Selection and Optimization of Mechanized Construction of Excavated Foundations

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Abstract. In this paper, a typical 220kV transmission line in mountainous terrain will be discussed as an example, to carry out the scheme selection and optimization research on the mechanized construction of the excavated foundation, and provides a theoretical basis for the whole process of mechanized construction.

Keywords-Mechanized construction, Excavated foundations, Transmission lines

1 INTRODUCTION

For a long time, there have been problems in line construction such as large labor investment, insufficient construction machinery research and development and investment, and lack of high-efficiency and dedicated construction machinery.Secondly, for the operators, the labor intensity is high, the efficiency is low, the construction period is long, and the operation risk is high, and some construction methods cannot fully consider the requirements of environmental protection[1-2].

Therefore, with the sustained and rapid economic and social development, the cost of human resources for power grid construction has increased significantly. Particularly, there is a shortage of front-line construction laborers, and their wages are also rising. At the same time, the State Grid has put forward higher requirements on the quality and duration of project construction. In terms of innovative design concepts and methods, safe and mechanized construction of the entire line, and reduction of labor input and operational risks, etc., certain improvements are needed. Thus, the quality and efficiency of project construction will be further improved, and the economic, environmental and social benefits will be enhanced. Judging from the existing transmission line construction operation mode, the link with the lowest degree of mechanization lies in the earthwork engineering and foundation engineering. The difficulty in improving the application level of mechanized construction lies in the transmission lines in mountainous areas, and it is impossible to apply existing construction equipment in other construction fields to line engineering.In this paper, a typical 220kV transmission line in mountainous terrain will be discussed as an example, to carry out the scheme selection and optimization research on the mechanized construction of the excavated foundation, and provides a theoretical basis for the whole process of mechanized construction[3-6].

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2 EXAMPLE:BASIC DESIGN CONDITIONS

The use of tower types for each tower position of a 220kV transmission line project is as follows in Table 1:

TABLE 1. BASIC FORCE PARAMETERS

Tower model	Downforce (kN)	X (kN)	Y (kN)	Pull-out force (kN)	X (kN)	Y (kN)	Tower position
SZC1	815	95	91	665	79	76	M1、M2
SZC2	996	120	113	796	100	94	M5、Z12
SZC3	1137	154	145	909	125	120	M4、Z11
SJC1	1602	265	236	1401	231	210	M3、Z24
SJC2	2068	357	325	1850	320	296	M6、Z21、Z22
SJC3	2160	406	363	1940	362	332	Z23
SDJC	2590	558	480	2376	472	506	Z25

Most of the route is located in the middle and low mountain and hilly areas. The landform units are mainly denuded hills and mountainous landforms, with some inter-mountain flats scattered here and there. Most of the areas where the route passes have well-developed vegetation, mainly including pine trees, fir trees, miscellaneous trees and shrubs.

The geological parameters of selected tower positions are shown in Table 2, and there is no groundwater in each tower position:

Due to the change of strata at different tower positions, the thickness of the soil layer is 4m for sandy cohesive soil, 5m for strongly weathered granite, and more than 10m for moderately weathered granite.

TABLE 2. FORMATION GEOLOGICAL PARAMETERS

Geological layer	q_{sik}	q_{pk}	C	Φ	γ	F_{ak}	Thickness
	kPa	*kPa*	*kPa*	°	*kN/ m³*	*kPa*	*m*
Silt	12～15		5～10	5～10	15～16.5	40～60	2～4(only one base)
Sandy Clayey Soil	30～50		20～25	18～22	17.5～18.5	160～220	2～6
Strongly Decomposed Granite	100～120	2000～3000	30～35	25～30	21～23	400～500	3～8
Moderately Weathered Granite	180～220	8000～10000			21～23	800～1000	＞10

3 BASIC TYPE SELECTION

The geographical location of the project is in the hilly area, the average buried depth of the weathered granite is about 5-14m, the cracks are developed, the upper part is sandy silty clay, and there is no groundwater. In general, two types of undisturbed soil foundations, excavation and excavated pile foundations, can be used to reduce the damage to the natural environment.

