Journal of Ocean Engineering and Technology, Vol. 4, No. 2, pp. 209~222, December, 1990

⊙ Technical Paper

A Study on the Spectral Fatigue Analysis for Offshore Structures

K. N. Cho*

(*Received December* 11, 1990)

海洋構造物의 스펙트럴 疲勞解析에 대한 考察

曺 圭 楠

Key Words : Wave Load(파력), Fatigue Life(피로수명), Stress Concentration Factor(응력집중계수), Sea-transportation(해상수송), Tubular Joint(튜불러 죠인트)

초 록

본 논문은 해양 구조물에 대한 확률적 기법을 이용한 스펙트럴 피로해석 방법에 대하여 기술하고 있다. 환경조건 특히 파도 및 관련된 해상상태, 파도 스펙트럼에 대하여 조사하였다. 각종 공식을 이용한 응력 집중계수와 유한요소법을 이용한 응력 집중계수 산출 방법 및 피로수명에 대한 그 영향에 대해서 연구하고, S−N선도의 선택과 해상상태의 간략화 문제 등에 관해서도 다루었다. 마지막으로 스펙트럴 피로해석 기법을 응용한 실제 피로해석 사례 연구를 통하여 본 방법의 유용성을 입증하였다.

1. Introduction

In 1965 an early example of fatigue damage occurred in a triangula semi-submersible drilling rig which began working in the Gulf of Mexico. From that time on various kinds of fatigue failures of ocean structures were reported and the importance of fatigue life estimation at the design stage is significantly recognized and various kinds of analysis approaches have been discussed[1].

Fatigue crack growth occurs when the loading is predominantly dynamic, local stresses are relatively high, high strength steels are applied and fabrication defects exist.

For the offshore structures which is related to the variable loads such as wave loads, a probabilistic approach using spectral analysis methods is preferable. Spectral analysis is a technique capable of relating, in a statistical manner, cause and effect due to randomly occurring phenomena[10].

* Member, Hyundai Maritime Research Institute

In this paper characteristics of the spectral method are studied and the elements of the approach are discussed. Environmental conditions, especially waves and related sea states and the wave spectrum representing the total energy in a particular sea state, which influence directly onto the offshore structures are reviewed. The concepts of maximum stress concentrations phenomenon at the certain points which are commonly referred to as hot spots and the stresses at these locations so called hot spots stresses are discussed. Various kinds of stress concentration factors formula and the application of F.E.M. for searching SCFs are also studied. Condensation of wave scatter diagram for the better and concise analysis scheme is proposed.

In the followings, the components of the spectral fatigue analysis are reviewed and the feasibility of the method is explored. Also the theory and the method are applied to typical offshore structures through case studies.

2. Environmental Loading Calculation

The response of offshore structures to environmental loading is of fundamental importance in the analysis of fatigue problem. The loads may be categorized as[1] :

- Permanent loads such as weight of the structure, weight of ballast and equipment etc..
- Live loads associated with stored materials, operational equipments, helicopters and so on.
- Deformation loads associated with imposed deformations.
- Environmental loads due to wind, waves, current, ice, earthquake and other environmental actions.

For the fatigue analysis of the main structure, especially the environmental loads are most influential one to be considered. However, the assumption that the environment that results in the largest lifetime extreme loads on the structure will also result in the lowest fatigue lives may not always be accurate. The calculation procedures of environmental loads based on the classification rules are adequate. In the following the general characteristics of wind, waves, currents, tide are briefly discussed and related environmental loads calculation procedures are introduced[2,3].

2.1 Wind

Wind is a horizontal movement of air in response to differences in air pressure caused primarily by differential heating and cooling. Wind loadings and effects are to be more important for marine structures since they are inherently more susceptible to extreme winds than land structures. Here dynamic effects over the range of wind speeds related to possible fatigue failure of the structures only are considered. The wind speed as a function of height above the mean water level and average time interval may be approximated by the power law[2] :

$$V_{tz}=\alpha\ V_{1\ hr\ 10}\left(\frac{z}{10}\right)^{\beta} \quad \cdots\cdots\cdots (1)$$

where

V_{tz} the wind speed averaged over a time interval t as defined by α and β, z meters above the mean water level.

$V_{1\ hr\ 10}$ the wind speed averaged over one hour, 10m above the mean water level.

α gust factor ; referenced to $V_{1\ hr\ 10}$

β height exponent

The gust factor α and the height exponent β for different averaging time intervals are given in Table 1[2].

Table 1 Factors in the power law for wind profiles

Factor	Averaging Time Interval					
	1hr.	*10min.*	*1min.*	*15sec*	*5sec*	*3sec*
α	1.000	1.060	1.180	1.260	1.310	1.330
β	0.150	0.130	0.113	0.106	0.102	0.100

For the possible fatigue failure, vortex shedding problem is to be considered[4)]. At certain flow speeds turbulent eddies known as vortices may break away from the trailing edge of all object alternatively from one side and then the other at a fixed, relatively high frequency. If the period of vortex shedding is near any natural period of the structure, resonance may result in a self-excited oscillatory motion. Below some critical speed for the given cross section the rate of vortex shedding is controlled by the wind speed. However, above some critical speed(V_{cr}) the oscillations of the structure, typically transverse to the wind direction, will cause the vortices to be cast away ; and thus the frequency of oscillation of the structure and that of the vortex shedding enhance one another. The frequency of vortex shedding is given by the Strouhal number (N_s) where :

$$N_s = \frac{fD}{V_{cr}} \qquad (2)$$

for which f is the frequency in cycles per second and D is the characteristic dimension of body. Strouhal number varies with Reynolds number. The possibility of resonance due to vortex shedding can be reduced by changing the cross section or natural period of the structure. The fatigue failure of the marine structures associated with winds may occur in view point of dynamic effects such as vortex shedding.

