Tower foundation selection and economic comparison of 110kV transmission line in plain area of South Hebei Power Grid

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Abstract: Based on the statistics of the typical geological conditions and the foundation forces of common tower modules in the plain area of Southern Hebei Power Grid, this paper analyzes the basic forces of tower modules, the common forms of foundation are introduced, in terms of technology, economy, etc, in order to provide reference for engineering design.

1. Summary
Tower foundation is an important part of transmission line, the quality of foundation design directly affects the cost, construction period and material consumption of the whole line project. According to relevant statistics: the construction period of transmission line foundation project accounts for about half of the whole construction period, the transportation volume accounts for about 60% of the whole project, and the cost accounts for 20% - 35% of the whole project[1].

The selection of foundation type shall be based on tower type, terrain along the line, geological conditions of tower location, construction and transportation, and combined with the characteristics of the project. Therefore, according to different geological conditions, foundation forces and other conditions, it is necessary to study the selection of foundation type under different boundary conditions[2].

2. common foundation forms
At present, the common foundation types of overhead transmission lines in Hebei Southern Power Grid include rigid step foundation, straight column flexible foundation and cast-in-place pile foundation, the characteristics and application scope of various foundation types are as follows.

2.1. Heavy excavation foundation
The common excavation foundation mainly includes straight column flexible slab foundation and rigid step foundation.

The vertical column flexible slab foundation has large base plate, shallow embedded depth, and bidirectional reinforcement by the bottom plate, it bears the bending moment and shear force caused by uplift and horizontal force of the tower. It is suitable for flat area, and can also be used in river network and swamp area with high bearing capacity. When the bearing capacity of foundation is low, slab foundation is often used[3].
Figure 1. Straight column flexible slab foundation

The rigid step foundation uses the weight of soil and concrete to resist uplift, the foundation slab is rigid and compression resistant without reinforcement. It is suitable for all kinds of geological and tower types, especially the corner tower with high groundwater level, difficult drainage and large foundation force, or the tower position which relies on the weight of the foundation to resist the uplift force [4].

Figure 2. Rigid step Foundation

The base plate of the rigid step foundation adopts rigid compression, without reinforcement, but the foundation is buried deep, there is a large amount of concrete, because of the unreasonable force, waste of materials, high cost, has been gradually eliminated, in addition, it is difficult to reach the design depth due to the ladder type collapse and quicksand area, it is only used in some areas, therefore, this paper will not analyze the rigid step foundation.

2.2. Cast in place pile foundation

The cast-in-place pile foundation mainly relies on the friction between the pile and the soil and the bearing capacity of the pile tip to bear the uplift and downward pressure of the foundation, the construction is convenient, the construction cost is high, the land occupation is small, and the risk factors are big when using manual construction. It is suitable for clayey soil and sandy soil foundation with high groundwater level, and also widely used for crossing river tower [5].

Figure 3. Cast in place pile foundation

3. Mechanical parameters of foundation soil and force of common tower foundation in plain area of South network of Hebei Province

3.1. Mechanical parameters of foundation

According to the investigation, the strata in the south network area of Hebei Province are mainly the North China Flood base plain landform, taihang Mountain Area in the West has mountainous and hilly landform, it can be seen that granite, granite gneiss and other bedrock are exposed, most of the central and eastern areas are flat and open, there are no obvious ups and downs, landslides, collapses, debris flows, gullies, karst caves and other adverse geological conditions are not considered, the groundwater in the foundation depth is generally invisible, and the frozen soil depth is less than 0.6m. In addition to the collapsible loess in the West and the soft foundation in the east coast, the foundation soil is mainly...
composed of silty clay, silt and sand, and the soil is uniform. The silt is mainly in slightly wet and slightly dense state, low dry strength, the plasticity of cohesive soil is mainly plastic to soft plastic. The representative geological parameters are shown in Table 1.

