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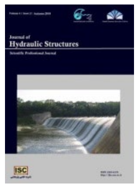

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Probabilistic design criterion for best arrangement of bracing configuration in JTOP structures

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Abstract

Fixed marine structures is widely utilized as production or oil recovering platform in the shallow sea, and are also subject to random loading. Jacket structures subject to random loading pose difficulties in both analysis and design, with solutions commonly only viably acquired employing a numerical technique. Performance of offshore jacket platforms is highly related to configuration of the braces. In this regard, probabilistic scheme is a good option for evaluating jacket structures. In this paper, the performance of Resalat jacket structure located in the Persian Gulf with different kinds of bracing configuration is investigated. We present a new measuring index for optimum arrangement of bracing configuration which is defined as probabilistic design criterion. The Latin Hypercube Sampling (LHS) method, which is a more advanced and appropriate form of the Monte Carlo simulation technique, is used to investigate different configurations. Hereof, probabilistic analysis is performed on different configurations of platform structure using the LHS method. The elastic modulus is employed as the random input variable for probabilistic analysis, and the maximum values of stress and horizontal displacement are selected as the random output variables. Also, at the end of the calculations, the optimum configuration can be found. It is demonstrated that the proposed probabilistic optimization algorithm is capable of effectively determining the optimum configuration of jacket platform structures. Therefore, an optimum bracing configuration can be useful in evaluating and designing the fixed marine structures.

Keywords: Offshore platform, Optimum configuration, Probabilistic design, Reliability, Best arrangement for bracing.

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1. Introduction

Jacket Type Offshore Platforms (JTOP) play a fundamental role in offshore oil and gas improvement, and therefore, it is very important to estimate their system reliability. The system reliability theory of complex structures generally has two meanings: First, the system is a combination of structural members, which have certain functional relationships. Second, there is a clear evolution of member's failure, leading to progressive alterations in the topological structure of the system undergoing failure. However, the redistribution of structural stress and strain increases the difficulty in detecting and evaluating structural failure [1-3]. For large statically indeterminate jacket structures, the failure of a single member generally does not lead to the failure of the entire structural system. After a single member fails, the internal forces will be redistributed among the other members, which will still be able to endure the redistributed internal forces. This indicates that the statically indeterminate structure will fail only when several element failures happen. Because of the large uncertainties associated with the evaluation of JTOP structures, there has been increasing interest in employing calculation techniques which are based on explicit considerations of reliability.

Hereof, American Petroleum Institute has improved recommendations for reliability-based evaluation of JTOP structures [4, 5]. The Monte Carlo simulation (MCS) scheme employs random number simulation to extrapolate probability density function values [6, 7]. The inputs for a simulation procedure for a variable are its mean value, either standard deviation or coefficient of variation (COV), as well as its type of distribution. Any input can be set as a probabilistic variable if its mean value, standard of deviation, and the distribution function type are presented. As stated by Baecher and Christian [6], the Monte Carlo skill has the superiority because it is relatively easy to implement on a computer and can deal with a wide range of functions. The main drawback is that the results may converge very slowly. According to [8], when a closed-form solution is assumed too approximate, MCS can be accomplished. The MCS scheme is more flexible and rigorous, and if enough simulations are employed, the results approach exact solutions; hence, the MCS technique is considered in this paper. Although MCS skill prepares a perfect and straightforward tool for accomplishment the reliability analysis of systems, nevertheless this method is time consuming and computationally expensive. Because of this fact, new approaches have been suggested such as Latin Hypercube Sampling (LHS), which are advantageous for reducing the needed simulations in reliability analysis [9, 10]. Tubular joint is one of the factors affecting the global static and dynamic responses of a jacket structure and such connections changes the natural frequencies of the structure. Also deterministic analyses generally result in conservative designs. This fact emphasizes the importance of design approaches in which the key parameters of the problem can be modeled as random variables [11, 12]. Most JTOP structures have complicated configurations, and their analysis has to be done employing computer-based numerical techniques. Two types of reliability have been utilized in structural optimization, namely, element reliability and system reliability. The former method focuses on the optimization of weight, shape, or cost based on the satisfaction of specified levels of reliability for individual elements, while the latter method considers possible modes in which the entire structural system might fail and calculates the probability of system failure via the utilization of reliability bounding concepts, and considers it in optimization [13]. The probabilistic optimization of structures has intrigued scholars for a number of years [14-16]. Lots of scholars investigated optimization approaches for JTOP structures. Feng et al. [17] suggested the shape optimization design for jacket platforms by seeking the nodal position and cross-sectional dimensions to acquire the minimum weight of platform. Liu et al. [18] offered acceleration-oriented design optimization of ice resistant jacket structures. This scheme concentrated on the dynamic performance of the JTOP structures to achieve an economical and rational design. Yang et al. [19] utilized the reliability based design optimization for the tripod sub-structure of offshore wind turbines.

A much higher reliability model is acquired based on the MCS. Nordal et al. [20] study the performance of X-braced versus K-braced probabilistically and presented a probabilistic format of reserve strength ratio. Hellan et al. [21] have accomplished shakedown analysis on JTOP structures and evaluated the integrity of structure for the ultimate limit state as well as progressive collapse limit state. Lee et al. [22] also compared approaches of reliability-based design optimization and deterministic optimization for a monopole transition piece in an offshore wind turbine structure. This study is implemented the probabilistic analysis of different configuration of the braces of offshore platforms, considering the Resalat platform as the case study. Hereof, two-dimensional modeling is accomplished, and analyses are also carried out using *ANSYS* software (*ANSYS Mechanical version 2016*). The elastic modulus is considered as the random input variable while maximum stress and horizontal displacement are selected as the random output variables. Probabilistic analysis is performed on different kinds of bracing configuration of the Resalat platform using MCS method. Then, probabilistic analysis and examination of different kinds of bracing configuration take place employing LHS method. Many papers considered the standard deviation of horizontal displacements as the target [23, 24].

We introduce a new measuring index for optimum arrangement of bracing configuration which is defined as probabilistic design criterion. Considering this index, the optimum configuration can be found and utilized in the process of designing new jacket structures as well as the assessment of existing ones. In addition, the present study has used probabilistic analysis to save cost and analysis time. The basic concepts of the developed scheme in the present study is mainly based on the work of Tabeshpour and Fatemi [25]. Figure 1 shows the flowchart of the current research process.

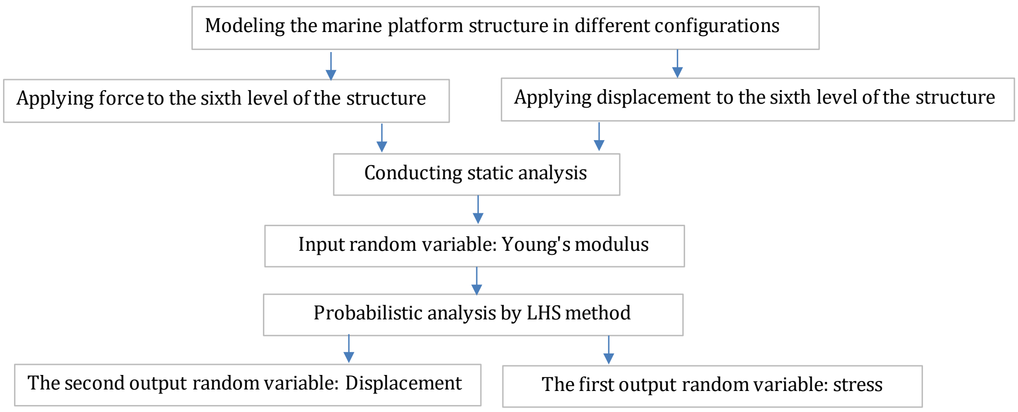


Figure 1. The flowchart of the current research process

2. Sampling method

The global static and dynamic responses of JTOP structures is important in both design and rehabilitation issues that depends on the bracing arrangement. Performance of jacket structures is highly related to configuration of the braces. As previously mentioned, this study is examined different arrangement of bracing configuration using probabilistic analysis. Resalat offshore platform is employed to examine various configurations of the braces. This platform has 4 legs and is located in the Persian Gulf at a depth of approximately 67 meters. More details about the Resalat offshore platform for structural modeling have been presented in [25]. Figure 2 shows the specifications of the jacket platform model.

