Abstract: The scale and characteristics of rock mass are important indexes of the rock mass structural plane classification. This paper firstly analyzes the spatial distribution characteristics, the structural plane types (original structural plane, tectonic structural plane and hypergenic structural plane) and the associated features of the Emeishan basalts and then studies the classification schemes of the built hydropower structure planes of different rock areas (the east district, the central district and the west district) in the Emeishan basalt distribution area, Southwest China. Based on the analysis and comparison of the scale and the engineering geological characteristics of the typical structure planes in the basalt hydroelectric Stations, the types of structural planes are used in the first order classification. The secondary order classification is made by considering the impact factors of rock mass quality, e.g., the state of the structural planes, infilling, joint opening, extending length, the grade of weathering and strength. The engineering geological classification for Emeishan basalt is proposed. Because there are no evidences of a large structure presenting in study area, the first-order (I) controlling structural planes do not appear in the classification, there only appear II, III, IV and V grade structural planes influencing the rock-mass quality. According to the different rock-block types in bedding fault zone, the second-grade (II) structural planes consisted of bedding fault zone is further classified into II1, II2 and II3. The third-grade (III) structural planes constructed by intraformational faulted zones are not subdivided. According to the different characteristics of intrusion, alteration and weathering unloading structural planes, the IV grade structure plane is divided into IV1, IV2 and IV3. According to the development characteristics of joints and fractures, the V grade structure plane is divided into fracture V1 and columnar joint V2. In all, the structural planes are classified into four groups with nine subsets. The research proposes the engineering geological classification of the structural plane for the hydropower project in the Emeishan basalts, and the result of the study has a potential application in similar regions.

Keywords: Emeishan basalt; Hydroelectric project; Structural plane; Bedding fault zone; Engineering geological classification

Introduction

Due to its special engineering geological characteristics and narrow valleys of deep dissection (Shellnutt and Jahn 2011), the Emeishan basalt of widely distributed in the southwest of China has become one of the main targets for
bedrock foundation of hydroelectric station projects (Jason et al. 2004). When it is used as dam foundation rock mass, it is required to investigate the characteristics of its structural planes and the engineering geological classification prior to a hydroelectric station construction. There are a number of large hydroelectric stations that have been built or are being built on the Emeishan basalt as rock mass of dam foundations (Figure 1 and Appendix 1).

The previous studies on basalt structural planes are slim (Huang et al. 2004). They generally focus on the investigation, simulation analysis and statistical model building of the structural planes of other lithology rock mass (Hu 1995; Zhou 1998; Han and Nie 2004), more generally focused on the structure planes classification for a single hydroelectric station the classification results are only applicable to this station (Wei 2007). The studies of the basalt structure planes on the regional scale are insufficient. Furthermore, there is no systematic classification scheme. In order to investigate the distribution features and the structural plane characteristics of the Emeishan basalt, it seems particularly important to put forward a realistic reasonable engineering geological classification scheme of the structural planes of the Emeishan basalt.

1 Distribution of Emeishan Basalt

The Emeishan basalt is concentrated on the southwestern margin of the Yangtze platform and limited by fault zones in the form of a diamond along north-south axis. Among them, the large faults of the southwestern area (the Hong River fault zone) and the northwestern area (the Xiaojing -Longmenshan Fault Zone) are connected with the Sanjiang faults. According to the temporal and spatial variations of the regularity of the magmatic eruptive phase and basalts assemblage series, the basalt area is divided into three regions: the east rock area (Guizhou plateau) is the basalt area to the east of Xiaojiang fault zone, which is distributed in Yunnan, Guizhou and Sichuan provinces; the central rock area is the Panxi rock zone; the west rock zone (Yanyuan-Lijiang rock area) (Lin 1985) is the widely distributed and uplifted basalt district between the Jinghe-Chenghai fault and Xiaojing fault zone (Figure 2).

