Fatigue life analysis on Floating Production Storage and Offloading (FPSO)

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Abstract. Floating Production Storage and Offloading (FPSO) is the mobile offshore structure like a ship where the wave load acts on the ship’s hull periodically. The influence of the cyclic load must be analyzed for the fatigue life of the FPSO. The objective of the present study is to analyze the fatigue life of the FPSO. Two models of FPSO are taken to be analyzed. To calculate fatigue life, JONSWAP wave spectrum is adopted. Then, calculate the Response Amplitude Operator (RAO) to obtain the stress response of the spectra. Based on the stress response spectra calculation, the zero and second moment may be determined using Simpson’s rule. The stress cycle can also be obtained and the failure cycle is determined from the S-N curve. From the S-N curve, the X parameter is used for the main parameter. According to this, the fatigue life of FPSO can be obtained.

1. Introduction
The fatigue life of the ship’s structure is influenced by wave called cyclic load during the voyage. Fatigue life is defined by cyclic stress with a load having an unlimited number. Fatigue strength is the maximum strength where load acts to structure without failure for the definite load. Fatigue life is depended on some factors such as material characteristic, crack, structural geometry, and so on. Damage caused by fatigue on Floating Production Storage and Offloading (FPSO) dominantly due to wave load. Stress caused by this load generally fluctuating and change randomly. Therefore, the fatigue life of FPSO under cyclic loading must be analyzed for structural failure.

Fatigue life analysis has been analyzed by some researches. Muis Alie [1] analyze the effect of symmetrical and unsymmetrical configuration shapes on buckling and fatigue strength analysis of the fixed offshore platform. Two models of the fixed offshore structure were taken to be analyzed with the same dimension but different configuration shapes. The numerical calculation was performed to analyze the buckling and fatigue strength of both structures. Muis Alie [2] discussed the configuration effect of fixed offshore structure with symmetrical and unsymmetrical shape toward buckling failure. Two kinds of offshore structure were analyzed. The numerical analysis was adopted to calculate buckling failure under axial and lateral load. Khalifa [3] assessed the fatigue life for single-side welded tubular joints of the fixed platform. The analysis procedure was presented for numerical fatigue assessment methods based on S-N curve approach for the American Petroleum Institute standard utilizing the simplified method and the spectral (stochastic) method. The effects of the current, the jacket natural period, and the jacket stability on fatigue life assessment have been investigated. Azarhoushang and Nikraz [4] investigated a jacket-type offshore structure using a
practical method for dynamic fatigue assessment. An accurate procedure for the random vibration computation of structure was developed using frequency domain techniques. Muis Alie [5] investigate the hull girder strength of asymmetrically damaged ship under sagging condition. Two kinds of ships were taken as an object of analysis. The ships hull reached their ultimate when the plate and stiffened plate element called critical point reach its ultimate strength. Tekgoz [6] analyzed a container ship under asymmetrical bending taking the influence of structural damage and associated neutral axis translation and rotation of the residual load-carrying capacity. The FE analysis was used and a formulation based on the Common Structural Rules (CSR). The ship was analyzed in intact and damaged condition.

In the present paper, fatigue life analysis of FPSO was conducted using analytical formulation. Two models of FPSO are taken to be analyzed. To calculate fatigue life, JONSWAP wave spectrum is adopted. Then, calculate the Response Amplitude Operator (RAO) to obtain the stress response of the spectra. Based on the stress response spectra calculation, the zero and second moment may be determined using Simpson's rule. The stress cycle can also be obtained and the failure cycle is determined from the S-N curve. The result obtained by the calculation by S-N curve is therefore used for the fatigue life of FPSO.

2. Formulation
The formulation to calculate fatigue life can be derived as follow. The zero and second moment are determined as follow;

\[ m_0 = \int_0^\infty S_R(\omega) d\omega \]  
\[ m_0 = \int_0^\infty \omega^2 S_R(\omega) d\omega \]  

The mean zero-crossing period to the stress;

\[ \sigma_z \sigma = 2\pi \sqrt{\frac{m_0}{m_2}} \]  

The stress significant can be determined as follow;

\[ \sigma = 4 \left( m_0 \right)^{0.5} \]  

To obtain effective amplitude stress;

\[ \sigma_{eff} = 0.776 \sigma \]  

