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Component, Joint and System Based Environmental Load Factor for Jacket Platforms in Malaysia

V.J. Kurian, Z. Nizamani, M.A.W. Mohamed and *M.S. Liew*

Civil Engineering Department, Universiti Teknologi PETRONAS, Tronoh, Malaysia

ABSTRACT

Environmental load factors, currently used by the codes of practice for jacket platform design in Malaysia, are based on calibration of platforms located in Gulf of Mexico and North Sea. This does not reflect the locations where moderate climate governs i.e. regions lying near equator like Malaysian waters which lies at about 7deg from the equator. Four platforms from three different regions of Malaysia were selected for the reliability analysis and in this paper one platform results are presented, which is located near Peninsular Malaysia. Modified environmental load factor is proposed for this region considering component, joint and system reliability based calibration.

KEY WORDS: Load uncertainty; Resistance uncertainty; Reliability; FORM; Monte Carlo Simulation; API (WSD) & ISO 19902 Codes

INTRODUCTION

Effective utilization of component, joints and overall system of jacket platform, is achieved by taking into consideration the uncertainty of material, i.e. steel and uncertainty of load i.e. environmental load. Six platforms were selected for finding the variability of resistance. Monte Carlo simulation was used to determine the variability of stresses based on ISO code equations. Environmental data from eight platform locations were used to find the variability of wave and current. The wave and current data for 10 years and 100 years were used for the determination of statistical distribution. Weibull two parameters fitted well with the regional characteristics of Malaysian waters. The data for load and resistance was statistically analyzed, taking into account the mean, coefficient of variation and bias values.

First Order Reliability Method (FORM) was used to find the reliability index. BOMEL's equation was used for surface fitting the response of Jackets for component and joint reliability. The code equations considered for component based reliability analysis were tension, compression, bending, combined tension and bending as well as combined compression and bending, with and without hydrostatic pressure. The load factors based on joint calibration were determined using actual stresses the joints undergo i.e. tension, compression, in-plane bending and out of plane bending. The target reliability was based on API RP2A (WSD) for component and joint. Jackets designed as per this code have already proved their robustness. Sensitivity analysis was done with different environmental to gravity load ratios. System based calibration was made to find the load factor for varying gravity load to environmental load ratios. Heideman's equation was used for surface fitting the response of Jacket. Platform specific data was used to find its coefficients using the load variables. Notional probability of failure given by Efthymiou and Melchers was used to set target failure probability/ reliability index for system environmental load factors.

OBJECTIVES

ISO 19900-1 prescribes that for each geographic region the environmental load factor is to be specific for that region. ISO 19902 clause A.9.9.3.3 reads that, "for structures with the same geometrical and structural properties, harmonization in safety levels (as are in GOM), hence requires location dependent partial action factors". Therefore, in this paper, an effort is made to find the environmental load factors for Malaysia using component, joint and system based calibration.

LITERATURE REVIEW

Environmental load factors proposed for different geographical regions are shown in Table 1, where the load factors differ according to their environmental conditions. Offshore industry of Malaysia follows the load factors based on calibration of GOM and North Sea which are considerably higher as compared to this region due to mild weather conditions of Malaysia. It is clear that different regions have different environmental loads and thus same can be evaluated for offshore Malaysia.

Table: 1 Environmental Load Factors for different regions of world

Regions	Load Factors Proposed	Load Factors used
Gulf of Mexico	1.35 (ISO19902 2007)	1.35
North Sea	1.25 (BOMEL 2003)	1.35
Indonesia	1.1 (Pradnyana, Surahman et al. 2000)	1.35

Basic uncertainty

Uncertainties are considered for anticipating how much load Jacket shall be designed for (loading) and how much load a structure can withstand (resistances). Uncertainty reflects lack of information; it could be on the load side or on resistance side (Anthony, paul et al. 1977).

Resistance uncertainty

This uncertainty relates to the randomness due to geometrical and material variations which relate to straightness, diameter, thickness, length and yield strength. The other is model uncertainty due to deviation of material strength in a component strength acquired from test results (Niels 2005). This type of uncertainty accounts for possible deviation of model assumptions of the resistance of a given section from the actual resistance of geometrical section.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 (ISO19902 2007).

Load uncertainty

The variability of load is considered random in nature and during reliability analysis, probability distribution and its parameters are used instead of deterministic values. The nominal / characteristic load value is the value of the random variable which has a probability of not being exceeded during reference period of 100 years as prescribed by ISO 19902. Environmental load uncertainty, considered safe during design of a jacket platform may become unsafe during one hurricane event in GOM. This was experienced during the hurricane Ivan in 2004. Extreme value distributions i.e. Gumbel, Fretchet and Weibul are three theoretical distributions which are commonly applied to model load uncertainty parameters (Kunda 2005). Environmental load factor calibration for API RP 2A LRFD considered only wave parameters with bias 0.7 and COV 37% (ISO19902 2007). As this was same for wind, only wave was considered for reliability analysis. Weibull distribution fits well with significant wave height (Grant, Dyer et al. 1995).

