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Analysis method of brittle failure probability of steel members

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Abstract. In recent years, researchers have been proposed various analytical methods to calculate the structural reliability. However, a series of low stress brittle fracture accidents occurred in steel structure, the brittle failure of steel members cannot be ignored. The analytical method of a steel structure with potentially brittle steel members was developed. The brittle failure of a steel members is represented by the brittle failure probability. However, the calculating method of brittle failure probability is still not clear. In order to evaluate structural reliability, the brittle failure probability should be more accurate. In this paper, a method was applied to calculate the brittle failure probability of steel members.

1 Introduction

The analysis of structural reliability is a discipline based on the theory of probability and mathematical statistics. It systematically analyzes the objective function of structure and provides a good scientific basis for structural design. Various analytical methods for calculating reliability have been developed [1-3]. For the design of steel structures, designers often only consider the ductile failure [4]. A series of low stress brittle fracture accidents have occurred in engineering; thus, the brittle failure cannot be ignored. A Heldweiller [5] proposed an analytical method which has considered the brittle failure of a structure. Then, Mai [6] proposed analytical method of a Steel Structure with potentially brittle steel members based on the relaxed linear programming bounds method (RLP) [7]. However, the brittle failure probability is replaced with the experience value in the method. In order to evaluate structural reliability, the brittle failure probability should be more accurate. A method was applied to calculate the brittle failure probability of steel members in this paper. The curve of brittle failure probability of steel members is obtained.

2 Calculating the brittle failure probability of members

After a large number of fracture accident analysis, researchers found that the occurrence of fracture accidents is related to the existence of cracks (inherent or caused by damage during manufacturing or using) in steel members [8]. Open-type (Type I) cracks are the main reason for the brittle failure of members, so the open-type (Type I) crack is the main point of this paper. There are many forms of Type I crack in a member, such as the center penetration Type I crack and the edge penetration Type I crack. The central penetration Type I crack is the main form considered in this paper.

From tensile member with crack damage (Figure 1), A Heldweiller [5] proposed that the failure form of member was determined by ductile strength Rd and brittle strength Rb. Both of them are random. Therefore, the member has a probability $P\ \{R_b > R_d\}$ of responding in a ductile behavior and a probability $P\ \{R_b < R_d\}$ of responding in a brittle behavior. The basic assumption of this method is that the material has sufficient deformation capacity, which can be represented by the solid line in Figure 2, c_b is half width of crack when $R_b = R_d$. The formulas are expressed as:

$$R_d = \sigma_y \cdot 2b \cdot t \tag{1}$$

$$R_b = \sigma_u \cdot (2b - 2c) \cdot t \tag{2}$$

where σ_y is the yield strength; σ_u is the ultimate strength; $2b$ and t are the geometric dimensions of plate; $2c$ is the width of crack.

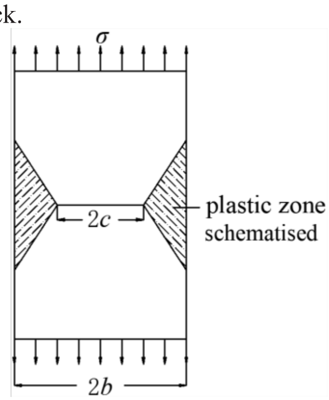

Figure 1. A schematic of tensile member.

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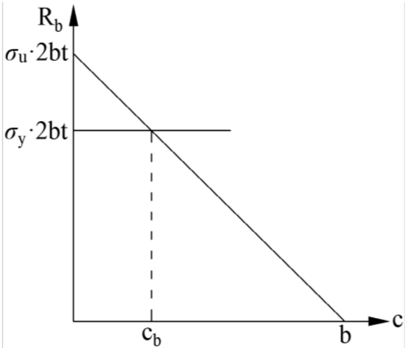

Figure 2. A schematic of R_b and R_d of the member with half width of crack changing.

In Figure 2, when the half width of crack c is changing from 0 to c_b, the member with crack damage mainly occurs ductile failure, and the ductile failure probability of member is $P\{R_b > R_d\}$; when the half width of crack c is changing from c_b to b, the member mainly occurs brittle failure, and the brittle failure probability of member is $P\{R_b < R_d\}$. Therefore, as shown in Figure 3, when the ductile strength R_d is smaller than the brittle strength R_b, the strength of member is determined by its ductile strength R_d. When the brittle strength R_b is smaller than the ductile strength R_d, the strength of member is determined by its brittle strength R_b. c_b is half width of crack when $R_b = R_d$.

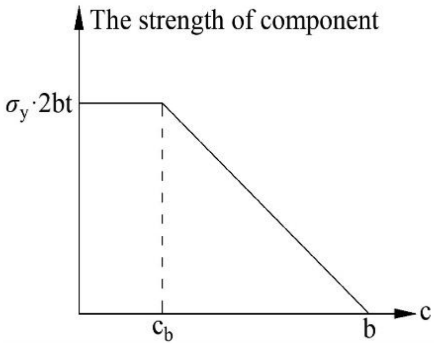

Figure 3. A schematic of the strength curve of member.

