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Research on Radius Influence of Foundation Pit Dewatering Considering the Effect of Waterproof Curtain

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Abstract:

The design scheme of the casing well dewatering of a deep foundation pit in Xi’an loess region has been conducted. Changes of water level of observational wells resulted from the waterproof curtain in the period of dewatering stable has been analyzed. The radius influence of waterproof curtain has been calculated and compared through formula and graphic methods according to experimental data. Similarity could be found from the results, which shows great difference comparing with the calculation results through traditional method. Consequently, experiencing formula has been revised and corrected according to the radius influence of waterproof curtain on casing well. After that, the newly modified formula has been exemplified in one pit engineering in Wuhan, which could provide the reference on the engineering dewatering design and construction based on the conditions with similar parameters.

Keywords: *Waterproof curtain, Foundation pit dewatering, Radius influence.*

I. INTRODUCTION

Practice has proved that the selection and calculation of geotechnical parameters will have a great impact on the surrounding environment of foundation pit in the dewatering design of foundation pit engineering. Su Tao [1] discusses the principle and method of calculating the dewatering parameters of deep foundation pit according to the dewatering characteristics of binary structure in soft soil area. Chen Shulin [2] conducted a field pumping test in the North Anchorage Area using the unsteady flow theory of incomplete wells. The results show that the parameters such as permeability coefficient obtained by the graphic method with specific straight line conditions are broader than those obtained by the linear graphical method. Zhao Hao [3] solved the permeability coefficient through the field test of foundation pit in loess area, and the

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results were in good agreement with the assumed initial values. However, traditional empirical formulas such as Kusakin are mostly used to calculate the influence radius of actual projects. However, many engineering examples show that the influence radius of precipitation determined by traditional empirical formulas is generally wider than that of actual precipitation, and its accuracy is also poor, especially under the condition of setting water-stop curtain. Wang Cuiying [4] demonstrated the rationality of incomplete wells, and optimized the design and analysis of the influence radius, which is the key parameter of water inflow calculation. Taking the foundation pit with surrounding waterproof curtain as a large well with equivalent radius r_0 as well radius r_w, the calculation formula of the influence radius with hanging waterproof curtain was obtained：

$$R = r_w / \sin\left\{\left(\frac{\pi}{2}\right) \times \left(\frac{S_R}{S_W}\right)\right\} \tag{1}$$

S_R—The water level drops deep at the distance r=R from the well,

S_W—The designed well depth s is the draw down at the well point,

Obviously, the formula does not consider the influence of water-stop curtain depth on precipitation influence radius. In this paper, the dewatering of foundation pit with water-stop curtain is studied, the general parameters of dewatering in loess area of Xi 'an are adopted, the effect of water-stop curtain and the influence radius of dewatering are analyzed by field pumping test, and the influence of curtain depth on empirical formula is considered to be revised. The applicable conditions of the revised formula are verified by examples, which can provide reference for the parameters of dewatering design of similar projects in the future.

II. ENGINEERING CASE ANALYSIS

2.1 Engineering Brief

Tonghua gate Station of Xi 'an Metro Line 1 is located on the west side of the intersection of Jinhua North Road and Changle Road in Xi 'an, and the interchange station with Metro Line 3 in the middle and long term is built at one time, and the whole station is arranged in a "T" shape. The length of the station of Line 1 is 150.2m, the width of the standard section of the station is 22.7m, the excavation depth at the center line of the station is 24.54m, the structure height is 21.24m, and the covering soil thickness is 3.5m. The length of the station of Line 3 is 148m, the width of the standard section is 30.9m, the excavation depth of the foundation pit at the center line of the station is 17.51m, the structure height is 13.37m, and the covering thickness is 4.2m. The main retaining structure of the station adopts the scheme of bored pile+jet grouting pile waterproof curtain+internal support, and the supporting system adopts steel pipe internal support.

