Analysis on 500 Kv Transmission Tower Influence Factors Based on Optimum Slope

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Abstract. In the design of 500 kV heavy ice area transmission tower, reasonable selection of tower slope can effectively reduce the cost of the project. Taking the type of 53ZBC33 tower, which is in a 20mm ice area 500 kV transmission line, as an example, a comprehensive calculation of 8 different slopes, which range from 0.09 to 0.16, in 60m, 54m, 48m and 42m body-high transmission towers is carried out. A total of 32 models are established. The construction of the tower is based on steel consumption cost, foundation cost and compensation for the occupied land of the tower foundation. From the price comparison analysis, the optimal gradient of transmission tower varies slightly when the body-high of the tower is different, but the overall optimal slope fluctuates in the range of 0.10 to 0.13. In the design project, the optimal slope of the tower can be quickly calculated by the range of 0.10-0.13.

1. Introduction
In the design of high voltage transmission tower, an appropriate slope could effectively reduce project investment. For a certain height of the same series tower, a lot of calculation was needed to determine the optimal slope. It is necessary to calculate the amount of tower materials, the amount of foundation and the influence of tower caused bad influence to the environment, so as to get the optimum slope of a tower with a certain height. In the engineering field, it is often necessary to design different heights towers. We need to know whether the optimal slope changed when a tower heights changed. In the current wave of UHV construction [1], the time for designing is usually very urgent, and it has few time to calculate an optimal slope for each slopes. Based on this situation, it is very important to study the influence of different heights on the optimal slope of the same series of transmission towers [2] [3], and find out the approximate rule of the optimal slope for guiding design.

2. Overview of the Project
Taking the 53ZBC33 type 500 kV transmission tower as an example, the tower designed by 27 m/s wind speed, 20 mm ice thickness, 4×JL/G1A-300/50 conductor type, 2.5 safety factor, JLB20A-150 ground line and 4.0 safety factor. Horizontal spacing is 600m, vertical spacing is 850m, design call is 60m, total height is 68.1m, and tower single line diagram is shown in Figure.1.
3. Optimum Slope Calculation of Transmission Towers with Different Heights

Taking the 53ZBC33 type 500 kV transmission tower as an example, the tower designed by 27 m/s wind speed, 20 mm ice. In order to study the influence of different heights on the optimum slope of the tower, four kinds of feature heights, 60m, 54m, 48m and 42m, are selected. According to the reference design, 0.01 was chosen as a gradient, the steel consumption of tower materials, the amount of foundation and the cost of root space for the tower from 0.09 to 0.16 are calculated detailly. A total of 32 tower models with four feature heights are constructed. Full stress analysis program (V2017.09) is used to calculate [4] [5]. The model and stress ratio intention are shown in Figure.2.

![Model diagram and stress diagram of transmission tower](image)

**Figure 2.** Model diagram and stress diagram of transmission tower

3.1. The Optimum Slope of 60m feature height tower

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According to the calculation model, the steel consumption of eight types with different feature heights transmission towers is summarized, as shown in Table 1.

From the overall trend, with the increase of the tower body slope, the steel consumption for the tower increases, but when the slope is 0.10, the amount of steel for the tower is the smallest. From the stress diagram and slenderness ratio distribution diagram of the slope of 0.10, it can be found that the stress
ratio of most material is more than 95%, and the auxiliary material is not only make full of use, but also very reasonable. Based on the topographic and geological conditions in mountainous areas, rock-embedded foundation is usually used for tower [6]. Therefore, rock-embedded foundation is chosen for designing to calculate the cost of foundation. The foundations of the eight models are designed and summarized. The size and cost of the foundations are shown in Table 1.

As can be seen from Table 1, with the increase of the tower slope, the foundation dimensions decreases gradually, and the amount of concrete and steel amount decreases gradually.

In the construction of transmission projects, the occupancy of tower is also an important factor. Under the current policy of environmental protection and water and soil conservation, the bigger occupancy of tower, the worse the damage to the environment [7]. The information of tower opening and occupancy of eight slopes is summarized as Table 1.

