Fracture and Fatigue Inspection Analysis of Offshore Piping

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Abstract - *The objective of this paper is to propose comprehensive theories with methodologies to capture the interaction effects of fracture and fatigue mechanisms such as ultra- low cycle fatigue, low cycle fatigue, high cycle fatigue, thermal induced fatigue and corrosion fatigue; which induce in oil and gas transmission pipelines/piping due to ageing, harsh weather conditions and operation related defects, damages and degradation. Also deriving comprehensive guidelines/strategies for assuring structural integrity via maintenance, assessment, inspection, repair and strengthening against the impairment are proposed. The applicability and significance of proposed theories with methodologies and strategies shall be validated via case studies with potential industry collaborations. The case studies shall cover both deterministic and probabilistic approaches comprehensively.*

Key Words: Offshore piping, Topside, Fatigue, Oil & Gas

1. INTRODUCTION

The fatigue, fracture and failures of topside piping for oil and gas offshore production platforms shall be studied where *fatigue dynamics of offshore structures[1]* is given priority. The results obtained by these fatigue estimate approaches will be stochastically[2] modeled, interpreted and compared.

The integrity of a piping system depends on the considerations and principles used in design, construction and maintenance of the system. Piping codes defines the requirements of design, fabrication, use of materials, tests and inspection of pipes and piping. Process piping is typically checked by Pipe Stress Engineers to verify that the routing, nozzle loads, hangers, and supports are properly placed and selected such that allowable pipe stress is not exceeded under different situations such as sustained, operating, pressure testing etc., as per the ASME B31, EN 13480[2] or other applicable codes and standards. It is necessary to evaluate the mechanical behavior of the piping under regular loads (internal pressure and thermal stresses) as well under occasional and intermittent loading cases such as earthquake, high wind or special vibration, and water hammer. This evaluation will be performed with the assistance of pipe stress analysis computer program such as CAESAR II[3], CAEPIPE and AUTOPIPE. This work will further analyze the experimental results in contract to probabilistic and deterministic descriptions of offshore waves.

2. PROJECT ANALYSIS

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3. CONCEPT DEFINITION OF FATIGUE IN OFFSHORE APPLICATIONS

Fatigue[4] is the weakening of a material caused by repeatedly applied loads on offshore piping. Fatigue occurs when a material is subjected to repeated loading and unloading. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit or the yield stress limit.

Vibration fatigue[5] methods find use wherever the structure experiences loading, that is caused by a random process. *Fluid Structure Interaction* (FSI) is of great interest in many engineering applications, such as hydrodynamic wave loading on ocean marine structures and offshore platforms etc. Such loads are first characterized statistically, by measurement and analysis. In offshore oil, marine or wind industry, construction of these offshore structures encompasses building of large foundations on which topside or wind turbine is placed. Often wave run-up and wave impacts causes fatigue damage to the existing platforms. The

vortices are shed alternately from each side of the body in a regular manner and give rise to an alternating force on the body. The phenomenon is so called *Vortex Induced Vibration* (VIV)[6]. Cylinder vibration at or near the vortex shedding frequency organizes the wake and changes the fluid force on the cylinder. These fatigue failures causing fracture are a result of a combination of the stress amplitudes and the number of cycles which induce in oil and gas transmission pipelines/piping due to ageing, harsh weather conditions and operation related defects, damages and degradation.

Fig.1. Offshore platform with topside piping (yellow color)

Waves induced vibration (WIV) of structure such as marine pipelines, oil terminals, tanks and ships by placing oscillatory pressure on the surface of the structure. These forces are often well-represented by the inviscid flow solution for many large structures such as ships and oil storage tanks. For smaller structures, viscous effects influence the fluid force and the fluid forces are determined experimentally. The Morison equation is used to compute the wave forces on slender cylindrical ocean structures such as pipelines and piers. The flow of a fluid through a pipe can impose pressures on the walls of the pipe causing it to deflect under certain flow conditions. This deflection of the pipe may lead to structural instability of the pipe.