Table 1. list of physical and mechanical properties of foundation rock and soil

| Geotechnical name | Thickness (m) | State         | Severity (kN/m³) | Cohesion C (kPa) | Friction φ (°) | Characteristic value of bearing capacity fak (kPa) | Cast in place pile |
|-------------------|---------------|---------------|------------------|-----------------|---------------|-------------------------------------------------|------------------|
|                   |               |               |                  |                 |               | Standard value of ultimate lateral resistance qsk (kPa) | Standard value of ultimate end resistance qpk (kPa) |
| Clay              | 4             | Plastic       | 19.0             | 30              | 10            | 160                                             | 40               | 600               |
| Silty clay        | 2             | Plastic       | 18.5             | 25              | 15            | 160                                             | 55               | 800               |
| Silt sand         | 3             | slightly dense| 18.5             | 25              | 15            | 140                                             | 50               | 350               |
| Silt sand         | 3             | dense         | 19.5             | 5               | 35            | 200                                             | 46               | 1100              |
| Silty clay        | 4             | Soft plastic  | 18.0             | 25              | 15            | 120                                             | 40               | 300               |
| Fine sand         | 6             | Slightly dense| 19.0             | 5               | 28            | 180                                             | 46               | 900               |
| Sand              | 8             | dense         | 19.5             | 0               | 30            | 220                                             | 76               | 2400              |

3.2. Ground force interval of common tower foundation

According to the typical design of State Grid, the range of foundation force of 110kV tower in plain area of South Hebei Power Grid is as follows:

Table 2. 110 kV foundation force range

| Tower type    | Number of loops | Pull up force range (kN) | Downforce range (kN) |
|---------------|-----------------|--------------------------|----------------------|
| Linear tower  | Single loop     | 99-289                   | 150-359              |
| Corner tower  | Double circuit  | 326.2-676                | 396.7-738            |
| Linear tower  |                | 156.3-458.15             | 206.44-578           |
| Corner tower  |                | 510.1-1623.78            | 651.44-1810.4        |

As can be seen from table 2, the pull-up force range of 110kV tower is 99-458 kN, the downforce ranges from 150 to 578 kN, the pull-up force range of angle tower is 326.2-1623 kN, the downforce ranges from 396.7 kn to 1810.4 kN.

4. Foundation selection and economic comparison

4.1. There is no groundwater condition

The geological conditions and parameters are shown in Table 1, according to the basic adaptability analysis, the vertical column flexible foundation and cast-in-place pile foundation can be selected for the geological conditions, through calculation, the concrete amount and the corresponding material price of the two foundation types are obtained, see Table 3 for details.

Table 3. Analysis of straight column flexible foundation and cast-in-place pile foundation

| Tower type | Sample space | Pull up force | Concrete quantity (m³) | Amount of reinforcement (kg) | Compressive cost (1000 yuan) | Concrete quantity (m³) | Amount of reinforcement (kg) | Compressive cost (1000 yuan) |
|------------|--------------|---------------|------------------------|----------------------------|------------------------------|------------------------|----------------------------|------------------------------|
| Linear     | 100          | 4.78          | 0.53                   | 0.88                       | 3.35                         | 0.30                   | 0.83                       | 3.35                         |
| Linear     | 200          | 7.71          | 0.75                   | 1.41                       | 5.68                         | 0.68                   | 1.40                       | 5.68                         |
4.2. Groundwater condition

As can be seen from Fig. 4-5, under the typical geological conditions in the South Network Plain Area of Hebei Province, when there is no groundwater, with the increase of the foundation force, the vertical column flexible foundation and the cast-in-place pile foundation will increase, the comprehensive unit price increases with the increasing difference; when the foundation force is less than 900kN, the difference of comprehensive unit price between the two is small. When the foundation force is greater than 900kN, the comprehensive cost difference between them is larger.

| Tower type | Straight column flexible foundation | Cast in place pile foundation |
|------------|-----------------------------------|-------------------------------|
|            | Pull up force | Concrete quantity (m³) | Amount of reinforcement (kg) | Comprehensive cost (10000 yuan) | Concrete quantity (m³) | Amount of reinforcement (kg) | Comprehensive cost (10000 yuan) |
|            | 300          | 10.64               | 1.03                          | 1.95                         | 8.01                   | 0.96                          | 1.98                          |
|            | 400          | 13.57               | 1.32                          | 2.49                         | 10.35                  | 1.24                          | 2.55                          |
|            | 500          | 16.51               | 1.60                          | 3.03                         | 12.68                  | 1.52                          | 3.13                          |
| Corner tower | 300          | 15.62               | 0.79                          | 2.86                         | 13.00                  | 1.36                          | 3.21                          |
|            | 400          | 19.84               | 1.35                          | 3.64                         | 16.23                  | 1.79                          | 4.00                          |
|            | 500          | 24.05               | 1.64                          | 4.41                         | 19.45                  | 2.14                          | 4.80                          |
|            | 600          | 28.26               | 1.92                          | 5.18                         | 22.67                  | 2.49                          | 5.59                          |
|            | 700          | 32.48               | 2.21                          | 5.95                         | 25.89                  | 2.85                          | 6.38                          |
|            | 800          | 36.69               | 2.51                          | 6.72                         | 29.09                  | 3.17                          | 7.17                          |
|            | 900          | 40.91               | 4.50                          | 7.50                         | 32.33                  | 3.56                          | 7.97                          |
|            | 1000         | 52.39               | 6.16                          | 9.60                         | 58.12                  | 6.39                          | 14.33                         |
|            | 1100         | 60.19               | 6.92                          | 11.03                        | 83.52                  | 9.19                          | 20.60                         |
|            | 1300         | 75.79               | 8.34                          | 13.89                        | 134.32                 | 13.78                         | 33.13                         |
|            | 1700         | 80.00               | 8.84                          | 14.39                        | 140.00                 | 14.39                         | 35.00                         |

