Research Journal of Applied Sciences, Engineering and Technology 5(3): 750-759, 2013
DOI:10.19026/rjaset.5.5018
ISSN: 2040-7459; E-ISSN: 2040-7467

Submitted: June 07, 2012 Accepted: July 09, 2012 Published: January 21, 2013

Research Article

Modelling for Uncertainties in Resistance for Jacket Platforms in Malaysia

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Abstract: Structural design strength is based on characteristic values of basic random variables of resistance. The behavior of these variables of strength may vary in such a way that they become unsafe during any time of their design life. The data for this study was collected from an ISO certified fabrication yard in Malaysia and was used to make statistical models. The collected data is based on jackets which were under construction at the yard. Statistical analysis of the data was performed, taking into account the mean, coefficient of variation and bias values. Initially basic random variables were analyzed and after their statistical parameters were found, the basic stresses were simulated based on ISO 19902 code equations. Finally recommendations are made for the statistical characteristics of the random variables to be used in this region for the reliability analysis for tubular members and joints for ultimate limit state design of jacket platforms in Malaysia.

Keywords: Distributions, jacket platform, material resistance, modeling uncertainty, monte-carlo simulation

INTRODUCTION

The uncertainty in resistance variable can play a major part in safety, performance and structural behavior of tubular members of jacket platform. There are 4 types of uncertainties in offshore engineering namely aleatory (inherent/physical randomness), epistemic (statistical/ lack of knowledge), model-related and human error based. The physical randomness is always present in our nature, like wind, wave and current. This inherent randomness is most difficult to forecast. Epistemic uncertainty relates to fewer amounts of available data to analyze it like yield stress, diameter and thickness of member. This could be improved by the increase of data. Model uncertainties are due to our lack of understanding and simplification of the equation provided by codes for arriving at the stresses/forces in the element. These are measured against the actual test results. The human error uncertainty depends on knowledge of person designing the structure, construction and operation of the structure.

These uncertainties can make variations in resistance that will lead ultimately to significant effect on the reliability analysis of jacket platforms. The actual strength is always random in nature and it tends to show its behavior in random way. To measure the uncertainty for reliability analysis, we need to define the basic variables involved in the limit state equation. These variables are used to define the probability/ cumulative density function along with other statistical properties like mean, coefficient of variance and bias. Once this random behavior is understood, it makes the task of designer much easier due to reduced uncertainty of material.

For reassessment of existing platforms, we need to define the actual uncertainties of the material and actual environmental loads acting at the site. Material uncertainties may change after some time due to degradation of material especially from fatigue and corrosion environment. These uncertainties are most important if we are considering lifetime extreme probability of failure instead of operational conditions of one year probability of failure.

The uncertainty related to prediction of resistance variability can be calculated using simulation techniques. In this study, Monte-Carlo simulation technique was used to generate values for fundamental resistance variable using their statistical distributions. Monte Carlo simulation was used by repetition of random samples using mathematical models. By simulation, the data was generated with consistent probabilities. This type of simulation is used, where assets are limited, experiments are not possible or extremely difficult to do. The transfer equation (the mathematical equation used for processing the data) is used for all the nine types of stresses. After the transfer equation is defined we need to find the distribution and its parameters for the random variables used in the given equations. The next step is to create high amount of random data in the order of $1*10^5$. This is due to the fact that our data include many values of that random variable small or large. Using the transfer equation, the large simulated data is generated based on our input

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random variables; this gives us reliable outcome without any experiments.

The study on these variations has been done on different land-based and offshore structures in other parts of the world and is available in literature. In this study, an effort is made to compile and analyze the data as per conditions in Malaysia which is required as per ISO 19902 requirement. There were three steps for this study. The first one was to collect the data i.e., data sets were made which were deemed appropriate for representing the random variables used in this study. The second step was to make statistical analysis of random variables used for design equations of jacket platforms i.e., tubular members. The Last step was to put these random variables in ISO 19902 code equations and get the basic parameters for the stresses. This step is more concerned with finding the probability distributions of these stresses. Here, nine random stresses are modeled using ISO 19902 code. After the analysis, it has been compared with other similar studies made in different regions related to offshore platforms.

LITERATURE REVIEW

Structure can fail if the characteristic value of load exceeds the characteristic load carrying capacity. Working Stress Design method is based on safety factor provided only to the resistance of the material without considering the uncertainties related to the loads as shown in (1):

$$S < \emptyset R \tag{1}$$

where,

S : Load

R : Resistance

$\emptyset$: Material strength safety factor and it covers the randomness of the material and the load

Thus in WSD, factor of safety is given by:

$$S.F. = R/S$$

Limit State theory is based on (2):

$$\emptyset R = \sum_{i=1}^{n} \gamma_i S_i \tag{2}$$

R : Characteristic/Nominal value of resistance

S_i : Characteristic/Nominal value of Load

$\emptyset$: Resistance Factor (for uncertainty in stress)

γ_i : Load Factor (for uncertainty in load)

n : Number/type of Load components

It is considered that a structure will fail if the load effect S, exceeds the resistance of the member R and structural failure is shown as (3):

$$P_f = P(R < S) \tag{3}$$

Structural safety requires that, required strength /Stress (R)>Design Strength/Loads (S). Variability in resistance parameters was found through collection of data and fitting of it based on probability distribution. Statistical parameters (mean, variation coefficient etc.) were obtained for geometrical and material properties.

