Research on the material properties of corroded angle steel members of the in-service transmission tower

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Abstract: The number of old transmission lines in China is increasing, and corrosion is a common problem on old transmission towers, which reduces the load-bearing performance of the tower and leads to potential safety hazards. The paper conducts investigation and sampling of the actual engineering line towers, analyzes the reasons for the corrosion of the towers, and carries out the tensile test of the specimens, and obtains the relationship curve of the elongation loss ratio, the yield strength loss ratio, the tensile strength loss ratio and the elastic modulus loss ratio with the cross-sectional loss ratio, which provides a basis for the evaluation of the load-bearing performance of the old transmission tower.

1. Introduction

Transmission towers service in outdoor environments for a long time, and corrosion is a common form of damage to transmission towers[1]. The survey found that there were more than 22,000 kilometers of old transmission lines with voltage levels of 110 (66) kV and above that have been in operation for more than 40 years in China. The common health problem of old transmission lines is the corrosion of tower materials. The failure of tower caused by corrosion has shown an upward trend year by year, causing huge economic losses.

At present, domestic research on steel corrosion is mainly concentrated on the corrosion of building steel structure and steel reinforcement in concrete[2-4]. Research on the corrosion of transmission line tower structure, especially the material properties of angle steel members after corrosion, is relatively lacking[5,6].

In this paper, by sampling the angle steel members of the in-service old transmission line tower structure, the material performance test is carried out, and the change law of elongation, yield strength, ultimate strength and elastic modulus is summarized. The research results can provide basis for the carrying performance evaluation of the old transmission line tower.

2. Analysis of the reasons for the corrosion of the in service tower

According to an on-site investigation of a certain project line, 1#-15# iron tower foot is the most severely corroded, and the 15# iron tower foot is the most typical, as shown in Figure 1. After measurement, the net thickness of the most rusted oblique material at the tower foot is only 2.18mm (nominal thickness is 5mm), the net thickness of the most rusted main material is 6.41mm (nominal thickness is 8mm), and the net thickness of the most rusted plate of tower foot is 4.12mm (nominal thickness is 8mm).
Fig. 1 Corrosion of main material and inclined material of 15# angle tower foot

Since the atmosphere should have basically the same degree of corrosive effect on the entire base iron tower, and the 15# iron tower is only corroded very seriously at the base of the tower, it can be ruled out that atmospheric corrosion is the main reason. The base material of the tower is corroded seriously, and the dark parts of the tower material are more severely corroded (tower base). The investigation shows that the No. 15 iron tower is located in farmland and dry land. The foot of the tower is often submerged by soil, which makes the foot of the tower easy to get damp, and the material has been in an environment with high humidity for a long time. The rust at the bolts of the tower foot plate is the most serious. It is judged that the bolts begin to corrode and then the corrosion spreads. The tower foot plate is a stiffened tower foot plate, and gaps of different sizes are easily formed between the bolts and the plate. When the gap distance is within 0.025–0.1mm, it is the sensitive area of crevice corrosion, and crevice corrosion is prone to occur.

3. Material performance test plan for corroded components

After the tower members are corroded, the material mechanical properties of the members will change to a certain extent, resulting in the reduction of the bearing capacity of the entire tower. In order to study the influence of tower members corrosion on the load-bearing capacity of the tower, the relationship between the mechanical properties of the tower members and the degree of corrosion must first be studied.

The tensile test material of the corroded angle member is taken from an actual transmission line, which has been in operation for more than 25 years and has been out of service. The strength grade of the sampling members is Q235. Each specification is divided into four levels of corrosion: A, B, C, and D. Category A is for almost no rusted members; Category B is for slightly rusted members; Category C is for more severely rusted members; and Category D is for heavily rusted members. Take 4 specimens of each specification and degree of rust for testing, a total of 64 members, each specimen is processed into a standard tensile specimen (Fig. 1), the specific parameters of the specimen are ashamed in Table 1[7].