2.2 Engineering Geological and Hydrological Conditions

The site of Jinhua North Road Station is high in the east and low in the west, and the geomorphic unit is loess liangwa. The groundwater exposed by drilling belongs to diving type. Holocene artificial fill (Q_4^{ml}) with uneven thickness is uniformly distributed on the surface, with a

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thickness of 0.5m～10.50m;Under it are the upper Pleistocene aeolian (Q_3^{eol}) layer thickness of 3.00 ~ 10.10 m new loess, 3-1-2 layer of 0.70 ~ 5.00 m saturated soft loess (Q_3^{eol}) and 3.40 ~ 5.10 m residual (Q_3^{el}) paleosol. Next, the old loess with the thickness of 8.20 ~ 11.90 m (Q_2^{eol}), alluvial (Q_2^{al}) silty clay with the maximum exposed thickness of 15.70m and medium sand with the thickness of 0.60 ~ 4.10 m, etc. See fig. 1 for the profile of soil layer position.

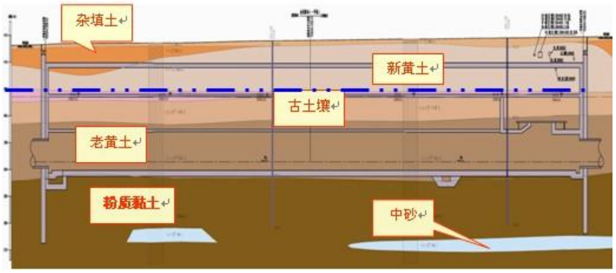

Fig 1: Profile of soil layer position

2.3 Foundation Pit Dewatering Scheme

According to the engineering geological and hydrogeological conditions and the environmental conditions of buildings around the foundation pit, the comprehensive scheme of tube well dewatering+observation well+recharge well is adopted for the foundation pit dewatering of Tonghua Gate Station, and the following factors are mainly considered:

(1)The aquifers within the depth range of foundation pit are mainly Q_3 loess, paleosol, Q_2 loess, sand interlayer and paleosol, etc. The comprehensive permeability coefficient is 5 ~ 10m/d, and the tube well dewatering scheme is adopted to ensure the effective pumping capacity of dewatering.

(2)According to the effect of water-stop curtain in Xi 'an, the water level outside the pit can be effectively controlled to drop by about 3m.

(3)Because there are many factors involved in foundation pit dewatering, in order to ensure its smooth progress, and to study the influence of setting water-stop curtain on foundation pit dewatering in this area, observation wells are arranged in the vicinity of dewatering wells.

2.4 Dewatering Design of Tube Well

2.4.1 Dewatering Design of Tube Well Without Considering Curtain Effect

According to the engineering geological survey report, combined with the actual experience of foundation pit precipitation in the loess area, the comprehensive soil permeability coefficient of this project is determined to be 8m/d. The depth of foundation pit of Tonghua Gate Station Line 1 and Line 3 is 25m and 18m respectively. The buried depth of current water level is 10m, the buried depth of control water level is 16m and 19m respectively, the precipitation depth is 18m and 9~10m, and the amplitude of groundwater level is 2m. The radius of dewatering well r_w=0.30m, and the thickness of aquifer H=40m.

(1)Equivalent radius r_0 and influence radius r of foundation pit

By formula

$$r_0 = 0.29 \times (a + b) \tag{2}$$

Then r_{01}=52.5m,r_{02}=53.65m。

By formula

$$R = 2S \times \sqrt{K \times H} \tag{3}$$

Get: R_1＝643m,R_2＝311m.

(2)According to the formula, the water inflow q of a complete submersible well is calculated:

$$Q = 1.366k\frac{(2H - S)S}{\lg(1 + R/r_0)} \tag{4}$$

ThenQ1＝10845 m^3/d,Q2＝5630 m^3/d,

Total water inflow Q＝16476 m^3/d.

(3)Single well water inflow q

Combined with the precipitation experience in Xi 'an, q = 360m^3/d (according to 15 m^3/h)

(4)Calculation of the number n of dewatering wells on Line 1 and Line 3

Then n1 = 33 and n2 = 18.

