Hydroelastic Behavior and Fatigue Damage of a Very Large Mobile Offshore Structure in a Realistic Sea Condition

by

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1. INTORODUCTION

The National Institute of Environmental Studies Japan proposed a concept of floating wind power plant [1], which has no mooring system but moves with sails and struts. The mobility of the structure is the key of this concept, since if the structure moves, it could maximize the generated power to take an appropriate route and it could evacuate from high seas. The structure composed of slender beams and lower-hulls so that the structure is constructed in lightweight possible for its propulsive performance. The sizes of the structure are 1,880m length, 70.2m width and 20m draught. Eleven 5MW class wind turbines are supported by two lower-hulls. The structure is advanced with sails, and it is navigated so that wind turbines are in service at beam wind. Many vertical struts are equipped on lower-hulls, which induce a lateral lift force to counter the wind drag force. We call this structure VLMOS (Very Large Mobile Offshore Structure).

To find the optimum routine to maximize the generated energy is very important to increase the energy profitable ratio which is defined as the ratio of net-output energy to total input energy through the lifetime of structure. Thus, we aim at building logic for finding optimum route with consideration of stormy weather and the rate of wind power in this project. The target figure of the rate of wind power is more than 40% of the maximum, in another word more than 40% of the capacity factor.

Another important issue is the structural strength. The structure is designed to have enough strength in 6m significant wave height, but she should evacuate if the significant wave height exceeds 6m. This design concept is different from that of the conventional ships or the conventional offshore structures. Thus, they are anxious to use a conventional methodology for estimate of fatigue damage in which an averaged long term sea condition is used. In this study, we use the result of a navigation simulation for estimate of the fatigue damage to improve the methodology more realistic one than conventional one.

2. HYDROELASTIC BEHAVIOR IN IRREGULAR WAVES

If the problem is linearized, we can use frequency domain analysis to obtain the hydroelastic response of the structure and the linear stochastic theory can be used to estimate the stochastic property of the structure in the sea. This is the standard procedure for the designing of the offshore structure. The response amplitude operator (RAO) plays an important roll in this procedure as an interpreter between the frequency domain analysis and the stochastic analysis.

Although a 3D-panel method to estimate the hydroelastic behavior of VLMOS has been used for the detailed investigation in the project, we use a simple method to know the general information for the fatigue assessment. Because the fatigue assessment requires many computations for various wave conditions, while the cost of 3D-computation is very expensive.

The following assumptions are employed in the simple method.

- The length of the structure is infinite, and the effect of struts for the boundary value problem is neglected. Thus, the problem is periodic in the longitudinal direction, and all properties vary sinusoidally.

·Static stability is estimated from the water line area of the strut, although the effect of struts is ignored for the hydrodynamic analysis as mentioned above.

·The strut and the transverse beam are assumed to be rigid for the estimate of structural strength.

Details of the simple method are found in [2].

Fig. 1 shows an example of stress RAO contour in oblique waves. The high stress is represented by the red color in this figure. It is found that the high stress region is narrow and sensitive for the variation of incident wave angle.

It is usually assumed that the wave spectrum is time-invariant in a short term sea condition. The structure is assumed to meet about one thousand encounter waves in one short term wave condition, which corresponds to two and half hours if the average period of encounter waves is 9 seconds. The spectrum of the stress in this short term sea condition is given from the RAO and wave spectrum, where the wave spectrum is assumed to be the ITTC spectrum and the directional wave distribution function is assumed to be cosin square distribution in this study.

It is well known that the probability density of the double amplitude is approximated by the Rayleigh distribution, if the wave spectrum is narrowband. Fig. 2 shows the significant value of the stress at a corner of the lower-hull in short crested irregular waves of unit significant wave height. It is obvious that the peak value becomes very low and the sharp peak becomes mild compared to those in Fig.1.

6. ESTIMATION OF FATIGUE DAMEGE

6.1 Conventional method

Once the operating aria is decided, stochastic data of short term sea conditions such as the wave period, the significant wave height and the dominant wave direction are given from observation data. The long term probability density of the stress is given as the product of the long term probability of a short term sea condition and the short term probability of the stress in the short term sea condition.

$$\varphi_L\left(\sigma,H,T,\chi\right)=\frac{\sigma}{r_\sigma\left(H,T,\chi\right)^2}\exp\left[-\frac{\sigma^2}{2r_\sigma\left(H,T,\chi\right)^2}\right]\varphi_W\left(H,T,\chi\right) \quad (1)$$

where $\varphi_W\left(H,T,\chi\right)$ denotes the long term probability density of the short term wave condition.