The Emeishan basalt has a distribution length of more than 1000 km from north to south, with a width of more than 900 km from east to west. An estimate based on the figure of the basalt thickness changes (Zhang et al. 1988) suggests that the total volume of the basalt is over $30\times10^4$ km$^3$, covering an area of $50\times10^4$ km$^2$. From west to east, its thickness and rock geochemical characteristics show regular changes. For example, the basaltic layer thickness is 5000 m in
Yunnan Bingchuan-Shangcang (West Rock Area), and extending to the east the thickness is from several tens to hundreds of meters in eastern Guizhou territory (Lin 1985). These reflect the features of thick south-west and thin north-east (Appendix 2). This is because the Guizhou plateau area (the east rock area) and Panxi rock area (the central rock area) formed on the Yangtze platform, where the crust is relatively thick, especially in the Panxi area (the central rock area). This central rock area is located in the old Kang Dian axis, with very complex and special tectonic background (Thompson et al. 2001). The Yanyuan-Lijiang rock area (the west rock area) formed on the western margin of the Yangtze plate, and the crust is thin.

In the study area, the Baihetan and Xiluodu hydroelectric stations on the Jinsha River and the Tongjiезi hydroelectric station on Dadu River are located in the east rock area. The Értan hydroelectric station on the Yalong River is located in the central rock area. The Guandi hydroelectric station on Yalong River, Longkaikou hydroelectric station, Jinanqiao hydroelectric station and Tiger Leaping Gorge hydroelectric station on the Jinsha River are located in the west rock area (Figure 1).

2 Engineering Geological Characteristics of Emeishan Basalt Structural Planes

2.1 Classification of structural planes

Structural planes refer to the geological interfaces (or belt) in a rock mass with certain directions (or thickness), relatively low mechanical strength, and the extension to two opposite directions, such as strata level, weak interlayer, and fractures, fissure, and joint plane, etc. with different origins (Richard et al. 2013; Zhang et al. 2009), all of which are the results of long-term internal and external dynamic geological processes (Peng et al. 2004; Dearman et al. 1978).

According to the origin, the structural planes can be classified as the primary structural plane, the tectonic structural plane and hypergenic structural plane (Knill and Jones 1965) (Table 1). On the basis of the mechanic characteristics of rock mass, the structural planes can be divided into four types: fracture structural plane, crushing structural plane, laminated structural plane and mudded structural plane (Sun and Sun 1997; Zhang et al. 2000).

2.1.1 The primary structural planes of basalt

The primary structural planes are the structural planes formed during the process of magma intrusion and condensation, which not only let basalt show stratoid structure and anisotropy, provide the basis for the weakening of rock mass quality and mechanical properties, but also are used by the later tectonic action and epigenetic reformation (Li and Yang 1994). The main types
<table>
<thead>
<tr>
<th>Genetic classification</th>
<th>Geological types</th>
<th>Types of structural planes</th>
<th>Major characteristics</th>
<th>Properties</th>
<th>Engineering geological evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The original structural planes</td>
<td>Interface between intrusions and surrounding area</td>
<td>Intrusion structural planes</td>
<td>Shows different properties of fusion and rupture, with rough and tensile fracture as the original joint interface</td>
<td></td>
<td>Combined with structural fault, rock mass slip can be formed.</td>
</tr>
<tr>
<td></td>
<td>Original condensing joint</td>
<td>Columnar joint, pillow structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Interface caused by volcanic eruption</td>
<td>Tuff interlayer, sedimentary layer, volcano breccia agglomerate interlayer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intermittent Interface formed by alteration</td>
<td>Alteration structural plane</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The tectonic structural planes</td>
<td>The plane is with joint and fault, pinnate fracture and fracture Cleavage</td>
<td>Intraformational faulted zone; Bedding fault zone</td>
<td>Short tensile fracture, far-extended torsion fault, with large scale of compressive fracture, but sometimes showing discontinuous distribution sheared by fault.</td>
<td>Uneven tensile fracture with secondary filling, strait torsion fault with pinnate fracture, belt-distributed compressive fracture often with fault gouge, mylonite.</td>
<td>Greatly impact on the stability of the rock mass. It often causes collapse of side slope and underground engineering.</td>
</tr>
<tr>
<td>The Hypergenic structural planes</td>
<td>Weathering, unloading crack; Muddled intercalation; Secondary mud.</td>
<td>Intraformational faulted zone</td>
<td>Determined by space and position of the fossil erosion surface and lateral surface. Mainly developed in the surface unloading and weathering zone.</td>
<td>Medium and gentle twisting faults, bedding fault zone, sliding surface, generally with mud filling.</td>
<td>Cause rock mass deformation and failure, induce geological disasters, also have an important influence on the dam foundation, dam abutment and shallow-buried tunnel.</td>
</tr>
</tbody>
</table>
are shown in Table 1.

