A dam anti-seepage reinforcement design research

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Abstract. The earth dam leakage is a major security risk for the water conservancy project. A permeability of the dam, seepage stability analysis, several principles, advantages and disadvantages, and applicability of the dam seepage technology analysis, comparison, selection and validation for seepage control and reinforcement of such works in the future the theory and design basis.

Keywords: Earth dam; seepage reinforcement; reinforcement program.

1. Analysis of permeability
The dam foundation soil is mainly silty clay and heavy silty loam, partially intercalated silty loam, and the deep foundation is silty sandstone. The allowable slope drop of dam foundation soil and dam body soil is shown in Table 1 according to the calculation M appendix (GB50287-99) of the [1] “Water Conservancy and Hydropower Engineering Geological Survey Code and the engineering geological survey report of this stage”.

| Name of site soil sample | Jcr   | J  | Type of destruction |
|--------------------------|-------|----|---------------------|
| Dam fill                 | 0.94  | 0.47| soil flow           |
| Contact of dam body and dam foundation | 0.90  | 0.45| soil flow           |
| the base of a dam ① layer Heavy silty loamy    | 0.96  | 0.48| soil flow           |
| the base of a dam ② silty clay                  | 0.97  | 0.485| soil flow          |

2. Calculation of seepage stability
This anti-seepage stability calculation adopts three typical sections, taken from the current situation of more serious seepage section 0+750~0+900 (in dam) and 1+ 400~1+700(right of dam) and the left section of dam (hereinafter referred to as the middle, right and left section of dam). Applying finite element calculation program of hydraulic structure of Hehai University (AUTOBANK) to calculate the unsteady seepage field at normal water level, design flood level and check flood level. At the same time, there are two conditions of water and water in the trunk canal of Chuhe River. The division of soil layers in three sections is shown in Figure 1, Figure 2, Figure 3. The permeability coefficient of dam body and foundation soil adopts the recommended value of this supplementary survey report. Among them, the permeability coefficient of dam fill is 1.0- E05, when the water level falls The permeability coefficients of each layer are shown in Table 2. The results are shown in Table 3.
Table 2. Permeability coefficient of dam body and foundation soil

| Soil layer | Name of soil layer | Permeability coefficient of Upper Dam | Permeability coefficient of lower dam |
|------------|--------------------|--------------------------------------|--------------------------------------|
|            |                    | Upper dam | Lower dam | Upper dam | Lower dam |
| 1 layer    | Plain fill dam     | 4.0E-05   | 5.0E-05   | 4.0E-05   | 5.0E-05   |
| 2-1 layer  | Heavy silty loam   | 5.0E-05   | 5.0E-05   | 4.0E-05   | 5.0E-05   |
| 2-2 layer  | silty clay         | 3.0E-06   | 3.0E-06   | 4.0E-05   | 5.0E-05   |
| 2-3 layer  | Heavy silty loam   | 2.0E-05   | 2.0E-05   | 4.0E-05   | 5.0E-05   |

Table 3. Calculation Results of Stable Seepage of Dam Status

| position  | Reservoir water level | Drainage water | Water level under dam | Outfall at dam foot slope | High escape degree | seepage discharge (10^-6 m^3/s) |
|-----------|-----------------------|----------------|-----------------------|---------------------------|--------------------|-------------------------------|
| 1+450~1+700 (Right dam) | 45.05 | anhydrous | anhydrous | 0.54 | 0.45 | 1.06 | 0.21 | 6.02 |
|           | 46.67 | 43.15 | | 0.46 | 0.71 | 3.5 | 1.73 |
|           | 47.66 | 43.15 | | 0.53 | 0.73 | 3.89 | 1.81 |
| 0+750~0+900 (middle of dam) | 45.05 | anhydrous | anhydrous | 0.54 | 0.59 | 0.92 | 0.14 | 3.1 |
|           | 46.67 | 43.15 | | 0.58 | 0.76 | 3.72 | 3.5 |
|           | 47.66 | 43.15 | | 0.60 | 0.77 | 4.23 | 3.5 |
| 0+200~0+600 (left dam) | 45.05 | anhydrous | anhydrous | 0.52 | 0.4 | 0.88 | 0.1 | 0.61 |
|           | 46.67 | 43.15 | | 0.43 | 0.51 | 3.36 | 1.87 |
|           | 47.66 | 43.15 | | 0.44 | 0.52 | 3.59 | 1.85 |

Figure 1. Calculation of seepage stability of right section of dam

Figure 2. Subdivision of soil layer dam section
According to the calculation results, the seepage slope drop in the upper and lower dam of the three sections is small, which is within the allowable slope drop range of the dam body and soil, but the slope drop value of the dam foot is too large, and the part exceeds the allowable value, especially 0+750~0+900 (section in dam) and 1+400~1+700 Overflow slope drop at the foot of upper and lower dam exceeds the allowable value under most working conditions, which is in good agreement with the actual situation. According to the calculation, it is inevitable that the dam foot is in the environment of high seepage ratio for a long time. At the same time, from the results, 0+750~0+900 and 1+400~1+700 The seepage flow is larger, the maximum amount of water under the normal water level has reached 6.02 $\times$ 10$^{-6}$ m$^3$/s/m, which cannot meet the economic, safe operation and management requirements of the reservoir. Therefore, through the seepage calculation review and combined with the actual leakage of the dam operation, it is considered that the dam seepage prevention and reinforcement is very necessary.