Uncertainty modeling is the first important step for the reliability analysis for the jacket platforms. The reliability analysis is significantly dependent and very susceptible to the modeling of uncertainty (Mark *et al.*, 2001). Structural analysis calculations of offshore platforms are also subject to uncertainties. Uncertainties are dealt with by taking into consideration random variable parameters of load and resistance. Uncertainties are analyzed based on how much basic information is available about that random variable parameter (Phani, 2006). Any structure designed and built with up-to-date knowledge, cannot be assumed as free from any chance of failure. It is a known fact that design involves many uncertainties which are not clear at the time of design and thus the structural engineer uses probabilistic reasoning for design of structure. Code developing authorities assume certain values for basic parameters, which are expected to cover for the uncertainties involved with the material properties during the entire life of the structure. Based on these uncertainties the model equations are developed which contains some factors. These are called factors of safety in WSD however load and resistance factors in limit state design and provide a high level of assurance that the structure will perform satisfactorily. Despite all these safety factors, some unforeseen load condition, may cause the failure of structure (Galambos, 1972).

Uncertainty determination is based on computational tools, which enable the certification of analytical results by determining the component safety, subjected to the uncertain variable loads and resistances during design (Phani, 2006). Generally load tends to increases with time where as resistance tends to decreases with time, thus uncertainty of load as well as resistance increases with time (Melchers, 1999). Ellingwood says that the result of uncertainty is risk, which is defined as ‘the product of the probability of failure and costs associated with failure of structure’ (Ellingwood, 1994). Materials like steel have variability due to construction practices. The structure can also fail due to material failure from variation in dimensions as well as fabrication error. These problems can only be solved by introducing the probability into account for the risks involved in the uncertain design of offshore jacket platforms. Probabilistic calculation techniques enable these uncertainties to be taken into account.

Table 1: Details of selected platforms for resistance uncertainty

Platform	Location	Jacket height (m)	Fabrication year	No. of jacket legs	Material source
A	Peninsular Malaysia	73.40	2009	4	Japan
B	Peninsular Malaysia	72.00	2009	4	Japan
C	Peninsular Malaysia	60.40	2007	4	Japan
D	Sarawak	56.70	2005	4	Japan
E	Sarawak	53.60	2008	4	Japan
F	Sabah	55.20	2009	3	Japan

Probabilistic calibration is done to find safety factors in a balanced manner, which takes into consideration the sources of uncertainty in environmental loads as well as material resistance (Niels, 2005).

ISO 19902 Clause 7.7.4 requires that the test/measured data should be validated by simulation for the resistance of material taking into account the structural behavior variability of material (International Standard Organization, 2007). DNV report 30.6 recommends that for resistance model normal distribution should be considered for the reliability analysis of jacket platforms (DNV, 1992). The difference between strength and load variable is highlighted by the fact that strength variable is considered unsuitable if its value is less than the mean value in case of failure. The load variable is unsuitable against failure, if it is greater than the mean value. Previous studies on resistance of material have been made by Paul *et al*. (2002), Moses (1995), Moses and Stahl (2000), Frieze *et al.* (1997), Bomel (2003) and Duan and Zhou (2005). The mean value should be greater than 1.0 which shows the conservativeness of code equations and usually normal distribution is assumed for it (Joint Committee on Structural Safety, 2001). Modeling uncertainties are introduced by all the physical models used to predict the load effects and the structural response (Guenard *et al*., 1987). The results are based on geometric as well as material variability of material. The uncertainty model (X_m) is shown by (4):

$$X_m = \frac{Actual\ Value}{Predicted\ value} \tag{4}$$

METHODOLOGY

This study is based on assumption that reliable models of uncertainty can be developed, based on limited amount of data. Monte Carlo simulation can be used to generate long simulated data, from which the natural variability can be estimated based on the type of distribution the actual data. These uncertainty models were used to find the reliability of jacket components and joints based on ultimate strength limit state design.

Collection of data: The data was collected from a fabrication yard in Perak state of Malaysia for three months in 2010. The material properties were based on mill test reports for 6 jacket platforms. The details of these platforms are provided in Table 1 which covers all three regions of Malaysia i.e. Peninsular Malaysia, Sabah and Sarawak. Diameter and thickness were determined by field measurements. In total 72 mill tests results were used to measure the variability of material properties of tubular members. For geometric variability, 220 specimens were taken for diameter variation and for thickness variation the samples size was 26. The data was collected in the form of field measurement as well as mill test reports, as shown in Table 2 Fig. 1 and 2.

