RELIABILITY ANALYSIS OF OFFSHORE STRUCTURE WITH SPATIAL CORRELATION OF NODAL WAVE FORCES

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ABSTRACT

The present research deals with the reliability analysis of offshore jacket structure taking into consideration the randomness in some structural parameters and the correlations between the induced loading especially the correlation variation between nodal wave forces. Wave forces, wind loads, deck loads and steel yield stress are assumed to be normally distributed random variables. An analytical form is used for the spatial correlation between the nodal wave forces. The Monte-Carlo simulation method is used to generate a set of statistically correlated random variables. A computer program based on the proposed method has been prepared for the reliability analysis of a space truss subjected to correlated loads. A parametric study is carried out to investigate the effect of variation of the spatial correlation between the nodal wave forces on the reliability measures of the entire structure. The correlation is varied while adjusting the coefficient of variation of the nodal wave forces in order to keep the coefficient of variation of the base shear to be constant. The statistical properties of the members internal forces and their reliability measures are studied for different correlations between equicorrelated nodal wave forces.

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INTRODUCTION

Theory of structures involves the derivation of equations relating structural response quantities (e.g. stress or deflection) to the structural parameters (e.g. dimensions , loading , moment of inertia, or modulus of elasticity). Therefore, if the structural parameters are random variables then the structural response quantities are consequently random variables. Methods for the computation of the uncertainty in the structural response quantities have attained substantial interest through the structural reliability analysis. There are three items which play a decisive role within the reliability analysis:

(1) The choice of input random variables, knowledge of their statistical parameters and probability distributions and incidental statistical correlation among them.
(2) The quality of the model for computation of the limit state function under question.
(3) The method for the reliability assessment, e.g. for the estimation of the theoretical failure probability (or reliability index or other measure of reliability).

The last item may be determined by several methods which are based on numerical integration and simulation.

Previously, the analysis and design of offshore structures have not considered reliability concept into consideration. Instead, a deterministic method of considering maximum loads and minimum resistances has been used. Recently, many studies took the reliability theory into account for the structural analysis and design of the offshore structures. Carl Andreas Holm, Peter Bjerager and Henrik O. Madsen [1] studied long-term system reliability of an offshore jacket structure. The extreme wave load was modeled in a realistic way as a function of the number of sea states. Sensitivity analysis with respect to various input parameters had been carried out for the structure. The analysis showed that the structure is sensitive with respect to the wave position. The worst case appeared when the wave crest is near the middle of the structure. Changes in the wave direction and the wave period showed that the reliability was almost independent of these two parameters.

Sigurdsson, G [9] examined the probabilistic fatigue of offshore structures. In this study stochastic reliability assessment for jacket type offshore structure subjected to wave loads in deep water environments was outlined. To estimate statistical measures of structural stress variations, the model spectral analysis method was applied. The reliability value was estimated using a first-order reliability method. Failure modes corresponding to fatigue failure were used. Different methods were used to estimate the distribution function of the stress amplitudes.

GENERATION OF STATISTICALLY CORRELATED RANDOM NUMBERS [3],[4]

The simulation problem is more complex if the random variables are statistically correlated. Consider the problem of generation of m sets of statistically correlated random numbers corresponding to n normally distributed random variables with the mean vector

$$\{ \bar{X} \} = \begin{bmatrix} \bar{X}_1 \\ \bar{X}_2 \\ . \\ . \\ \bar{X}_n \end{bmatrix}$$

and the covariance matrix

$$[S_x] = \begin{bmatrix} V[X_1] & C[X_1,X_2] & \ldots\ldots & C[X_1,X_n] \\ C[X_2,X_1] & V[X_2] & \ldots\ldots & C[X_2,X_n] \\ . & . & \ldots\ldots & . \\ . & . & \ldots\ldots & . \\ C[X_n,X_1] & C[X_n,X_2] & \ldots\ldots & V[X_n] \end{bmatrix}$$

Assume that one desires to generate m random numbers for each random variable. The jth generated random number for the ith random variable is denoted

$$^{(j)}X_i \; ; \; j=1,2,\ldots\ldots,m \text{ and } i=1,2,\ldots\ldots,n$$

The random number generation process involves first generating n sets of statistically independent normally distributed random numbers for which to be specified mean vector and covariance matrix. These random numbers are denoted

$$^{(j)}Y_i \; ; \; j=1,2,\ldots\ldots,m \text{ and } i=1,2,\ldots\ldots,n$$

A linear transformation is then defined, which couples the Y random variables in such a way as to form the correlated X random variables. That is,

$$^{(j)}X_i = \sum_{k=1}^{n} C_{ik} \, ^{(j)}Y_k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$= C_{i1} \, ^{(j)}Y_1 + C_{i2} \, ^{(j)}Y_2 + \ldots\ldots + C_{in} \, ^{(j)}Y_n$$

$$; \; j=1,2,\ldots,m \text{ and } i=1,2,\ldots,n$$

or alternately

$$\underset{(m\times 1)}{\{{}^{(j)}X\}} = \underset{(m\times m)}{[C]} \cdot \underset{(m\times 1)}{\{{}^{(j)}y\}} \quad \ldots\ldots (2)$$

