Causes of Fatigue in Offshore Structures

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Abstract: The assessment of fatigue phenomenon has commenced very recently. In fact, fatigue behavior in structural members was still a phenomenon to master, which implies that the reliability of the fatigue crack inspection and monitoring techniques was unknown. As time went on, the progress of the researches has given a clearer idea on this matter, but still more knowledge is needed in this area because fatigue phenomenon in some cases is very subtle.

This paper briefly reviews the literature; explain the fatigue mechanism in offshore structural elements and present the main sources of fatigue for better understanding.

Keywords - Reliability, fatigue phenomenon, structural members, crack.

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1.INTRODUCTION

The phenomenon of fatigue in materials caught the attention of many researchers from the middle of 19th century. Braithwaite initially used the term "fatigue" in the literature in 1854 after conducting many work to understand the issue of repeated cyclic loading. Afterward, it has been found that structures are continuously subjected to environmental loading because of waves, wind and current. Indeed, fatigue has been the cause of many offshore structures failure in the history of oil and gas production. Most of the reported failures of offshore structures are in fact fatigue failures and this has been the center of the research in offshore structural Engineering field until today.

Although several scientific methods have been suggested and improved over years, researches are still carrying on to get full understanding of fatigue failure in offshore structures.

The main objective of this paper is to present the process of fatigue: how fatigue is induced in the offshore structures subtly in the first part and the second part is devoted to the sources of fatigue analysis.

2. LITERATURE REVIEW

1.Mechanism of fatigue

Fatigue is a failure known as silent killer characterized by gradual reduction in the of structural elements strength to withstand cyclic loading. It is known that a metal may fracture at a relatively low stress if that stress is applied a great number of times. This fracture or damage is the cumulative result of large number of repeated action of applied stresses. The initially small cracks at the point of localized stress grow under cyclic loading and spread until the remaining solid cross section of the load-carrying member is not sufficient to transmit the load and the member fractures. Such fractures are referred to as fatigue failure.

In general, the fatigue phenomenon is considered and studied in three main stages:

2.2.1 Stage 1: Initial cracking

The initial stage of the cracking in the member and the joints is within the range of the microscopic behavior of the materials. These cracks are usually formed due to the special geometry of the joint and the secondary effects and imperfections of the weld site, which occur either in the form of very tiny internal cracks or at the welding surface.

2.2.2 Stage 2: Spread of cracking

In the second stage, first, the rate of crack propagation in the initial stage is very slow and this is nothing but propagation along the direction of the crystallography close packed direction of the material and can be controlled when the stage of the spread of the crack is still more recognizable. On the other hand, when the crack length actually increases or exits the critical crack length for the failure of the component in that case, the crack proceeds at a rapid rate in the stage two. In this stage crack is very difficult to control, therefore crack propagation rate depends on the toughness of the component.

In addition, the depth of the initial cracks and the geometry of welds also have a significant effect on the spread of the cracks.

2.2.3 Stage 3: Final fracture

The stage of final fracture takes place when the spread of cracks reaches its critical level.

The final failure depends on some factors such as stress level, crack size, and the hardness of the material. Like the initial cracking stage, the final fracture stage has also little importance in the fatigue life.

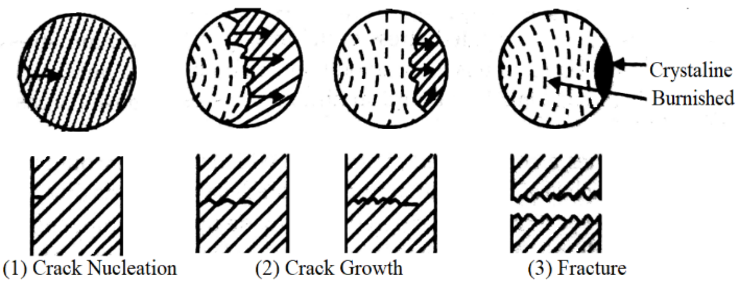


Figure 1: Fatigue cracks on the surface of the structure

3. CAUSES OF FATIGUE

3.1 GENERAL:

Causes of fatigue in offshore structures are multiple, after reviewing many scientific researches, this section present the main sources of fatigue and explain how fatigue is induced in the structures.