Table 2: Variability of material properties as shown in mill test report

Mechanical test		
Yield stress	Tensile strength	Elongation
319	475	31
308	471	24
320	475	28
318	471	31
357	505	26
364	508	26
338	499	26
357	505	26
388	508	22
361	499	23
388	521	22

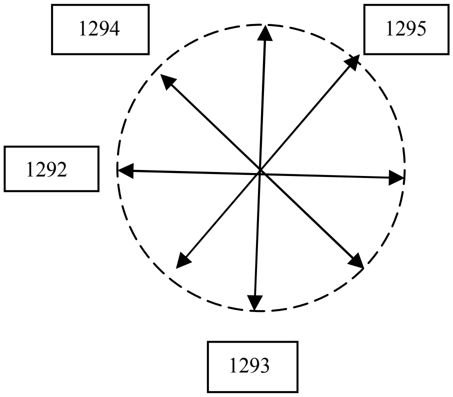

Fig. 1: Variability of diameter

Statistical assessment: The strength of jacket depends on the variability of its components from which the member is built. The primary members of jacket are piles, legs, horizontal periphery braces, horizontal internal braces and vertical diagonal braces. All these members are in nine different types of stresses when

Fig. 2: Data collection for diameter and thickness of tubular members of jacket platform at fabrication yard

Table 3: Resistance uncertainties for jacket platforms

Types of resistance uncertainty	Example
Material uncertainty	Yield strength, modulus of elasticity
Geometric uncertainty	Diameter, thickness
Fatigue uncertainty	Degradation of material
Corrosion uncertainty	Degradation of material

loaded. Codes provide equations to find these stresses based on resistance of random variables from which members are fabricated. Resistance variability includes dimensional variability like member diameter, thickness or material variability like yield strength, tensile strength or elongation properties of steel, modulus of elasticity. Table 3 shows the uncertainties related to offshore jacket platforms. Here in this study material and geometric uncertainties are discussed, due to their relevance to ultimate limit state design.

Geometric and material properties: The geometrical uncertainty relates to the randomness due to geometrical variations which come from straightness, diameter, thickness, length. Though this type of uncertainty can be dealt properly, with the application of quality control used by manufacturing industry as per international standards, still there remains some uncertainty. There were variations between characteristic values mentioned on structural drawings and fabricated component of platform. For instance in the case of diameter, there were four values measured at each $90°$ were available. The characteristic value was already mentioned on the structural drawings. The mean bias was calculated by (5):

$$\text{Mean bias} = \frac{Measured}{Nominal/mean} \tag{5}$$

The mean bias values were then statistically analyzed and respective distributions are reported. Coefficient of variation shows the variability in the model. For reliability analysis on resistance model we are concerned that for 95% the value taken by design engineer is higher than that value of resistance.

The material uncertainty includes yield strength, ductility and elongation, modulus of elasticity. Mill test reports were used to find the statistical properties of the tubular members. As per ISO requirement the ration of yield to ultimate tensile strength is given by' Frieze *et al.* (1997):

$$\frac{Yield\ strength}{Ultimate\ tensile\ Strength} = \frac{355}{490} = 0.724 < 0.85$$

All variables in this study are assumed to be independently distributed. The data is analyzed by using three goodness of fit test, i.e., Kolmogrov-Smirnov Anderson Darling and Chi-Square test. The results were based on these test reports. The recommended values in this study are reported as MS (Malaysian study). The distribution types, Bias and Coefficient of Variations for materials found are used for the reliability analysis of steel tubular members of jacket platforms in Malaysia.

RESULTS AND DISCUSSION

Statistical properties of fundamental variable for resistance: The basic variables of resistance are thickness, diameter, yield strength and modulus of elasticity. The results from this study were compared with studies in China and North Sea.

Geometric properties: The uncertainties for Geometric properties, considered in this study are the diameter and thickness for legs and braces. These are the basic variables for the reliability analysis. Samples collected for thickness variations were 26, for leg diameter 260 and for brace diameters 113. The analyzed data is shown in Table 4 and Fig. 3 to 5. The mean bias and variation coefficient of current study is shown in column 1 of these tables. Statistical analysis was used to find the parameters of distribution and probability density function based on goodness of fit tests. Three distributions were fitted and three best fit were reported. The results show that the best fit was achieved with normal distribution. The best distribution fit achieved for China and North Sea (DNV) code and ISO 19902 was also normal.

