

# Study on Fatigue Reliability of High-Strength Bolt Joint in Corrosion Environment

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**Abstract**—The performance of high-strength bolt corrosion fatigue related to the safety of structure. It is generally thought that high-strength bolt crack size and the critical crack size conform to logarithmic normal distribution. If the probability density functions of crack size and the critical crack size interfered, high-strength bolt maybe destroyed. Based on the fracture mechanics theory, according to the Gerberich-Chen formula, the corrosion fracture growth threshold value of high-strength bolt was estimated. According to fracture mechanics method, based on reliability theory, the high-strength bolt corrosion fatigue reliability model was deduced. And high-strength bolt corrosion fatigue reliability was analyzed. It was easy and convenient that analysis high-strength bolt joint corrosion fatigue reliability by this model. Hence the high-strength bolt joint corrosion fatigue can be predicted. This method may provide the reference for the high-strength bolt joint fatigue analysis.

**Keywords**—high-strength bolt; corrosion; fatigue; fracture; reliability;

## I. INTRODUCTION

The high-strength bolt connection is common in the steel structure erection joint. 1,500,000 sets of high-strength bolt was used on the Jiu Jiang Bridge, and more than 100 ten thousand sets high strength bolt was used on Chongqing Chao Tian Men bridge. The fatigue performance of high-strength bolt joint affects the bridge structure security. However many steel structures are in the corrosion environment, so the fatigue life of high-strength bolt joint will reduce under the coupling function of the corrosion and the fatigue load. Therefore, high-strength bolt's corrosion fatigue performance is worth paying attention. It found that the main factors influencing the safety of steel bridge were corrosion and fatigue. Many cross-ocean bridges had constructed, and most cross-ocean bridges were the steel bridge. Lots of high-strength bolts are applied to steel bridge, especially steel truss bridge, such as Okashi Kaiko Bridge, Golden Gate Bridge. The fatigue performance of high-strength bolt joint is critical to security of bridge. Many important steel bridges were in

the coastal area. High-Strength bolt joint of steel bridge were under coupling effect of corrosion and fatigue. Hence high-strength bolt joint corrosion fatigue had to be studied.

Ridong adopts GTN model to forecast high-strength bolt's breaking load. Zhang Haifeng uses many kinds of analysis methods, carrying on analysis to the bolt's fracture and the substrate. In order to study the detention break reason during the use of high-strength bolt, Yang Xinglin has established high-strength bolt stress corrosion break mathematical model. Based on two stage loose theory based on two stage loose theory, Yamamoto and Kasei<sup>[1]</sup> proposed bolt and nut relative sliding model. Yanyao Jiang<sup>[2]</sup> obtained the high-strength bolt joint typical loose process through model experiment under lateral load. Marcelo<sup>[3]</sup> studied the fatigue performance of different type high-strength bolt by model experiment. Hobbs<sup>[4]</sup> studied the fatigue performance of high-strength bolt under eccentric load. Jiang Zhongliang, Zhang Meng and Huang Hongzhong<sup>[5-7]</sup> studied the fracture mechanics characteristic of high-strength bolt under corrosive environment. Korin<sup>[8]</sup> studied fatigue crack of high-strength bolt. According to fracture mechanics method, based on reliability theory, high-strength bolt corrosion fatigue reliability is analyzed in this article.

## II. HIGH-STRENGTH BOLT CORROSION FATIGUE BREAK CRACK

The fracture mechanics believes that the micro crack on the surface only starts to expand when the alternating load achieves some threshold value, namely stress intensity factor  $K_I$  achieves material's stress intensity factor  $K_{th}$ . The stress intensity factor may be calculated according to<sup>[9]</sup>

$$K_I = Y \sigma \sqrt{\pi t} \quad (1)$$

In which  $Y = f(\theta) F\left(\frac{d}{D}\right)$ .

In the formula  $f(\theta)$  is influence coefficient of crack gap angle  $\theta$ ,

$$f(\theta) = \frac{1 - e^{-0.9(\pi - 2\theta)\sqrt{D/a}}}{1 - e^{-0.9\pi\sqrt{D/a}}}$$

$F\left(\frac{d}{D}\right)$  is the influence coefficient of the mutual interferences between threads.

$$F\left(\frac{d}{D}\right) = \frac{1}{2} \left[ \left(\frac{d}{D}\right)^{1/2} + \frac{1}{2} \left(\frac{d}{D}\right)^{3/2} + \frac{3}{8} \left(\frac{d}{D}\right)^{5/2} - 0.363 \left(\frac{d}{D}\right)^{5/2} + 0.731 \left(\frac{d}{D}\right)^{9/2} \right]$$

$D$  and  $d$  are great diameter and minor diameter of the thread,  $\sigma$  is bolt operating stress,  $a$  is the height of thread,  $t$  is the crack depth, as shown in Fig.1.

