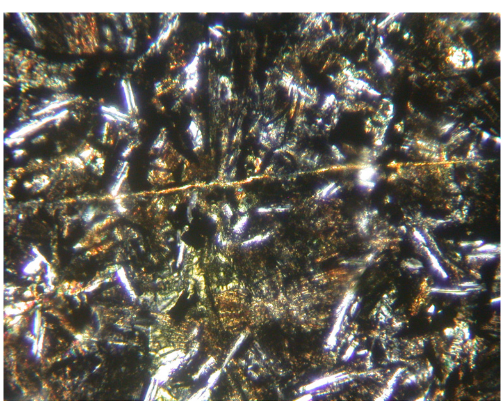

Fig. 6 The implicit microfracture developed in rock mass thin section

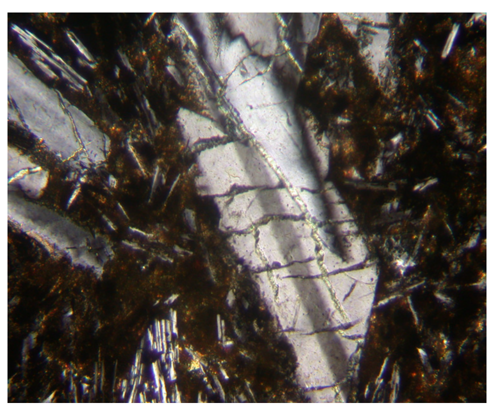

Fig. 7 Implicit microfracture of plagioclase phenocryst of phenocryst basalts

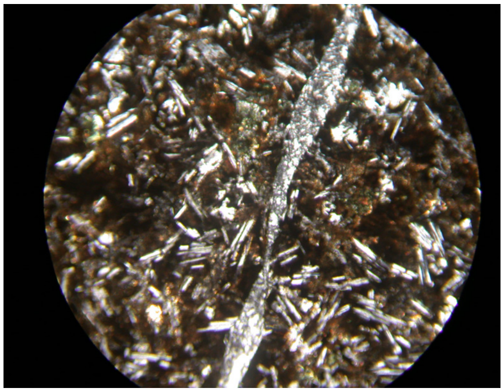

Fig. 8 Filling dike fracture(quartz vein)in thin section

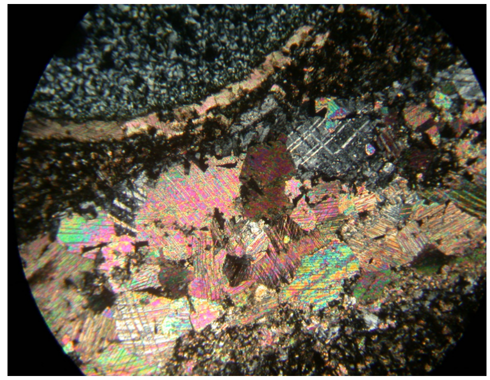

Fig. 9 Filling dike (tremolite)in thin section

3.2 Mineral Characteristics

In the process of plagioclase weathering, plagioclase gradually decomposed as secondary minerals of clay type,because clay have uptated composition of iron oxide after feldspar weathering, the bright-dark degree of the surface of feldspar, the transformation of redish brown color and optical properties under crossed polarizer have provided an analysis basis for plagioclase weathering thickness. In measuring the degree of secondary alteration of rock, we can represent it by alteration factor. Alteration degrees were classified as five grades (representation of number)on the base of rock-forming minerals, plagioclase microcrystalline(diameter <0.2mm), pyroxene microcrystalline can be classified referring to standard as follows:

The 1st grade（0~1）：Non altered (including weathering) or basically non altered, minerals basically remain fresh.

The 2ed grade（1~2）：Slightly altered, alteration is partially observed, and crystal form is relatively complete, the primary characteristics of rock-forming minerals are basically unchanged, the composition of rock-forming mineral can be measured

The 3rd grade（2~3）：Slightly altered, alteration was clearly observed, but not referred to the whole minerals, the primary characteristics of rock-forming minerals are without observable change, section appeared slight opacity, the composition of great part of minerals can be measured.