Material properties: Material property uncertainties considered in this study were yield stress, tensile

Table 4: Statistical variation in tubular geometry

		MS			Bomel (2003)	Adams *et al.* (1998)
Type of variability	Statistical parameters	Leg>1000 mm	Brace<1000 mm	Duan and Zhou (2005)	ISO	
Diameter (mm)	Distribution	Normal	Normal	Normal	-	Normal
	S.D./V.C.	0.0014	0.0018	0.0025	0.001	0.0025
	M.C.	1.0010	0.9993	1.0000	1.005	1.0000
Wall thickness (mm)	Distribution	Normal	Normal	Normal	-	Normal
	S.D./V.C.	0.0160	0.0160	0.015-0.050	0.0024+0.25/T	0.0210
	M.C.	1.0240	1.0240	1.0000	1.000	1.0000

MC: Mean coefficient; S.D./V.C.: Standard deviation/variation coefficient

Table 5: Statistical variation in yield stress

	MS	Duan and Zhou (2005)	Bomel/ISO Bomel (2003)	Adams *et al.* (1998)
Distribution	Normal	Normal	Log-normal	Log-normal
S.D./V.C.	0.05	0.050	0.06	-
M.C (Bias of mean)	1.23	1.120	1.13	1.02-1.09

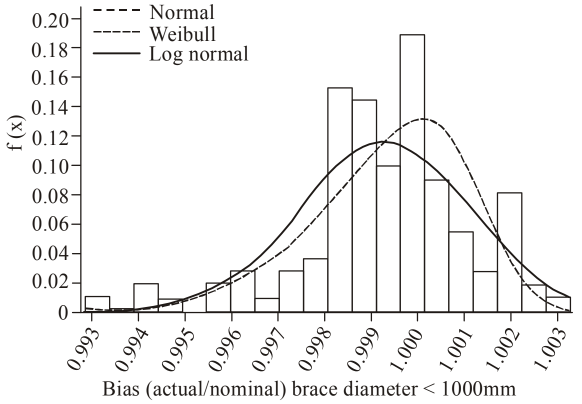

Fig. 3: Probability density function for brace diameter <1000 mm

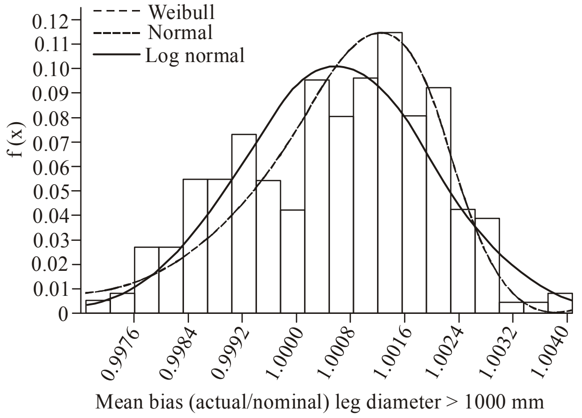

Fig. 4: Probability density function for leg diameter >1000 mm

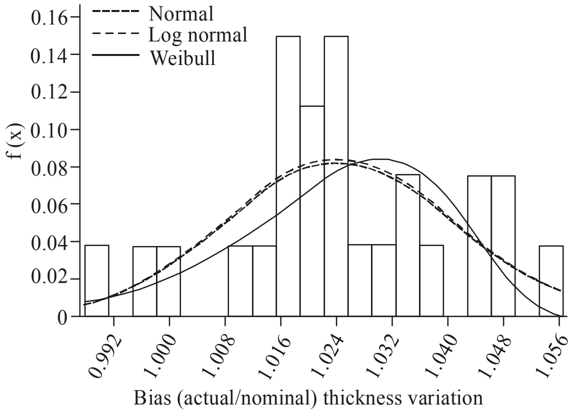

Fig. 5: Probability density function for thickness variation

strength and elongation. Table 5 and Fig. 6 to 8 show the statistical properties and probability density function. The sample size for yield strength obtained from mill certificates were 72 with nominal yield strength of 345 and 355 MPa, respectively. The mean bias and variation coefficient of current study is shown in column 1 of Table 5. Three distributions were fitted and the best fit out of three are reported as per goodness of fit tests. The analysis shows that the collected data fits with the normal distribution. The results achieved in China report normal Distribution and North Sea (DNV) Code and ISO 19902 reported Log-Normal, though (DNV, 1992) recommends the normal distribution for resistance or strength of members.

For tensile strength no comparison from literature review was available the sample size was 72 and mill tests reported characteristic strength of 490 MPa. The best fit was found to be normal distribution; other parameters were mean bias 1.123 and COV (Coefficient of Variation) 0.039.

For elongation also no comparison from literature was available. The sample size was 70 and characteristic value of 18-20% was reported in mill certificates. After analysis the distribution as per goodness of fit test was found to be normal, with mean bias of 1.52 and COV of 0.09.

