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TREATMENT FOR A FULL WEATHERING ROCK DAM FOUNDATION

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ABSTRACT

The main dam for the upper reservoir of the Tianhuanping pumped storage power station is a rockfill dam with an asphalt concrete impervious lining on the upstream face constructed on a full weathering rock foundation. In this paper, we present the case study on the treatment for this full weathering rock dam foundation. The treatment includes the partial excavation of the full weathering rock at the main dam foundation, the increase of the transition curvature at the parts where the lining is extended from the upstream face to the reservoir bottom and turned to both the left and the right banks, and the reinforcement for the asphalt concrete impervious lining with a layer of polyester mesh at the parts where the tensile strain of the lining is large. A 3D FEM analysis is carried out for the main dam. The calculated results provide a good basis for the above compound treatment method. So far, this project has operated well for more than three years, illustrating the success of the treatment for the full weathering rock dam foundation.

INTRODUCTION

Tianhuanping pumped storage power station, abbreviated as THP project, is one of the largest purely pumped storage power stations in China completed in the later of 1990s, with a total installed capacity of 1800MW. The project consists of an upper reservoir, a lower reservoir, a water conveyance system and an underground powerhouse. The upper reservoir has a catchment area of about 0.33km^2 and a storage capacity of 8.85 million m^3, and is created by excavating and filling a natural depression between Tianhuanping and Getianling mountains. It has a main dam and four subsidiary dams constructed in the valleys of nearby mountains. The main dam, with a maximum height of 59m, a crest length of 503m, a crest width of 8m, an upstream slope of 1V:2H and an average downstream slope of 1V:2.1H, is a rockfill dam lined with imperious asphalt concrete at the upstream face and constructed on a non-homogeneous full weathering rock. In this paper, we present the treatment for this non-homogeneous full weathering rock foundation, which was one of the key and challenging technical problems during the design and construction of the dam.

DISTRIBUTIONS AND PROPERTIES OF THE FULL WEATHERING ROCK

Fig.1 shows the contour lines of the low limit of the full weathering rock, together with the contour lines of the topography at the site of the main dam. The difference between them comprises the thickness of the full weathering rock and the overburden. The overburden is less than 1m thick at the left bank, 1.5〜3.3m thick at the right bank and 2.8〜8.5m thick in the valley bottom where there were farm lands before the project. After deducing such overburden thickness, we can know, from Fig.1, the thickness distribution of the full weathering rock in the main dam foundation. It is non-homogeneous: 3〜5m thick (7.9m in some places) at the left bank, 10〜17m thick in the valley bottom, and as thick as 27〜35m at the right bank.

The parent rocks of the fully weathered soils are mainly gravel-bearing rhyolite, andesite porphyrite, and layered rhyolite with similar mineral composites of potashfeldspar, quartz, kaolinite and illite. As there is no inclusion of montmorillonite, the full weathering rock behaves low cation exchange capacity and weak hydration. It has a low dry density of about 1.1〜1.3g/cm^3, a medium compression modulus of 8〜9MPa, and a high natural water content of about ??. Water wetting may induce the collapsing failure for this soil. The measured N-values increase with the depth, because the soil structure remains undisturbed and even some unweathered rocks are included in the deep soil.

In the design, such non-homogeneous full weathering rock foundation dominated the selection of the lining type of the dam. Among several alternatives, the asphalt concrete faced rockfill dam was determined. But, the non-homogeneous full weathering rock foundation has to be treated; otherwise the large uneven settlement deformation of the foundation will induce large tensile strains in the asphalt concrete lining, causing the damage of the lining.

TREATMENT FOR THE FULL WEATHERING ROCK (Wang & Liu, 2001)

Four alternatives have been studied for the treatment of the full weathering rock foundation. They are preloading consolidation, dynamic compaction, vibroflotation and excavation. Due to lack of preloaded materials and limitation of the construction periods, the preloading consolidation method is not suitable, whereas the dynamic compaction will destroy the soil structure and it is difficult to form stone columns in the rock-contained soil foundation by vibroflotation. Finally, it was determined to adopt the excavation method. However, it is uneconomical and impossible to excavate all the full weathering rocks. After considering the construction periods, costs and other factors, we proposed a compound treatment method. It includes the partial excavation of the full weathering rocks and the improvement of

