Study on the effect of seepage control measures in double-barrel ultra-deep working wells of pumping stations

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Abstract. Aiming at the problem of seepage control during the construction period of ultra-deep working wells adjacent to reservoirs, a three-dimensional seepage numerical model was established based on the working well of Qinglinjing Pumping Station in Shenzhen. The influence mechanism of reservoir water level, consolidation grouting, integrity of diaphragm wall and curtain on seepage field was systematically analyzed, and the seepage evolution laws of three excavation methods were compared. The results show that the consolidation grouting can reduce the seepage flow by 98.2 % and increase the anti-floating coefficient to 1.17 compared with the non-grouting scheme. The integrity of the diaphragm wall dominates the anti-seepage efficiency; different excavation methods have significant influence on the characteristics of seepage field during the construction of seepage wells. The results provide theoretical support for the seepage control design of deep and large shaft near reservoir.

Keywords: Ultra-deep working well; seepage control; consolidation grouting; ground connecting wall; step-by-step excavation; numerical simulation.

1. Introduction

Geological changes during excavation and a dynamic stress field have led to significant stability issues in the vertical-shaft pumping station due to seepage, which is the primary concern.[1, 2]. Seepage may lead to structural deformation, cracking and failure[3], induce quicksand, piping, heave, and instability of excavation/shaft walls[4], causing serious consequences[5]. In deep foundation pits and super deep shaft process, seepage control measures need to be comprehensively selected and combined based on factors such as engineering geological and hydrologic conditions, excavation depth, support system, and sensitivity of the surrounding environment for the integrated application of seepage control methods including "blocking, lowering, draining, grouting, and monitoring[6-7].

The research on the Groundwater seepage field in the foundation pit and seepage control measures is mainly based on the Poroelasticity theory and the Effective stress principle. Yu Jun [8], Zeng, Yulin et al.[9] derived the explicit analytical solution of the steady-state seepage field around the foundation under anisotropic conditions, and studied the influences of the width of the foundation pit, the distance between the retaining wall and the impermeable layer, and the anisotropic seepage conditions on the total head. Feng Yunpeng et al.[10] established a seepage-stress-damage coupling model and algorithm based on the Hoek-Brown strength criterion for foundation pit excavation in karst areas to analyze the stability of foundation pit excavation. Yang Qingyuan[11], et al. studied the changes in ground surface subsidence outside the foundation pit caused by dewatering from incomplete wells within the pit under conditions where the confined aquifer inside and outside the pit is not fully isolated. Zhang Yaohui[12], etc. analyzed the influence of different insertion depths of the water-stop curtain on the deformation of the foundation pit and the seepage field. Cui Haodong[13], et al. studied the seepage control effectiveness of the integrity and effectiveness of the diaphragm wall in suppressing the confined aquifer heave risk in deep foundation pits, and in reducing ground subsidence outside the pit and environmental impacts. Li Liang[14], etc. conducted research on the effects of foundation pit bottom sealing on controlling the decline of the water table outside the pit and surrounding settlements, enhancing the strength and stiffness of the soil at the pit bottom, and improving the overall stability of the support structure.

The Qinglinjing Pump Station No. 2 Working Shaft, a key node of the Pearl River Delta Water Resources Allocation Project in Shenzhen, faces high-head seepage challenges. Located near the Qinglinjing Reservoir, the shaft reaches 56.81 meters in depth, with a base slab subjected to over

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40 meters of water head pressure and three water-conducting fault zones, posing risks of water inrush, mud inrush, buoyancy-induced instability, and rock permeation failure. Traditional suspended waterproofing systems are ineffective due to unsealed bottom seepage channels, and existing research lacks systematic analysis of multi-layer waterproofing structures and step-by-step construction seepage patterns, limiting design optimization in high-risk areas. This study integrates 3D seepage field simulation with multi-scenario comparisons to systematically analyze four factors, providing theoretical support for deep-buried tunnel design near reservoirs. The findings have been applied to ensure safe construction of the water resources allocation project in Shenzhen.

