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Multivariate Risk Assessment for Offshore Jacket Platforms by Gaidai Reliability Method

Oleg Gaidai[1], Yu Cao[1], Yan Zhu[2], Fuxi Zhang[1] and Hongchen Li[1]

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Abstract
Novel structural reliability methodology presented in this study being especially well-suited for multi-dimensional structural dynamics, being physically measured, or numerically simulated over a representative timelapse. Gaidai multivariate reliability method has been applied to the operational offshore Jacket platform, operating in Bohai Bay. This study demonstrates that it is feasible to accurtely estimate dynamic system collapse risks under in situ environmental stressors. Modern reliability methods do not cope easily with high dimensionality of real engineering dynamic systems along with nonlinear inter-correlations between various structural components. Jacket offshore platform has been selected as the case study for this reliability analysis because of the variety of hotspot stresses, synchronously arising in several structural parts. The authors provided straightforward, precise method for estimating overall risks of operational failure, damage, or hazard for nonlinear multidimensional dynamic systems. When it comes to a design stage, the latter tool is of crucial importance for offshore engineers.

Keywords Monte Carlo simulation; System reliability; Jacket offshore structure; Bohai bay; Energy.

Article Highlights

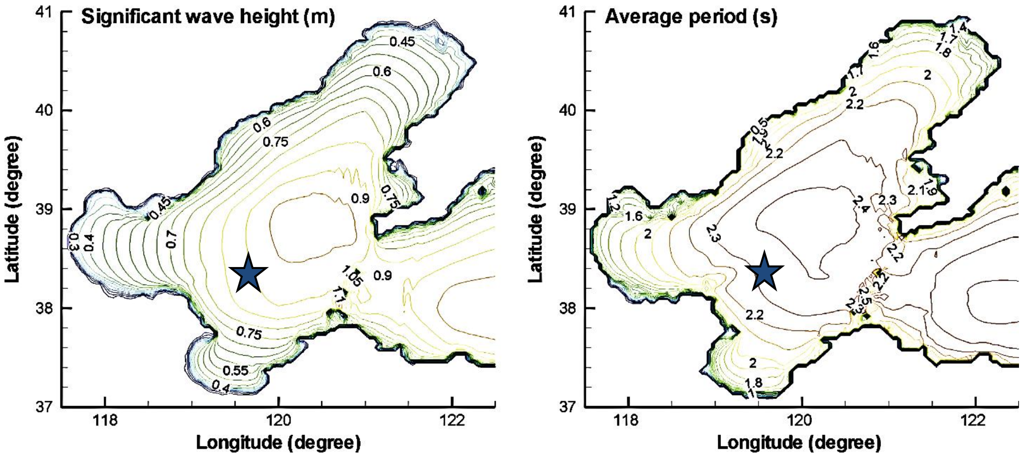
- State of the art multivariate Gaidai reliability methodology applied to 4D (4-dimensional) dynamic system, consisting of Jacket hot-spot stresses
- Structural system's reliability assessed, confidence bands given
- Generic nature of advocated methodology discussed

1 Introduction

This study investigates offshore Jacket platform responses to drag-dominated hydrodynamic forces, acting on its support structure. Operating WHPB (Well Head Platform B) Jacket platform, located 50 kilometers offshore in the Bohai Bay BZ25-1 oilfield, was chosen for this study. Bohai Bay is the only China's inner sea, and in recent years it attracted significant industrial and research interests, due to increase in scientific and economic activities, notably within ocean renewable energy, marine engineering, and offshore (oil and gas) industry. In situ environmental parameters at the Bohai Sea are the primary input for both offshore structural and reliability studies, [1], [2] for Bohai bay operational venue were processed according to DNV (Det Norske Veritas) offshore engineering standards, [3], [4]. Using traditional engineering reliability methodologies to predict multi-dimensional structural system's reliability and risks being often challenging, [6]-[8]. Challenges arise not only from a high number of system's degrees of freedom, but also due to nonlinear cross-correlations between critical/key system components. Direct numerical MC (Monte Carlo) simulations, or adequate measurements may be used to determine reliability-based design parameters for complex nonlinear structural systems, [9], [10], but often those datasets being quite limited. For other contemporary approaches to system's reliability study, see [11], [12]. Hence, for many nonlinear highly-dimensional engineering nonlinear dynamic systems, experimental and computational methods often may not present an affordable way of assessing structural risks, especially with long return periods, as being required by contemporary design. Novel Gaidai reliability methodology advocated here, being especially suitable for complex nonlinear structural systems, and it utilizes available dataset in a quite efficient way, thus reducing efforts, associated with either measurements, or numerical calculations. This study investigates structural stresses of offshore Jacket's support structure, monitored simultaneously in various critical/hotspot locations, given realistic in situ environmental loads; no model simplifications or linearization of nonlinear effects has been required.