Component, Joint Reliability& Environmental Load factor

Reliability is defined as an ability to achieve a desired purpose of platform under operational and extreme conditions during its desired life. Performance of a platform is measured in terms of reliability index or return period (probability of failure). Here in this study FORM method of reliability analysis was used to find the reliability index. The environmental load factor proposed by Moses and Bomel for API RP2A LRFD and ISO 19902 was 1.35 (Moses and Stahl 2000). Theophantos suggests use of target code WSD / LRFD RP 2A / ISO 19902 for selection of target safety index and determination of separate partial factors for individual component and load effect types (Theophantos, R.Cazzulo et al. 1992).

System Reliability & Environmental Load factor

Progress from elastic design to inelastic design is considered to be an evolution towards more efficient steel structure design based on system strength evaluation (Hellan, Moan et al. 1994). Failure of a structure is said to be global collapse i.e. load exceeding the ultimate capacity of the jacket (Mark.M, Birger.E et al. 2001). System reliability starts with a single member failure but it eventually causes the failure of whole structure. Reliability of jacket platform depends on performance of components but it is governed by structural system (Ferguson 1990). Reliability of a system is the product of individual member reliabilities. System reliability is higher than component reliability or system probability of failure is lower as compared to component probability of failure (Moan 1998). The environmental load factor for North Sea has been proposed by BOMEL based on system reliability. Though the report presents a load factor of 1.25, it was recommended to take it as 1.35 obtained for component reliability. The target probability of failure was set one step higher i.e. $3*10^{-5}$as proposed by Efthymiou for system reliability (Efthymiou and Graham 1990).

METHODOLOGY

Resistance uncertainty

The basic parameters were statistically analyzed using data collected from a fabrication yard in Malaysia. The Easy fit software was used for this purpose. The data was analyzed by using three goodness of fit test, i.e. Kolmogrov-Smirnov, Anderson Darling and Chi-Square test. The variability of model uncertainty for component and joint mathematical models given by ISO 19902 Code was achieved using Monte Carlo simulation. The probability of failure is shown by (1):

$$P_f = \frac{N_f}{N} \tag{1}$$

N_f= Number of failures, N = total number of simulation
The result achieved from Monte Carlo simulations were used in Easy Fit and based on best fit, the results are presented.

Load uncertainty

The data was collected from an offshore working entity in Malaysia. There were 8 data sets from (Peninsular Malaysian) region as shown Table 6. Available data was in shape of 1, 10, 50, and 100 years. In this study, 10 and 100 year data was taken for analysis due to consistency of data. For extreme conditions, Gumbel and Weibull distributions are the most important ones as these can capture the rare tail end events better. The reliability analysis results are sensitive to tail of probability distribution and therefore choice of distribution type is always crucial and resistance is most of the time normally distributed (DNV 1992).In this study, both Weibull two parameter and Gumbel were used but as Gumbel over predicted, Weibull was used for reliability analysis. Weibull distribution variable x, has the CDF as shown in (2),

$$Fx;(a,b) = 1 - exp\left\{-\left(\frac{x}{a}\right)^b\right\} \tag{2}$$

Parameters *a*= scale and *b*= shape

Table 2 shows the wave heights available in this region. Offshore Malaysia is divided into three regions i.e. Peninsular Malaysia (PM), Sabah and Sarawak. The H_{max}/H_s ratio for significant wave height (H_s) 5.3 m and maximum wave height (H_{max}) 10.9 m was 2.05.

Table: 2 Platform-Load Parameters

Parameter	10 year	100 year	Scale	Shape
H_{max} (m)	9.6	10.8	8.3315	5.8849
T_p (s)	10.3	10.8	9.7289	14.6227
Current (m/s)	0.98	1.10	0.8528	6.0006

Component, Joint Reliability & Environmental Load factor

Jacket consists of many members. In this study it was divided into different bays and those were further sub-divided into types of members. The members selected were horizontal braces at periphery, horizontal diagonal braces, vertical diagonals and leg members. Then they were grouped with reference to slenderness ratio. Then these group members were analyzed. Similar process was adopted for joints also. SACS software was used for the analysis of Jackets used for reliability analysis. The water depth was 61.7 m and Jacket length 78.2 m with design wave of 10.8 m.

