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Numerical stress-deformation analysis of cut-off wall in clay-core rockfill dam on thick overburden

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Abstract

The cut-off wall in a clay-core rockfill dam built on a thick overburden layer is subjected to a large compressive pressure under the action of the loads such as the dead weight of both the dam and the overburden layer, the frictional force induced by the differential settlement between the cut-off wall and surrounding soils, and the water pressure. Thus, reduction of the stress of the cut-off wall has become one of the main problems for consideration in engineering design. In this paper, numerical analysis of a core rockfill dam built on a thick overburden layer was conducted and some factors influencing the stress-strain behaviors of the cut-off wall were investigated. The factors include the improvement of the overburden layer, the modeling approach for interfacial contact between the cut-off wall and surrounding soils, the modulus of the cut-off wall concrete, and the connected pattern between the cut-off wall and the clay core. The result shows that improving the overburden layer, selecting plastic concrete with a low modulus and high strength, and optimizing the connection between the cut-off wall and the clay core of the dam are effective measures of reducing the deformations and compressive stresses of the cut-off wall. In addition, both the Goodman element and the mud-layer element are suitable for simulating the interfacial contact between the cut-off wall and surrounding soils.

Keywords: Overburden layer; Core rockfill dam; Cut-off wall; Numerical analysis; Stress and deformation analysis

1. Introduction

In recent years, the number of clay-core rockfill dams built on a thick overburden layer has been increasing gradually. The anti-seepage treatment of the thick overburden layer is very important in the design of these dam projects for ensuring safe operation. In general, there are two methods of treatment: one is to excavate the overburden deposits under the clay core, and the other is to build concrete cut-off walls inside the overburden deposits. The latter is now widely used in China (Gao, 2000). As the concrete cut-off wall is built under the clay core, it is subjected to the large dead load of the upper dam body and the water head difference between upstream and downstream water level during the construction and impounding. As a result, the stress-deformation characteristics of cut-off walls are very complex.

A centrifugal model test, field monitoring, and the numerical analysis method have usually been used to study the behavior of cut-off walls. For example, the interaction mechanism between the cut-off wall and surrounding soils in the upstream cofferdam of the Three Gorges Project has been investigated through a centrifugal model test and numerical analysis (Bao, 2007). The strain and deformation of this cut-

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off wall were monitored (Zhang et al., 2000; Cheng, 2004). Many numerical analyses have been carried out to investigate the interaction of overburden soils and the cut-off wall, and the influence of the cut-off wall's thickness, the properties of alluvium deposits, the valley boundary, and the cut-off wall construction sequence on the stress-deformation behaviors of cut-off walls (Lu and Wang, 1998; Wang et al., 2006; Li et al., 2007; Jia et al., 2008; Pan et al., 2013; Ding et al., 2013).

In this study, numerical analysis of a clay-core rockfill dam built on a deep overburden layer was conducted and some factors affecting the stress-strain behaviors of the cut-off wall were investigated comprehensively. The factors investigated include the improvement of the overburden layer, the modeling approach for interfacial contact between the cut-off wall and its surrounding soil, the modulus of cut-off wall concrete, and the connected pattern between the cut-off wall and the clay core.

2. Finite element analysis for rockfill dam

In this study, two-dimensional finite element analysis was carried out on a clay-core rockfill dam, which was built on an overburden layer with a thickness ranging from 39.5 m to 81.3 m. Fig. 1 shows a typical cross-section of this rockfill dam. The dam had a height of 120 m and a crest width of 12 m. Both the upstream and downstream slopes were 1:2. The slopes of the core wall, filter zones, and transition zones were 1:0.25. The normal water storage level of the dam reservoir is 2485 m. The overburden layer of the dam foundation is composed of sand alluvium and talus deposit. Along the depth, the overburden foundation is divided into six layers: layer 1, spreading over the river bed, is composed of sand and gravel with a loose structure and moderate permeability; layer 2 is composed of silty clay with a percentage of silt of 54% and a percentage of clay of 26%; layers 3 and 4 are composed of coarse sand that contains gravel and gravel that contains mud, with a loose structure and moderate permeability; layer 5 is composed of coarse sand that contains gravel with a percentage of silt of 32% and a percentage of clay of 8%; and layer 6 is composed of gravel that contains mud with a loose structure and moderate permeability.

