Research on Choice of Dam Foundation Elevation in Hydropower Engineering

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Abstract

It is an important problem about how to choose an optimum foundation elevation of concrete gravity dam in the field of hydropower engineering design and geology engineering. In this research, finite element method was main tool and ANSYS software was used and we provided a practical method. Firstly, weak weathering layer was subdivided. Secondly, permeation condition, against slide stability condition, against pressure intensity condition and deformation condition should be fulfilled. At last, the elevation was confirmed. It is applied in a gravity dam and can be a valuable reference to other hydropower projects.

Introduction

Hydropower projects are constructed above certain geology environment and engineering rock mass. Especially for dams, there are always complex problems about foundation rock mass which exist in a certain geology environment and are affected by outer and inner geology action. One of the major concern of utility of dam basement rock mass is certain an optimum foundation elevation. The depth of excavation affects engineering cost, construction time and safety of structure. Unnecessary excavation not only increases the construction measure, length the construction dates, but also enhances the area of enduring water pressure, augments the total load. So the trend of technique development is try our best to decrease excavation depth with the priority of reinforce measures. In this paper, with the help of ANSYS software, we provide a practical method to choose the optimum dam foundation elevation.

The key technique of choosing basement elevation

1) Subdivision of weathering layer

The practice of engineering indicates that rock of different degree of weathering have different engineering characteristics. In China, the department of hydropower engineering parts the weathering layer to four zones—totally weathered, strongly weathered, weakly weathered, and slightly weathered. This is a qualitative method. Many investigators of the word have begun to part the weathering layer with method of quantity since 1970s. In a word, accurate partition of weathering layers and mechanical parameters are the base of using dam base rock correctly. The focus of utility of dam foundation rock mass is weakly weathered layer which can be subdivided to two or three parts.

2) Conditions should be fulfilled

Commonly, the rock mass of dam foundation should fulfill the following conditions: slide stability condition, compress deformation condition, against pressure condition, permeability condition, and etc.

Strength or bearing capability and shearing resistance or the foundation materials can be very important factors in determining the suitability of a site for a gravity dam. For the higher gravity dams to be founded on rock, shearing resistance is the more critical factor. If shearing resistance of the foundation material is low, an increase in volume of concrete may be required.

If contraction joints are to be grouted in the gravity dam, highly deformable foundation and abutment material may produce undesirable stress concentrations.

Generally, grouting curtains and drainage system are provided for concrete dams on a rock foundation to reduce seepage and the buildup of hydrostatic pressures within the foundation. Such pressure has a significant effect on the stability of gravity dams and can be the cause of increase in base thickness and volume of concrete required.

We provide a flow chart below (Figure 1) and a choice will be credible if it can go through the chart successfully. The slide destruction usually is the control factor to the dam base rock mass. The stability of a dam is ordinarily expressed in terms of its factor of safety against sliding. The factor of safety against sliding is simply the ratio of the total frictional force which the foundation can develop to the force tending to cause sliding.

If we get the data of stress of every element along the interface between the dam and foundation, the factor of stability (K) will be available through the formula below where c' and f' are shear strength. The design criterion of gravity dam in China commends the formula. The criterion prescribed that under basic load conditions, K should be greater than or equal to 3.0 and under special load conditions, K should be greater than or equal to 2.5.

$$K = \frac{(\sum_{i=1}^{n} \sigma_i \Delta L_i) \cdot f' + (\sum_{i=1}^{n} \Delta L_i) \cdot c'}{\sum_{i=1}^{n} \tau_i \cdot \Delta L_i}$$