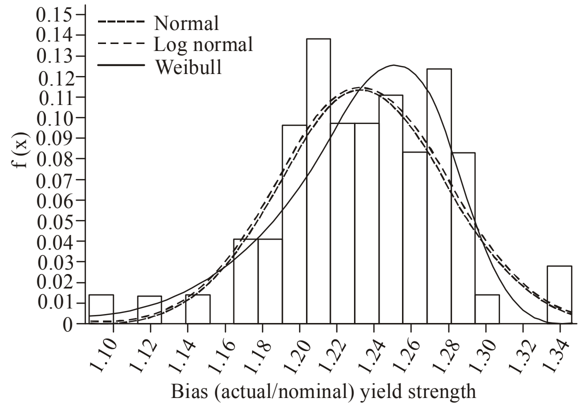

Fig. 6: Probability density function for yield strength

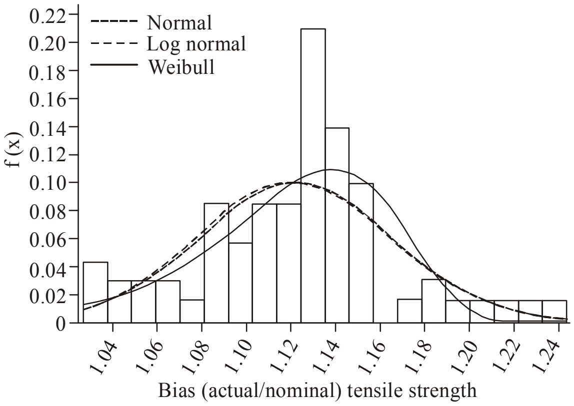

Fig. 7: Probability density function for tensile strength

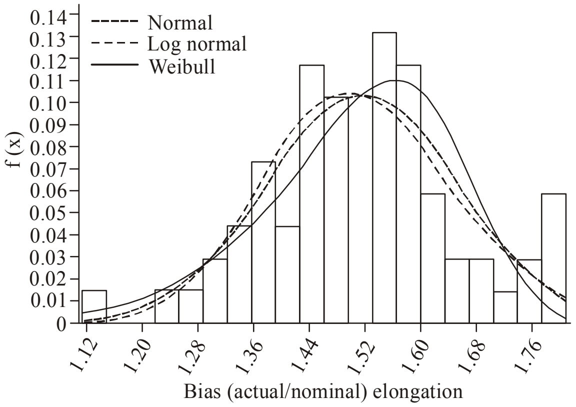

Fig. 8: Probability density function for elongation

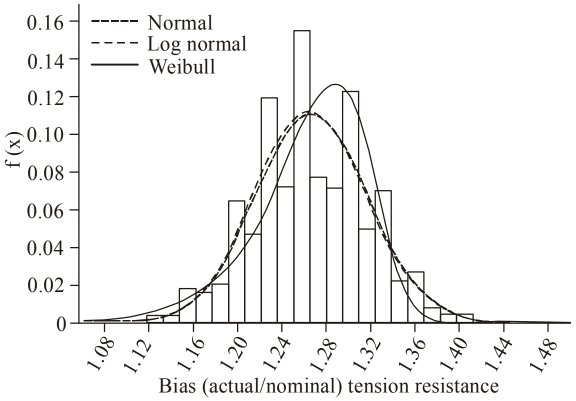

Fig. 9: Probability density function for tension resistance

Probabilistic model stresses used in ISO code 19902: API RP2A WSD and ISO 19902 code of practice identify nine types of stresses which jacket members can undergo during operating and storm loading conditions. Equation used for the model is taken from ISO 19902. Monte-Carlo simulation was used during

Table 6: Resistance model for one stress

Types of stresses	Statistical parameters	MS	Bomel/ (Bomel, 2003) ISO	Duan and Zhou (2005)	MSL (2000)			HSE (Bomel, 2001)	Moses (1995)
					ISO	LRFD	WSD		
Axial tension resistance	M.C.	1.26	1.00	1.19	-	-	-	-	-
	S.D./V.C.	0.05	0.00	0.07	-	-	-	-	-
Axial compression (column buckling) resistance	M.C.	1.26	1.05	1.16	1.26	1.23	1.16	1.06	1.19
	S.D./V.C.	0.05	0.04	0.12	0.06	0.05	0.08	0.05	0.12
Axial compression (local buckling) resistance	M.C.	1.24	1.07	1.233	1.26	1.32	1.40	1.07	-
	S.D./V.C.	0.05	0.07	0.10	0.09	0.08	0.08	0.07	-
Bending resistance	M.C.	1.13	1.11	1.32	1.16	1.16	1.43	1.11	1.26
	S.D./V.C.	0.05	0.09	0.11	0.09	0.10	0.12	0.10	0.11
Shear resistance	M.C.	1.26	1.00[*]	0.19	-	-	-	-	-
	S.D./V.C.	0.05	0.05	0.09	-	-	-	-	-
Hydrostatic resistance	M.C.	1.59	1.14[a]	-	1.43	1.43	1.85	1.14	1.05
	S.D./V.C.	0.16	0.14	-	0.12	0.12	0.12	0.12	0.11-0.15

