Study on the seepage control effect for the dam foundation of CHIPWI hydropower Station at upper stream IRRAWADDY RIVER

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Abstract. Impervious curtain and intensive drainage holes take important roles to control the seepage field in the foundation of dam such as that with fault for Chipwi Hydropower Station. The three-dimensional seepage field is modelled with finite element method, and the efficiency is analysed for impervious curtain and drainage holes to control the seepage field. The results indicate that the curtain with less permeability is more efficient, especially for the area with fault. Drainage hole spacing does not influence the seepage field greatly. While the drainage hole spacing is doubled, whole discharge increases but the uplift pressure still meets the requirement according to design code.

1. Introduction

The impervious curtain and densely distributed drainage holes are usually used as seepage control measures in Gravity dam foundation, and the effect is one of the key factors that influence engineering safety. The dam foundation has large scale faults in Chipwi Hydropower Station at upstream Irrawaddy river in Burma, in this paper, the three-dimensional seepage field is modelled with refined finite element method, and the effect is analysed for impervious curtain and drainage holes to control the seepage field. The main objective of this study is to analyse seepage control effect within the scope of anti-seepage curtain failure or drainage hole spacing increase, and the rationality and reliability of seepage control measures is evaluated.

2. Numerical method for seepage field

The simulation of phreatic surface and dense drainage holes is usually involved in hydraulic engineering, underground engineering and high slope engineering, the fine efficient solution of complex seepage field analysis is the key. The seepage calculation of dam foundation involves precise simulation methods of solving seepage free surface, drain holes, summarized as follows.

2.1 Procedure of Nodal Virtual Flux for Unconfined Seepage Filed

In unconfined seepage problem, the free surface of seepage is nonlinear boundary. The location of the free surface, the line of exit points and the real domain of seepage are unknown first, which need iteration to obtain the solution to the unconfined seepage problem. The procedure of nodal virtual flux that is progressively developed and perfected by some scholars (Su & Zhu, 1991; Cui & Zhu, 2009),
which can solve this problem conveniently without mesh modification and the relevant iteration formula is as follows.

\[ K_h = Q - Q^2 + \Delta Q \]  

Where \( K_h \), \( h \) and \( Q \) are the conductive matrix, the vectors of hydraulic head and the nodal equivalent flux related to the total calculation domain of \( \Omega = \Omega_1 + \Omega_2 \), respectively; \( Q^2 \) represents the vector of virtual nodal equivalent fluxes; \( \Delta Q = K_h h \) denotes the vector of the nodal fluxes which are contributed by virtual elements and transient elements in the virtual domain \( \Omega_2 \); \( \Omega_1 \) denotes the real domain of seepage below free surface of seepage and \( \Omega_2 \) denotes the virtual domain of seepage located above the free surface.

2.2 Simulation of Seepage Behaviors of Drainage hole

There are many drainage measures including a lot of drainage holes which play a role of water discharge and pressure relief in the seepage field in the channel or dam foundation, if the location of free surfaces at the holes is higher than the top surfaces, the holes are fully filled with seepage water, otherwise there is no water overflowing out from the holes in bottom or slope of channel. The holes action is required on both the theory and algorithms rigorous simulation techniques to solve the drainage holes of its impact on seepage field; The procedure of simulation of holes progressively developed and perfected in the references [4] can solve this problem conveniently without mesh modification and the drainage hole relevant iteration formula is the "equivalent nodal flow method"(Zhu,1997) in each hole, its mathematical formulation is as follows Eq. 2:

\[ Q(x_i) = - \sum \sum K_{ij}(h)^{ji} \]  

Where in each symbol, drainage holes and validation of solving specific references (Cui, et al., 2008). This overhaul of the channel flow calculations, channel slope holes handle that uses the method.

Finite element method is well developed to solve the nonlinear model. Program SSC-3D modified by Cui (2008), which was developed originally by Zhu (1997), is suitable for the simulation of the seepage field.

3. The efficiency is analysed for gravity dam foundation

3.1 Design essential

This dam locates in upstream Irrawaddy River in Burma. The maximum height of the concrete gravity dam is 206 m, the maximum stream wise length is 185 m. The length of dam axis is 1323 m including the riverbed overflow dam and the light and right non-overflow dam, the normal pool level is 400m, and the water level for check flood is 405.27 m. The total storage capacity is 0.19×1010 m3 and installed capacity is 3400 MW.

