Research on Wear Damage of Anchor Chain under Different Load Modes

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Abstract. In the marine environment, mooring anchor chains bear complex loads such as axial tension and out of plane bending. These loads cause wear and corrosion damage to the anchor chain, reducing its fatigue strength, and even leading to fatigue fracture. The inspection load applied to the anchor chain before leaving the factory will generate residual stress, which will affect the stress characteristics and fatigue life of the anchor chain during service. This article aims to obtain the residual stress generated by the test load on the anchor chain through numerical simulation, and explore the impact of the test load residual stress on the stress characteristics and wear performance of the anchor chain; Analyze the stress and contact characteristics of anchor chains under different bending angles and wear depths, and obtain the locations where fatigue damage is prone to occur in the later stage of anchor chain wear.

Keywords: Anchor chain; Out of plane bending; Residual stress; Abrasion.

1. Introduction

A good mooring system is the foundation for the normal operation of the platform. The anchor chain is an important component of the mooring system. It is subjected to various complex loads such as axial tension, bending, and torsion, and there is stress concentration in key positions, which is prone to fatigue damage; At the same time, due to the general service life of anchor chains being 20 years, the chain links are gradually damaged due to seawater corrosion and wear between the links, which will also make their fatigue life unable to meet the original requirements.

Pacheco P et al. [1] found that the presence of residual stress significantly changes the stress distribution and fatigue life of anchor chains. Therefore, an elastic-plastic model should be used for finite element analysis of anchor chains. Denney et al. [2] conducted research on two FPSO anchor chain fracture accidents and determined that the root cause was the contact surface deformation caused by the inspection load, which increased the friction between the anchor chains, hindered the rolling between the chain links, and the combination of bending fatigue stress and tension damaged the strength of the anchor chains. Bastid P et al. [3] found that the inspection load generated very high tensile residual stress at the edge of the anchor chain contact area, and fatigue fracture first occurred at this location.

In response to the above issues, this article sets up multiple sets of comparative examples using ANSYS finite element software, aiming to study the out of plane bending phenomenon of anchor chains under residual stress, and analyze their stress and contact characteristics at different wear depths.

2. Organization of the Text

The research process of this article is divided into two parts: elastic-plastic finite element analysis of anchor chains under residual stress, and finite element analysis of anchor chain out of plane bending under different wear depths.

This article selects a general unstopped anchor chain with a cross-sectional diameter of 130mm as the research object

This article uses three continuous chain links as models for calculation and analysis. The Z-axis positive direction link is defined as a fixed end link, the Z-axis negative direction link is defined as a tension end link, the middle link is an out of plane bending target link, its plane OXZ is the out of plane bending target plane, and the out of plane bending direction is the Y-axis direction. The finite element model is shown in Figure 2.1.

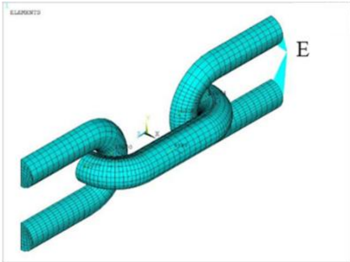


Figure 2.1 Finite Element Mode

2.1 Finite element analysis of residual stress in anchor chains

Research has shown that residual stress in anchor chains has a significant impact on fatigue life. This article considers the influence of residual stress on the test load. In finite element calculation, the simulation of residual stress is divided into two steps: applying the test load and unloading. When loading, considering the influence of residual stress in the inspection load, the four loading steps shown in Figure 2.2 are used for loading.

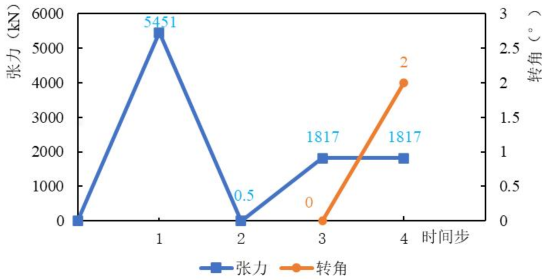


Figure 2.2 Loading Steps Considering Inspection Load

2.2 Finite element analysis of out of plane bending of anchor chains with different wear depths

The out of plane bending angle of anchor chains is generally below 2 ° [7]. This article aims to explore the influence of residual stress on the general phenomenon of out of plane bending and wear of anchor chains. Therefore, this chapter will appropriately increase the angle, select 7 working conditions including 0 °, 1 °, 2 °, 3 °, 4 °, 5 °, and 6 ° to establish an elastic-plastic finite element model, and analyze the stress characteristics and contact state of anchor chains under out of plane bending loads.

3. Calculation Results and Analysis

3.1 Finite element analysis of out of plane bending of anchor chains without wear

3.1.1 Not considering the influence of residual stress

Extracting the finite element calculation without considering residual stress, the slip distance and contact compressive stress of the intermediate link between 0 ° -6 ° are shown in Figures 3.1 and 3.2, respectively. As the bending angle increases, the overall range of stress values is relatively small. The maximum slip distance increases linearly with the increase of bending angle. Superposition the slip distance and contact compressive stress, as shown in Figure 3.3. The superposition value continues to increase, without considering residual stress, as the bending angle outside the plane increases, the wear amount of the anchor chain also gradually increases, and the volume rate of wear loss within adjacent angles gradually accelerates.