✉ Yu Cao
y_cao@shou.edu.cn

1 Shanghai Ocean University, Shanghai, China
2 Jiangsu University of Science and Technology, Zhenjiang, China



(a) Significant wave-heights (b) Average wave-periods

Figure 1 Wave-height and wave-period geographical contours in Bohai Bay, on annual basis [1]; star marks Jacket platform location

Figure **1** presents location for Jacket platform in the Bohai Sea area, along with environmental wave height/period contour lines.

Figure 2 Example of offshore Jacket platform

Figure 2 illustrates Jacket platform, that is comparable to the Jacket studied here. Figure 3 shows the long-term MC statistical/reliability analysis flowchart.

Figure 3 Flowchart for long-term environmental statistical/reliability analysis

In contrast to univariate/bivariate statistical approaches, the multi-variate strategy, able to account for stresses at several crucial Jacket support locations, accounts for intrinsic stress dependence/coupling. The latter being obviously important feature for offshore engineers, particularly during the design phase. To summarize key contributions of this study:

- Realistic offshore engineering installation has been studied, using novel system reliability methodology;
- Structural damage risks have been assessed, using a multi-state spatiotemporal assessment model;
- CIs for estimated return periods of interest have been provided.

To put current study into historical perspective, following chronology may be referred to:

1987-System Reliability of Offshore Jacket Structures by Ideal Plastic Analysis
1990-Wave Loading Effect In Offshore Structural Reliability
1998-A reliability-based design format for jacket platforms under wave loads
2003-System reliability of jack-up structures based on fatigue degradation
2009-Reliability-Based Earthquake Design of Jacket-Type Offshore Platforms Considering Pile-Soil-Structure Interaction
2011-System failure probability of offshore jack-up platforms in the combination of fatigue and fracture
2012-Structural reliability of offshore platforms considering fatigue damage and different failure scenarios
2014-Seismic Reliability of a Fixed Offshore Platform Against Collapse
2018-Probabilistic Seismic Collapse Analysis of Jacket Offshore Platforms, [12], [14].

For alternative probabilistic design approaches, used for offshore platforms along with their structural elements, see e.g., [15]-[21]. Estimating multivariate design failure/damage probability/risk often being challenging in complex engineering contexts, [22], [23].

2 Gaidai reliability method

Considering piecewise jointly-stationary, MDOF (Multiple Degrees of Freedom) dynamic system, having key/critical components $X(t),\ Y(t),\ Z(t), \ldots$ being parts of the system's dynamic MDOF time-record $(X(t),\ Y(t),\ Z(t),\ \ldots)$, observed/recorded/measured over sufficient (representative) timelapse $(0,T)$. 1D system key/critical component's global maxima being denoted here as $X_T^{\max} = \max_{0\le t\le T} X(t)$, $Y_T^{\max} = \max_{0\le t\le T} Y(t)$, $Z_T^{\max} = \max_{0\le t\le T} Z(t), \ldots$ for the whole timelapse $(0,T)$. By suitably long (representative) timelapse T, one essentially means large enough value of T with respect to dynamic system's auto-correlation, and relaxation times. Let $X_1, \ldots, X_{N_X}$ be dynamic system key component's local maxima of the component process $X(t)$ at discrete instants of time-instants, temporally increasing, $t_1^X < \ldots < t_{N_X}^X$ within $(0,T)$. Definitions for remaining MDOF dynamic system's key components, $Y(t),\ Z(t), \ldots$ with $Y_1, \ldots, Y_{N_Y};\ Z_1, \ldots, Z_{N_Z}$ etc., being quite similar. For ease of use, it has been assumed that all dynamic system's key component's local maxima being non-negative. The goal is to accurately determine risks of Jacket dynamic system hazard/failure, or target dynamic system's hazard/failure risk/probability

$$P_F = \mathrm{Prob}(X_T^{\max} > \eta_X\ \cup\ Y_T^{\max} > \eta_Y\ \cup\ Z_T^{\max} > \eta_Z\ \cup\ \ldots) \tag{1}$$

related to target system's survival probability P, expressed as

$$P \equiv 1 - P_F = \iiint_{(0,\ 0,\ 0,\ ,\ldots)}^{(\eta_X,\ \eta_Y,\ \eta_Z,\ \ldots)} p_{X_T^{\max},\ Y_T^{\max},\ Z_T^{\max},\ \ldots}(x_T^{\max}, y_T^{\max}, z_T^{\max}, \ldots)\, dx_T^{\max} dy_T^{\max} dz_T^{\max} \ldots \tag{2}$$