2.4.2 Precipitation Design Considering Curtain Action

(1)Calculation of water inflow of foundation pit

The basic parameters are the same as above, and the water inflow Q is calculated according to the following formula:

$$Q = 1.366k\frac{(2H - S)S}{2\lg(R + r_0) - \lg r_0(2b + r_0)} \tag{5}$$

According to the plan and profile of foundation pit, the distance between dewatering well and curtain is 3m.

According to the calculation, Q_1 = 5660m^3/d, Q_3 = 2870m^3/d, and Q = 8530m^3/d of the total water inflow of the foundation pit of Line 1.

(2)Number of dewatering wells

With the same single well water yield q = 360m^3/d, the number of dewatering wells in line 1 is n1 = 16, the number of dewatering wells in line 3 is n2 = 9, and the total water yield q = 16476m^3/d.

(3)Depth calculation of dewatering well

The neutral line depth of some foundation pit platforms on Line 1 is 24.68m, the depth of jet grouting pile is 28.328m, and the depth of embedded foundation pit is 3.65m. The depth of dewatering well on Line 1 is determined as 50m.

The depth of the center line of some foundation pits on Line 3 is 17.56m, the depth of jet grouting pile is 27.8m, and the depth of embedded basement is 10.4m. The depth of dewatering well is 35m.

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Obviously, considering the effect of curtain, the total water inflow of foundation pit is small, so the basic parameters of tube well dewatering in Tonghua Gate Station are determined as shown in TABLE I:

TABLE I. Parameters of dewatering well

Name	Well diameter(m)	Well spacing(m)	Well depth(m)	Number of wells	Head of water selection pump(m)
Line 1	0.8	16.5	50	21	40
Line 3	0.8	17.0	35	12	30

According to the total length of foundation pit and the number of dewatering wells, the average spacing of dewatering wells in Metro Line 1 is calculated to be 16.5m, and that in Metro Line 3 is about 17m. The well point position of Line 1 is shown in Figure 2:

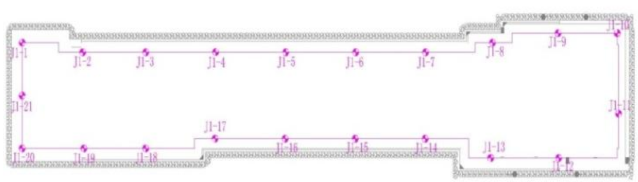

Fig 2: Location plan of dewatering well

III. ACTUAL MEASUREMENT AND ANALYSIS OF WATER-STOP CURTAIN EFFECT AND ITS INFLUENCE RADIUS

3.1 Analysis of Water Level Change of Observation Well Under Water-Stop Curtain

In order to know the influence radius of precipitation with water-stop curtain in loess area in detail, the field drilling test was carried out, and observation wells were arranged around the foundation pit, as shown in Figure 3. Through the experimental data, the hypothetical calculation was obtained. The influence radius of precipitation with curtain is determined to be 100m, which is far lower than the reference data of 260m provided by the foundation investigation report, indicating that the protection effect of water-stop curtain is obvious.

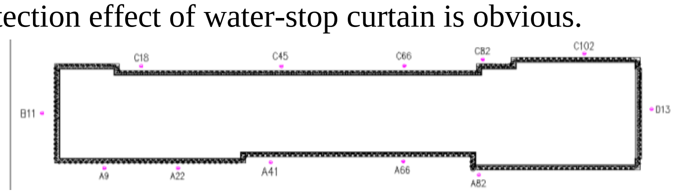

Fig 3: Plane position of site observation well

During the stable stage of foundation pit dewatering, the cumulative change of water level of observation wells arranged around the foundation pit is measured, as shown in Figure 4. It can be seen that the cumulative change of observed well water level in stable precipitation period is

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about 2m, of which A41 decreases by 3.66m, which is the maximum change of observed well water level. B11 water level drops by 1.57m, which is the minimum value of each water level change. According to the orientation of observation wells, the number of dewatering wells in the north side of the foundation pit is uniform, while the number of dewatering wells in the south side is less. Therefore, the water level in the north side of the foundation pit changes more than that in the south side and is greatly affected by the precipitation in the foundation pit, while the water level in the west side changes less.