Element Type	Dimension(cm)	Material Specification
Leg	12×1.5	$E = 2.07 \times 10^7\ N/m^2$
Beam	12×1.5	
Brace	10×1	

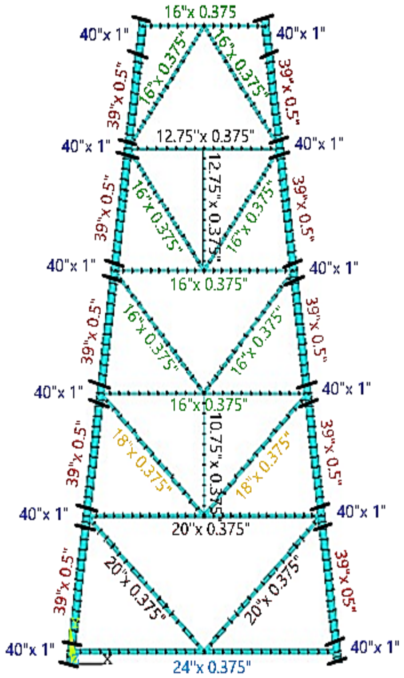


Figure 2. The specifications of the jacket platform model (inches)

Two-dimensional modeling of the platform is accomplished in *ANSYS* software. *ANSYS* software works based on finite element method that can perform probabilistic analysis. The configurations of the braces are taken from the study of [25]. The main legs and horizontal as well as vertical braces are made using pipes. The pipe 16 element has been used to model the pipe members. It is a uniaxial member with compressive, tensile, torsional, and flexural capabilities, and its input data include the exterior diameter and thickness of the element wall. High ability of MCS skills has been led to ever increasing application of such approaches in a wide variety of different fields counting structural reliability. This specific methodology has been based on event simulation utilizing random sample procedure and assessment of their results. Inputs for a MCS of a variable contain the variable's mean value, coefficient of variation (COV) and its distribution type. According to Figure 3, MCS employs random number simulations to create the probability density function of parameter values for every probabilistic variable [26].

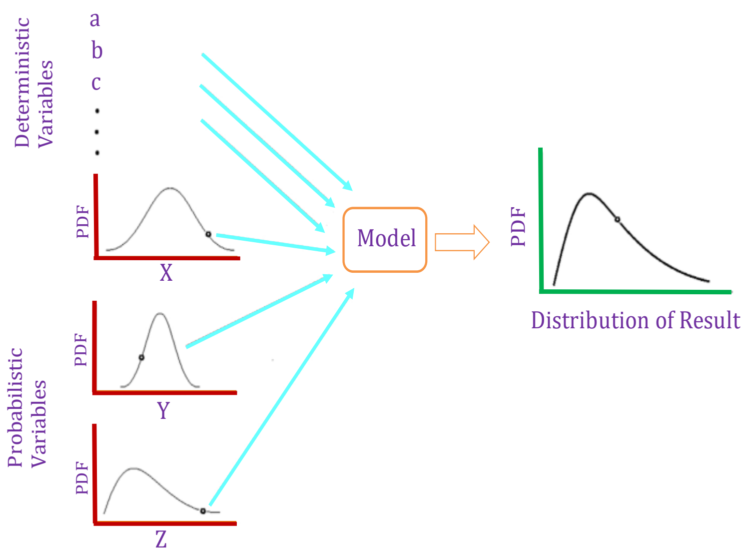


Figure 3. Schematic of MCS.

MCS approaches, including LHS, Direct Sampling, and Wizard are employed for probabilistic analysis of Resalat platform. LHS is a statistical scheme for generating a near-random sample of parameter values from a multidimensional distribution. LHS was described by Michael McKay of Los Alamos National Laboratory in 1979. One of the advantages of the LHS method is the selection of states with low probability, or in other words, they are located at the beginning and end of the cumulative distribution function graph. The first step to perform the LHS method is to determine the sampling size, which is represented by "n". The cumulative distribution function is divided into N equal parts, each of which has equal probabilities, and Equation (1) is used to select the representative of each sub-part. More information is found in reference [27].

$$X = f\left(\frac{n-rand}{N}\right) \quad (1)$$

The elastic modulus is considered as the random input variable while maximum stress and horizontal displacement are selected as the random output variables. The mean value of the elastic modulus is 1.96×10^{11} N/m^2 with a standard deviation of 5% and Gaussian distribution. Also, the Poisson ratio is constant and equal to 0.3. MCS approaches (Direct Sampling, LHS and Wizard) are utilized for probabilistic analysis in the current paper, indicating no significant differences. Therefore, the LHS method, which is a more advanced and appropriate form of the MCS method, is used to investigate different arrangement of bracing configuration. The elastic modulus is used as the random input variable for probabilistic analysis, and the maximum values of stress and horizontal displacement are selected as the random output variables. Static analysis is implemented in this study by separate application of displacement and force in the X direction to the sixth level (Figure 4). Then, probabilistic analysis is performed on different configurations of platform structure utilizing the LHS method. Also, considering an index that is a combination of the maximum stress and displacement, different configurations are compared to select the best one. Table 1 shows the results of changes in horizontal displacement and equivalent stress in terms of the number of samples (Figures 5 and 6). As shown in Table 1, the values of horizontal displacement and equivalent stress are not significantly different in the three methods; thus, the LHS method will be used for probabilistic analysis of other configurations.

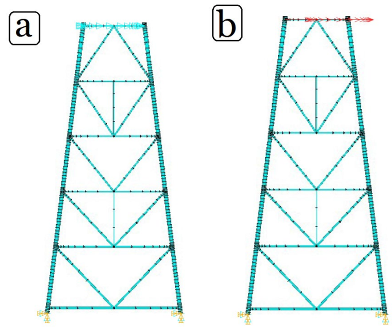


Figure 4. (a) Application of displacement to the sixth level along X direction; (b) Application of force to the sixth level along X direction.

As shown in Figure 4, force application to the sixth level is employed to examine the displacement of the configurations of the braces. Displacement application to the sixth level is also considered to examine the stress of the configurations of the braces. It is noteworthy that each of the analyses (force and displacement application) is executed separately (Figures 7 and 8). The results are listed in Table 2.

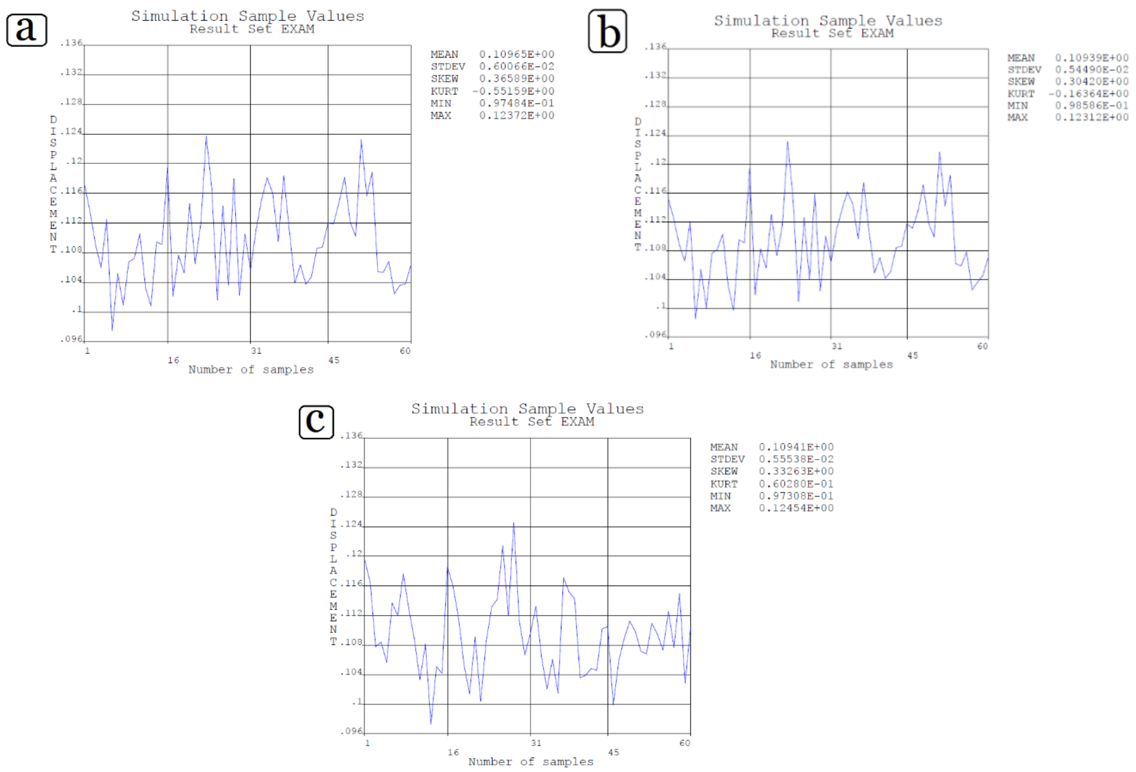


Figure 5. Changes in horizontal displacement using: (a) Direct Sampling, (b) LHS, (c) Wizard method