being target dynamic system's probability of non-exceedance of all dynamic system's critical/key component's values η_X, η_Y, $\eta_Z, \ldots$ simultaneously; with $\cup$ standing for logical unity operation; and $p_{X_T^{\max},\ Y_T^{\max},\ Z_T^{\max},\ \ldots}$ being target joint PDF of key component's global maxima, over observational timelapse $(0,T)$. Next, MDOF dynamic system's vector $(X(t),\ Y(t),\ Z(t),\ \ldots)$ to be scaled to its nondimensional version: $(\widetilde{X}, \widetilde{Y}, \widetilde{Z}, \ldots)$, with $\widetilde{X} = \frac{X}{\eta_X}, \widetilde{Y} = \frac{Y}{\eta_Y}, \widetilde{Z} = \frac{Z}{\eta_Z}$. It is not practicable to directly assess the latter dynamic Jacket system's joint PDF (Probability Density Function), due to dynamic system's high-dimensionality, and given limitations of the underlying raw dataset. More specifically, dynamic system being considered to have failed/damaged, or entered into state of hazard, when either system's key components $X(t)$ exceeds η_X, or $Y(t)$ exceeds η_Y, or $Z(t)$ exceeds η_Z, etc., or, equivalently, when either $\widetilde{X}, \widetilde{Y}, \widetilde{Z}, \ldots$ eexceeds 1. Let one arrange system's key component's local maxima time-instants $[t_1^X < \ldots < t_{N_X}^X;\ t_1^Y < \ldots < t_{N_Y}^Y;\ t_1^Z < \ldots < t_{N_Z}^Z]$ into a single temporal merged system's vector, $t_1 \le \ldots \le t_N$, in a monotonously non-decreasing temporal order, with $t_N = \max\{t_{N_X}^X,\ t_{N_Y}^Y,\ t_{N_Z}^Z,\ \ldots\}$, $N \le N_X + N_Y + N_Z + \ldots$ Local maxima of each of MDOF dynamic system's load/response key components, namely $X(t)$ or $Y(t)$, or $Z(t)$, etc., being represented with their occurrence times t_j. System's 1D key components $(\widetilde{X}, \widetilde{Y}, \widetilde{Z}, \ldots)$ local maxima being combined/coalesced, coherent with merged/coalesced temporal vector $t_1 \le \ldots \le t_N$, forming temporally increasing synthetic nondimensional system's vector $\boldsymbol{R}(t) \equiv \vec{R} = (R_1, R_2, \ldots, R_N)$, with $R_j = \max\{(\widetilde{X}_j \mid \exists\, j_X, t_{j_X}^X = t_j),\ (\widetilde{Y}_j \mid \exists\, j_Y, t_{j_Y}^Y = t_j),\ (\widetilde{Z}_j \mid \exists\, j_Z, t_{j_Z}^Z = t_j), \ldots\}$ for $j = 1, \ldots, N$, see Red ellipse highlights case of simultaneous maxima for 2 different Jacket system's components.

Figure 4. Next, "scaling" parameter $0 < \lambda \le 1$ will be introduced, in order to artificially reduce hazard/limit/risk values for all system's nondimensionalized key components. System's survival probability $P(\lambda)$ being defined as smooth function of scaling parameter λ; with $P \equiv P(1)$ according to Eq. (1). In order to account for dependency between neighboring R_j, following memory approximation (conditioning level k) being implemented

$$\mathrm{Prob}\{R_j \le \lambda \mid R_{j-1} \le \lambda, \ldots, R_1 \le \lambda\} \approx \mathrm{Prob}\{R_j \le \lambda \mid R_{j-1} \le \lambda, \ldots, R_{j-k} \le \lambda\},\ j > k \tag{3}$$

By tracking each individual hazard/failure/risk event, that happened locally prior in time, the intention is now to prevent cascading/clustering FPSO system's inter-correlated exceedances. Since MDOF dynamic process $\boldsymbol{R}(t)$ has been considered to be piecewise ergodic, hence quasi-stationary, probability/risk $p_k(\lambda) := \mathrm{Prob}\{R_j > \lambda \mid R_{j-1} \le \lambda, \ldots, R_{j-k} \le \lambda\}$ for $j > k$ will be also independent of j and solely dependent on conditioning level k. As a result, non-exceedance (survival) probability may be approximately calculated, using Poisson assumption

$$P_k(\lambda) \approx \exp\,(-N \cdot p_k(\lambda))\ ,\ k \ge 1 \tag{4}$$

Note that Eq. (3) follows from Eq. (2) if neglecting $\mathrm{Prob}(R_1 \le \eta_1^{\lambda}) \approx 1$, as design failure/damage probability being of small order of magnitude, with $N \gg k$. It should be noted that Eq. (4) is comparable to a well-known MUR (Mean Up-crossing Rate) equation for the hazard/failure probability/risk (probability of exceedance). Regarding conditioning parameter k, convergence is present

$$P = \lim_{k\to\infty} P_k(1);\quad p(\lambda) = \lim_{k\to\infty} p_k(\lambda) \tag{5}$$