Curve fitting

For fitting the response, surface fit equation (3) was used as given by (BOMEL 2003) and coefficients for K-joints are shown in Table 3.

$$W = aH_{max}{}^2 + bH_{max} + cV_c{}^2 + dV_c + e \quad (3)$$

Where H_{max} and V_c are the wave height and current speed based on Weibull distribution. Figure 1 show the joint stress values obtained from SACS analysis for one particular joint and the values obtained using (3). The result shows that the surface fit showed great approximation of real values obtained from actual analysis of Jacket.

Table: 3 Surface Fitting Load Coefficients for K-Joint

K-Joint					
Stress Type	a	b	c	d	e
Axial	0.01218	-0.0796	0.1052	-0.06624	0.259
IPB	0.01652	-0.1365	-0.00648	0.02542	0.388
OPB	0.05543	-0.9178	-0.02879	0.2514	4.008

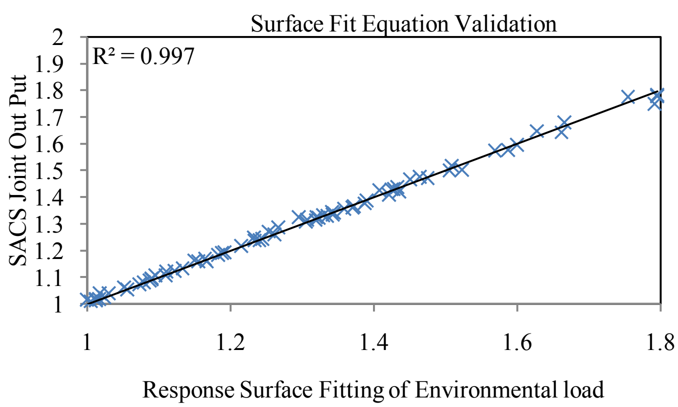

Figure 1: SACS output for joint stresses and surface fitting

Case study for reliability index for Axial Tension:

API (WSD) equation for axial tension is shown in (4)

$$F_t = 0.6F_y \quad (4)$$

Resistance of component is taken using ISO code equation (5)

$$R = f_{yi} * A_i * X_m \quad (5)$$

Where f_{yi} , A_i, X_m are random variables of yield strength, area and mathematical model uncertainty for axial tension.Now applied stresses are given by (6-7):

ISO (LRFD) : $S = f_{yn} * A_n$ (6)

API (WSD): $S = 0.6 * F_{yn} * A_n$ (7)

Here F_{yn} ,A_n are the nominal values. The load effect is shown by (8)

$$L_r = dD + lL + wW/X_w \quad (8)$$

Where,d ,l, w = Dead, Live and Environmental load ratios respectively, and , L, W,X_w= random variables of dead, live and environmental load and mathematical model uncertainty of environmental load. The main part of reliability analysis is that we need to know at what point the whole component or joint is fully utilized. Now the factor of safety in API WSD and ISO was utilized to give component or joint to be fully utilized, which requires that Factor of safety (FS) is evaluated as (9-10).

$$FS(API\ WSD) = \frac{4}{3*1.67} \quad (9)$$

$$FS(ISO) = \frac{(1/1.05)*(D+L+W/X_w)}{(1.1D+1.1L+(1.35*W/X_w))} \quad (10)$$

Thus, now actual load will be as (11)

$$Q = S * L_r/FS \quad (11)$$

The limit state equation is shown in (12):

$$g = R - Q \quad (12)$$

It is considered that a structure will fail if the load effect Q, exceeds the resistance of the member R. If g> 0 then the structure is safe; If g< 0 then the structure fails, where R and Q are random variables of resistance and loads. Structural failure is shown as (13)

$$P_f = P(R < Q) \quad (13)$$

Thus probability of survival can be shown by (14),

$$\beta = \Phi^{-1}(P_f) \quad (14)$$

Φ^{-1}=Inverse standard normal distribution

System Reliability & Environmental Load factor

Design capacity of component in ISO code is shown by (15),

$$\frac{R}{\gamma_c} \leq (\gamma_d * P_d + \gamma_w * P_w) \quad (15)$$

Here P_d, P_w are gravity and environmental load ratios, γ_d,γ_w are the gravity and environmental load ratios i.e. 1.1 and 1.35, γ_c= resistance factor for compression i.e. 1.18 and R is resistance of material.There is a relationship between API (WSD) RSR and ISO(LRFD) RSR. ISO

RSR can be found from the equation (16-19) given by(BOMEL 2003).

$$RSR_{ISO} = MOS_{ISO} * MF * ICSF * SR * P_d P_w \quad (16)$$

$$MOS_{\ ISO} = \left(\frac{\gamma_d * P_d + \gamma_w * P_w}{P_d + P_w}\right)\gamma_c \quad (17)$$