The 4th grade（3~4）：Alteration is relatively strong, section appeared opacity, lithological characters are indistinct, the characteristics of the minerals basically can not be measured although they are perfectly preserved.

The 5th grade（4~5）：The intensity of alteration or 80% of mineral section was replaced by fresh minerals; most of the primary characteristics of minerals was disappeared and can not be measured.

Sampled every 5.0m of the depth of coastal slope, and calculated the alteration coefficient by thin section analysis, see Fig.10 ,Fig.11 for the alteration coefficient of plagioclase microcrystalline , pyroxene microcrystalline and adit depth in dam site.

It can be seen from Fig.10, Fig.11 that the columnar joints basalt alterations are mainly chlorite, kaolinite, epidote, tremolite. Plagioclase phenocryst alterations are generally weak, alteration coefficients are mainly within 2, plagioclase microcrystalline alterations are relatively strong, alteration coefficients are mainly between 2 and 2.5,isolated ones reach to 3.5. Pyroxene microcrystalline alterations are weaker, alteration coefficients are mainly at about 1.5.

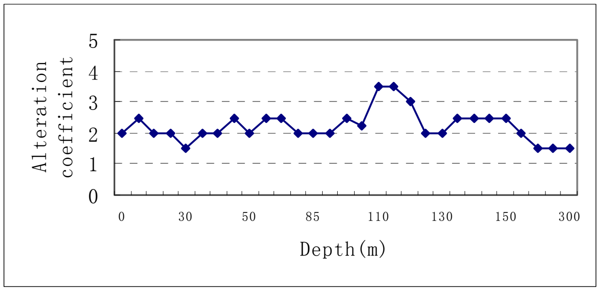

Fig.10 The curve of plagioclase microcrystalline alteration coefficient and adit depth in dam site

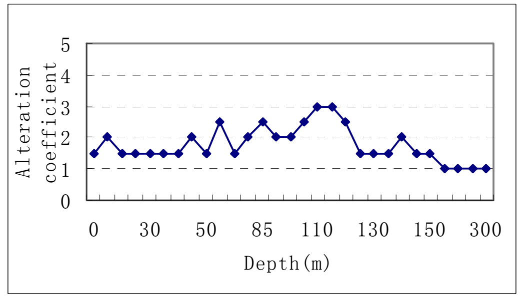

Fig.11 The curve of augite microcrystalline alteration coefficient and adit depth in dam site

Large alteration part of coefficients of plagioclase microcrystalline and pyroxene microcrystalline have developed with faults, intrastratal faulted zone by comparative analysis on distribution of alteration coefficients and geological conditions.For example, the depth of coastal slope is between 25~50m, and it has developed with faults, intrastratal faulted zone, alterations and have a larger alteration, the depth of it is between 110~122m, cleavage belt of faults,alteration belt and fault belt were found here, alteration coefficients are large. On the whole, rock minerals are slightly altered, no chemical weathering was basically found in rock.

3.3 Chemical Characteristics

In order to study the chemical characteristics of columnar jointed basalt, an analysis was made for chemical component of adit PD61 sampling every 5m,see table 1 for chemical component analysis. It can be seen from the table that chemical component of every small layer of columnar jointed basalt is basically the same and the chemical component of different weathering zone shows little change.

See table 2 for calculation of content of CIPW standard mineral of petrochemistry sampling. It can be seen from calculation result that the content of CIPW standard mineral of adit PD61 is approximately consistent , CIPW standard mineral is mainly plagioclase pyroxene minerals,a few small amount of apatite, ilmenite, magnetite,partly calcium silicate fayalite, forsterite, olivine.

