Security and Management in Modern Civil Engineering
Volume 1, Issue 1, No. 2
Received 20 April 2022; Accepted 18 June 2022
Published Online June 25 2022

Research on seepage volume calculation of foundation pit with drop waterproof curtain

Xiaola Feng[1,2], Jiaojiao Cai[1], Zonghai Xiong[1,2]
[1]Department of Engineering, China University of Geosciences, Wuhan, Hubei, China
[2]Wu Han Feng Da Geological Engineering Ltd, Wuhan, Hubei, China

Abstract. The seepage volume calculation of foundation pit with drop waterproof curtain is a difficult technical problem due to the leakage. In this paper, the existing methods of the seepage volume calculation are summarized and analyzed. Then an operable and practical method, named method of apparent parameter, is proposed. Then this method is applied to a practical project in Wuhan for the calculation of apparent parameter and seepage volume. In the meantime, the actual sealing effect of the drop waterproof curtain has been evaluated. The calculation results are in accordance with the reality, which shows the method of apparent parameter is practicable to use for foundation pit dewatering design and actual sealing effect evaluate. The method of seepage volume calculation for the project example can be used for reference of the similar engineering projects.

Keywords. drop waterproof curtain, foundation pit dewatering, seepage volume, method of optimized apparent parameter.

1. Introduction

In recent years, the precipitation methods combing ultra-deep drop (also known as rock-embedded or closed) water curtain with deep well points for precipitation are widely adopted in the deep foundation pit project in Wuhan and other regions. However, due to the leakage of the waterproof curtain, seepage volume calculation of the foundation pit with drop waterproof curtain is still a technical problem to be solved.

At present, only a handful of scholars have studied this problem. In this paper, the existing research results are summarized and contrasted. On this basis, an optimized practical parameter method is proposed. In the end, a deep foundation pit engineering project in Wuhan is taken as example, and the apparent permeability coefficient and seepage volume are calculated by the improved apparent parameter method. In addition, the seepage effect of water curtain is evaluated by the calculation of water stop coefficient and compared with that of actual engineering effect.

2. Summary of existing calculation method

2.1. Complete closure method

As for the calculation of seepage volume of foundation pit (also called closed pit) under drop waterproof curtain, a calculation formula for the ideal closed pit precipitation can be found in the Excavation engineering handbook[1]. In this case, the waterproof curtain completely isolates the internal and external hydraulic connection, groundwater outside the foundation pit can’t enter the pit, this formula only takes the water yield of aquifer within the closed pit into consideration.

This method of calculating the seepage volume of foundation pit is to regard the closed pit as completely closed, but as there is no absolute water-resisting layer, and the construction technology is limited, the construction of underground continuous wall can be perfect, especially at the seams, these imperfections will develop into gushing points during the precipitation, causing the groundwater outside the pit flood into the pit. To sum up, this method is inapplicable for engineering practice.

2.2. Empirical coefficient method

Considering the seepage effect of waterproof curtain, the current practice of foundation pit dewatering design usually do some reduction based on the calculation result of the open pit seepage volume (reduction factor depends on the designer's engineering experience). This method is called the empirical coefficient method.

The seepage volume calculated by this traditional method is inaccurate and lacks of reliable theoretical basis.

2.3. Leakage analysis method

According to the previous research, the seepage volume of deep foundation pit with drop waterproof curtain is mainly determined by the water-bearing capacity Q0 of the original aquifers in the enclosed foundation pit, the potential sidewall leakage Qc and the bottom- Rock fissure leakage Qd [2]. Based on this, a new idea to calculate the seepage volume of foundation pit from the determinant of leakage is proposed.

This method takes the dynamic process of precipitation and recharge into consideration, but the calculation of seepage volume of each part still needs further study.

2.4. Equivalent suspension method

Xu Yangqing [3] et al. proposed a method to concentrate the uncertain leakage point on the drop waterproof curtain in the numerical simulation analysis, which takes the waterproof effect of drop waterproof curtain equivalent to a certain length of hanging waterproof curtain, and uses a three-dimensional numerical model of groundwater seepage movement to simulate the flow field of foundation pit with drop waterproof curtain after the centralized treatment. Therefore, this method is called "equivalent suspension method."

