Distinct element analysis for regional tectonic stress fields at Baihetan Power Station, China

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Abstract: Baihetan Hydro-electrical Power Station, which has a 275 m dam height and 12,000 MW installed capacity, is one of the largest plants in southwest China, and is planned to be built on the lower reaches of the Jinsha River near Xichang city, Sichuan Province.

On the based of analysis and measurement of regional tectonic stresses, this paper describes the simulation of the value and direction of the regional tectonic stress field surrounding the Baihetan hydroelectric station by using systematic numerical modelling of the distinct element method with UDEC code. In situ stress measurement results indicated that both magnitude and orientation of stress vary greatly. It is thought that these variations are related to the development of fractures. The results show that the activities of the fractures change from place to place under the current regional stress field. Based on the analysis and simulated regional tectonic stress, the maximum principal stress is 15.0~18.0 MPa, and the direction is N70°W. The results also show that both magnitude and orientation of stress change in the vicinity of fractured zones coincide well with the measured result. The principal stress reorientates near the fractured zone and the reoriented angle depends on the angle between fractured zone and the direction of the boundary stress. The result provided quantitative data for the evaluation of the regional tectonic stability of the hydropower station.

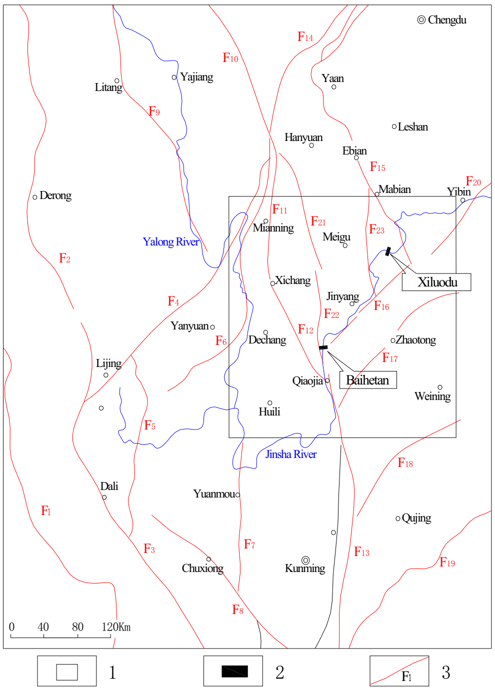
Résumé: La centrale hydraulique Baihetan comptant construit localise aux environs de la ville Xichang de la Province Sichuan en aval du fleuve Jinsha. La hauteur du barrage est de 275m. La capacité installée est de 12 000MW. Elle est une des grandes centrales hydrauliques du sud-ouest du pays.

D'après l'analyse de la caractère de structure de champs de contrainte de la zone de centrale hydraulique et synthétisant une partie des dossiers de contrainte de la mesure pratique in situ utilisant la méthode de simulation de la valeur d'élement séparé pour analyser la grandeur et la direction de champs de contrainte de cette zone et la faille faisant de l'effet le champs de contrainte. Selon le résultat de simulation, on a obtnu la variation distincte de la valeur et de la direction de la contrainte de terre aux environs de la faille. Il coincide avec le résultat de mesure pratique. D'après l'analyse et la simulation, la valeur maximum de la contrainte principale de cette zone est de 15.0-18.0Mpa. La direction est de N70ºW. Ce résultat donne des données d'analyse dimensionnelle pour l'évaluation de la stabilité dans la zone de centrale hydraulique. Et aussi, la méthode d'élement séparé est un moyen effectif pour simuler le camps de contrainte au zone du développemnt de failleux.

Keywords: Hydro-electrical power station, regional tectonic stress field, distinct element method, numerical simulation ,fractured zone, Jinsha River

INTRODUCTION

Baihetan Hydro-electrical Power Station, which has a 275 m dam height and 12,000 MW installed capacity, is one of the largest plants in southwest China, and is planned to be built on the lower reaches of the Jinsha River near Xichang city, Sichuan Province. This region is located in the combining site of the SW borderland in Yangzi platform and the SE borderland in Qinghai-Tibet plateau. The controlling trunk fractures in region mostly include as follows: the nearly SN strike Xianshuihe - Xiaojiang fracture (including Anninghe fracture and Liangshan fracture) that composes the SN strike tectonic zone in Sichuan - Yunnan fracture, the NE strike Longmenshan fracture and the Western Jinhe - Qinghe fracture. The sub-first structure includes the NNW striking Zemuhe fracture, the NE striking Lianfeng - Huayingshan fracture and the SN strike Ebian - Jinyang fracture. Baihetan Hydropower Station is located in the wedge-shaped block of these fractures shown in Figure 1.