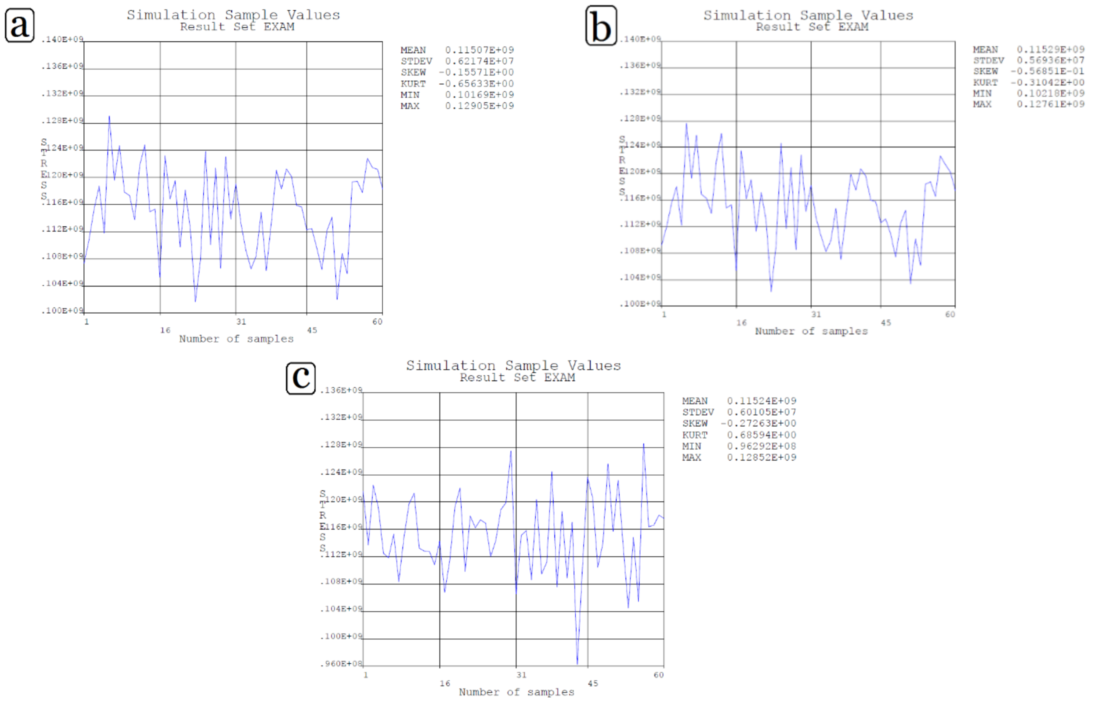
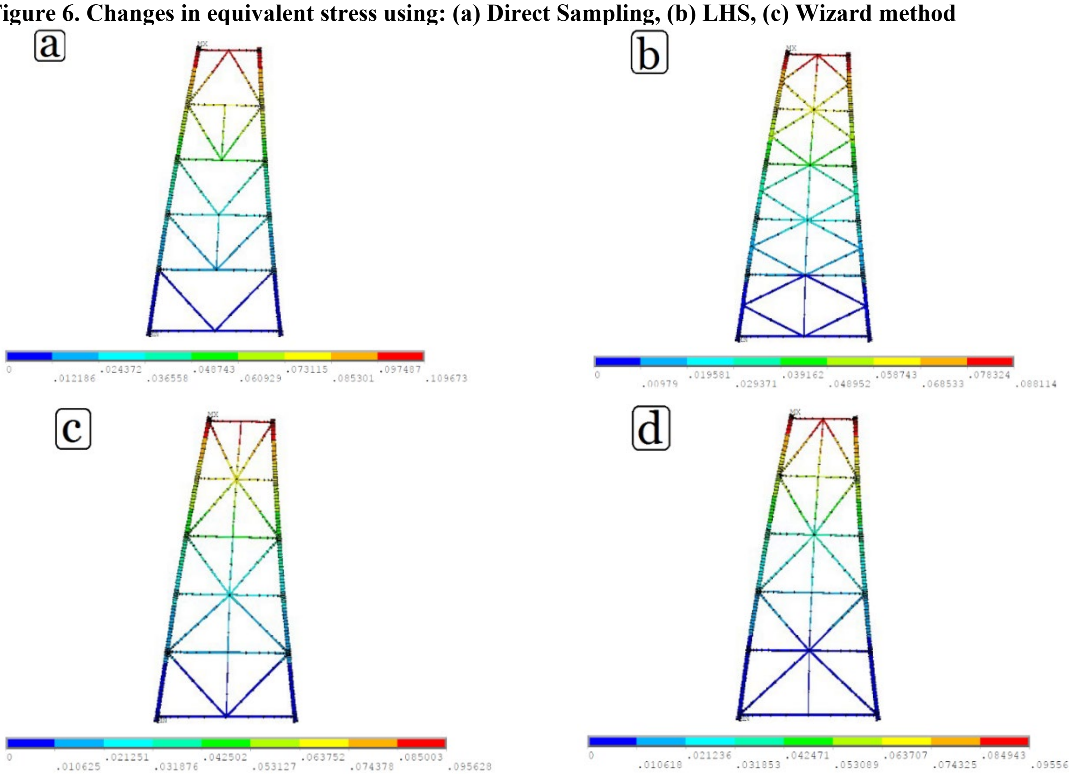


Figure 6. Changes in equivalent stress using: (a) Direct Sampling, (b) LHS, (c) Wizard method



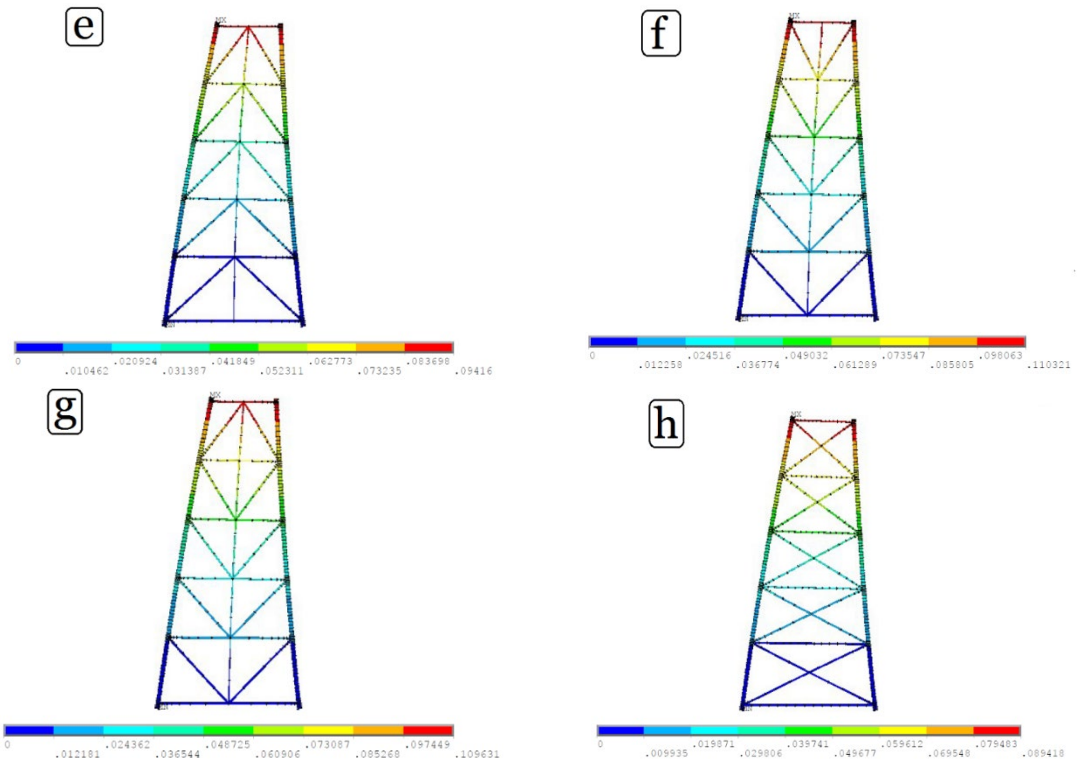
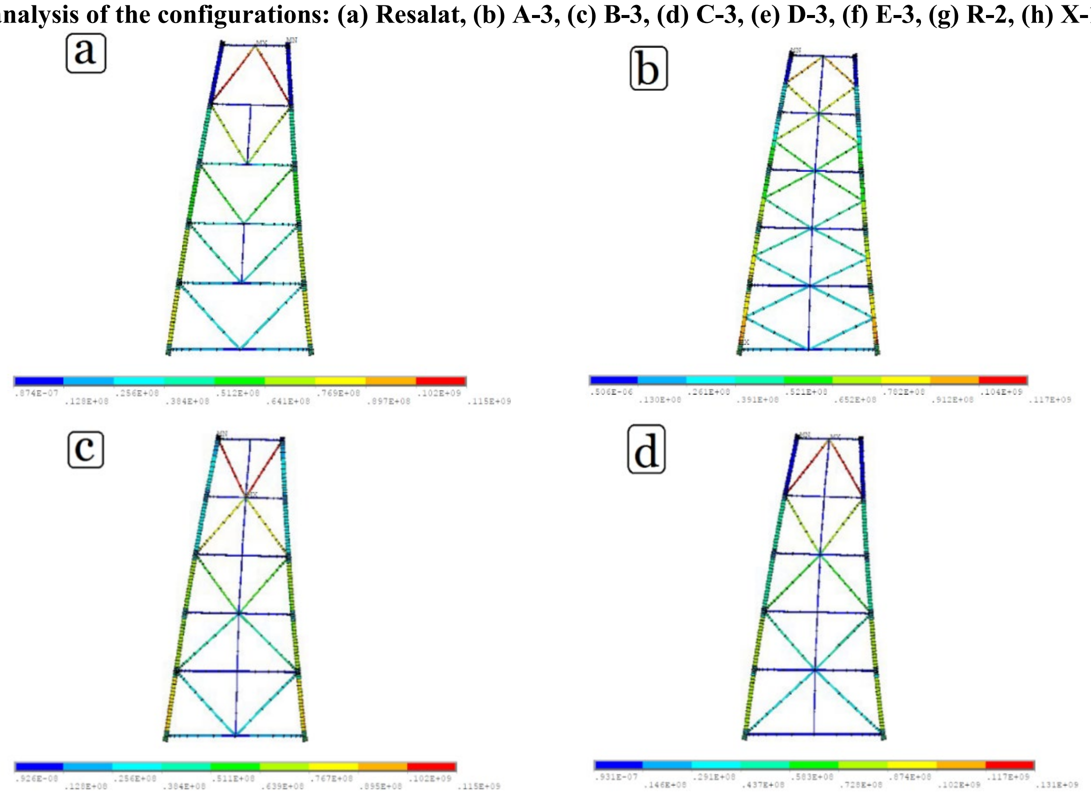