2.1.2 The tectonic structural planes of basalt

The tectonic structural planes are the intra-formational faulted zone and bedding fault zone, which form because of tectonic action makes the rock mass shear dislocation along early primary structural plane, the joint, and fracture surface (Zhang et al. 2009). Because of the large number and wide distribution of the intra-formational faulted zones and bedding fault zones in the basalt dam, greatly affected the integrity of the rock mass, controlled the engineering geological characteristics of the rock mass. This is one of the controlling boundary conditions for the engineering geological problem.

2.1.3 The hypergenic structural planes of basalt

The hypergenic structural planes are the deformation rupture structures of the rock mass caused by stress field redistribution due to the cutting and unloading of the river valley. The structural planes presented as the change of the material composition and structure of the original structure plane, variation of engineering geological properties, and the appearing of micro fissures.

2.2 Engineering geological characteristics of typical structural planes

The tectonic conditions, eruption mode and eruption environment of the basalt all impact the rock mass material composition and structure. These conditions will not only change the rock type and the structure form, but also result in different structural planes, and make differences between the rock mass quality and the engineering characters in different rock zones.

2.2.1 Bedding fault zone

The strength of a bedding fault zone structural plane is controlled by the tectonite composition or interlayer bonding strength in interlayer structure. A bedding fault zone is the controlling boundary of rock mass stability for the dam abutment and dam foundation of hydroelectric stations. The typical representatives are the Baihetan, the Dadu River Hydropower and the Xiluodu Hydropower Station.

(1) Bedding fault zone formed with the tuff interlayer

The Baihetan hydroelectric station basalt develops 11 layers of the bedding fault zones which are composed of the tuffaceous (rock) interlayers (designated as II grade structural plane) with gentle dip angles throughout the whole dam area. They are mainly located among the middle and low dense basalt. These interlayers are easily broken. The tuffaceous rock is abnormally sensitive to water. The clay mineral of the sliding layer mainly is a mixture of illite and montmorillonite. The rock mass easily slides along the bedding fault zones after filling water, thereby, reducing the structural plane strength of the interlayers and influencing the rock mass strength of the dam area. The classification results of the weak structural planes are shown in Appendix 3.

(2) Bedding fault zone formed with sedimentary interlayer

At the Dadu River Tongjiezi hydroelectric station of the east rock district, the bedding fault zone consists of the sedimentary interlayers (II grade) formed by pyroclastic rocks etc. The interlayer has good continuity and is consistent with the attitude of rock stratum, distributing over the whole dam foundation. The Emeishan basalt exposed from the dam foundation has five eruption cycles. Each cycle bottom piles up a layer of sedimentary interlayer. Due to the tectonic compression, later structural damage, and groundwater physical and chemical reactions, these interlayers form the bedding fault zone which has a strong control on the stability of the dam foundation (in Appendix 4, C4, C5).

(3) Bedding faulted zone formed with breccia agglomerate interlayer

The Xiluodu hydroelectric station in the east rock area has 14 rock flow layers (P2β1-P2β14). The bedding faulted zone constituted by the interlayers of volcano breccia agglomerate has developed in each surface of the rock flow layers. The bedding faulted zone formed with breccia agglomerate (which mostly are basalt breccia, fragment, partly fractured rocks with small amount of debris) has a thickness of 5-10 cm. The interlayers have a flat type along the bedding joint with stable extension.
and a zone cleft type showing dense zonal extension, big thickness and fluctuation.

The occurrence of the bedding fault zone is nearly consistent with the rock flow layers. The structural planes are divided into both rigid structure (without filling, discontinuous distributed shallow seam) and weak structural plane (filling, with discontinuous or linear distributed concave rock). The rigid structural plane is mainly steep dip fissure, with high strength. The rock mass of the structural plane on both sides is fresh and intact and has no filling and close combination.