Table 1. Summary information for 60m feature height Towers with Different Slopes.

| k  | a(m) | m1(t) | p1  | C11 | H(m) | d(m) | F1(m³) | G1(kg) | C12  | S1(m²) | p2   | C13   |
|----|------|-------|-----|-----|------|------|--------|--------|------|-------|------|-------|
| 0.09 | 12.83 | 43.368 | 7800 | 338.3 | 4.3 | 1.0 | 23.48 | 1144.4 | 93.4 | 250.59 | 52.5 | 13.2   |
| 0.10 | 13.7  | 42.835 | 7800 | 334.1 | 4.0 | 1.0 | 22.56 | 1001.6 | 88.0 | 278.89 | 52.5 | 14.6   |
| 0.11 | 14.57 | 44.002 | 7800 | 343.2 | 3.9 | 1.0 | 22.24 | 985.6  | 86.7 | 308.70 | 52.5 | 15.6   |
| 0.12 | 15.44 | 44.607 | 7800 | 347.9 | 3.7 | 1.0 | 21.60 | 873.6  | 82.8 | 340.03 | 52.5 | 16.9   |
| 0.13 | 16.31 | 45.042 | 7800 | 351.3 | 3.6 | 1.0 | 21.28 | 836.8  | 81.1 | 372.88 | 52.5 | 18.2   |
| 0.14 | 17.18 | 45.482 | 7800 | 354.8 | 3.4 | 1.0 | 20.68 | 732.8  | 77.4 | 407.23 | 52.5 | 20.4   |
| 0.15 | 18.05 | 45.753 | 7800 | 356.9 | 3.3 | 1.0 | 20.36 | 720.0  | 76.2 | 443.10 | 52.5 | 22.6   |
| 0.16 | 18.92 | 45.927 | 7800 | 358.2 | 3.2 | 1.0 | 20.04 | 702.0  | 74.9 | 480.49 | 52.5 | 25.2   |

k stand for slope, a stand for root span, m1 stand for steel quantity, p1 stand for comprehensive unit price of galvanized angle steel, C11 stand for tower body cost. H stand for foundation depth, d stand for pile diameter, F1 stand for amount of concrete, G1 stand for amount of reinforcement, C12 stand for cost of foundation, based on the concrete is 780 yuan/m³ and the reinforcing steel is 4400 yuan/t. S1 stand for area, p2 stand for unit price of compensation for land occupation, for 52.5 yuan/m², C13 stand for Payment for land occupied by tower. Unit: thousand yuan

As Table 1 shown, the larger slope of the tower, the larger foundation occupied. When the slope of the tower body is 0.09, the tower root span is only 12.83m. When the slope of the tower body is 0.19, the tower root span is 21.53m, and the root span increases nearly twice as much as the body of 0.09. It is shown that reasonable slope can effectively reduce the damage to the environment.

3.2. The Optimum Slope of 54m feature height tower

The steel consumption of 54m feature height transmission towers with different slope is summarized as Table 2.

Table 2. Summary information for 54m feature height Towers with Different Slopes.

