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Failure Analysis of Cracked Pipe-type Transmission Tower

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1. Introduction

Recently, a power transmission tower that transmits high-voltage power has been replaced with a pipe-type tower that is welded rather than a truss structure that tightens a bolt and nut in consideration of aesthetics. Accordingly, it is becoming more important to secure reliability in the processing and operation of the newly installed tubular steel towers. In relation to the sudden failure of the pipe-type tower that occurred in early 2012, in this paper, the cracks that existed from the beginning of the manufacture were identified and the stability was evaluated.

Fig. 1 Failure of pipe-type transmission tower

2. Failure analysis

The specimen was taken from the damaged steel tower and analyzed. As a result, the seam weld line and the transverse crack perpendicular to the fracture section were observed. The cracks occurred simultaneously in the center welding layer and the inner welding layer of the welded section, not the parent material. Fig. 2 shows the traces of the paint entering the cracks of the heat affected zone facing the center of the weld bead and the roots on both sides.

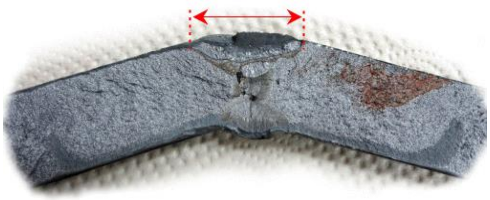
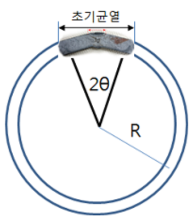


Fig. 2 Transverse crack on the fracture surface

As shown in Fig. 2, there was already a visible crack on the surface of the inner weld bead before the finish coating on the inner surface of the steel tower, and the paint has flowed into the parent material part.

2.1 Cracking risk assessment

The allowable stresses in the 95 mm penetrated transverse cracks identified after fracture, were analyzed because it was not possible to confirm the level of initial crack propagation due to the load increase when the steel tower was installed. The purpose of this analysis is to confirm whether the initial crack size existing at the time of an external load of 188 MPa at the wire hook is dangerous level.



$$K_I = \sigma_b \sqrt{\pi R \theta} F_b$$

$$\sigma_b = \frac{M}{\pi R^2 t}$$

$$F_b = 1 + A\left[4.5967\left(\frac{\theta}{\pi}\right)^{1.5} + 2.6422\left(\frac{\theta}{\pi}\right)^{4.24}\right]$$

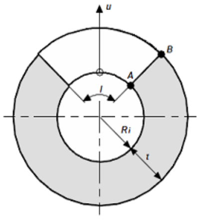
$$A = \left(0.4\frac{R}{t} - 3.0\right)^{0.25}$$

Fig. 3 Stress intensity solutions for circumferential through-wall flaws in cylinders

The length of the transverse cracks confirmed by the analysis of the fracture surface after fracture is 95mm ($\theta = 0.046$) and the radius R of the steel tower cross-section is 1,022mm. If the fracture toughness of steel tower material A572 steel is assumed to be normal carbon steel, the critical load at fracture due to bending is 128MPa. Therefore, if the working load is 188 MPa considering the tension and the wind load due to the transmission lines installed on the steel tower before the failure, the crack size of 95 mm can lead to potential dangerous failure.

2.2 Failure assessment

A stability assessment perspective using the FAD (Failure assessment diagram) is an extension of the crack risk assessment carried out in 2.1. It is necessary to confirm the degree of deviation from the stable region in consideration of the size of the crack and the working load after the fracture, and to check the critical load or the critical crack size in the damage evaluation chart in addition.



$$Lr = \frac{\sigma_m}{s_m} = \frac{\sigma_{bg}}{s_{bg}}$$

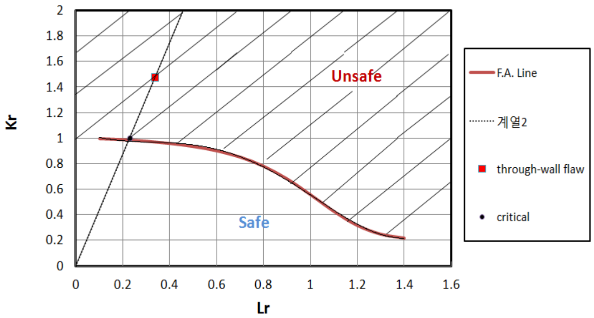
$$Kr = \left[1+0.5Lr^2\right]^{-1/2} \times \left[0.3+0.7\exp(-0.6Lr^6)\right]$$

$$\frac{s_{bg}}{\sigma_y} = \frac{4}{\pi}\sin\beta - \frac{2}{\pi}\sin\theta$$

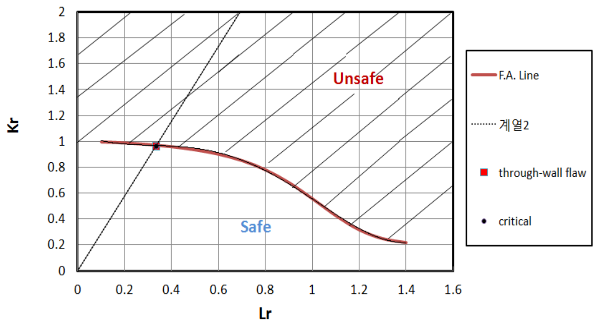
Fig. 4 Failure assessment equations

The basic procedures of the FAD evaluation are as follows;

- safety assessment according to the area where the calculated point is located
- coordinates can move to the dangerous area along the loading line due to crack growth or load increase even in the current stable area
- failure assessment line and critical point where the load line intersects and moving to the unsafe area causes damage to the structure.



(a) Critical load from FAD



(b) Critical crack size from FAD

Fig. 5 FAD analysis results

Assuming a fracture toughness of $50MPa\sqrt{m}$, the crack size is 95 mm and the working load is 188 MPa. When the crack size is 95 mm, the critical load is 128 MPa. Therefore, when the working load of 188 MPa is fixed, the critical crack size is 40 mm and the pipe-typed tower is damaged due to transverse cracks in the weld.

Table 1 Critical load and critical crack size

Initial crack size	Critical load
95mm	128MPa
Load	Critical crack size
188MPa	40mm

3. Conclusion

A large transverse crack with paint was found on the cross section of the welded part of the bottom of the transmission tower in which the accident occurred. The transverse cracks existing in the cross section of the steel tower in the accident are at a risk level because they are 95 mm length and exceeds the critical crack size of 40 mm, which is evaluated based on the fracture toughness of the material. As a result, the direct cause of the pipe-type steel tower failure is the transverse crack, which was present at the beginning.

It is well known that transverse cracks occur mainly in diffusible hydrogen and residual stress and in hardened material. In addition, it may occur depending on welding processes such as constraint, welding speed and heat input during welding, and transverse crack may occur even if residual stress is large. In the case of transverse cracks analyzed in this study, it is concluded that there is a defect in the welding process which is generated by welding with welding rod and welding condition which does not meet the standard. In the future, we will conduct actual load tests for representative types to evaluate the stability of initial micro cracks and partial penetration failure for the operation of reliable steel towers.

Acknowledgment

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