Figure 7. Maximum horizontal displacement with the application of force in the sixth level in static analysis of the configurations: (a) Resalat, (b) A-3, (c) B-3, (d) C-3, (e) D-3, (f) E-3, (g) R-2, (h) X-1



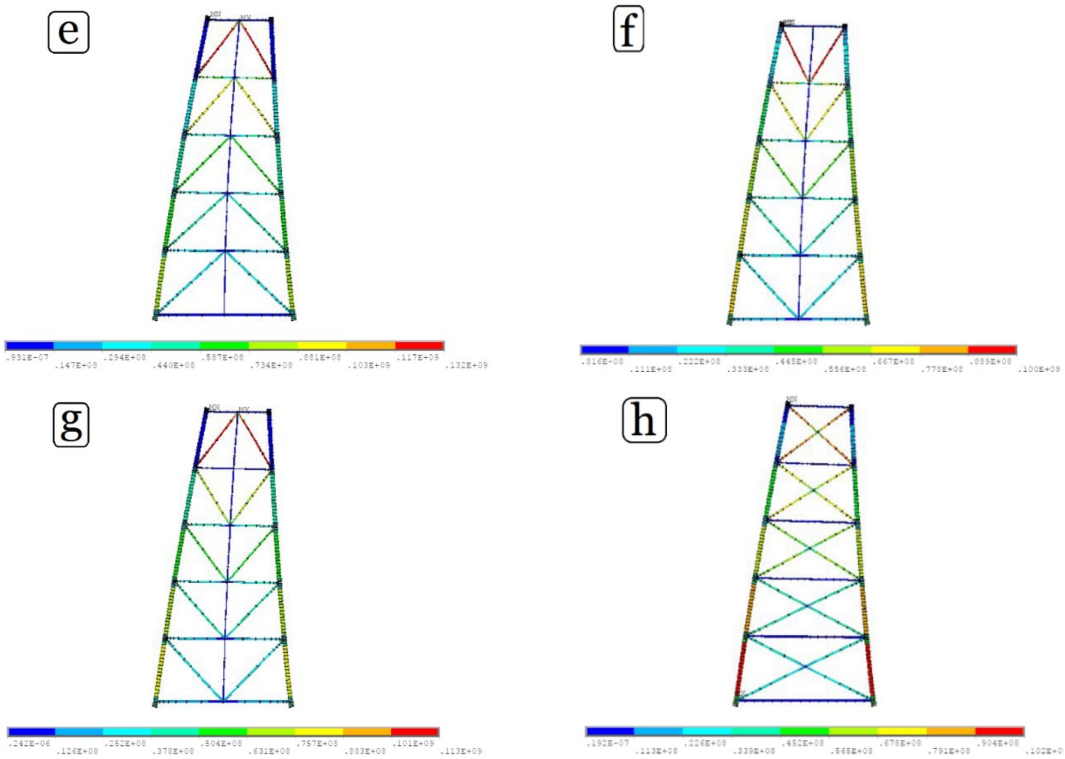


Figure 8. Maximum stress with the application of displacement in the sixth level in static analysis of the configurations: (a) Resalat, (b) A-3, (c) B-3, (d) C-3, (e) D-3, (f) E-3, (g) R-2, (h) X-1

As mentioned, the elastic modulus is the input random variable for probabilistic analysis. The mean value of the elastic modulus is 1.96×10^{11} N/m^2 with a standard deviation of 5% and Gaussian distribution. In fact, standard deviation indicates how disperse the data is in relation to the mean. In other words, lower values of standard deviation show that data are less dispersed. Figure 9 presents the elastic modulus distribution diagram of the Gaussian type. One of the features of this curve is its symmetry relative to the vertical axis, with most data at mean values. Accordingly, as the distance from the mean increases, the likelihood of data will also increase. This function is often used to model random variables whose behavior is not completely understood.

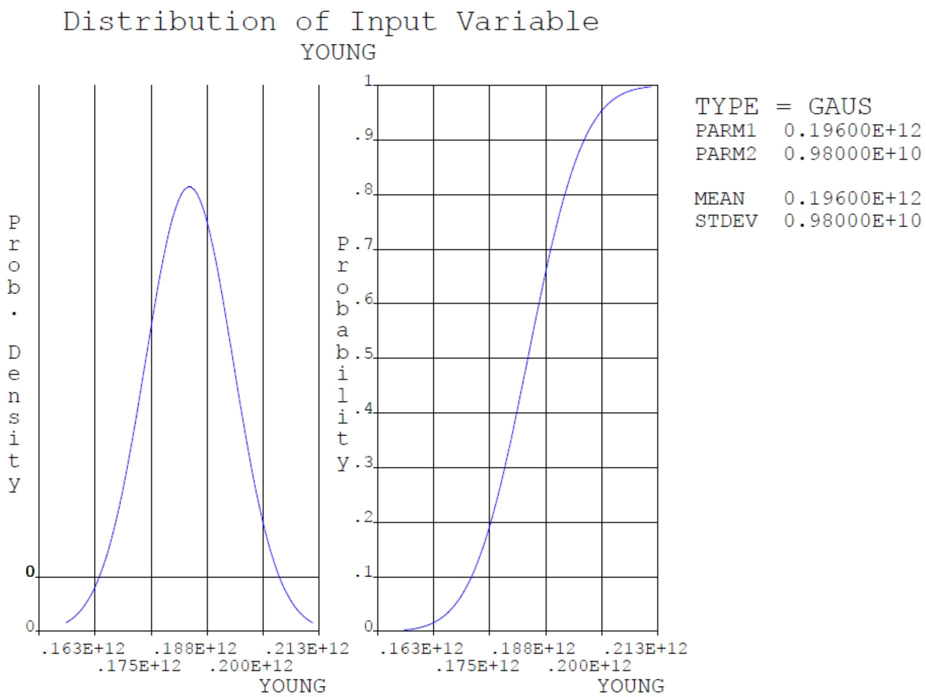


Figure 9. Gaussian type elastic modulus distribution

Table 1. Comparison of the results of probabilistic analysis using different simulations

Configurations	Stress			Displacement		
	S_{Max} (N/m^2)	S_{Min} (N/m^2)	S_{Mean} (N/m^2)	D_{Max} (m)	D_{Min} (m)	D_{Mean} (m)
Direct Sampling	0.12905E+9	0.10169E+9	0.11507E+9	0.12372	0.097484	0.10965
Latin Hypercube Sampling	0.12761E+9	0.10218E+9	0.11529E+9	0.12312	0.098586	0.10939
Wizard	0.12852E+9	0.96292E+8	0.11524E+9	0.12454	0.097308	0.10941

Table 2. Values of maximum stress and horizontal displacement in static analysis

Responses	Configurations							
	Resalat	A-3	B-3	C-3	D-3	E-3	R-2	X-1
D_{MAX} (m)	0.109673	0.088114	0.095628	0.095556	0.09416	0.110321	0.109631	0.089418
S_{MAX}(N/m^2)	0.115E+9	0.117E+9	0.115E+9	0.131E+9	0.132E+9	0.100E+9	0.113E+9	0.102E+9

3. Results and Discussion

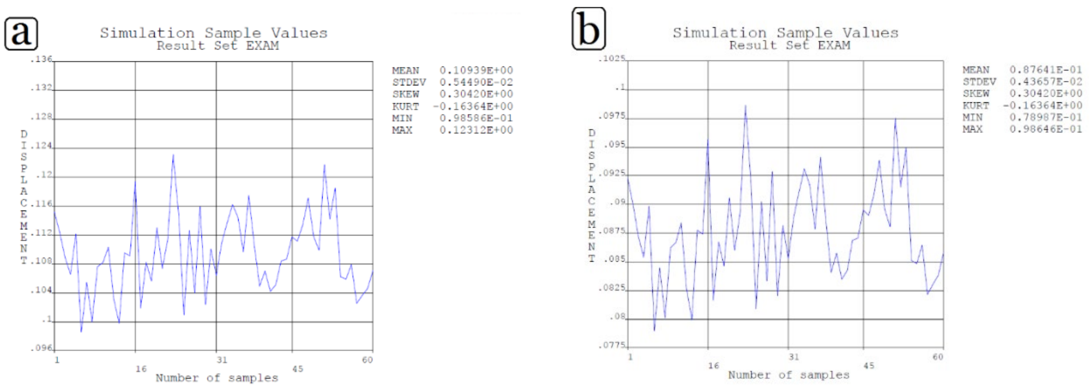
3.1. Probability distribution of structural responses

Horizontal displacement and equivalent stress are the output stochastic variables. The number of samples in the MCS (LHS method) is 60 for each configuration. Figures 10 and 11 show the history of changes in horizontal displacement and equivalent stress in terms of the number of samples. Table 3 indicates the results of changes in horizontal displacement and equivalent stress. According to the results of probabilistic analyses, the configuration of A-3 have the least horizontal displacement in both analyses, and the least stress has been applied to the E-3 configuration. It should also be noted that the maximum stress and horizontal displacement in the probabilistic analysis have increased compared to the static analysis so that the values of maximum strass and displacement in static analysis are approximately equal to the mean values of those in the probabilistic analysis. Next, the configurations will be analyzed and examined considering an index that is a combination of horizontal displacement and equivalent stress. This study investigates the mean value of the input parameter in the simulation loops as a function of the number of loops.