If two sets of random variables are related by a linear transformation , i.e.,

$$\{X\} = [C]\ \{Y\} \quad \ldots\ldots (3)$$

then,

$$\{\bar{X}\} = [C]\ \{\bar{Y}\} \quad \ldots\ldots (4)$$

and

$$[S_x] = [C]\ [S_y]\ [C]^T \quad \ldots\ldots (5)$$

where

$\{\bar{X}\}, \{\bar{Y}\}$ = mean vectors

$[S_x]$, $[S_y]$ = covariance matrices

Note that $\{\bar{X}\}$ and $[S_x]$ are known and one must find $[C]$, $\{\bar{Y}\}$ and $[S_y]$.

The Choleski decomposition method is useful in several areas of structural mechanics. It states that a symmetric matrix of order nxn denoted [A], can be decomposed into the matrix product

$$[A] = [V]\ [D]\ [V]^T \quad \ldots\ldots (6)$$

[V] is a lower triangular matrix of order nxn with ones on the principal diagonal, and [D] is a diagonal matrix of order n. The elements of these matrices are

$$D_{11} = A_{11} \quad \ldots\ldots (7)$$

$$V_{ii} = 1 \qquad ; i=1,2,\ldots,n \quad \ldots\ldots (8)$$

$$V_{j1} = A_{1j}/D_{11} \qquad ; j\geq 2 \quad \ldots\ldots (9)$$

$$D_{ii} = A_{ii} - \sum_{l=1}^{i-1} V^2_{li}\, D_{ll} \quad ; i\geq 2 \quad \ldots\ldots (10)$$

$$V_{ji} = \frac{1}{D_{ii}} \left[A_{ij} - \sum_{l=1}^{i-1} V_{li}\, V_{jl}\, D_{ll} \right] \quad ; \begin{array}{l} j>2 \\ j\geq i+1 \end{array} \quad \ldots\ldots (11)$$

It can be seen that

$[A] = [S_x]$

$[C] = [V]$ (lower triangular matrix)

$[S_y] = [D]$ (diagonal matrix)

and therefore the appropriate linear transformation matrix, [C], and covariance matrix, $[S_y]$ are now defined. The diagonal covariance matrix implies independence of the Y random variables, therefore:

$$\{Y\} = \{\bar{Y}\} + [S_Y]^{1/2} \cdot \{h\} \quad \text{.....(12)}$$

where, $\{h\}$ is a vector of normally distributed random numbers.

From Equations (3) and (4), one gets

$$\{Y\} = [C]^{-1} \cdot \{X\} \quad \text{.....(13)}$$

and

$$\{\bar{Y}\} = [C]^{-1} \cdot \{\bar{X}\} \quad \text{.....(14)}$$

by substituting $\{Y\}$ and $\{\bar{Y}\}$ in Equation (12), therefore,

$$[C]^{-1} \{X\} = [C]^{-1} \cdot \{\bar{X}\} + [S_Y]^{1/2} \cdot \{h\}$$

$$\{X\} = \{\bar{X}\} + [C] \cdot [S_Y]^{1/2} \cdot \{h\} \quad \text{.....(15)}$$

The $\{X\}$ random variables are normally distributed because they are obtained by a linear transformation of a set of normal random values.

OFFSHORE JACKET STRUCTURE

The reliability analysis of the offshore jacket structure is carried out using limit state functions and Monte-Carlo simulation method which are described in [6].The correlation between the applied loads, especially nodal wave loads, is taken into consideration. The correlated random values are generated as explained previously then the reliability measures are obtained. In this study the values of all random variables such as yield stress, wind loads, deck loads and wave loads are generated using normal probability distribution function. A computer program was written especially for this study.

The treated structure is a steel jacket offshore platform consisting of 16 joints and 48 members. The structure and its geometry are shown in " Fig. 1 ". All structural elements are tubular elements made of steel with modulus of elasticity, E = 2100 t/cm² and density, = 7800 Kg/m³. The unit weight of the interior of the members is 250 Kg/m³, this includes gravity loads from internal stiffeners. The dimensions and the geometry of the structure are assumed to be deterministic. The dimensions of the members cross sections are given in " Table 1 ". The yield stress of each member is assumed to be an independent random variable with a mean value of 3600 Kg/cm² and coefficient of variation 10% [5].