*: Log-normal; [a]: Not known

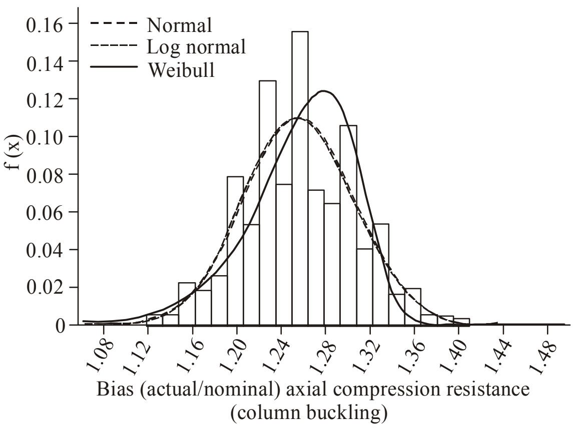

Fig. 10: Probability density function for axial compression resistance (column buckling)

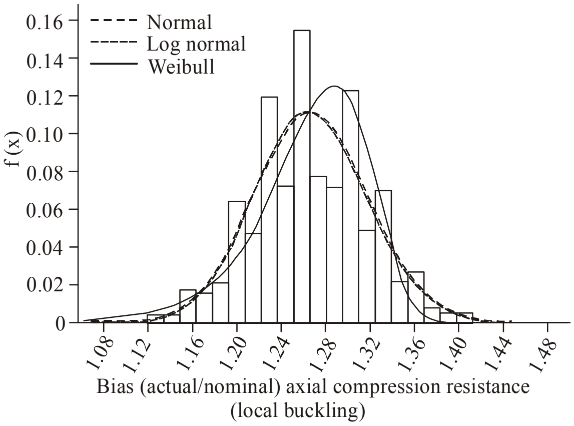

Fig. 11: Probability density function for axial compression resistance (local buckling)

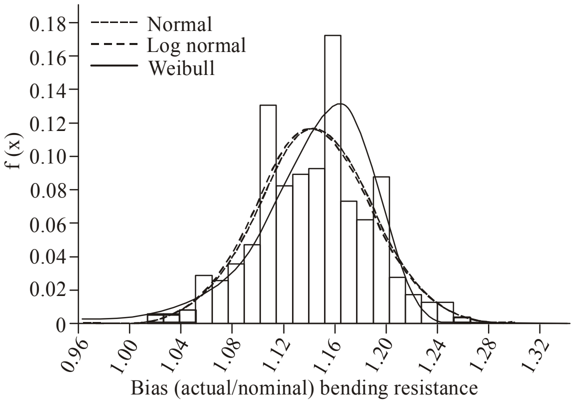

Fig. 12: Probability density function for bending resistance

this study. Simulated sample size was fixed at $1*10^5$ and the nominal f_y used was 345/355 MPa.

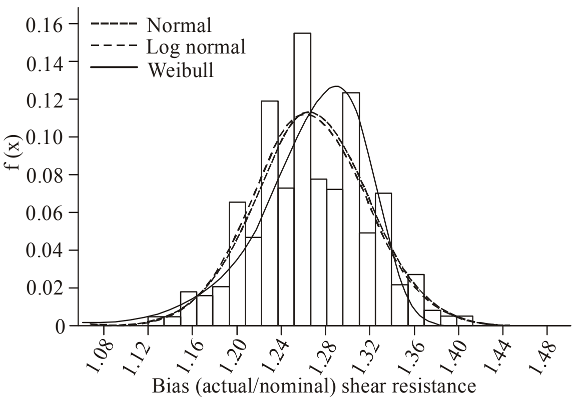

Fig. 13: Probability density function for shear resistance

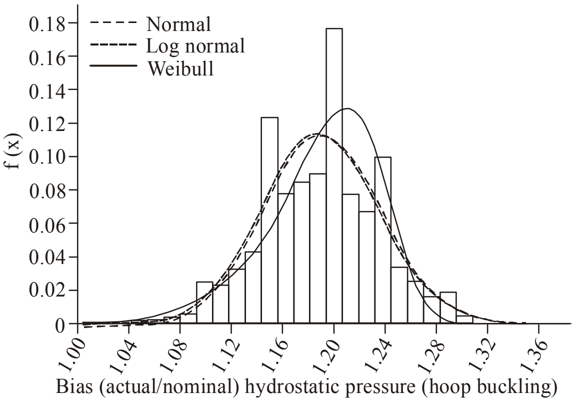

Fig. 14: Probability density function for hydrostatic pressure (hoop buckling)

Single stresses: ISO 19902 and API RP2A code identify following types of member stresses, in which jacket platform undergoes during operation. These are:

- Axial tension
- Axial compression (local buckling) and (column buckling)
- Bending
- Shear
- Hydrostatic pressure/hoop buckling

Table 6 and Fig. 9 to 14 show the statistical properties and probability density function of the single stresses. The parameters of distribution for geometric and material properties, used in the given equation were normal. The law of probability says that combined distributions will give the result of normal distribution. The mean bias and variation coefficient of current study is shown in column 3 of these tables. Column 4 shows the data reported for North Sea which was incorporated in ISO code and column 5 shows data development of LRFD code for China.