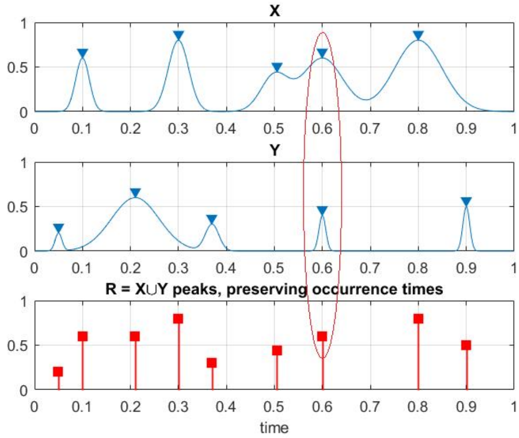
A well-known non-exceedance (survival) probability relationship with a matching MUR rate function results from Eq. (4) for $k = 1$, as can be shown

$$P(\lambda) \approx \exp\,(-\nu^+(\lambda)\,T);\quad \nu^+(\lambda) = \int_0^\infty \zeta p_{R\dot{R}}(\lambda,\zeta)d\zeta \tag{6}$$

with $\nu^+(\lambda)$ denoting MUR of the risk level λ for the above assembled non-dimensional vector $R(t)$, assembled from scaled MDOF FOWT system's critical/key components $\left(\frac{X}{\eta_X}, \frac{Y}{\eta_Y}, \frac{Z}{\eta_Z}, \ldots\right)$. Eq. (4) turning into well-known non-exceedance probability relationship with corresponding MUR (Mean Up-crossing Rate) function

$$P(\lambda) \approx \exp\,(-\nu^+(\lambda)\,T);\ \nu^+(\lambda) = \int_0^\infty \zeta p_{R\dot{R}}(\lambda,\zeta)d\zeta \tag{7}$$

with $\nu^+(\lambda)$ being MUR of dynamic response level λ for non-dimensional dynamic Jacket system's vector $R(t)$, introduced above. The Rice's formula, given by Eq. (7), yields MUR, with $p_{R\dot{R}}$ being the joint PDF for $(R, \dot{R})$, with $\dot{R}$ being time derivative $R'(t)$, [47]



Red ellipse highlights case of simultaneous maxima for 2 different Jacket system's components.

Figure 4 Illustration on how 2 exemplary processes X and Y being combined into 1 new synthetic vector $R(t)$

In the above, stationarity assumption has been used, [53], [54]. The proposed methodology may also treat wide range of non-stationary cases. The following is an example of how the suggested technique may be applied to handle non-stationary circumstances. Given in-situ scatter diagram, consisting of $m = 1, .., M$ environmental sea-states, each short-term environmental state having individual occurrence probabilities q_m, so that $\sum_{m=1}^{M} q_m = 1$. Corresponding long-term equation being

$$p_k(\lambda) \equiv \sum_{m=1}^{M} p_k(\lambda, m)\, q_m \qquad (8)$$

with $p_k(\lambda, m)$ being the same function as in Eq. (6), but corresponding to a specific short-term environmental state, indexed with number m. The above presented $p_k(\lambda)$ functions are often regular in their distribution tail, namely for extreme values of λ approaching 1. For $\lambda \geq \lambda_{\text{cut-on}}$, PDF tail behaves similar to $\exp\{-(a\lambda + b)^c + d\}$ with a, b, c, d being 4 fitted constants, matching appropriate PDF tail cut-on $\lambda_{\text{cut-on}}$ value. Optimal values of 4 parameters a, b, c, d may be determined, using SQP (Sequential Quadratic Programming) technique, implemented in NAG (Numerical Algorithm Group) library, [45]. Major advantage of suggested methodology, compared to traditional MC-based methods for MDOF offshore systems, is that will Gaidai reliability methodology is capable of reliability assessment of MDOF systems, with practically unlimited NDOF (Number of Degrees Of Freedom), see integral in Eq. (2), as hence it cannot be straightforwardly compared to classic reliability methods, typically covering only dynamic systems with NDOF≤ 2.