Offshore structures are usually fabricated using tubular members, which are interconnected through welded joints. These joints, however, experience fatigue damage mainly due to the presence of small defects caused by welding, high stress concentrations at the intersection and the load variations due to environmental loads. It is well known that the magnitude of load to cause failure decreases with increasing number of load applications. Therefore, some example of load, which contribute to fatigue damage, may be the following:

3.1 Loads induced on the structures

3.1.2 Loads induced during transportation

Transportation involves many processes to be followed for the offshore structures to arrive safely at the right destination. During the lifting or launching of the structure, damage may occur as the structure. If the structure is not lifted through its center of gravity, it may hit the barge or fall from the crane. In addition to that, on the barge, the sea fastening should be well designed to avoid the structure to be jostled and be at the mercy of the current and the wave during the transportation. If care is not taken during this process, the structures may be subjected to some extra or intra loads. In fact, these load produce fatigue that might be accumulated in the structure during the transportation, which directly or indirectly weaken its strength. Therefore, the following must be well planned in advanced:

- Means of transportation
- Environmental conditions
- Route to be following
- And the period of transportation

Here the process of the transportation of offshore should be well analyzed with respect to fatigue design.

3.1.3 Loads induced during installation

An example of a jacket installation receiving heavy load which may induce stresses in the structure in the sense that around 2 m diameter of heavy steel piles are inserted in the skirt and driven into ground by the use of heavy hammer. Of course, the pile plus the hammer is an additional load on the structure that should not be neglected because when the hammer hits the anvil, stress is transmitted through the cushioning systems into the top of the pile. The top of the pile moves downwards and compressive stress-strain wave stats to travel down the pile. The application of the hammer producing several blows and vibrations tend to create stresses in the whole jacket structure and microscopic or very small cracks may be developed in the structures that may contribute to fatigue failure.

3.2 Environmental Loading

Environmental factors can also significantly influence the fatigue failure behavior of the structure.

3.2.1 Loads induced by wave, current and wind.

The sea environment is characterized mainly by the heavy wind, surface waves and currents. The loading imposed by waves and currents on the offshore structural members represent one of the major analysis and design considerations.

In deep water areas, currents are typically higher than in shallower areas, which try to uproot the jacket inserted into the seabed throughout the jacket's life. Heavy wave load, storm generated by heavy wind on the surface of the seawater afflict heavy load on the structure and try to rotate it. Heavy waves that routinely strike offshore structures may contribute in producing fatigue. Therefore, offshore structures that are subjected to a large number of wave cycles should be designed adequately for a fatigue life that largely depends upon the useful life of the oil reservoir.

3.2.2 Wave loads

The wave load is the major force applied to the offshore platforms. The wave load, due to its repetition exert forces on the whole structure cause fatigue in the members and joints of the structure. Due to the concentration of stress and welding defects in the platform joints areas, they have a high sensitivity to fatigue failure.

3.3 Pressure variations

Offshore structures support heavy machinery that produce vibrations while running. These vibrations are repeatedly produced during the lifetime of the platform and are endured by the structures. In fact, the structure being shaken by the repeated vibration may be subjected to cracks, which might lead to a sudden failure over times.

3.3.1 Machinery induced vibrations

In the case of fixed and floating offshore platforms, it is usually the in-place environmental loads due to waves, which contribute mostly to fatigue damage. However, the production of petrol and gas needs heavy equipment such us pumps, compressors and rotating which generate strong vibration in the whole structure. According to some researchers, this repetitive vibration over a long duration of time may lead to propagation of the crack and eventual failure of the equipment.

The amount of damage is related to the magnitude and frequency of vibration and results in the form of brittle cracking.

