Introduction of Steel Structure Fatigue Damage Characteristics

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Abstract

With the development of economy, China appeared all kinds of steel structures and other structures, in recent years, both inside and outside of industry are advocated to develop the steel structure; some of the new type of structure and manufacting process in modern steel structure, however, the fatigue property of steel structure needs special attention in the design and construction. This paper is the process of steel structure fatigue of session and characteristics, the influence factors of fatigue damage and fatigue calculation of the basic theory and design method for a brief overview.

Keywords

Steel Structure, Fatigue Damage, Fatigue Design, Fatigue Calculation.

1. Introduction

The definition of fatigue refers to the steel under the action of cyclic stress or strain and the material has a local defect location gradually formed crack, and further extend to the fracture of a steel. But would like to point out here is fatigue and problems in the traditional sense of the strength have essential difference.Frist, load of the fatigue damage is lower than the ultimate strength of materials, some are more lower than the yield strength. Second, fatigue is the cumulative effect of multiple stress cycle results.Thrid, fatigue damage not only has relation with steel, but also components of its stress distribution and environmental factors.

Though fatigue damage is the result of long-term damage accumulation of steel structural components, there is no obvious deformation before the steel damage, which belongs to brittle failure, in this sense ,the fatigue damage is very dangerous. In the event of this type of damage happened which will bring huge losses of lives and property. At the same time will have negative influence on the social level.

2. The process and characteristics of fatigue

2.1 The process of fatigue damage

In the actual structure of the steel for the development of the fatigue damage process:(1)The formation of the crack; (2)slowly growing crack;(3)rapid expansion of the crack;(4)rupture, As is shown in figure 1.

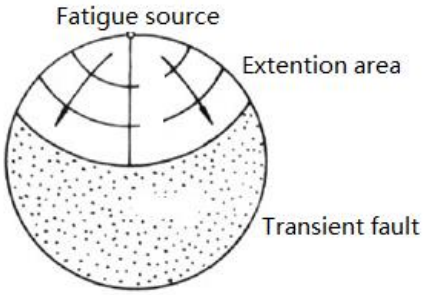

Figure 1. Steel development process of fatigue

The first is crack, fissure formation, in the process of steel production and steel structure manufacture, there is a local defects in the certain place of the materials that we cannot be avoided more or less. For example, steel contains some of the chemical composition of proportion is not appropriate and some

non-metallic impurities; Welded components might also exist notch, defects of steel rolling and flame cutting technology brings crack to the steel members, welding slag will invade the weld toe and welding joint may exist porosity. These defects are the important factors which can cause crack. When under repeated continuous load, in these parts of the cross-section the stress will be maldistribution and then cause the stress concentration phenomenon. The location at the peak stress will appear tiny crack first, then is the stage of slow extension, under the repeated stress loads the crack extends slowly, the last stage is rapid destruction, after a long time the damage accumulation of the crack reaches a so high value that the effective area of the cross section unable to bear the load, under the accidental vibration or impact the structures will be damaged.

2.2 The characteristics of fatigue damage

Combined with the test and resistance index, load, stress calculation, stress checking, and in comparison with material failure strength and unstable failure the fatigue damage characteristics of steel structure has the following several aspects:

(1) As for the test and the resistance index ,strength failure and buckling failure using the design value is the maximum stress value which comes from structure in service or in the process of the text. So here we can take the maximum damage stress as the stress index. But it is worth nothing that the fatigue cracking measure need to repeatedly force, expressing its resistance include at least three arguments: the maximum stress, minimum stress and cycles. Based on the experience of strength checking and stability checking, folks take the maximum stress as the calculating index, after a series of experiments study we can think that the stress can be taken as a measure of fatigue strength.

(2) As for load, for the instability and the strength damage, we should use maximum internal force in components to determine the need of load. When making the investigation and study about the load, experts should focus on the combination of maximum load value, but for fatigue cracking is the result of multiple stress. Therefore, in order to checking fatigue calculation need load crack investigation and need to focus on the more common load combination.

(3) According to the calculated structural stress, generally divided into two steps, internal force analysis and stress calculation, and these two steps are according to the structure in the elastic stage hypothesis. But for the component strength and steady limit state which need stress calculation, in fact, considering the component before the destruction of plasticizing phenomenon. Fatigue cracking is in the load is small but a lot of stress cycles. It's analysis of internal force and stress calculation not only on the situation but also must be carried out in accordance with the elastic state. The most important is that fatigue damage must consider the role of the number of times about stress.

(4) Checking the problem which will be solved and taking the cross section, strength calculation is to prevent a wide range of yield, On the strength of the maximum stress point to select the section. Stability calculation is in order to prevent the instability, but it can't one-sided understanding as one section, just write it as section calculation on the situation. Fatigue calculation is to prevent cross section. So we should chose all potential crack source points as dangerous cross sections.

