Study on the Composite Structure Type of Concrete Wall - Rockfill Dam

Heng Zhou 1,2,*, Xi Lu 1,2, Liu Jing 1,2, Shengjie Di1,2 and Peng Huang1,2

1 Northwest Engineering Corporation Limited, Power China, Xi'an, Shaanxi, 710065, China
2 High Slope and Geological Hazard Research & Management branch, National Energy and Hydropower Engineering Technology R&D Center, Xi’an, Shaanxi, 710065, China

*Corresponding author’s e-mail: 1728@nwh.cn

Abstract. This paper focuses on the proposed new structure type of "concrete wall - rockfill dam combination structure", through the comparison of the downstream slope ratio of concrete wall, contact mode with rockfill body, contact mode with bedrock, wall height and other parameters, and the comparison with conventional rockfill dam structure, this paper provides a reference for the selection of the combined structure type. This new type can greatly improve the stress state of the panel rockfill dam, and effectively enhance the maintainability of the panel rockfill dam, partially solve the current problems of the panel rockfill dam, and can be popularized and applied.

1. Introduction

The concrete face rockfill dam has been developed rapidly in China in the past 30 years because of its strong adaptability to the topographic and geological conditions of the dam site, excellent economy, safety and reliability [1], but complex topography and geological conditions and environment for the construction of the high dam after the bad weather and long-term safe operation has brought serious challenges. Through the in-depth study of the face dam built in recent years [2 ~ 4], the prominent problems of extra-high panel dam are too large deformation ratio calculation, too large panel compression failure, too large panel crack, too large dam leakage and so on.

This article from the current existing problems of extra-high panel dam, put forward "concrete wall rockfill dam combination structure", in the riverbed dam heel adopts reinforced concrete wall to replace the concrete face of deep water area, not only can improve the strength of concrete structure of deep water area, also can reduce the length of the concrete face, improve the panel stress, but also can make the dam heel concrete slabs of concrete wall above include all the artificial maintenance conditions. In this paper, the influence of concrete wall at dam heel on stress and deformation of rockfill dam is studied and preliminarily revealed, which provides an important reference for the design and extension of new structure. According to the topographic and geological conditions of the project, the preliminarily drafted concrete wall-rockfill dam combination structure figure is shown in Figure 1, and the general structure layout figure is shown in Figure 2.
2. Research plan

Surrounding concrete wall - rockfill dam compound combination structure in the dam heel of concrete wall related parameters research, including downstream slope ratio and the concrete walls of contact, contact with the bedrock and way, the height of the wall, drew up six schemes are shown in Table 1, calculate and evaluate the concrete wall and rockfill dam downstream compound combination structure deformation and stress of displacement, stress and deflection, peripheral joint panel, etc., and compared with conventional concrete face rockfill dam, recommend suitable wall type double entry structure size. During the study, the top of the concrete wall is 8 m wide and connected by connecting plate and toe plate. The working conditions are divided into completion period and storage period.

| Number | Wall height | The slope ratio of upper and lower reaches of the wall | Contact mode between wall and rockfill | Contact mode between wall and bedrock |
|--------|-------------|------------------------------------------------------|---------------------------------------|--------------------------------------|
| Scheme 1 | 70 m        | 1:0.1                                                | Ordinary gravel                       | Consolidation                        |
| Scheme 2 | 70 m        | 1:0.1                                                | Ordinary gravel                       | Friction                             |
| Scheme 3 | 70 m        | 1:0.25                                               | Ordinary gravel                       | Consolidation                        |
| Scheme 4 | 70 m        | 1:0.35                                               | Ordinary gravel                       | Consolidation                        |
| Scheme 5 | 70 m        | 1:0.1                                                | Grain material with increased modulus | Friction                             |
| Scheme 6 | 50 m        | 1:0.1                                                | Grain material with increased modulus | Friction                             |

Duncan E-B nonlinear model was used to calculate the rockfill body, linear elastic model was used to calculate the concrete structure and bedrock, and model parameters were determined by indoor large-scale triaxial test. Goodman element simulation was adopted between the concrete panel and the pad, which was determined based on engineering experience [5]. The panel peripheral joints and vertical joints are simulated by connection unit.