2. Project Overview

The Qinglinjing Pump Station is the core hub of the Shenzhen Gongming Reservoir-Qinglinjing Reservoir Interconnection Project, located on the right bank slope top downstream of Dam No. 6 of the Qinglinjing Reservoir, approximately 1.3 km from the reservoir. The overall terrain of the site is convex and strip-like. The location and general layout of the pump station are shown in Figure 1. The pump station adopts a "square-above, round-below, dual-tube" vertical shaft structure (Tubes A and B), with an inner diameter of 28.0 meters for each working shaft. The excavation base slab elevation is 28.19 meters, the top elevation is 85.00 meters, and the shaft depth is 55.81 meters. Its main function is to achieve inter-connectivity between the water sources of the West River (via the Gongming Reservoir) and the East River (to the Qinglinjing Reservoir), thereby enhancing the water resources allocation capacity of Shenzhen City.

Fig.1 Schematic diagram of pump station location and overall layout

The terrain within the working range of the pump station is greatly undulating, and there is a steep slope near the reservoir bank. The surface layer consists of 1–2 m thick colluvial sandy clay with medium water permeability and 3–5 m thick gravel soil with medium water permeability. The underlying bedrock is the strongly to weakly weathered fine sandstone of the Carboniferous Daluhu Formation and siltstone interbedded with fine sandstone and quartz sandstone with water permeability ranging from weak to medium. The typical geological section of the pump station is shown in Figure 2. Based on regional data and geological mapping results, there are a total of three water-conducting faults developed near the station site, namely F1244（trending NE) and F3531（trending NW), with a permeability coefficient of up to 1.23 m/d, forming the main seepage channels. The groundwater level is at a depth of 14.5 m, occurring within the Quaternary gravel soil and bedrock fractures, and is 40 m above the slab. Moreover, the site is adjacent to a reservoir, which poses risks of wellbore water gushing and mud surging during construction, as well as instability of the slab due to buoyancy.

To address the seepage and stability issues, a composite structure of "diaphragm wall + lining wall" is adopted: the main structure employs a 1.2 m thick, 60.68 m deep diaphragm wall that extends 5 m below the slab and combines with a 1.5 m thick, 48.81 m high lining wall and a 5 m thick slab to form a double-layer waterproofing system,and the slab is underpinned by anchor bars and plum blossom pattern consolidation grouting. The seepage control measures involve installing three rows of grout curtains 10 m outside the well to block peripheral seepage, and capping the diaphragm wall and lining wall with a crown beam for closure.