3. The influence factors of fatigue damage

3.1 stress-number of cycles

Stress-number of cycles is continuous under repeated loading and stress value is the maximum to the minimum cycles of number. Under the influence of different stress amplitude, all kind of components and their connection will produce different stress cycles fatigue damage. The less stress amplitude, the greeter the cycles, whereas the more. When the stress amplitude is smaller than a certain value, even if the stress infinite loop for many times, also won't produce fatigue damage, which is a general designation of the fatigue limit. Generally folks could think $N=5\times10^6$ times as the number of stress fatigue limit cycles.

3.2 Stress ratio

Stress ration is the ratio of the minimum stress and the maximum stress, stress ratios can be used to describe the characteristics of the stress cycle. At the same time, we should fully understand the steel structure and its connection's fatigue characteristics. Need to get the different stress cycle fatigue strength and the curve of the stress cycles. The structure of the fatigue strength is associated with the stress ratio through referring to the references. The smaller stress ratio and the lower fatigue strength.

3.3 Stress amplitude

Stress amplitude is defined as maximum stress value minus the minimum stress value. When the welding components used for supporting the fatigue load, projects from practice gradually realize that instead of the stress ratio structure fatigue strength is closely related to the stress amplitude. Because in the weld zone will produce residual stress which will reaches the yield point. The actual stress state of the main parts will change, thus will change the stress state about the stress amplitude. There can get a conclusion that fatigue load is closely related to the stress amplitude.

3.4 The fatigue resistance of steel

ABC curve in figure 2,point B shows the stop point of the low toughness material crack slowly expending area, point C said the stop point of the high toughness material crack slowly expending area. From point B to point C,the cycle number increases in ΔN_3,thus it can be seen, the high toughness materials have a longer fatigue life.

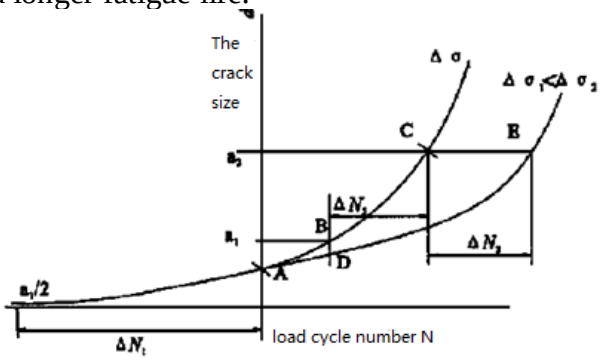

Figure 2.Fatigue life curve

In the international community, as a result of material fatigue cause of accidents are also common, in 1994, for example, in late October. Located in Seoul, South Korea's han river holy water bridge, there are over 50 meters long beam, because of the reason of the fatigue fracture, falling into the river. And it happened at rush hours of traffic, the result is very serious.Later,the accident investigation committee according to the survey gain a result, the holy water bridge's suppuration material fatigue life is very short. It just has 12 years fatigue life, in another words, holy water bridge will be broken after 12 years and the reason is fatigue damage.

But in fact, this bridge have 15 years life. Some experts have many given reasonable explanations. One of them, because the top of the piers cover somethings which have positive effects about anti-fatigue. Next is because 6 pillars support frame are not all damaged. From what has been discussed above, holy water bridge damage time could be delayed for 3 years.Howerer,diect cause of the accident is due to the contractor is not in accordance with the requirements of the drawings for the construction, and cutting corners during the construction. And the steel is very poor fatigue resistance.

3.5 The larger stress concentration

Under the action of static loads, the inside of the steel structure has general stress concentration. Its peak stress often decreases because of the development of plastic steel. But low stress area stress is increased. The result is that section of the non-uniform stress tend to be more uniform, and will not affect the section ultimate bearing capacity. At the time of design need not consider the effect of it.But serious stress concentration, in the peak stress area there is always has bigger stress field, which makes steel plastic deformation more difficult and as a result is the steel will be brittle fracture. For

example, in the poor marine environment,wind,sea water ,ice in cold waters and the tide play a very adverse effect on the ocean drilling platform. One of the most prominent problem is the Marine steel structure fatigue damage. And the steel pipe node is high stress concentration. Facing with the Marine steel structures is the most pressing problem.

3.6 Maching defects

Weld defects will also bring some fatal defects to the steel structure, for example, welding residual stress, stress construction, welding residual deformation. In real life also has a lot of examples with weld defects causing serious consequences.1967 sea jewel ship was on the shift and at the same time damaged. Result in the hull appeared crack and sank into sea, the direct cause of the consequence is platform support fillet weld fatigue cracking. Type of crack defects also had a great influence on the fatigue strength. Above figure 2 minish the initial crack size α_1

to $\alpha_1/2$,so the consequence is that component can withstand cycles increased by ΔN_1,the increase number about cycle is very considerable. The root cause is that at the time of crack size is small the crack propagation rate $d\alpha/dN$ is very low.

