FUNDAMENTALS OF THE THEORY AND PRACTICE OF THE ORIGIN AND SPREAD FATIGUE CRACKS FOR OFFSHORE OIL AND GAS INSTALLATIONS

Starokon I.V., Zaycev A.A., Kirichenko A.A.

Gubkin Russian State University of Oil and Gas, Moscow, e-mail: starokon79@mail.ru

It was made the analysis of the contemporary theories of the origin and spread of fatigue cracks. Result of this analysis showed that, there is no theory for offshore oil and gas installations, which would allow to objectively describe the nature of this phenomenon and give analytical dependence of influence of various factors on the parameters of spread of fatigue cracks in offshore conditions. The existing studies establish a link between the number of cycles of the wave load and the maximum permissible stress. The author aims to systematize the impact, affecting the development of fatigue cracks offshore oil and gas installations, and to give a conclusion on the degree of their influence on the study process of fatigue crack formation. Based on the analysis of experience of exploitation of the structures, located on the shelf of the Black sea, the author concludes that, in addition to force influence on the process of the development of fatigue cracks influenced by temperature, corrosion and vibration impacts. The article briefly describes the mechanism of this influence. As a result the conclusion is made about the fact, which of the following effects plays a key role in the processes of crack formation in the offshore oil and gas facilities in various zones (surface, underwater and in the areas of periodic wetting).

Keywords: fatigue cracks, offshore oil and gas structures, thermal effects, vibration impacts, corrosion effects, variable stress

Continuous operation of steel offshore oil and gas constructions leads to the necessity of introduction of the fatigue criteria. Fatigue cracks, that formed on the different areas of the offshore oil and gas structures, represent quite serious danger and may lead to the destroy of the construction in particular conditions. Furthermore, fatigue cracks may break vacuum rating of the structure, entail the leakiness with the further submersion, that, probably, took place in the accident with “Kolskaya” platform. The basis mechanism, caused the development of the fatigue cracks, is the influence of the fluctuating loads and impacts. As it was shown in a work [1], there is a principal difference between the term “load” and “impact”. In the author’s opinion, if some attention was give for the questions of loads’ influences, which caused the alternating stresses, and, therefore, for the development of the fatigue cracks, then for the questions of “influence of the impacts”, which also makes different alternating stresses, there was lack of attention. At the present time, there is no method for offshore oil and gas constructions, which allows substantively describe the nature of these impacts and gives the numerical analytic dependences of influence of these impacts on the parameters of the fatigue cracks’ initiation and development . The few studies of native and foreign authors, who were searching those questions, are dispersed in various fields of science, and the decisions, given them, cannot be easily adopted for the offshore oil and gas constructions [2, 3]. That’s why author aims to systemize the impacts, which are influence on the development of the fatigue cracks of the offshore constructions, and to develop the mathematical tool, which allows to definite the concrete numerical value of the alternating stresses, caused by these influences, and give the conclusion about the degree of their impact on the investigating process of the fatigue failures. Statistical data on the conditions of operation of offshore oil and gas constructions allow to distinguish three types of key influences affecting the development of fatigue cracks – corrosion, vibration and temperature. Let us examine them in more detail.

Corrosion impact. As it is known, immersion of metal in a liquid may lead to formation of cracks in it, even at zero voltage. Aggressive sea water environment, which is typical operating conditions for offshore oil and gas structures, corrodes metal. Stress, caused by various loads, leads to corrosive cracking. As shown the analyzes of “ Shelf “ institute materials for the diagnosis of fixed offshore platforms, which was made with participation of the author, structural elements found in the same areas (atmosphere, underwater and alternating wetting) have the varying degrees of corrosion damage. In the atmospheric zone there is a different degree of wear and corrosion kinds of corrosive damage. This is due to the fact that the corrosion rate is affected by the state and chemical composition of the material of construction, the intensity of solar radiation, the season, the temperature of air and water, humidity and other factors. Conducted structural analysis of the elements of the topsides showed that the average corrosion wear upper truss chords platform MSP-4 (Marine Stationary Platform), which is in operation for more than 30 years, is 10.8%, lower apron – 14,6%, for cross-stay – 10% and bracing struts 9%. On the Marine Stationary Platform

MSP-5, which is in operation for more than 20 years and has established in the same area, corrosive wear of the elements of the topsides higher (average 18,9 %) than in the platform, noticed above. This example supports the assertion that the intensity of corrosion damage depends on many factors. The maximum values of corrosion wear make up 25–40 %. The average rate of corrosion elements topsides is in the range 0,04–0,13 mm / yr. Assessing the degree of damage to steel production support blocks of MSPs, it should be noted that all the elements of platforms were affected by corrosion, but the intensity of the corrosion process depends on the positions of the elements, of their design and workmanship. Fatigue cracks and stress corrosion cracking are observed for MSPs structures in general presence of a solid and pitting corrosion