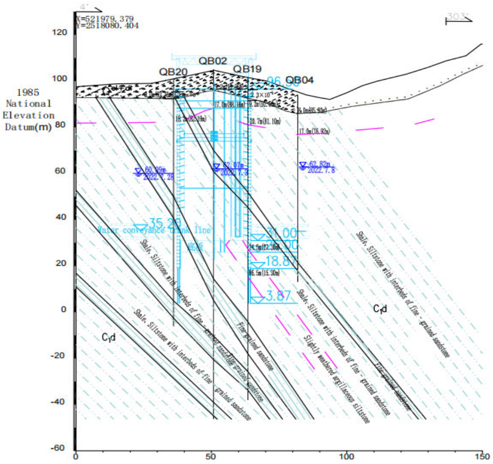


Fig.2 Typical engineering geological profile of the pump station

3. Construction of a 3D Steady-State Seepage Analysis Model

The seepage analysis area is determined based on the engineering geological investigation data and hydrogeological data of the project area (Figure 3). The Qinglinjing Reservoir (Q1–Q7) is simplified as a constant-head boundary, with the water level set at the normal storage level of 79.13 m or the corresponding reservoir water level during the construction period. To eliminate the influence of the boundary on the groundwater seepage at the working well, according to the experience from previous projects, the boundary should be extended beyond 500 m. For this calculation, the distant mountain boundaries are taken to the locations of faults F1244 and F3531. According to geological data, the permeability coefficient of these faults is 5×10-4 to 5×10-3 cm/s , indicating that they are water-bearing faults. Therefore, in the model, these two faults are considered as deep-cutting constant-head boundaries. The water level at the D1 to D2 boundary is set at 85.5 m, based on a groundwater depth of 14.5 m. The water level at the D2–Q1 constant-head boundary is determined by linear interpolation between 85.5 m and the water level of the Qinglinjing Reservoir.The Q5 – D1 boundary is determined based on the interpolation results between the water level of 85.5 m and that of the Qinglinjing Reservoir. The boundary is a constant-head boundary. The schematic diagram of the seepage model grid is shown in Figure 4. The steady-state seepage numerical model employs the permeability coefficients of the rock strata as the primary computational parameters, which are primarily determined based on geotechnical recommended values. The permeability coefficients of the retaining structures are assigned according to conventional experience. The values for the seepage model calculations are given in Table 1.

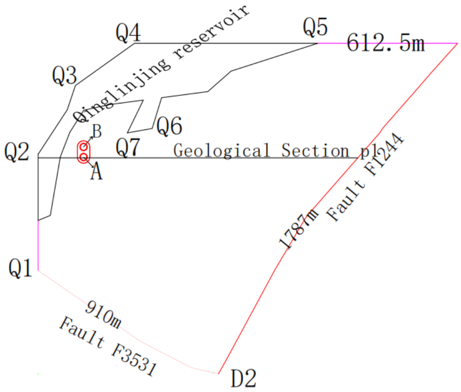


Fig.3 Model generalization plan view

a. Three-dimensional grid diagram when working pit is excavated

b. Grid diagram of the working pit enclosure structure

Fig.4 Schematic diagram of the seepage model grid

Table 1. Permeability coefficient values for seepage calculation in working wells

Numble	Strata	Vertical stratification	Geological recommended values	Calculated values/(cm . s-¹)
K1	Sandy cohesive soil	/	5×10^{-4}~5×10^{-3}	5×10^{-4}、5×10^{-3}
K2		Completely weathered	5×10^{-4}	5.0×10^{-4}
K3	Fine-grained sandstone	Highly weathered	5×10^{-4}~5×10^{-3}	5×10^{-4}、5×10^{-3}
K4		Slightly weathered	5×10^{-5}~5×10^{-4}	5×10^{-5}、5×10^{-4}
K5	Shale, clayey siltstone interbedded with fine - grained sandstone	Completely weathered	5×10^{-6}~5×10^{-5}	5×10^{-6}、5×10^{-5}
K6		Highly weathered	5×10^{-5}~5×10^{-4}	5×10^{-5}、5×10^{-4}
K7		Slighly weathered	7.0×10^{-4}	7.0×10^{-4}
K8	Sub - fresh rock mass	/	/	1.0×10^{-5}
K9	curtain	/	/	1.0×10^{-5}
K10	Diaphragm wall	/	/	$1.0\times10^{-7}/1.0\times10^{-6}$
K11	Lining	/	/	1.0×10^{-7}
K12	Concrete slab	/	/	1.0×10^{-7}
K13	Consolidation grouting strata	/	/	1.0×10^{-5}、1.0×10^{-4}

4. Analysis of Influencing Factors on Seepage Field

4.1 Influence of Qinglinjing Reservoir Water Level on Seepage at Working Well

Due to the working well of the Qinglinjing Pump Station is adjacent to the Qinglinjing Reservoir, to analyze the change between the reservoir water level and the seepage flow during the working well excavation, seepage calculations were conducted for different bottom sealing schemes during synchronized double-barrel excavation, corresponding to the normal storage level of 79.13 m and the low water level of 65 m during the construction period.

The working wells A and B were excavated simultaneously to the lowest elevation of 28.19 m. For the calculations related to the water level of the Qinglinjing Reservoir, the initial seepage control design features a grout curtain base elevation of 8.32 m and a diaphragm wall base elevation of 23.19 m. The bottom sealing schemes include a 5 m thick concrete layer and grouting in the rock layer within the wells to a depth of 10 m. The series of schemes is designed for calculations under different bottom sealing schemes when the Qinglinjing Reservoir is at the low water level of 65 m and the high water level of 79.13 m (normal storage level) to analyze the influence of reservoir water level on seepage during the excavation of the working well. The specific schemes and corresponding calculation results are shown in Table 2.