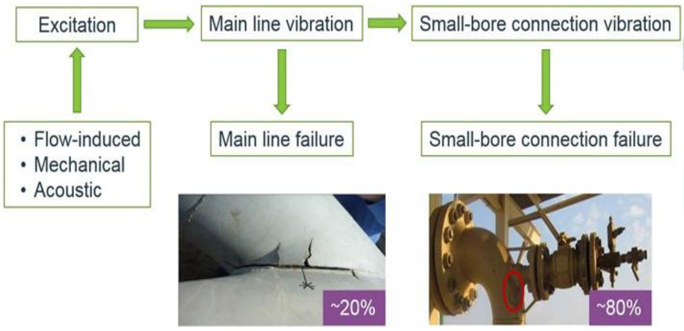


Figure 2: Mechanism of induced vibration

3.4 Corrosion

Corrosion causes a chemical process at the most highly stressed region at the crack tip. Corrosive action on the surface of metals may cause a general roughness of the surface, with further formation of corrosion pits and this enhances the crack propagation rate. These can become initiation sites for fatigue cracks when the material is subjected to fluctuating stress.

Base on some researches, it was demonstrated that high-strength steels are more susceptible to corrosion fatigue and hydrogen induced stress corrosion cracking, the main conclusion drawn from investigation was that the generation of hydrogen from the sacrificial anode systems protecting high-strength steel structures at levels that are excessively negative can enhance fatigue crack growth and should be avoided. The effect of corrosion on the structures can also be important in the way that it has been observed in experiments Haibach, 1976 that corrosion promotes the growth of cracks.

For structures such as long pipelines, where passive galvanic cathodic protection is inadequate, localised corrosion can occur due to galvanic corrosion. In either scenario thinning or perforations of the carbon steel can occur. Seawater, being a corrosive environment may have the effect of accelerating the growth of fatigue cracks, and therefore reducing overall fatigue performance. It is good to know that catodic protection totally the structure from corrosion over its life.

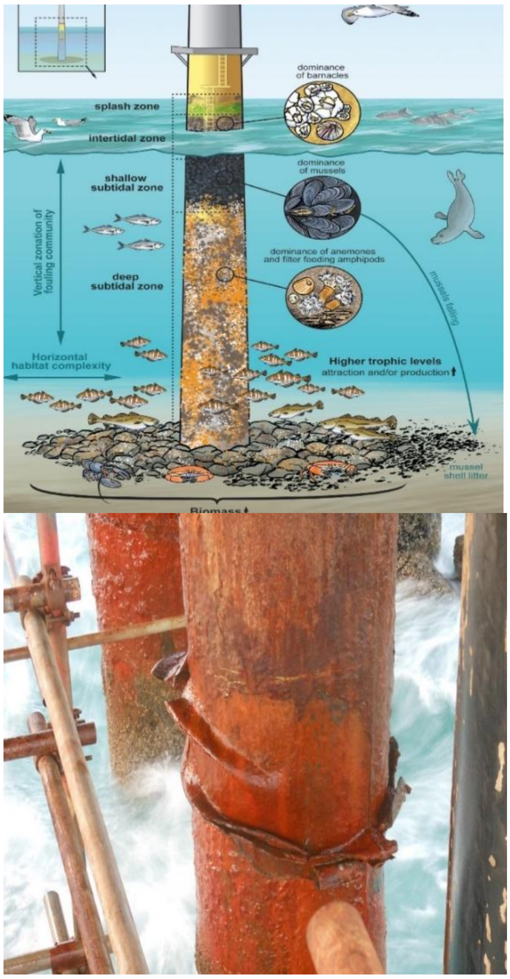


Figure 3: Corrosion

3.5 Fatigue due to welding defects

Offshore structures are fabricated by joining many steel pieces together through welding. These welding connections or joints are the main parts of the solidity of the structures are subjected to different type loads. Fatigue on welded steel occurs when a load is repeatedly applied on a single application on the welded joints. When the load exceeds a certain threshold, it creates microscopic cracks on the joints, which gradually reach a critical size and propagate unexpectedly; causing structural failure. These loads tends to weaken the welded joints and therefore may reduce the solidity of the structure.