2. 2 Wave

Waves are periodic undulations of the sea's surface, the complexity of which is most challenging to those working in the oceans. They impose highly variable and fatigue-type loadings on offshore structures. For the evaluation of loads and stresses on marine structures, the selection of wave parameters, a height and period or range of periods, and/or a complete wave height and period spectrum are prerequisite.

For a dynamic analysis including fatigue analysis, it is not sufficient to select a design wave, but a complete spectrum or series of storm spectra are required to determine the frequency content and the structure's response.

Wave statistics should preferably be used on the basis of instrumentally recorded data. When wave statistics are presented in terms of visual observed wave heights and period Hv, Tv, these data may be transformed to estimates of significant wave height Hs and average zero-upcrossing period Tz at the same probability level by the following relationships[2)] :

$$Hs = 1.68Hv^{0.75} \qquad (3)$$

$$Tz = 0.82Tv^{0.96} \qquad (4)$$

The development of sea spectra and application of spectral analysis techniques is consequently required in the dynamic and fatigue analysis of offshore structures. Short term stationary irregular sea states may be described by wave power density spectra such as the Pierson-Moskowitz or the Jonswap spectrum, the modified Pierson-Moskowitz spectrum etc.. Generally the modified Pierson-Moskowitz spectrum is applied in the related analysis.

The modified Pierson-Moskowitz spectrum may be written in non-dimensional form as[2-4)] :

$$\frac{S(\omega)}{Hs^2Tz} = \frac{1}{8\pi^2}\left(\frac{\omega Tz}{2\pi}\right)^{-5}\exp\left[\frac{-1}{\pi}\left(\frac{\omega Tz}{2\pi}\right)^{-4}\right] \qquad (5)$$

where

Hs significant wave height

$S(\omega)$ power spectral density

T wave period

Tz average zero-upcrossing wave period

ω angular wave frequency

The Jonswap spectrum in dimensional form is written :

$$S(f)=\alpha \cdot g^2 \cdot (2\pi)^{-4}\, f^{-5}\, \exp[-\frac{5}{4}(\frac{f}{fp})^{-4}] \cdot \gamma^{\exp[-\frac{(f-fp)^2}{2\sigma^2 fp^2}]} \quad \cdots\cdots (6)$$

where

f frequency (Hz)

fp frequency of spectral peak (Hz)

g acceleration due to gravity (m/sec^2)

α Phillips constant

σ spectral width parameter

γ peakedness parameter

Directional short-crested wave power density spectra may be derived from the unidirectional long-crested wave power density spectra as follows :

$$S(\omega, \alpha)=S(\omega) \cdot f(\alpha) \quad \cdots\cdots (7)$$

where

α angle between direction of elementary wave trains and the main direction of the short-crested wave system

$S(\omega, \alpha)$ directional short-crested wave power density spectrum

$S(\omega)$ unidirectional long-crested wave power density spectrum

$f(\alpha)$ directionality function

One commonly used theoretical form for $f(\alpha)$ is the circular normal function[3] :

$$f(\alpha)=\frac{\exp[a \cos\alpha]}{2\pi\, Io(a)} \quad \cdots\cdots (8)$$

where axis $\alpha=0$ is taken along the wind direction

a a measure of the energy concentration about this axis

Io the modified Bessel function of zero order

Other directionality functions may be accepted if shown to be appropriate for the case considered.

In the spectral fatigue analysis, the stress spectrum is obtained by multiplying the above wave spectrum by the square of the transfer function. Since currents and tide are thought to be insignificant factors in the fatigue analysis, they are not considered here.

3. Stress Concentration Factors(SCF)

Stress concentration can be defined as a condition in which a stress distribution has high localized stresses : usually induced by an abrupt change in the shape of a member ; in the vicinity of notches, holes, changes in diameter of a shaft, and so on, maximum stress is several times greater than where there is no geometrical discontinuity. The stress concentration factor is the ratio of the greatest stress in the region of stress concentration to the corresponding nominal stress. The location of the stress concentrations are called hot spots. In the fatigue analysis of offshore structures, the SCF is considered to play a most important role[5].

The SCF may be calculated from theory of elasticity by various methods. Analytical methods tend to become mathematically complicated, and are applicable to simple geometries only. Finite element methods are more versatile. For 3-dimensional case, the finite element method is still practical, but is very expensive in many cases.

3. 1 SCF Formulas

There are many formulas for SCF calculation which were obtained from numerical analysis or experiment. Several researchers have suggested empirical approximations for SCFs in tubular joints. Generally, nondimensional ratios of geometric parameters are used to allow for the generalization of the results to many joint sizes. SCF is assumed as a function of parameter γ, β, τ, ξ, θ as :

$$SCF = f_1(\gamma) \cdot f_2(\beta) \cdot f_3(\tau) \cdot f_4(\xi) \cdot f_5(\theta) \quad \cdots\cdots \quad (9)$$

where

$\gamma = D/2T$ chord diameter to thickness ratio

$\beta = d/D$ brace diameter to chord diameter ratio

$\tau = t/T$ brace thickness to chord thickness ratio

$\xi = g/D$ gap to chord diameter ratio

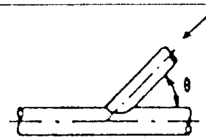
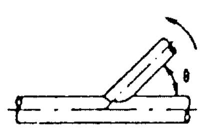
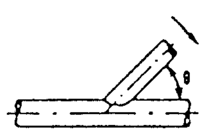
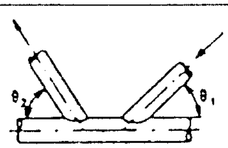
θ brace angle with the chord