Table 2 Statistical list of the results of the results of CIPW standard mineral of Columnar jointed petrochemistry

Rock steatum	Decency degree	or*	ab*	an*	dwo*	den*	dfs*	di*	hen*	hfs*	hy*	q*	ap*	il*	mt*	cs*	fa*	fo*	ol*	∑
$P_2β_3^{3-3}$	upper segment of weak weathering	6.5	16.97	23.70	7.55	4.64	2.48	14.67	7.32	4.00	11.32	8.04	0.99	7.79	5.98					95.95
$P_2β_3^{3-2}$	upper segment of weak weathering	7.89	15.74	23.62	8.19	5.16	2.52	15.87	6.34	3.11	9.44	8.64	0.94	7.84	6.38					96.37
	lower segment of weak weathering	7.94	18.21	22.54	8.10	5.05	2.56	15.71	6.91	3.30	10.21	8.08	0.95	7.8	5.93	1.52				96.15
$P_2β_3^{3-1}$	slightly weathering	6.38	17.6	24.23	7.87	5.17	2.14	15.18	7.06	2.92	9.98	7.82	0.94	8.02	6.44					96.59
$P_2β_3^{2-2}$	slightly weathering	10.33	20.40	20.64	7.60	4.73	2.41	14.74	6.12	3.21	9.33	6.98	0.95	8.06	6.00		1.51	2.97	4.47	96.92

*Note: or : feldspar, ab : albite, an : amphodelite, dwo : mussite， aedelforsite, den : mussite orthoferrosilite, dfs : clinoferrosilite, di : mussite, hen : hypersthene protobastite, hfs : hypersthene clinoferrosilite, hy : hypersthene, q : quartz, ap : agustite, il : kidelophane, mt : magnetite, cs : calcium silicate, fa : fayalite, fo : forsterite, ol : peridot.

Pyroxene minerals are mainly basic magmatic minerals which is the mineral composition of basalt, as Pyroxene minerals is rich in magnesium,it usually changed as chlorite ,serpentine, talc and tremolite,etc.,remolite are the main minerals here. Fayalite, forsterite, olivine etc. can produce changed minerals of magnetite and enstatite under high oxidation condition , and produce a green minerals, namely the combination of chlorite and montmorillonite layer mixed-layer mineral.Because of the secondary change of basalt pyroxene , olivine, etc., on basalt in this area, especially on columnar joint surface, the chlorite content is very high.

4 INDOOR EXPERIMENTAL STUDY ON PHYSICS CHARACTER

4.1 Experimental studies on physics character

There have been 317 pieces of indoor experimental study on physics character of columnar jointed basalt; See table 3 for the result of the experiment.

Table 3 The physics character of columnar jointed basalt

Rock Name	Span	Block Density Natural	Block Density Dry	Block Density Humid	Grain density	Water content	nature water absorption	saturated water absorption	Porosity
		(g/cm^3)				(%)			
columnar jointed basalt	Min	2.85	2.83	2.86	2.90	0.21	0.31	0.32	0.95
	Max	2.94	2.93	2.94	2.97	0.75	0.89	0.93	2.67
	Mean	2.90	2.89	2.90	2.93	0.46	0.55	0.58	1.68
	Statistic magnitude	17	17	17	17	17	17	17	17

4.2 Experimental Study on Rock

See table 4 for the result of high uniaxial tension and tension resist test of rock..The figure suggest that the average value of uniaxial tension of columnar jointed basalt is above 100MPa,after a forced saturation, uniaxial tension dropped to 81.9MPa,and its softening coefficient is 0.72 which suggest that after saturation when meeting water, rock strength showed a remarkable decrease.