Table 2 Seepage calculation results of Qinglinjing Reservoir water level sensitivity analysis scheme

Number	Reservoir water level condition	Excavation condition	Retaining structure	Flow rate of A tube/($\mathrm{m}^3 \cdot \mathrm{d}^{-1}$)	Flow rate of B tube/($\mathrm{m}^3 \cdot \mathrm{d}^{-1}$)
AB-K1-1	Normal Reservoir Water Level 79.13m	A and B shafts are excavated synchronously to the lowest elevation of 28.19m.	Cutoff curtain + Diaphragm wall + No bottom slab pouring.	1692.64	1680.58
AB-K1-2			Cutoff curtain + Diaphragm wall + Consolidation grouting of the bottom rock mass for 10m, with a permeability coefficient of 1.0×10^{-4} cm/s.	449.84	441.76
AB-K1-3			Cutoff curtain + Diaphragm wall + Consolidation grouting of the bottom rock mass for 10m, with a permeability coefficient of 1.0×10^{-5}cm/s.	54.67	53.48
AB-K1-4			Cutoff curtain + Diaphragm wall + 5m thick concrete layer for bottom sealing.	2.72	2.51
AB-K2-1	Construction Period Low Water Level 65m	Construction Period Low Water Level 65m	Cutoff curtain + Diaphragm wall + No bottom slab pouring.	1360.92	1300.13
AB-K2-2			Cutoff curtain + Diaphragm wall + Consolidation grouting of the bottom rock mass for 10m, with a permeability coefficient of 1.0×10^{-4} cm/s.	367.05	359.24
AB-K2-3			Cutoff curtain + Diaphragm wall + Consolidation grouting of the bottom rock mass for 10m, with a permeability coefficient of 1.0×10^{-5} cm/s.	44.73	43.62
AB-K2-4			Cutoff curtain + Diaphragm wall + 5m thick concrete layer for bottom pouring.	2.16	1.99

In Table 2, the seepage flow during the excavation of the working well is highly correlated with the permeability coefficient of the sealing layer and is also closely related to the water level of the Qinglinjing Reservoir. In Scheme AB-K1-1, the water level of the Qinglinjing Reservoir is 79.13 m. The rock layer within the well is neither sealed nor grouted. When excavated to the lowest elevation of 28.19 m, the seepage flow of groundwater in Well A is 1692.64 m^3/d, and in Well B is 1680.58 m^3/d. When the reservoir water level drops to 65 m, Scheme AB-K2-1 indicates that the seepage flows in Wells A and B are reduced to 1360.92 m^3/d and 1300.13 m^3/d respectively, with a reduction of approximately 21%. The calculation results of Schemes AB-K1-2 and AB-K2-2 show that when the rock layer below the well bottom is grouted to a depth of 10 m (with a permeability coefficient of 1.0×10-4cm/s), and the water level of the Qinglinjing Reservoir drops from 79.13 m to 65 m, the seepage flow of the working well is reduced by approximately 18%. The calculation results of Schemes AB-K1-4 and AB-K2-4 show that, after the implementation of the 5 m thick concrete bottom sealing within the wells, the seepage flow in the working wells is significantly dropped: in Scheme AB-K1-4, the water level of the Qinglinjing Reservoir is 79.13 m. The seepage flow of groundwater in Well A is 2.72 m^3/d, and in Well B is 2.51 m^3/d. When the water level of the reservoir in Scheme AB-K2-4 drops to 65 m, the seepage flows in Wells A and B are reduced to 2.16 m^3/d and 1.99 m^3/d, respectively, representing a decrease of approximately 20%.