f'---coefficient of internal friction

c'---cohesion intercept

σ_i、τ_i---normal stress and shear stress of elements，

ΔL_i---length of element

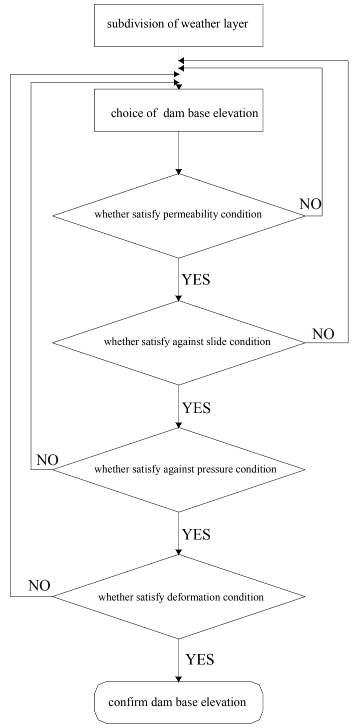

Figure 1. Flow chart of analysis

Project Example

Using above method, we analysis a concrete gravity dam, which height is 110m, in Province Fujian, China and provide our enhancement plan. The rock of dam base is rhylite which is compact and rigidity and has a good mechanics characteristic. The canyon shape of dam site is straitness and symmetrical V-shape. The main geology structure is faults and intrusive rock belts. But all the faults are bigger dip and can't form latent slide plane.

A hypothetical material capable of sustaining only compressive stresses and straining without resistance in tension is in many respects similar to an ideal plastic material. While in practice probably such an ideal material does not exist, it gives a close approximation to the behavior of randomly jointed rock. Table 1 is about material mechanical parameters and material zones are shown in Figure 2. The failure criteria used by the computation is Drucker-Prager (DP) criteria .This option (DP) is applicable to granular (frictional) material such as soils, rock, and concrete and uses the outer cone approximation to the Mohr-Coulomb law. The form of the Mohr-Coulomb surface is angular in the π–plane and in addition has a singular vertex point in the principal stress space. To avoid such angularity Drucker and Prager (1952) have introduced an inscribed cone which still possesses a vertex but in which the 'ridge' corners have been smoothed.

Based of field reconnaissance and test result, we part the weakly weathered layer to three parts---up, middle and down. Original device set dam base at down and we change to middle. Firstly, we analysis the seepage condition and test result indicate that the penetration of dam rock is small. Middle part can fulfill the seepage condition. Secondly, reconnaissance and numerical computation indicate that deformation and against pressure conditions can fulfill require. At last we take 0+39.5 section of right of the dam as example

Table 1 Material Mechanical Parameters

Number/Property/Value		E (KPa)	μ	γ (KN/M^3)	*C* (KPa)	*f*
1	Concrete	25.5E6	0.167	23.8	3000	1.09
2	Upside of weakly weathered	15e6	0.3	26.5	800	0.70
3	Downside of weakly weathered	20E6	0.3	26.5	900	0.78
4	Slightly weathered and fresh	25E6	0.3	26.5	1100	1.1
5	F_3	12e6	0.32	26	600	0.35
6	F_8	12e6	0.32	26	600	0.35

and Figure 2 is the mesh graph. In the two-dimension analysis, we use a two-dimensional plane strain model and adopt mapping mesh whole. The mesh of dam below and the neighborhood of dam toe and dam heel are finer. The type of element is PLANE42 and there are 747 elements and 800 nodes in the model. PLANE42 is used for 2-D modeling of solid structures. The element can be used either as a plane element (plane stress or plane strain) or as an axisymmetric element. The element is defined by four nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities. The loads considered in the computation are: dead load, head water and tail water pressure, uplift, earth and silt pressure.

Original device elevation is 68.5m which locate the below of the weather layer. According this we provide 3 different elevations--68.5m, 70m and 71m. With the data of normal stress and shear stress from finite element method computation, we use limit equilibrium method to get the stability coefficient. In 70m altitude, contours of the 1st and 3rd under normal reservoir elevation are given in Figure 4 and Figure 5. Figures show that tensile stress is concentrated in heel of the dam and pressure stress is concentrated in the hoe of the dam. The maximum compressive stress and tensile stress are less than the allowable stress. Seepage condition, slide stability condition, compress deformation condition, against pressure condition and etc can be fulfilled in altitude of 70m which is locate the middle part of weathering layer. Displacement vector under normal reservoir elevation is given in Figure 3 and maximum displacement is 0.0231m.

