Fatigue performance analysis of frictional type high strength bolts of overlapped joints

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Abstract: According to the fatigue crack extension theory of the fracture mechanics, this paper analysis the relationship between the property of the high-strength bolts and the connection surface friction coefficient, as well as the relationship between the property of the high-strength bolts and temperature. The fatigue life and fatigue damage degree under different anti-friction coefficient and different temperature are calculated by high-strength bolt three-dimension FEM model. After recycling for the same times, the fatigue life will decrease with the increase of the anti-fiction coefficient as well as the temperature. The bigger the anti-friction coefficient is, the more serious the fatigue damage is. The higher the temperature is, the more serious the fatigue damage degree is. With the increase of the anti-friction coefficient, the structure safety factor will decrease, for the increased anti-friction coefficient makes the connection surface geometric discontinuities degree become serious, then the crack extension rate will be faster. With the increase of the temperature, the structure safety factor will also decrease. The conclusions can be used as a reference for the afterwards fatigue design about such components.

Keywords: Fatigue Life, Fatigue Damage, Safe factor, Fracture mechanics

1. Introduction

Because of convenient installation, high-strength material of steel bridge, it was adapted by engineer, as the main form of the structure of large- span bridge design. Factory welding and construction site bolt connection as the general connection between Steel components. As welding connection mode restrictions by welding process and construction environmental, it was difficult to ensure the construction quality when the construction site in the way. So components on site installation connected often use high strength bolt connection. Because bridge often bears car live load function etc, as a result the bridge always under repeated load, will eventually cause fatigue damage of steel bridge. Now a lot of research on the fatigue of the connection method for welding, but for the high strength bolts of fatigue performance opposite less, but bolt-connection structure also had fatigue problems. In this article we use three dimension finite element model of double plate joints connected by high strength friction type bolt, and analysis the node fatigue performance under different temperature and different interface handle methods.

2 Fatigue crack expansion and estimate fatigue life of structure

Fatigue phenomenon produced when the cyclic stress impact on the structure, caused by the subtle crack and steady state expansion, most components considered having the internal defects, having the propagation of the crack which eventually leads to fatigue damage. The maximum stress reached probably in t elastic deformation range in the entire stress object, so effective prediction of fatigue life is the key to guarantee the safety of component. Fracture mechanics applied to solve the problem of the fatigue crack propagation law made well. Etc of variable load in the fatigue crack propagation characteristics can be made by Pairs formula says:

$$\frac{da}{dN} = A \bullet (\Delta K)^n \qquad ()$$

a—Crack length,N—Cycle, ΔK —Stress intensity factor range, A, n material constants

From the formula, we can see the fatigue crack growth rate has a close relationship with the stress intensity factor of the materials. Stress intensity factor can be used to characterize crack toughness of the materials that the ability of gap materials to bear loads and plastic deformation under slow loading and linear elastic properties. Generally the critical stress intensity factor (K_C) is used to describe it. Generally speaking, the structure crack toughness, especially steel, increased with temperature, the destroyed stress intensity factor will increase the range and will increase the crack growth rate.

Another factor of fatigue crack propagation is stress concentration .The influence of the geometric not continuity will increase the nominal stress value of bearing structure parts. For fatigue crack with stress concentration expansion laws can be shown as (2) formula express:

$$\frac{da}{dN} = A \bullet (\Delta K_{eff})^n \qquad (2)$$

In the formula： A ， n ——material constant, $\Delta K_{eff} \propto K_t(a)\Delta\sigma\sqrt{a}$, $\Delta\sigma$ —Nominal stress range, a ——Crack length, $K_t(a)$ ——The stress concentration factor.

The strength problem of engineering structure , often need to estimation fatigue life of the dangerous parts in the structure. If knowing the material fatigue performance data, fatigue load spectrum, in principle we can estimation life by cumulative damage theory.

In this article, the circulation of the cumulative damage as circulation method, namely to crack length as the measure of the damage, the initial damage is described by initial crack length, the critical damage is described by critical crack length,the cumulative damage produced by each load cycles is described wit the crack propagation incremental produced by one load cycles. So damage accumulation formula can express into (3) type:

$$a_c = a_0 + \sum_{i=1}^{N_c} \Delta a_i = a_0 + \sum_{i=1}^{N_c} \Delta(\frac{da}{dN})_i \qquad (3)$$

a_c—Critical crack length, a_0—Initial crack length, Δa_i—Crack propagation incremental, i —Cycle time, N_c — Cycle times reached the critical crack length.