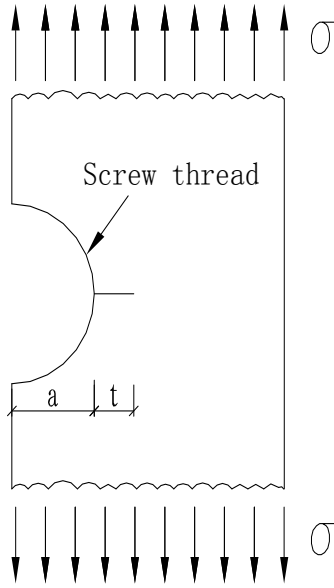


Figure 1. Stress diagram of bolt

The high-strength bolt is often outside, corrupted by damp air and rain water medium for a long time. If the micro crack had existed in the thread root during the process, they will seriously reduce the crack breeding life as the stress corrosion crack. Based on the breaking of stress corrosion, the condition that the micro crack in the thread root does not take place the stress corrosion expansion is<sup>[10]</sup>

$$K_I \leq K_{ISCC} \quad (2)$$

$K_{ISCC}$  is the stress corrosion crack propagation threshold value of the high-strength bolt. At present there is not the precise expression. It could be estimated by Gerberich-Chen equation<sup>[6]</sup>

$$K_{ISCC} = \frac{RT}{2\bar{V}_H} \ln\left(\frac{\beta}{\sigma_s}\right) - \frac{\sigma_s}{2\alpha} \quad (3)$$

In the formula,  $R$  is gas constant,  $R = 8.314 \times 10^{-6} \text{ MN} \cdot \text{m}/^\circ\text{C Mol}$ .  $T$  is absolute

temperature,  $T = 273 + 20 = 293\text{K}$ .  $\bar{V}_H$  is partial molar volume of hydrogen,  $\bar{V}_H = 2 \times 10^{-6} \text{ m}^3/\text{Mol}$ .  $\alpha = 13 \text{ m}^{-1/2}$ ,  $\beta = 3170 \text{ MN} \cdot \text{m}$ .  $\sigma_s$  is material yield strength.

Critical crack size  $a_c$  is decided the component material the fracture toughness and stress level. According to the break theory

$$a_c = \left( \frac{K_{ISCC}}{Y\sigma\sqrt{\pi}} \right)^2 \quad (4)$$

### III. HIGH-STRENGTH BOLT CORROSION FATIGUE FAILURE PROBABILITY

Crack size  $a$  and critical crack size  $a_c$  varied with time. The high-strength bolt crack size and the critical crack size conform to certain probability distribution. After a certain time,  $a$  and  $a_c$  interfered (Fig.2). Hence the structure may destroy possibly. The failure probability is

$$P_f = \int_{-\infty}^{+\infty} f_a(x) f_{a_c}(x) dx \quad (5)$$

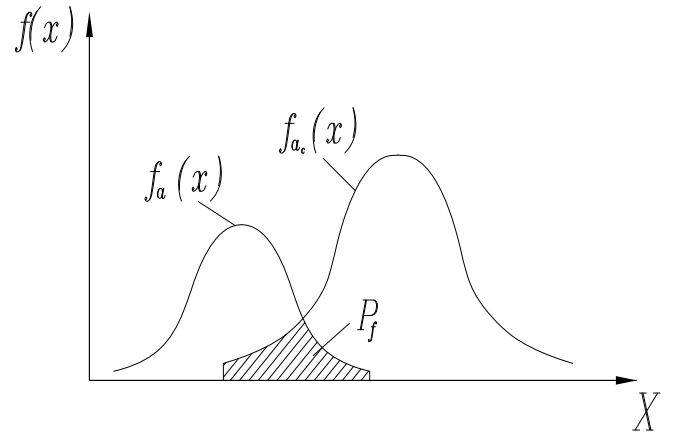


Figure 2.  $a$  and  $a_c$  probability density function

Generally high-strength bolt crack size and the critical crack size conform to logarithmic normal distribution<sup>[11]</sup>

$$f_a(x) = \frac{1}{\sqrt{2\pi} x \sigma_{la}} \exp \left[ -\frac{1}{2} \left( \frac{\ln x - \mu_{la}}{\sigma_{la}} \right)^2 \right] \quad (6)$$

$$f_{a_c}(x) = \frac{1}{\sqrt{2\pi} x \sigma_{lac}} \exp \left[ -\frac{1}{2} \left( \frac{\ln x - \mu_{lac}}{\sigma_{lac}} \right)^2 \right] \quad (7)$$

In which,  $\mu_{la}$ ,  $\mu_{lac}$  and  $\sigma_{la}$ ,  $\sigma_{lac}$  respectively is  $\ln a$ ,  $\ln a_c$  mean value and standard deviation.