3. Study on the structure Type of wall type double retaining water

3.1. Analysis of slope ratio of upper and lower reaches of concrete wall structure

The plane finite element calculation of scheme 1, scheme 3 and Scheme 4, namely the concrete wall dam slope is 1:0.1, 1:0.25 and 1:0.35 respectively, to study and analyze the influence of the ratio of upper and lower slope of the wall to the dam body, concrete wall and face plate.

(1) As shown in Figure. 3, the horizontal displacement of the rockfill body (upstream during completion period and downstream during storage period) decreases as the ratio of slope to upstream and downstream increases. The slope ratio has no effect on the maximum settlement value, large principal stress and small principal stress of dam body.
(2) As shown in Figure 4, the horizontal displacement, vertical displacement, horizontal and vertical stress and shear stress of concrete walls all decrease with the increase of the ratio of upper and lower slopes.

(3) As shown in Figure 5, maximum deflection of concrete panel, downslope compressive stress, lateral seam opening and dislocation all decrease with the increase of the concrete wall upstream or downstream slope ratio, but the panel the slope to the tensile stress, concrete wall and the connecting plate even open seams and dislocation all increase with the increase of the concrete wall slope ratio.

Comprehensive the above analysis shows that when the bottom of wall and foundation consolidation, double wall slope ratio on concrete wall-rockfill dam of deformation and stress influence combination structure is not big, but put a gentle slope ratio, can improve concrete wall and combination structure deformation and stress of concrete wall rockfill dam double entry, panel, deflection, stress and displacement of peripheral joint, it will even joint displacement of concrete wall and connecting plate.

3.2. Study on contact Mode between concrete wall and foundation
Finite element analysis is carried out according to two contact modes, the fixed connection between concrete wall structure and bedrock (scheme 1) and the friction contact connection (scheme 2), to
explain the influence of different contact modes on the stress and deformation of the concrete wall-rockfill dam complex water-retaining structure. Reasonable contact modes are recommended, and the results are shown in Table 2-6.

(1) For the stress and displacement of the rockfill body, the horizontal displacement at completion stage has a smaller fixed connection mode of upstream displacement and a smaller frictional contact mode of downstream displacement. The horizontal displacement to the downstream fixed connection mode is small during the storage period. The vertical displacement and stress of the rockfill are not significantly different between the completion period and the storage period.

(2) For the stress and displacement of the concrete wall, the horizontal displacement and vertical displacement fixed connection modes of the concrete wall during the completion period and storage period are relatively small. The fixed connection mode of horizontal stress at completion stage is smaller, while the friction contact connection mode of vertical stress and shear stress is smaller. During the storage period, the vertical normal stress and shear stress of the concrete wall have little frictional contact.

(3) For the sloping stress and deflection of the face plate, the displacement of the peripheral joints and the displacement of joints between the concrete wall and connecting plate, the frictional contact mode is small.

Based on the above comparative analysis, it can be seen that the stress state of the wall and the displacement of the surrounding joints obviously deteriorate after the consolidation connection between the wall and the bedrock, and the contact mode between the wall and the bedrock has little influence on the stress deformation state of the rockfill dam body and the face plate. Therefore, from the perspective of the safety of impermeable body, it is recommended to adopt the frictional contact mode between the concrete wall and the bedrock.

### Table 2. Calculation results of dam at completion period.

| Project | Horizontal displacement/cm | The settlement/cm | Stress/MPa |
|---------|---------------------------|------------------|------------|
|         | Horizontal displacement   |                  | High principal compressive stress | Small principal compressive stress |
|         | (cm)                      | (cm)             | (MPa)      | (MPa)       |
| Upstream| Downstream                |                  |            |             |
| Scheme 1| 37.61                     | 49.44            | 147.1      | 4.44        | 1.84 |
| Scheme 2| 41.05                     | 48.50            | 147.5      | 4.45        | 1.84 |
| Scheme 5| 36.95                     | 48.66            | 146.8      | 4.45        | 1.85 |
| Scheme 6| 41.1                      | 55.5             | 189        | 4.85        | 1.66 |