The actual state of the upper works metal parts of the manufacturing units in the variable wetting zone is characterized by significant corrosion wear, defects in welding joints, bundles of pipe material and significant cracks. Average wear in this area ranges from 25 to 40 %. Maximum deterioration of the individual elements reaches 75–85 %. The average corrosion rate according to data, obtained in the survey process, is 0,15–0,35 mm / year. In 2008 the Norwegian community DET NORSKE VERITAS was developed a standard DNV-RP-C103 [1–10], which contains fatigue analysis of corrosion for the various elements of the offshore oil and gas installations. Document [1–10] is based on experiments, which were made under laboratory conditions, with some fatigue test specimens until at least the destruction takes place. A significant disadvantage of these tests, as the practice showed, was static stresses while in practice during the operating of the offshore oil and gas constructions there is a constant redistribution of stresses that have a significant impact on the development dynamic of the cracks. Moreover, it was seen the correlation of stresses generated by wave loading and corrosion. the authors of the normative document were not considered, all other loads and impacts, affecting the fatigue life of structural elements of the offshore oil and gas structures. On the basis of the carried out tests the authors of the normative document built the so-called S-N curves , which relate the number of cycles of the wave loads with maximum size of the stresses acting on sections of the structural elements of the offshore oil and gas structures above which the characteristics of the fatigue cracks become critical . These studies were conducted with the corrosive conditions in the fully immersed in water and the sample element in the air. Also takes into account the influence of cathodic protection systems on the rate of crack propagation and growth to its critical value. These data suggest that for the same number of cycles of the wave loads on offshore oil and gas installations in the presence of cathodic protection systems , greatly reducing the intensity of corrosion processes , the maximum voltage is significantly higher than that in the absence of such protective systems. This once again confirms the conclusion that the corrosive effect has a significant influence on the development of fatigue cracks in the offshore oil and gas structures. One of the most important effects, affecting the fatigue failure, is vibration impact. In the operation of offshore oil and gas installations under the action of different loads, especially wind and wave experiencing cyclical fluctuations voltages having different origins and frequency. The sources of vibration on offshore facilities are: vibration of the mechanical equipment, the resonance vibration of the wave loads, slowly changing forces caused by waves and wind, tidal phenomena. One of the most important mechanisms, that cause vibration, is the formation and breakdown of vortices from the surface of the component of offshore oil and gas installations that occur when is the steady hydrodynamic flow or wind flow [1]. Under the effect of these fluctuations is cyclical change in the position of sections of structural elements of the offshore oil and gas structures on their initial position. The vibration amplitude varies from zero to a maximum value with different frequence, causing the change magnitude and direction of the stresses in the cross sections of structural elements of the offshore oil and gas structures. The total stress caused by vibrations, characterized by two components -static and dynamic components. Static component is constant and dynamic depends on the amplitude of oscillation. Full voltage, which in the study vibration impacts will be considered as the sum of the voltage obtained from the vibration and all the other pressures and influences. Full voltage changes twice during one period of oscillation in the range of the amount of static and resonant stresses to a minimum and maximum amount of static resonant stresses. In each subsequent period, the total voltage decreases as the damping of the oscillations. In the case of resonance oscillations are not damped, and the values the minimum and maximum resonant stresses remain constant. In general we can say that in the structural elements of the offshore oil and gas structures are permanent variable resonant stresses. In case of such exposure fatigue damage accumulates in the material of the offshore oil and gas structures, that significantly reduce the strength properties of metal , and the destruction of the offshore oil and gas structures can occur when the value is less than the maximum operating voltage [1]. Metal fatigue occurs when there are a large series of voltage changes, regardless of the material from which made the offshore construction. Even in a completely new material can be some defects. In the operation due to changes in the stress state of the element with fluctuations there is a gradual increase in these defects, change of their size and shape is of a casual nature. Therefore, the development of fatigue cracks and defects is characterized by the possible random events caused by the probabilistic nature of the fatigue. Probabilistic or random nature of fatigue destruction makes it impossible to accurately calculate the time when the fatigue failure of the variables resonant stresses will come. By now, it has been developed several theories, which allow making a determination of the time when the fatigue damage, caused by variables vibratory stresses, onset. The most significant among these methods is the method of testing samples of material or directly structural elements of the offshore oil and gas installations, determining the number of cycles of alternating resonant stresses up to direct their destruction. When considering the fatigue phenomena, outside of these studies is the study of the influence of the variables of temperature fields. Therefore, the author aims to assess the impact of the variables of the ***temperature effects*** on the development of one of the most dangerous defects of the offshore oil and gas structures – fatigue cracks. Let's analyze the challenge of influence of the temperature fields in details. According to the authors' opinion, it is reasonable to mark 3 rates of temperature influence's zones: 1) subsea; 2) atmospheric; 3) zone of cyclic wetting. Subsea zone is characterized by nonhomogeneous temperature field, which is determined by different streams. Temperatures in the subsea deepwater zones are plus degrees. With a decrease in the depth, the temperature