Combination of two stresses: These are identified as:

- Axial tension and bending
- Axial compression local buckling and bending
- Axial compression column buckling and bending

Table 7 and Fig. 15 to 17 show the uncertainty model for the code equations. This uncertainty model was used for the reliability analysis for jacket platforms in Malaysia. The coefficient of variation and mean bias values are reported in the given tables. In this study the mean values achieved were 1.19 to 1.28. For ISO code the same were in range of 1.03 to 1.25 which is not much different from this study. The variation coefficient achieved in this study was in range of 0.047-0.050 but the same achieved for ISO code was 0.083-0.094 which shows more variation in the results. This is due to difference in basic uncertainty models used for geometry and material properties used in the given equations. There may be other reasons also such as improved quality of material as well as fabrication variation coefficients introduced in the manufacturing industries. Due to this reason uncertainties are reduced, with less variability in material and in fabrication of tubular members.

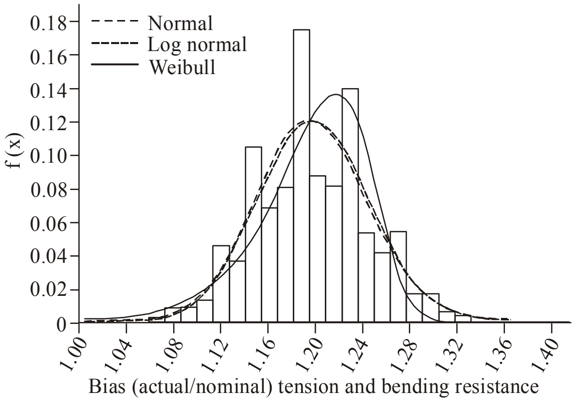

Fig. 15: Probability density function for tension and bending resistance

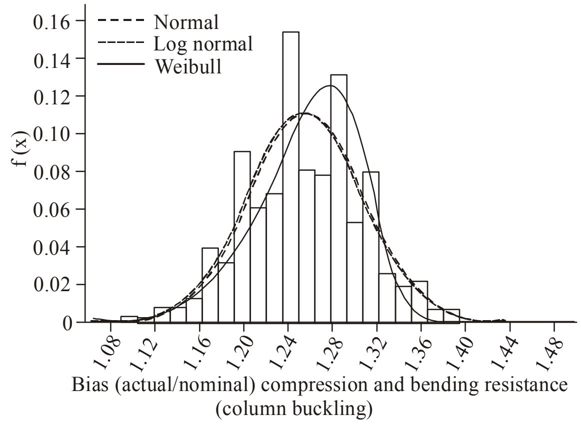

Fig. 16: Probability density function for compression and bending resistance (column buckling)

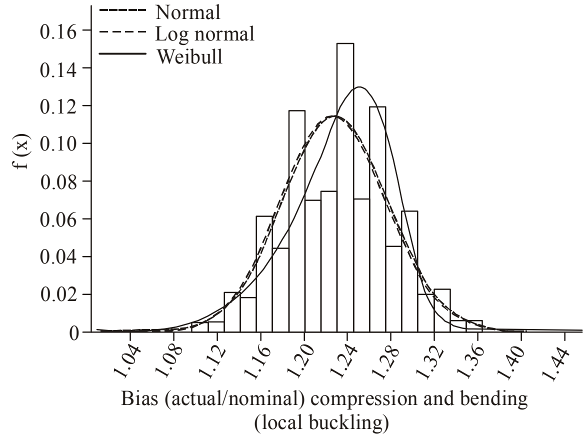

Fig. 17: Probability density function for compression and bending (local buckling)

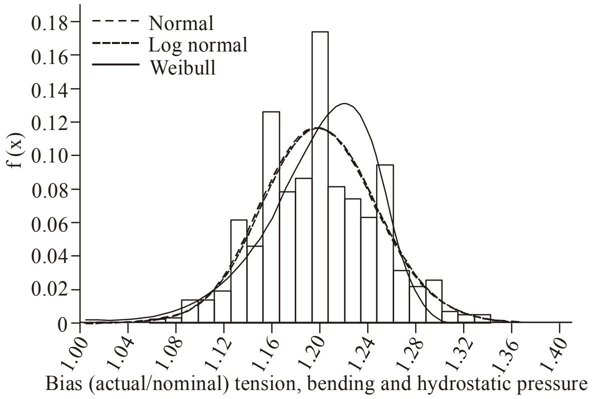

Fig. 18: Probability density function for tension, bending and hydrostatic pressure

Combination of three stresses: Offshore Jacket design codes identify three types of stresses which a platform is subjected. These are:

- Axial tension, bending and hydrostatic pressure/hoop buckling and
- Axial compression local buckling, bending and hydrostatic pressure
- Axial compression column buckling, bending and hydrostatic pressure