| k  | a(m) | m2(t) | p1  | C21 | H(m) | d(m) | F2(m³) | G2(kg) | C22  | S2(m²) | p2   | C23   |
|----|------|-------|-----|-----|------|------|--------|--------|------|-------|------|-------|
| 0.09 | 11.75 | 39.083 | 7800 | 304.9 | 4.0 | 1.0 | 22.56 | 1001.6 | 88.0 | 254.56 | 52.5 | 14.4   |
| 0.10 | 12.50 | 39.175 | 7800 | 305.6 | 3.9 | 1.0 | 22.24 | 985.6  | 87.9 | 280.24 | 52.5 | 15.7   |
| 0.11 | 13.25 | 39.403 | 7800 | 307.3 | 3.7 | 1.0 | 21.60 | 873.6  | 82.8 | 312.06 | 52.5 | 17.0   |
| 0.12 | 14.00 | 39.608 | 7800 | 308.9 | 3.5 | 1.0 | 21.00 | 822.4  | 80.0 | 344.00 | 52.5 | 18.4   |
| 0.13 | 14.75 | 39.860 | 7800 | 310.9 | 3.4 | 1.0 | 20.68 | 732.8  | 77.4 | 375.06 | 52.5 | 19.7   |
| 0.14 | 15.50 | 40.031 | 7800 | 312.2 | 3.2 | 1.0 | 20.04 | 702.2  | 74.9 | 394.25 | 52.5 | 21.0   |
| 0.15 | 16.25 | 40.755 | 7800 | 317.9 | 3.1 | 1.0 | 19.72 | 689.2  | 73.7 | 420.56 | 52.5 | 22.4   |
| 0.16 | 17.00 | 41.138 | 7800 | 320.9 | 3.0 | 1.0 | 19.40 | 671.2  | 72.3 | 440.00 | 52.5 | 23.8   |
$m_2$ stands for steel quantity, $C_{21}$ stand for tower body cost. $F_2$ stand for amount of concrete, $G_2$ stand for amount of reinforcement, $C_{22}$ stand for cost of foundation. $S_2$ stand for area, $C_{23}$ stand for payment for land occupied by tower. Unit: thousand yuan.

Based on the rock-embedded foundation, the foundations of eight models are designed and summarized. The size, volume and cost of the foundations are shown in Table 2. From Table 2, it can be seen that with the increase of the tower slope, the foundation force decreases gradually, and the amount of concrete and steel bars in the foundation decreases gradually. The compensation fees for towers occupation are summarized in Table 2.

### 3.3. The Optimum Slope of 48m feature height tower

The steel consumption of transmission towers with different slopes is summarized as Table 3.

Based on the rock-embedded foundation, the foundations of eight models are designed and summarized. The size, volume and cost of the foundations are shown in Table 3. From Table 3, it can be seen that with the increase of tower slope, the foundation force decreases gradually, and the amount of concrete and steel in the foundation decreases gradually. The compensation fees for tower occupation are summarized in Table 3.

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| $k$ | $a$(m) | $m_3$(t) | $p_1$ | $C_{31}$ | $H$(m) | d(m) | $F_3$(m$^3$) | $G_3$(kg) |
| 0.09 | 10.67 | 34.812 | 7800 | 271.5 | 3.9 | 1.0 | 22.24 | 985.6 |
| 0.10 | 11.30 | 35.006 | 7800 | 273.0 | 3.7 | 1.0 | 21.6 | 873.6 |
| 0.11 | 11.93 | 34.913 | 7800 | 272.3 | 3.5 | 1.0 | 21.00 | 822.4 |
| 0.12 | 12.56 | 35.113 | 7800 | 273.9 | 3.4 | 1.0 | 20.68 | 802.8 |
| 0.13 | 13.19 | 34.944 | 7800 | 272.6 | 3.3 | 1.0 | 20.36 | 720.0 |
| 0.14 | 13.82 | 35.152 | 7800 | 274.2 | 3.2 | 1.0 | 20.04 | 702.0 |
| 0.15 | 14.45 | 35.618 | 7800 | 277.8 | 3.1 | 1.0 | 19.72 | 689.2 |
| 0.16 | 15.08 | 36.103 | 7800 | 281.6 | 3.0 | 1.0 | 19.40 | 671.2 |

$m_3$ stand for steel quantity, $C_{31}$ stand for tower body cost. $F_3$ stand for amount of concrete, $G_3$ stand for amount of reinforcement, $C_{32}$ stand for cost of foundation. $S_3$ stand for area, $C_{33}$ stand for payment for land occupied by tower. Unit: thousand yuan.