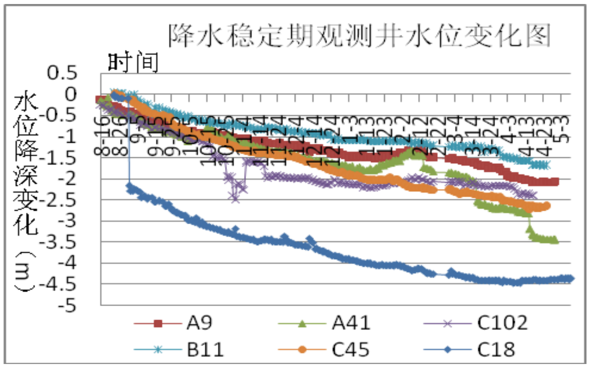

Fig 4: Water level change diagram of each observation well

3.2 Analysis and Calculation of Pumping Influence Radius

There are many empirical formulas for calculating the influence radius, but their accuracy is poor. Practice has proved that considering the large well loss and the influence of pumping aquifer change, it is more accurate to calculate the influence radius by using the formula of observed well water level draw down. The following empirical formula and foundation pit pumping test data are used to analyze and calculate the influence radius of foundation pit under the condition of setting water-stop curtain.

3.2.1 Calculation of Influence Radius without Water Stop Curtain

The influence radius of single well pumping test is determined by Kusakin formula and experience;

$$R = 2s_w\sqrt{hK} \tag{6}$$

In which:s_w ——After the pumping is stable, the water level in the pumping well drops deep, m;

h——Thickness of phreatic aquifer after pumping stability, m;

K——Permeability coefficient, m/d.

This formula is suitable for pumping water from large-diameter wells in sand phreatic aquifer, but the calculated value for small-diameter wells (drilling holes) is too small. In this project: precipitation depth s_w=18m, aquifer thickness h=35m, and comprehensive permeability coefficient K=8m/d ..

Then $R = 2s_w\sqrt{hK}$ $=2\times18\sqrt{35\times8}$ =602.4.m

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When the thickness of aquifer is not considered, the accuracy is poor, and the influence range of precipitation on the environment can be estimated by empirical formula (7) [5], while when the thickness of aquifer is large and the pumping time is long, more accurate results can be obtained.

$$R = 10 s_w \sqrt{K} \tag{7}$$

Then $R = 10 s_w \sqrt{K} = 10 \times 18\sqrt{8} = 509.1\text{m}$

According to formulas (6) and (7), the influence radius of precipitation is 602.4m and 509.1m, respectively, and these two formulas are calculated without considering the water-stop curtain in foundation pit precipitation.

3.2.2 Calculation of Influence Radius of Foundation Pit with Water-Stop Curtain

In order to study the true value of the influence radius of foundation pit dewatering under the water-stop curtain, some water level observation wells have been set around the station before excavation, and two dewatering observation wells JS1 and JS2 have been continuously added in different ranges from the vertical foundation pit. The plane position of the additional well is shown in Figure 5, and the water level measurement results are shown in TABLE II.

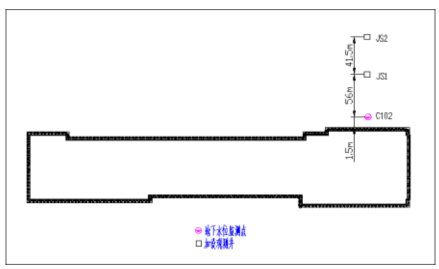

Fig 5: Add well plane position map

TABLE II. Add well parameter table

Well point number	Distance between well point and foundation pit edge(m)	Water level in well shop(m)	Water level draw down(m)
JS1	57.5	14.45	0.96
JS2	99	13.90	0.41
C102	1.5	15.70	2.21

Based on the above experimental data, the influence radius of pumping under the action of curtain is calculated by graphic method and formula method respectively.