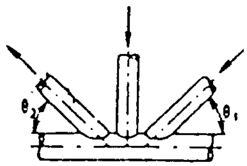
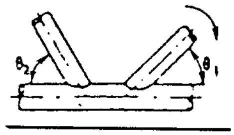
With the above assumptions for SCF, the actual curve fit of the SCFs was performed in a graphical manner. If it is assumed that the variation of the SCF with respect to each geometric parameter is in the form of the parameter raised to a power, then a plot of SCF versus the appropriate parameter on log-log scale will yield a straight line whose slope may be interpreted as the power to which the parameter is raised[6]. Finally the empirical equation in the form shown below is obtained.

$$SCF = a \cdot \gamma^{m1} \cdot \beta^{m2} \cdot \tau^{m3} \cdot \xi^{m4} \cdot \sin^{m5}\theta \quad \cdots \quad (10)$$

Table 2 shows a typical SCF formula obtained using the above procedures. Obviously any set of empirical guidelines must be restrained within certain limitations to minimize data dispersion and maintain design applicability. Comprehensive SCF related research work was carried out recently[7].

Table 2 Kuang's SCF formulas

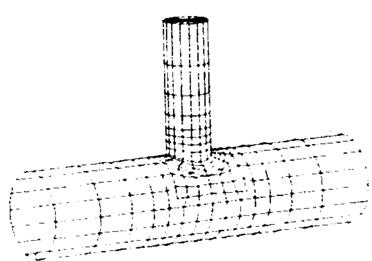
Application	Kuang's stress concentration formulas	Validity range see end of table
	Chord	
	$SCF = 2.060 \cdot \gamma^{0.808} \cdot e^{-1.2\beta^3} \cdot \tau^{1.333} \cdot a^{0.057} \cdot \sin^{1.694}\theta$	I
	Brace	
	$SCF = 4.076 \cdot \gamma^{0.55} \cdot e^{1.35\beta^3} \cdot \tau \cdot a^{0.12} \cdot \sin^{1.94}\theta$	I
	Chord	
	$SCF = 0.702 \cdot \gamma^{0.6} \cdot \beta^{-0.04} \cdot \tau^{0.86} \cdot \sin^{0.57}\theta$	I
	Brace	
	$SCF = 1.301 \cdot \gamma^{0.23} \cdot \beta^{-0.38} \cdot \tau^{0.38} \cdot \sin^{0.21}\theta$	I
	Chord	I+
	$SCF = 1.024 \cdot \gamma^{1.014} \cdot \beta^{0.787} \cdot \tau^{0.889} \cdot \sin^{1.557}\theta$	$0.3 < \beta < 0.55$
	$SCF = 0.462 \cdot \gamma^{1.014} \cdot \beta^{-0.619} \cdot \tau^{0.889} \cdot \sin^{1.557}\theta$	$0.55 < \beta < 0.75$
	Brace	I+
	$SCF = 1.52 \cdot \gamma^{0.852} \cdot \beta^{0.801} \cdot \tau^{0.543} \cdot \sin^{2.033}\theta$	$0.3 < \beta < 0.55$
	$SCF = 0.796\gamma^{0.852} \cdot \beta^{-0.281} \cdot \tau^{0.543} \cdot \sin^{2.033}\theta$	$0.55 < \beta < 0.75$
	Chord	II+
	$SCF = 1.526 \cdot \gamma^{0.666} \cdot \beta^{-0.59} \cdot \tau^{1.104} \cdot p^{0.067} \cdot \sin^{1.521}\theta$	$30° < \theta < 90°$
	Brace	II+
	$SCF = 0.920 \cdot \gamma^{0.157} \cdot \beta^{-0.441} \cdot \tau^{0.560} \cdot p^{0.058} \cdot e^{1.448}\sin\theta$	$30° < \theta < 90°$

	Chord $SCF=1.83 \cdot \gamma^{0.54} \cdot \beta^{0.12} \cdot \tau^{1.068} \cdot \sin\theta$ Brace normal to chord and inclined $SCF=4.89 \cdot \gamma^{0.123} \cdot \beta^{-0.396} \cdot \tau^{0.672} \cdot (p_1+p_2)^{0.159} \cdot \sin^{2.267}\theta_2$ $SCF=6.056 \cdot \gamma^{0.1} \cdot \beta^{-0.36} \cdot \tau^{0.68} \cdot (p_1+p_2)^{0.126} \cdot \sin^{0.5}\theta$ $SCF=13.804 \cdot \gamma^{0.1} \cdot \beta^{-0.36} \cdot \tau^{0.68} \cdot (p_1+p_2)^{0.126} \cdot \sin^{2.88}\theta$	II+ $0° < u < 90°$ II+ $0° < \theta < 45°$ $45° < \theta < 90°$
	Chord $SCF=1.822 \cdot \gamma^{0.38} \cdot \beta^{0.06} \cdot \tau^{0.94} \cdot \sin^{0.9}\theta$ Brace $SCF=2.827 \cdot \beta^{-0.35} \cdot \tau^{0.35} \cdot \sin^{0.5}\theta$	II+ $0° < \theta < 90°$ II+ $0° < \theta < 90°$
	I: $8.3 < \gamma < 33.3$, $0.3 < \beta < 0.88$, $0.2 < \tau < 0.8$, $3.3 < \alpha < 20$, $0° < \theta < 90°$ II: $8.3 < \gamma < 33.3$, $0.3 < \beta < 0.88$, $0.2 < \tau < 0.8$, $0.01 = p < 1.0$	

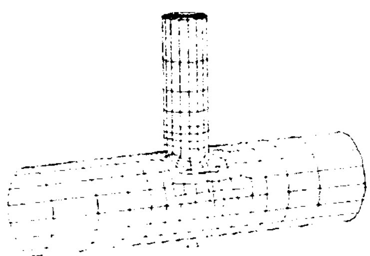
3.2 Finite Element Methods for SCF Calculation

Finite element methods is used commonly to determine the stress distribution and hot spot stress especially for complex tubular joints. Shell element traditionally have been used for the SCF calculation. However it is difficult to include the geometry in the weld region in the FEM modeling. Stress analysis by FEM is the most efficient, reliable and economical tool for detailied stress analysis of tubular joint with the rapid development of computation skills and modeling techniques and high speed computers[1,7].