Dead and live loads from the deck structure are modeled by four vertical loads acting at the four top level nodes. Each force is a random variable with a mean value 500 t, and a coefficient of variation 10%. The four fórces are equi-correlated with a correlation coefficient 0.5 [1].

Gravity loads of the structure itself are referred to nodes as concentrated deterministic forces. Buoyancy loads are assumed also to be deterministic. Selfweights and buoyancy loads are added to the random nodal forces.

Wind load on the deck structure is modeled by horizontal and vertical forces at each of the four top level nodes. These forces are perfectly correlated random variables with coefficients of variation of 30% [1]. " Fig. 2 " shows the mean values of wind forces for wind acting in X-direction and in a direction of 45 degrees with one side of the truss structure. Wind load on the jacket structure itself is neglected.

The wave loads are modeled as random lateral nodal forces with a spatial correlation between them. " Fig. 3 " shows the mean values of the nodal wave forces for wave acting in X-direction and in a direction of 45 degrees with one side of the structure.

The Spatial Correlation of Nodal Wave Forces

The spatial distribution of correlations between the nodal wave forces is modeled using the following analytical form,[7].

$$\rho_{ij} = \rho_o + (0.999 - \rho_o)\left[\exp\left\{-\left[\frac{X_i - X_j}{r_x}\right]^2 - \left[\frac{Y_i - Y_j}{r_y}\right]^2 - \left[\frac{Z_i - Z_j}{r_z}\right]^2\right\}\right] \quad \ldots.(16)$$

Where, ρ_{ij} : Correlation between X - direction lateral nodal wave forces at node # $i(X_i, Y_i, Z_i)$ and node # $j(X_j, Y_j, Z_j)$.

ρ_o : base level correlation arising from the fact that all nodal wave forces arise from the same wave characterized by its height and period.

r_x, r_y, r_z : correlation lengths in X,Y and Z directions respectively.

" Table 2 " represents samples of correlation values generated by using Equation (16). The correlation lengths are equal to one meter for sharp variations. For gradual correlation variations of nodal wave forces, the correlation lengths are selected to be proportional to the dimension of the structure for each direction,(see " Table 2 ").

It was assumed that each of those lateral nodal wave forces has the same coefficient of variation. It was assumed also that the wave nodal forces in X and Y directions at each node, i, are fully correlated and hence were characterized through a single random variable equal to F_i,

which is the nodal wave force acting at node,i in the X-direction.

In the parametric study carried out in the present study, the approach was to vary the correlation structure while adjusting the coefficient of variation of the nodal wave forces in order to keep the coefficient of variation of the base shear to be constant. The base shear, F, in the X-direction is the sum of the nodal wave forces in the same direction [7]; i.e :

$$F = \sum_i F_i \quad \text{.....(17)}$$

then, $$E[F] = \sum_i E[F_i] \quad \text{.....(18)}$$

and $$V[F] = \sum_i V[F_i] + \sum_{i \neq j} \sum \rho_{ij} \sqrt{V[F_i]} \sqrt{V[F_j]} \quad \text{.....(19)}$$

To maintain the same coefficient of variation of the base shear, $\delta_B = \sqrt{V[F]}/E[F]$, the coefficient of variation of individual nodal wave forces in X-direction, $\delta = \sqrt{V[F_i]}/E[F_i]$, can be calculated according to the following expression:

$$\delta = \delta_B \frac{\sum_i E[F_i]}{\sqrt{\sum_{i \neq j} \sum \rho_{ij} E[F_i] E[F_j] + \sum_i (E[F_i])^2}} \quad \text{.....(20)}$$

In the present study the coefficient of variation of base shear, δ_B, is assumed equal to 40% [7].

Results of the study

The reliability analysis was carried out for two different wave directions, wave acting in X-direction and in a direction of 45 degrees with X-axis. The wind load is considered in the same direction of the wave. For the wave acting in X-direction, the effects of the spatial correlation variation are studied in the all three directions (X,Y and Z). The effects of the correlation variation in X and Y-directions are studied for the diagonal wave.

The results of the system reliability analysis are presented in terms of reliability and reliability index of the entire structure. Also the reliability measures of the individual members are presented for case of equi-correlated nodal wave forces. The coefficients of variation of the nodal wave forces are presented for all cases.