Flow Induced Pulsation (FLIP)[7] occurs for rough bore flexible pipes, pipes with a corrugated metallic inner liner (carcass), used for dry gas transport. The pressure pulsations are generated due to vortex shedding on corrugations of the innermost layer of the flexible riser carcass. These pressure pulsations can be sufficiently extreme to cause "*vibration induced piping fatigue failures[7]*". Dynamic pressures are also seen in the topside piping system.

Well head flow lines are designed to transport production hydrocarbon (liquid or gas) from a reservoir production well under pressure to process separator systems and as the same way these can be used to inject water or gas to the reservoir from water or gas injection manifolds. These lines are exposed to high cyclic loadings from Christmas tree movements and due to this, flow lines must be subjected to a comprehensive fatigue analysis.

On the job assignment working with *Trans Asia Pipelines*, I visited the offshore TOTAL oil platforms (Abu Al Bhukoosh) offcoast city Abu Dhabi on survey of subsea pipelines and topside piping maintenance and commissioning activities. Here it is observed that many types of Jacket leg platforms i.e. production/wellhead platforms tied together with bridges so called development platforms; and unmanned satellite platforms from where gathering pipelines are jointed to pipeline end manifolds (PLEM) near production platforms and further transported ashore to tank terminals and batteries. Flipside the bridges of offshore platforms are inter connected/pinned to those production/wellhead jacket type platforms. Due of high wave forces the platforms relatively move each other. The relative movements can be calculated by using different wave theories and hydrodynamic analyses[1]. By calculating the stiffness of the platforms, it can be possible to calculate the maximum deflection of the platforms. These maximum deflections are given by the marine or the structural engineers to the piping stress engineers. The wave conditions about wave heights, periods and frequencies is obtained from a Buoy transmission records. The wave history frequency-time domain FFT data is analyzed using JONSWAP wave spectrum (Probabilistic description). Deterministic descriptions (Linear and Nonlinear theories) are used to characterize short time scale feature of waves. Probabilistic are used to characterize long time scale features of offshore waves. In both deterministic and probabilistic descriptions, linear wave theory is used and is simple to apply when estimating forces on offshore structures during the preliminary phase design and estimates the probability of failure of a given structure.

4. PROJECT APPROACH

The fatigue life will be estimated through following approaches to predict loading conditions for single degree of motion offshore structures[1]. The results obtained by these approaches will be stochastically modeled, interpreted and compared.

The dynamic response characteristics are of two types, natural frequency and time history of displacement or rotation. The frequency calculation is necessary to assure the integrity of structural design. This is because an offshore structure in depths exceeding 70m has a natural frequency falling in the range of expected wave frequencies which may lead to dangerous condition of structural resonance. The natural frequencies and dynamic responses of selected linear and non linear structural models of offshore fixed leg structures will be evaluated.

1) Fatigue life estimation by Fracture Mechanics

Fracture mechanics is concerned with the study of the propagation of cracks in materials. It uses methods of analytical solid mechanics to calculate the driving force on a crack and those of experimental solid mechanics to characterize the material's resistance to fracture. Fracture mechanics is an important tool in improving the mechanical performance of mechanical components to predict the macroscopic mechanical failure of bodies. The most important parameter or variable in fracture mechanics is the initial defect size. The system should be designed and inspected thoroughly so that the maximum initial defect size would not propagate in to a critical size during the service life or within inspection interval. The inspection interval is a critical parameter and it should be shorter than the duration for the crack to grow from a NDT detectable size to a critical crack size. By doing the crack propagation calculation, it is possible to determine the fatigue crack growth life.

2) SN curve approach of calculating Fatigue behavior

SN curves have been made on the basis of laboratory tests and those characterize the fatigue behavior of materials. The SN curve expresses the number of cycles a material can withstand under repeated loading at a given stress level before the fatigue failure. There have been many fatigue SN curves developed during the time for different materials, systems, geometries, welded and un-welded components and etc. When consider the fatigue assessment of a piping system which consist of welded joints, the weakest link is the weld. Since the most offshore topside piping is without the cathodic protection and is not submerged in the seawater, the SN curves developed for the structures in open atmosphere have been suitable.

