Research on Foundation Type Selection of Overhead Transmission Lines under Different Environmental Conditions

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Abstract. The foundation engineering is an important part of the transmission line engineering system, which has a direct impact on the safe operation of the line project. According to different topography and geological conditions, this article draws a conclusion of foundation type that are more in line with technical conditions and actual conditions under different environmental conditions through comparing and studying various applicable foundations. It aims to provide certain reference significance for the selection of transmission line foundations.

Keywords: foundation type, selection, Geology, topography.

1. Introduction
The transmission line is an important part of the power grid, and the foundation of the iron tower is the main part of the line project, which accounts for about 30\% of the Ontology engineering cost. In different regions and different geology, the bearing capacity of the foundation varies greatly, resulting in the large difference of cost on the foundation part (including earth-rock excavation and foundation pouring). Data of project settlement in recent years shows that the investment waste caused by improper foundation selection is obvious. Therefore, on the basis of economic rationality, it is conducive to shortening the construction period, controlling the cost, enabling the effective use of resources, and promoting the sustainable development of power grid construction within the method of selecting iron tower foundation types with advanced technology, convenient transportation, environmental protection, safety and reliability, and optimizing design.

The boundary conditions of the foundation parameters are firstly set, that is, the force in the typical design tower type is used as the design load of the foundation, and foundation types of three common topography types are selected for parameter calculation. Making calculation of the foundation cost according to the technical indicators, and then choose a reasonable plan to control the project cost after economic comparison.
2. Common topography and common foundation types

2.1. Common topography

The topography division of overhead line engineering mainly includes flat land, undulating topography and mountain topography. Compared with the flat land, the unit investment of undulating topography and mountain topography projects is much larger, especially in the performance of foundation projects. The correctness of the foundation selection is not only related to the safety and quality of the project, but also plays a crucial role in controlling the cost.

In addition to the flat land, the tower base mainly has two topography: undulating topography (with and without water) and mountain topography. In this paper, typical foundation calculations and economic comparisons are conducted for these three situations.

2.2. Common foundation types

The foundation types are generally divided into two categories: undisturbed soil foundation and excavation backfill foundation, according to the excavation method of the foundation pit and the degree of disturbance to the rock and soil body. The characteristics of the two foundation types are analyzed as below.

(1) Undisturbed soil foundation

There are two main types of undisturbed soil foundation: excavated foundation and pile foundation. The excavation foundation type is mainly straight excavation foundation, which can be divided into full excavation and half excavation.

The pile foundations are mainly drilled bored pile foundations and artificially excavated pile foundations. Drilling bored pile foundations are generally used in poorly soiled, deep-supporting plastic and soft-flow plastic paddy fields and river network areas and river crossing locations that need to resist water erosion and drifting objects, etc. Pile holes may be punched by the punch of a punching machine to form holes. The foundation construction requires large-scale machinery and tools, which require high construction technology and difficulty in construction. After pile formation, foundation pile integrity testing or timely bearing capacity testing is required, and the requirements for entry and exit of hole-forming machinery are high, and the construction cost is high. Common types of such foundations include single pile, double pile cap, multiple pile cap and single pile connecting beam. Artificial digging pile foundation is suitable for deep groundwater and strong weathered rock tower with the advantage of small excavation volume and little damage to the environment. In the construction of artificial digging pile foundation, the construction of cast-in-place concrete wall with reinforced ribs needs to be completed. Generally, the low strain method is used to check the integrity of the pile body. The length of the foundation pile is usually not greater than 15m.

(2) excavation backfill foundation

The excavation backfill foundation mainly includes slab foundation, stepped foundation and combined foundation.

According to whether the foundation column is inclined to the center of the tower, the slab foundation can be divided into a straight column foundation and an inclined column foundation. According to the appearance characteristics of the bottom plate, it can be divided into an expansion foundation and a step foundation. When the groundwater is buried shallowly, a straight column foundation should be used to reduce the difficulty of supporting formwork.

The stepped foundation is generally used for foundations with good bearing capacity and low compressibility, which can be divided into straight column type and inclined column type. At present, such foundations are only used in towers with special conditions such as high groundwater levels.

The combined foundation is suitable for tower foundations with high groundwater level and shallow burial, which is difficult to excavate and form, and prone to uneven settlement. The excavation of the foundation pit is generally within 3m.
3. Foundation type selection under different environmental conditions

3.1. Comparison and selection of foundation economic technology for Undulating topography (with groundwater)

For the undulating topography, there are mainly two types of foundations: straight column slab foundation (with groundwater) and cast-in-place pile foundation. In order to make comparison of the economics, two typical towers of Z27102A and J27102A are calculated respectively, and conduct economic and technical comparison analysis.

The surface soil is silty clay, and the mechanical characteristics are plastic. The groundwater level is 0m.