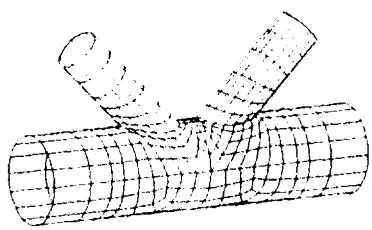
In Fig. 1 tubular joint models are shown using the SESAM'80[8] to calculate the SCF. The analysis was done in HMRI[7] recently. Fig. 2 shows the



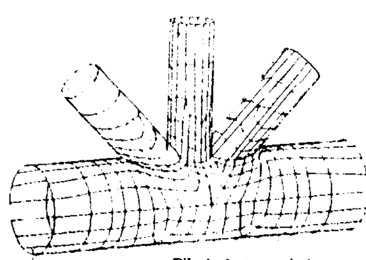
T joint model without ring stiffener



T joint model with ring stiffener



K joint model



TK joint model

Fig. 1 Various kinds of models for SCF calculation by F. E. M.

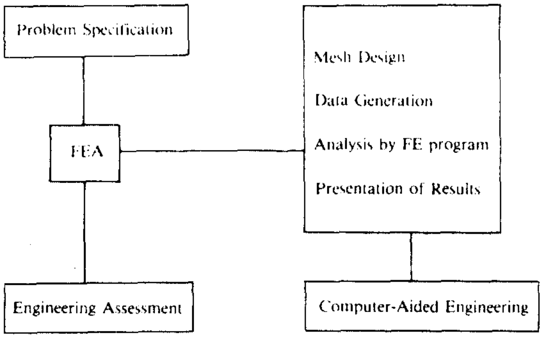


Fig. 2 Stages in stress analysis of joints by F. E. M.

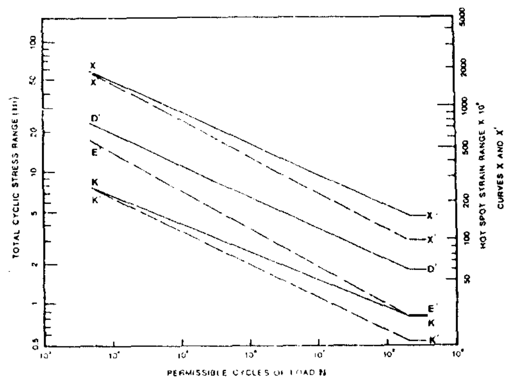
stages of the stress analysis using so called Computer-Aided Engineering (CAE) techniques.

Generally, FEM analysis is necessary for complex joints to which known SCF formulas cannot be applied. For simple T, K, joints and similar ones formulas such as Gibstein's, Kuang's, Wordsworth's, Smedley's, Kinra's, Efthymiou's are applicable according to the characteristics of the joints considered[6, 7]

4. S−N Curve

A S−N curve is an empirical description of the number of cycles to failure, for given values of constant amplitude cyclic stress range. Sources are from the guidance given by the U. K. Department of Energy for Offshore Structures or from various kinds of test data. In any given situation, the appropriate S−N curve should be selected in a manner consistent with the structural detail location and details of the structural analysis. Typically, the overall geometry effects will not be included in the S−N curve for ship structure analysis but for offshore structures the overall geometry effects and hot spot concepts are included in the S−N curve[1, 5, 9].

Scatter in fatigue data should be appropriately accounted for. In practice, 97.5% survival S−N curves are used. Instead of using small specimen, particular S−N data from component fatigue tests may be used. Among various S−N curves API S−N curves are generally used for the analysis as shown in Fig. 3[11].



NOTE−These curves may be represented mathematically as

$$N = 2\times 10^6\left(\frac{\Delta\sigma}{\Delta\sigma_{ref}}\right)^{-m}$$

where N is the permissible number of cycles for applied cyclic stress range $\Delta\sigma$, with $\Delta\sigma_{ref}$ and m as listed below.

Curve	$\Delta\sigma_{ref}$ Stress Range At 2Million Cycles	m Inverse Log-Log Slope
X	14.5 ksi(100MPa)	4.38
X'	11.4 ksi(79MPa)	3.74
D'	5.8 ksi(40MPa)	4.38
E'	3.0 ksi(21MPa)	3.48
K	2.15 ksi(15MPa)	4.66
K'	1.7 ksi(12MPa)	4.19

Fig. 3 API S−N curve

5. Spectral Fatigue Analysis Procedure of Offshore Structures

5. 1 General Procedure

Metal fatigue in welded structures is a complex phenomenon, affected by a number of synergistic factors, the most important being the cyclic stress range[9].

For most offshore structures, a spectral fatigue analysis approach, wherein the entire long term distribution of fatigue stresses is determined in each specific case, considering the characteristics, such as significant wave height, representative wave period, of each sea state and the time spent in it, may be performed without any difficulties[5,12].