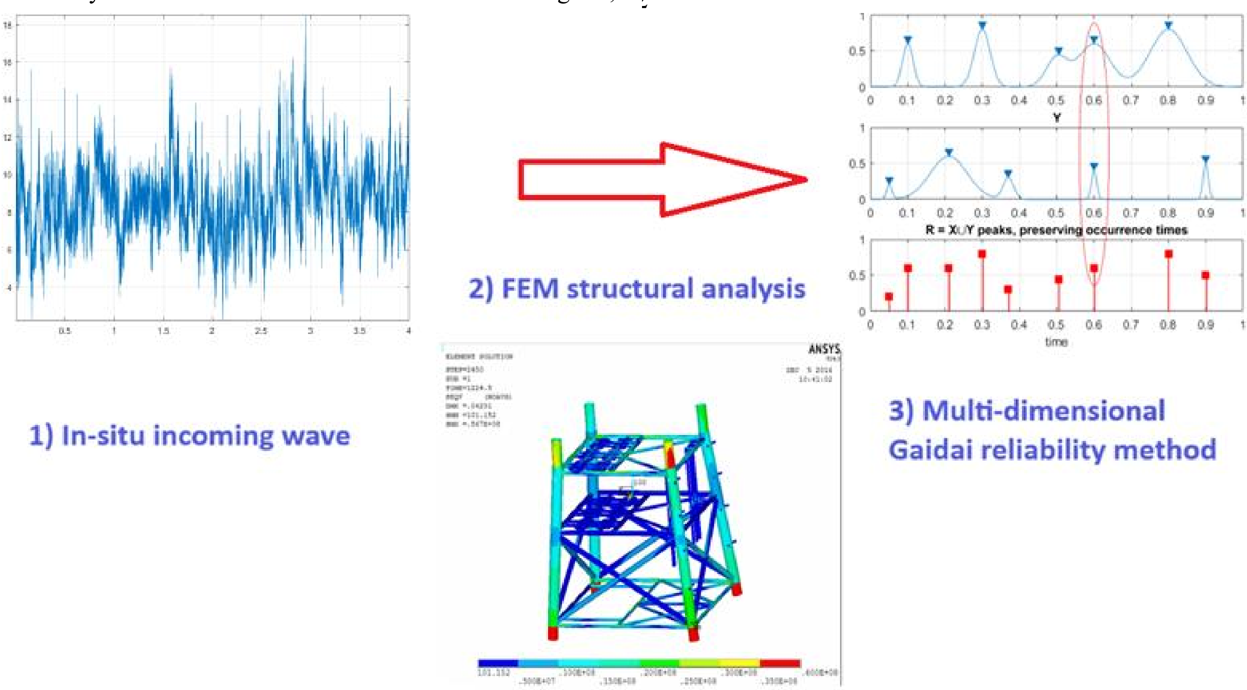


Figure 5 MDOF Jacket structural reliability approach

Figure 5 schematically illustrates suggested MDOF Jacket's structural reliability approach, basically consisting of 3 distinct steps: in-situ environmental input; structural dynamic analysis, including key hot-spot stress locations; application of the Gaidai multi-dimensional structural reliability method.

3 Environmental, structural, material models

Using ANSYS FEM (Finite Element Method) software, version 2022 R2 (22.2), Offshore Jacket platform has been modeled as a MDOF 4D structure, [34]. To create an accurate wave scatter map for the Bohai Bay region, satellite-based worldwide wave statistics has been employed. Global Wave Statistics Online, [43] dataset has been utilized. With the use of an in-place star, Figure **1** illustrates the geographical PDF of wave heights and wave periods for the Bohai Bay Jacket in situ zone.

Table 1 Bohai bay wind-waves in situ directional probabilities, [43].

Direction	Annual (%)
Northeast	14.9
East	11.1
Southeast	10.0
South	13.2
Southwest	7.7
West	8.2
Northwest	14.2
North	20.8

Table 1 presents presumed in situ directional probabilities of wind-waves in Bohai bay, averaged over 1 year. For each ambient sea condition, 3-hour stationary storm MC simulations have been performed. Sea/ocean state scatter diagram for the Bohai bay area was taken from [43], averaged for the whole year and per all directions. For each sea/ocean state (H_s, T_z), zero crossing period T_z was assumed to be approximately linearly related with the spectral peak wave period T_p, see DNV's rule [3]. One-sided wave elevation PSD (Power Spectral Density), provided by JONSWAP (Joint North Sea Wave Project) wave spectrum, has been used to specify stationary sea/ocean condition $\eta(t)$, with PSD denoted here by $S_\eta^+(\omega)$, $\omega > 0$

$$S_\eta^+(\omega) = \frac{\alpha g^2}{\omega^5} \exp\{-\frac{5}{4}(\frac{\omega_p}{\omega})^4 + \ln\gamma \exp[-\frac{1}{2\sigma^2}(\frac{\omega}{\omega_p} \tag{9}$$