Table 3. The results of changes in horizontal displacement and equivalent stress in probabilistic analysis

Configurations	Stress			Displacement		
	S_{Max}(N/m^2)	S_{Min}(N/m^2)	S_{Mean}(N/m^2)	D_{Max}(m)	D_{Min}(m)	D_{Mean}(m)
Resalat	0.12761E+9	0.10218E+9	0.11529E+9	0.12312	0.098586	0.10939
A-3	0.12983E+9	0.10396E+9	0.11729E+9	0.098646	0.078987	0.087641
B-3	0.12693E+9	0.10163E+9	0.11467E+9	0.1072	0.085834	0.095238
C-3	0.14507E+9	0.11616E+9	0.13106E+9	0.10715	0.085799	0.095199
D-3	0.14624E+9	0.11709E+9	0.13212E+9	0.10575	0.084675	0.093948
E-3	0.11069E+9	0.088632E+9	0.1E+9	0.12375	0.099085	0.10994
R-2	0.12561E+9	0.10057E+9	0.11439E+9	0.12308	0.098549	0.10935
X-1	0.11251E+9	0.090086E+9	0.10164E+9	0.1002	0.080233	0.89023

The direct observation of the simulation loops as a function of the number of loops under study is the most fundamental form of results post-processing. Accordingly, the values of simulation, the mean minimum and maximum, and the standard deviation can be observed. The history of mean values and standard deviations for the MCS method helps the user to determine whether the number of loops executed has been sufficient for convergence or not. When the drawn curve becomes horizontal in terms of the number of loops, convergence is observed. A number of 60 samples is considered for each configuration in the present study.



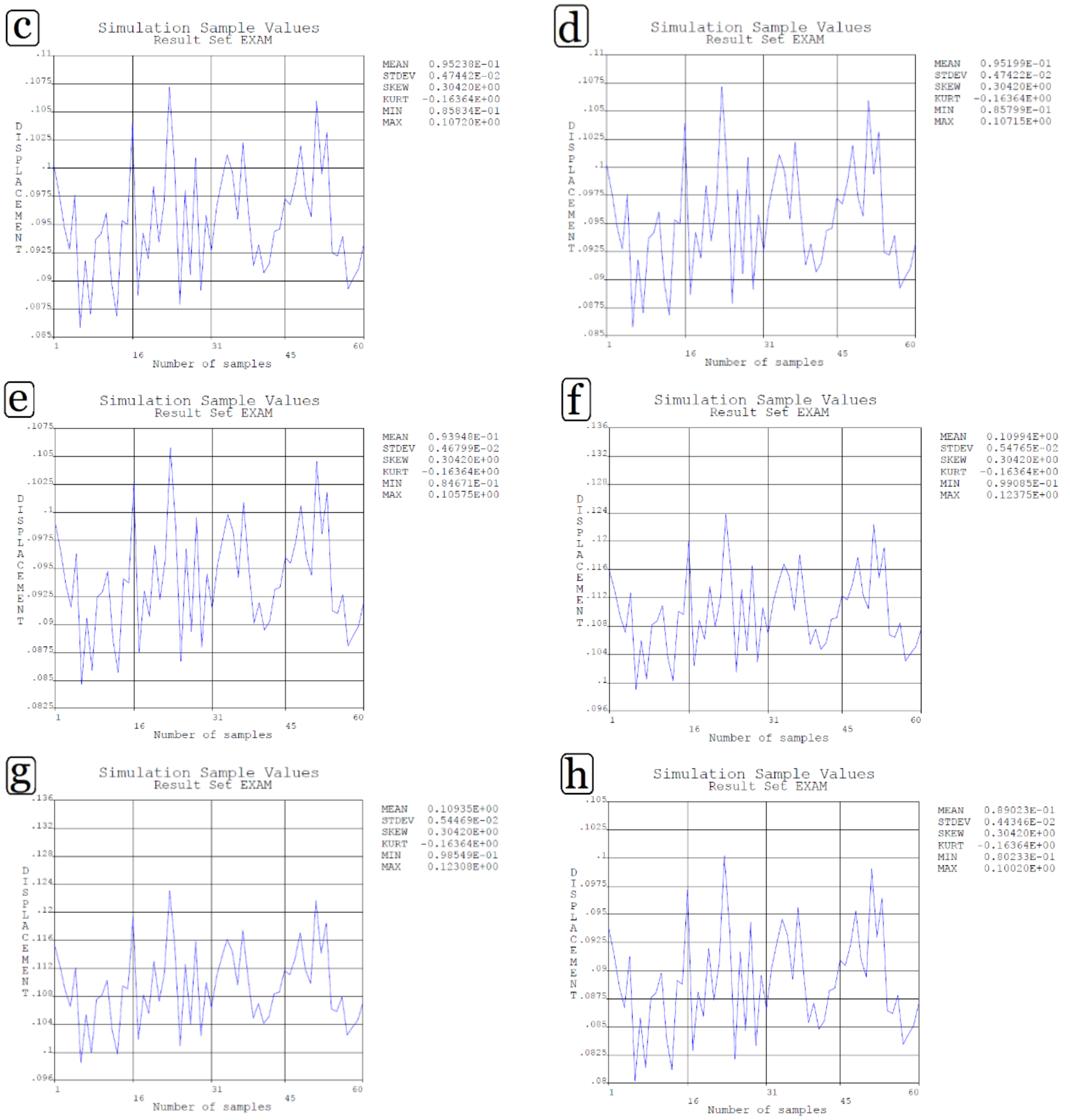


Figure 10. History of changes in horizontal displacement in terms of the number of samples: (a) Resalat, (b) A-3, (c) B-3, (d) C-3, (e) D-3, (f) E-3, (g) R-2, (h) X-1

For example, Figure 12 shows the changes in the mean value of the horizontal displacement and equivalent stress in Resalat platform relative to the number of samples. According to these graphs, the curves are almost horizontal after 35 samples, which means that the minimum number of samples in this analysis is 35. Histogram is an overview of the data frequency in a grouped manner. Histogram is generally used to represent the distribution of a probabilistic design variable. This graphical display is available for both random input and output variables. For instance, Figure 13 shows the histogram of elastic modulus, horizontal displacement and equivalent stress in Resalat platform. Accordingly, the area of each rectangle indicates the probability of displacement or stress at that level. Therefore, the total area of the rectangles is equal to one. As can be seen from the histograms, the rectangles with the highest surface area belong to the mean values.