Besides, the quality of the welding is an important factor, which depends on the materials used. In fact, the welding must be of good quality to avoid defects, which may lead to crack. In the same way when the thickness

of the welded joint is less to support the concentrated load on it, failure occurs which is the result of default in design. Once cracks are initiated in the welded joints during either the fabrication transportation or installation process, they progress inside the whole welded joint. This causes the detachment of the joint from the structure and hence destroy slowly the structure. In fact, in some cases the failure may be obvious plastic deformation that you can easily detect and repair appropriately and that is called static failure.
On the one hand, Fatigue failure often begins with microscopic cracks that gradually increase in size, reducing the load-carrying effectiveness of welded join area. Failure to detect the cracks early often leads to sudden catastrophic structural and equipment failures.
Indeed the welding connections (joints) are the transmitters of the loads from the top of the structure to the bottom resting on the seabed therefore the fatigue analysis on these parts of the structures should be well performed by the Engineers.

Figure 4: Weld defect

3.5.1. Fatigue Growth from the Weld Toe into the Base Material

As most of the offshore structures used are welded structures, consequently the most frequent failure mode is fatigue, crack starts from weld toes into the base material. Researchers have proven that stress is high at the weld toe due to the geometric stress and the weld notch;hence, a small defect is more than enough to initiate cracks. This crack will be progressing from the toe to the base material or parental material.
Moreover, poorly made welds are susceptible to crack from the toe. Welding process often leads to defects occurring in, or adjacent to, the weld metal. These may be macroscopic defects such as lack of fusion between weld metal and parent plate.
However, even in sound welds a range of microscopic defects may occur. These are commonly encountered at the weld toe where melted weld metal meets unmelted parent metal.
Additionally it has been demonstrated that the rapid cooling of the weld metal promotes material heterogeneities and the formation of a range of microscopic defects, which may include porosity, slag inclusions and sharp undercuts. When these defects start developing under the stress concentration at the weld, it ultimately becomes the initiation sites of fatigue cracks shown in Figures.

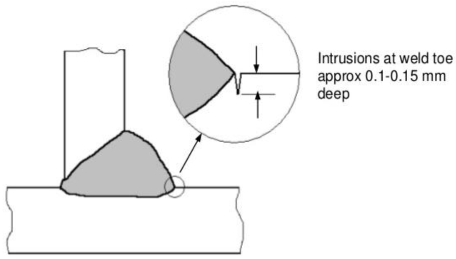


Figure 5: Cracks initiation at weld toes

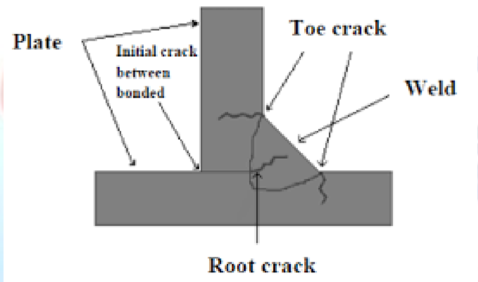
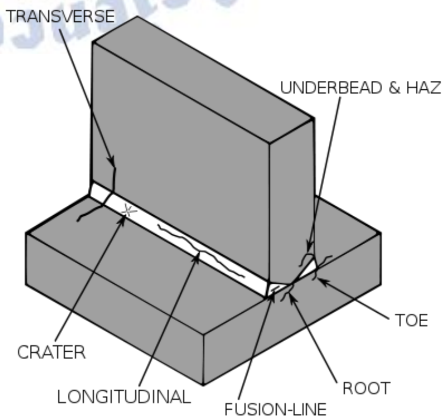


Figure 6: Microscopic intrusions at the toe of a sound weld

Finally, fatigue cracking from the root of fillet welds is another important failure, with crack growth through the weld. Fatigue crack growth from the weld root into the section under the weld, as indicated and can be observed during the service life of structures.