with $g = 9.81$ m/s^2, ω_p is the peak frequency in rad/s; α, γ and σ are parameters related to the spectral shape; $\sigma = 0.07$ when $\omega \le \omega_p$, $\sigma = 0.09$ when $\omega > \omega_p$. For Bohai bay in situ parameter γ has been chosen to be equal 3.3, [2]. Parameter α has been determined from equation $\alpha = 5.06(\frac{H_s}{T_p^2})^2(1 - 0.287\ln\gamma)$; with H_s being the significant wave height, and $T_p = 2\pi/\omega_p$ being spectral peak wave period. The Jacket platform has been modelled using ANSYS FEM (Finite Element Method) software, as nonlinear MDOF structure. Figure 6 depicts investigated Jacket platform, operating in Bohai Continental Shelf. Jacket's VM (von Mises) stresses have been utilized in this investigation, and the structural material has been steel with stresses below the yield level (i.e., no plastic/irreversible deformations). A convergence check was done, in order to determine proper timestep. Response time histories are simulated using the ANSYS FEM software, [24]. Jacket dynamic model presumes discrete nodes placement from the Jacket deck MDOF structure down to the seafloor, distributing lumped hydrodynamic forces, acting on the Jacket platform. Lumped parameter model can be expressed in the following dynamic vector form

$$\mathbf{M}\ddot{\mathbf{X}} + \mathbf{C}\dot{\mathbf{X}} + \mathbf{K}\mathbf{X} = \mathbf{F}_{in} + \mathbf{F}_d . \tag{10}$$

with **M**, **C**, and **K** are constant matrices (geometric non-linearity is not modelled). Response vector $\mathbf{X} = (X_1, ..., X_N)^T$ consisting of components $X_k = X_k(t), k = 1..., N$, being the k-th DOF (Degree Of Freedom); N being the number DOFs in FEM model. $\mathbf{F}_{\text{in}}$ and $\mathbf{F}_d$ being inertia, drag force components respectively. Dynamic equation to be solved through full integral method, geometrical non-linearities have been accounted. Jacket platform structural MDOF model has been focused on accurate description on Jacket legs deformation characteristics, especially critical tubular support elements, those have been modelled by equivalent beam/tubular/shell structural elements.

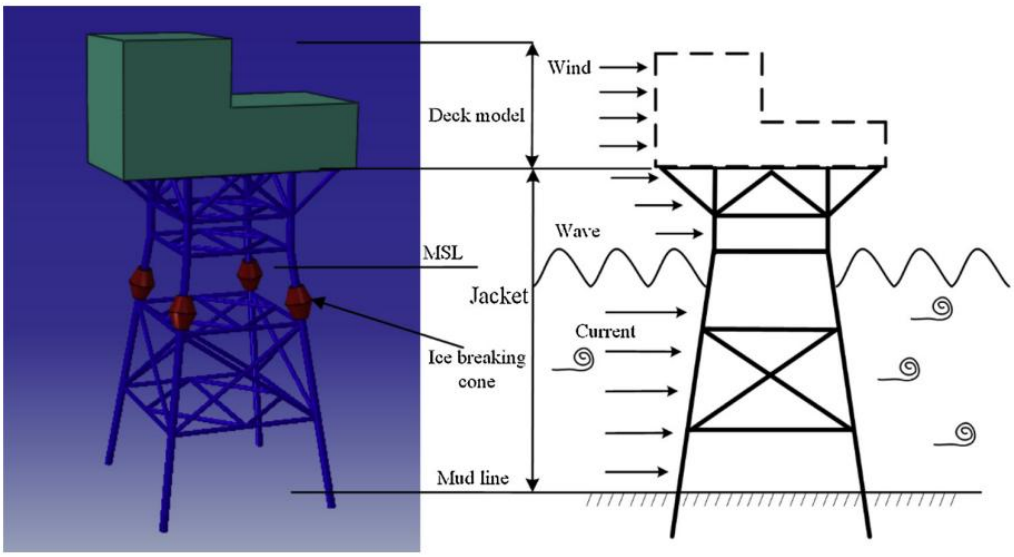
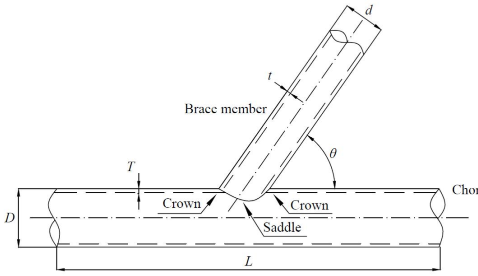
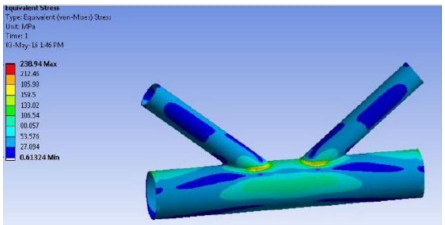


Figure 6 Jacket structural loadings [8]

For the whole Jacket MDOF structure (Figure 6), especially its area above the sea floor mudline, proper FEM models to be utilized (Figure 8). Jacket legs extend 90 meters below the seabed mudline, and the average depth of the water is 17 meters. The airgap between the lowest deck and mean water level (MWL), has been about 12 m.



(a) Geometric sketch of typical Y- and T-joints



Equivalent Stress

Maximum deformation

(b) K-joint deformation by ANSIS

Figure 7 Examples of welded tubular joints.