Material factor (MF) is based on the yield strength and ISO code recommends it as 1.15. System redundancy (SR) values are based on platform specific given by SACS collapse analysis. Implicit code safety factor (ICSF) is the difference between applied stresses

$$ICSF = \frac{RSR_{WSD}}{\left(P_d/P_w\right) * SR * MF * MOS_{WSD}} \quad (18)$$

Safety margin MOS_{WSD} are set as reported by code i.e. for extreme conditions there should be one third increases in the required stresses. In this study it has been fixed as 1.32 as also suggested by (BOMEL 2003), RSR_{WSD}= Platform specific reserve strength ratio taken from SACS collapse analysis.

$$RS\acute{R} = ICSF * MF * S_R \quad (19)$$

Surface fit was made by equation (20)given by Heideman (Gerhard 2005)

$$W = a_1 * (H_{max} + a_2 * u)^{a_3} \quad (20)$$

Here a_1 ,a_2 , a_3 are taken from curve fitting and u=surface current. The limit state equation for load and resistance is shown by (21-22):

$$Load = RSR_{WSD} * \left[Dd + Ll + w\left(\frac{a_1(H_{max} + a_2 u)^{a_3}}{X_w}\right)\right] \quad (21)$$

$$Resistance = a_1\left(H_{\max\,(des)} + a_2 u\right)^{a_3} * MOS_{\ ISO} * P_d P_{w\,ISO} * RS\acute{R} * X_w \quad (22)$$

RESULTS AND DISCUSSION

Resistance geometrical and material uncertainty

Characteristic resistance should have low probability of being exceeded at any specified design life of Jacket. It is the 5th percentile of test results most of the time, which is considered as the most unfavorable event (Holland 1977). The mean bias and standard deviations of the present Malaysian study is shown along with comparative results from China and North Sea in Table 4 and Figure 2.

Table 4: Statistical Variation in Geometry of Tubular Component and Joints

Type of Variability	Statistical parameter	Malaysia: Leg >1000 mm	Malaysia: Brace< 1000 mm	China (Duan 2005)	North Sea (BOMEL 2003)
Diameter (mm)	Distribution	Normal	Normal	Normal	
	MC	1.001	0.9993	1.0	1.005
	VC	0.0014	0.0018	0.0025	0.001
Wall thickness (mm)	Distribution	Normal	Normal	Normal	-
	MC	1.024		1.0	1.0
	VC	0.016		0.015-0.050	0.0024+ 0.25/T
Yield Stress	Distribution	Normal		Normal	Log-Normal
	MC	1.23		1.12	1.13
	VC	0.05		0.050	0.06

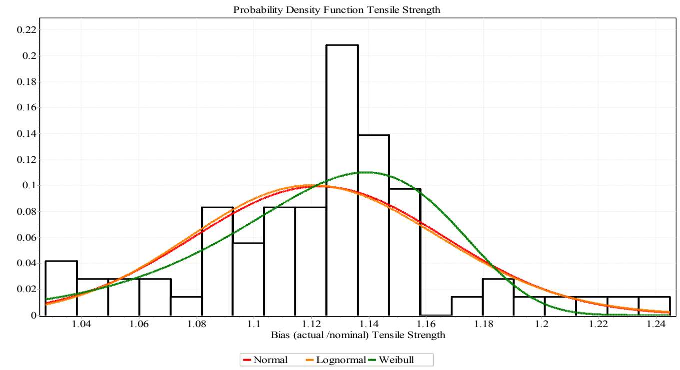

Figure 2: Probability Density Function for Tensile Strength

Resistance Model uncertainty

Resistance model uncertainty for seven code stresses and four joint stresses were developed using Monte Carlo simulation. Here, only combined stress data is shown in Table 5 and Figure 3 shows the resistance uncertainty model for X-joint under axial tension. The results show that there are similarities in the resistance uncertainty with the world regions because the material nowadays is more standardized as they follow ISO standard.

Table 5: Resistance model uncertainty for combined stresses

Types of Stresses		MS	(BOMEL 2003)	(MSL 2000) ISO	(MSL 2000) LRFD	(MSL 2000) WSD
TB	MC	1.19	1.11	-	-	-
	VC	0.05	0.10	-	-	-
CB (Column Buckling)	MC	1.27	1.03	1.14	1.15	1.15
	VC	0.05	0.08	0.10	0.10	0.09
CB (Local Buckling)	MC	1.23	1.25	1.41	1.43	1.61
	VC	0.05	0.08	0.06	0.05	0.11