Layers 1 and 2 were excavated, and layer 3 was improved using vibro-replacement stone columns. Meanwhile, a 1.2 m-thick concrete cut-off wall, embedded in the bedrock with a depth of 0.5 m, was constructed inside the overburden layer. The curtain grouting was carried out in the bedrock under the cut-off wall to ensure a reliable connection between the cut-off wall and the bedrock. The cut-off wall was connected with the clay core of the dam through a gallery.

Static and dynamic analysis software for the dam's stress and seepage (Liu, 2008; Xiang et al., 1991), which was developed on the basis of the Biot consolidation theory for saturated soils to take into account the coupling between the seepage and the stress field, was used in this study.

The finite element mesh for the dam body and the overburden foundation consisted of 2631 elements and 2523 nodes. As shown in Fig. 2, four columns of meshes were used for the 1.2 m-thick cut-off wall and 136 contact elements were arranged between the cut-off wall and surrounding soils. If the hollow junction was used for the connection between the cut-off wall and clay core, the modulus in the shadow area on the right side of Fig. 2 was set to be 0. According to the processes of dam construction and impounding, 34 steps were set in the finite element calculation. The process of dam filling from the dam base to an elevation of 2440.0 m was simulated in the first 14 steps, which took 495 days. Then, the process of impounding from the river bed to an elevation of 2437.0 m was simulated in steps 15 to 20, which took 30 days. After that, the process of the dam filling from the elevation 2440.0 m to an elevation of 2480.0 m was simulated in steps 21–28, which took 285 days. The process of impounding from the elevation 2437.0 m to 2475.0 m was simulated in the last five steps, which took 60 days. In the simulation of impounding, the water pressure and water head were applied on the upstream face of the clay core.

The consolidated settlement of the overburden foundation has already been stable over hundreds of thousands of years. Thus, the displacement of the overburden foundation was set to zero at the beginning of the calculation. However, the initial earth stress of the overburden foundation should be considered. It was calculated using the unbalanced force iterative method.

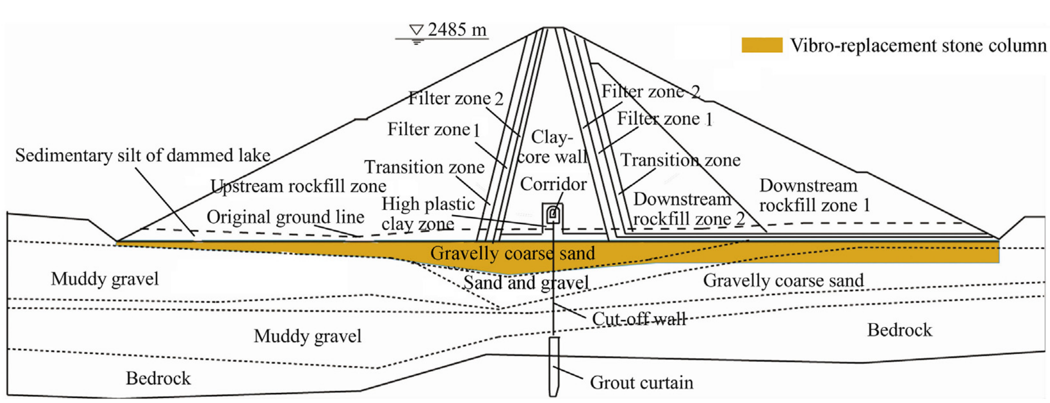

Fig. 1. Typical cross-section of rockfill dam.