The spectral method applies the theory of stochastic processes for calculation of the response to environmental loading especially wave loading. For a particular sea state, the spectrum of a response variable is found by combining the wave spectrum with the transfer function relating the wave amplitude to the amplitude of the response. By integrating the response spectrum, the variance of the response and the spectral moments can be calculated. Once the stress is known, predictions of the stresses experienced at that location can be made. All statistical stress predictions are related to the moments of the relevant stress spectrum about the origin.

The spectral fatigue analysis procedures are well introduced[10,12]. The basic components of the method are as follows.

1) Description of the environmental conditions including the probabilistic description of the sea
2) Calculation of motions, motion induced load etc.
3) Generation of stress transfer functions
4) Stress concentration factor calculation for hot spot stress response spectrum
5) Fatigue life calculation based on proper S−N curves and Palmgren-Miner Rule.

The analysis steps are briefly discussed in the followings.

1) Selection of environmental conditions, i. e., various kinds of corresponding sea states. Sea states may be expressed in terms of wave energy spectrum as shown in 2. 2.
2) For a wave component of an assumed direction, amplitude and period, the amplitudes of the stress response at all points of interest within the structure are determined in order to obtain the ratio of the stress amplitude to the wave amplitude at each point. This process is repeated for a sufficient number of wave periods to define the ratio throughout the range of realistic wave frequencies for the particular direction of wave approach. The results yield the required stress transfer function.
3) Stress concentration factors(SCF) incorporated with in order to obtain the stress transfer function of hot spots as defined in chapter 3.
4) The stress spectrum is obtained by multiplying the wave spectrum by the square of the transfer function as shown below.

$$S\sigma(\omega, \alpha) = H\sigma^2(\omega, \alpha) \cdot S(\omega) \quad \cdots\cdots\cdots\cdots\cdots \quad (11)$$

where $S\sigma(\omega, \alpha)$ stress spectrum as a function of the wave frequency and the wave direction with respect to the structure

$H\sigma(\omega, \alpha)$ response amplitude function or transfer function

$S(\omega)$ wave spectrum

5) Statistical stress distributions during one particular stationary sea state, i. e., short-term stress statististics are obtained.
6) Statistical stress distributions during an extended period of time in which many different sea states occur, i. e., long-term stress statistics are obtained.
7) The fatigue life is calculated based on the assumption of linear cumulative damage (Palmgren-Miner rule). Application of this assumption implies that the long-term distribution of stress range is replaced by a stress histogram consisting of a convenient number of constant amplitude stress range blocks, σi, each with a number

of stress repetitions. The fatigue criteria then reads as equation (12). In calculation of fatigue life, proper S−N curve as discussed in chapter 4 is incorporated.

Detailed flow chart of spectral fatigue analysis is shown in Fig. 4.

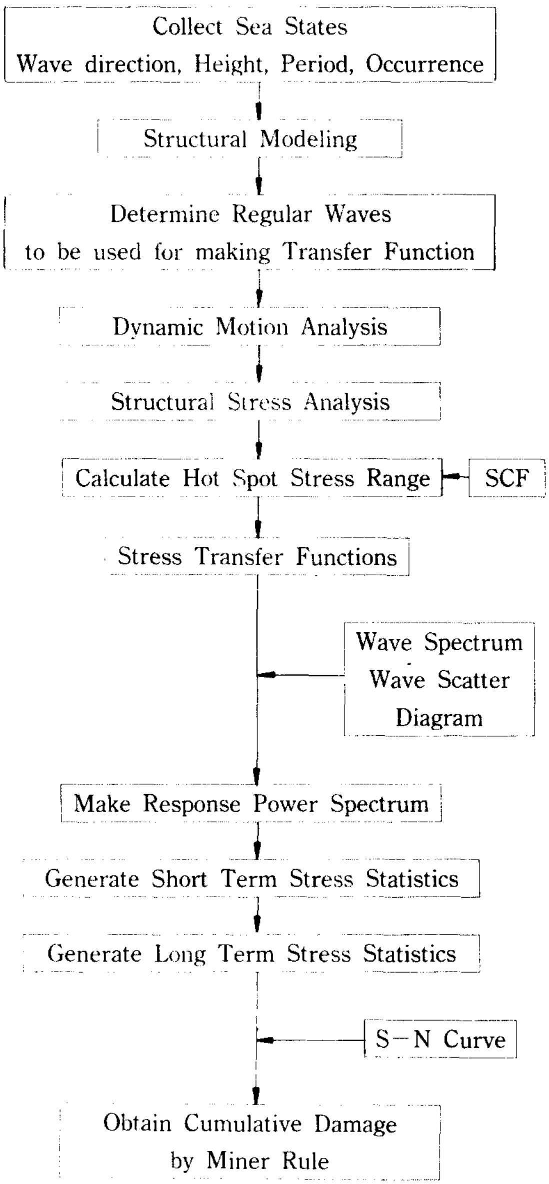


Fig. 4 Flow chart of spectral fatigue analysis

5. 2 Discussions on Fatigue Life Calculation

The fatigue life calculated based on the assumption of linear cumulative damage implies that the true time history of the local stresses is simplified in that it is assumed to be adequately described in statistical terms by a reasonable number of stress blocks. Thus the sequence of variations in the true stress history is lost. However the Miner's rule as shown below is the most frequently used one in spite of the inherent difficulties[10].

$$DR=\sum_{i=1}^{k}\frac{ni}{Ni} \quad \cdots\cdots (12)$$

where DR damage ratio

k number of stress blocks considered

ni actual number of stress cycles for stress block i

Ni allowable number of stress cycles of stress ragne σi

A fatigue failure is assumed to occur when the damage ratio, DR, reaches unity. Generally the number of stress blocks, k, is to be large enough to ensure reasonable numerical accuracy, and should not be less than 20.