### Table 3. Calculation results of concrete wall at completion period.

| Project | Horizontal displacement/cm | Vertical displacement/cm | Horizontal normal stress/MPa | Vertical normal stress/MPa | Shear stress/MPa |
|---------|---------------------------|--------------------------|------------------------------|----------------------------|-----------------|
|         | Horizontal displacement   | Vertical displacement    | Compressive stress           | Compressive stress         | Tensile stress  |
|         | (cm)                      | (cm)                     | (MPa)                        | (MPa)                      | (MPa)           |
| Upstream| Downstream                |                           |                              |                            |                 |
| Scheme 1| 7.81                      | 1.18                      | 1.07                         | 15                         | 6.51            | 2.84 |
| Scheme 2| 18.91                     | 5.05                      | 2.49                         | 6.11                       | 0.55            | 1.28 |
| Scheme 5| 13.36                     | 4.83                      | 2.03                         | 6.67                       | 0.10            | 1.18 |
| Scheme 6| 8.83                      | 1.18                      | 1.59                         | 4.19                       | 0               | 0.63 |
Table 4. Calculation results of dam at storage period.

| Project | Horizontal displacement/cm | Settlement/cm | Stress/MPa |
|---------|---------------------------|---------------|------------|
|         | upstream | downstream | upstream | downstream | upstream | downstream |
| Scheme 1 | 4.31 | 68.55 | 152.5 | 4.76 | 1.98 |
| Scheme 2 | 2.01 | 69.32 | 152.0 | 4.79 | 1.98 |
| Scheme 5 | 1.93 | 68.70 | 151.6 | 4.79 | 1.99 |
| Scheme 6 | 15.2 | 68.4 | 195.4 | 5.08 | 1.77 |

Table 5. Calculation results of concrete wall at storage period.

| Project | Horizontal displacement/cm | Vertical displacement/cm | Horizontal normal stress/MPa | Vertical normal stress/MPa | Shear stress/MPa |
|---------|---------------------------|--------------------------|-----------------------------|----------------------------|-----------------|
|         | Upstream | Downstream | Compressive stress | Compressive stress | Compressive stress |
| Scheme 1 | 23.17 | 3.44 | 2.25 | 28.9 | 23.77 | 6.39 |
| Scheme 2 | 57.57 | 10.82 | 3.51 | 6.16 | 0 | 1.59 |
| Scheme 5 | 55.51 | 10.61 | 4.03 | 5.93 | 0 | 1.56 |
| Scheme 6 | 22.1 | 3.38 | 1.73 | 8.93 | 0 | 1.01 |

3.3. Research on filling materials behind concrete walls

Concrete wall after filling material modulus also directly decides the concrete wall and rockfill dam compound combinationstructure of the pros and cons of each index, according to the concrete wall construction of the downstream ordinary sand gravel (scheme 2) and improve the modulus of granular material (scheme 5) two different modulus of filling material, calculation and analysis of its, the results as shown in table 2 ~ 6.

(1) For the stress and displacement of the rockfill body, the horizontal displacement and vertical displacement of the upstream displacement during the completion period and water storage period are relatively small. There is no significant difference between the stress values of the rockfill during the completion period and the storage period.

(2) For the stress and displacement of the concrete wall, the horizontal displacement and vertical displacement of the concrete wall during the completion period and storage period are small; The horizontal stress and shear stress of the completion period are small; Scheme 2 of horizontal normal stress and Scheme 5 of vertical normal stress of concrete walls during the storage period are relatively small, and the two schemes are equivalent in shear stress during the storage period.

(3) For the sloping stress and deflection of the panel, the two schemes are basically equivalent; For the displacement of the peripheral joints and the joints between the concrete wall and the connecting plate, the opening and dislocation displacement between the joints in scheme 5 is improved compared with that in scheme 2.