### 4. Influence factors of optimal slope transmission tower

The cost of the tower in transmission project is mainly composed of three parts, the cost of the tower itself, the cost of the foundation and the compensation for the occupied area of the tower base. The cost of three aspects of the tower with different slope is summarized, as shown in Table 4.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $k$ | $C_{11}$ | $C_{12}$ | $C_{13}$ | $C_{14}$ | $C_{21}$ | $C_{22}$ | $C_{23}$ | $C_{24}$ | $C_{31}$ | $C_{32}$ | $C_{33}$ | $C_{34}$ |
| 0.09 | 338.3 | 93.4 | 13.2 | 444.8 | 0.09 | 304.9 | 88.0 | 11.4 | 404.3 | 0.09 | 271.5 | 86.7 | 9.8 | 368.1 |
| 0.10 | 334.1 | 88.0 | 14.6 | 436.8 | 0.10 | 305.6 | 86.7 | 12.6 | 404.9 | 0.10 | 273.0 | 82.8 | 10.7 | 366.6 |
| 0.11 | 343.2 | 86.7 | 16.2 | 446.2 | 0.11 | 307.3 | 82.8 | 13.9 | 404.0 | 0.11 | 272.3 | 80.0 | 11.7 | 364.0 |
| 0.12 | 347.9 | 82.8 | 17.9 | 448.6 | 0.12 | 308.9 | 80.0 | 15.2 | 404.1 | 0.12 | 273.9 | 78.7 | 12.7 | 365.2 |
| 0.13 | 351.3 | 81.1 | 19.6 | 452.0 | 0.13 | 310.9 | 77.4 | 16.5 | 404.9 | 0.13 | 272.6 | 76.2 | 13.8 | 362.5 |
| 0.14 | 354.8 | 77.4 | 21.4 | 453.6 | 0.14 | 312.2 | 74.9 | 18.0 | 405.1 | 0.14 | 274.2 | 74.9 | 14.9 | 363.9 |
| 0.15 | 356.9 | 76.2 | 23.3 | 456.3 | 0.15 | 317.9 | 73.7 | 19.5 | 411.0 | 0.15 | 277.8 | 73.7 | 16.0 | 367.5 |
| 0.16 | 358.2 | 74.9 | 25.2 | 458.3 | 0.16 | 320.9 | 72.3 | 21.0 | 414.2 | 0.16 | 281.6 | 72.3 | 17.2 | 371.1 |

Unit: thousand yuan.
As can be seen from Table 4, for 60m feature height Towers, when the slope of the tower body is 0.10, the total cost of the project is the lowest. And we can found that when the slope of the tower body is smaller, the cost of the project is also trend lower. It can be seen that when the slope of the tower is 0.11, the total cost of the project is the lowest. It can be seen that when the slope of tower body is 0.13, the total cost of the project is the lowest.

The main body cost, basic cost, occupation cost and total cost of each tower with different slopes are shown in Figure.3 ~ Figure.6.

From Figure.3, it can be seen that with the increase of slope, the steel consumption of tower materials increases and the cost increases. From Figure.4, it can be seen that with the increase of slope, the cost of foundation decreases, and when the slope is 0.16, the cost of foundation decreases by more than 50%. From Figure.5, it can be seen that the cost of land occupation increases with the increase of slope and increases almost linearly. From Figure.6, combined with table 4, table 8 and table 12, it can be seen that the optimum gradient is 0.10 for a 60 feature height tower, 0.11 for a 54 feature height tower, 0.13 for a 48 feature height tower. The optimal slope of transmission towers with different feature heights fluctuates between 0.10 and 0.13.

To sum up, the optimal slope of the tower with different feature heights is fluctuated, but it mainly concentrates in the range of 0.10-0.13.
5. Conclusion

Through establishing models and calculation of transmission towers with different slopes in 500 kV heavy ice area, the main conclusions are as follows:

1) The total cost of the tower project is highly positively correlated with the steel consumption cost of the tower itself.

2) The cost of foundation decreases with the increase of tower slope, and the cost of occupied land increases with the increase of tower slope. The root span of tower with smallest slope is only about 70% of that of tower with largest slope. When using smallest slope, the applicability of tower to mountainous topography is significantly enhanced.

3) The optimal slope of the tower varies with the feature heights, but for the cost and the environmental protection, the optimal slope concentrates between 0.10 and 0.13. This range of slopes is more economical, reasonable and environmentally friendly.

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