4.2 Influence of Consolidation Grouting on Seepage at Working Wells

The well walls and the underlying rock mass of the working wells exhibit high permeability. If the rock layer at the bottom of the working wells is not pre-grouted, groundwater can bypass the bottom and seep into the wells due to the suspended nature of the grout curtain and the diaphragm wall. This may lead to potential permeability stability issues in the rock layer during the excavation of the working wells. After grouting the bottom rock layer, the consolidated rock layer serves as a waterproofing support layer for the diaphragm wall, thereby creating a relatively complete seepage cutoff effect. A single-barrel excavation scheme was employed to analyze the impact of bottom rock layer grouting on seepage during the excavation of the working well. The A-GJ series of schemes are designed to calculate the influence of grouting depth, range, and permeability coefficient of the rock layer on seepage during the excavation of Working Well A. In this series, the reservoir water level is considered as the normal storage level of 79.13 m, the distant boundary water level is set at 85.5 m, and the rock layer permeability coefficient is taken as a higher value. The results of the seepage simulation calculations are shown in Table 3

Table 3 Seepage results of working well under different consolidation grouting conditions

Number	**Condition**	**Permeability Coefficient of Grouted Cutoff Curtain/(cm · s^{-1})**	**Retaining Structure**	**Grouting Condition**	**Flow Rate of A Shaft//(m^3 · d^{-1})**	**Buoyancy Resistance Coefficient of Rock Mass**
A-GJ1	A Shaft Excavated Alone to the Lowest Elevation of 28.19m	1.0×10^{-5}cm/s	Cutoff curtain + Diaphragm wall + No bottom sealing	No grouting, cutoff curtain bottom elevation at 8.19m	1616.51	/
A-GJ2			Cutoff curtain + Diaphragm wall + No bottom sealing + Grouting inside the shaft for 10m	Cutoff curtain bottom elevation at 8.19m, grouting of rock mass inside the shaft from elevation 28.19m to 18.19m, other conditions same as A-GJ1	53.44	0.47
A- GJ3			Cutoff curtain + Diaphragm wall + No bottom sealing + Grouting inside the shaft for 25m, no grouting outside the shaft	Cutoff curtain bottom elevation at 3.19m, grouting inside the shaft from elevation 28.19m to 23.19m, grouting outside the shaft same as A-GJ2	33.99	1.17
A-GJ4		1.0×10-5cm/s	Cutoff curtain + Diaphragm wall + No bottom sealing + Grouting inside the shaft for 25m, grouting outside the shaft for 5m	Grouting of rock mass inside the shaft from elevation 28.19m to 23.19m, grouting of rock mass outside the shaft to the cutoff curtain from elevation 28.19m to 23.19m, other conditions same as A-GJ3	33.65	1.17

The calculation results show that when no grouting measures are taken for the working well (Scheme A-GJ1), the seepage flow is as high as 1616.51 m^3/d, and the maximum exit gradient of the bottom rock layer is 5.16 (far exceeding the safety threshold), indicating a severe lack of permeability stability. When only internal grouting is taken but the depth is insufficient (Scheme A-GJ2), the seepage flow is reduced to 53.44 m^3/d, a decrease of 96.7%, but the self-weight anti-floating coefficient of the grouted rock mass is only 0.47 (insufficient anti-floating), and the risk of bypass seepage exists outside the barrel due to the lack of grouting. When the internal grouting depth is consistently increasing to 25 m and the curtain is deepened to the bottom elevation of 3.19 m (Scheme A-GJ3), the seepage flow inside the well is further reduced by 36.4% compared to Scheme A-GJ2, and the anti-floating coefficient is increased to 1.17 (meeting the requirements), but the risk of local permeability failure still exists outside the barrel due to the lack of grouting. As the external grouting depth gradually increases (Schemes A-GJ4 to 6), the seepage flow inside the working well is further reduced. When the external grouting depth is ⩾10 m (exceeding the bottom of the diaphragm wall), the grouted rock mass and the diaphragm wall form an integrated waterproof system, and the anti-floating coefficient stabilizes at 1.17, meeting the safety requirements. If the permeability coefficient increases from 1×10^{-5}cm/s cm/s to 1×10^{-4}cm/s, the seepage flow surges to 243.70 m^3 /d . In summary, the key to blocking bypass seepage and ensuring anti-floating stability is the coordinated deep grouting inside and outside the barrel (25 m inside + 10 m outside) and strict control of the permeability coefficient (1×10^{-5}cm/s).