This method provides a new idea for the numerical simulation of foundation pit precipitation with drop waterproof curtain. However, the method is very complicated and more applicable to scientific research rather than engineering practice.

2.5. Apparent parameter method

The permeability coefficient is one of the most important parameters in the design of foundation pit. Theoretically, if the shape and size of soil granular, particle gradation and the viscosity of the groundwater are determined for certain aquifer in the foundation pit, then the permeability coefficient shall be determined. Considering the effect of waterproof curtain on the groundwater seepage field around the foundation pit and its waterproof effect, the author of this paper proposes the concept of apparent permeability coefficient K’, and its value is calculated by the pumping test and connectivity test before and after the establishment of waterproof curtain [4].

In the process of calculating the apparent permeability coefficient, the pumping test used in obtaining the parameters is complicated. It is necessary to carry out pumping test and connectivity test on the same group of test wells before and after the establishment of waterproof curtain. Firstly, it is difficult to meet the requirements of the test in practical engineering; Secondly, the calculation process of apparent permeability coefficient (including a large number of coefficients) is very complicated and difficult, and many human factors are involved in the calculation, affecting the objectivity and accuracy of the result.

3. Optimized apparent parameter method

In order to solve some problems of apparent parameter method, a new calculation method of apparent permeability coefficient is proposed below to optimize apparent parameter method.

The calculating parameter of this method is also obtained from field tests, but the only test required is the connectivity test after the establishment of the waterproof curtain. As the permeability of the waterproof curtains such as the underground continuous wall are very uneven, the data obtained from two observation wells in the same pumping well and different positions outside the pit usually can’t reflect the same permeability, so the connectivity test shall have 2 experiment wells of each group, including a pumping well in the pit and an observation well outside the pit, the well layout is shown in Figure 1.

As single-well pumping exerts a less impact on groundwater level outside of the pit due to the influence of drop waterproof curtain, so the test should meet two basic conditions: ① the layout of experiment wells should be close to the waterproof curtain, far distance from the waterproof curtain is not suggested, ② groundwater level should be relatively unaffected by other factors. In practical engineering, due to limited space, it is quite common to meet the first distance requirement; while the second requirement can be meet only when the aquifer for precipitation is confined aquifer.

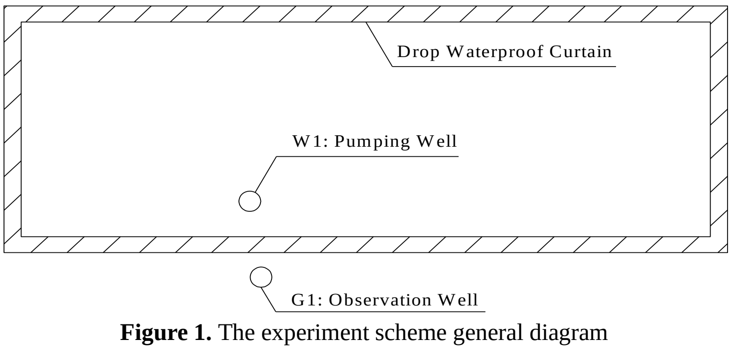

Figure 1. The experiment scheme general diagram

The calculation formula of permeability coefficient [1] can be determined by the pumping test of single observation hole:

partially penetrating well: $$K = \frac{0.16Q\left[\ln\frac{r_1}{r_w} + 0.5(\xi_0 - \xi_1)\right]}{M(S_w - S_1)} \tag{1}$$

fully penetrating well: $K = \frac{Q}{2\pi M\left(S_{w} - S_{1}\right)} \ln \frac{r_{1}}{r_{w}}$ (2)

Where:

K: Permeability coefficient, m/d;

Q: seepage volume of pumping well, m3/d;

M: thickness of confined aquifer, m;

*r*1: the distance between observation well and pumping well, m;

*r*w: the radius of the pumping well, m;

*S*1: Drawdown of observation well, m;

*S*w: Drawdown of pumping well, m;

*ξ*0、*ξ*1: correlation coefficient, related to parameters of precipitation well, can be determined by the chart

As can be seen from the formula, the factors that affect the permeability coefficient include seepage volume Q, confined aquifer thickness M, drawdown difference between pumping wells and observation wells (Sw-S1), the ratio of distance between observation wells and pumping wells to pumping well radius (r1 / rw), and the like. In the given test conditions, the amount of seepage volume and the thickness of the confined aquifer are determined. Therefore, only two observation wells are required to observe the water level descent and measure the distance between the observation well and the pumping well. In addition, relevant parameters are required to determine when using partially penetrating wells in the test.