2.2.2 Intraformational faulted zones

Intraformational faulted zone (the fillers are mainly debris, no mud and clay minerals (Richards et al. 1989)) affects the stability of the rock mass of the dam foundation, dam abutment, cavern, slopes and so on in large range or local area (Chung and Jahn, 1988) and plays as controlling sliding surface. Compared to the bedding fault zone, the distribution of the intraformational faulted zone is random and complicated. In each rock flow layer, more or less, there are intraformational faulted zones (Ju, 2001). The typical representatives are the Baihetan and the Xiluodu Hydropower Station.

(1) Engineering geological characteristics of intraformational faulted zones in the Baihetan hydroelectric station

The intraformational faulted zones in the Baihetan hydroelectric station (the III grade structural plane) have relatively small scale compared with the structural planes of the bedding fault zone and controlling faults. However, because of its wide distribution, large amount, and poor property, it has a certain controlling effect on the rock stability of the dam abutment. Eleven lithologic members have developed in the research area. Each lithologic member constitute a small cycles. The junction of two small cycles represents a short eruption intermittent, constituting a weak structural plane. After the later tectonic dislocation or epigenetic reformation, it forms intraformational faulted zone. From its generation position, it can be seen that the intraformational faulted zone is relatively concentrated. The mechanical property is different from the brittle dense basalt and the plastic basalt of other types.

The intraformational faulted zones are mainly developed in the brittle basalt. The unloading or tectonic effects cause tensile crack, the cracks become the mediated water space. On the slope superficial part, the expansion region often becomes exposed channel for groundwater, showing as moist seepage (Figure 3(a)), and even like femoral appearance seepage (Figure 3(b)).

(2) Engineering geological characteristics of the Xiluodu hydroelectric station intraformational faulted zones

The intraformational faulted zones of the Xiluodu hydroelectric station are mainly the tectonite zone formed by breakage and deformation. The width, material composition and characteristics of the intraformational faulted zone are basically the same as the bedding faulted zone. The scale is smaller but the number is larger. The intraformational faulted zone has uneven length, generally 10-30 m, but the long one exceeds 100 m. It is randomly distributed (Appendix 5). Therefore, it is one of the controlling boundaries of the

Figure 3 Xiluodu hydroelectric station intraformational faulted zones. (In red line: intraformational faulted zones; in yellow line: femoral seepage)

(a) Moist seepage of the downstream wall located at the horizontal depth 12m of PD33 adit

(b) Femoral seepage of the intraformational faulted zone in PD61 adit
At the Xiluodu hydroelectric station, a limited number of the intraformational faulted zones develop in partial sections of volcano breccia. The vast majority of the intraformational faulted zones develop within the dense basalt in the lower part of each rock layer. Its distribution features can be explained by the following three points. Firstly, the development of the intraformational faulted zones is relatively concentrated. Secondly, the lithology (it actually is the original structure – layer joints) controls the development of the intraformational faulted zones, because it is easy for rock layers with relative uniformity structure, composition and relatively high heat to form layer joints. Thirdly, the intraformational faulted zones of the dam area mostly develop along the original joints and the bedding plane structures. The investigation finds that the faulted zones in this area are caused by shearing due to the Majiahe Dam fault extrusion and superposed folds. It reveals that the tectonic deformation (stress) is an important factor influencing faulted zones development in dam area (Qin 2003).

2.2.3 Alteration structural plane

The alteration structural plane in the area of the Jin’anqiao hydroelectric station dam is composed of epidote, chlorite, quartz vein fault zone. The structural plane has a width of 3~60 m, and a length of 18~116 m, strong alteration. It is mainly distributed in the cracks of the basalt, with debris and mud filling, substantially parallel to the approximate rock plane of the tuff. Therefore, its mechanical properties are poorer than the basalt of the dam area (Wang 2005).

The structural plane is divided into two categories. One type is smooth and straight or slightly undulating without filling rigid epidote, chlorite, and quartz faulted surface. This faulted zone type is basically closed (Figure 4(a)). Another type is the faulted plane with the pieces of epidote, chlorite, and quartz vein due to extrusion and slippage (Figure 4(b)) or the faulted plane open, filled with mud and cuttings (Figure 4(c)).