Legend: 1) Region of the study, 2) Hydropower Station of arranged build, 3) the main fracture and the number.
The main fractures: F_1 Lancangjiang fracture, F_2 Jinshajiang fracture, F_3 Honghe fracture, F_4 Lijiang fracture, F_5 Chenghai-Binjiang fracture, F_6 Jinhe-Qinghe fracture, F_7 Yuanmou fracture, F_8 Qujiang fracture, F_9 Litang fracture, F_{10} Xianshuihe fracture, F_{11} Anninghe fracture, F_{12} Zemuhe fracture, F_{13} Xiaojiang fracture, F_{14} Longmenshan fracture, F_{15} Mabian fracture, F_{16} Lianfeng fracture, F_{17} Zhaotong fracture, F_{18} Xuanwei fracture, F_{19} Mile fracture, F_{20} Huayingshan fracture, F_{21} Lianshan fracture, F_{22} Sikai fracture, F_{23} Ebian-Jinyang fracture.

Figure 1. Sketching map of geological structure

THE CHARACTERISTICS OF REGIONAL TECTONIC STRESS FIELD

Under the influence of the regional tectonism, the research data indicate that the regional tectonic stress field has the following characteristics:

(1) The regional tectonic stress field inherits basically the stress field characteristics of the late period of Himalayan tectonic movement and forms the stress field which principal compressive stress is NWW-SEE strike.

(2) Xiluodu Hydropower Station, which located in same tectonic element with the zones of study, is measured multi-group terrestrial stress. The deepness of measure is great, which eliminate basically the influence of landform. Based on the relevant data by measuring the terrestrial stress, the maximum principal stress is 17 - 20MPa, and the direction is NWW, which may give the basic value of stress in this zone.

DISTINCT ELEMENT METHOD ANALYSIS FOR REGIONAL TECTONIC STRESS FIELD

The collectivity regularity of the regional tectonic stress field is produced which may based on investigating the newly activity characteristics of fractures, fault plane solution of focal mechanism and the measured terrestrial stress. But, for the sake of quantitative reflecting the regional tectonic stress field, determining the stress concentration position and assessing the regional stability, using the distinct element method, the regional tectonic stress field is simulated and analysed as follow.

Summarize of distinct element method

The distinct element method has progressed for a period of over 20 years, beginning with the initial presentation by Cundall (1971). This method simulates the response of discontinuous media (such as a jointed rock mass). In the early, numerical program of the distinct element method, the blocks behave as rigid, so this method is restricted in simulating the stress field. Later, with the advancements of numerical program, the blocks behave as either rigid or deformable material. Consequently, the stress field may be simulated by the distinct element method. The Universal Distinct Element Code (UDEC) is a two-dimensional numerical program based on the distinct element method, which developed by Itasca and used in this paper. In UDEC, the discontinuous medium is represented as an assemblage of discrete blocks and the discontinuities are treated as boundary conditions between blocks. Individual blocks that represented as rock mass, behave as either rigid or deformable material.

Computing model

Range of the model

The size of model range is the important factor of influence the rationality and precision of computation. So when confirmed the model range, the range give prominence to the subject investigated, as well as farthest include the geological factor that obviously influence the subject investigated. Based on mention, this model range centre on Bahetan power station, which periphery include that of nearly SN strike Anninghe fracture (F_{11}), Xiaojiang fracture (F_{13}), Liangshan fracture (F_{21}), Sikai fracture (F_{22}) and Ebian-Jiangyang fracture (F_{23}), that of NNW strike Zemuhe fracture (F_{12}) and Mabian (F_{15}), that of NE strike Lianfeng fracture (F_{16}) and Zhaotong fracture (F_{17}), which show in Figure 2.

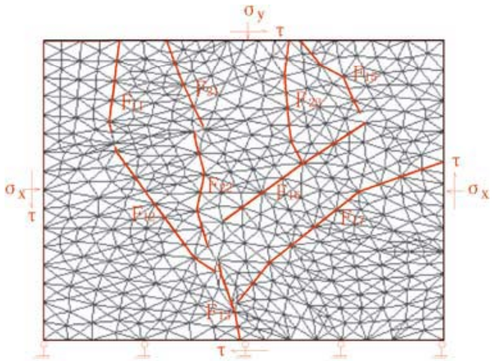


Figure 2. Computation model and boundary conditions

Boundary conditions

The measuring result of terrestrial stress in Xiluodu Hydropower Station indicate that the maximum principal stress is 17 - 20MPa , and the direction is NWW, which is consistent with the regional tectonic stress field direction – NNW strike, which is the result of the fault plane solution of focal mechanism and the research of regional neotectonic movement. Based on above, the boundary conditions are given in Figure 2 which shows that the south boundary is fixed in single direction.

Model structure and calculation parameters

Based on geological conditions, a distinct element model is built in Figure 2. The model material include intact rock mass and fracture zone. The intact rock mass divides into magmatic rock and sedimentary rock. The fracture zone separates into four types based on activity level and scope. The calculating parameters of mode are listed in table 1, which are comprehensive results of both lab test and the research data of other power station.