Table 7: Resistance model for combined two stresses

Types of stresses	Statistical parameters	MS	Bomel/ISO (Bomel, 2003)	MSL (2000)			HSE (Bomel, 2001)
				ISO	LRFD	WSD	
Tensile & bending resistance	M.C.	1.19	1.11	-	-	-	-
	S.D./V.C.	0.05	0.10	-	-	-	-
Compression & bending resistance (column buckling)	M.C.	1.27	1.03	1.14	1.15	1.15	1.03
	S.D./V.C.	0.05	0.08	0.10	0.10	0.09	0.08
Compression & bending resistance (local buckling)	M.C.	1.23	1.25	1.41	1.43	1.61	1.25
	S.D./V.C.	0.05	0.08	0.06	0.05	0.11	0.08

Table 8: Resistance model for member under combined three stresses

Types of stresses	Statistical parameters	MS	Bomel/ISO (Bomel, 2003)	MSL (2000)			HSE (Bomel, 2001)
				ISO	LRFD	WSD	
Tension, bending and hydrostatic resistance	M.C.	1.27	1.08	-	-	-	-
	S.D./V.C.	0.05	0.11	-	-	-	-
Compression bending and hydrostatic resistance column buckling	M.C	1.28	1.20	1.33	1.29	1.43	1.25
	S.D./V.C.	0.05	0.11	0.16	0.12	0.20	0.14
Compression bending and hydrostatic resistance local buckling	M.C.	1.30	1.20	1.35	1.36	1.63	1.25
	S.D./V.C.	0.05	0.16	0.19	0.13	0.19	0.14

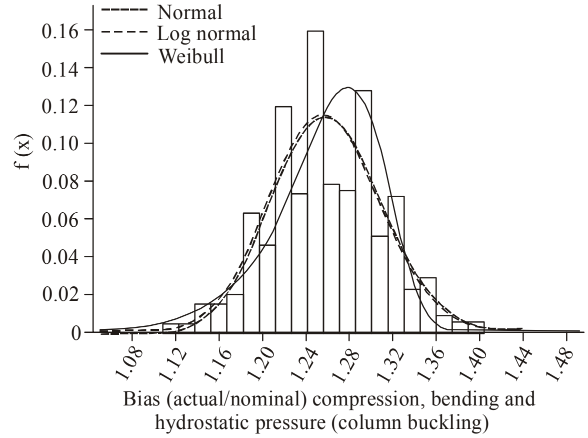

Fig. 19: Probability density function for compression, bending and hydrostatic pressure (column buckling)

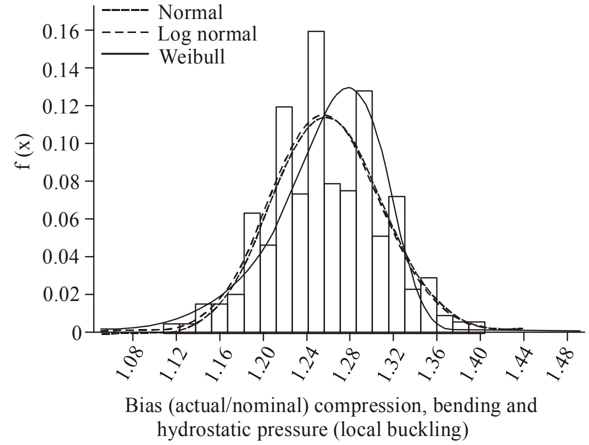

Fig. 20: Probability density function for compression, bending and hydrostatic pressure (local buckling)

Table 8 and Fig. 18 to 20 show the uncertainty model in these equations. The mean bias values achieved for this study was 1.30 and the same for ISO was in the range of 1.08-1.20. This shows that mean values for this study are higher by small margin as compared to ISO code. The variation coefficient for this study was 0.05 and for ISO it is 0.11 to 0.16 which is higher than the present study, showing higher variation in ISO data. Thus the variability in this study is less than as reported in literature. Thus with less uncertainty, higher reliability can be achieved.

CONCLUSION

The actual strength of tubular member varies from the characteristic/nominal strength, which is taken for design of platforms. This is due to the variation in basic variables like material strength and dimensional properties like yield stress, elastic modulus, diameter and thickness. The bias and COV evaluated in this study, on the basis of database of actual data, reflects the geometry and material variability in Malaysia. To develop reliability models we need to identify the variability in actual tubular members and model stress equations used by ISO code and API WSD code. Following results were achieved during this study:

- Uncertain basic variables i.e., thickness, diameter, yield strength, tensile strength and elongation are modeled based on actual variability in the material available in Malaysia. The variation coefficient and mean bias values are reported. The reported values either meet the required criteria set by ISO or even show less variability in basic parameters used in equations for finding stresses in tubular members of jacket platforms.
- Nine stress equations were statistically modeled in this study. The model equations recommended by ISO code were used to find the variability in these equations. The uncertainty models achieved in this study were compared with models developed for ISO 19902 and LRFD code development in China. The variation in current study is less than that reported in literature with less variability in uncertainty model. Using this variability in the reliability model, our structure will have higher reliability. The results from this research were used for reliability analysis of components and joints for ultimate limit state design of jacket platforms in Malaysia.

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