The bedrock is composed of metamorphic rocks, the local distribution of late Magmatite intrusion, metamorphic rocks are the Porphyroblastic granite gneiss, mica quartz schist and granite gneiss in site of the dam. Fault rocks exist in the left dam shoulder, including F41, F42 fault in large scale, longitudinal along the left bank near the bed is NNE direction, length of more than 15 km. In most parts of the bedrock fracture density is sparse, with steep dip fissures mainly (Figure 1). The seepage control measures such as the grout curtain, drainage holes in the dam foundation are shown in Figures 1 and 2. Dam foundation seepage control engineering scheme adopts vertical curtain grouting and drainage curtain of dam foundation for behind the scenes; the main drainage curtain, hole depth mainly the first row curtain hole depth of 1/2 ~ 2/3, pitch 2.0 m, enclosed inside the dam foundation curtain closed drainage curtain, the grid like layout as the auxiliary drainage curtain, closed and auxiliary drainage hole depth is 35 m, the hole spacing is 3m; aperture uniform for 0.11 m. The criterion for dam foundation main impervious curtain rock permeable rate \( q \leq 1 \) Lu (Lu gon) after grouting; closed curtain and ends the part is rock permeable rate is \( q \leq 3 \) Lu after grouting. The maximum grouting depth is 120.5 m in left F41, F42 fault zone.
3.2 Parameters and cases

In order to meet the anti-seepage requirements, according to the regulations, the impervious curtain and drainage holes are designed, especially, the dam foundation is grouted in shallow. The permeability of fault zone (F41 and F42 fault zone of influence) as shown in Figure 1, permeability coefficient is range between $1.4 \times 10^{-5}$ cm and $1.4 \times 10^{-4}$ cm/s. The seepage zone is considered as isotropic, the coefficient of permeability of sand and gravel is considered as $1 \times 10^{-1}$ cm/s, the clay gravel is $1.2 \times 10^{-2}$ cm/s, surface granite is $5 \times 10^{-4}$ cm/s, weakly weathered zone of $5 \times 10^{-5}$ cm/s, impervious curtain is $1.4 \times 10^{-5}$ cm/s, the concrete cushion is $1 \times 10^{-9}$ cm/s.

Figure 1. Left dam foundation geological section and seepage control layout.

Figure 2. Plan view of the layout of seepage control for gravity dam foundation.
For the analysis of different conditions of dam foundation seepage control measures effect, three cases are assumed. The case 1 is basic case; the grout curtain was assumed failure within the zone of fault in the case 2 base on the case 1; all drainage hole spacing is expanded to 2 times, the equivalent of half drainage holes failure occurred in case 3 basis on the case 1. Comparative simulations were performed at normal pool level 400 m and tail water level of 247.8 m, the water level of the left bank is 462 m, the watershed of right bank is supposed as impermeable boundary. Steady seepage flow was simulated with water head at boundary nodes immerged by reservoir water and tail water known as the respective water level. The downstream slope was assumed as possible exit surface. The bottom and the both side boundaries of the model were assumed as impermeable.

The original point of calculation model is the junction point of the twenty-fifth and sixth dam in the plane of the Figure 2, the Y axis is alone the downstream, the X axis is direction to the right and perpendicular to the Y axis, The Z axis is perpendicular to the XOY plane, direction to upright and on zero elevation plane origin. According to the above coordinate system the range of the calculation model is -810 m ≤ x ≤ 550 m, -250 m ≤ y ≤ 450 m, the depth of the elevation is -290 m in level model, the height is about 510 m from the dam foundation bottom to surface, about 2.5 times the maximum dam height. The model element is 6 sided 8-node element, the node number is 116 382 and the element number is 107 348. The grid of dam foundation and the drainage holes meshes are shown in Figure 3 and Figure 4.

3.3 Simulation results

Case 1 is the preliminary design case, according to the different section water head contour of the dam foundation, which indicates the distribution of seepage field reasonably, the contour shape, direction and intensity are correctly reflect the seepage control measures characteristic, rock mass seepage properties and boundary conditions at the corresponding position. The seepage field is controlled by the measures of dam foundation significantly (Figure 5~ Figure 7).
We can see the water head contour distribution intensive near the dam foundation drainage hole in Figure 7, the water head is less than 230 m within the riverbed of large range (the riverbed dam height 220 m), which shows the water head pressure was cut by the impervious curtain and the main and sub drainage holes in the dam foundation region. The groundwater level is high in the left bank of the mountain, the seepage field of left bank dam abutment is supplied by groundwater significantly (Figure 5), but due to the combined effects of dam closed anti-seepage curtain and auxiliary drainage holes, so that the water head pressure has been effectively controlled in dam foundation seepage field. According to analysis of pressure reduction coefficient with the typical profile, the reduction coefficient is about 0.11 in foundation of the max height dam, far less than the code value of 0.2 (Specifications, 1998); the water head pressure is only 5.2 m after through the main drainage holes, the reduction coefficient is about 0.05 in the key fault zone and the water head pressure distribution shows in Figure 8.