T, Y, K - joints being typical for Jacket offshore platforms, see Figure 7.

The soil has been modeled following *p-y* curve method, [25]. For sand, equation was

$$P = AP_U \tanh\left(\frac{KH}{AP_U}Y\right) \tag{11}$$

with $A = 0.9$ representing cyclic loading, P_U being the soil resistance level limit of the pile side for the unit area, K being subgrade reaction's initial modulus, H being depth below the surface of the Jacket pile in the mud, Y being lateral deformation of the pile. In ANSYS FEM analysis, Jacket leg's tubes, weld joints have been made of steel, for material properties see Table 2.

Table 2 Carbon steel material characteristics

Young's modulus, E (GPa)	200
Poisson's ratio, μ	0.3
Yield limit, σ_s (MPa)	205
Density, ρ (kg/m^3)	$7.8 \cdot 10^3$

4 Results

Statistical findings for chosen Jacket tubular support member's von Mises stresses to be presented in this section. Figure 8 presents Jacket illustration having 4 critical (i.e., hot-spot) stress locations being selected.

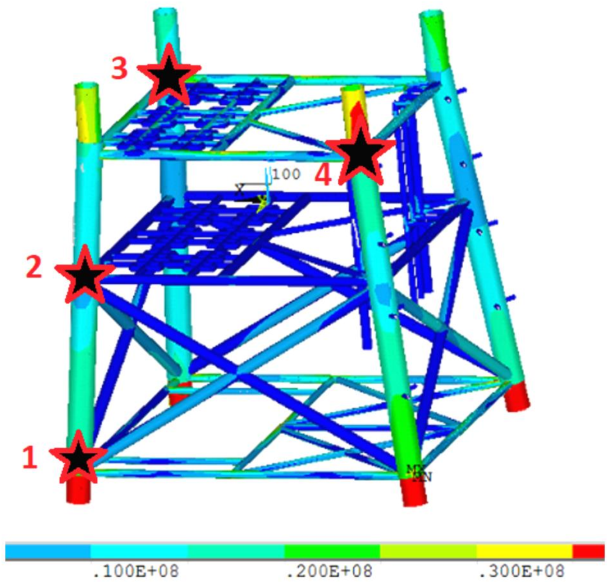
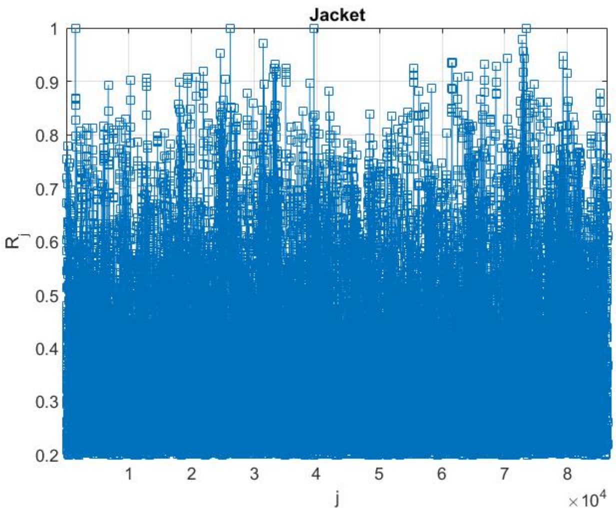
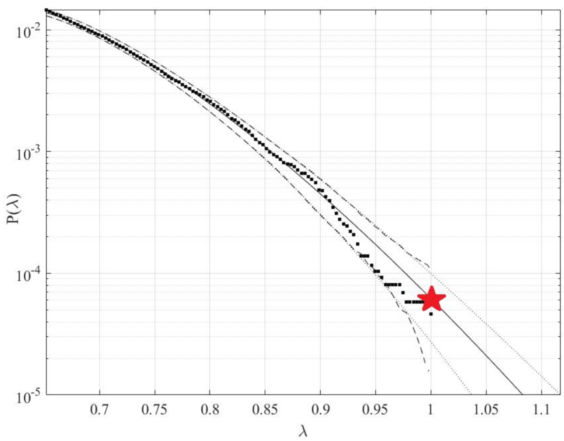


Figure 8 Slightly deformed Jacket's part illustration with 4 critical VM stress monitoring location hot-spots, stresses indicated with colours**.**

Figure 8 presents Jacket part illustration with 4 stress monitoring location spots, stresses due to external (wave) loadings have been computed, using ANSYS FEM software, VM stresses highlighted with colours. Failure/hazard/risk limits all equal to 1. 4 measured/simulated timeseries with system's key component's local maxima have been kept in temporally non-decreasing order, combined into 1 synthetic Jacket system's synthetic vector ***R***, [55]-[61].



