FAILURE ANALYSIS OF CONCRETE GRAVITY DAM BASED ON INTERFACE ELEMENT METHOD OF DISCONTINUOUS MECHANICS

Qing Zhang* a), Kang Xu**
* State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University Nanjing, 210098, China
**Department of Engineering Mechanics,Hohai University,, Nanjing,210098, China

Summary Based on the interface element method of discontinuous mechanics, this paper has proposed a computing model, and suggested a corresponding numerical analysis method for failure analysis of concrete dam.The computational results show that the model can naturally describe discontinuous deformation of rock mass. Besides, this method is characterized by good adaptability, calculation conveniently and high compatibility, thus being regarded as an effective way to make an failure analysis of concrete dam

INTRUDUCTION

The stability and safety of a gravity dam to guard against shallow sliding along the base interface, and deep sliding along the foundation, are key factors that must be addressed in the design of gravity dams. Experience proves that, as long as the strength and rigidity of the foundation is ensured, overall stability is achieved. The rigid body limit equilibrium method and the nonlinear finite element method are often used in the analysis of anti-sliding stability in deep foundation of gravity dam. But the rigid body limit equilibrium method can not reflect the process of progressive instability and mechanical mechanism on failure for rock mass while the nonlinear finite element method is difficult to solve the displacement discontinuity of weak structural plane. Based on the interface element method (IEM) of discontinuous mechanics, this paper has proposed a computing model, and suggested a corresponding numerical analysis method in accordance with the Xiangjiaba Hydropower Station in the lower reach of the Jinsha River in China.

COMPUTATIONAL MODEL

The model assumes that the deformations of discrete element accumulate on the interface, and then the discrete element only has rigid displacement. The structural displacement field can be constructed with piecewise rigid displacement pattern, and have

$$\mathbf{u} = \mathbf{N}\mathbf{u}_g \tag{1}$$

Where, $\mathbf{u} = [u \quad v \quad w]^T$ is the displacement of arbitrary point in the discrete element; $\boldsymbol{u}_g$ is the three linear displacements and three angular displacements of the element centroid, which are the primary unknowns to be solved; $\mathbf{N}$ is the shape function matrix, whose elements should make the displacement components obtained by the above formula satisfy the condition that the strain components are zero.

Assume we express stress field by piece interface stress, then the interface stress $\boldsymbol{T}$ of an arbitrary point on the interface can be obtained by the relative deformation of the adjacent discrete elements and the material properties, which is expressed as follows

$$\boldsymbol{T} = \boldsymbol{D}\boldsymbol{L}^{(1)}(\boldsymbol{u}^{(2)} - \boldsymbol{u}^{(1)}) = \boldsymbol{D}\boldsymbol{L}^{*}\boldsymbol{N}^{*}\boldsymbol{u}_g^{*} \tag{2}$$

Where, the upper mark 1, 2 express the identifiers of the discrete elements on the two sides of the interface, respectively. $\boldsymbol{T} = [\sigma_n, \tau_{s1}, \tau_{s2}]^T$ indicates the array assembled by the normal and shear stress of an arbitrary point on the interface; $\boldsymbol{L}^* = [\boldsymbol{L}^{(2)}, \boldsymbol{L}^{(1)}]^T$, $\boldsymbol{L}^{(i)}$ is a directional cosine matrix of interface local coordinate vector in the global coordinate system. Note that the local coordinate directions on interface of two adjacent elements are opposite, so we have $\boldsymbol{L}^{(2)} = -\boldsymbol{L}^{(1)}$. $\boldsymbol{u}_g^* = [\boldsymbol{u}_g^{(1)}, \boldsymbol{u}_g^{(2)}]^T$, $\boldsymbol{N}^*$ is composed of $N^{(1)}$ and $N^{(2)}$.D is elastic matrix., whose form has been deduced.

The virtual work principle of ISEM can be expressed as follows

$$-\sum_e \int_{s_0^e} \delta\boldsymbol{u}^T \boldsymbol{T} ds = \sum_e [\int_{\Omega^e} \delta\boldsymbol{u}^T \boldsymbol{f} d\Omega + \int_{S_\sigma^e} \delta\boldsymbol{u}^T \overline{\boldsymbol{p}} ds] \tag{3}$$

Where, S_0^e is the interface among discrete elements. Inserting partitioned rigid body displacement model and interface stress formula into Eq.(3) we can get the govering equation

$$\boldsymbol{KU} = \boldsymbol{Q} \tag{4}$$

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a) Corresponding author. Email: lxzhangqing@hhu.edu.cn.