Table 2. computation result

Altitude(m)	f'	c'	K
68.5	1	1000	3.75
70	0.78	900	3.10
71	0.70	800	2.82

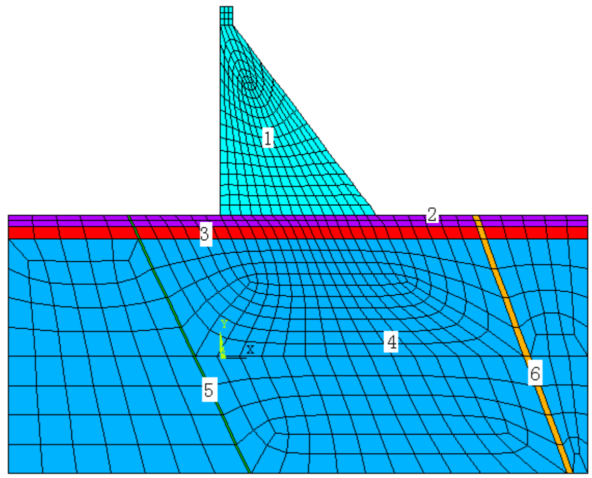

Figure 2. Finite element mesh of section 39.5m

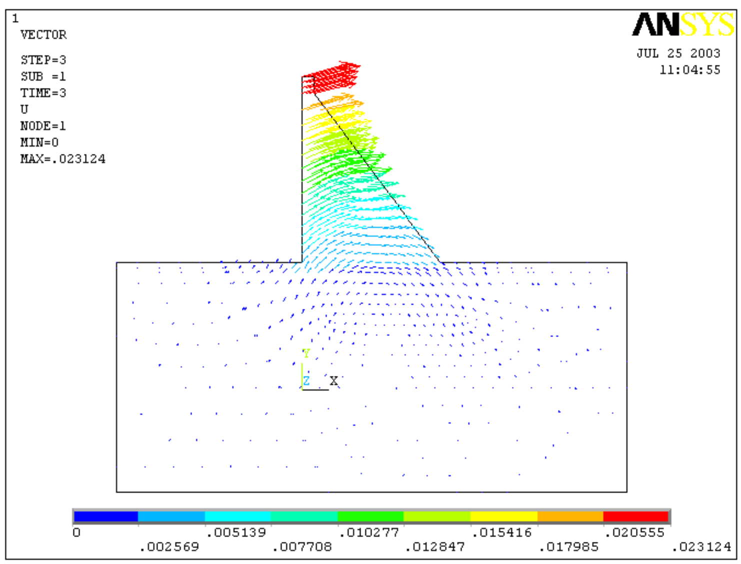

Figure 3. Total Displacement Vector (unit / m)

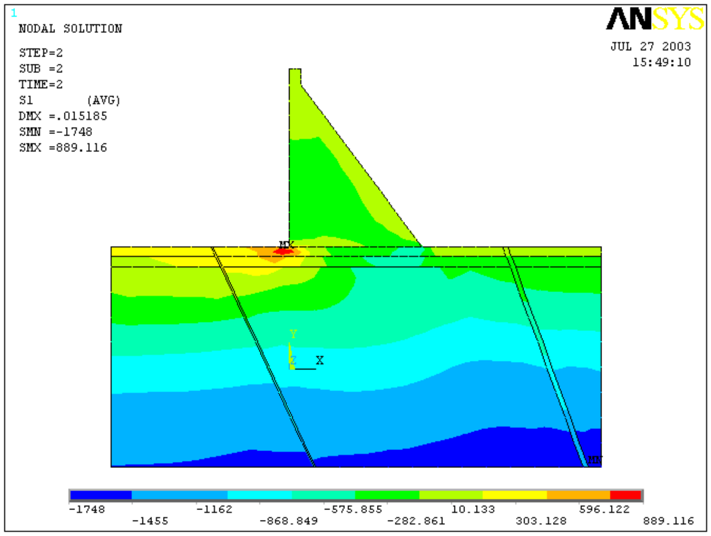

Figure 4. Contours of the 1st principal stress (unit / KPa)