Graphic method: based on the above data, a graph with the distance between observation point and foundation pit edge as X axis and water level drop depth as Y axis can be obtained, as shown in fig. 6.

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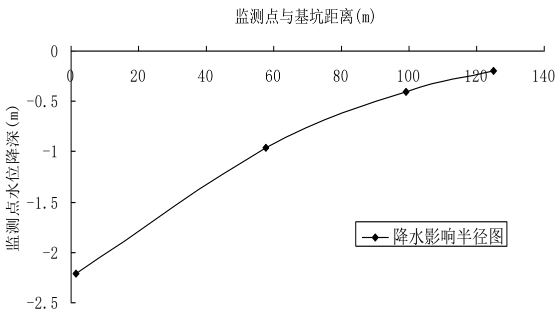

Fig 6: Precipitation influence radius map

Formula method: for phreatic aquifer with two observation well, the influence radius R can be calculated according to the following formula:

$$\lg R=\frac{s_1(2H-s_1)\lg r_2-s_2(2H-s_2)\lg r_1}{(s_1-s_2)(2H-s_1-s_2)} \quad (8)$$

$$=\frac{0.96(2\times 35-0.96)\lg 100.5-0.41(2\times 35-0.41)\lg 59}{(0.96-0.41)\times(70-0.41-0.96)}$$

$=2.177$

s_1, s_2—Depth of water level drop in observation well (m),

r_1, r_2—Distance from pumping well to observation well (m),

Calculate to get R=150.31 m

The above is a study on the influence radius of precipitation when pumping reaches a stable stage. It can be seen that the influence radius obtained by the above two methods is almost the same.

3.3 Influence of Water-Stop Curtain on Precipitation

The foundation pit adopts tube well dewatering. The depth of water-stop curtain formed by cast-in-place pile and jet grouting pile is 28m, the depth of foundation pit is about 25m, and the depth of filter tube of foundation pit dewatering well is 25.5～33m. Under this condition, the precipitation influence radius calculated by the above two methods is much smaller than the 602.4m and 509.1m calculated by the empirical formula, which is inconsistent with the actual construction. Therefore, it can be known that:

(1)Although the water-stop curtain is less than 4m deep into the bottom of foundation pit, the top of filter tube of dewatering well is only 2.5m higher than the curtain, and the bottom of filter tube is lower than the curtain with a height difference of about 5m, the water-stop curtain has changed the seepage direction of groundwater and extended the seepage path of groundwater, and its depth has reached the minimum value which can extend the seepage path of groundwater outside the foundation pit. By observing the change of water level in the well, it shows that it has effectively prevented the water level around the foundation pit from dropping too much and played an obvious role.

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(2)By analyzing the influence radius of foundation pit with water-stop curtain, the measured influence radius is very small compared with that without curtain, and the former is about 24.6% ~ 29.1% of the latter. It can be seen that water-stop curtain plays a very important role in reducing the influence of precipitation on the surrounding environment.

Because the waterproof curtain extends the seepage path of groundwater, the greater the depth of the curtain embedded in the foundation pit, the more obvious the water retaining effect and the smaller the influence radius of precipitation; When the curtain goes deep into the bottom of aquifer, it can be called the bottom-falling water-stop curtain. At this time, there is no water inflow outside the foundation pit, but only precipitation in the pit. Under the same pumping capacity, there is no water supply outside the pit, and the precipitation will reach a stable state as soon as possible. Therefore, the traditional calculation formula of influence radius can be improved by field experiments. It is considered that the influence radius of precipitation is inversely proportional to the depth of curtain embedded in foundation pit.