Where, $\boldsymbol{K}$ represents global stiffness matrix assembled by each interface's stiffness; $\boldsymbol{Q}$ is general load array acting on each element centroid，which can be assembled by equivalent load array q of each discrete element；$\boldsymbol{U}$ is global displacement array constituted by the displacement of each discrete element centroid.

COMPUTATIONAL RESULTS

The failure analysis for 12th monolith of Xiangjiaba Hydropower Station has been carried out based on the IEM. The computation mesh of 12th monolith which are discreted by using IEM is shown in Fig.1. Fig.2 shows the distribution of yield zone for dam foundation by the M-C yield criterion under the working condition of normal water level.

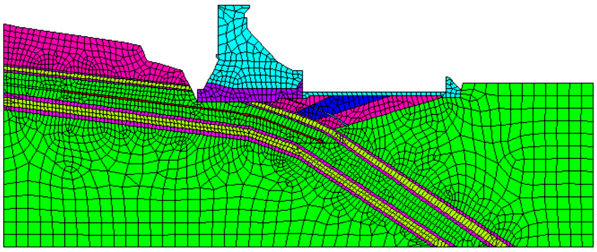

Fig.1 Computation mesh for 12th monolith

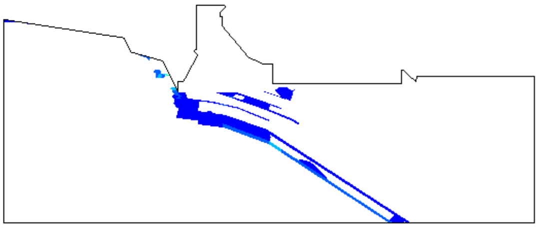

Fig.2 Distribution of yield zone

The strength reserve factor (SRF) method is also adopted to simulate progressive failure and possible unstable modes of the dam's foundation system. Fig.3 and Fig.4 show the distribution of yield zone by the M-C yield criterion when the strength reserve factor K is 2.0 and 3.5.

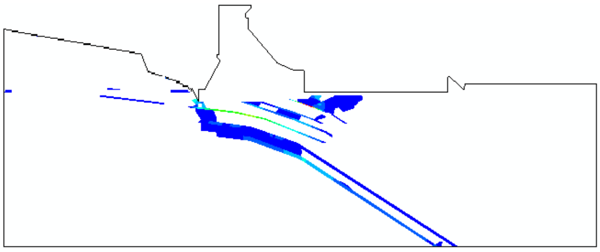

Fig.3 Distribution of yield zone for K=2.0

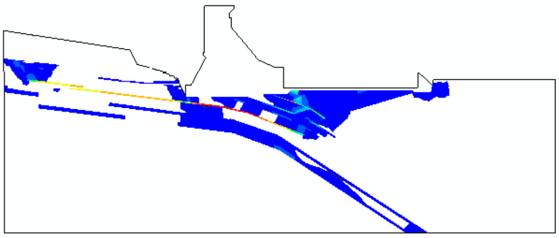

Fig.4 Distribution of yield zone for K=3.5

CONCLUSIONS

The computational result of the 12th monolith of Xiangjiaba project with IEM has shown that there is a large area of tension stress in the central parts of the foundation surface of dam. And the tensile stress concentration is found at the junction region on the interface of the foundation surface. The results can supply most dangerous location, the scope and distribution of failure zone in weak structural plane and process of progressive failure in dam foundation as well as the safety coefficient of possible sliding body. These achievements provide an important technical reference reliance for dam foundation treatment measures. The computational results show that the IEM has higher accuracy as compared with traditional FEM. As the interface displacement compatibility condition is neglected, the interface element method can naturally describe discontinuous deformation of rock mass such as dislocation, openness and sliding. Besides, this method is characterized by good adaptability, calculation conveniently and high compatibility, thus being regarded as an effective way to make an analysis of anti-sliding stability in deep foundation of gravity dam.

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