According to logarithmic normal distribution theory

$$\mu_{la} = \ln \mu_a - \sigma_a^2 / 2 \quad (8)$$

$$\sigma_{la} = \ln(V_a^2 + 1) \quad (9)$$

In which,  $V_a = \frac{\sigma_a}{\mu_a}$ ,  $\mu_a, \mu_{ac}$  and  $\sigma_a, \sigma_{ac}$  respectively

is  $a, a_c$  mean value and standard deviation.

According to the probability design theory, the high-strength bolt corrosion fatigue reliability is<sup>[12]</sup>

$$P_f = \Phi \left( -\frac{\mu_{la} - \mu_{lac}}{\sqrt{V_a^2 + V_{ac}^2}} \right) \quad (10)$$

$\Phi(\bullet)$  is standardized normal distribution function.

#### IV. EXAMPLE

Take some high-strength bolt joint as the example (Fig.3). M24 high-strength bolts were used. The material quality is 20MnTiB, the tensile strength  $\sigma_b = 1130MPa$ , yield strength  $\sigma_s = 930MPa$ . One end was fixed, another end resisted distributed load  $q = 10MPa$ . The bolts pretightening loads was 155KN.

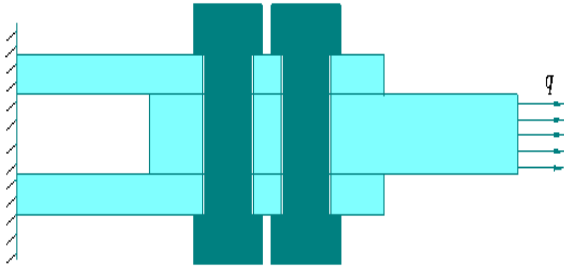


Figure 3. High-strength bolt joint

By FEM, bolts use stress was  $\sigma = 572MPa$  (Fig.4).

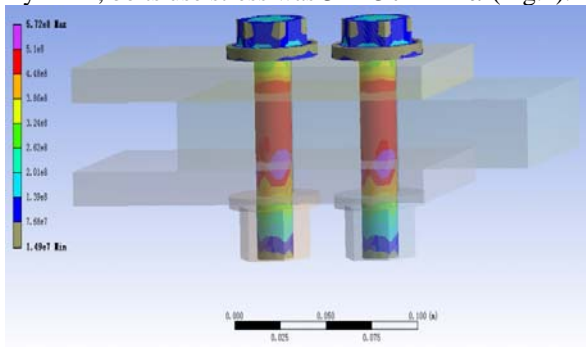


Figure 4. High-strength bolt stress state

According to formula,  $K_{ISCC} = 711.03 MN / m^{3/2}$ . Assuming  $\theta = 0.001$ , according to formula(1),  $Y = 1.029$ .

According to formula(4), the critical crack size  $a_c = 0.46mm$ . Assuming  $a_0 = 0.15 mm$ ,  $\sigma_a = 0.06mm$ ,  $\sigma_{ac} = 0.13mm$ . According to formula(8),  $\mu_{la} = -1.89mm$ ,  $\mu_{lac} = -0.78mm$ .

According to formula(10), the high-strength bolt joint corrosion fatigue reliability is  $P_f = \Phi(2.54) = 0.9945$ .

#### V. CONCLUSIONS

The performance of high-strength bolt corrosion fatigue related to the safety of structure. It is generally thought that high-strength bolt crack size and the critical crack size conform to logarithmic normal distribution. If the probability density functions of crack size and the critical crack size interfered, high-strength bolt maybe destroyed.

According to the Gerberich-Chen formula, the corrosion fracture growth threshold value of high-strength bolt was estimated. Exact value can be obtained by further experiments.

According to fracture mechanics method, based on reliability theory, the high-strength bolt corrosion fatigue reliability model was deduced. And high-strength bolt corrosion fatigue reliability was analyzed. It was easy and convenient that analysis high-strength bolt joint corrosion fatigue reliability by this model. Hence the high-strength bolt joint corrosion fatigue can be predicted. This method may provide the reference for the high-strength bolt joint fatigue analysis.

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