Let △h=h2-h1, μ, and α be empirical coefficients.

h_1 —Elevation of foundation pit bottom,

h_2 —Elevation at bottom water stop curtain,

If the thickness of aquifer is considered, the formula (6) can be improved as follows:

$$R = \mu \frac{s_w \sqrt{hK}}{h_2 - h_1} \tag{9}$$

Substituting the known data into equation (9), after calculation, we can get: μ=1.77. For this project, the permeability coefficient K=5~10, the value should be 1.37~1.94.

Then

$$R = 1.77 \frac{s_w \sqrt{hK}}{h_2 - h_1} \tag{10}$$

If the thickness of aquifer is not considered, the formula (7) is improved as follows:

$$R = \alpha \frac{s_w \sqrt{K}}{h_2 - h_1} \tag{11}$$

Substituting the known data into equation (11), we can get α=10 after calculation.

Permeability coefficient K=5~10, α=7.75~10.9. Then

$$R = 10 \frac{s_w \sqrt{K}}{h_2 - h_1} \tag{12}$$

For precipitation in foundation pits with curtains in loess areas and similar soils, it may be advisable to use formulas (10) and (12) to estimate and verify the influence radius. Because the influence of aquifer thickness is not considered in the actual dewatering process of foundation pit, only formula (10) is verified in practical engineering in this paper.

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IV. INSTANCE VERIFICATION

Taking the precipitation of a foundation pit project in Wuhan as an example, the influence radius of precipitation is verified [6]. The foundation pit is 120m long and 72m wide, and the excavation depth is about 18m. The underground diaphragm wall with a depth of 22m is used as the supporting structure of the foundation pit and also as the water stop curtain. According to hydrogeological data, the ground water in the site is mainly upper diving, diving and confined water. Confined water is mainly in fine sand and medium coarse sand layer, with the buried depth of pressure head 4m, and the dewatering well is also laid in pit, with the depth of dewatering well 38m and the filter tube of 17m. The parameters of each soil layer of this project are shown in TABLE III.

TABLE III. Parameters of each soil layer

Layer	**Clay, silty clay**	**Silt mixed with silty clay**	**Silty fine sand mixed with clay**	**Silty fine sand mixed with silty clay**	**Medium coarse sand**	**Medium coarse sand and mixed gravel**
Thickness(m)	9.0	2.0	7.0	8.0	15.5	12.5
Permeability coefficient (m/d)	0.04	0.2	3	4	14	20

The comprehensive permeability coefficient of the project is K=15m/d, the aquifer thickness H is considered as 26m, and the confined water level drops to 18.88m. The dewatering radius is about 172m, which is obtained by pumping test of pressure-bearing incomplete wells. Here, we use the modified formula (10) to get the pumping influence radius:

$$R = 1.77 \frac{s_w \sqrt{hK}}{h_2 - h_1}$$

$$= 1.77 \times \frac{18.88 \times \sqrt{26 \times 15}}{4} = 164.99m$$

It can be seen that it is close to the influence radius of 172m obtained by field pumping experiment. For this project, the modified formula can also be used as a reference for confined water with fine sand and medium coarse sand.

V. SUMMARY

Calculation parameters such as aquifer permeability coefficient and precipitation influence radius in foundation pit dewatering have important influence on foundation pit engineering design and subsequent construction safety. Sometimes, blindly carrying out dewatering design

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according to relevant formulas or look-up tables will inevitably lead to large errors, which will lead to failure of dewatering in foundation pits or affect the surrounding environment, especially when water-stop curtains are set. Based on the discussion of dewatering design scheme of a foundation pit tube well in loess area of Xi 'an and the change of water level of observation wells around the foundation pit during the stable period of dewatering, this paper analyzes the function of water stop curtain and the calculation method of influence radius. Based on the experimental data of precipitation in this foundation pit, the influence radius of precipitation with curtain is calculated by graphic method and formula method, and the results are consistent, but quite different from those calculated by traditional formula. Therefore, considering the depth of water-stop curtain, the traditional formula of influence radius of foundation pit precipitation is revised. Finally, the revised formula is verified by a foundation pit project in Wuhan, which shows the applicability of the formula and provides design and reference basis for foundation pit construction under similar conditions in the future.

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