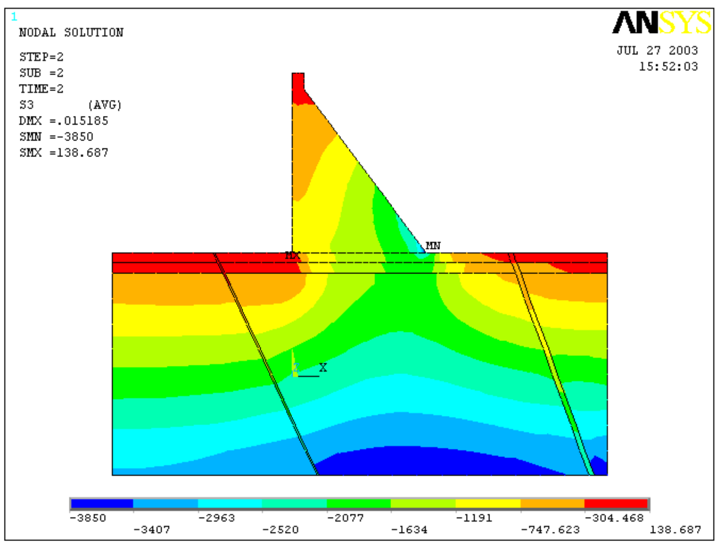

Figure 5. Contours of the 3rd principal stress (unit / KPa)

At the same time we computed other sections of different dam part. Based on these results we provide the plan that the dam part of riverbed enhance 1~1.5m and dam part of bank slope enhance 2~2.5m. Then we do three-dimension computation and Figure 6 is the mesh graphic.

Structures located in narrow valleys between steep abutments and dams with varying rock moduli which vary across the valley are conditions that necessitate three-dimensional modeling.

In the three-dimension analysis, the symmetry of valley was considered fully. With the help of partition command, which will join two or more entities to create three or new entities that encompass all parts of the originals, the contraction joints were considered in the model. Joints can be seen from Figure 7, 8 and 9 clearly.

Y-axis of coordinate is along the direction of valley, X-axis of coordinate is vertical the direction of valley and upright is Z-axis. The whole size of the model is 520m along X-axis, 380m along Y-axis and the bottom of Z-axis is -150m. The distance between downstream boundary and toe of dam was 1.5 times of the height of the dam and the distance between upstream boundary and heel of dam was 1.2 times of the height of the dam. The type of element is SOLID95 and there are 23 670 elements and 51 539 nodes in the model. SOLID95 elements have compatible displacement shapes and are well suited to model curved boundaries. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The element may have any spatial orientation. SOLID95 has plasticity, creep, stress stiffening, large deflection, and large strain capabilities. Figure 6 is 3-D finite element mesh from different visual angles.

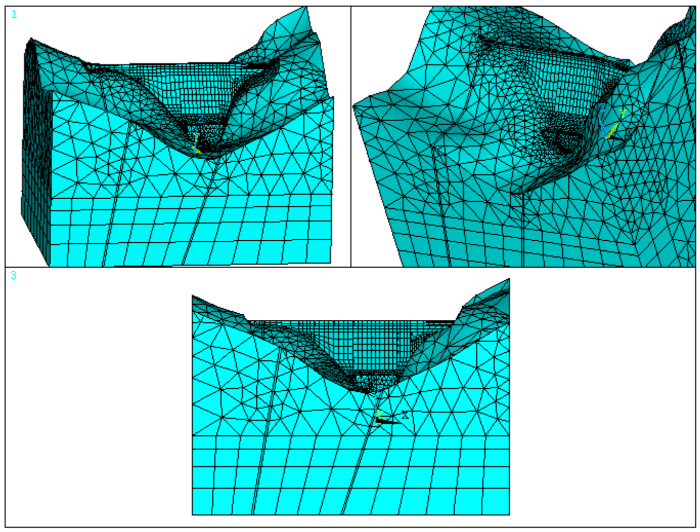

Figure 6. 3-D Finite element model of dam-foundation system

The choosing solver is PCG which especially well suited for large models with solid elements. Figure7 shows the displacement condition and maximum displacement is 0.0248m.Contours of the 1st and 3rd under normal reservoir elevation are given in Figure 8 and Figure 9. Displacement contour under normal reservoir elevation is given in Figure 7. Figures show that tensile stress is concentrated in toe of the dam and pressure stress is concentrated in heel of the dam.