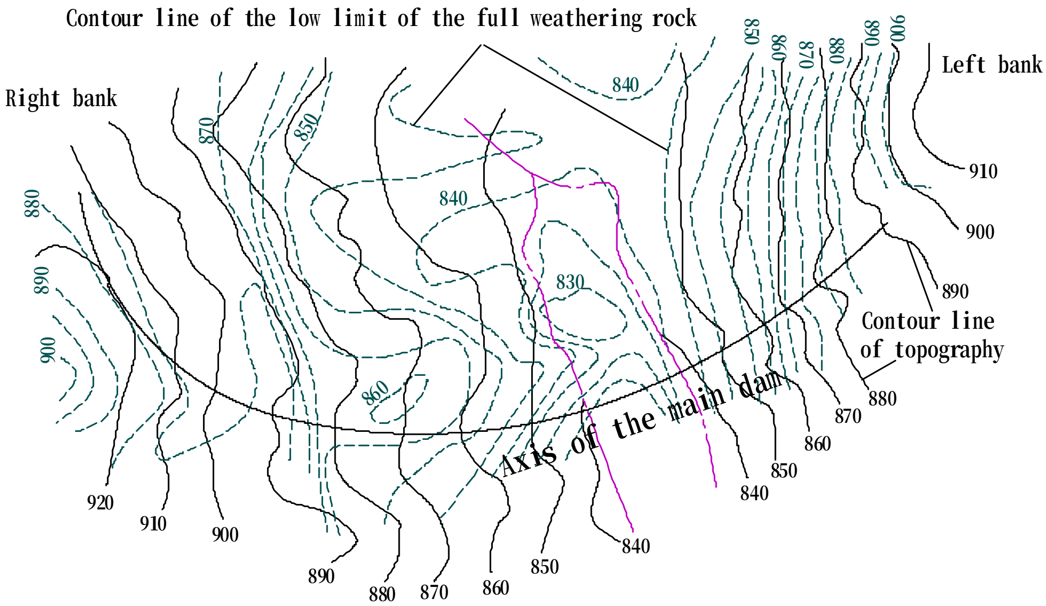

Fig.1. Contours of the full weathering rock and topography at the site of the main dam of the upper reservoir in the THP project.

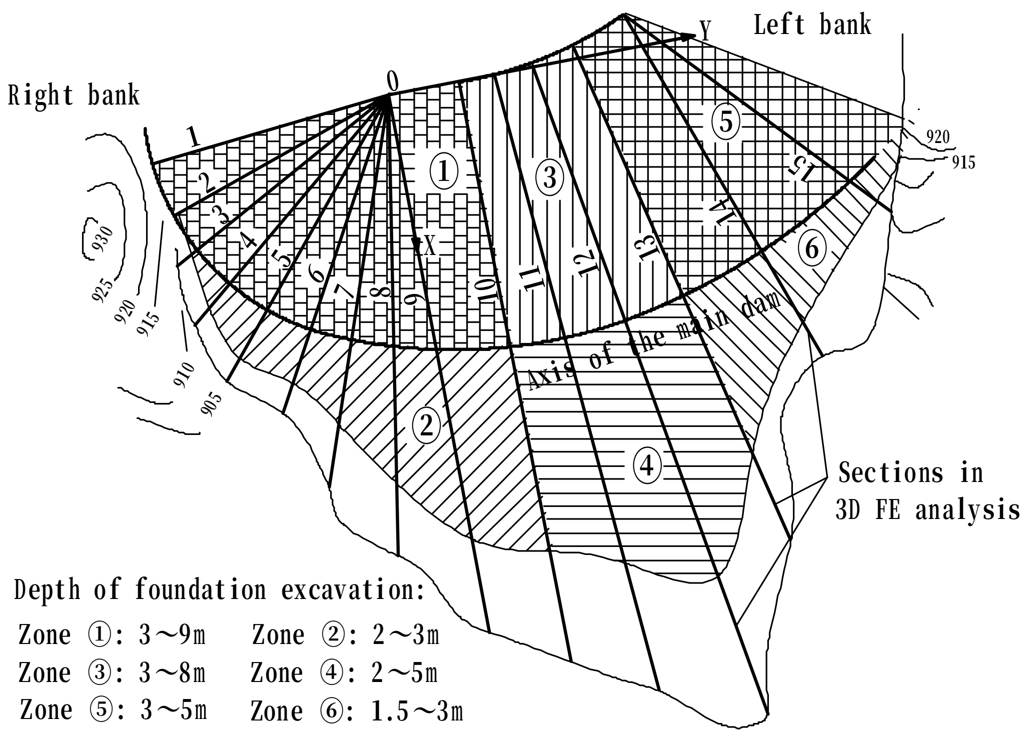

Fig.2. Depth zones for the excavation of the full weathering rocks at the main dam site and the division sections for 3D FEM analysis.