" Table 3 " summarizes results from system reliability analysis with parametric variations in ρ_o, r_x, r_y and r_z for wave acting in X-direction. All cases in set A, cases A.1 through A.7, describe results if the nodal wave forces are equi-correlated . The correlation coefficients between X-direction lateral nodal wave forces at any two nodes i and j, ρ_{ij}, are equal to the base level correlation, ρ_o. Case A.1 represents the base case where all the nodal wave forces are perfectly correlated , and consequently individual nodal wave forces have the same coefficient of variation of the base shear. This is the case against which the effects of modeling the correlation are compared. Case A.7 represents the case of the other extreme when the nodal wave forces are independent. The distributions of safety margin of the whole structure, for different correlation coefficients ,are shown in " Fig. 4 ".

Cases B.I.1 through B.II.4 represent correlation variation of nodal wave forces with only vertical Z-direction separation between nodes. Cases B.I.1 through B.I.4 represent the case when the variation is sharp, whereas cases B.II.1 through B.II.4 represent cases with gradual variation in correlation level. The gradual variation with Z-direction separation of the nodes is considered for correlation length r_z = 60m.

In cases C.I.1 through C.II.4 correlation levels vary only with X-direction (the direction of wave travel). The variation is sharp in cases C.I.1 through C.I.4, and gradual in cases C.II.1 through C.II.4 for correlation length r_x = 30 m.

Cases D.I.1 through D.II.4 represent correlation variation in Y-direction (orthogonal to the direction of the wave travel) only. The variation is sharp in cases D.I.1 through D.I.4 , and gradual in cases D.II.1 through D.II.4 for correlation length r_y = 30 m.

In cases E.I.1 through E.II.4 correlation levels vary with both X and Y-directions separation distance of the nodes. The variation is sharp in cases E.I.1 through E.I.4 , and gradual in cases E.II.1 through E.II.4 for correlation lengths r_x = r_y = 40 m.

In cases A.1 through A.7 and cases F.I.1 through F.I.4 ,"Table 3 ", correlation between nodal wave forces were allowed to vary with all three directional separations between nodes (X , Y and Z). The variation is gradual in cases F.I.1 through F.I.4 for correlation lengths r_x = r_y = r_z = 70 m., and sharp in cases A.1 through A.7.

For the wave acting in a direction 45 degrees with X-axis " Table 4 " summarizes results from system reliability analysis for the correlation variation in X and Y

directions. Cases G.I.1 through G.II.4 represent correlation variation of nodal wave forces only with X directional separation between nodes. Cases G.I.1 through G.I.4 represent the case when the variation is sharp, whereas cases G.II.1 through G.II.4 represent the case when the variation is gradual. The gradual variation is considered for correlation length r_x = 30 m .

For cases L.I.1 through L.II.4 correlation levels vary with both X and Y direction separation distances of the nodes. The variation is sharp in cases L.I.1 through L.I.4, and gradual in cases L.II.1 through L.II.4 for correlation lengths $r_x = r_y$ = 40 m.

For the wave acting in X-direction," Figs. 5-a and 5-b " show a comparison between the different patterns of the spatial correlation for both gradual and sharp variation respectively.

For the wave acting in a direction of 45 degrees with X-axis," Figs. 6-a and 6-b " show the reliability values of different correlation variation patterns in X and Y directions for both the gradual and sharp variation respectively.

"Tables 5 and 6 " show the reliability measures and the statistical properties of the internal members forces, for only two selected members 14 and 26 respectively. Members 14 and 26 are selected to study two different types of members, vertical and diagonal members respectively. For member 14, the values of reliability are greater than 0.9995 so that these values can't be accurately determined, because the accuracy of the used reliability analysis method is 0.0005.

CONCLUSIONS

According to the limits and conditions considered in this study,the following conclusions can be pointed out.

1- With the reduction in the correlation between the equi-correlated nodal wave forces, the reliability measures of both element and system are decreased. This is because the reduction in the correlation increases the coefficient of variation of the members internal forces.
2- The coefficient of variation of the equi-correlated nodal wave forces is decreased with the increase in the base level correlation. This is because the base shear coefficient of variation is kept constant.
3- The reliability measures in the cases of sharp correlation variation are usually smaller than that of gradual variation, especially for low base level correlation. In the sharp variation, the correlation between the nodal wave force are decreased very rapidly to the base level correlation. This explains why the

sharp variation of the spatial correlation is more critical than the gradual variation.

4- For the wave acting in X-direction, the correlation variation in the direction orthogonal to the wave travel (Y-direction) gives the smallest reliability measures while the variation in the direction of the wave travel (X-direction) gives the biggest reliability values. This is because the correlation variation in Y-direction increases the difference between the nodal wave forces separated in the direction perpendicular to the wave forces; this leads to an increase in the torsional moment on the structure about Z-axis, which is the most critical case of loading.