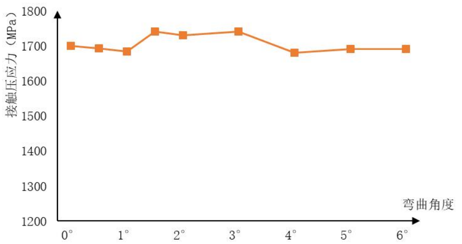


Figure 3.1 Compression stress on contact surfaces at different bending angles without residual stress

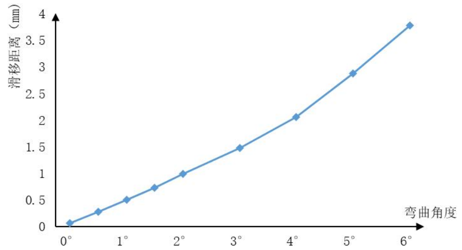


Figure 3.2 Slip distance of chain link contact surface without residual stress

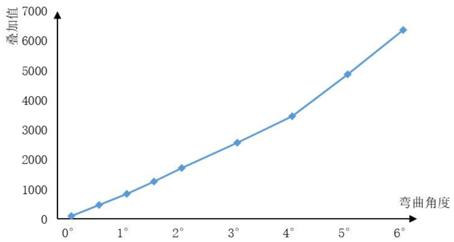


Figure 3.3 Superimposed value of anchor chain contact state without residual stress

3.1.2 Considering the influence of residual stress

The calculation results of the contact compressive stress and relative slip distance of the intermediate link under the extraction of residual stress are shown in Figures 3.4 and 3.5. As shown in the figure, with the increase of bending angle, the maximum compressive stress in the contact area increases rapidly at 0 ° -1 °, and gradually slows down at 1 ° -6 °, showing an approximate linear growth. The sliding distance of the contact surface also increases approximately linearly. The sliding distance and contact stress were superimposed, and the sum of the two values continued to increase. The results showed that when considering residual stress, as the out of plane bending angle increased, the wear amount of the chain link gradually increased and the rate of wear loss volume gradually accelerated.

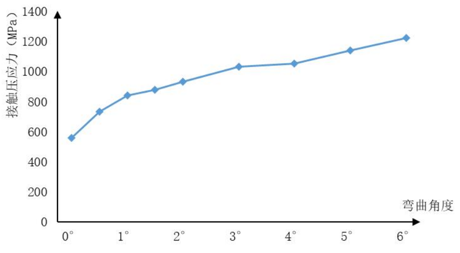


Figure 3.4 Pressure stress on the contact surface of anchor links at different bending angles

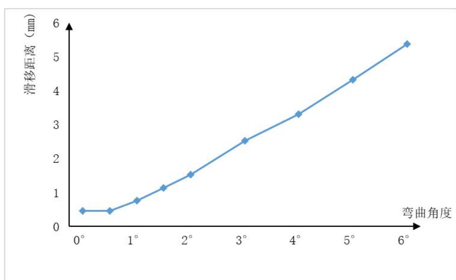


Figure 3.5 Sliding distance of contact surfaces at different bending angles

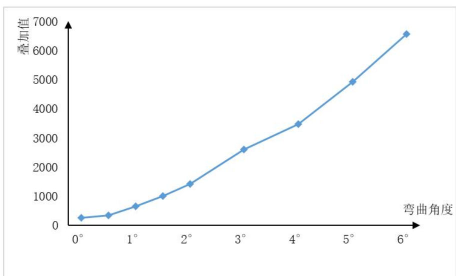


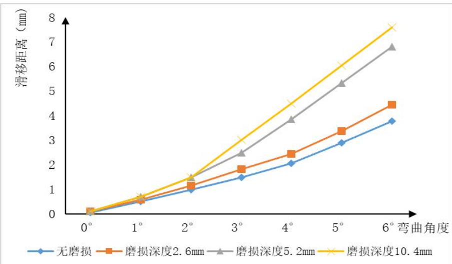
Figure 3.6 Maximum Superimposed Value of Contact Surface Considering Residual Stress

3.2 Finite element analysis of out of plane bending of anchor chains under different wear depths

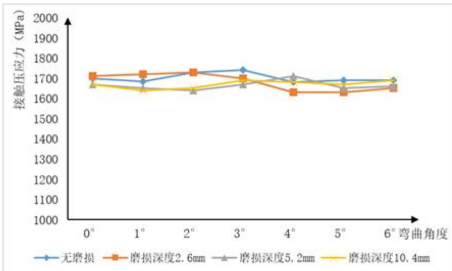
3.2.1 Failure to consider the effect of residual stress

The calculation results of the compressive stress, slip distance, and corresponding superposition values of the node contact surface under three wear depths and without wear are shown in Figure 3.7.