Calculation results of straight column slab foundation (with groundwater) and cast-in-place pile foundation are showed in Table 1 and Table 2.

Table 1. Calculation results of straight column slab foundation (one leg)

| number | tower type | foundation slab width (m) | foundation slab depth (m) | earthwork volumes (m³) | concrete C25 (m³) | cushion (m³) | rebar (t) | remarks |
|--------|------------|---------------------------|---------------------------|------------------------|------------------|-------------|----------|---------|
| 1      | Z27102A    | 5.4                       | 3.8                       | 218.02                 | 27.5             | 6.5         | 1.55     |         |
| 2      | J27102A    | 13.2                      | 4.2                       | 1012.75                | 151.9            | 31          | 10.47    |         |

Table 2. Calculation results of cast-in-place pile foundation (one leg)

| number | Tower type | pile number | pile diameter (m) | Pilelength (m) | concrete C25 (m³) | concrete C30 (m³) | cushion C15 (m³) | rebar (t) | remarks |
|--------|------------|-------------|-------------------|----------------|-------------------|-------------------|------------------|----------|---------|
| 1      | Z27102A    | 1           | 1.0               | 13             | 0.0               | 10.5              | 0                | 1.09     |         |
| 2      | J27102A    | 4           | 0.8               | 14             | 21.00             | 32                | 1.8              | 6.34     |         |

Calculate the construction cost of the above foundation types separately, including material costs, construction and installation costs, mud ponds, etc., and perform economic comparative analysis. See Table 3 for details.

Table 3. Foundation cost of different types (one leg)

| number | tower type | foundation type | materials expenses | installation costs | mud pools fee | pile foundation inspection | comprehensive cost | increase proportion |
|--------|------------|-----------------|--------------------|--------------------|---------------|---------------------------|---------------------|---------------------|
| 1      | Z27102A-60 | Straight column plate | 10649 | 56762 | / | / | 67411 | -38.00% |
|        |            | cast-in-place pile foundation | 5301 | 23246 | 12500 | 750 | 38993 |
| 2      | J27102A-57 | Straight column plate | 63004 | 286593 | / | / | 349597 | -51.40% |
|        |            | cast-in-place pile foundation | 28580 | 125822 | 12500 | 3000 | 169902 |

Remarks: the above straight column slab foundation construction and installation costs has included the cost of foundation pit precipitation and support.

From Table 3, it can be found that the comprehensive cost of the linear tower cast-in-place pile foundation is 38.00% less than that of the straight-column plate foundation; the comprehensive cost of the tensile-strength cast-in-place pile foundation is 51.40% less than that of the straight-column plate foundation.
It is difficult to construct large foundations which are under groundwater, and it is difficult to drain away water, even a huge amount of prescribing, an enormous harm to the environment, a large amount of spoil and environmental protection restoration projects, in addition, it is difficult to pass the acceptance of environmental protection, so from these considerations, it is recommended to use cast-in-place pile foundation.

Based on the above factors, for undulating topography with water-plastic layers, it is recommended to use cast-in-place pile foundation.

3.2. Comparison and selection of economic and technology of undulating topography (without groundwater)

For the undulating topography, there are mainly two types of foundations: straight column slab foundation (without groundwater) and cast-in-place pile foundation. In order to make comparison of the economics, two typical towers of Z27102A and J27102A are calculated respectively, and conduct economic and technical comparison analysis.

The surface soil is silty clay, and the mechanical characteristics are plastic. The groundwater is considered anhydrous.

The parameters of cast-in-place piles are as follows:

| name of the geotechnical | colour | state       | A depth | B depth | C depth | D depth | ρ(g/cm³) | c(kPa) | φ(°) | q_sik (kPa) | q_pk (kPa) | m (MN/m⁴) | 6mm/10mm |
|-------------------------|--------|-------------|---------|---------|---------|---------|---------|--------|------|------------|------------|-----------|---------|
| silty clay              | tawny  | plastic     | 5.0     | 5.0     | 5.0     | 5.0     | 1.92    | 28     | 9.5  | 55         | /          | 15/9      |         |
| silty clay              | tawny  | hard plastic| 14.7    | 14.7    | 14.7    | 14.7    | 1.95    | 35     | 12.0 | 80         | 1500       | 35/15     |         |
| silty clay              | tawny  | hard        | 18.5    | 18.5    | 18.5    | 18.5    | 1.96    | 36     | 13.0 | 95         | 1600       | /         |         |
| siltstone               | henna  | strong weathered | 23.4  | 23.4    | 23.4    | 23.4    | 2.10    | 60     | 22.0 | 200        | 2500       | /         |         |
| siltstone               | henna  | moderately weathered | 35.0  | 35.0    | 35.0    | 35.0    | 2.20    | 200    | 30.0 | 250        | 3000       | /         |         |