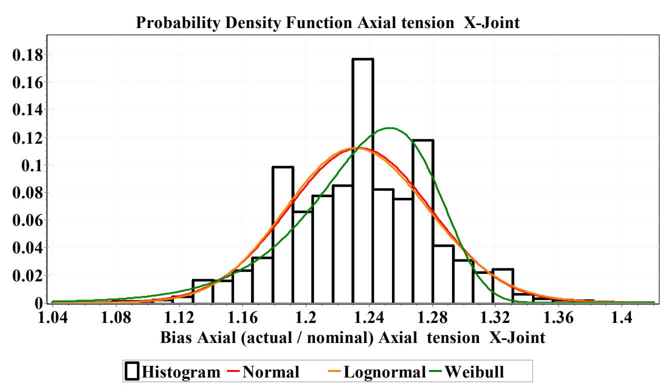

Figure 3: Probability Density Function for X-Joint Axial tension

Load Uncertainty Modelling

Significant wave height defines the characteristic wave height of a random wave and it is the basic and major parameter of environmental data for offshore structures. Tables 6 and 7 show significant wave height and current speed distributed as per Weibull distributions.

Table 6: Return Period and Parameters of Significant wave height based on Weibull distributions in PM region

PM	Return Period in Years		Weibull Distribution Parameters		
	10	10^2	Mean	Standard Deviation	COV
A	4.9	5.3	4.22	0.57	0.14
B	4.8	5.2	4.12	0.57	0.14
C	5.2	5.6	4.51	0.58	0.13
D	5.5	6.5	4.09	1.11	0.27
E	5.1	5.5	4.41	0.58	0.13
F	4.9	5.4	4.08	0.67	0.17
G	4.3	4.6	3.78	0.44	0.12
H	5.7	6.8	4.17	1.19	0.29

The coefficient of variation (COV) for wave, distributed as Weibull gave variation between 12%-30%. But COV for other regions was as high as 78%. Therefore there is large variation in significant wave height and current speed values.

Table 7: Return Period and Parameters of Current speed based on Weibull distributions in PM

PM	Return Period in Years		Weibull Distribution Parameters		
	10	10^2	Mean	SD	COV
A	0.98	1.1	0.79	0.15	0.19
B	1.14	1.25	0.96	0.15	0.16
C	1.15	1.3	0.92	0.19	0.20
D	1.15	1.35	0.86	0.23	0.26
E	1.05	1.2	0.82	0.18	0.22
F	1.06	1.2	0.84	0.17	0.21
G	1.05	1.21	0.81	0.19	0.23
H	1.07	1.2	0.87	0.17	0.19

Component Reliability & Environmental Load factor (ELF):

Figs. 4-5 show reliability index for combined stresses of compression and bending case tubular member. It can be seen that with increase of We/G ratio, reliability decreases for both codes. The ISO (LRFD) code gave higher values as compared to API (WSD), which shows the consistency of ISO code. Figs. 6-9 show the member environmental load cases using ISO and API codes. The dashed line shows API averaged target reliability and solid line shows the ISO code. The intersection points are important for these Figures.