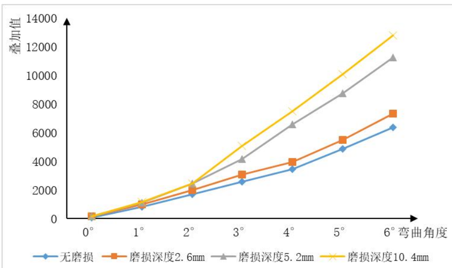
As shown in Figure a), when there is no residual stress, the slip distance of the chain link increases with the deepening of wear depth; As the bending angle increases, the slip distance of the chain link also increases continuously, and the increase is more significant when the bending angle is above 2 °. As shown in Figure b), when the wear depth is constant, the contact compressive stress values of the chain links under the four working conditions vary approximately equally with the increase of bending angle; When the bending angle is constant, the stress value of the chain link under different wear depths is approximately equal. Therefore, when there is no residual stress, the contact compressive stress value of the chain link tends to be fixed, independent of the wear depth and bending angle. As shown in Figure c), the sliding distance and contact compressive stress are superimposed, and the superimposed value always increases with the increase of bending angle and wear depth. This indicates that when the bending angle is the same, the rate of anchor chain wear volume loss is positively correlated with the wear depth.



a) Slip distance



b) Slip distance



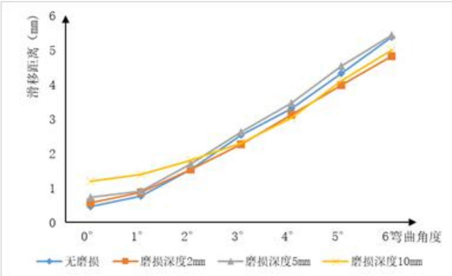
c) Overlay value

Figure 3.7 Calculation Results of Contact Surface for Chain Links with Different Wear Depths

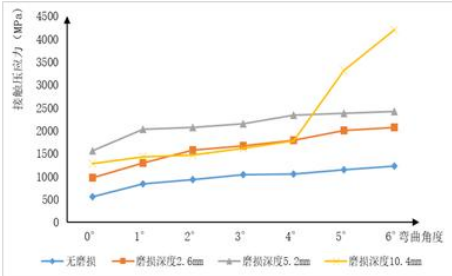
3.2.2 Considering the influence of residual stress

The calculation results of the compressive stress, slip distance, and corresponding superposition values of the node contact surface under three wear depths and without wear are shown in Figure 3.8

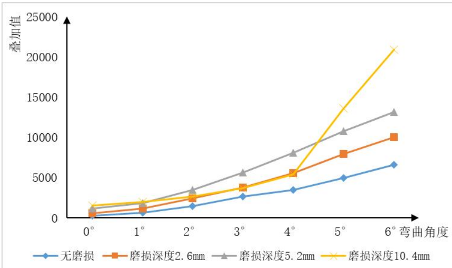
.As shown in Figure a), under the residual stress of the inspection load, the slip distance of the chain link always increases with the increase of the bending angle, and the maximum value occurs in the middle stage of wear. As shown in Figure b), under the residual stress of the inspection load, before the middle stage of wear, the contact compressive stress value of the chain link always increases with the increase of bending angle and wear depth; In the later stage of wear, as the bending angle increases, due to the unsmooth contact, significant contact compressive stress occurs in the contact area B at the lower end of the chain link. Superimposing the sliding distance and contact compressive stress, as shown in Figure c), the volume rate of wear loss is positively correlated with the bending angle; When the bending angle is below 4 °, the volume rate of wear loss in the middle stage is the highest. As the bending angle increases, in the later stage of wear, due to the geometric roughness of the contact area B, significant contact compressive stress and superimposed values are generated.



a) Slip distance



b) Contact compressive stress



c) Overlay value

Figure 3.8 Calculation Results of Contact Surface for Chain Links with Different Wear Depths

4. Summary

1) under working load, the presence of residual stress of the inspection load in the contact section of the chain link reduces the stress concentration phenomenon inside the chain link, and increases the stress concentration phenomenon in the hot spot area on the outer surface of the chain link.

2) As the wear depth increases, residual stress causes the anchor chain to produce approximately equal slip distance. The main factor affecting the calculation of wear in the next feedback cycle is contact compressive stress, and the influence of bending angle cannot be ignored in wear calculation.

3) In the later stage of wear, as the bending angle increases, the anchor chain under residual stress experiences significant contact compressive stress and superimposed values due to the geometric contact being not smooth. Therefore, when studying the wear of anchor chains, the influence of residual stress in the inspection load cannot be ignored.

References

[1] Pacheco P, Kenedi P P, Jorge J. Elastoplastic analysis of the residual stress in chain links [C]//Asme Interational Conference on Offshore Mechanics & Arctic Engineering. 2002

[2] Denney, Dennis. Chain failure by bending on deepwater mooring systems [J]. Journal of Petroleum Technology,2006,58(02):72-73.

[3] Bastid P, Smith S D. Numerical analysis of contact stresses between mooring chain links and potential consequences for fatigue damage [C]//Asme International Conference on Ocean. 2013.

[4] Bureau Veritas (BV). Fatigue of top chain of mooring lines due to in-plane and out-of-plane bendings: Guidance Note NI 604 DT R00 E[S]. 2014.