regime in the area of underwater largely depends on the ambient temperature. For example, in the area of Subbotinskoe deposit in the Black Sea there are the strongest temperature variations recorded at a depth of 50 meters, but below this mark of temperature changes do not take place . Since the depth zone of 50 meters, the temperature does not change and is within 8 degrees Celsius. And up to a depth of 1500 meters the temperature is in the range of about 9 degrees Celsius. This indicates that with increasing of the depth influence of the variables thermal stresses on the development of fatigue damage decreases. Temperature of the sea at a depth of 30 m is determined primarily by atmospheric temperature factor. Gradually with increase of the depth of 50 meters the effect of this factor decreases and approaches a constant temperature of around 9 degrees Celsius. Atmospheric zone is characterized by fluctuation of temperature from – 65 °C to + 5…+ 10 °C for Nordic fields and from + 10 °C to + 60 °C for the fields in the Persian Gulf region. It should also be noted that despite the fact that the temperature of air in the area of Subbotinskoe field rarely heated over 40 °C, the structural elements of the offshore constructions (as shown conducted directly by the author in the field of measurement) under the influence of solar radiation at peak solar activity is heated to + 80 °C or more. During the night hours of the temperature of the structural elements the offshore constructions dropped to 20 °C ... 25 °C. These data suggest that twice during the day drop of the temperature of structural elements of the offshore structures can reach $\Delta T = 40\,°C$, that causes, according to preliminary calculations, conducted by the author, a variable voltage , which can reach values approximately 70 N/mm2 (calculations were carried out for the element of bearing block of the offshore stationary platform on the Subbotinskoe, which is made of steel VST3SP5 and has a cylindrical shape with a diameter of 1220 mm and a wall thickness of 12 mm). Theoretically, the most unfavorable from the point of view of kinetic effects of temperature fields is periodic wetting zone, as it is within range of ambient temperature field and the temperature field of the oncoming wave flows characterized by a high frequency. However, as it was shown by the measurements, led by the author in the area of Subbotinskoe field, the temperature fields of the sea water and the air in the range – 10 m < G.V. < 15 m (GV – water horizon) particularly are not differ from each other. This is probably due to the predominant influence of the temperature of the atmosphere at the temperature of the sea water at depths up to 30 m Therefore, the assumption that the zone of alternating wet from the point of view of the impact of the variables of temperature fields is the most unfavorable for the formation of fatigue cracks, at least in terms of Subbotinskoe field, according to the author, can be considered erroneous. Perhaps this assumption may not be true under conditions of strong vertical currents rising from the depth of the water body having a lower than in the surface layers of temperature, accompanied by excitement, however, in natural measurements, similar results were not recorded , and this assumption remains theoretical. Changing of the temperature field of environment, which is around offshore structure, leads to a change in the temperature field of marine oil and gas facilities, changing its current state of stress. The hazards of the tensile stress, which resulted cracks in a body of structural elements of the offshore structures. can be called a thermal fatigue. Note that the tensile stresses occur at the time of lowering the temperature of structural elements of the offshore structures. The situation is somewhat exacerbated when considering offshore oil and gas pipelines , as in this situation, in addition to the listed cases there is a third temperature field by the pumped product . Typically, this field is considerably different from the ambient temperature and has a certain value due to an increase in oil viscosity and the impossibility of its transport by pipeline enlarge certain temperature or the formation of gas condensate plugs during gas pumping. Furthermore, the temperature of oil, exiting from the well, can reach 100°. Therefore the solution of the problem of the influence of variable temperature field on the reliability, safety and durability of the offshore constructions is relevant and timely. The solution of this problem is offered in terms of the classical theory of thermo-elasticity and is reduced to the following steps. The first step is to determine the temperature fields acting on sections of structural elements of the offshore structures, the method of determination described in [1–10]. The second step is to determine the relationship between the temperature field and stress, arising from its actions, according to the formulas given in [1–10]. Analytical results of numerical simulations, conducted by the author on the pipeline, made of steel 09G2S with diameter of 530 mm and a wall thickness of 25 mm, indicates that the temperature difference between the inner and outer walls of the pipeline is in all 0,5 °C, hoop stress is approximately 28 N/mm2, and with a difference of 2 °C these stresses reach values of about 140 N/mm2. Experimental measurements on the pipeline in the area of Subbotinskoe deposit showed that the outer tube wall temperature depends primarily on the temperature of the pumped product, and to a lesser extent the ambient temperature. Thus, we can say that is not currently developed theories of the origin and development of fatigue cracks in relation of the offshore constructions, and existing researches, when considering this issue, only take account of the impact of the wave, neglecting temperature and vibration effects. The author proposes a new theory of the development of fatigue cracks of the offshore structures, which are taken into account in addition to the power impacts the corrosive, temperature and vibration effects. As a result of the study the author found that the formation of fatigue cracks temperature effects are most active in the area above water and underwater to a depth of 30 m, corrosive effects of stronger influence in the variable wetting and vibration effects contribute to the growth of fatigue cracks in the zones of maximum influence of hydrodynamic and wind flows. The author continues to carry out experimental research in the direction of fatigue cracking of the offshore structures, the results of which will be published later.

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