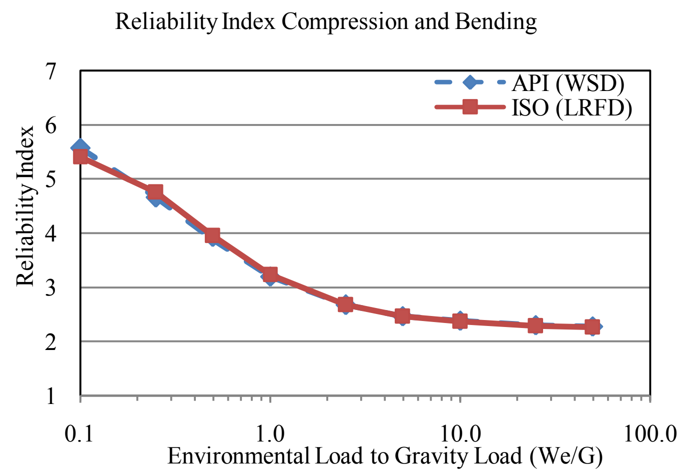

Figure 4: Reliability index for component in compression and bending

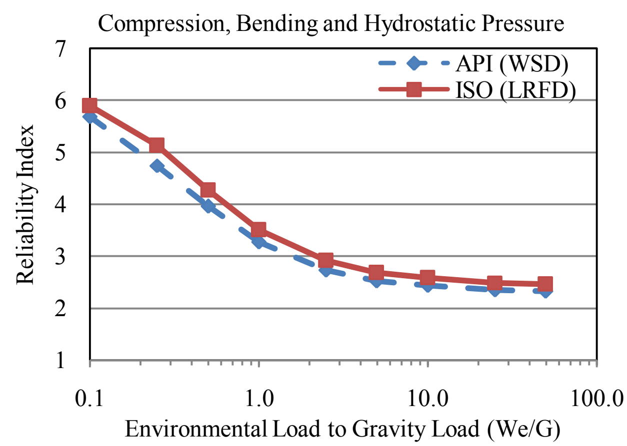

Figure 5: Reliability index for component in compression and bending

The point where ISO code overtakes the target reliability and thus environmental load can be taken as the load factor. Here the API (WSD) and ISO (LRFD) load factors are evaluated at We/G ratio of 1.0 as considered in (BOMEL 2003). Fig. 6 shows the horizontal periphery member load factor to be 1.22. Fig. 7 shows the horizontal diagonal member load factor to be 1.29. Fig. 8 shows the vertical diagonal member load factor to be 1.15. Fig. 9 shows the leg member with a load factor of 1.25. Finally, Fig. 10 shows the averaged load factor to be 1.22 for all components at the PM region