![Fig. 2 Processing drawing of tensile standard specimen](image-url)
Table 1 Dimensions of the tensile standard specimen

| angle specification | b/mm | r/mm | L0/mm | Lc/mm | B/mm | d/mm | quantity |
|---------------------|------|------|-------|-------|------|------|----------|
| L75×8               | 20   | 20   | 75    | 90    | 30   | 80   | 16       |
| L63×6               | 20   | 20   | 65    | 80    | 30   | 80   | 16       |
| L50×5               | 20   | 20   | 50    | 70    | 30   | 80   | 16       |
| L40×4               | 20   | 20   | 50    | 70    | 30   | 80   | 3        |

According to the "Metallic materials — tensile testing — Part 1: method of test at room temperature" (GB/T 228.1-2010)[8], a universal testing machine for mechanical properties is used. Both ends of the specimen are clamped by chucks, and the test uses one-time loading until the specimen is damaged. Since the specimen is sampled from a tower that has been in operation for 25 years, the specimen has a certain degree of deformation. In order to ensure the accuracy of the tensile test, the specimen is pre-tensioned within the elastic range before the test, so that the material is as straight as possible. A displacement gauge is installed in the middle of the specimen with the length of 50 mm.

4. Analysis on the law of strength attenuation of corroded components

Define the corrosion loss ratio of the angle steel section as \( \rho \). Assuming that the width of the rusted angle steel specimen is the same as that of the non-corroded angle steel specimen, then

\[
\rho = 1 - \frac{t_s}{t_0}
\]

In the formula: \( t_s \) —— the net thickness of the minimum thickness of the rusted specimen;
\( t_0 \) —— the net thickness of the group of non-corroded specimens.

Define the elongation loss ratio of rusted specimens as \( \Delta \delta \), yield strength loss ratio of rusted specimens as \( \Delta \sigma_s \), ultimate strength loss ratio of rusted specimens as \( \Delta \sigma_p \), and elastic modulus loss ratio of rusted specimens as \( \Delta E_s \), as shown in the following formulas:

\[
\Delta \delta = 1 - \frac{\delta_s}{\delta_0}
\]

\[
\Delta \sigma_s = 1 - \frac{\sigma_{ss}}{\sigma_{s0}}
\]

\[
\sigma_p = 1 - \frac{\sigma_{ps}}{\sigma_{p0}}
\]

\[
\Delta E_s = 1 - \frac{E_{ss}}{E_{s0}}
\]

Where:
\( \delta_s, \delta_0 \) — Respectively the elongation of the rusted specimen and the non-corroded component;
\( \sigma_{ss}, \sigma_{s0} \) — Respectively the yield strength of the rusted specimen and the non-corroded component;
\( \sigma_{ps}, \sigma_{p0} \) — Respectively, the ultimate strength of the rusted specimen and the non-corroded component;
\( E_{ss}, E_{s0} \) — Respectively the elastic modulus of the rusted specimen and the non-corroded component.

According to the tensile test results of the specimen, the relationship between the elongation loss...
ratio, the yield strength loss ratio, the ultimate strength loss ratio, the elastic modulus loss ratio and the cross-sectional loss ratio of the corroded specimen is shown in Fig. 3.

It can be seen from the figure that with the increase of the section loss ratio, the yield strength loss ratio and ultimate strength loss ratio of corroded specimens have an obvious linear increase trend, and the elastic modulus loss ratio has a slight increase trend. The elongation of corroded specimens shows a downward trend, but there is no obvious change rule with the cross-section loss ratio. The main reasons for the decrease of the yield strength and ultimate strength of the specimens after corrosion are as follows: First, the effective cross-sectional area of the angle steel becomes smaller after corrosion, and the tensile force it can resist decreases; the second is that the surface of the corroded angle steel is uneven due to the presence of rust pits. After the force is applied, the stress concentration here further reduces its tensile capacity.

5. Conclusion
This paper analyzes the main reasons for the corrosion of the steel tower by investigating the actual engineering tower, and conducts the material characteristic test of the corroded members, and obtains the main law of the material characteristic change of the corroded members. The main conclusions are as follows:

(1) The rust at the bolts of the steel tower foot plate is the most serious. The reason is that the bolts begin to corrode and then the corrosion spreads. Analysis of the main reasons for corrosion is: the tower foot is often submerged by soil, which makes the tower foot easy to be damp; the tower foot is a stiffened tower foot plate, and gaps of different sizes are easily formed between the bolts and the plate. When the gap distance is within 0.025mm ~0.1mm, the area is the sensitive area which is prone to crevice corrosion.
With the increase of the section loss ratio, the yield strength loss ratio and ultimate strength loss ratio of corroded members have a clear linear increase trend, and the elastic modulus loss ratio has a slight increase trend. The elongation rate of corroded members shows a downward trend, but there is no obvious change pattern with the cross-sectional loss ratio.

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