In this project, mechanically constructed tower positions are selected, and most of them basically have a pulling force between 660 kN and 3200 kN. Among them, the engineering quantities of the three types of foundations, which have a smaller pull-out force of 910 kN, 1850 kN, and 3200 kN, are selected for comparison. The comparison results are shown in Table 3. The amount of foundation reinforcement of the excavated pile foundation is higher than that of the fully excavated foundation, but the amount of concrete is much less than that of the fully excavated foundation. Combined with the background of this project, mechanized construction is more suitable for excavated pile foundation[7-8].

TABLE 3. COMPARISON OF EXCAVATION AND EXCAVATION PILE FOUNDATION ENGINEERING QUANTITY

Pull-out force(kN)	Project	Hole diameter（m）	Reaming diameter（m）	Calculation exposed（m）	Concrete（m^3）	Reinforcement（kg）
910	fully excavated	φ1.0	φ3.8	1.0	12.8	367.3
	excavated pile	Φ0.8	Φ0.8	1.0	6.5	841
1850	fully excavated	Φ1.4	Φ3.8	1.0	20.1	967.7
	excavated pile	φ1.0	Φ1.0	1.0	12.6	1945.7
3200	fully excavated	Φ1.8	Φ3.9	1.0	32.3	1329.8
	excavated pile	φ1.2	Φ1.2	1.0	17.5	2501.3

And in this project, where the covering layer is relatively thin and the entire bedrock is exposed, the rock bolt foundation is adopted as a complete medium to slightly weathered rock after on-site investigation.

4 DESIGN OPTIMIZATION OF EXCAVATED FOUNDATION

4.1General optimization measures

Because the rotary drilling bit of construction machinery is a shaped product provided by the equipment manufacturer, it cannot be set to any hole diameter like manual excavation, and the hole diameter difference is generally 0.2m. Therefore, it is necessary to determine a reasonable pile diameter suitable for the project, which can also reduce construction. Equipment input[9].

When the foundation is controlled by the pull-out force, a lower hole diameter can be used to increase the depth to meet the bearing capacity requirements of the foundation, and it can also reduce the amount of foundation work. The lower hole diameter d (pile length L1) and the higher level The relationship between the amount of foundation concrete for the hole diameter D (pile length L2) is $d^2 \times L_1 / (D^2 \times L_2)$. According to calculation results, the engineering quantity change caused by replacing the higher-level diameter with the lower-level diameter of the single-hole foundation are shown in Table 4 It can be seen from the table that reducing the hole diameter and increasing the buried depth can reduce the foundation engineering quantity.

Although the concrete of the small pile diameter foundation has been reduced, the area of the steel reinforcement has increased a lot, and the distance between the steel bars of the small pile diameter foundation cannot be satisfied. So the pile diameter cannot be adjusted much smaller.

TABLE 4. THE ENGINEERING QUANTITY AFTER THE DIAMETER CHANGE OF THE SINGLE HOLE FOUNDATION CONTROLLED BY THE PULL-OUT FORCE STABILITY

Original base diameter D（m）	φ1.4	φ1.3	φ1.2
Base diameter after change d（m）	φ1.3	φ1.2	φ1.1
Concrete percentage after change	92.9%	92%	91.7%
Reinforcement percentage after change	118.0%	118.5%	119.5%

When the foundation is controlled by the strength or displacement of the pile side soil, if the porous foundation with small diameter (d) is used instead of the single hole (D) foundation, a lot of engineering will be added due to the setting of the cap. However, the pullout force on the foundation of this project is relatively large, and the calculated reinforcement area of the corresponding piles is relatively large. Too small diameter cannot meet the requirements for reinforcement layout. Therefore, the minimum aperture of the multi-pile foundation is 1.0m. As a result, the amount of concrete and steel bars in the porous foundation is more than that in the single-hole foundation.The variation of the pile foundation with different numbers of holes on the type 2 corner tower of this project is shown in Table 5. According to the calculation results in the table, the excavation foundation with fewer holes is used, the more the engineering quantity is saved, and the specification of the cap can also be reduced , and reducing the amount of excavation of the cap base.