Table 4 Statistical list of the results on uniaxial compressive strength ,compression deformationand tensile resistance

Span	Tensile strength (MPa) natural	Tensile strength (MPa) saturation	softening coefficient	Single axle compression strength (MPa) natural	Single axle compression strength (MPa) saturation	softening coefficient	Deformation modulus (GPa) natural	Deformation modulus (GPa) saturation	Elastic ratio (GPa) natural	Elastic ratio (GPa) saturation	Poisson's ratio natural	Poisson's ratio saturation
Min	2.51	1.58		47.7	27.2		47.0	11.0	50.9	12.2	0.17	0.24
Max	10.1	8.70		255	162		83.4	68.3	86.6	71.1	0.26	0.27
Mean	6.02	4.80	0.80	114	81.9	0.72	65.1	51.6	68.3	54.2	0.23	0.25
Statistic magnitude	25	17		22	19		6	4	6	4	4	3

There have been 4 triaxial compression tests in relation to columnar jointed basalt, all of which showed natural state. See Fig.12 for the statistical list of the result. The columnar jointed basalt triaxial compression shows lower intensity parameters, friction coefficient and high cohesion from the figure.

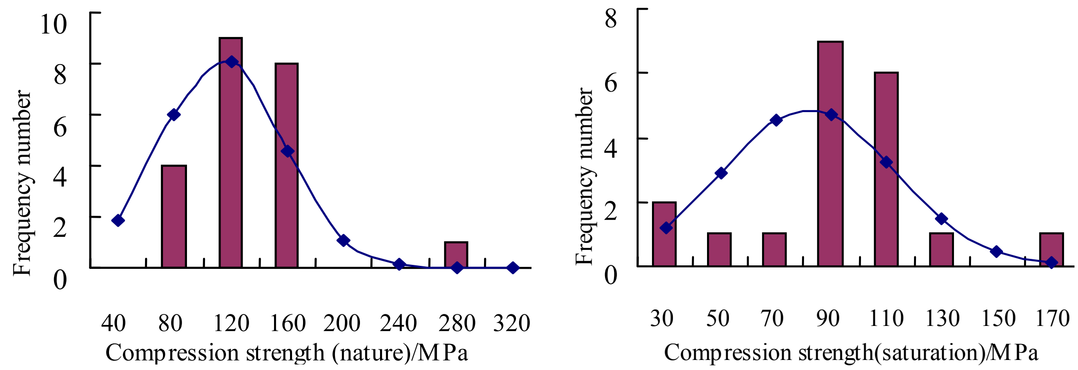

Figure 12 statistical histogram of uniaxial compressive strength of columnar jointed basalt

4.3 Experimental Studies on Rock Deformation

See Fig.4 for the experimental study on rock deformation. The Fig.4 suggests that the average value of natural rock deformation modulus is 65.1GPa; the average value of saturation deformation modulus is 51.6GPa, which suggest that after saturation when meeting water, the intensity of rock deformation shows remarkable decrease.

5 EXPERIMENTAL STUDY ON MECHANICAL PROPERTIES

5.1 Large-sized Experiment of Rock Mass

There have been 13 sets of shear test on columnar jointed basalt (9 sets of which are slightly weathered rock mass and 4 sets of which are weakly weathered rock mass).According to different types of rock mass, they were conducted with proper reduction with arithmetical average as standard valve and combined with code of hydropower investigation, See table 5 for suggested values of anti-shearing intensity of rock mass.

Table 5 Anti-shearing intensity of columnar jointed basalt

rock mass level	shearing resisting		shear		remarks
	f'	c'	f	c	
slightly weathering	1.2~1.3	1.3~1.5	0.8	0	
lower segment of weak weathering	1.0~1.2	0.8~1.0	0.7	0	
upper segment of weak weathering	0.8~1.0	0.6~0.8	0.6	0	

It can be seen from the table that slightly weathered columnar jointed basalt shows a higher intensity index, which suggests that this kind of rock mass shows a higher intensity under the condition of less disturbance or even in situ.

5.2 Experimental Study on Rock Deformation

5.2.1 Deformation tests of flexible central hole

The deformation tests of flexible central hole are set in adit PD36 and adit PD133 of left bank of dam site, eight deformation tests of central hole have been carried out here. See table 6 for distribution of test point, see table 7 for the experimental result of deformation.