Among the major elements of any fatigue analysis, for example, environmental condition, stress concentration factor, S−N curve, the most crucial element is found to be the stress concentration factor. Typical sensitivity analysis shows that the only 2 times increase in SCF gives 21 times increase in damage ratio[5]. SCF may be said to be the most sensitive factor in fatigue behavior of offshore structures.

Another interesting aspect of fatigue life calculation is the simplification of the environmental conditions. Especially the condensation of the original wave scatter diagrams into the simplified one which represents the original one without any significant losses can be utilized. The original wave scatter diagram consisting of so many seastates and directions may be condensed. In simplifying seastates, some blocks are constructed based on the seastates having large duration time. Duration time of the seastates within each block is summed to give the resultant duration time of that block. Seastates having very small duration time or small zero crossing period are merged into neighboring block. The obtained condensed sea states has shown to act as the original one with only insignificant influence in fatigue life calculation[5].

Even though there are many uncertainties in the calculation of fatigue lives as described above, the application of spectral analysis techniques to the fatigue analysis of offshore structures is quite reasonable.

6. Case Studies

The spectral fatigue analysis technique is applied for the analysis of bracing members of typical semi-submersible drilling rig structure and for the analysis of element members of jacket structure during its ocean transportation[12,13]. Two structures, i.e., semi-submersible drilling rig and jacket structure are thought to be fundamental offshore structures.

6. 1 Typical Semi-submersible Case

The spectral fatigue analysis is carried out to estimate the fatigue life of the bracing elements of the semi-submersible. The analysis is based on the following assumptions.

1) Short creasted sea
2) Transfer functions are built up using 14 single wave periods
3) Modified Pierson-Moskowitz spectrum is used
4) The wave spectra are discretized to 8 main direction with equal probability
5) The wave data for the analysis is taken from North Sea.

Fig. 5 shows the investigated sections in the horizontal trusses of a semi-submersible. Figs. 6−8 show the typical wave spectrum, local stress transfer function and response spectrum in this analysis, respectively.

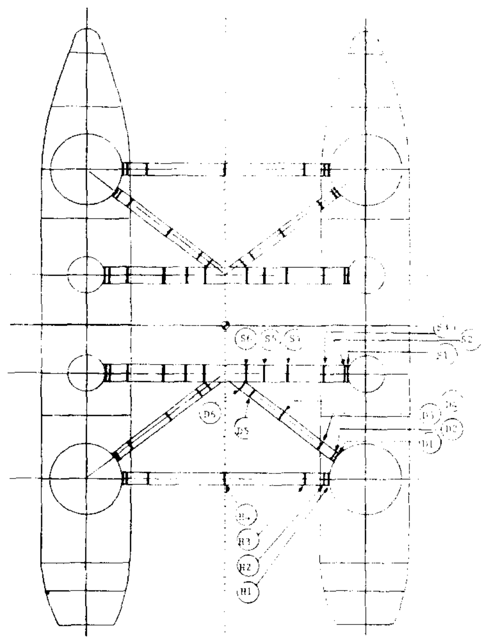


Fig. 5 The analysed sections of the semi-submersible

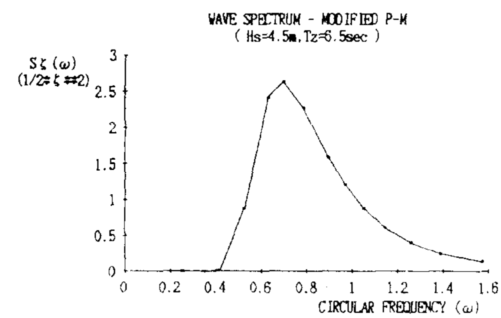


Fig. 6 Typical wave spectrum

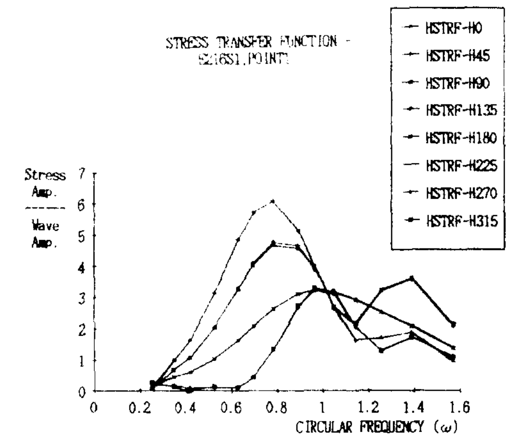


Fig. 7 Typical local stress transfer function

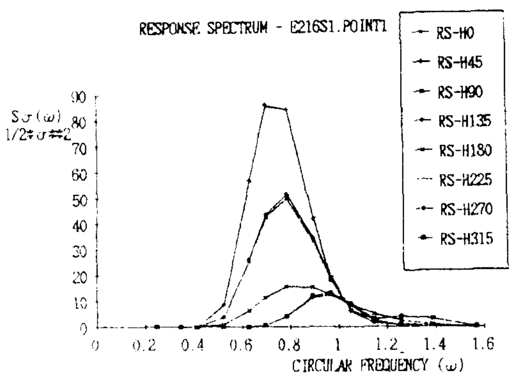


Fig. 8 Typical stress response spectrum

Table 3 shows the calculated fatigue life of most critical points of the semi-submersible drilling rig structrue.

The result shows that the vessel has sufficient strength in the horizontal trusses to withstand more than 20 years of operation.

6. 2 Fatigue Analysis During Sea-transportation

In this case, fatigue analysis for the typical jacket joints and tie-down members during its ocean towage are performed for two possible towing routes (Fig. 9). The analysis is based on

Table 3 Fatigue life of critical points

Section type	Fatigue life(*years*)
S1	36.9
S2	40.5
S3	4.24
S4	122.0
S5	132.1
S6	69.7
D1	61.7
D2	45.5
D3	22.4
D4	35.4
D5	24.1
D6	38.7
H1	47.6
H2	53.4
H3	26.3
H4	28.3

the following assumptions.