Table 1. Mechanics parameters of the model

Material types		Elastic ratio E (MPa)	Poisson's ratio	Cohesion force C (MPa)	Internal friction angle φ (°)	Density of rock p (g/cm3)
fracture	F_{11},F_{12},F_{13}	20000	0.26	0.7	28	
	F_{21},F_{22}	22000	0.25	0.8	30	
	F_{16},F_{17}	24000	0.25	0.9	32	
	F_{15},F_{23}	26000	0.25	1.0	34	
magmatic rock		42000	0.21	5.0	45	2.65
sedimentary rock		35000	0.23	3.0	40	2.50

Simulating results analysis

Characteristics of the maximum principal stress (σ_1)

The maximum principal stresses are given in Figure 3, which shows that the direction is N70°W and coincide well with the regional tectonic stress field direction on the whole. The principal stress reorientates near the fractured zone and the reoriented angle depends on the angle between fractured zone and the direction of the boundary stress.

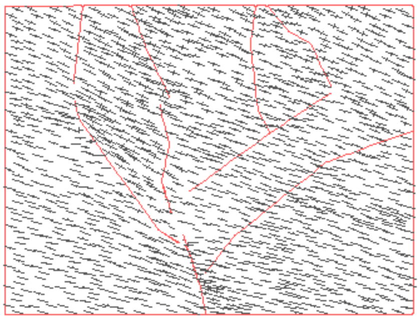


Figure 3. Orientation of maximum principle stress

The simulating results are presented in Figure 4, which shows that the maximum principal stress is 15 - 18MPa, which coincide with the measured result in table 2 and accord with the basic characteristics of the regional tectonic stress field. There is different concentration of the maximum principal stress distributing the intersection of Anninghe fracture, Zemuhe fracture and Xiaojiang fracture.

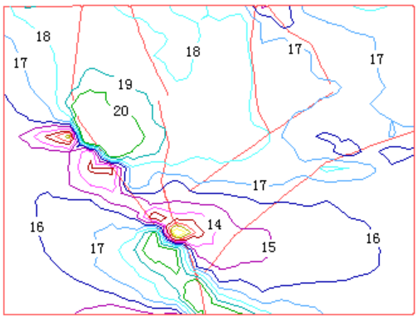


Figure 4. Contour of maximum principal stress

Table 2. The correlation between analysis and measured results of σ_1

Position	The orientation of σ_1		The magnitude of σ_1 (MPa)	
	Computation	Measurement	Computation	Measurement
Xiluodu power station	N70°W	N63.7°- 70.4°W	17.6	14.74 - 21.06
Baihetan power station	N72°W	N68°- 74°W	15.5	13.4 - 20.4

Characteristics of the minimum principal stress (σ_3)

The minimum principal stress is presented in Figure 5, which shows that the magnitude is 6 - 8MPa in the north and 2 - 4MPa in the south. There is different concentration of compressive stress distributing in the end of every fractures and especially in the intersection of Anninghe fracture and Zemuhe fracture.

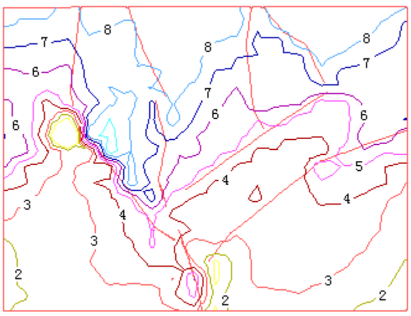


Figure 5. Contour of minimum principal stress

Characteristics of the maximum shearing stress (τ_{max})

The distribution features of the maximum shearing stress are similar to σ_1 and shown in Figure 6. There is different stress concentration distributing in the intersection of Anninghe fracture, Zemuhe fracture and Xiaojiang fracture.

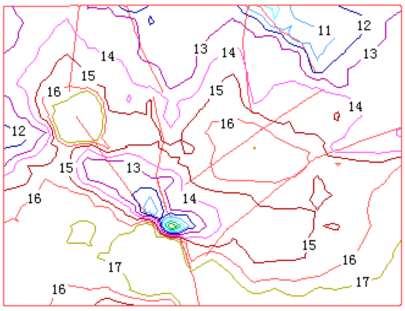


Figure 6. Contour of maximum shearing stress

CONCLUSIONS

Based on the analysis and computation above-mentioned, the following initial conclusions may be drawn:

(1) The maximum principal stress is 15 - 18 MPa, and the direction is N70°W, which coincide with the regional tectonic stress field and the measured result.

(2) The results also show that both magnitude and orientation of stress change in the vicinity and the intersection of fractured zones.

(3) The results presented the characteristics of the regional tectonic stress field and provided quantitative data for the evaluation of the regional tectonic stability of the hydropower station.

(4) The results of this paper indicate that the distinct element method is an effective numerical simulation method on simulating the regional tectonic stress field.

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