The apparent permeability coefficient K' can be calculated by using the data observed in connectivity test:

$$\Delta S = S_{w} - S_{1}$$

$$r' = \frac{r_{1}}{r_{w}}$$

Then the apparent permeability coefficient:

partially penetrating well: $K' = \frac{0.16Q\left[\ln r' + 0.5\left(\xi_{0} - \xi_{1}\right)\right]}{\Delta SM}$ (3)

fully penetrating well: $K' = \frac{Q}{2\pi M\Delta S} \ln r'$ (4)

Where:

ΔS: The drawdown difference between observation well 1 and 2, m;

r': the ratio of the distance between observation well 2 and pumping well to that of observation well 1;

M, *Q*, ξ0, ξ1 are same as mentioned above.

The permeability of the waterproof curtains such as underground continuous wall are uneven, it is larger in the site of cracks, and smaller in sites with no cracks, so if test number is too small, the calculation result of apparent permeability coefficient will be inaccurate. In order to accurately reflect the effect of waterproof curtain on the permeability coefficient, the experiment wells shall be arranged along the waterproof curtain of foundation pit, through connectivity test, several sub-apparent permeability coefficients shall be obtained and their average value can be used as comprehensive apparent permeability coefficient.

The comprehensive apparent permeability coefficient (or sub-apparent permeability coefficient) K' can be obtained through the above calculation, and the apparent seepage coefficient λ can be defined as:

$$\lambda = \frac{K'}{K} \quad (5)$$

The obtained apparent seepage coefficient can be used to evaluate the seepage-proofing effect of segmented waterproof curtain and estimate the potential leakage point according to Table 1. The comprehensive apparent seepage coefficient can be used to evaluate the overall seepage-proofing effect of waterproof curtain, and be used in the following formula to calculate the seepage volume Q.

$$Q = \lambda Q_{1} \quad (6)$$

Where:

*Q*1: (open) foundation pit seepage volume when no waterproof curtain, m3/d.

Table 1. Waterproof effect grade division

Effect	Good	Medium	Bad
Apparent seepage coefficient λ	λ≤0.25	0.25＜λ≤0.50	λ＞0.50

4. Engineering example

4.1. Project overview

The deep foundation pit project is located in Qiaokou district of Wuhan City, between Jinghan Avenue and Shun Road, to the south of Wuhan International Convention and Exhibition Center. The foundation pit is close to the light rail, roads and residential buildings, excavation area is about 78702m2, general excavation depth of 18.45 ~ 20.45m under the site elevation, the pit depth is 2.525 ~ 5.300m. The importance grade of the foundation pit is grade one.

The foundation pit is excavated with open-cut construction method, and the surrounding deep-bottomed underground diaphragm wall is used as supplementary waterproof curtain. The wall is no less than 2 meters into the strong weathered mudstone. 97 wells with size of 50t / h were arranged in the foundation pit, and 23 observation wells were arranged outside the foundation pit.

4.2. Engineering geological conditions

The landform unit can be classified into Yangtze River I terrace. The surface layer is a set of 50 ~ 60m Quaternary Holocene alluvial strata, the surface is miscellaneous fill, the lower layer has a typical binary structure, from top to bottom are silt, silty clay, Silty sand, interbedded silt, silty fine sand (local clip silty clay), medium coarse sand gravel pebble, the underlying bedrock is Silurian mudstone, the stratigraphic section is shown in Figure 2.

The groundwater in the field area is mainly composed of upper stagnant water and interlayer confined water. The major influencing factor of excavation is the confined water in fine sand layer. During the investigation, the measured water pressure of the confined water in the observation well was 5.62m below the ground level, and the annual variation range of confined water head in the sandy soil layer of Wuhan Yangtze River terraces was between 3.0m and 4.0m. According to the hydrogeological investigation and pumping test report in the field area, the permeability coefficient K of the confined aquifer is 20m / d, and the influence radius is 235m. The pit bottom after excavation is located in the fine sand layer.