Through the cycle by the expression of the total circulation damage theory we can see, the fatigue life of the component has a close relationship to the crack growth rate In practical engineering, the maximum length of fatigue crack propagation general is considered to be certain value, we usually think the maximum length of bolt connection is the pure distance between two bolt hole. So the crack's growth rate directly affects the fatigue life of components.

3 The finite element analysis

3.1 Calculation model size and material parameters

In this paper the calculation model is a double board lap connected by high strength bolt with tension load impacting on the axis of it. The joints has a top and a bottom board and one middle connection plate And thickness of joining board is 12 mm &Q345q steel, the connecting slab is 24 mm. the magnitude of bolt is 10.9 specification.&M20. Friction type aperture of the high strength bolts is 1.5~2mm more than bolt stem nominal diameter .During the calculation process bolt aperture takes 22 mm. In the process of computation, steel plate and bolts are assumed for isotropic elastic material, characteristic parameters of material see table 1. For material fatigue properties, there are many scientific research data as a reference, material fatigue properties in this paper using literature [5], [6] research data.

Table 1 Material parameter table

Member	$E(N\cdot mm^{-2})$	$\rho(kg\cdot m^{-3})$	μ	$f_y(N\cdot mm^{-2})$	$\alpha(℃^{-1})$
Gusset plate	201	7850	0.3	420	1.4e-7
Connected plate	201	7850	0.3	420	1.4e-7
High-strength bolts	206	7850	0.3	942	1.4e-7

3.2 Unit selection and boundary conditions

Because screw, nut, washer are the same material, in order to reduce the contact surface analysis and unit number to increase the simulation efficiency ,the bolt model ignored the contact among screw, nut and washer ,built whole bolt. This paper we simulated high strength bolt and ignored the impact of tightening the nut on the bolt lever torque. The cell division of the finite element model is shown in Figure 1. The model is divided into seven entities part by regular hexahedron unit . the Meshing number is 1333 unit. Bolts and nuts adopted bound connection contact , reaction in the form of a confrontation between two binding contact area designated as the two roles are equal and opposing. Nut with connecting plate and connected to the backplane, connected to the base plate and connecting plate using frictional contact, this contact before the relative sliding can assume a certain level of shear stress in the two contact surfaces. Freedom at one end of the adapter plate, the intermediate connecting both DON stress is applied at one end of the freedom of the upper and lower splicing plates fixed constraints. The simulation consider different temperatures, temperature load is applied at the same time.

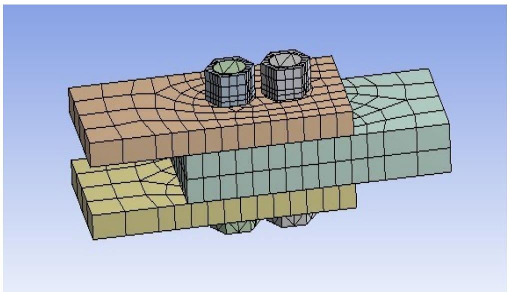

Fig 1 3D Single lap connecting slab model finite element grid partition

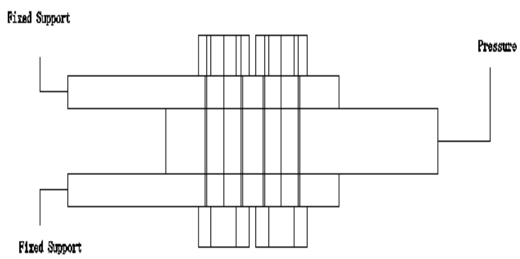

Fig 2 Boundary condition and the load

Different friction coefficients were chosen 0.35,0.40,0.55, many studies were studied for the effects of temperature, this taking into account the temperature difference between the bridge actual working environment, respectively, of -45 a working temperature of -25, 0, 25, 45, etc., fatigue performance simulation.

4 Results analysis

This paper the finite element model of the design life of the times, a major concern under constant stress amplitude fatigue damage D (design life and the useful life of the ratio), the expression can be expressed as (4). Safety factor S (in a given design life, the failure probability), the fatigue life of F (member fatigue failure when the number of load cycles).

$$D = \frac{L_A}{L_D} \tag{4}$$

D—Fatigue damage, L_D—Fatigue design life, L_A—Available fatigue life.

As can be seen from Figure 3 to 5 leads to the difference in coefficient of the contact surface of the anti-friction, after the same number of times in the cycle as the anti-friction coefficient increases effective fatigue life is gradually reduced, resulting in increased fatigue damage due to the contact surface of the processing in different ways, The safety factor is gradually reduced.