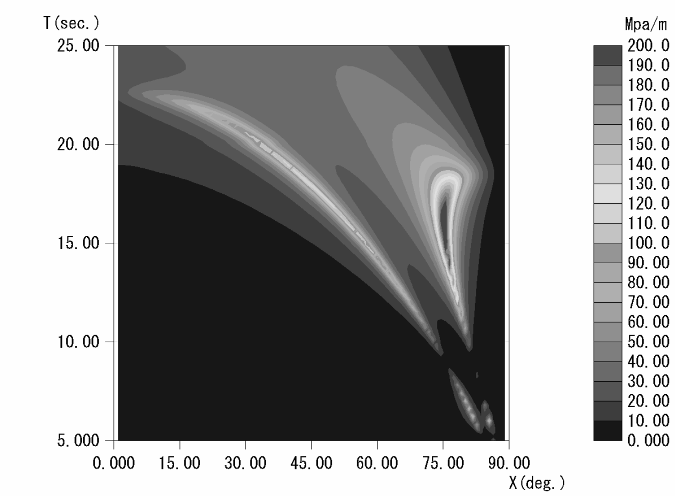

Fig.1 Response amplitude operator of the stress at a corner of the lower-hull.

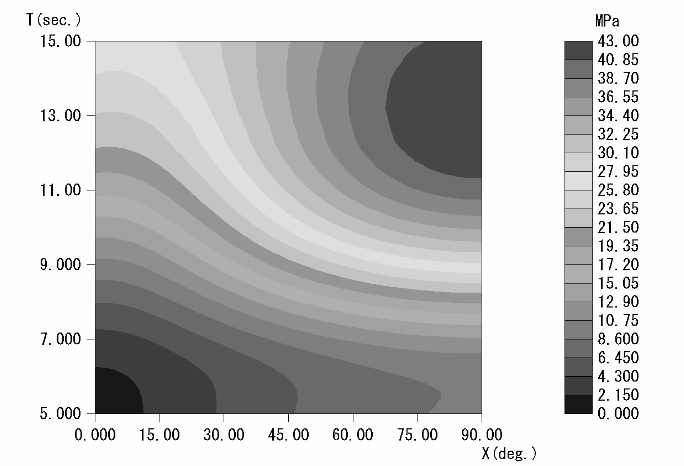

Fig.2 Significant value of the stress at a corner of the lower-hull in short crested irregular waves of unit significant wave height.

H is the significant wave height, T the mean wave period and χ the dominant wave direction. σ is the double amplitude of the stress at a corner of the lower hull of the VLMOS and γ_σ^2 the variance of the stress in the short term sea condition.

The total fatigue damage in the long term sea condition is usually assumed to be given by the Palmgren-Miner rule of the linear accumulation of damage

$$D_F = \sum_k \frac{n_k}{N_k} \tag{2}$$

where n_k denotes the number of times during the period that stress ranges fall into class S_k and $N(\sigma_k)$ is the allowable number of cycles until failure due to progressive fatigue cracking occurs for class S_k. The relation between S_k and $N(\sigma_k)$ is given as a S-N curve, which has the following form

$$N = C / S^m \tag{3}$$

where C and m is usually given from the experimental data, although we use an available S-N curve for double hull oil tankers.

If we consider the small stress range, n_k is obtained from the long term probability density of the stress

$$n_k \simeq N_0 \varphi_L(\sigma, H, T, \chi)\, d\sigma dH dT d\chi \tag{4}$$

where N_0 denotes the total number of cycles. Thus, the cumulative fatigue damage D_F is obtained as

$$D_F = \frac{N_0}{C}\int_0^\infty \sigma^m \int_0^\infty \int_0^\infty \int_{-\pi}^{\pi} \varphi_L(\sigma, H, T, \chi)\, d\sigma dH dT d\chi\ . \tag{5}$$

This is the conventional procedure to obtain the cumulative fatigue damage, which is well established in the field of ship structure. It is apparent that the stochastic data of the long term sea conditions plays significant roll in this procedure. We often use the stochastic data at the North Pacific Ocean [3] for the ship design and it is well known that the probability of the significant wave height can be approximated by the Weibull distribution, which is often used for the fatigue damage estimation. However, averaged data is supposed not to be appropriate for the estimation of the fatigue damage of the VLMOS, since she pursues the good wind condition area, in which usually the sea is rough.

6.2 Navigation simulation

In order to know more realistic sea condition, a navigation simulation for one year is carried out using weather hind-cast data, which is calculated by Wave Watch Ⅲ. The track of the VLMOS is calculated based on the maneuverability equation in which MMG model and experimentally obtained coefficients are used. In the simulation, it is assumued that the course of the VLMOS is searched every 12 hours since the turning operation takes a few hours. The course is searched so that the obtained wind power is maximized and the VLMOS doesn't meet the high sea in which the significant wave height exceeds 6m. The detail of the navigation simulation is found in [4].