3 Engineering Geological Classification of Emeishan Basalt Structural Planes

The structural planes of basalts are mainly composed of faults, intraformational faulted zone, bedding faulted zone, extrusion belt, rock fracture and columnar joints, pillow structure. The faults, the intraformational faulted zone and bedding faulted zone constitute the framework of the macro structure of the engineering rock mass. The rock fracture and columnar joints, etc. affect the local structure and integrity of the rock mass (Jin and Yang 2007). Under the engineering loading effect, the scale and characteristics of the rock mass affect the stability of the rock mass and their mechanical effect. In the engineering geological classification of the structural plane, people mainly consider the two indexes (Lan 2009). The size of the structural plane directly affects its controlling range of the rock mass stability. Therefore, the grading of the structural plane can be firstly according to the scale. The properties of the structural plane (For example, the state of structural plane, filler, joint opening, extension length and grade of weathering and so on) have direct influences on the quality score of the rock mass, and are the secondary level factors that are considered in the classification level of the rock mass.

3.1 Engineering geological classification of the basalt structural plane

This study summarizes and analyzes the scale, nature, engineering geological significance and characteristics of the typical hydroelectric station’s basalt structural planes. Then proposed the engineering geological classification scheme of the structural planes of the Emeishan basalt.

(1) Classification of the rock mass structural planes for the Xiluodu hydroelectric station

Based on types of the structural planes in hydroelectric stations dam the structural planes will be divided into 4 categories. Each category is divided into different sub-categories according to the size and different engineering geological characteristics. Therefore, there are 4 categories and 8 sub-categories (Deere et al. 1969; Huang and Hu 1997) (Appendix 6).

(2) Classification of the rock mass structural plane of the Tongjiezi hydroelectric station

The structural planes of the hydroelectric
station dam foundation are mainly the faults and the dislocation interfaces. The structure planes are divided into four grades according to the size, characteristics, and mechanical properties (Gu 1979; Wang et al. 1996) (Appendix 7).

(3) Rock mass structural planes classification of the Guandi hydroelectric station

As there is no regional fault (the I-grade) found in the dam area, the rock mass structural planes of the hydroelectric station are divided into II, III, IV, V grades according to the size and general characteristics (Wang et al. 1997) (see Appendix 8).

(4) Classification of the rock mass structural planes of the Longkaikou hydroelectric station

The most important control factors of the hydroelectric station dam rock deformation failure are: the scale and the properties of the rock mass structural planes development. So the rock mass structural planes are classified as four first-grade structural planes and seven second-grade structural planes (Xu et al. 2005) (see Appendix 9).

(5) The classification of structural planes of the Baihetan hydroelectric station rock mass

The structural planes of the hydroelectric station dam area are mainly composed of faults, bedding faulted zone, intraformational faulted zone, extrusion belt, fracture and columnar joints. The faults, bedding faulted zone, and intraformational faulted zone (the II, III, IV grades structural planes) constitute the basic framework of the rock mass structure in dam area, and the basal joints and the columnar joint (V-grade structural plane) in the rock mass control the integrity of partial rock mass. Therefore, the dam structural planes are classified into five grades and 10 sub-grades (Appendix 10).

3.2 Engineering geological classification scheme of Emeishan basalt structural plane
Through the above analysis, it is evident that
(1) The bedding faulted zones are not only the
main structure planes, but also the controlling
boundaries of the rock mass stability for dam areas
(dam abutments, dam foundations). (2) The
intraformational faulted zones are stable
boundaries of part and large scope of the rock mass.
The influence of primary fractures or structural
cracks on the rock mass quality is mainly
determined by the connectivity rate of fractures.
Comparing with the bedding faulted zone, the
effect of the intraformational faulted zones is
relatively weak.
(3) The strong weathered layers have the weak
properties, and only develop in the internal layers.
When their thickness are more large, they can
bring about the non-uniformity partially
deformation of the rock mass, which can affect the
local rock mass quality.
(4) The paleo-weathering layers are distributed
above the crest of the dams, with small range and
scale, only influencing the rock mass near the
surface.
(5) The columnar joints are the original structure
of the basalt. They make the basalt show
anisotropic and stratiform-like structure, are used
by later tectonic action and epigenetic reformation,
and impact the integrity of rock mass (Zhang et al.
2009).