For this method, when the geometric dimensions of member are determined, the ductile strength R_d and brittle strength R_b have supposed to be independent. Nevertheless, there is a correlation between the ductile strength R_d and brittle strength R_b because of the crack in a member. The correlation will not be considered in this paper. Then, the distribution function of yield strength and ultimate strength should be normal or lognormal distribution [9]. According to formula (1) and (2), the R_b and R_d of member are the normal distribution. Therefore, based on the nature of the normal distribution, the brittle failure probability of a member is:

$$P\{R_b - R_d < 0\} = \Phi\left(\frac{-(\mu_b - \mu_d)}{\sqrt{\sigma_b^2 + \sigma_d^2}}\right) \tag{3}$$

where $\Phi(\cdot)$ is the distribution function of standard normal distribution; μ_b and μ_d are the mean values of R_b and R_d, respectively; the corresponding standard deviations are σ_b and σ_d.

3 Examples

The materials of members are used Q235 steel. The main physical and mechanical parameters of these materials are shown in Table 1. The geometric dimensions of member are shown in Table 2. According to Table 1, when the thickness is from 0 to 16mm, the yield ratio of Q235 is 0.6351.

Table 1. The main physical and mechanical parameters of Q235 steel.

	Yield strength (MPa) t = 0 - 16mm	Ultimate strength (MPa) t = 0 - 16mm	Elasticity modulus (MPa)
Q235	235	370	206000

Table 2. Geometric dimensions of members.

Geometric dimensions	Thicknesses	Widths
Values (mm)	4	500

According to formula (1) and (2), with the width of crack from 0 to 500mm, the ductile strength R_d and brittle strength R_b are shown in Table 3.

Table 3. the ductile strength Rd and brittle strength R_b with the width of crack from 0 to 500mm.

Yield ratio	Yield strength (MPa)	Ultimate strength (MPa)	Width (mm)	Thickness (mm)	The width of crack (mm)	Ductile strength (kN)	Brittle strength (kN)
0.6351	235	370	500	4	0	470.0000	740.0000
0.6351	235	370	500	4	2	470.0000	737.0400
0.6351	235	370	500	4	4	470.0000	734.0800

0.6351	235	370	500	4	6	470.0000	731.1200
0.6351	235	370	500	4	172	470.0000	234.9635
0.6351	235	370	500	4	174	470.0000	232.1068
0.6351	235	370	500	4	176	470.0000	229.2676
0.6351	235	370	500	4	178	470.0000	226.4459
0.6351	235	370	500	4	180	470.0000	223.6416
0.6351	235	370	500	4	182	470.0000	220.8548
0.6351	235	370	500	4	494	470.0000	0.0786
0.6351	235	370	500	4	496	470.0000	0.0349
0.6351	235	370	500	4	498	470.0000	0.0087
0.6351	235	370	500	4	500	470.0000	0.0000

Taking the Group 4 data in Table 3 as an example. The distribution function of ductile strength R_d and brittle strength R_b are as follows:

$R_d \sim N(470.0000, 47^2)$; $R_b \sim N(731.1200, 73.112^2)$.

The coefficient of variation $Cov = \sigma_d / \mu_d = \sigma_b / \mu_b = 0.1$. Generally, the values of Cov from 0.03 to 0.1 is used in engineering. Considering the worse situation, the coefficient of variation Cov = 0.1 is preferred.

According to formula (3), brittle failure probability of the member is $P\{R_b < R_d\} = 1.33\times10^{-3}$. With the width of crack from 0 to 500mm, Curve of brittle failure probability of members made of Q235 steel is shown in Figure 4.

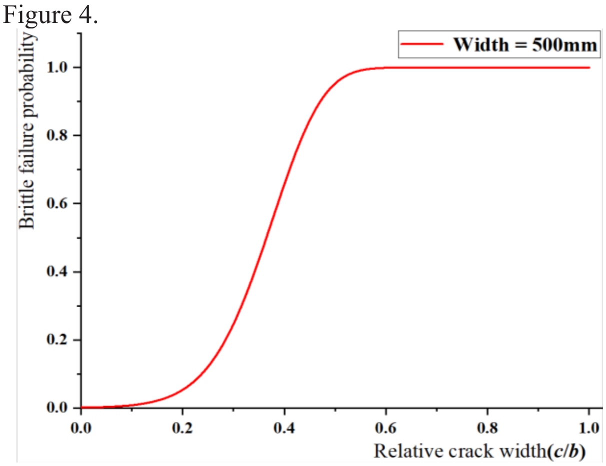

Figure 4. Curve of brittle failure probability of members made of Q235 steel.

4 Conclusion

Based on the ductile strength R_d and the brittle strength R_b of member, this paper applied a method to calculate the brittle failure probability of steel members. For the method, the ductile strength R_d and brittle strength R_b have supposed to be independent. When the geometric dimensions of member are determined, the curve of brittle failure probability of steel members is obtained.

Acknowledgments

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