5- For the wave acting in a direction of 45 degrees with X-axis, the reliability measures for different correlation variation patterns in X and Y directions are affected significantly, because the correlations are decreased with the direction orthogonal to the wave forces. Also the reliability measures are relatively close because the diagonal wave forces have equal components in both X and Y directions.

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Table (1) Cross sectional data for structural elements.

Element No.	Diameter (m)	Thickness (cm)
1 to 4	2.00	3.40
5 to 8	1.50	2.60
9 to 12	1.00	1.80
13 to 24	2.50	4.20
25 to 32	1.50	2.60
33 to 48	1.20	2.00

Table (2) Sample correlations generated by Equation (1).

Node # i	Node # j	| Xi-Xj | (m)	| Yi-Yj | (m)	| Zi-Zj | (m)	rx (m)	ry (m)	rz (m)	ρ_{ij} ρ_c=0.2	ρ_c=0.4	ρ_c=0.6
5	7	31.860	31.860	–	1000	1000	60	0.997	0.998	0.998
5	9	3.256	3.256	28	1000	1000	60	0.843	0.882	0.921
5	13	5.930	5.930	51	1000	1000	60	0.588	0.691	0.794
5	7	31.860	31.860	–	1000	1000	1	0.997	0.998	0.998
5	9	3.256	3.256	28	1000	1000	1	0.200	0.400	0.600
9	12	–	20.000	–	30	1000	1000	0.999	0.999	0.999
9	5	3.256	3.256	28	30	1000	1000	0.989	0.992	0.994
9	10	25.348	–	–	30	1000	1000	0.591	0.693	0.795
9	12	–	20.000	–	1	1000	1000	0.999	0.999	0.999
9	5	3.256	3.256	28	1	1000	1000	0.200	0.400	0.600
9	13	2.674	2.674	23	40	40	1000	0.992	0.994	0.995
9	10	25.348	–	–	40	40	1000	0.735	0.801	0.867
9	11	25.348	25.348	–	40	40	1000	0.558	0.668	0.779
9	13	2.674	2.674	23	1	1	1000	0.200	0.400	0.600
5	9	3.256	3.256	28	70	70	70	0.878	0.908	0.939
5	11	28.604	28.604	28	70	70	70	0.688	0.766	0.843
5	15	25.930	25.930	51	70	70	70	0.557	0.668	0.778
5	9	3.256	3.256	28	1	1	1	0.200	0.400	0.600

Table (3) Summary of system reliability analysis with parametric variation in spatial correlation between nodal wave forces, for wave acting in X-direction.

Case #	ρ_c	rx (m)	ry (m)	rz (m)	Nodal force C.O.V. δ	Reliability	Reliability index
A.1	1	1	1	1	0.4000	0.9680	1.9356
A.2	0.9	1	1	1	0.4192	0.9605	1.7950
A.3	0.6	1	1	1	0.4992	0.9395	1.5468
A.4	0.4	1	1	1	0.5877	0.9055	1.3523
A.5	0.2	1	1	1	0.7502	0.8510	1.0455
A.6	0.1	1	1	1	0.9062	0.7855	0.7884
A.7	0	1	1	1	1.2317	0.6435	0.3444
F.1	0.9	70	70	70	0.4049	0.9615	1.8486
F.2	0.6	70	70	70	0.4201	0.9575	1.7238
F.3	0.4	70	70	70	0.4313	0.9495	1.6599
F.4	0.2	70	70	70	0.4435	0.9425	1.6005
B.I.1	0.9	1000	1000	1	0.4122	0.9650	1.8513
B.I.2	0.6	1000	1000	1	0.4564	0.9540	1.7186
B.I.3	0.4	1000	1000	1	0.4952	0.9430	1.6324
B.I.4	0.2	1000	1000	1	0.5461	0.9365	1.5335
B.II.1	0.9	1000	1000	60	0.4029	0.9670	1.8981
B.II.2	0.6	1000	1000	60	0.4115	0.9630	1.8391
B.II.3	0.4	1000	1000	60	0.4175	0.9625	1.8087
B.II.4	0.2	1000	1000	60	0.4238	0.9615	1.7810
C.I.1	0.9	1	1000	1000	0.4168	0.9645	1.8674
C.I.2	0.6	1	1000	1000	0.4836	0.9580	1.7598
C.I.3	0.4	1	1000	1000	0.5514	0.9510	1.6805
C.I.4	0.2	1	1000	1000	0.6590	0.9375	1.5679
C.II.1	0.9	30	1000	1000	0.4061	0.9670	1.9257
C.II.2	0.6	30	1000	1000	0.4258	0.9645	1.9067
C.II.3	0.4	30	1000	1000	0.4406	0.9640	1.8950
C.II.4	0.2	30	1000	1000	0.4571	0.9640	1.8828