3. Design of dam anti-seepage reinforcement

Due to the different soil distribution, clearing quality and filling quality of the dam foundation, the seepage behavior of each dam section of about 2000 m, is different. According to the calculation results, the results of this survey and the seepage situation on the spot, different reinforcement measures are to be taken in sections. The leakage and dispersion of slope foot in the site is more serious than 0+750~0+900,1+000~1+230 and 1+400~1+700 is carried out, and considering that the dam section between sections is short and the amount of engineering is not much, the design of this reinforcement is to be adopted in the upper dam 0 700~1 The reinforcement scheme of vertical impervious wall is set up in section 700, and the treatment measures of clay cone grouting for strengthening dam body are proposed in other dam sections.

The downstream slope foot of the lower dam is wet all year round, and some of the dam sections have become swamped. In this reinforcement, the clay cone grouting scheme is used to strengthen the dam body, and the downstream slope drainage is added to fill the reservoir at the foot of the dam.

3.1. Selection of Vertical Permeability Reinforcement Scheme

The vertical seepage prevention treatment scheme of the dam top is to build the wall from the high pressure grouting of the dam top, deep to the relatively impermeable layer, cut off the leakage passage, and form the impervious body. There are many forms of vertical anti-seepage wall, this reinforcement design adopts three construction schemes: high pressure swing grouting grouting wall, casing hole punching fill impervious wall and saw groove pouring plastic concrete wall. According to the current construction technology level and construction experience, these three schemes all apply to the project.

   Scheme 1: [2] High pressure jet grouting wall

Using drilling rig to make holes, the grouting pipe with nozzle is lowered to the predetermined position of soil layer, and the soil is mixed with high pressure water jet to change the structure and composition of the original layer. At the same time, the impervious wall is formed by pouring cement slurry (10~15º). According to other similar engineering experience, this project adopts a row of holes to build walls, and preliminarily draws up the hole spacing of 1.2 m. The construction is carried out in two order, using cross broken line connection mode and cement slurry. The top height of concrete impervious wall is slightly higher than that of check flood level 47.66 m, determined to be 48.0 m, and
the bottom of wall extends into dam foundation soil layer not less than 1.5 m. Length of impervious wall along dam axis 1000 m, total length of borehole 10656 m, and grouting length 9989 m.

Pendulum spray wall has the advantages of thin wall, saving engineering quantity, not being affected by environment, fast construction speed, increasing dam body strength and reliable connection with flood sluice. The disadvantages are that the slope of borehole is high, the thickness of impervious wall is uneven and discontinuous.

Scheme 2: Cover hole to catch fill impervious wall
A single row of holes along the axis of the dam, According to the main, casing layout, A set of intersecting walls, Backfill clay in the well, After tamping, a continuous clay core wall is formed. Single row of holes, pitch-row 1m, bore diameter 1.5m, and Effective thickness 1.0 m. of impervious wall. Of impervious wall Backfill requires clay content of 35%~50%, In order to improve the strength and anti-seepage performance of backfill, Mix appropriate amount of cement (about 100 kg in 1m³soil) in backfill. 48.0 m, of the top of the wall 1000 m, of seepage wall along dam axis 12787 m, of borehole total Backfill 17646 m³.

The construction cost is low, the construction is simple, and the thickness of impervious core wall is easy to meet the requirements of impervious design. The disadvantages are: large amount of whole making and backfill material, difficult to control the construction quality under the current construction environment; narrow site in dam top construction.

Scheme 2: [3] Saw-slot cast-in-place plastic concrete wall
By using mud to fix the wall, the trench machine is used to dig the groove from the top of the dam to 1 m, in the soil layer of the dam foundation, and then the concrete is poured into the concrete to form the upper and lower equal thickness concrete walls. The design wall thickness is initially set to 0.5 m, single row, each slot length 8~10 m, mud solid wall, and underwater conduit pouring concrete. The height of the top of the impervious wall is 48.0 m, the length of the concrete impervious wall along the axis of the dam is 1000 m, and of 12780 m². Of wall construction is required

The thickness and quality of the wall constructed by this method can easily meet the requirements of anti-seepage. The disadvantages are: the mud skin with solid wall mud will form through joint at the joint of segmented wall; the possible inclination of slot hole will make the thickness of joint surface of segmented wall insufficient; in dam top construction, the site is narrow and the mechanical arrangement is difficult.