TABLE 5. CHANGES IN ENGINEERING QUANTITY AFTER POROUS FOUNDATION CONTROLLED BY PILE SIDE SOIL STRENGTH OR DISPLACEMENT CHANGES TO SINGLE HOLE FOUNDATION

Basic pull-out force	4915 kN	4915 kN	4915 kN
Base type	WJ14215	2J10190	4J10120
Number of holes	1	2	4
Diameter（m）	1.4	1.0	1.0
Hole depth（m）	21.5	19.0	12.0
Concrete（m3）	33.9	47.65	75.55
Reinforcement（kg）	5178.5	9351.9	8833.7

Because the foundation force of this project is relatively large, when the number of holes is small, the corresponding hole diameter must also be large relatively, too. Moreover, this project is a mountainous terrain, and the end of the foundation will be embedded in the moderately weathered rock formation. In the case of large diameter, the required rotary excavation torque will be greater, which will result in dependence on large mechanical equipment. Therefore, the maximum diameter is considered to be 1.4m.

If the effect of reaming diameter at the bottom of pile is included in the excavated pile foundation, the pull-out capacity of the foundation can be increased to about "1+5(D-d)/h" times (hole depth is h). In this project: the end of the foundation is often embedded in the moderately weathered rock formation, and its saturated uniaxial compressive strength is greater than 10MPa. Considering the parameters provided by the mechanical equipment manufacturer and the experience of previous pilot projects, reaming diameter at the bottom of pile is not recommended, to prevent reduce mechanical loss. If the bearing capacity of the foundation is insufficient, it can be solved by increasing the depth of the foundation during foundation design.

4.2Polyline excavated foundation

When the exposed height of the foundation is greater than 1.5 meters, in order to reduce the adverse effects of the horizontal force, a broken-line pile foundation structure can be adopted, as shown in Figure 1, the slope value of the broken line at the inclined upper section 2 of the pile top can be based on the horizontal force transmitted from the upper structure The ratio of H to the vertical force is adjusted.

Calculation method: set the height of the inclined upper section 2 as L, the eccentricity of the inclined upper section 2 (that is, the horizontal distance between the upper end surface center O2 of the inclined upper section 2 and the upper end surface center O1 of the inclined lower section 1) as e, and the horizontal force H , the vertical force N, and the self-gravity G1 of the inclined upper section 2, the bending moment is equal to the difference between the positive bending moment M1 and the negative bending moment M2. And M1=H×L, M2=N×e+G1×e/2, the calculation schematic diagram is shown in Figure 2. Compared with ordinary pile foundations, the polyline pile foundation structure reduces the horizontal load effect, and reduces the calculation of the bending moment value at the ground without increasing the horizontal and vertical loads, thereby improving the bearing capacity of the foundation. The rest of the calculation method is consistent with ordinary pile foundation.