As a result of the fixed offshore platform structure is located in the oceans for a long time, check the structure's crack which under the sea is extremely difficult.Therefore,if the component under the water damaged, will bring very grave consequences. For example, in 1980 British north sea Mr Coffey oilfield had an offshore platform named A.L.gilliard suddenly felt a shock from the deep sea, and then was a loud noise, platform immediately lose stability. As a result,123 people lost their precious lives. In the related organization investigation,consistant results was presented: due to the underwater support bar appeared fatigue crack, and let them extension, made the poles broken. One of the poles was broken, made the adjacent five support bars gain excess load destruction. Then made the upper platform lose stability capsized in a very short time.

4. The basic principle of fatigue calculation

The traditional calculation method is according to the results of test specimen, identify the detail structure graph of relation in constant amplitude fatigue strength and life, that is the S-N curve. Then according to the stress ratio form calculation cross section, and using the strength theory to calculate. But this approach still has many problems, after engineering study, in the welded structure, the stress ratio is not related to fatigue strength but the stress amplitude. As the actual repetition stress in the structure is not often of circulation but the amplitude of variation circulation. Therefore, we need more understanding about the process of the fatigue damage.

4.1 The basic parameters

The fatigue stress changes over time in the engineering called stress spectrum,from the general sense, the stress process is random and the amplitude is random too. Some parameters of the Often stress spectrum and stress amplitude of variation spectrum: $\sigma_m=(\sigma_{max}+\sigma_{min})/2$ represents the average stress, $\Delta\sigma=\sigma_{max}-\sigma_{min}$ represents the stress amplitude; $\Delta\sigma_a=(\sigma_{max}-\sigma_{min})/2$ represents a half of the stress amplitude; $\rho=\sigma_{min}/\sigma_{max}$ represents stress ratio, σ_{max} is maximum stress , σ_{min} is minimum stress.

4.2 S-N curve

S-N curve is fatigue resistance curve, it reflects the relationship between component applied stress level and fatigue life. Component had ever experienced stress before the fatigue failure or the number of cycle about stain is a important measure to define the fatigue life. And use "N" to represents the number of cycle. Fatigue test usually can get S-N curve.

4.3 P-S-N curve

The specimen which in the fatigue test showed the large discreteness.Therefore,the fatigue life of specimen and stress level, they are not the one-to-one relationship, but has a strong link with survival rate "P" of the specimens.S-N curve which mentioned in the previous section only can represent the differences between fatigue life and horizontal stress influence. The P-N curves which under the different stress level can be obtained according to the normal distribution. After we connect the data

points which are same survival rate, then we can get the S-N curve. Each curve represents a survival rate respectively under the relationship between the stress and the life. This curve is known as a p-s-n curve.

5. Fatigue design method

5.1 Safety life method

First of all need to estimate a load spectrum, then through the analysis and experiment find out the key components, and introduce the safety factor, then calculate the safe life. Safe life decides the service life, components are fast approaching safety life need to be replaced immediately.

5.2 Damage safety method

When a structure has cracks, ensure that cracks were found before other parts of the component can also bearing load safely and the local failure will not affect the all the component.

Therefore, we often need to examine artifacts and overhaul. If not, according to the standard which called the probability of a times deviation to determine the allowable stress.

5.3 The service life method

It likes safety life method, but it different from safety method is when the structure will run out its safe life, often do not immediately scrapped. And thinks that cracks in safety life is possible. It is not to do fatigue test for specimens in general. But will use the typical details of the structure to analysis and calculate results.

6. Method to improve the fatigue life

There are many methods to improve the fatigue life of steel structure, here only several representative are listed.Frist we can use appropriate structure details, and let structure size calculated by the static control rather than fatigue control as far as possible. But the structure is uncertain, and fatigue problem is not influenced by one factor. Even we use the above method may not be able to eliminate the possibility of fatigue damage. Therefore, ensure another important link is guarantee the quality of construction. This approach is ensure that reduce the details of cracks at the beginning of the formed components. The two methods are listed in the final: one is reducing the component stress amplitude, the other is using good toughness materials.

7. Conclusion

The characteristics of the steel structure are lighter weight, stronger carrying capacity. In recent years, China vigorously promote the use of steel structure in civil industry, but the fatigue of the steel structure in the steel structure design is a difficult and inevitable problem. And that is worth to our attention: once the structure has fatigue damage will happen serious consequence.

This paper briefly introduced the causes of fatigue in steel structure and characteristics and influencing of fatigue damage, the basic theory of fatigue calculation and design method.

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