the asphalt concrete faced structure. Fig.2 shows the excavation depths of the full weathering rocks in different zones of the main dam foundation. The excavated surfaces of the full weathering rocks are well compacted with vibrator and then a layer of filter materials with good gradation are placed over them before filling the dam body. Some springs exposing in the excavated surfaces are treated with geotextiles combined with filter materials, and diverted into the nearest gallery through a drainage trench. The improvement of the asphalt concrete faced structure includes the enlargement of the transition curvature at the parts where the lining is extended from the upstream face to the reservoir bottom and turned to both the left and the right banks, and the reinforcement for the asphalt concrete impervious lining with a layer of polyester mesh at the parts where the tensile strain of the lining is large. This compound treatment was based on the results of a 3D FEM analysis presented in the following section.

3D FEM ANALYSES (Liu & Wang, 1993)

As the main dam had a complex geometric structure and was constructed on the foundation with non-homogeneous full weathering rocks, a 3D FEM calculation was carried out for the main dam. The dam body, including the full weathering rock foundation, was divided radially into 15 sections along the curved dam axis, as shown in Fig.2, forming 2,045 isoparametric eight-noded elements. The full weathering rock as well as the overlying rockfills of the dam body were characterized with a non-linear Duncun-Zhang constitute model. In order to account approximately for the effect of the immediate principle stress σ_2, we replaced σ_3 and $(\sigma_1 - \sigma_3)$ in the original equations of the Duncun-Zhang constitute model with mean principal stress p and deviatoric stress q, respectively, which was first proposed and applied by G.C. Gu of Hohai University. As aforementioned, the weathered soil is non-homogeneous in depth. In fact, it is also non-homogeneous in space locations of the dam foundation. A series of triaxial compression tests were carried out on the specimens sampled from the boring drills at different places of the main dam foundation. The obtained model parameters for the full weathering rock are scattered greatly. In our calculation, for simplicity, the average values from the tests were adopted. They are R_f=0.58, K=131.0, n=0.335 (related to tangential modulus of elasticity), and G=0.214, F=0.14, D=4.39 (related to tangent Poisson's ratio) as well as ϕ=29°, c=93kPa and γ_t=1.6g/cm^3. The model parameters for the materials of the dam body are not listed here.

As the compression of the full weathering rock foundation is larger than that of the overlying compacted rockfills, the maximum displacement of the calculated sections takes place typically at the top surface of the full weathering rock foundation. Figs.3 and 4 show the distributions of the vertical displacements (settlement deformations) at the top surface of the full weathering rock foundation after the construction completion and caused by the initial impoundment, respectively. It is seen from Fig.3 that after the construction completion, the maximum vertical displacement takes place at the right bank near the dam axis with a value of 75cm. As shown in Fig.4, the water impoundment causes the displacements mainly in the area on the upstream side of the dam, and there are little changes for the displacements on the downstream side of the dam. The

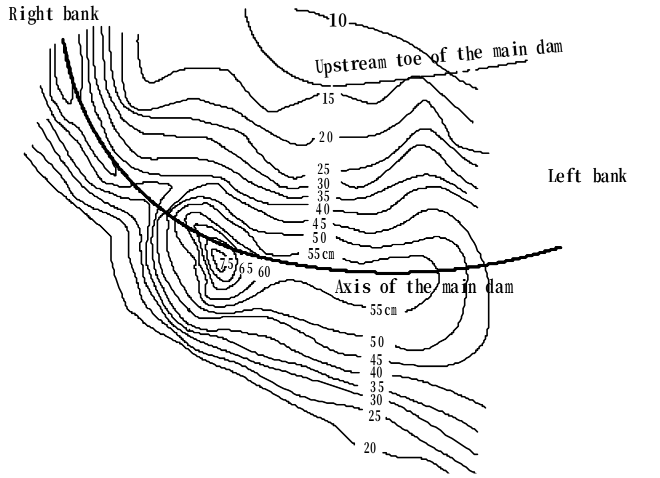

Fig.3. Calculated contours of the vertical displacements (settlements) at the top surface of the full weathering rock foundation of the main dam at the construction completion.

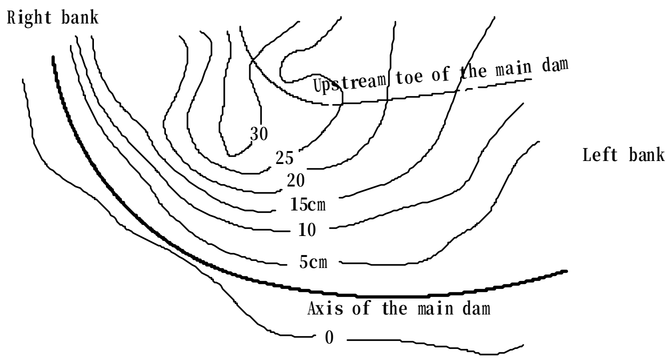

Fig.4. Calculated contours of the vertical displacements (settlements) at the top surface of the full weathering rock foundation of the main dam due to the initial water impoundment.