1) The two sea routes as shown in Fig. 9 are used for sea data
2) Six frequencies are selected for the motion analysis
3) Modified Pierson-Moskowitz spectrum is used.
4) Barge flexibility is not included
5) API-X' S-N curve is used in this analysis

Fig. 10 shows the barge and jacket structural model as they are transported. Table 4, Table 5 list the largest cumulative damage ratios among the most highly impaired members for two routes, respectively. The results show that the jacket members can be less impaired by fatigue by employing the transportation route adequately, i.e., in this example by employing the south route via Hawaii. Also it is concluded that the tie-down members are safe enough to withstand the fatigue under the assumptions made in this analysis.

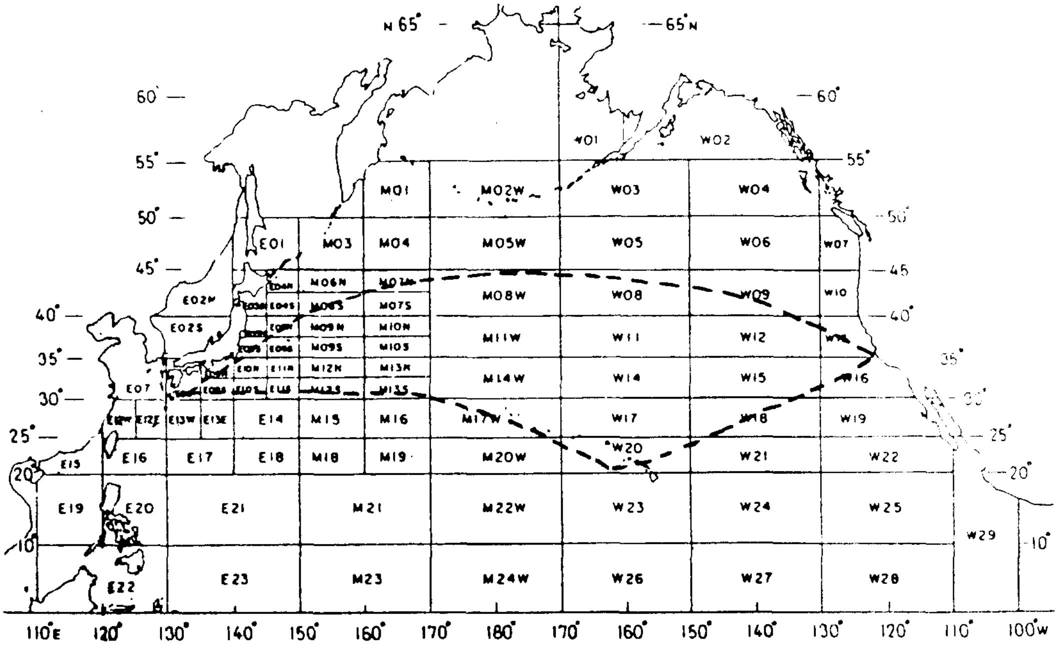


Fig. 9 Transportation routes from Korea to U.S.A.

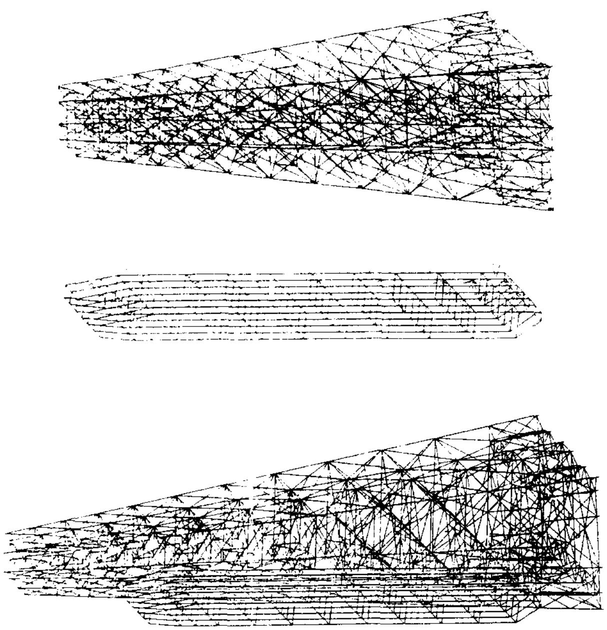


Fig. 10 Jacket/Barge/Sea fastenings ; Combined model

Table 4 Cumulative damage ratio - jacket members

Route I			Route II		
Member		Damage ratio	Member		Damage ratio
Joint	Joint		Joint	Joint	
J1161	J1133	0.44	J1161	J1133	0.33
J0322	J0332	0.38	J0322	J0332	0.28
J0332	J0322	0.35	J0332	J0322	0.25
J1165	J1137	0.32	J1165	J1137	0.23
J0410	J0457	0.30	J0325	J0339	0.20
J0411	J0457	0.29	J0410	J0457	0.20
J0325	J0338	0.29	J0411	J0457	0.20
J0338	J0325	0.28	J0338	J0365	0.19
J0462	J0442	0.27	J9492	J0442	0.18
J0464	J0444	0.26	J0464	J0444	0.18
J0362	J0316	0.25	J0310	J0350	0.16
J0562	J0542	0.25	J0362	J0316	0.16
J0564	J0544	0.25	J0562	J0542	0.16
J0310	J0350	0.24	J0564	J0544	0.16