Figure 4. Comparison chart of comprehensive cost of linear tower foundation

Figure 5. Comparison of comprehensive cost of cost tension tower foundation

4.2. Groundwater condition

The geological conditions and parameters are shown in Table 1, considering 0 m groundwater, according to the foundation adaptability analysis, the vertical column flexible foundation and cast-in-place pile foundation can be selected for the geological conditions, through calculation, the concrete consumption and corresponding material prices of the two foundation types are obtained. See Table 4 for details.
Table 4. Analysis of straight column flexible foundation and cast-in-place pile foundation

| Tower type | Pull up force | Concrete quantity (m³) | Amount of reinforcement (kg) | Comprehensive cost (10000 yuan) | Concrete quantity (m³) | Amount of reinforcement (kg) | Comprehensive cost (10000 yuan) |
|------------|--------------|------------------------|-----------------------------|--------------------------------|------------------------|----------------------------|--------------------------------|
| Linear tower |
| 100        | 4.78         | 0.53                   | 0.88                        | 3.35                          | 0.30                   | 0.83                       |
| 200        | 7.71         | 0.75                   | 1.41                        | 5.68                          | 0.68                   | 1.40                       |
| 300        | 10.64        | 1.03                   | 1.95                        | 8.01                          | 0.96                   | 1.98                       |
| 400        | 13.57        | 1.32                   | 2.49                        | 10.35                         | 1.24                   | 2.55                       |
| 500        | 16.51        | 1.60                   | 3.03                        | 12.68                         | 1.52                   | 3.13                       |
| 600        | 19.48        | 1.89                   | 3.64                        | 16.23                         | 1.79                   | 4.00                       |
| Corne r tower |
| 300        | 15.62        | 0.79                   | 2.86                        | 13.00                         | 1.36                   | 3.21                       |
| 400        | 19.84        | 1.35                   | 3.64                        | 16.23                         | 1.79                   | 4.00                       |
| 500        | 24.05        | 1.64                   | 4.41                        | 19.45                         | 2.14                   | 4.80                       |
| 600        | 28.26        | 1.92                   | 5.18                        | 22.67                         | 2.49                   | 5.59                       |
| 700        | 32.48        | 2.21                   | 5.95                        | 25.89                         | 2.85                   | 6.38                       |
| 800        | 36.69        | 2.51                   | 6.72                        | 29.09                         | 3.17                   | 7.17                       |
| 900        | 40.91        | 4.50                   | 7.50                        | 32.33                         | 3.56                   | 7.97                       |
| 1100       | 52.39        | 6.16                   | 9.60                        | 58.12                         | 6.39                   | 14.33                      |
| 1300       | 60.19        | 6.92                   | 11.03                       | 83.52                         | 9.19                   | 20.60                      |
| 1700       | 75.79        | 8.34                   | 13.89                       | 134.32                        | 13.78                  | 33.13                      |

Figure 6. Comparison chart of comprehensive cost of linear tower foundation

Figure 7. Comparison of comprehensive cost of cost tension tower foundation

As can be seen from Fig. 6-7, 0 m underground water, when the foundation force is less than or equal to 900kN, the comprehensive unit price of the two is quite different, when the foundation force is more than 900 kN, the difference between the two is small.

5. Conclusion
In this paper, the economic comparison and selection of common foundation forms under typical geological conditions in the southern plain of Hebei Province is carried out, when there is no underground water and the construction period is satisfied, flexible slab foundation with straight column is preferred, 0 m underground water, the comprehensive cost of cast-in-place pile foundation is low, Cast in place pile foundation is preferred.

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