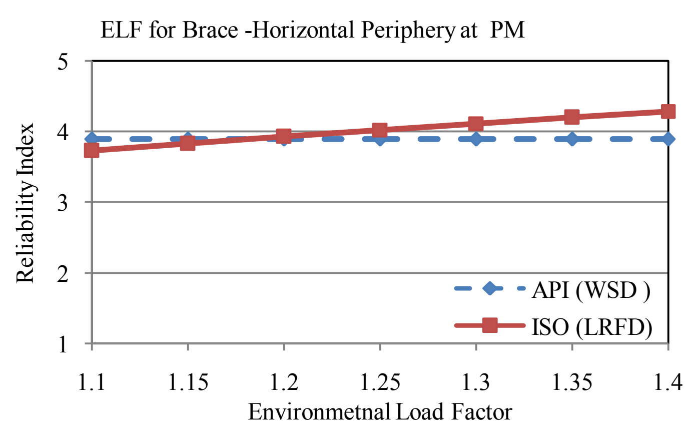

Figure 6: Environmental load Factor for HP Member

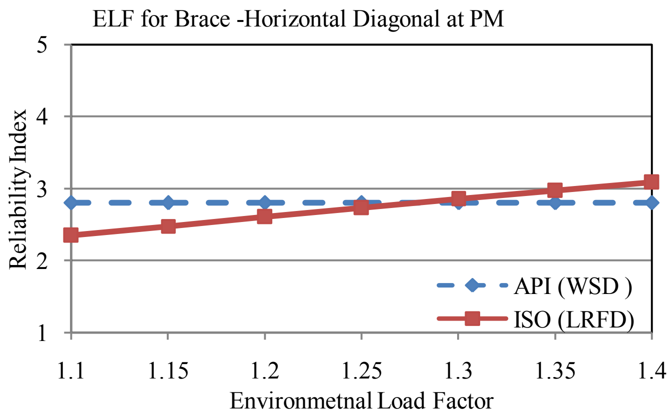

Figure 7: Environmental load Factor for HD Member

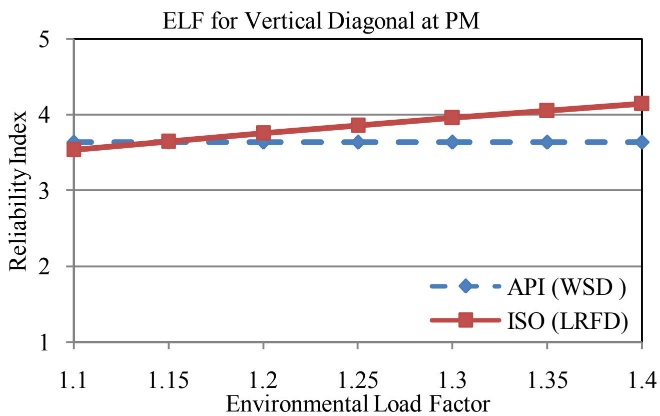

Figure 8: Environmental load Factor for VD Member

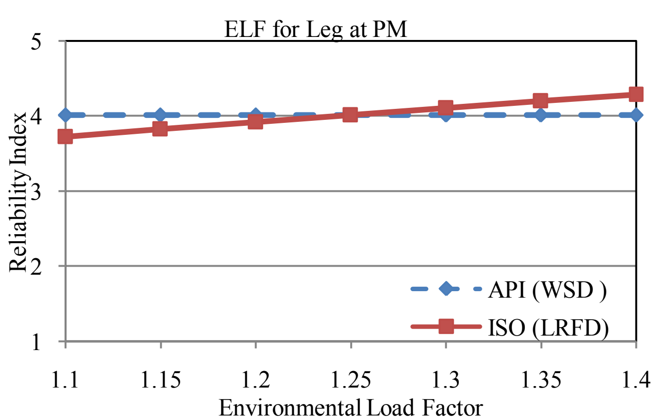

Figure 9: Environmental load Factor for Leg Member

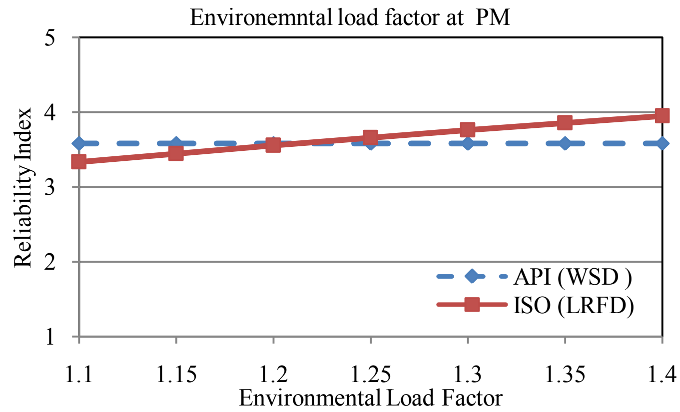

Figure 10: Environmental load Factor

Joint Reliability & Environmental Load factor

The three types of joints were analyzed for four types of stresses and their average results are presented in this section for the platform from PM region. Figs. 11-13 show load factor for K, T/Y and X type of joints. Fig. 11 shows the load factor of 1.3 for K joint, Fig. 12 shows T/Y joint with the load factor of 1.2 and Fig. 13 shows the X-joint with a load factor of 1.29. Fig. 14 shows the averaged load factor based on all three types of joints to be 1.27. Considering that a single factor is to be proposed for the ease of designers, a factor of 1.25 is proposed in this study based on results achieved.

