Analysis of Stress and Deformation Characteristics of Different Dam Heights in Deep Overburden

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Abstract. Relying on an actual project, this paper carries out the application analysis and prediction research of the dam height 150m-200m concrete-faced rockfill dam on deep overburden. Through the finite element calculation results, the stress and deformation of the dam and the structural design of the seepage control system are analyzed. Several preliminary standards have been adopted to control its safety and provide a reasonable basis and technical support for the construction of a 150m-200m high dam on deep overburden.

Keywords: Deep overburden; dam heights; concrete-faced rockfill dam; settlement.

1. Introduction

In recent years, in the process of China's hydropower development, it has been generally found that loose deposits with a thickness of tens of meters or even hundreds of meters are generally accumulated under the modern riverbeds of major rivers, especially in the western region [1]. The existence of deep overburden in the river bed not only seriously affects the selection of the project dam site, but also brings great difficulties to the dam design such as the selection of dam type and the design of anti-seepage measures [2]. With the development of the theory and practice of concrete-faced rockfill dams, faced rockfill dams built directly on the overburden began to appear gradually in the 1990s [3] .

The stress and deformation of concrete-faced rockfill dams built on the overburden are more complicated [4, 5]. Because the quality and rigidity of the overburden cut-off wall and the dam are very different. The entire system will produce large settlement deformation and uneven settlement under the action of the dam body filling and water pressure. Because the overburden is usually more permeable, it has an important and directly impact on the stress and deformation properties of the seepage control system. Therefore, it is necessary to conduct in-depth research on the concrete-faced slab dam scheme with the toe board builting on the deep overburden [6].

2. Calculation conditions and parameters

2.1. Project Overview

The dam site area of a concrete-faced rockfill dam project has a deep overburden, with a maximum thickness of 57m. The overburden is not excavated and a vertical concrete wall is used as a seepage control measure. The toe board is built on the overburden, and the thickness of the toe board and connecting plate is 1m. The toe board is 4m in length, and the two connecting boards are each 3m in length. A typical profile is shown in Figure 1.

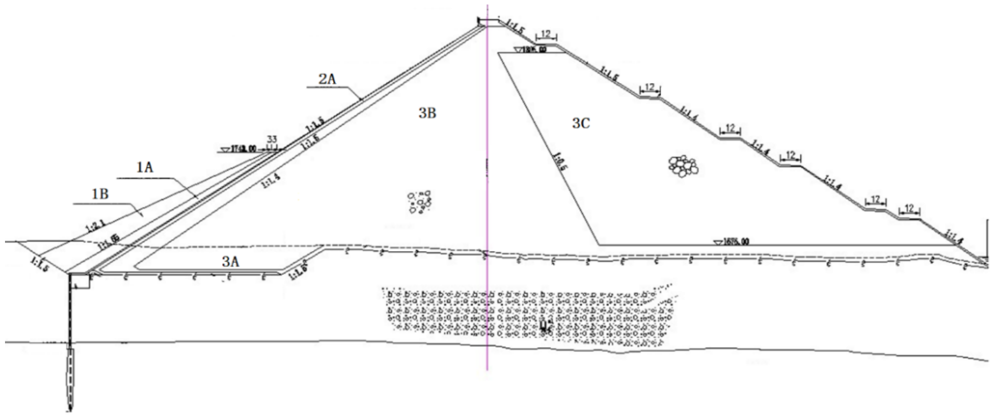


Figure 1. Typical profile.

2.2. Calculation model and parameters

In order to study the feasibility of constructing a 150m-200m high concrete-faced rockfill dam on a deep overburden, the stress and deformation of the dam is calculated when the dam heights of a certain hydropower station concrete-faced rockfill dam are 150m, 180m, and 200m.