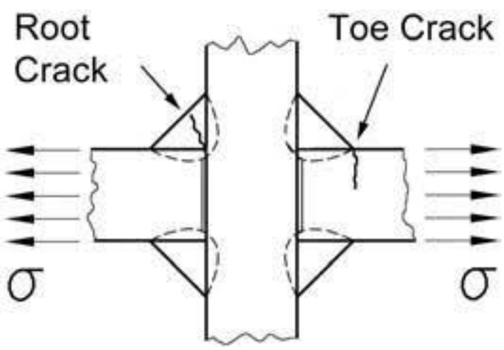


Figure 7: Cracks at sound weld

3.6 Default in steel material

3.6.1 Manufacturing defects

The fabrication can also affect the fatigue behavior of a connection largely. The quality of welding is of primary importance as the elements are potential Source of stress concentration and cracks. Post weld heat treatment is a practical approach for minimizing the stress concentration at joints due to welding.

The general ideas is as follow. Suppose a structure component breaks after some general plastics yield. Clearly, a failure of this kind could be traced to design error, which caused inadequate section strength, or to the application of an overload. The fracture failures, which were difficult to understand, are those, which occur in a rather brittle manner at stress levels no larger than were expected when the structure was designed. Fracture of this second kind, in a special way, are also due to overloads. If one considers the stress redistribution around a pre-existing crack subjected to tension, it is clear that the region adjacent to the perimeter of the crack is overloaded due to the severe stress concentration and that local plastic strain must occur.

If the toughness is limited, the plastic strain at the crack border may be accompanied by crack extension.

However, from similitude, the crack border overload increases with crack size. Thus progressive crack extension tends to be self-stimulating.

3.6.2 Impurities, defects on the surface, surfaceirregularity

The irregularity on the Surface of the structures can promote failure. In fact, crack initiation is due to the presence of imperfections, defects and impurities on the surface. Fatigue life of steel depends on their surface state and the existence of defects such as micro cracks, inclusions present on it. The fatigue process initiates in the defected small cracks present at the surface of the steel structure should not be neglected for they may lead to severe destruction. Progressive crack extension along with recognition of the fact that real structures contain discontinuities. Some discontinuities are prior cracks and others develop into cracks with applications of stress. Given a prior crack, and a material of limited toughness, the possibility for development of rapid fracturing prior to general yielding is therefore evident.

Fatigue cracking in the base material is a failure mode that can occur in components

With high stress cycles. In such instances the fatigue cracks often initiate from notchesor grooves in the components or from small surface defects or irregularities.

The reasons behind the crack initiation are: Crack initiation or fatigue crack initiation is dependent on surface imperfection; therefore, surface should be free from flaws, imperfection, defects, and inclusions and there should not be a stress concentration points at the surface. In fact, the surface of the structure should be harden and stuff in such a way that stage of propagation is reduces to a large extent because When the cracks progress to the stage two no surface treatment can prevent its propagation.

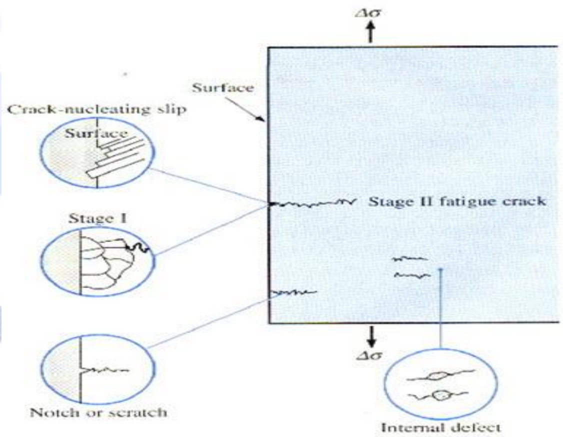


Figure 8: Crack progress

4.CONCLUSIONS:

This paper has gone through the main sources of fatigue of the offshore structure, explained how fatigue occurs. All this should be taken into consideration. It is recommended that care should be taken in the manipulation of the structures in all the steps of the offshore construction from the analysis to the design until the end of the service life.

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