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Fully Stochastic Fatigue Analysis for FPSO Based on Shipyard Practices

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Pending controversies between oil companies and shipyards concerning stochastic fatigue strength analyses for FPSO (floating-production-storage-offloading), one of the representative floaters, are explained based on shipyard practices. Focused on how the issues affect on the spectral fatigue evaluation, the items under discussion are: diversified wave conditions, cases of spectrum combinations, screening methods, CJP welding requirements, fabrication tolerances, overlapping of corrosion margins and Morison loads on slender members. Theoretical reviews are also introduced in calculation sequences of spectral fatigue analysis, where derivation of hotspot stress is discussed in detail. In order to resolve large parts of the issues and requirements from major oil companies, a fully stochastic spectral fatigue analysis program is developed and outstanding features of the program are introduced.

INTRODUCTION

Until the mid-1990s, offshore oil wells were mainly developed in shallow seas less than 500 m in water depth. Now, oil resources in shallow seas are on the decrease day by day, and the development trend of new oil reservoirs is toward seas deeper than 1000 m. After the opening of China's economy to the outside world, China came out as the biggest oil consumer following the U.S., and this has been one of the principal reasons for the sudden rise of oil prices since early 2004. The arrival of record-breaking oil prices has accelerated the development of deep-sea oil reservoirs and the consequent need for offshore floaters suitable for deep-sea developments. FPSO (floating-production-storage-offloading), known as one of the most competitive facilities for deep-sea development, can produce oil and gas from oil reservoirs, store these in hull compartments and offload to shuttle tankers or through subsea pipelines. FPSO now hold approximately a 60% share among various types of offshore floaters such as SPAR, TLP and semisubmersibles.

Every leading oil company, which usually means the 6 so-called supermajors (BP, Shell, IMT, TotalFina, BHPB, Chevron), offers an FPSO with its own specifications. These are conservatively and subjectively documented in proportion to FPSO's continuous operation condition under any harsh environment during the design life. FPSO shipyards (mainly the 3 major shipyards of DSME, HHI and SHI) are even requested to satisfy currently published academic researches by specifications.

FPSO's structural configurations are complicated due to structural members such as various appurtenances and topside structures. As a result, there are probabilities of structural discontinuities in the member connections and support structures where a potential fatigue crack could occur. For this reason, oil companies order rigorous fatigue design with conservative safety factors whose values are also found in a number of industrial standards or classification rules.

Fatigue damages in FPSO mostly originate from loads induced by sea waves characterized by irregularity and unpredictability. In accordance with these wave features, the structural responses of FPSO under wave loads are considered to be irregular. Stochastic fatigue analysis methodology has been developed through the combination of classical fatigue theory based on the S-N approach and statistics associated with irregular wave theory. It is assumed that wave loads and structural responses (stresses) have a completely linear relationship in stochastic fatigue analysis. In the case of load component-based spectral fatigue analysis, stress RAO (Response Amplitude Operators) are derived from the combinations of stresses induced by DLP (Dominant Load Parameter) such as bending moments or shear forces, while stress RAO are calculated by directly applying wave loads to a FE model in the case of fully spectral fatigue analysis. Since the latter explicitly reflects the physical phenomenon without any assumption for derivation of stress RAO, unlike the former, the global trend tends to the latter methodology following the rapid evolution of computers. However, it should be noted that fully stochastic fatigue analysis still requires enormous analysis costs and is not suitable in the initial design stage with its frequent design changes.

Wang, Cheng, Wirsching and Sun (2005) comparatively investigated the FDF (Fatigue Design Factor) in the fatigue design of FPSO. The Fatigue Methodology Specification (FMS) for FPSO, still accepted as the top authority today, was jointly presented by DNV and ExxonMobil (1999). Most FMS contents have been the basis of DNV-RP-C203(2005) and DNV-RP-C206(2006). DNV Classsification Notes No.30.7 (2001) is believed to be the best recommended publication for fatigue strength of ship structures. Fricke (2001) showed how the hotspot stress was calculated from FEA (Finite Element Analysis), and how the hotspot stress S-N curve was linked to recovered hotspot stress in the early phase of the FPSO Fatigue Capacity JIP. Much experimental and theoretical research was carried in the FPSO Fatigue Capacity JIP (Bergan and Lotsberg, 2004).

Most oil companies demand not only high conservatism but also high accuracy in fatigue design. For example, FDF is even up to 10 for structures that cannot be accessed or inspected. More and more, wave conditions for development fields are diversified, so enormous numerical computation is left from the load cases in structural analyses and spectrum combinations. To make matters worse, it is practically impossible to fulfill owners' requirements, just in time, with the current upgrade speed of commercial software. Hence, the development of an in-house spectral fatigue analysis program is urgent.

This study will background and explain in detail why an internally developed fatigue analysis program is needed by investigating technical issues and trends of requirements of oil companies. After sequentially describing the theory of stochastic fatigue analysis, the outstanding features of developed program will be presented.

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KEY WORDS: FPSO (floating-production-storage-offloading), stochastic fatigue, spectrum combination, CJP welding, screening, corrosion margins, Morison loads.