According above the analysis, within the range of complex geological conditions dam seepage control measures and overall, the distribution of program seepage field basically reflects the impact of dam formation, seepage control measures, faults, etc. the uplift pressure of the key zone satisfy code requirements, which indicates design of seepage control measures is reasonable and effective in the case.

We can see from Figure 6 near the dam foundation drainage hole head contour distribution intensive, the riverbed dam foundation of large range (the riverbed dam height 220m) head value within 230m, show that the region in the impervious curtain and the main and sub drainage holes, pressure head was cut. The mountain on the left bank side of high water level, groundwater replenishment effect on left bank abutment infiltration (Figure 5), but due to the combined effect of...
dam foundation closed curtain and auxiliary drainage hole seepage control measures, so that the pressure head within the scope of effective control of dam foundation.

![Figure 8. Water head pressure for section of Z = 240 m in F41 fault zone (x-166 m, case 1).]

The seepage distribution of each profile water head contours in case 2 is similar to case 1 (Figure 9), it is no longer listed because of the limited space. In case 2, the impervious curtain is failure in the fault zone, however, the seepage distribution did not change significantly compared with case 1, especially, the uplift pressure is close to the case 1 in the fault zone, far less than the code value. All drainage hole spacing is expanded to 2 times in the case 3, the equivalent of half drainage holes failure occurred in case 3 basis on the case 1, the impaction of seepage control hole spacing is analysed. The results shows that the water head contours is affected by the drainage hole spacing slightly, and the uplift pressure increased slightly in the dam heel and toe of the dam site. However, drainage capacity of drainage holes remains strong and the pressure reduction coefficient also meets the code requirements.

![Figure 9. Water head contour for section of z = 215.0 m (case 2).]

In addition to the distribution of seepage field, the foundation discharge can also reflect the effect of different seepage control measures (Cui et al, 2009). The dam foundation discharge is little difference in the case 1 and case 3, but it is about two times to preliminary design case in the left bank of foundation in case 2, indicating that the failure of the left bank of the dam foundation drainage holes at fault zone, making discharge a big increase in the left bank of the dam foundation, but the right bank no influence. The distribution of seepage field is not impacted by drainage hole spacing increase nearly, that indicates the drainage capacity of the drainage holes did not reduce in case 2.

| Site               | Case 1 | Case 2 | Case 3 |
|--------------------|--------|--------|--------|
| Left dam foundation| 2440   | 4320   | 2440   |
| Right dam foundation| 1250  | 1250   | 1240   |

4. Discussion
Normal seepage field as a complete anti-seepage and drainage holes system provided with a complete anti-seepage and drainage system formed by grout curtain and drainage holes as Case 1, and the seepage field will be controlled as normal one expected by design engineers. The reduction coefficient
is far less than the code value in the dam foundation even if the impervious curtain is failure in the fault zone in case 2, in addition to the discharge increases in the left bank in case 2, so that dam stability would be guaranteed.

The seepage field is affected by the drainage hole spacing within twice in dam foundation slightly, so the spacing of drainage holes can be adjusted within the scope of size.

5. Conclusions
(1) According to the three-dimensional dam seepage field analysis, the effect of seepage control measures is significantly, the preliminary design case is reasonable and feasible;
   (2) The main impervious curtain is failure in the fault zone, the seepage distribution do not change significantly compared with the preliminary design case, however, because of the permeability of the fault zone is strong, as the drain holes outlet of the penetration water, it need to take appropriate filtration protective measures to prevent the dam foundation rock, especially the occurrence of the fault zone infiltration and sabotage;
   (3) The drainage hole spacing is expanded twice, foundation seepage field and uplift pressure distribution is consistent with the preliminary design case nearly, in the actual project, drainage holes curtain can make the appropriate optimization or adjustment.

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