Table (3) (... Continue)

Case #	ρ_c	rx (m)	ry (m)	rz (m)	Nodal force C.O.V. δ	Reliability	Reliability index
D.I.1	0.9	1000	1	1000	0.4168	0.9560	1.7242
D.I.2	0.6	1000	1	1000	0.4836	0.9185	1.3840
D.I.3	0.4	1000	1	1000	0.5514	0.8705	1.1468
D.I.4	0.2	1000	1	1000	0.6590	0.8015	0.8412
D.II.1	0.9	1000	30	1000	0.4061	0.9560	1.7895
D.II.2	0.6	1000	30	1000	0.4258	0.9410	1.6038
D.II.3	0.4	1000	30	1000	0.4406	0.9275	1.5049
D.II.4	0.2	1000	30	1000	0.4571	0.9195	1.4102
E.I.1	0.9	1	1	1000	0.4192	0.9605	1.7950
E.I.2	0.6	1	1	1000	0.4992	0.9395	1.5468
E.I.3	0.4	1	1	1000	0.5877	0.9055	1.3523
E.I.4	0.2	1	1	1000	0.7502	0.8510	1.0455
E.II.1	0.9	40	40	1000	0.4073	0.9600	1.8318
E.II.2	0.6	40	40	1000	0.4315	0.9510	1.6935
E.II.3	0.4	40	40	1000	0.4502	0.9455	1.6178
E.II.4	0.2	40	40	1000	0.4717	0.9355	1.5437

Table (4) Summary of system reliability analysis with parametric variation in spatial correlation between nodal wave forces, for wave acting in diagonal direction.

Case #	ρ_c	rx (m)	ry (m)	rz (m)	Nodal force C.O.V. δ	Reliability	Reliability index
G.I.1	0.9	1	1000	1000	0.4168	0.8415	1.0285
G.I.2	0.6	1	1000	1000	0.4836	0.8200	0.9385
G.I.3	0.4	1	1000	1000	0.5514	0.7920	0.8421
G.I.4	0.2	1	1000	1000	0.6590	0.7565	0.6913
G.II.1	0.9	30	1000	1000	0.4061	0.8390	1.0346
G.II.2	0.6	30	1000	1000	0.4258	0.8250	0.9719
G.II.3	0.4	30	1000	1000	0.4406	0.8170	0.9338
G.II.4	0.2	30	1000	1000	0.4571	0.8060	0.8945
L.I.1	0.9	1	1	1000	0.4192	0.8425	1.0310
L.I.2	0.6	1	1	1000	0.4992	0.8215	0.9468
L.I.3	0.4	1	1	1000	0.5877	0.7950	0.8433
L.I.4	0.2	1	1	1000	0.7502	0.7640	0.7040
L.II.1	0.9	40	40	1000	0.4073	0.8400	1.0274
L.II.2	0.6	40	40	1000	0.4315	0.8220	0.9544
L.II.3	0.4	40	40	1000	0.4502	0.8155	0.9116
L.II.4	0.2	40	40	1000	0.4717	0.8010	0.8686

Table (5) Reliability analysis of member (14) for different correlations between equicorrelated nodal wave forces

Case #	Correlation coef., ρ	Mean force (t)	C.O.V.	Reliability	Reliability Index	CFS
A.1	1.00	-2695.22	0.328	*	8.8138	4.0711
A.2	0.90	-2700.13	0.332	*	8.6816	4.0611
A.3	0.60	-2705.44	0.343	*	8.4063	4.0502
A.4	0.40	-2708.43	0.356	*	8.1131	4.0440
A.5	0.20	-2712.40	0.384	*	7.5503	4.0352
A.6	0.10	-2715.71	0.416	*	7.0159	4.0266
A.7	0.00	-2721.92	0.491	*	6.0633	3.9980

* 1.0 > Reliability > 0.9995

- Deterministic internal force = -2690.559 t.

Table (6) Reliability analysis of member (26) for different correlations between equicorrelated nodal wave forces

Case #	Correlation coef., ρ	Mean force (t)	C.O.V.	Reliability	Reliability index	CFS
A.1	1	-1524.57	0.387	0.9705	1.9587	1.7551
A.2	0.9	-1526.47	0.392	0.9680	1.9285	1.7524
A.3	0.6	-1527.94	0.406	0.9690	1.8687	1.7491
A.4	0.4	-1528.29	0.421	0.9620	1.8046	1.7471
A.5	0.2	-1528.39	0.455	0.9480	1.6754	1.7450
A.6	0.1	-1528.42	0.492	0.9390	1.5578	1.7404
A.7	0	-1528.50	0.579	0.9055	1.3444	1.7222

- Deterministic internal force = -1522.782 t.