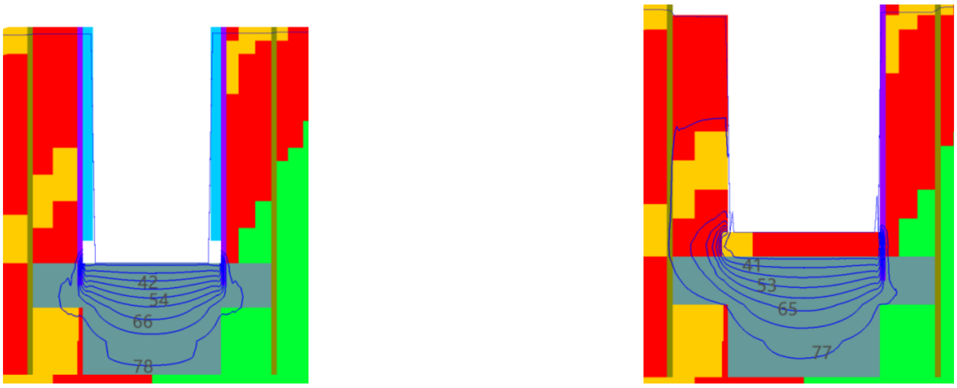
4.3 Impact of Diaphragm Wall on Seepage in Working Wells

The A-DLQ series of schemes are designed to assess the impact of diaphragm wall defects on seepage during single-barrel excavation. In Scheme A-DLQ1, the working well is excavated to the lowest elevation of 28.19 m, with the diaphragm wall construction quality assumed to be intact and a permeability coefficient of 1.0×10-7cm/s. In Scheme A-DLQ2, the permeability coefficient of the diaphragm wall is increased to 1.0×10-6 cm/s due to poor wall formation quality, with all other conditions being the same as in Scheme A-DLQ1. In Scheme A-DLQ3, when Well A is excavated to 33.19 m, a gap exists in the diaphragm wall within the fine sandstone towards the Qinglinjing Reservoir direction at the elevation of 29.19﹣28.19 m. The gap measures 1 m in height, 1.5 m in width, and 1.2 m in thickness, with the permeability coefficient at the gap taken as that of the surrounding rock. In Scheme A-DLQ4, when Well A is excavated to 33.19 m, a gap exists in the diaphragm wall towards the Qinglinjing Reservoir direction due to joint failure, spanning from an elevation of 85 m to 23.19 m. The permeability coefficient at the gap is taken as that of the surrounding rock. The results of the seepage simulation calculations are shown in Table 4.

Table 4 Calculation results of the effect of ground-connected wall on seepage in the working well

Number	Excavation Condition	Retaining Structure	Defect Conditions of Diaphragm Wall	Flow Rate of A Shaft（m^3/d）	Maximum Gradient
A-DLQ1	Shaft A is excavated alone to the lowest elevation of 28.19m.	Cutoff curtain + Diaphragm wall + Grouting inside the shaft for 25m and outside the shaft for 10m + No bottom sealing, diaphragm wall without defects	No defects, permeability coefficient 1.0×10^{-7}cm/s	29.31	/
A-DLQ2		Poor wall quality, diaphragm wall permeability coefficient 1.0×10^{-6} cm/s, other conditions same as A-DLQ1	Poor wall quality, diaphragm wall permeability coefficient 1.0×10^{-6}cm/s	35.90	/
A-DLQ3	Shaft A is excavated alone to the lowest elevation of 33.19m	Local defects exist at elevation 29.19m to 23.19m, defect size 1m (height) × 1.5m (width) × 1.2m (thickness), other conditions same as A-DLQ1	Local defects exist at elevation 29.19m to 28.19m, defect size 1m (height) × 1.5m (width) × 1.2m (thickness)	69.06	0.99
A-DLQ4		Local defects exist at elevation 85m to 23.19m, defect size 1.5m (width) × 1.2m (thickness), other conditions same as A-DLQ1	One joint failure at elevation 85m to 23.19m, defect size 1.5m (width) × 1.2m (thickness)	127.54	0.69