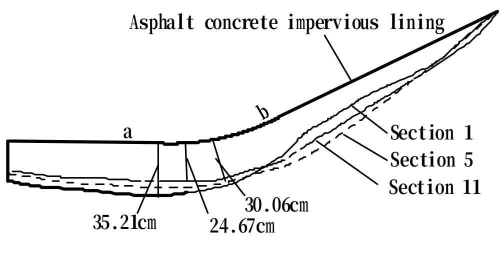

Fig.5. Deflections (normal displacements) of the asphalt concrete impervious lining along some calculated sections due to the initial water impoundment.

maximum vertical displacement due to the impoundment is 30cm, occurring in the curved section at the right bank where the profile of the dam changes sharply. The initial water impoundment also causes downstream-directed horizontal displacements in the upstream area with a maximum value of 17cm.

Fig. 5 shows the deflections (normal displacements) of the asphalt concrete faced lining on some calculated sections. It is seen that the maximum value occurs at the curved part of the asphalt concrete faced lining. It is also found from our calculation that the tensile strains of the lining are largest at the curved parts. The calculated maximum value of the tensile strain of the lining is 0.5%, which is close to the design ultimate value of 0.5～1%. Moreover, the curved parts of the lining are also the weak places where the underlying lining layer and dam body are difficult to be well compacted in construction. Therefore, we proposed to reinforce the curved part of the asphalt concrete lining with a layer of polyester mesh, as shown in Fig.6. The used polyester mesh has an allowable tension of 13% and an ultimate tensile strength of 50kN/m. To evaluate the effect of the polyester mesh reinforcement, we performed a 2D FEM analysis for the section where the maximum tensile strain of the lining structure takes place at the curved part according to the above 3D FEM calculation. The polyester mesh reinforcement is modeled with such bar elements that can only withstand tensile forces when they are extended. The calculated maximum tensile strain of the lining is reduced to be 1.88×10^{-3}, much lower than the design ultimate value of 0.5～1%.

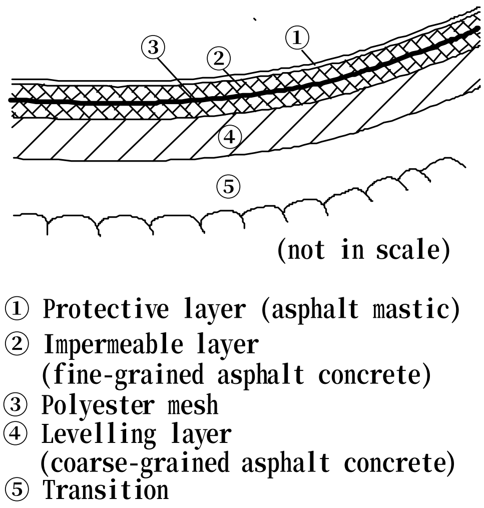

Fig.6. Reinforcement for the asphalt concrete lining at the curved part ("ab" section in Fig.5) with a layer of polyester mesh having an allowable tensile strain of 13% and an ultimate tensile strength of 50kN/m.

CONCLUDING REMARKS

The determination of the asphalt concrete faced rockfill dam for the main dam of the upper reservoir in the THP project was affected greatly by the non-homogeneous full weathering rock foundation at the dam site. Through the full examinations on the characteristics of the full weathering rock and other factors in construction, we proposed a compound treatment for the full weathering rock foundation. It includes the partial excavation of the upper full weathering rock at the main dam foundation, the improvement of the geometric profiles for the dam body and the asphalt concrete lining as well as the reinforcement for the asphalt concrete lining at the curved parts with a layer of polyester mesh. This compound treatment has the advantages of not destroying the original skeletons of the underlying weathering rock (soil), shortening the construction period, reducing the construction costs and so on. The upper reservoir began water filling in July 1998. Up to now, there have been 3 water empties for the maintenance of the asphalt concrete lining. But, the leakage did not take place in the area of the main dam where the compound treatment had been implemented. It took place in the southern bottom of the reservoir due to the uneven settlements between the excavation area and the filling area. Therefore, it can be said that the compound treatment for the full weathering rock foundation of the main dam at the upper reservoir of the THP project is successful.

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