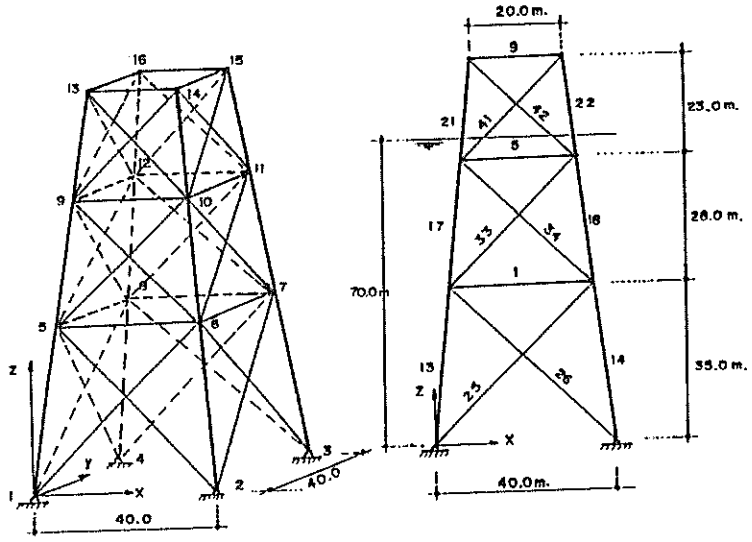


Fig. (1) Steel jacket offshore structure.

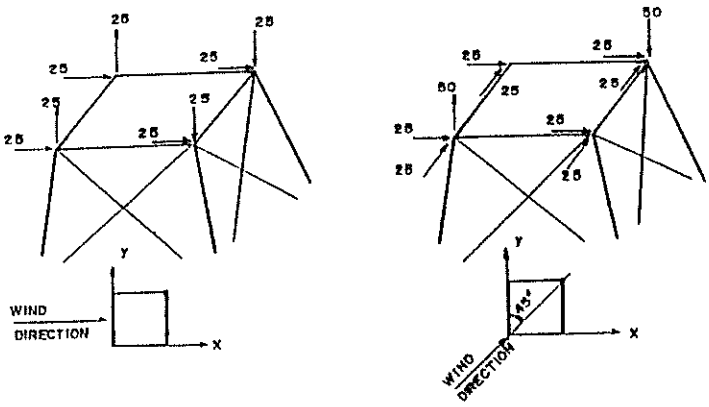


Fig. (2) Wind loads on the deck structure (in tons).

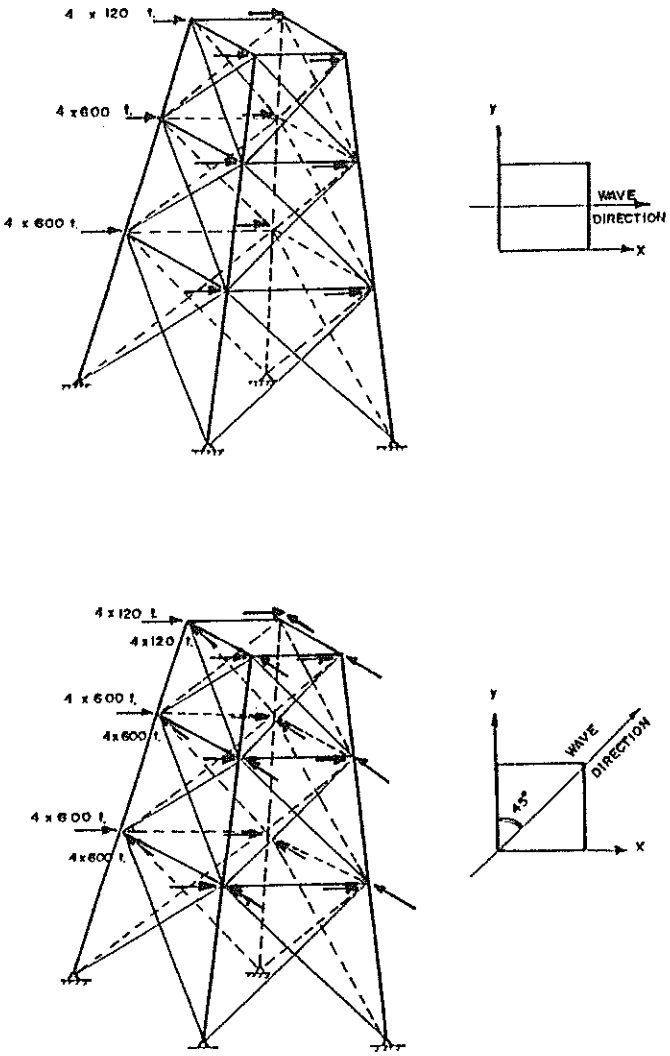


Fig. (3) Nodal wave forces on the jacket structure.