According to the engineering geological
classification results of the structural planes above
five hydroelectric stations, considering the main
controlling factors of the structural plane
classification, scale and properties, the structural
planes of the Emeishan basalt are classified into
four categories and nine sub categories (Figure 5,
Table 2). Because there are no large regional
structure in the study area, so there are no 1-grade
controlling structural plane.

4 Conclusions

The type, scale and distribution characteristics
of the structure planes are the important factors in
the rock mass stability of hydroelectric station dam
foundation. The engineering geological
classification of the structural planes of the five
hydropower stations (basalt as a foundation rock)
on the Jinsha River, Dadu River and Yalong River
is established on the basis of engineering practice,
and has been tested by practical work. This
research is based on the results of this research on
expanded. By studying the engineering geological
characteristics of the typical structural planes of
each project, proposed the engineering geology
classification of the Emeishan basalt structural
planes for hydropower project, divided into four
categories and the nine subclasses. The research
has a certain guiding significance for the
development of hydroelectric engineering projects
of the Emeishan basalt area in the later period. At
the same time, the research on the distribution
characteristics and structural planes properties of
the Emeishan basalt in Southwest China can
provide some help for the production and
construction of the residents living in this area.
As the Emeishan basalt wide distribution and due
to the time and financial constraints, this work can
only cover a few of typical hydroelectric stations
built on the Emeishan basalt in the southwest of
China. Future studies are required to include all
the other remaining hydroelectric stations.
<table>
<thead>
<tr>
<th>Level Type</th>
<th>Sub-type</th>
<th>Geological type</th>
<th>Classification basis</th>
<th>Engineering significance</th>
<th>Engineering geological characteristics</th>
<th>Typical structural planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>II1</td>
<td>Bedding faulted zone formed in tuff interlayer</td>
<td>Developed in between layers of rock flow, low angle stably extending throughout the whole dam.</td>
<td>Fillings are debris with mud, mud with debris, and rock block with debris. In sliding layers, clay minerals are mixture of illite and montmorillonite (55%), which are easily slide filling with water.</td>
<td>Controlling boundary of the rock mass stability of dam area (dam abutment and dam foundation), controlling evolution direction of rock mass deformation and destroying.</td>
<td>The structure dislocation of rock flow layer interface is weaker, keeping tuff original construction, the properties and strength of rock mass are greatly influenced by weathering, unloading and groundwater.</td>
<td>C1-C20</td>
</tr>
<tr>
<td>II2</td>
<td>Intraformational faulted zone formed in deposition interlayer</td>
<td>With good continuity, the planes are consistent with the attitude of rock, running throughout the whole dam foundation, fracture zone with thickness of 0.3-0.4 m. Deposits of Asanuma and lake, composing of tuff and elastic rock, mainly mineral kaolinite, partly chlorite.</td>
<td>Tectonic rocks developed basal rock flow layers, the planes are II grade structural planes with the strongest controlling effect on the stability of dam foundation.</td>
<td>Low anti-shearing strength, running throughout the whole dam foundation, with fully developed tectonic rocks, large clay content, continuous and intermittent faulted mud layer.</td>
<td>C5</td>
<td></td>
</tr>
<tr>
<td>II3</td>
<td>Bedding faulted zone formed in breccia agglomerate layer</td>
<td>Generally with 5-10cm thickness, near-surface thickness up to 20-30 cm, fractured rocks as upper and lower influencing belt, with maximum width of 0.4-0.6 m. 0.5-3 cm diameter basaltic breccia, fragments, partly diameter &gt;6cm fractured rock masses, with minor 1-2cm cuttings, little mud, squeezed tightly in unloading zone.</td>
<td>The main forms are straight type and zone cleft type. The straight type, developing along the straight section of bedding plane structure, extends stable. Zone cleft type, developing along the bedding plane structure and X joint form the dense belts of bedding faulted zone, with large thickness and unstable attitude. A single fault zone is small in scale, with large fluctuation.</td>
<td>More crude particulate matter, &gt;0.075 mm particle content &gt;95% (70%-80% of 2-5mm fine breccia, approximately 20% of 0.075-2 mm debris content), with strong permeability, piping failure. Particles mainly are breccia mass, and with compact structure.</td>
<td>C1,C5,C7,C9,C12</td>
<td></td>
</tr>
</tbody>
</table>

(To be continued-)
### Table 2: Classification of typical structural planes of Emeishan basalt