3) Fatigue analysis through equivalent stress range approach

The equivalent stress range approach can be further developed for the two slopes SN curves by considering the Miner's summation theory. Two groups can be considered such as stress ranges above the knee point of the two slopes SN curve and the stress ranges below the knee point. The concept will be illustrated through equivalent stress range approach for two slopes SN curves.

4) Fatigue analysis by deterministic and probabilistic approach

This analysis is performed by assuming that the stress range is Weibull distributed. So the calculated stress range is assumed as Weibull distributed and divided into two groups as using the two slopes fatigue curves.

5) The Standards PD5500 or EN 13445

The Standard provides rules for the design, fabrication, inspection and testing of Pressure vessels which will be used as a reference industrial approach to estimate fatigue life.

5. PROJECT IDENTIFICATION VARIABLES

The main idea of piping stress analysis is to avoid the pipe failures. The pipes can be failed in different modes with many different mechanisms. The below modes of failure will be studied.

1) Static Stress Rupture
2) Fatigue Failure
3) Creep Rupture
4) Stability Failure

A piping system is subjected to stresses and strains in different situations of its initial fabrication to service life of the system. When the piping system is in service, it is restrained by pipe supports and/or attached equipment's. Mostly for the design purpose and the stress analysis purpose, it is only considered the loadings that are applied in the service life of the piping system. The below loads will be taken into consideration for piping stress analysis.

1) Dead weight loads
2) Internal pressure
3) Sustained loads
4) Occasional loads
5) Environmental loads
6) Live loads
7) Displacement loads
8) Accidental loads

The below theories of failure in strength of materials will be considered.

1) Maximum stress theory

The theory suggests that the material will yield when the absolute magnitude of any principle stresses reaches the yield strength of the material.

2) Maximum strain theory

The theory predicts that the material will yield when the maximum strain reaches the yield strain.

3) Maximum shear theory

The maximum shear theory stated that the material will yield when the maximum shear stress reaches the maximum shear stress at the yield point. The ASME is based on this theory for its piping and pressure vessel codes.

The below piping stresses in piping stress analysis will be taken into consideration.

1) Primary stresses

The primary stresses are developed by the imposed loadings and are not self-limiting. The sustained loads which are dead weight and internal pressure are examples of typical loadings that result to the primary stresses.

2) Secondary stresses

When a piping system is limiting its free displacement, the stresses developed due to thermal loads or imposed

displacements are called the secondary stresses. These stresses are self-limiting.

3) Peak stresses

The highest stresses in the considered stress region are called the peak stresses and always should take into consideration in fatigue and fracture mechanics calculations.

The stresses in a piping component can be categorized as i. stresses due to static or dynamic pressure, internal or external; ii. Stresses due to forces and moments generated by weight, thermal expansion, wind, earth quake and etc. The following stresses will be considered.

1) Stresses due to internal pressure – Longitudinal stress, Hoop stress, Radial stress
2) Stresses due to forces
3) Stresses due to moments

In the piping stress analysis, one of the main requirements is to check the flexibility of the piping system. Most international design codes are limited to static and dynamic stress analysis, the following analysis methods will be considered for given Thesis problem.

1) Static analysis
2) Quasi Static analysis
3) Dynamic analysis – Modal analysis, Harmonic analysis, Respond spectrum analysis, Time history analysis

6. CONCLUSION

The study based on methodologies to capture the interaction effects of fracture and fatigue mechanisms of offshore topside piping is studied. To necessitate, the theory on static and dynamic analysis of piping systems is overlooked to understand the fatigue environment for Wave induced vibration (WIV) and Flow induced pulsation (FLIP) as a criterion.

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BIOGRAPHIES

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