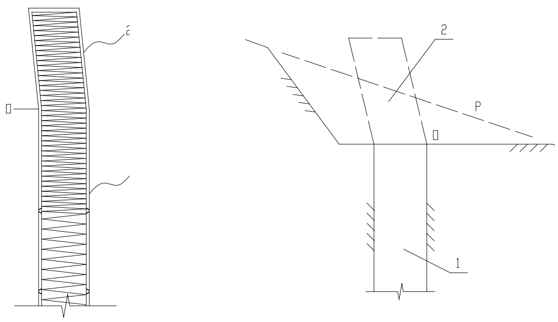

Figure 1. Schematic diagram of polyline pile foundation

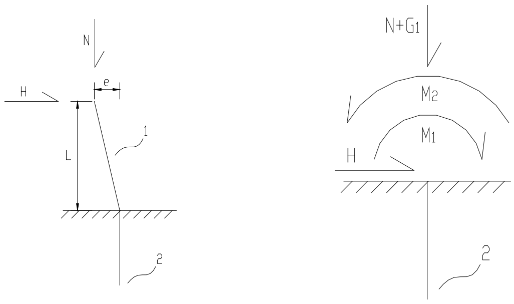

Figure 2. Schematic diagram of polyline pile foundation force

4.3Variable cross-section excavated foundation

The drilling efficiency of is determined by the pore size and the saturated uniaxial compressive strength of the rock formation. For example, in a moderately weathered hard rock formation, the smaller the pore size, the easier it is to form a hole, and vice versa.It can be seen from the previous analysis that, under the same index requirements of the foundation bearing capacity, increasing the buried depth can reduce the increase in the engineering quantity, compared with increasing the hole diameter or the number of holes, but it increases the difficulty of digging holes, especially in moderately weathered rock formations.To solve this problem, variable section pile foundations can be used. As shown in Figure 3, in the soil and strong weathered rock formations that are easy to drill holes with a drilling rig, a larger pile diameter can be used.It can make full use of the side resistance of the undisturbed soil foundation to resist the pull-out force and compression loads of the iron tower. Moreover, the larger pile diameter at the upper part can effectively reduce the displacement of the pile top.And in moderately weathered rock formations, it is difficult for large diameter piles to drill into moderately weathered rock formations, limited by the maximum power and torque of the equipment. Therefore, a smaller pile diameter can be used to continue drilling, and the main reinforcement of the pile with a small diameter in the lower part should be flared into a trumpet shape and welded with the main reinforcement of the upper pile[10-11].

Their calculation method as followed: when calculating the upper larger diameter pile, the variable section surface is regarded as the consolidation end, and the other calculation methods are the same as the conventional pile calculation method.For the lower pile, the strength and reinforcement of the lower pile are calculated based on the load at the variable section of the pile. The anchorage length of the main reinforcement of the lower pile extending into the upper part is calculated by combining the vertical force, horizontal force and bending moment at the variable section and the length required by the structure.

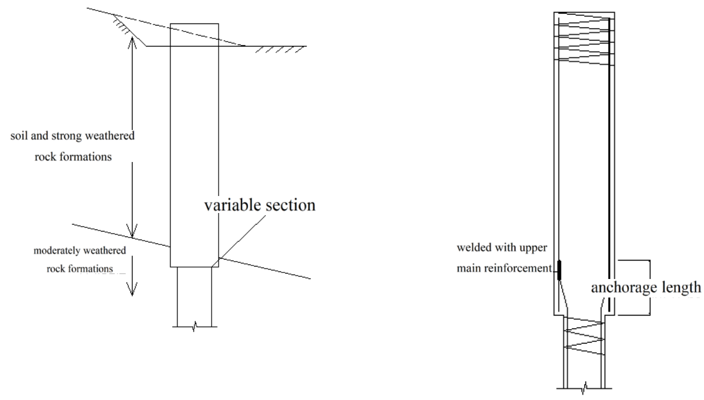

Figure 3. Schematic diagram of variable section pile foundation

4.4Test and result

The test of uniaxial uplifting or uplifting combined with horizontal load were conducted on the digged foundation with different foundation and sizes, the ultimate load, displacement values, load-displacement curves , the crack distribution characteristics of the surface, and typical failure mode of the digged foundation under limit state were analyzed. Combined with the basic displacement limit that affected the normal use function of the upper tower structure, the bearing characteristics and the most unfavorable limit state of the excavation foundation under the uplift condition were studied[12] . The research showed that the relationship between the uplifting load and the displacement of the excavation foundation was steep and brittle failure. The bearing failure was mainly caused by the overall shear failure of the foundation soil. The foundation cracking failure did not affect the normal use of the excavation foundation and the superstructure. That is to say, the excavation foundation was the first to exceed the limit state of the bearing capacity of the foundation.

5 CONCLUSIONS

- The maximum design diameter is 1.2m, the minimum diameter is 1.0m, and the step difference is 0.2m, so as to reduce the hole diameter specification as much as possible.
- It is not recommended to expand the bottom of the excavated foundation of this project. If the bearing capacity of the foundation is insufficient, it can be solved by increasing the buried depth of the foundation during foundation design.
- The single-hole foundation with small hole diameter is preferred. By increasing the burial depth to meet the bearing capacity requirements, the advantage of greater excavation depth for mechanical construction can be brought into play. When the single-hole foundation does not meet the bearing capacity requirements, consider choosing a porous foundation with a

small number of pores. The pore size of the porous foundation should be reduced as much as possible without increasing the number of pores.

- When the foundation exposure height of the terrain where the tower is located is greater than or equal to 1.5 meters, a polyline excavation foundation is used. If the exposure height is small, the anchor bolts are arranged eccentrically to reduce the horizontal load effect, thereby reducing the hole diameter.
- When the lower end of the excavated foundation enters the moderately weathered rock formation, the variable.
- The parameters such as the depth of the foundation of the transmission tower and the diameter of the base of the transmission tower were designed according to the limit state of the bearing capacity of the foundation，the basic force could be calculated according to the corresponding state load combination，and the basic combination controlled by the variable action was mainly adopted.

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