Table 6 Distribution of Deformation test point of central hole

experimental points number	Decency degree	experimental points position	load orientation	experimental points amounr	remarks
EC36Z-102~ 103	lower segment of weak weathering	The 36th adit at the depth of 32.0m & 7.3~10.5m from the left adit.	horizontal	2	
EC36Z-201~ 203	lower segment of weak weathering	The 36th adit at the depth of 32.0m & 7.4~14.2m from the bottom adit.	plumb	3	
EC133Z-201~ 203	slightly weathering	The 133th adit at the depth of 100~115m of the bottom grount compartment.	plumb	3	

Table 7 testing results of the deep rock mass deformation of Baihetan Columnar jointed basalt

experimental points number	Decency degree	load orientation	maximum load（MPa）	measuring points depth（m）	deformation modulus（GPa）	remarks
EC36Z-102	lower segment of weak weathering	horizontal	8.76	0.60	7.51	
EC36Z-103			7.00	1.00	14.09	
EC36Z-201		plumb	8.00	0.80	10.20	
EC36Z-202			7.93	0.86	10.95	
EC36Z-203			8.30	0.60	9.71	
EC133Z-201	slightly weathering	plumb	7.45	0.80	14.34	
EC133Z-202			4.60	0.85	10.31	
EC133Z-203			7.00	1.00	7.22	

It can be seen from table 7 that from lower segment of weak weathering, The deformation modulus of slightly weathered columnar jointed basalt is 7.5~14.3GP by the test of flexible central hole,and the deformation modulus of slightly weathered rock mass is slightly above that of slightly weathered rock mass.

5.2.2 Result analysis deformation of rigid bearing plate test

In order to reduce the influence of adit excavation blasting,At the depth of 96m and 125m in adit PD61,upperstream wall was artificial dug for branch adit experiment, Test was conducted on lower segment of weak and light weathered rock mass deformation, See Fig.13 for distribution of test point. Some other test points have been chosen at adit base plate and lateral wall.

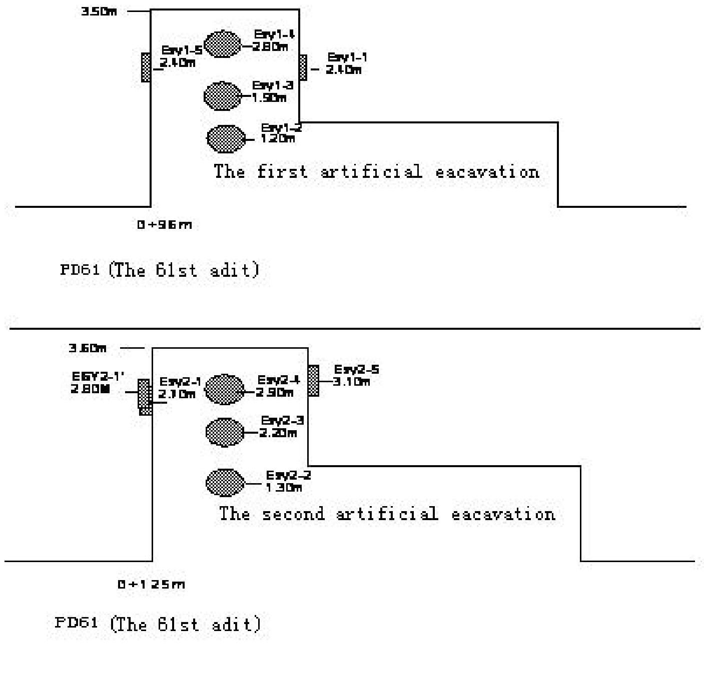

Figure 13: The location map of test points of artificial chiseling loosing-circle deformation in the 61st adit.

Calculating Left and right bank of 54 test points with rigid bearing plate for deformation modulus according to the type of rock mass and load orientation, see Table 8.