Table 4 shows that the impact of the diaphragm wall permeability coefficient on the seepage flow in the working well is much lower than that of quality defects. Figure 5 illustrates the equipotential line distributions for various diaphragm wall schemes. When a local gap exists in the diaphragm wall, the seepage flow in the working well more than doubles. The exit gradient of groundwater in the unexcavated fine sandstone drops to 0.99. Moreover, it is evident from Figure 5b that the equipotential lines bulge outward at the defect location, indicating a weakened waterproofing effect. When the diaphragm wall joint fails on the side adjacent to the Qinglinjing Reservoir, and there is a vertical gap extending from the top to the bottom at the joint, the exit gradient of groundwater at the bottom slab elevation of 33.19 m is 0.69. For this scheme, the seepage flow in the working well increases to 127.54 m^3 /d, which is approximately double compared to that with a local defect. Thus, it is evident that the quality of the diaphragm wall is crucial for the seepage safety during the excavation of the working well.



a. Distribution diagram of equipotential lines of cylinder A in scheme A-DLQ1

c. Distribution of equipotential lines of cylinder A in scheme A-DLQ4

Fig.5 Distribution of equipotential lines of different ground-connected wall schemes

4.4 Analysis of Grout Curtain Impact Calculation Scheme

The grout curtain series of schemes A-WM serves as a comparison to the diaphragm wall series of schemes A-DLQ. The purpose is to analyze and calculate the seepage of groundwater in the working well when there are defects in the diaphragm wall, such as reduced curtain depth or missing curtain sections, in order to assess the impact of the grout curtain. The simulation calculation results are shown in Table 5. Schemes A-WM1 and A-WM2 correspond to Scheme A-DLQ1 to analyze the impact of the grout curtain and a shortened grout curtain on seepage in the working well. Scheme A-WM1 has no grout curtain; Scheme A-WM2 includes a grout curtain, but the curtain is shortened by 15 m, with the same bottom elevation and the grouted layer outside the barrel at 18.19 m. Scheme A-WM3 corresponds to Scheme A-DLQ2 but lacks a waterproof grout curtain, with the overall diaphragm wall quality being poor, resulting in an increased permeability coefficient to 1.0×10-6cm/s, to analyze the role of the grout curtain when the diaphragm wall permeability coefficient increases. A-WM4 corresponds to Scheme A-DLQ3, with no waterproof grout curtain, and Well A excavated to 33.19 m, featuring a gap in the diaphragm wall in the fine sandstone towards the Qinglinjing Reservoir direction from an elevation of 29.19 m to 28.19 m, to analyze the impact of the grout curtain on seepage in the working well area when there is a local gap in the diaphragm wall. Scheme A-WM5 corresponds to Scheme A-DLQ4, with no waterproof grout curtain, and Well A excavated to 33.19m, featuring a gap in the diaphragm wall in the fine sandstone towards the Qinglinjing Reservoir direction from an elevation of 85 m to 23.19 m, to analyze the impact of the grout curtain on seepage in the working well area when there is joint failure in the diaphragm wall.