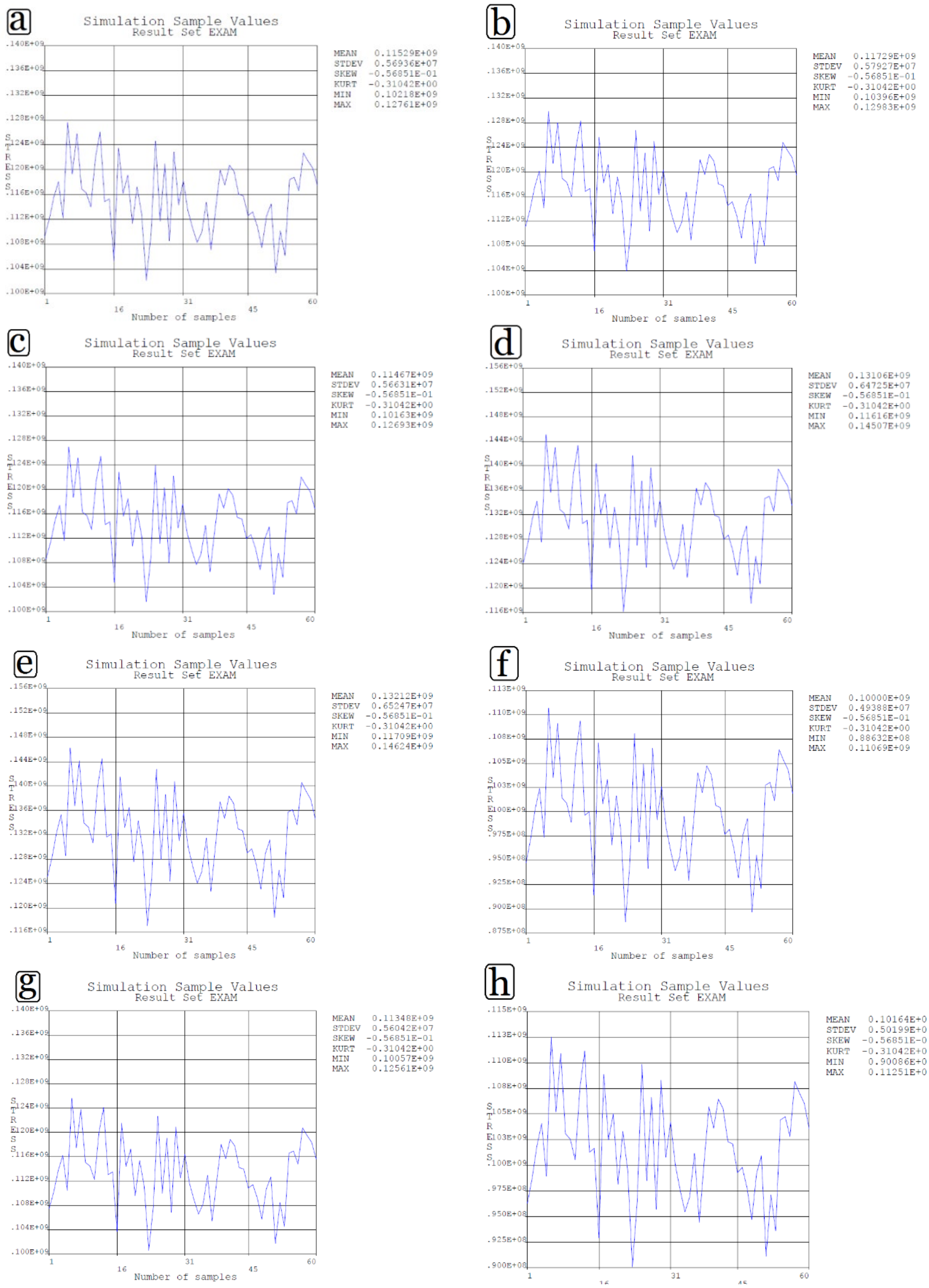


Figure 11. History of changes in equivalent stress in terms of the number of samples: (a) Resalat, (b) A-3, (c) B-3, (d) C-3, (e) D-3, (f) E-3, (g) R-2, (h) X-1

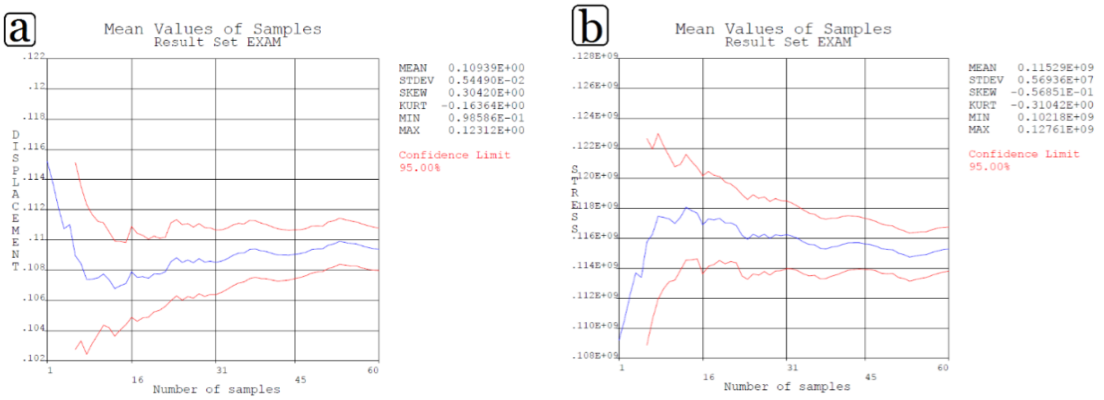


Figure 12. (a) Changes in the mean value of the horizontal displacement of Resalat platform, (b) Changes in the mean value of the stress of Resalat platform

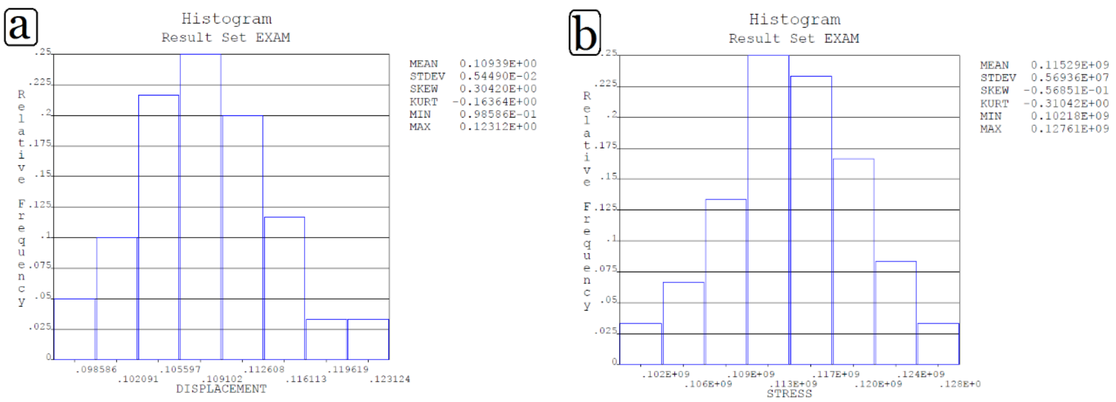
3.2. Probabilistic design system (PDS)

The structural design theory has three basic components and a basic differentiation between the variable types, as in any system design issue. In particular a vector of behavior variables may be determined as $\mathcal{Z} = (\mathcal{Z}_1.\mathcal{Z}_2.\ldots.\mathcal{Z}_n)^T$ and a vector of design variables as $\mathcal{W} = (\mathcal{W}_1.\mathcal{W}_2.\ldots.\mathcal{W}_r)^T$. Behavior variables normally relate to quantities such as structural responses, ... , while control variables' relate to the quantities directly influenced by the designer such as structural specifications. An optimality measure, system model and design constraints may be presented as relationships between $\mathcal{Z}$ and $\mathcal{W}$.

The optimality measure may be expressed as

$$\tilde{\mathcal{R}} = G(\mathcal{Z}.\mathcal{W}) \qquad (2)$$

where G denotes a scalar function of its arguments. Note that this is a probabilistic quantity, as its arguments are probabilistic, and therefore is an unsuitable criterion.



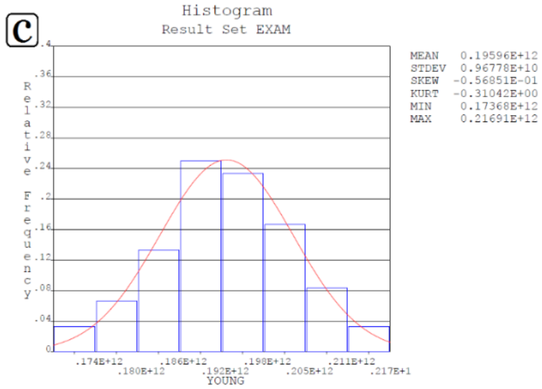


Figure 13. Histogram (a) Horizontal displacement, (b) Equivalent stress (c) Elastic modulus for Resalat platform

An appropriate criterion however is in terms of its expected value

$$\mathcal{R} = E\{G(\mathcal{Z}.\mathcal{W})\} \tag{3}$$

For instance in a serviceability design problem $\tilde{\mathcal{R}}$ may only be a function of $\mathcal{Z}$, here related to structural responses. The system model relates the behaviors and controls and may be given the description

$$F(\mathcal{Z}.\mathcal{W}.\gamma) = 0 \tag{4}$$

where F denotes a vector function of the arguments shown and γ denotes a vector of random quantities of presumed known probabilistic form, i.e. its probability density or probability mass function is known. Appropriate models for framed structures contain matrix stiffness (or flexibility) relationships connecting the applied joint loading to the joint rotations and displacements. The design restrictions arise from serviceability, integrity and geometric limitations on the design and usually take the form