The calculation area of the plane finite element is: the upper and downstream boundaries are 400m from the upper and downstream dam foot respectively, and the bottom boundary is 1m deep into the bedrock. The bottom boundary is a fixed constraint, and the upper and downstream boundaries are horizontal constraints. The coordinate system is set as follows: x axis is along the river, pointing downstream is positive. Y axis is vertical, pointing upward is positive.

Figure 2 is a finite element meshing diagram of a concrete-faced rockfill dam. The cut-off wall is divided into 3 rows of units along the river, and the faceplate is divided into 2 rows of units along the river. 3cm thick mud skin units are set around the cut-off wall. 15cm thick sediment is set at the bottom.

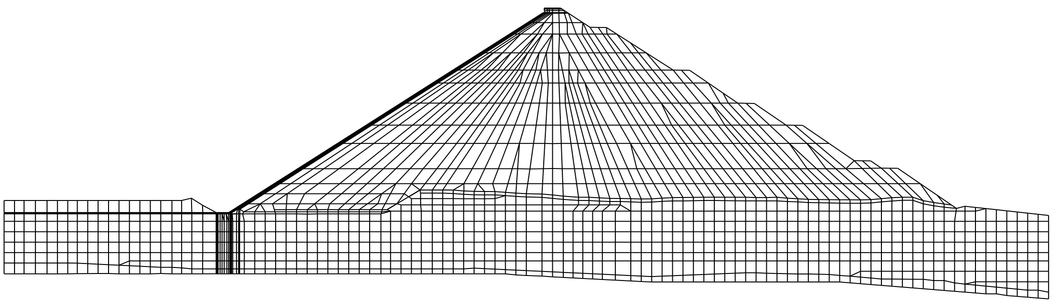


Figure 2. Finite element meshing diagram.

The parameters of the "South Water" double yield surface model used in the calculation are shown in Table 1. The parameters of the dam material and overburden are recommended by the indoor test.

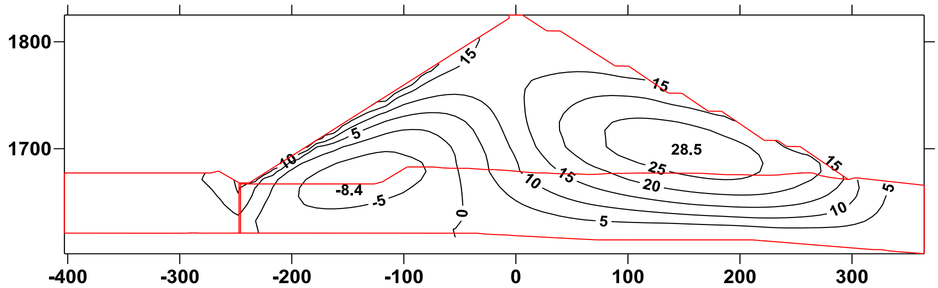
Table 1. "South Water" double yield surface model calculation parameters.

Project	ρ_d g/cm^3	c kPa	ϕ_0 (°)	$\Delta\phi$ (°)	R_f -	k -	k_{ur} -	n -	C_d %	N_d -	R_d -
Overburden	2.21	0	51.9	7.8	0.63	800	1200	0.39	0.32	0.68	0.55
Cushion 2A	2.28	0	51.8	7.0	0.69	1100	1650	0.31	0.32	0.58	0.68
Transition layer 3A	2.21	0	52.7	8.2	0.67	1130	1400	0.21	0.31	0.77	0.66
Main pile 3B	2.19	0	52.3	8.3	0.68	1000	1500	0.20	0.36	0.84	0.67
Downstream rockfill 3C	2.18	0	53.4	8.8	0.64	1050	1575	0.22	0.27	0.6	0.68
Impermeable wall	2.40	E=28GPa;μ=0.167									
Concrete cut-off structure	2.40	E=30GPa;μ=0.167									
Bedrock	2.60	E=28GPa;μ=0.27									