<table>
<thead>
<tr>
<th>Level Type</th>
<th>Sub-type</th>
<th>Geological Type</th>
<th>Classification basis</th>
<th>Engineering significance</th>
<th>Engineering geological characteristics</th>
<th>Typical structural planes</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td></td>
<td>Intraformational faulted zone</td>
<td>Developing in lower part of rock flow layers, with gentle angle, extending 5-100m, with thickness of 0.5-10 cm.</td>
<td>The planes are further structural dislocation product of original fractures or fracture, with greatly varied properties, ranging from (with) lithic lapilli, fractured rock block (quartz epidote belt) and fracture scrape, etc.</td>
<td>Tectonic fault zone is relatively weak, of the fault zone material is rock block and cuttings.</td>
<td>PD39-Lc8-1/1, PD36-Lc8</td>
</tr>
<tr>
<td>IV$_1$</td>
<td></td>
<td>Extrusion structural plane</td>
<td>The spatial distribution is very irregular, with maximum width of 10-15 m.</td>
<td>Because of syenite intrusion, the structural planes are formed after basalt suffers crushing and hydrothermal alteration.</td>
<td>Uneven rock alteration, with gradual transition with surrounding rock and no obvious interface.</td>
<td>Tightly compressed structure plane, with rock mass of block and cataclastic structure, filling of a lot of soft metamorphic mineral. Containing in soft mineral tale, chlorite, and montmorillonite in cracks, which decrease rock mechanical strength.</td>
</tr>
<tr>
<td>IV$_2$</td>
<td></td>
<td>Alteration structural plane</td>
<td>General thickness of 2-65 cm</td>
<td>With strong rock alteration, fibrous crystalloplastic or fibrous blastoporphyritic structure.</td>
<td>Uralization basalt rock mass is with cataclastic structure, and extremely poor integrity.</td>
<td>P$_{a\beta}$. III</td>
</tr>
<tr>
<td>IV$_3$</td>
<td></td>
<td>Weathering and unloading zone</td>
<td>Developed in the rock flow layers, running through the whole dam are. The fractured rigid structural planes developed in dam are with random distribution, intermittent extension, and extension length &lt;10 m.</td>
<td>Distributed in rock flow roof, thickness of 2-3m, containing clay mineral, which is easily collapsed with water. Steep cracks are straight and smooth, while gentle cracks are straight and rough or rough and fluctuated. Distribution of a nonuniformity, and steep and gentle cracks often with alternating.</td>
<td>Located above the crest, having an effect on some ancillary buildings, with poor properties near the surface.</td>
<td>C$_{n\beta\top}$</td>
</tr>
<tr>
<td>V$_1$</td>
<td></td>
<td>Fracture</td>
<td>With 25-40 cm column diameter, &lt;4.0 m length.</td>
<td>Columnar joints are with uneven development, and different column size and length. The columns make basalt reveal as layer-like structure and anisotropy, which are combined with later tectonic action and epigenetic reformation to impact rock mass integrity.</td>
<td>The rock masses are cut into regular polygonal column, which are perpendicular to the lava layer.</td>
<td>P$<em>{a\beta}$.33, P$</em>{a\beta}$.34</td>
</tr>
<tr>
<td>V$_2$</td>
<td></td>
<td>Columnar joints</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Acknowledgments

This study is funded by the National Natural Science Foundation of China (Grant No. 41072228). The authors thank LU Guo-ping, ZHANG Cheng-jiang, WU Meng-qiu, GOU Cong, and YUAN Guang and two anonymous reviewers for constructive discussions and comments on earlier versions of this manuscript.

Electronic Supplementary Material: Supplementary materials (Appendices 1 to 10) are available in the online version of this article at http://doi.org/10.1007/s11629-014-3244-5.

References

Lan CY (2009) Study on causes of the dislocation interface and engineering characteristics of the dam of Balheitan hydroelectric power station, Jinsha River. MS Thesis, Chengdu University of Technology, Chengdu, China. (In Chinese)
Qi LM (2001) The structural features of the dislocation interface around the dam of the Jinsha River Xiluodu hydroelectric power station and it's engineering affects. MS Thesis, Chengdu University of Technology, Chengdu, China. (In Chinese)