Calculation results of straight column slab foundation (with groundwater) and cast-in-place pile foundation are showed in Table5 and Table 6.

| number | tower type | foundation slab width (m) | foundation slab depth(m) | earthwork volumes (m³) | concrete C25(m³) | concrete C30(m³) | cushion C15(m³) | rebar (t) | remarks |
|--------|------------|---------------------------|--------------------------|------------------------|-----------------|-----------------|---------------------|-----------|---------|
| 1      | Z27102A    | 4.4                       | 3.8                      | 164.75                 | 11.7            | 4.8             | 1.13                |           |         |
| 2      | J27102A    | 8.7                       | 4.5                      | 563.1                  | 78.2            | 16.7            | 5.14                |           |         |

Calculate the construction cost of the above foundation types separately, including material costs, construction and installation costs, mud ponds, etc., and perform economic comparative analysis. See Table 7 for details.
Table 7. Foundation cost of different types (one leg)

| number | tower type | foundation type                  | materials expenses | installation costs | mud pools fee | pile foundation inspection | comprehensive cost | increase proportion |
|--------|------------|----------------------------------|--------------------|-------------------|---------------|---------------------------|--------------------|---------------------|
| 1      | Z27102A    | Straight column plate            | 6128               | 23164             | /             | /                         | 29292              | 29.65%              |
|        |            | cast-in-place pile foundation    | 4770               | 19957             | 12500         | 750                       | 37977              |                     |
| 2      | J27102A    | Straight column plate            | 31904              | 112243            | /             | /                         | 144147             | 26.66%              |
|        |            | cast-in-place pile foundation    | 28454              | 138620            | 12500         | 3000                      | 182574             |                     |

From Table 7, it can be found that the comprehensive cost of the linear tower cast-in-place pile foundation is 29.65% more than that of the straight-column plate foundation. The comprehensive cost of the tensile-strength cast-in-place pile foundation is 26.66% more than that of the straight-column plate foundation. Straight column slab foundation has obvious economic advantages, and there is no problem of foundation pit precipitation and support during construction, but it still needs to pay attention to details such as temporary storage of excavated earth and vegetation restoration after backfill.

Based on the above factors, for undulating topography without water-plastic layers, it is recommended to use straight-column plate foundation.

3.3. Comparison and selection of economic and technology of mountain topography

For the mountain topography, there are mainly two types of foundations: artificially excavated pile foundations and rock foundation. In order to make comparison of the economics, two typical towers of Z27102A and J27102A are calculated respectively, and conduct economic and technical comparison analysis. See Table 8 for details.

Table 8. Comparison and selection of economic and technology of artificially excavated pile foundation and rock foundation (one leg)

| number | tower type | foundation type                  | column diameter (m) | Depth (m) | earthwork volumes (m³) | concrete C25 (m³) | rebar (t) | materials expenses | installation costs | total |
|--------|------------|----------------------------------|---------------------|-----------|------------------------|-------------------|-----------|--------------------|--------------------|-------|
| 1      | ZC27102A   | rock foundation                  | 1.2                 | 5.5       | 14.30                  | 13.36             | 0.93      | 5352               | 27248              | 32600 |
| 2      | ZC27102A   | artificially excavated pile foundation | 1.2              | 7.8       | 16.26                  | 15.2              | 1.15      | 6332               | 35275              | 41607 |
| 3      | JC27102A   | rock foundation                  | 1.6                 | 7.7       | 27.50                  | 25.70             | 3.91      | 15896              | 62756              | 78652 |
| 4      | JC27102A   | artificially excavated pile foundation | 1.8              | 14        | 43.34                  | 40.5              | 6.6       | 26208              | 99635              | 125843|

From Table 8, it can be found that the comprehensive cost of artificially excavated pile foundation is 27.63% more than that of the rock foundation, the comprehensive cost of the tensile-strength artificially excavated pile foundation is 60.00% more than that of the rock foundation. The rock foundation has more advantages.

Based on the above analysis, rock foundation is proposed to use when the rock is strong weathered and moderately weathered with thin cover at mountain topography. For the towers with easy mechanical access and the terrain slope of less than 25 degrees, the group anchor rock foundation is used.

4. Conclusion

The foundation selection of transmission lines has a direct impact on the project. Therefore, when considering the foundation type, it is necessary to combine the stress of the tower and the topography and geology along the line, select a reasonable foundation type to meet the schedule, environmental
protection requirements and the overall project benefits. The specific conclusions of the foundation selection are as follows:

1. For undulating topography, it is recommended to use cast-in-place pile foundation for water-plastic layers.
2. For undulating topography, it is recommended to use large slab foundation for water-free strata.
3. For mountainous topography and weathered broken rock foundation, it is recommended to use digging and expanding bottom pile foundation.
4. It is recommended to use rock foundation for mountainous topography which the rock foundation base is strong weathered or moderately weathered with thin cover.

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