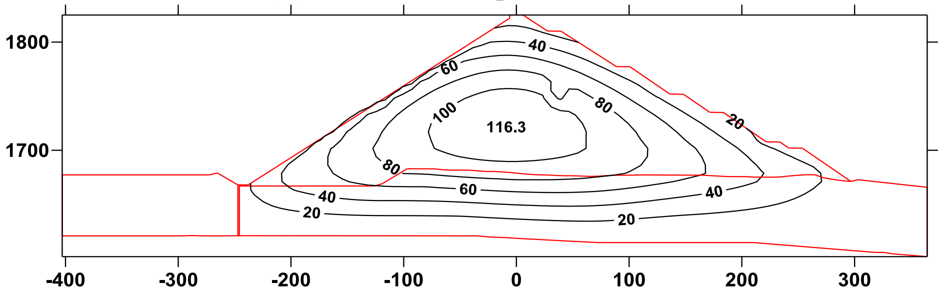
3. Seismic response150m dam height calculation result

3.1. Dam deformation and stress

The contour map of the deformation of the 150m concrete-faced rockfill dam is shown in Figure 3. During the impoundment period, the dam settlement increased to 116.3cm, the dam settlement rate was 0.56%. The overburden settlement was 92.7cm, accounting for 1.63% of the total overburden thickness. During the impoundment period, the upstream deformation of the dam decreases, and the downstream deformation increases. The maximum upstream displacement is 8.4cm, and the maximum downstream displacement is 28.5cm.



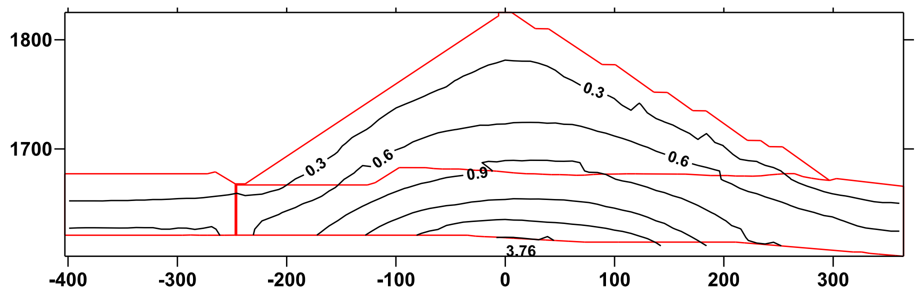
(a) Horizontal displacement/cm



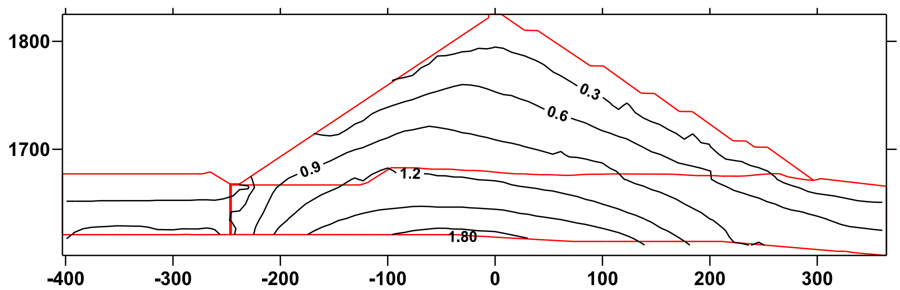
(b) Settlement/cm

Figure 3. Deformation of concrete-faced rockfill dam during impoundment period.

The stress contour map of the concrete-faced rockfill dam is shown in Figure 4. During the impoundment period, the maximum major principal stress in the dam and the overburden were 3.76 MPa, and the maximum minor principal stress was 1.80 MPa.



(a) Major principal stress/MPa



(b) Minor principal stress/MPa

Figure 4. Stress distribution of concrete-faced rockfill dam during impoundment period.

3.2. Deformation and stress of cut-off wall

The lateral deformation distribution of the cut-off wall is shown in Figure 5. The cut-off wall deforms upstream during the completion period, and the maximum deformation is 11.9cm. The cut-off wall deforms downstream during the impoundment period, and the maximum downstream deformation is 11.9cm which located on the top of the wall.