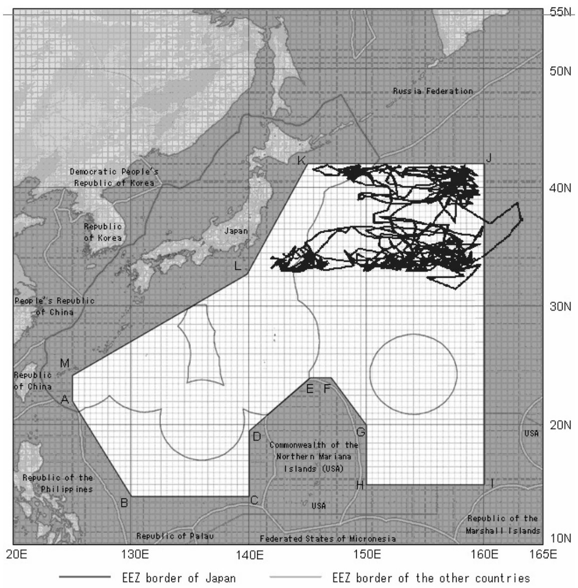

Fig.3 An example of the navigation simulation.

6.3 Comparison of fatigue damages

As a conventional method, the long term probability of the significant wave height is obtained by averaging the wave data in the operational region which is shown in Fig. 3. On the other hand, the more realistic long term probability is obtained based on the navigation simulation which is explained in the previous section. Fig.4 shows the stochastic distributions of the significant wave height. It is noted that the stochastic data should be obtained from many simulation results using different wave data, i.e. data of different year, different initial position of VLMOS and so on. However, it is supposed that we can guess the influence of selected route on the fatigue damage. The result show that the navigation simulation deviates to the high wave height range compared to the averaged one. In addition, an averaged data in the North Pacific Ocean [3] is also shown in the figure as a reference.

Fig.5 shows the cumulative fatigue damage for twenty years operation by using different long term probabilities. The result shows that the navigation simulation gets the higher fatigue damage, where the wave period is assumed to be $T = 3.56\sqrt{H}$. If we use the simulated wave period, the cumulative fatigue damage is lowered. This is shown as “Simulation-T” in the figure.

7. CONCLUSIONS

It is found that the wave irregularity and short crestedness plays significant roll to reduce the resonant phenomena in hydroelastic behavior of the VLMOS, since it is very peaky. Deformation of the long term probability distribution of the significant wave height based on the navigation simulation shows the influence of selected route. However, it is stated that the structure has enough fatigue strength for the twenty year operation even if the VLOMOS pursues the strong wind area. It is noted that this result only concern the global structural stress, and local structural analysis is needed for more detailed assessment and, of course, more realistic weather data is essential to finalize this study.

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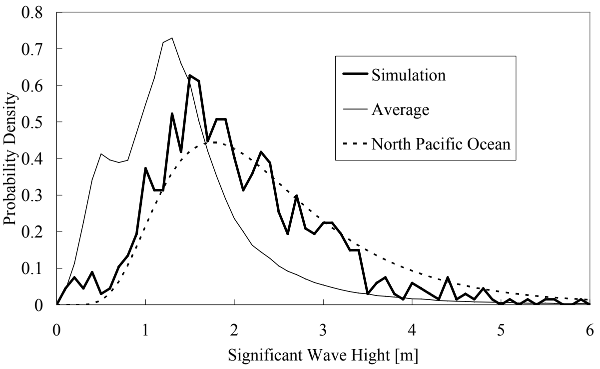

Fig.4 Probability density of significant wave height.

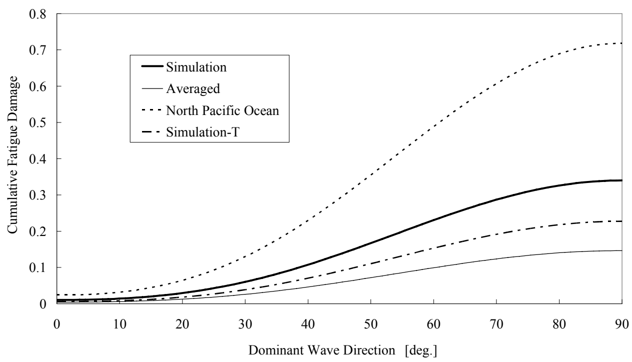

Fig.5 Cumulative fatigue damage.