Table 8 Statistical list of rock mass deformation modulus of rigid bearing plate

Decency degree	load orientation	river bank	data amount check	0～8MPa deformation modulus（GPa）		8MPa tangent modulus（GPa）	
				range value	Mean	range value	Mean
slightly weathering ~fresh	horizontal	left	3	22.31~31.99	26.18	23.02~27.36	24.65
	vertical		3	9.83~15.99	11.95	9.30~14.72	11.35
lower segment of weak weathering	horizontal	left	5	8.89~21.38	13.61	9.97~20.09	14.02
		right	4	13.59~31.35	24.68	13.93~34.12	24.23
	vertical	left	11	3.22~12.47	7.41	4.32~12.09	7.94
		right	5	9.47~12.75	12.57	11.76~16.00	13.02
upper segment of weak weathering	horizontal	left	5	10.02~18.93	13.36	10.10~18.58	12.88
		right	4	11.74~13.83	13.10	11.37~14.73	12.99
	vertical	left	9	4.47~13.49	7.13	4.45~14.73	8.11
		right	5	4.30~9.73	7.74	4.87~12.45	8.98

It can be seen from table that with the enhanced weathering degree,deformation modulus of rock mass were gradually decreased. On the horizontal direction the average deformation modulus were all above 13GPa. The average deformation modulus in plumb direction was in sequence of 7.0GPa.It can be seen comparatively from Left and right bank that deformation modulus of right bank rock mass is higher than left bank rock mass.

5.2.3 Experimental study of rock mass deformation modulus by borehole elastic modulus test

Experimental study of rock mass deformation modulus by borehole elastic modulus test has tested 121,See Table 9 for the result of the deformation modulus by calculating rock mass quality class.

Table 9 Statistical list of deformation modulus of rock mass by borehole elastic modulus test

rock mass category	project	horizontal		plumb		remarks
		deformation modulus Eo （GPa）	elastic modulus Ee （GPa）	deformation modulus Eo （GPa）	elastic modulus Ee （GPa）	
fresh	number	25	25	/	/	
	Max	18.16	30.90	/	/	
	Min	4.85	6.77	/	/	
	Mean	12.22	20.01	/	/	
lower segment of weak weathering	number	14	14	/	/	
	Max	24.75	46.31	/	/	
	Min	7.95	12.93	/	/	
	Mean	15.30	25.65	/	/	
upper segment of weak weathering	number	82	82	95	95	
	Max	23.13	40.20	22.36	36.60	
	Min	0.88	0.96	2.15	3.72	
	Mean	11.29	17.15	9.08	15.52	

It can be seen from table 9 that the deformation modulus of weak weathered rock mass is 12.22GPa, the deformation modulus of lower segment of weak weathered rock mass is 15.30GPa, and the deformation modulus of higher segment of weak weathered rock mass is 11.29GPa. Deformation modulus of rock mass ranged from lightly weathered to fresh is higher than that of lower segment of weak weathered rock mass, Deformation modulus of rock mass in horizontal direction is higher than that of horizontal direction, which suggest that rock mass have anisotropy.

6 CONCLUSION

The study comes to a conclusion as follows:

（1）Columnar joints at Baihetan dam site were formed as a result of the cooling and shrinkage effect of magma.

（2）Columnar jointed basalt easy microfissure ,submicrofissure,and it is filled with quartz and local tremolite vein, columnar joints basalt are mainly chlorite, kaolinite, epidote, tremolite chemical reactions and the content of columnar joints are mainly chlorite.

（3）The results from indoor physics experiment suggest that columnar joints basalt showed high uniaxial tension test, low coefficient of friction and high cohesion.

（4）The results from large-sized experiment, deformation experiment, and indoor “small rock mass” triaxial experiment suggest that columnar jointed rock mass showed higher tension and formation index,which can be directly used as dam foundation if enforced with strict discipline of operation rules and reduced disturbance.

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