The distribution of horizontal stress, vertical stress and major and minor principal stresses on the cut-off wall is shown in Figure 6. The maximum principal stress of the cut-off wall during the completion period is 4.05MPa, and the maximum tensile stress is 0.09MPa, which is located near the top of the wall. During the impoundment period, the maximum principal stress of the cut-off wall is 17.82MPa, and the maximum compressive stress of the small principal stress is 1.79MPa. The compressive stress of the impermeable wall is within the C25 strength range.

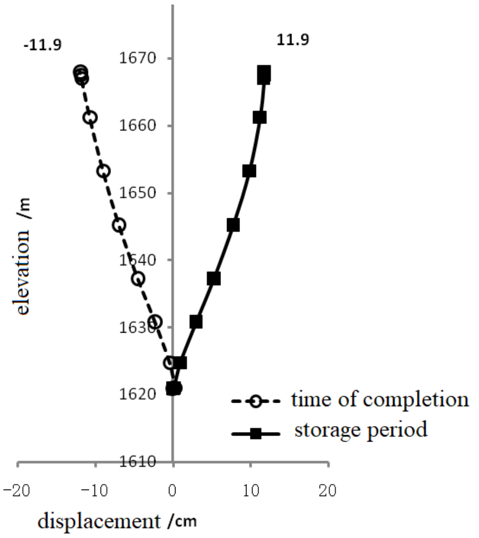


Figure 5. Deformation of cut-off wall.

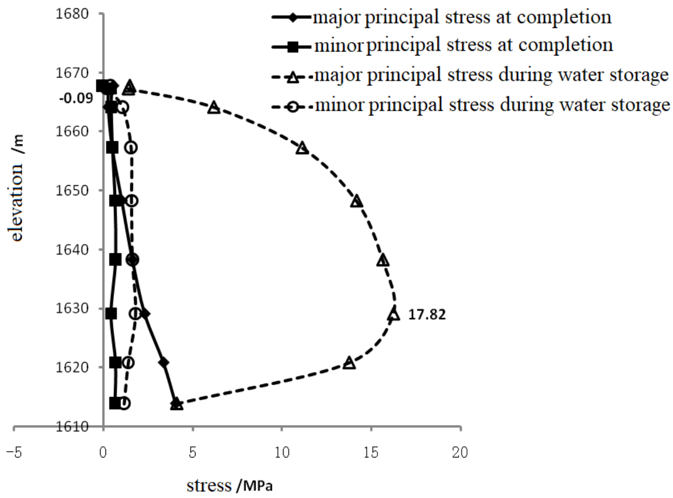


Figure 6. Stress distribution of cut-off wall.

4. Calculation results of different dam heights

Table 2 shows the deformation characteristic values of the dams and seepage control systems of 150m, 180m, and 200m high concrete-faced dams. The results show that:

Table 2. Deformation values of dams with different dam heights and seepage control systems.

dam heights(m)	Dam body settlement during impoundment period(cm)	Dam settlement rate(%)	Overburden settlement(cm)	Overburden settlement rate(%)	Deformation of cut-off wall caused by water storage
150	116.3	0.56	92.7	1.63	23.8
180	158.6	0.67	107.9	1.89	28.4
200	181.4	0.74	117.7	2.06	32.2

5. Conclusions

According to the calculation results of different dam heights, the feasibility of constructing a 150m-200m high concrete-faced rockfill dam on the deep overburden is analyzed, and the following standards are preliminarily determined to control its safety.

1) Dam settlement rate (dam settlement/dam height)≦1%;

2) The settlement rate of the overburden (settlement on the surface of the overburden/thickness of the overburden)≦2%

3) The deflection of the impermeable wall (displacement in the downstream direction caused by water storage) ≦ 30cm.

Acknowledgments

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