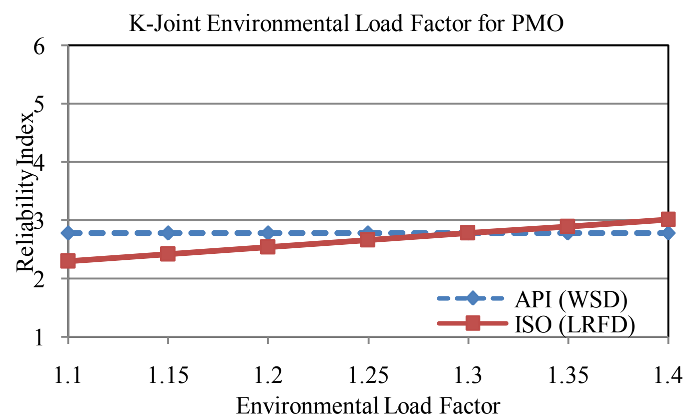

Figure 11: Environmental Load Factor for K-Joint

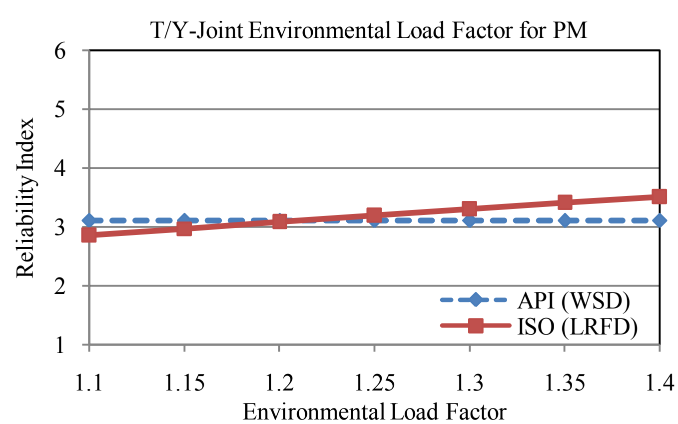

Figure 12: Environmental Load Factor for T/Y-Joint

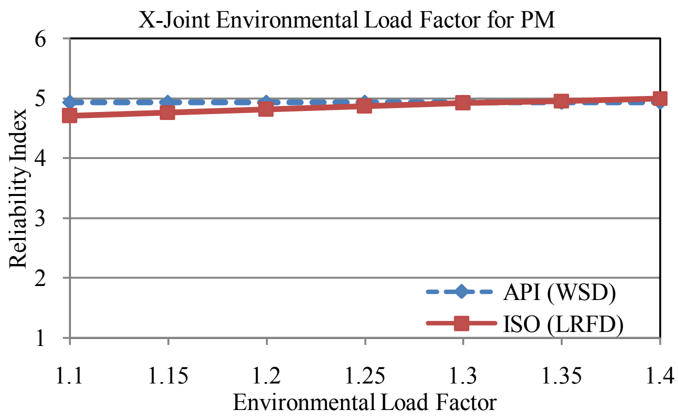

Figure 13: Environmental Load Factor for X-Joint

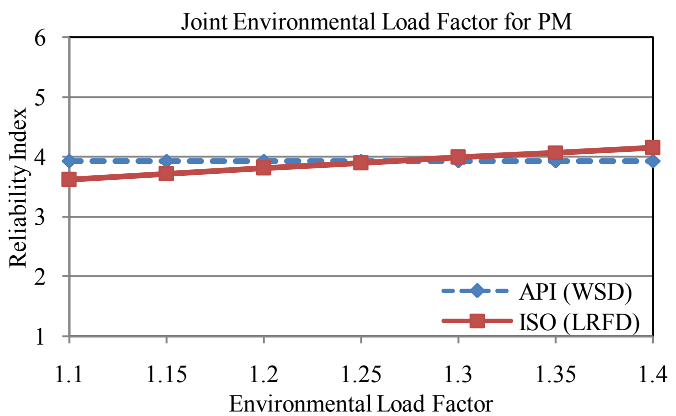

Figure 14: Environmental Load Factor for Joint

System Reliability & Environmental Load factor

Figs. 15-16 show the load factor based on system reliability. For system, the target reliability indexes were 4 and 3.8 based on notional system reliability index proposed by Efthymiou and Melchers respectively. Fig. 15 shows that the same trend (component and joint) was present for reliability index. The reliability index decreases with increase of environmental load. The load factor of 1.1 can be set as load factor for this region using the referred target reliability.

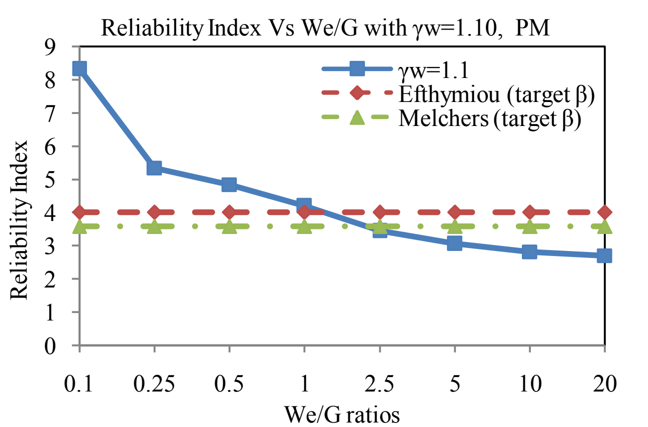

Figure 15: Environmental load factor of 1.1 for Jacket Platform

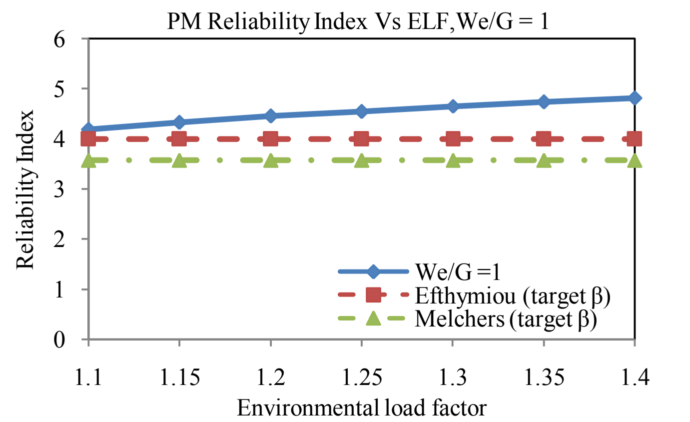

Figure 16: Effect of environmental load factors on β against different for Jacket Platform with W_e/G

CONCLUSIONS

In this study, Jacket platforms in Malaysia were analysed and reliability analyses was performed for evaluating the environmental load factors for this region. Results were presented for one region i.e. Peninsular Malaysia. The main conclusions can be drawn as below:

1) Statistical uncertainty modeling showed that trend of geometrical, material uncertainty and stress model was similar to the results of studies made in GOM, North Sea and China.

2) Environmental load parameters of wave, wind and current could be well represented by using Weibull 2-parameter distribution, as Gumbel distribution over predicted the mean values. This study was based on available model data of 10 and 100 years.

3) The target reliability index based on API (WSD) for component and joint was 3.6 and 4.0 respectively.

4) The environmental load factor for component and joint came out to be 1.22 and 1.27. As a single factor for design, the factor of 1.25 is proposed in this study.

5) Using system reliability analysis, the load factor suggested in this study is 1.1. The codes of practice are based on design of component and joint reliability. The system load factor can only be used for assessment and evaluation of overall system strength considering ductility of jacket.

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