$$h(\mathcal{Z}.\mathcal{W}.\gamma) \leq 0 \tag{5}$$

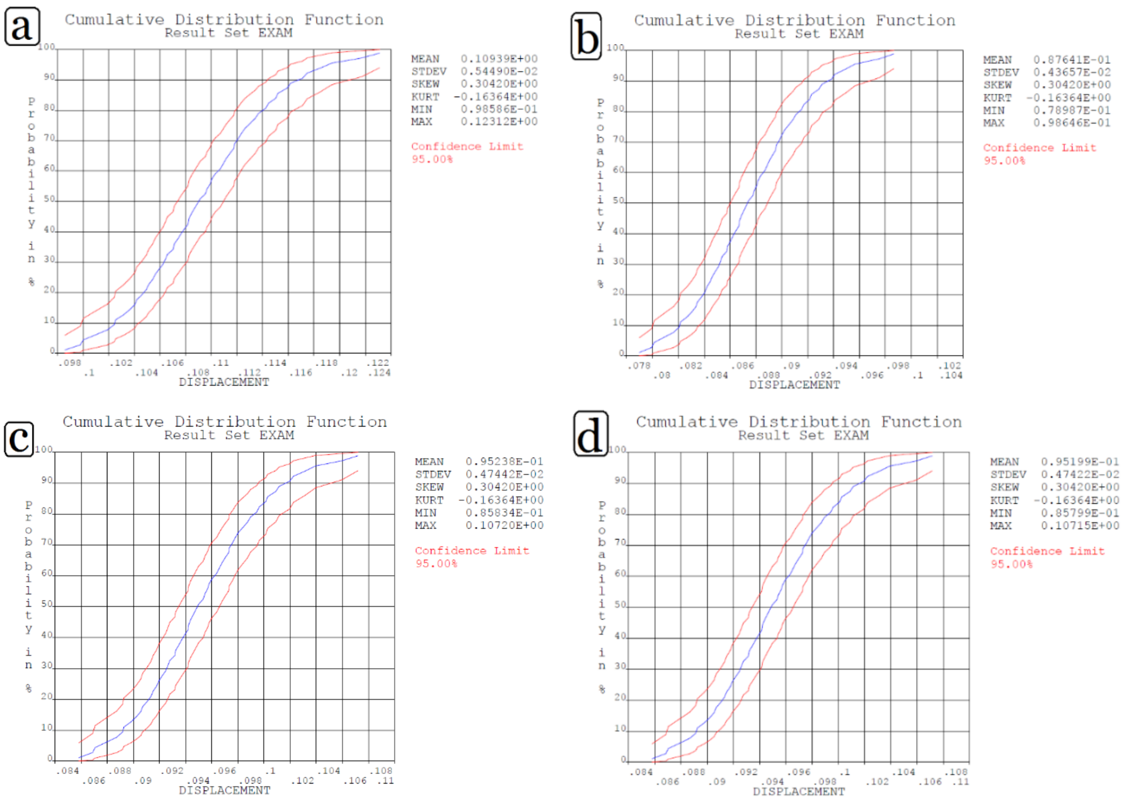
where h denotes a vector function. Reliability limitations are of this form. The optimization problem is then to conclude the control variables to extremize the measure subject to the solution satisfying the system model and design constraints [28].

Since events occur randomly, it is natural to consider a certain a random value for each of them. Cumulative Distribution Function (CDF) is a primary observation tool which can be utilized to analyze reliability or uncertainty.

Figures 14 and 15 show CDF for maximum displacement and stress. These diagrams examine the values of maximum displacement and stress (static analysis) for different configurations of the braces. The probability of maximum displacement and stress below this value is also shown. For example, according to diagram (a) in Figures 14 and 15, the probability that the maximum displacement is less than the static maximum displacement, which is 0.109673 m, will be 55%, and the probability that the maximum stress is less than the static maximum stress, which is 0.115×10^9 N/m^2, is 61%. Table 4 shows the results of probability distribution diagrams for different configurations of the braces.

Table 4. Results from probability distribution diagrams for maximum stress and displacement in different configurations of the platform

Configurations	Maximum displacement in static analysis	Maximum stress in static analysis	The probability that the maximum displacement is less than the maximum displacement in static analysis (percentage)	Probability that the maximum stress is less than the maximum stress in static analysis (percentage)
Resalat	0.109673	0.115E+9	55	61
A-3	0.088114	0.117E+9	56	63
B-3	0.095628	0.115E+9	51	68
C-3	0.095556	0.131E+9	51	63
D-3	0.09416	0.132E+9	52	63
E-3	0.110321	0.1E+9	52	66
R-2	0.109631	0.113E+9	56	60
X-1	0.089418	0.102E+9	53	67



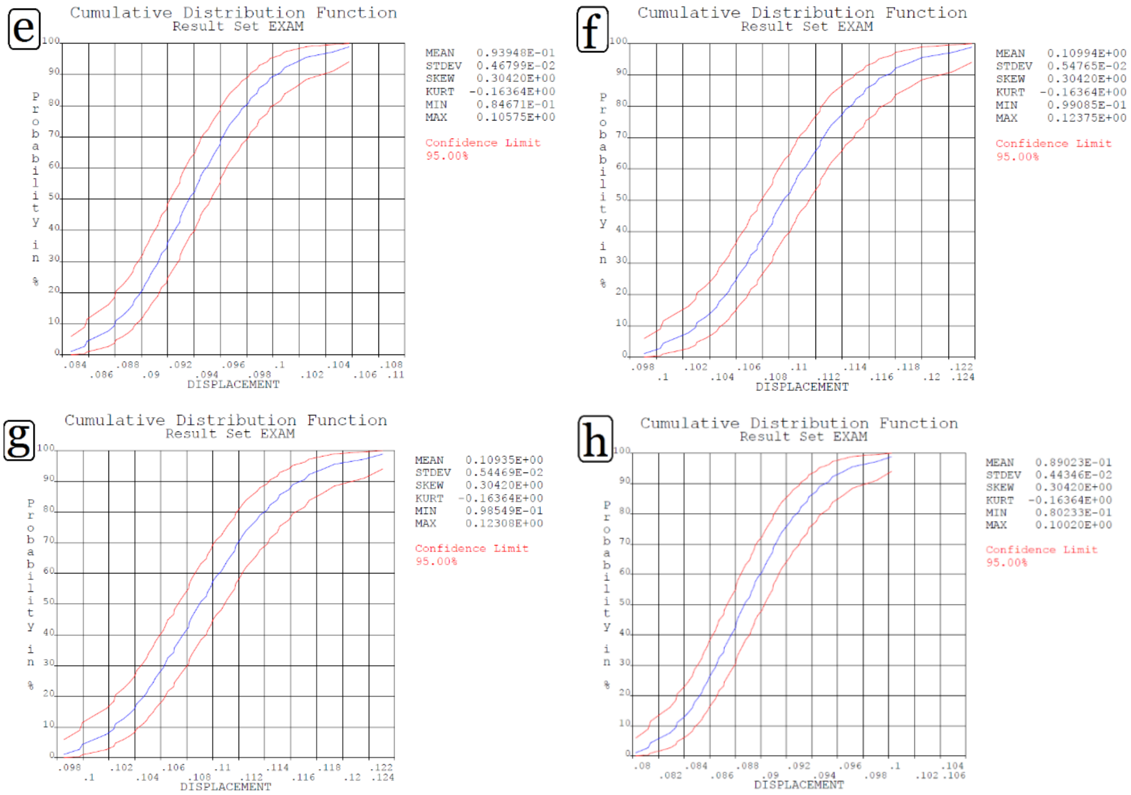


Figure 14. Distribution of maximum displacement probability in configurations: (a) Resalat, (b) A-3, (c) B-3, (d) C-3, (e) D-3, (f) E-3, (g) R-2, (h) X-1

PDS diagram provide more complete information than probability sensitivity diagrams. PDS allows the distribution plotting of each probabilistic design variable based on another. Figure 16 shows the distribution plotting of horizontal displacement and equivalent stress in terms of elastic modulus for the Resalat platform. The correlation coefficient is an important parameter in the calculation of structural reliability and is defined using the formula of covariance.

$$\rho_{XY} = \frac{Cov(X,Y)}{\sqrt{Var(X)Var(Y)}} \qquad -1 \leq \rho_{XY} \leq +1 \tag{6}$$

The correlation coefficient is limited to values of -1 and $+1$ since the covariance and the correlation coefficient matrices are positive and definite. The value of ρ_{XY} indicates the degree of linear dependence between the random variables of X and Y. When ρ_{XY} is close to 1, X and Y show linear proportionality, and when ρ_{XY} is close to 0, they are not linearly proportional. In general, the correlation coefficient considers the linear relationship between two random variables, and the values close to zero show that there is no correlation in general. As shown in Figure 16, the random input variable for the elastic modulus is correlated with the random output variables of maximum displacement and stress, because the correlation coefficient between the variables of elastic modulus and maximum stress is $+1$ and equal to -1 between the elastic modulus and displacement. Table 5 shows the results for the best arrangement of bracing configuration after performing the probabilistic analysis on different offshore platforms. Accordingly, the best configuration has the least combination of the maximum displacement and stress. According to Table 5, the X-1 configuration is the best according to the defined index.