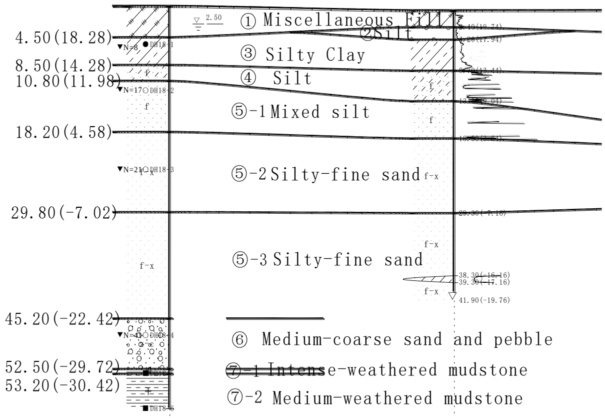

Figure 2. Geologic structure's longitudinal plan

4.3. Connectivity test scheme

According to the layout of foundation pit, this connectivity test was conducted in five groups, the experimental test arrangement of each group are shown in Table 2, well plan arrangement are shown in Fig. 3, the distance between the test wells and other information can be found in Table 3. The test wells are all partially penetrating well, each pumping about 7 hours, the water level is basically stable.

Table 2. Arrangement of experimental well

Group	Arrangement of experimental well	
Group 1	Pumping Well: SJ10	Observation Well: CJ16
Group 2	Pumping Well: SJ81	Observation Well: CJ13, CJ14
Group 3	Pumping Well: SJ21	Observation Well: CJ04, CJ05
Group 4	Pumping Well: SJ02	Observation Well: CJ01, CJ02
Group 5	Pumping Well: SJ37	Observation Well: CJ22

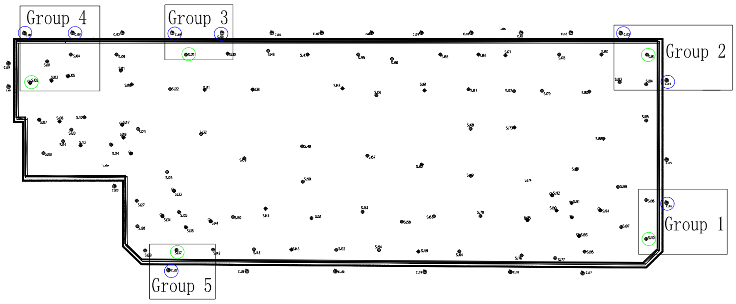

Figure 3. Experiment well plane arrangement chart
Table 3 Result of pumping test

4.4. Experiment results and analysis

According to the observation data of the connectivity test and the optimized apparent permeability coefficient method proposed in this paper, the apparent permeability coefficient of each group can be obtained according to the calculation formula of partially penetrating well, as shown in Table 3.

Table 3. Permeability coefficient of each group

Group	Pumping Well	Observation Well	Seepage volume /（m³/d）	Aquifer thickness/ m	Drawdown of Pumping Well / m	Drawdown of Observation Well/ m	Radius of Well *N* / m	Distance between pumping well and observation well / m	ε0	ε1	Apparent permeability coefficient /（m/d）
Group 1	SJ10	CJ16	1200	44	4.84	0.12	0.125	17	12.9	0.39	10.32
Group 2	SJ81	CJ14	1200	44	4.77	0.04	0.125	19	12.9	0.39	10.40
	SJ81	CJ13	1200	44	4.77	0.075	0.125	20	12.9	0.39	10.53
Group 3	SJ21	CJ05	1200	44	9.83	0.06	0.125	25	12.9	0.39	5.16
	SJ21	CJ04	1200	44	9.83	0.15	0.125	18	12.9	0.39	5.06
Group 4	SJ02	CJ02	1200	44	10.47	0.147	0.125	47	12.9	0.39	5.15
	SJ02	CJ01	1200	44	10.47	0.115	0.125	36	12.9	0.39	5.02
Group 5	SJ37	CJ22	1200	44	10.495	0.06	0.125	12	12.9	0.39	4.52

Based on the above results, the average apparent permeability coefficient can be obtained as 7.02m / d, then according to the precipitation experience in Wuhan [5], the total yield can be calculated by formula (6):

Where $Q_1 = \dfrac{2.73\,KMS}{\log\left(1+\dfrac{R}{r_0}\right)}$, K=20m/d, M=44m, S=16m. R=235m, $r0$= $\sqrt{A/\pi}$ =158.3m, λ=0.35, then calculated:

Q=33730m3/d

If 50t / h pumping well are used for precipitation, then 29 wells are needed.