Comprehensive comparison and analysis above, the wall after filling to enhance modulus of granular material is compared with common sand gravel filling, compound can improve the concrete wall - rockfill dam of the deformation and stress, combination structure deformation and stress of the concrete wall, panel, deflection, stress and displacement of peripheral joint as well as the concrete wall and connecting plate joint displacement. It is recommended to fill concrete wall with granular materials to increase modulus after concrete wall of the compound retaining structure of rockfill dam.
3.4. Research on the height of concrete wall structure
Through the comparison of the above parameters, it is preliminarily determined that the upper and lower slope ratio of the concrete wall in the wall-rockfill dam compound retaining structure is 1:0.1, the bottom of the wall is in contact with the bedrock, and the back of the wall is in contact with the granular material that increases the modulus. On this basis, the height of the wall is finally selected. Two different wall structure heights of 50m (Scheme 6) and 70m (scheme 5) were selected for analysis, and the results are shown in Table 2-6.

With the increase of high concrete wall wall, wall type double entry structure deformation and stress of the rockfill dam rockfill are improved, the panel deflection and slope to the compressive stress is reduced, but the deformation and stress of the wall height increase against the concrete wall and the concrete wall and the connecting plate joint dislocation, and increased the panel to tensile stress in the slope, and peripheral joint dislocation reduced amplitude is smaller. The increase of the height of the concrete wall will increase the amount of concrete work, resulting in the increase of project investment. Therefore, according to the topographic and geological conditions of the Dashixia project, after comprehensive consideration of the safety and economic factors of the concrete wall-rockfill dam compound retaining structure, it is recommended to adopt 50m in the height of the concrete wall wall of the concrete wall-rockfill dam complex retaining structure.

4. Comparison of conventional retaining structures
According to the above research results, the concrete wall-rockfill dam double retaining structure is proposed as follows: the downstream rockfill body is divided into sections using dashixia conventional concrete face rockfill dam; The concrete wall is made of C25 concrete, 50m in height and 8m in roof width. Symmetrical slope ratio is 1:0.1 for upper and lower reaches, which is connected by connecting plate and toe plate. The contact mode between concrete wall and foundation is considered as friction contact; The concrete wall is filled with bulk material to increase modulus. The advantages and disadvantages of the new structure are compared and analyzed by comparing the stress and deformation of the concrete wall-rockfill dam with the conventional concrete face rockfill dam.

For the stress and displacement, horizontal displacement, deflection and downslope stress of the rockfill body during the impoundment period, the concrete wall-rockfill dam complex retaining structure decreases obviously, and the settlement and stress of the dam body do not differ much. For the stress and displacement of the concrete wall, due to the friction contact between the wall and the bedrock, the concrete wall of the wall type compound dam scheme can better adapt to the soil deformation, the tensile and compressive stresses of the wall are small, the wall will not occur tension and compression failure. Compared with the conventional face rockfill dam scheme, the face deflection of the concrete wall-rockfill dam complex retaining structure scheme is reduced by 21.2% and the downslope stress by 34.0%.

As for the displacement of the surrounding joints, compared with that of the conventional face rockfill dam, the subsidence of the surrounding joints decreases and the tension increases during the storage period, which is directly related to the location of the surrounding joints. The toe board of the conventional face rockfill dam is placed on the bedrock, the toe board will not be deformed, and the filling material thickness under the surrounding joints is small; The toe board of the concrete wall-rockfill dam double retaining structure is placed on the filling material and connected with the concrete wall through the connecting board. The thickness of the filling material under the surrounding joints is relatively thick, and the toe board is also in deformation.

5. Conclusion
This paper innovatively puts forward a new type of dam body structure form of concrete walls-double structure extra-high face rockfill dam. Through the comparison of multiple schemes, it provides a reference for the design form of this new type of structure, and the suitable structure can be selected according to the research results. The stress of this structure can meet the requirement of material strength, the displacement of peripheral joints and displacement of joint between concrete wall and
connecting plate can meet the requirement of water-tight material adaptability, which can improve the stress state of face slab to a great extent, and partly solve the bottleneck problem of rockfill dam.

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