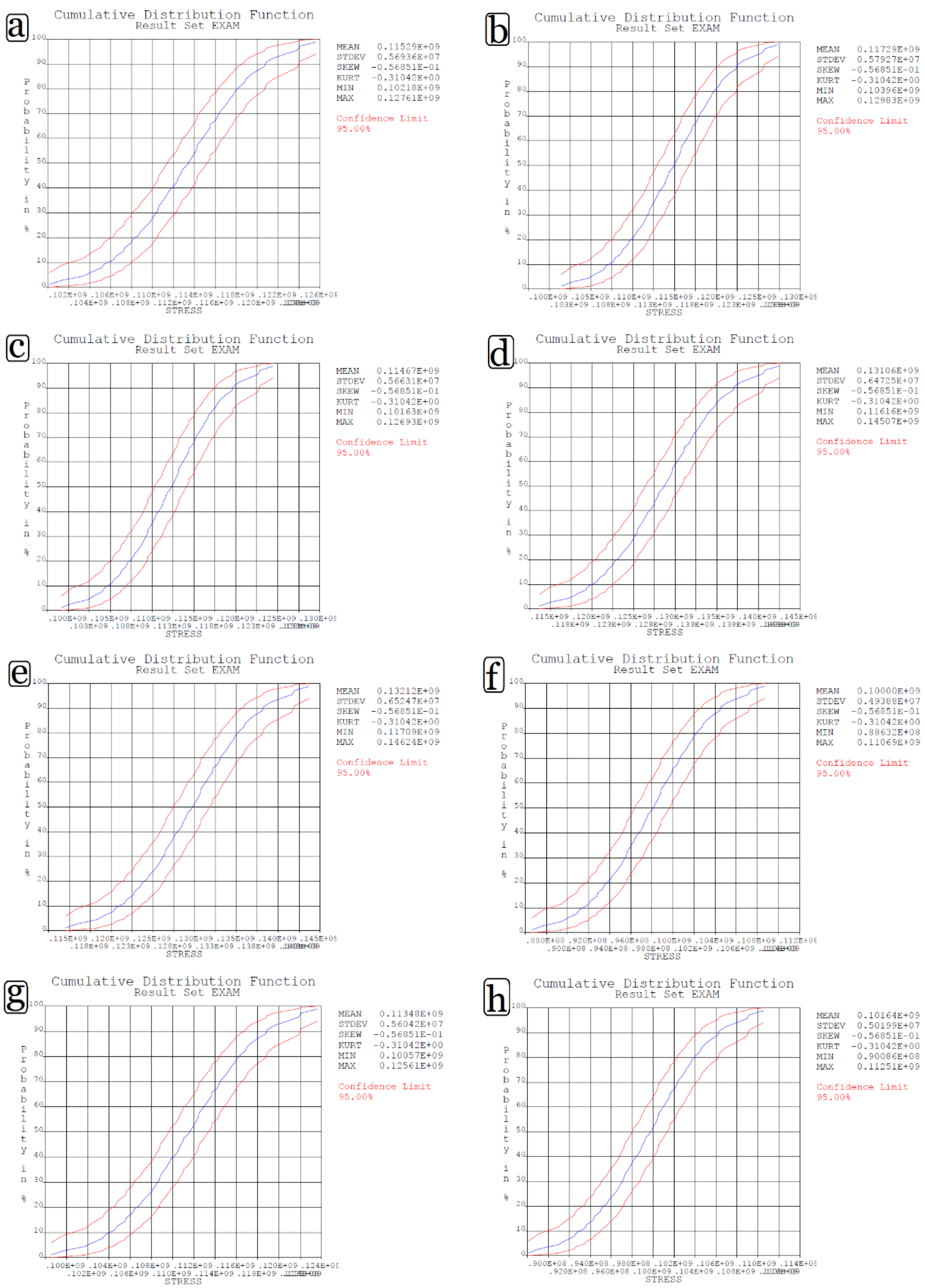


Figure 15. Distribution of maximum stress probability in configurations: (a) Resalat, (b) A-3, (c) B-3, (d) C-3, (e) D-3, (f) E-3, (g) R-2, (h) X-1

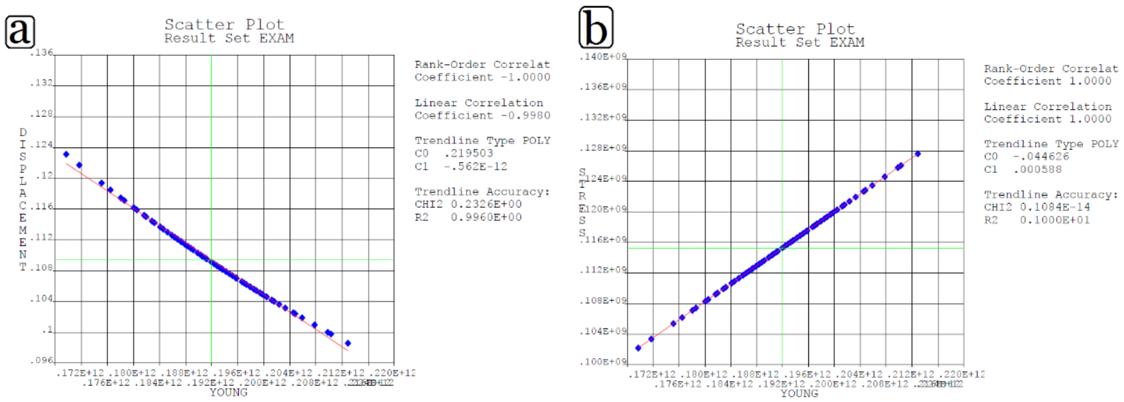
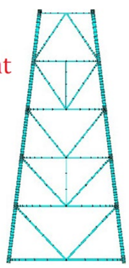
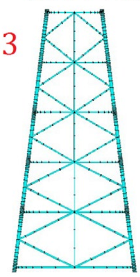
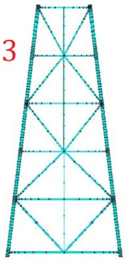
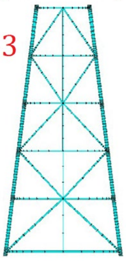
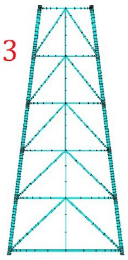
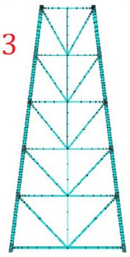
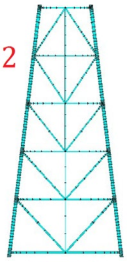
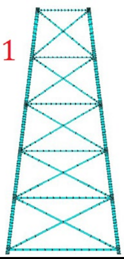


Figure 16. (a) Distribution plotting of horizontal displacement in terms of elastic modulus, (b) Distribution plotting of equivalent stress in terms of elastic modulus for Resalat platform configurations.

Tabeshpour and Fatemi [25] employed pushover analysis to examine the strength and ductility of different configurations. Then the configurations are compared considering an engineering index (P_b), which is a combination of normal strength and normal ductility. Configurations C-3 and X-1 are selected as the optimum arrangement of braces according to the combined energy based index considered by [25]. So by considering both indicators simultaneously, the X-1 configuration will be optimum compared to the other configurations.

Table 5. Comparison of different offshore platform configurations using the results of probabilistic analysis

Configuration	Maximum stress (S_{Max})	Normalized maximum stress ($S_{Max\ N}$)	Maximum displacement (D_{Max})	Normalized maximum displacement ($D_{Max\ N}$)	$S_{Max\ N} \times D_{Max\ N}$
Resalat 	0.12761E+9	1	0.12312	1	**1**
A-3 	0.12983E+9	1.02	0.098646	0.8	0.82

B-3 	0.12693E+9	0.99	0.10720	0.87	0.86
C-3 	0.14507E+9	1.14	0.10715	0.87	0.99
D-3 	0.14624E+9	1.16	0.10575	0.86	1
E-3 	0.11069E+9	0.87	0.12375	1.01	0.88
R-2 	0.12561E+9	0.98	0.12308	1	0.98
X-1 	0.11251E+9	0.88	0.10020	0.81	0.71

4. Conclusion

This work executed the PDS of different configurations of jacket structures, considering the Resalat platform as the case study. Two-dimensional modeling is accomplished, and analyses are done utilizing *ANSYS* software. The elastic modulus is considered as the random input variable while maximum stress and horizontal displacement are selected as the random output variables. Probabilistic analyses are performed on the different kinds of bracing configuration of the Resalat platform via LHS method. The configuration of X-1 with an index of 0.71 is better than other configurations, considering the index used in the current paper as a combination of the maximum normal stress and maximum normal displacement. Based on past studies, it can be said that in probabilistic analysis, the random output variables are stress and displacement, and no other output can be considered. In marine structures, especially the upper part of the structure (deck) should experience the least displacement, and therefore the ductility criterion is not very justified in this regard. In addition, the jacket structure is only exposed to waves at the installation site and can withstand these forces well. As a result, the structure should provide a safe environment for the staff (residents) with minimal movement in the deck area.

As a result it can be taken that the X-1 configuration is the optimum bracing configuration according to the PDS index (present work) and the combined energy based index [25]. So by considering both indicators simultaneously, the X-1 configuration will be optimum compared to the other configurations. As a result it can be taken that the X-1 configuration is the optimum bracing configuration according to the PDS index (present work) and the combined energy based index [23]. According to this study, it can also be said that configuration C-3 is not a good configuration in terms of probability index. As shown in this paper, best arrangement of bracing configuration in JTOP structures based on PDS is different from the configuration obtained from other methods. Due to the progress of design codes towards probabilistic scheme, it may be a perspective design scheme to other JTOP structures in the future. In addition, Tabeshpour and Fatemi [23] used a nonlinear analysis (massive and time consuming calculations) with high simplification assumptions (high probability of error). This is while we used a reliable probabilistic method (ANSYS software). On the other hand, Damage in structural members are among the primary harms and are not very dangerous at first. Over time conditions change and the cracks grow and affect the stiffness of the members. This problem disrupts the performance of the structure. So, when the cracks have the greatest effect on the reduction of stiffness, the elastic modules as uncertain variables can be used.

Although the results of these two studies are close to each other, so for a more detailed study can be done by conducting a laboratory study to judge the results of these two studies. This part of the work could be the subject of future studies. Of course, other practical problems have been remaining unsolved and they must be considered as the topics of the futures researches and the method must be improved by treating of them, during the furthering studies.

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