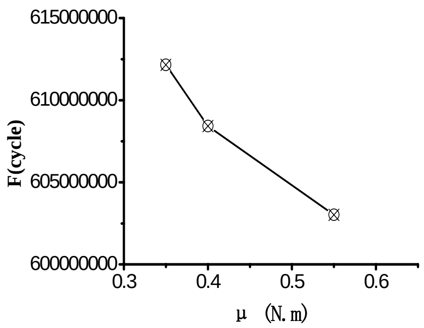

Fig 3 Fatigue life under different friction factor

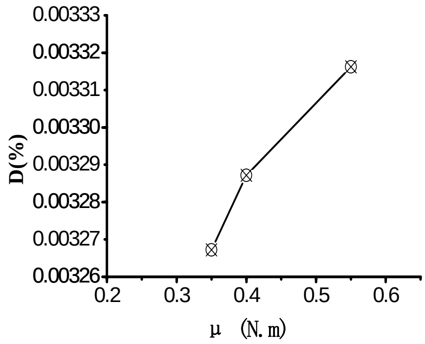

Fig 4 Fatigue damage under different friction coefficient

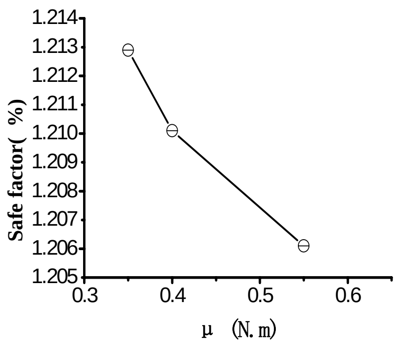

Fig 5 Safe factor with different friction factor

The different friction coefficients reflect the different processing side, the increase in friction coefficient can effectively reduce the relative slippage between the connecting plate, but so that the contact surface between the geometric discontinuity degree increases, resulting in a discontinuous area near the nominal stress value increases, The fatigue crack growth faster, reduce the safety factor of the structure[9].

As can be seen from Figure 6 to 8 with the temperature increasing the effective life of the same times in the cycle after the fatigue decreased, resulting in increase in the fatigue damage in the function of temperature, the safety factor of the structure decreases.

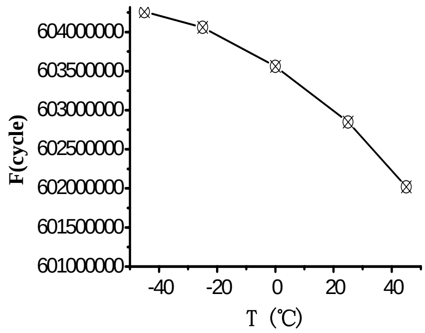

Fig 6 Fatigue life under different temperature

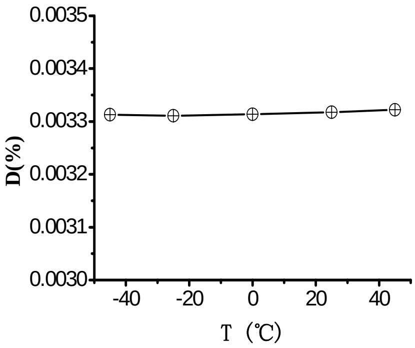

Fig 7 Fatigue damage under different temperature

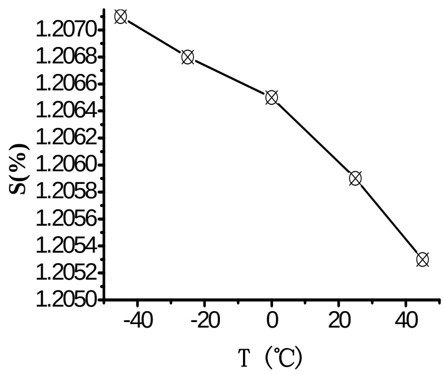

Fig 8 Safe factor with different temperature

5 Conclusion

By the theoretical analysis and finite element analysis, we can get about fatigue life and fatigue damage as well as the structure of the safety factor, the following conclusions:

(1) the effective life of the cycle the same number of times of fatigue due to the approach, in the contact surface between the structure of the different working environment varies, the contact surface more rough lower fatigue life, the lower the higher the fatigue life of the temperature of the working environment.

(2) of the contact surface of the node using a different approach and structure in a different working environment showed a different degree of damage. Contact surface more rough structure of fatigue damage is more severe, and the greater the higher the temperature of the work environment the structure of the fatigue damage.

(3) The different treatment of the contact surface causes the contact surface of the geometric discontinuity degree is increased, resulting in crack growth rate is accelerated to the structure of the lower safety coefficient; increase the safety of the structure with the elevated temperature of the fatigue crack growth rate coefficient is reduced.

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