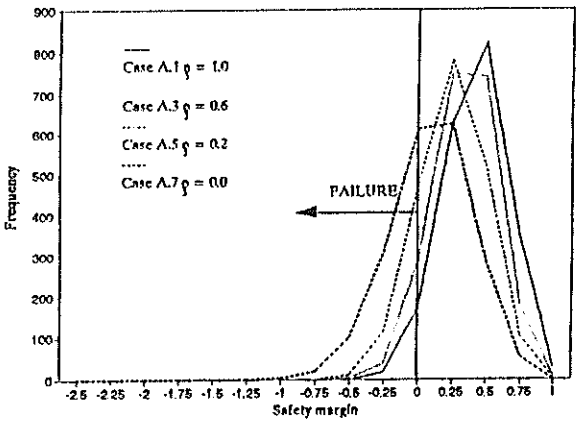
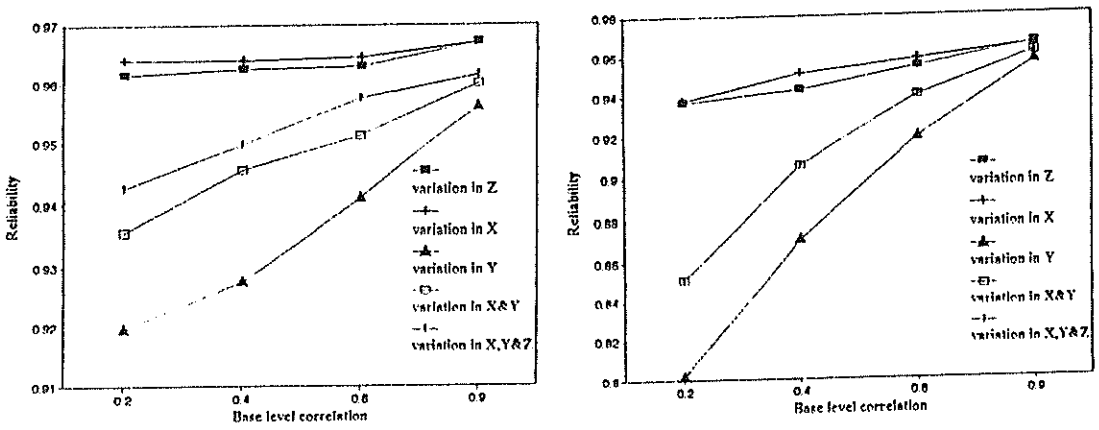
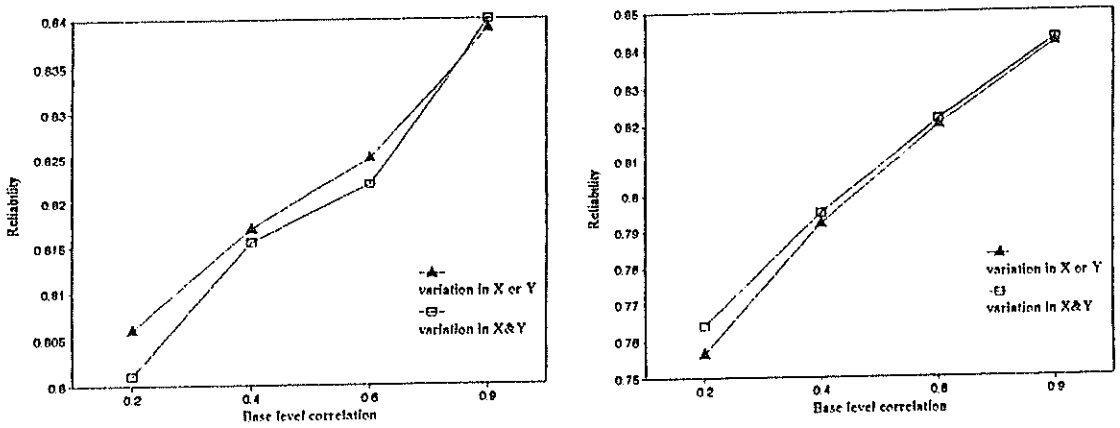


Fig. (4) Distributions of safety margin for different correlations between equicorrelated nodal wave forces.



(a) Gradual variations. (b) Sharp variations.

Fig. (5) Reliability for different variations of the spatial correlation between nodal wave forces (wave acting in X-direction).



(a) Gradual variations. (b) Sharp variations.

Fig. (6) Reliability for different variations of the spatial correlation between nodal wave forces (wave acting in diagonal direction).