The above three schemes are compared in detail in this anti-seepage reinforcement design. The comparative engineering quantity and investment of the three schemes and the advantages and disadvantages of each scheme are shown in Table 4. The results show that the construction quality of the wall is not easy to control because of the influence of external factors. The high-spray grouting wall has the advantages of good anti-seepage effect, moderate cost, reliable connection with surrounding buildings, simple construction and fast construction speed, while the plastic concrete impervious wall has high cost and large project investment. Therefore, comprehensive technical, economic and other factors, this recommendation to adopt the first scheme, that is, high-pressure jet grouting wall construction scheme.
Table 4. Economic and Technical Comparison of Dam Seepage Control and Reinforcement Scheme

| Project                                | Dam Seepage Control | Reinforcement Scheme |
|----------------------------------------|---------------------|----------------------|
| Job practice                           | drill hole, High pressure spray | Flushing holes into grooves, backfilling clay; drilling holes, high pressure jet cement slurry into walls |
| Main quantities                        | Poremaking 10656 m, grouting 9989 m | Punching hole 12787 m, backfilling 17646 m³ |
| Comparable cost(ten thousand yuan)     | 479                 | 374                  |
| Advantage, weak point                  | Advantage: Low cost, no environmental impact, it can increase the strength of dam body and connect reliably with flood sluice. Weak point: the requirement of drilling construction is high, the thickness is uneven and discontinuous, etc. | Advantage: The cost is low, the backfill construction is simple and so on. Weak point: The construction is greatly affected by the environment, the construction quality is not easy to control, the construction period is long and the integrity of the dam body is damaged. | Advantage: The wall is uniform and continuous, and the reliability is high. Weak point: The construction cost is high, the construction is greatly affected by the environment, the construction period is relatively long and the integrity of the dam body is damaged. |

3.2. Design of high pressure jet grouting impervious wall

Impervious Wall 0+ 700~1+ 700 The height of the top of the wall is slightly higher than that of the check flood water level 47.66 m, determined to be 48.0 m, the length of the dam axis is 1000 m, a total of 10656 boreholes m, 9989 m. grouting are required The hole distance is 1.2 m, and the hole depth is not less than 1.5 m in the dam foundation soil layer m, and the maximum depth of the impervious wall is 15.6 m. In the construction stage, the hole distance is determined by field grouting test.

The high pressure jet grouting wall adopts the small angle pendulum spray type, according to the two sequence whole construction, the impervious plate wall axis line connection. The construction procedure of high-spray grouting is divided into drilling, grouting pipe, injection and lifting, etc. The grouting material is made of cement slurry, and the suitable water cement ratio and adding material are determined by field formula test. The technical parameters of each construction process are determined by field test. At the end of grouting, cement slurry is used to seal the hole mechanically. After the slurry in the whole sinks, it is filled again the next day and then rammed with clay seal after 3 days. The thickness of high pressure jet grouting cutoff wall is 0.1~0.3 m, the permeability coefficient is not more than \( i \times 10^{-6} \), 28d the compressive strength is more than 3.0 MPa. In order to check the grouting quality, the dam impervious wall should be checked by water injection around the well after construction, and the seepage state and leakage amount of the dam should be observed on the spot to check the seepage prevention effect of the impervious wall.

3.3. Calculation of seepage stabilization after reinforcement

According to the type of dam reinforcement section after the dam body reaches the standard and high grouting seepage prevention and reinforcement, the seepage stability calculation of the above three typical sections is carried out. The finite element calculation program (AUTOBANK) of hydraulic structure of Hehai University is used to calculate the normal water level, design flood level and check
the stable seepage field under flood water level and unstable seepage field during water level landing period. The results are shown in Table 5.

**Table 5. Calculation Results of Stable Seepage after Dam Reinforcement**

| position       | Reservoir water level | Drainage water | Downstream water level of the dam | Dam foot escape slope drop | Exit height | seepage quantity (10^-6 m^3/s/m) |
|----------------|-----------------------|----------------|-----------------------------------|---------------------------|-------------|----------------------------------|
| Right dam      | 45.05                 | anhydrous      | anhydrous                         | 0.17                      | 0.16        | 0.1                              | 45               |
| Section        | 46.67                 | 43.15          | anhydrous                         | 0.14                      | 0.42        | 3.24                             | 0.7              |
|                | 47.66                 | 43.15          | anhydrous                         | 0.16                      | 0.46        | 3.25                             | 0.82             |
| Middle of dam  | 45.05                 | anhydrous      | anhydrous                         | 0.39                      | 0.21        | 0.37                             | 0.12             |
| Section        | 46.67                 | 43.15          | anhydrous                         | 0.15                      | 0.43        | 3.09                             | 0.52             |
|                | 47.66                 | 43.15          | anhydrous                         | 0.20                      | 0.41        | 3.16                             | 0.51             |
| Left dam       | 45.05                 | anhydrous      | anhydrous                         | 0.45                      | 0.35        | 0.71                             | 0.13             |
| Section        | 46.67                 | 43.15          | anhydrous                         | 0.33                      | 0.42        | 3.24                             | 1.5              |
|                | 47.66                 | 43.15          | anhydrous                         | 0.40                      | 0.47        | 3.27                             | 1.62             |

4. Summary
From the calculation results, the seepage slope drop and the exit slope drop of the dam foot in the three calculated sections are obviously reduced, the height of the overflow point is reduced, the exit slope drop of the dam foot is smaller than the allowable slope drop of the dam foot soil layer, and some working conditions exceed the allowable slope foot.

References
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