J0311	J0350	0.23	J1265	J1242	0.16
J0364	J0360	0.23	J0311	J0350	0.15
J0364	J0314	0.23	J0362	J0360	0.15
J0362	J0360	0.22	J0364	J0314	0.15
J0711	J0766	0.22	J0364	J0314	0.15
J0710	J0768	0.21	J0710	J0768	0.14

Table 5 Cumulative Damage Ratio－Tiedowns

Route I			Route II		
Member		Damage ratio	Member		Damage ratio
Joint	Joint		Joint	Joint	
J0303	B0142	0.59	J0303	B0142	0.46
J0302	B0142	0.51	J0302	B0142	0.40
J0302	B0132	0.50	J0302	B0132	0.39
J0303	B0142	0.49	J0303	B0142	0.37
J0303	B0252	0.48	J0303	B0252	0.36
J0302	B0132	0.45	J0302	B0132	0.33
J0303	B0252	0.45	J0302	B0232	0.33
J0302	B0142	0.44	J0303	B0252	0.33
J0302	B0332	0.43	J0302	B0142	0.32
J0303	B0262	0.43	J0303	B0152	0.32
J0302	B0222	0.42	J0303	B0262	0.31
J0303	B0151	0.42	J0302	B0222	0.30
J0303	B0151	0.42	J0303	B0152	0.30
J0302	B0232	0.41	J0302	B0232	0.29
J0303	B0242	0.41	J0303	B0242	0.29
J0302	B0242	0.39	J0302	B0242	0.28
J0403	B0232	0.36	J0302	B0342	0.28
J0302	B0242	0.36	J0303	B0342	0.28
J0302	B0242	0.36	J0302	B0242	0.27
J0403	B0352	0.33	J0302	B0242	0.26

7. Discussions

A fully satisfactory solution of fatigue problem has not been achieved yet. Several kinds of approaches are sought. The discrete method which utilizes the static structural analysis due to the assumed regular waves can be employed. The main difficulty of the discrete method is the lack of the precise dynamic characteristics considerations, even though the method is used in a simple calculation resulting in less computational time. On the contrary, the spectral method described here represents physical characteristics more realistically comparing with the discrete method. However, the wave force calculations in the spectral method need to be paid special attentions. The wave force on the elements of the offshore structure is given by so called Morison's equation which is represented as sum of the drag term and the inertia term.[3] The non-linear drag term in some cases should be dealt with carefully. The non-linear effects associated with the drag term may be incorporated with the calibration to suit the spectral analysis.[10] This procedure can reduce the corresponding errors. There are many sources of uncertainty in the calculation of fatigue lives of the offshore structures besides the above mentioned items. Further research efforts in the field are encouraged.

8. Conclusions

Spectral fatigue analysis procedures and their feasibility are studied through environmental conditions, stress concentration phenomena, S－N curves and Miner Rules, case studies. The following conclusions may be drawn.

1) Stress Concentration Factor is the most crucial factor in the fatigue life estimation. In order to obtain accurate fatigue life calculations, a reasonable estimation of stress concentration factors(SCF) is essential. F. E. M. analysis is necessary for finding SCF for complex offshore structure joints.

2) Simplified sea state, i. e., condensation of wave scatter diagram can be used in the analysis and gives reasonable results.
3) The spectral fatigue analysis is by far the most reliable technique for searching realistic structural fatigue behavior even though it has inherent difficulties like the loss of the true time history of the stress.
4) Case studies show that the spectral fatigue analysis is capable of solving various kinds of offshore related fatigue problems.

References

1) Almar-Naess, A., "Fatigue Handbook-Offshore Steel Structures", Tapir, 1985
2) DnV, "Rules for the Design, Construction and Inspection of Offshore Structures", Appendix A-Environmental Conditions, 1982
3) Brebbia, C. A., S. Walker, "Dynamic Analysis of Offshore Structures", Newnes-Butterworths, 1979
4) Gaythwaite, J., "The Marine Environment and Structural Design", Van Nostrand Reinhold Co., 1981
5) Jang, Y. S., W. S. Yi, K. N. Cho, "Transportation Technique Development for ONGC Jacket Structrue", Part I Fatigue Strength, HMRI Report (OD) 87042, 1987
6) Kuang, J. G., A. B. Potvin, R. D. Leick, "Stress Concentration in Tubular Joints", Proceedings of Offshore Technology Conference, 2205, 1975
7) Jang, Y. S., "SCF Calculations for Various Tubular Joints", HMRI Report 2S87176, 1989
8) VERITEC, SESAM'80 User's Manual, 1989
9) ABS, "R & D Department Technical Report RD-89020F"., 1989
10) Vughts, J. H., R. K. Kinra, "Probabilistic Fatigue Analysis of Fixed Offshore Structures", Proceedings of Offshore Technology Conference, 2608, 1976
11) American Petroleum Institute, "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms", RP 2A, 16th edition, 1986
12) Kim, D. Y., K. N. Cho, "Basic Design Development of H520/H521 Part 3, Fatigue Analysis", HMRI Report (SD)87225-3, 1988
13) Kim, D. Y., Y. S. Jang, S. Y. Yoon, K. N. Cho, "Fatigue Analysis for EXXON Harmony Jacket During Transportation", HMRI Report (OD)2M85394, 1986

★會員加入案內★

本學會 入會를 원하시는 분은 學會所定樣式의 入會願과 우편대체 납입료를 이용하셔서 所定의 年會費를 學會 事務局으로 送付하시면 理事會의 議決을 거쳐 定式入會를 通告해 드립니다.
詳細한 것은 電話로 問議하여 주십시요.

韓國海洋工學會

釜山市 沙下區 下端洞 840 東亞大學校 工科大學 內
電話 : (051) 205-2325