In fact, in the excavation process, the number of wells opened during same period of time is up to 26. By comparison, it can be found that the error is within the allowable range of the project. Possible reasons for this error include: the impact of the curtain on the radius of influence is neglected; the number of test groups is too small and so on. But in general, it is reasonable to use this method to calculate the seepage volume and apply it into engineering practice.

In addition, the apparent permeability coefficient and the comprehensive apparent permeability coefficient obtained from the tests in different locations can be used to evaluate each section of waterproof curtain and the overall waterproof effect. The evaluation results are shown in Table 4.

It can be seen from the table that, seepage effect of the west side of the foundation pit waterproof curtain is significantly better than that of east side of the pit. According to site observation and monitoring of the foundation pit, the ground around the east side of the foundation pit shows settlement, particularly in the southeast side. This phenomenon may be caused by waterproof curtain seepage during process of precipitation in the pit, and it confirms the results shown in Table 4. Therefore, connectivity test and optimized apparent parameter method not only can be used for the calculation of seepage volume of foundation pit with drop waterproof curtain, but also can be used to effectively predict the seepage-proofing effect.

Table 4. The effect of waterproof

Group	Coefficient	Effect	Location
Group 1	0.52	Bad	East side
Group 2	0.52	Bad	East side
Group 3	0.26	Medium	West side
Group 4	0.23	Good	West side
Group 5	0.23	Good	West side
Overall	0.35	Medium	All pit

5. Conclusion

(1) The complete closure method is proposed based on the ideal closed pit and inapplicable to the actual project.

(2) At present, the seepage volume calculated by this traditional method is inaccurate and lacks of reliable theoretical basis.

(3) The leakage analysis method takes the dynamic process of precipitation and recharge into consideration, but the calculation of seepage volume of each part still needs further study.

(4) The equivalent suspension method provides a new idea for the numerical simulation of foundation pit precipitation with drop waterproof curtain. However, the method is very complicated and more applicable to scientific research rather than engineering practice.

(5) The field test required by the apparent parameter method is very complex and the process of calculating the apparent permeability coefficient is very complicated. A large number of coefficients are involved in the calculation, affecting the objectivity and accuracy of the result.

(6) Optimized apparent parameter method adopts relatively simple field test and calculation method to obtain the apparent permeability coefficient, calculating the seepage volume of foundation pit with drop waterproof curtain according to the apparent permeability coefficient, as well as evaluating the seepage effect of segmented or the overall seepage curtain. However, this method is mainly applicable to the case where the target layer for precipitation is a confined aquifer.

(7) Multi-point connectivity test should be conducted in similar foundation pit engineering projects by adopting optimized apparent parameter method in the pit foundation pit design, so as to obtain a more accurate apparent permeability coefficient for the timely detection of water curtain defects as well as the prevention of accident.

References

[1] LIU Guobing, WANG Weidong. Manual of foundation pit[M]. Beijing: China Architecture Building Press, 2009.

[2] FENG Xiaola, Cai Jiaojiao, Xiong Zonghai,el. Research on well group pumping test for foundation pit with drop waterproof curtain[J]. Hydrogeology & Engineering Geology, 2016, 44(6).

[3] XU Yangqing, LIU Guofeng, SHENG Yong qing. Analysis and evaluation of sealing effect of rock-socketed underground diaphragm in deep foundation pit[J]. Rock and Soil Mechanics,2013,34(10).

[4] FENG Xiaola, LI Dongguang. Quantitative study on the impact of foundation pit dewatering from the cut-off wall insert into impermeable layer[J]. Hydrogeology &Engineering Geology, 2013, 40(5).

[5] FAN Shi-kai, YANG Yu-wen. Groundwater control and practice of deep foundation pits in terrace along Yangtze River[J]. Chinese Journal of Geotechnical Engineering, 2010, 32 Supp.1