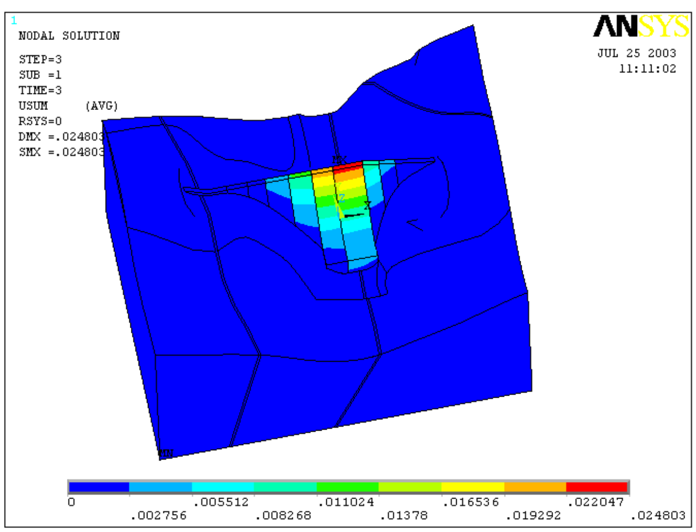

Figure 7. Total Displacement Vector (unit /m)

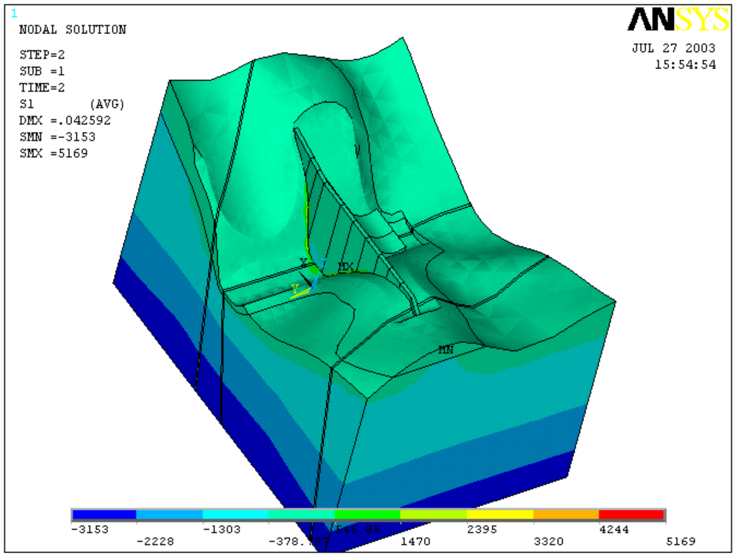

Figure 8. Contours of the 1st principal stress (unit / KPa)

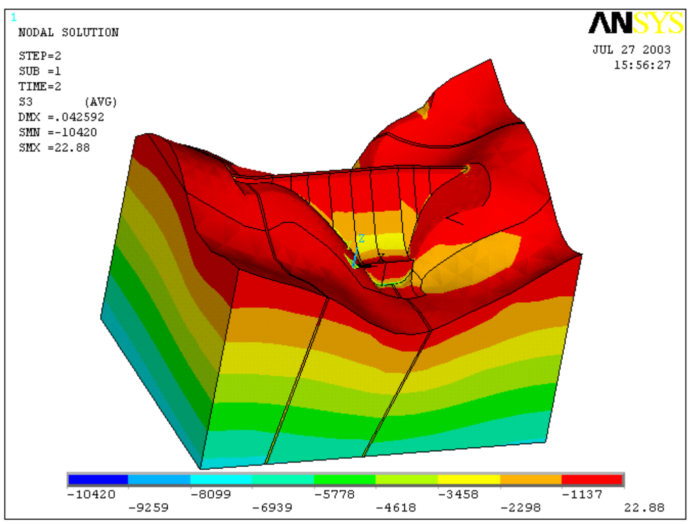

Figure 9. Contours of the 3rd principal stress (unit / KPa)

Conclusion

Computation result can fulfill the request of criterion of gravity dam design after heighten of the foundation elevation despite some locals where geology disadvantages need reinforce. This can save money and time and can reach the aim of optimization.

ANSYS provides the capability of modeling complex geometries and wide variations in material properties. The stresses at corners, around openings, and in tension zones can be approximated with a finite element model. It can model concrete thermal behavior and couple thermal stresses with other loads. An important advantage of this method is that complicated foundations involving various materials, weak joints on seams, and fracturing can be readily modeled.

Prominent preprocessor functions and postprocessing functions, powerful computation functions are the main reasons we choose ANSYS software which help us finish the research about dam foundation successfully. With the development of technique of survey and measure, ANSYS software will do a more role in choosing a premium dam foundation elevation and will provide more instructions in the field of hydropower engineering.

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