(a) Nondimensional assembled synthetic vector ***R***



(b) Extrapolation of $p(\lambda)$ towards critical level (star)
Empirical data (*), extrapolation (solid line), extrapolated empirical 95% CI, marked with 2 dotted lines

Figure 9 Assembled vector $\vec{R}$ and corresponding extrapolation.

Empirical data (*), extrapolation (solid line), extrapolated empirical 95% CI, marked with 2 dotted lines

Figure 9(a) presents an example of non-dimensional assembled vector $\vec{R}$, consisting of assembled local Jacket stresses at 4 critical/hot-spot locations, see Figure 8; $\lambda_{\text{cut-on}} = 0.6$ cut-on limit has been selected as an example since lower values $\lambda < \lambda_{\text{cut-on}}$ are clearly irrelevant for the desired failure/hazard PDF tail's extrapolation. $\lambda = 1$, [62]-[73]. Note that system vector $\vec{R}$ does not have physical meaning on its own, as it is being purely synthetic. Index j being a running index of system's key components local maxima, sorted in temporally non-decreasing order, [45]. Empirical data (*), extrapolation (solid line), extrapolated empirical 95% CI, marked with 2 dotted lines

Figure 9 b) presents extrapolation following Eq. (9) towards target failure/hazard level $\lambda = 1$. 2 dotted lines indicate 95% extrapolated CI (Confidence Interval). According to Eq. (6), function $p(\lambda)$ being directly related to target system's failure/hazard risk/probability $1 - P$ from Eq. (1). Following Eq. (5), Jacket platform dynamic system's failure/hazard probability/risk $1 - P \approx 1 - P_k(1)$ may be now estimated. Note that in Eq. (4) parameter N corresponds to a total number of system components local maxima within synthetic system's vector $\vec{R}$, [74]-[77]. Empirical data (*), extrapolation (solid line), extrapolated empirical 95% CI, marked with 2 dotted lines

Figure 9 b) exhibits reasonably narrow 95% CI, even the underlying dataset was limited. Empirical data (*), extrapolation (solid line), extrapolated empirical 95% CI, marked with 2 dotted lines

Figure 9(b) shows extrapolation about 5 decimal orders of magnitude down, means 10^5 efficiency compared to MC simulation, what regards extrapolation. For complex MDOF system to be MC simulated, number of system's key dimensions/components may become computationally prohibitive, [78], [79].

In order to cross-validate Gaidai multivariate reliability method without performing extensive direct MC simulations, one has to deploy alternative multivariate reliability method. To the authors knowledge, there are no currently available reliability method able to treat systems with dimensions NDOF > 2 , while Gaidai multivariate reliability method is basically NDOF $= \infty$. Hence cross-validation to be done for NDOF $= 2$, thus taking into account only 2 most critical hot-spot stresses. For cross-validation of Gaidai multivariate reliability method, given 2D Jacket system (i.e., only 2 stresses selected) and the modified 4-parameter Weibull bivariate method, see recent study [73].

Advocated Gaidai reliability methodology delivering practical engineering benefits of being able to effectively utilize raw/unfiltered measured/simulated datasets, due to its ability to handle dynamic system's multidimensionality, using accurate extrapolation tools, when analysis being based even on a relatively limited dataset. Empirical data (*), extrapolation (solid line), extrapolated empirical 95% CI, marked with 2 dotted lines

Figure 9 b) demonstrates extrapolation depth, i.e., how many decimal orders of magnitude, has been covered by extrapolation, in other words how much CPU (Central Processing Unit) time can be spared.

5 Concluding remarks

Traditional reliability methods are not easily applicable to complex systems with large number of key cross-correlated components. Ability of Gaidai multivariate reliability method to assess reliability of high-dimensional nonlinear dynamic systems being its main practical benefit. This study evaluated dynamic hot spot stresses at several offshore Jacket platform support structure locations. Jacket support structure has been modelled as multi-dimensional engineering dynamic system. Theoretical rationale of Gaidai multivariate reliability method has been briefly presented. While it may be appealing to analyze Jacket structural reliability through direct measurement or extensive MC simulations, complexity and high dimensionality of dynamic systems require development of novel, accurate, yet robust techniques that can handle even limited underlying datasets, making optimal use of them. Methodology employed in this study has demonstrated efficacy across a range of intricate nonlinear engineering systems, [80]-[86]. The main goal of this research has been to propose an all-purpose, trustworthy, and user-friendly multi-dimensional reliability strategy for offshore engineers. The suggested method produced reasonably narrow CIs. As a result, the proposed method might be used at design stage for a wide range of nonlinear dynamic systems. Validation of Gaidai multivariate reliability method versus well established bivariate Weibull method has been carried out. Gaidai multivariate reliability method may be used for a variety of offshore engineering structures, not limited to offshore Jacket platforms.

Competing interest The authors have no competing interests to declare that are relevant to the content of this article.

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