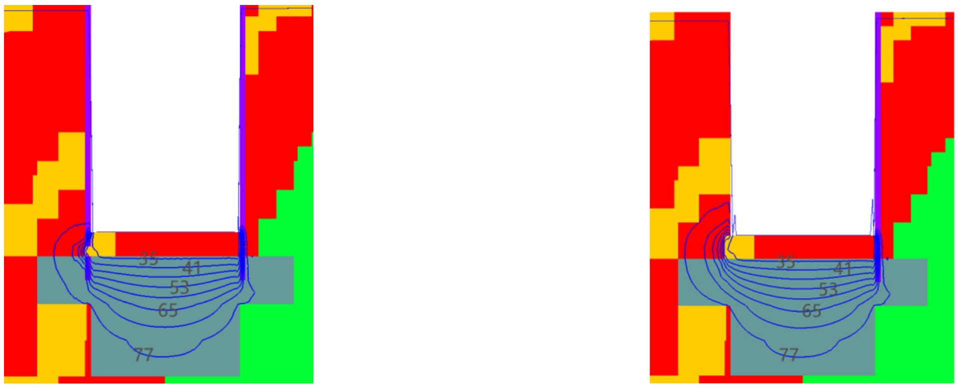
Table 5 Calculation results of the effect of the curtain on seepage in working well excavation

Number	Excavation Condition	Scheme Description	Flow Rate of A Shaft （m3/d）	Maximum Gradient of Groundwater Emergence
A-WM1	Shaft A is excavated alone to the lowest elevation of 28.19m	No cutoff curtain, other conditions same as A-DLQ1	29.37	/
A-WM2		With cutoff curtain, curtain depth reduced by 15m, bottom elevation 18.19m, other conditions same as A-DLQ1	29.33	/
A-WM3		No cutoff curtain, diaphragm wall permeability coefficient 1.0×10^{-6} cm/s, other conditions same as A-DLQ2	36.25	/
A-WM4	Shaft A is excavated alone to the highest elevation of 33.19m	No cutoff curtain, gap in the diaphragm wall on the Qinglinjing Reservoir side at elevation 29.19m to 28.19m, other conditions same as A-DLQ3	75.34	1.12
A-WM5		No cutoff curtain, local defects in the diaphragm wall on the Qinglinjing Reservoir side at elevation 85m to 23.19m, defect size 1.5m (width) × 1.2m (thickness), other conditions same as A-DLQ4	146.25	0.84

Table 5 shows that when the diaphragm wall is intact, the absence or reduced depth of the grout curtain has almost no impact on the seepage flow in the working well. When the permeability of the diaphragm wall increases, comparing with Scheme A-DLQ2 which has a grout curtain, the seepage flow of groundwater increases by only 1% from 35.90 m³/d, further demonstrating the importance of an intact diaphragm wall. When the diaphragm wall exhibits local defects and no grout curtain is installed, the seepage flow in the working well significantly increases by 9.1% to 14.7%. In combination with the equipotential line distribution of seepage in the working well with a grout curtain (Figure 6), it can be seen that the grout curtain can only partially reinforce the seepage channels in the rock mass and cannot fundamentally address the seepage risks caused by wall defects.

a. Distribution diagram of equipotential lines in working wells in Scheme A-WM1

b. Distribution diagram of equipotential lines in working wells in scheme A-WM3



c. Distribution diagram of equipotential lines in working wells in Scheme A-WM4

d. Distribution diagram of equipotential lines of working wells in Scheme A-WM5

Fig.6 Distribution diagram of seepage equipotential lines in working wells of curtain series scheme

5. Conclusion

Based on the "geology-structure-construction" multi-factor coupled seepage control optimization model established for the Qinglinjing Pumping Station working wells, this essay investigates the main controlling factors of the seepage field and the influence mechanism of excavation methods, and draws the following conclusions:
(1) If the retaining structure does not form a complete closed waterproofing system, the water level of the Qinglinjing Reservoir will have a significant impact on the seepage flow during the excavation of the working well.
(2) The diaphragm wall plays a primary role in controlling the seepage of groundwater during the excavation of the working well. When the diaphragm wall has defects, it will lead to an increase in the seepage flow within the barrel and a greater exit gradient at the defect location, thereby increasing the seepage risk.
(3) It is necessary to grout the rock mass below the lowest excavation base plate in advance during the excavation of the working well. It is recommended to grout the rock mass outside the barrel in advance and appropriately increase the grouting depth inside the barrel so that the grouted rock mass inside and outside the barrel and the diaphragm wall form an integrated waterproofing system.

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