The stress range and number of the cycle can be calculated by the following formula;

\[ n = \frac{T}{T_z \sigma} \]
Fatigue life for one year can be determined as follow;

\[ D = \sum \frac{n}{N_i} \]  \hspace{1cm} (7)

Then, the fatigue life can be determined by the following equation;

\[ Fatigue\ Life(FL) = \frac{1}{D} \]  \hspace{1cm} (8)

3. Results and discussion
Two models of FPSO were taken as the object of the ship, namely type-1 and type-2. The full cross-sectional is used for fatigue analysis. The models can be seen in figures 1 and 2, respectively as follow,

**Figure 1.** Cross-sectional of FPSO type-1

**Figure 2.** Cross-sectional of FPSO type-2
To calculate fatigue analysis, the JONSWAP wave spectra and wave frequency parameter are determined. Figure 3 shows the relationship of JONSWAP wave spectra and wave frequency parameter two kinds of the ship for type-1 and type-2, respectively. To obtain stress response spectra, the response amplitude operator is firstly calculated for type-1 and type-2, respectively, as shown in figure 4. The numerical analysis is performed to obtain the stress of the structure.
**Figure 3.** JONSWAP wave spectra-frequency relationship

(a) Type-1

(b) Type-2

**Figure 4.** Response Amplitude Operator (RAO)-frequency relationship
Figure 5. Stress response spectra-frequency relationship

Figure 5 shows the stress response spectra-frequency relationship for type-1 and type-2. The fatigue life calculation was conducted by using basic formulation and those could be summarized as follow,
## Table 1. Summary of fatigue life calculation for type-1

| No | Items                              | Formula                                      | Results         |
|----|------------------------------------|----------------------------------------------|-----------------|
| 1  | Zero Moment                        | $m_0 = \int_0^m S_R(\omega) d\omega$         | 10712.73 (N/mm$^2$)² |
| 2  | Second Moment                      | $m_2 = \int_0^m \omega^2 S_R(\omega) d\omega$ | 19162.46 (N/mm$^2$)² |
| 3  | Mean Zero Crossing Period ($T_3$)  | $T_{3\sigma} = 2\pi \frac{m_0}{m_2}$                  | 4.70 Second     |
| 4  | Stress Significant (SS)            | $SS = (4m_0)^{0.5}$                           | 207.01 (N/mm$^2$)² |
| 5  | Number of Cycle (n)                | $n = \frac{r}{T_{3\sigma}}$                  | 6716183.00432   |
| 6  | Number of Cycle Failure (N)        | $N = 2 \times 10^6 \left( \frac{\Delta \sigma}{\Delta \sigma_{eff}} \right)^{-m}$ | 524766186.44    |
| 7  | Fatigue per year (D)               | $D = \sum N_i$                               | 0.013           |
| 8  | Fatigue Life                       | $\frac{1}{D}$                                | 78.14           |

## Table 2. Summary of fatigue life calculation for type-2

| No | Items                              | Formula                                      | Results         |
|----|------------------------------------|----------------------------------------------|-----------------|
| 1  | Zero Moment                        | $m_0 = \int_0^m S_F(\omega) d\omega$         | 182060.0214 (N/mm$^2$)² |
| 2  | Second Moment                      | $m_2 = \int_0^m \omega^2 S_r(\omega) d\omega$ | 420646.13 (N/mm$^2$)² |
| 3  | Mean Zero Crossing Period ($T_2$)  | $T_{2\sigma} = 2\pi \frac{m_0}{m_2}$                  | 4.132 Second     |
| 4  | Stress Significant (SS)            | $SS = (4m_0)^{0.5}$                           | 853.37 (N/mm$^2$)² |
| 5  | Number of Cycle (n)                | $n = \frac{r}{T_{2\sigma}}$                  | 152661003.3     |
| 6  | Number of Cycle Failure (N)        | $N = 2 \times 10^6 \left( \frac{\Delta \sigma}{\Delta \sigma_{eff}} \right)^{-m}$ | 10058225478     |
| 7  | Fatigue per year (D)               | $D = \sum \frac{n_i}{N_i}$                  | 0.0152           |
4. Conclusions
Fatigue life analysis of FPSO was performed using the analytical formulation. Tables 1 and 2 show the comparison of the fatigue life calculation of two FPSO for type-1 and type-2, respectively. It was observed that the fatigue lives for type-1 and type-2 were 78 and 65 years. The different of fatigue life of two ships probably due to stress significant, number of cycles, and so on.

5. References
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