VOL. 6, NO. 12, DECEMBER 2011 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

RISK BASED ASSESSMENT FOR OFFSHORE JACKET PLATFORM IN NIGER DELTA, NIGERIA (CORROSION AND FATIGUE HAZARDS)

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ABSTRACT

Offshore structures are imperative for uninterrupted crude oil production which is the main stay of Nigerian economy. Fatigue and corrosion have been identified to be the most prevalent structural hazards in offshore environment. Jacket platform may be exposed to certain seawater wave which often leads to structural failure, particularly when the platform is subjected to corrosion and fatigue hazards. Therefore, corrosion and fatigue hazards require detail evaluation to prevent jacket platform from untimely failure. Risk based assessment method has been identified as the appropriate tool to determine the risk levels associated with damaged component as a result of several hazards with different scenarios. The outcome of this work revealed that simultaneously corroded and fatigued components exhibit unacceptable risk level and is the appropriate limiting damage scenario for marine structures underwater inspection. The risk based assessment technique proved to be an accurate and the most appropriate procedure for management of hazards, safety and environmental protection.

Keyword: risk assessment, jacket platform, corrosion, fatigue.

1. INTRODUCTION

Offshore civil engineering structural failure such as jacket platform may be attributed to component degradation due to corrosion and fatigue hazards with potential impact on personnel safety and environment. Jacket structures component with limited access is noted for corrosion and fatigue degradation. Corrosion and fatigue are simply two different failure mechanisms working together. One mechanism is corrosion and the other is mechanical. While the corrosion defect grows, the stress concentration at the tip of the defect increases.

The transition from the corrosion controlled phase to the fatigue-controlled phase can be characterized by Equation (1) [1].

$$\Delta K \geq \Delta K_{th} , \left(\frac{da}{dt} \right)_{FM} \geq \left(\frac{da}{dt} \right)_{Pi} \qquad (1)$$

where, ΔK is stress intensity range, ΔK_{th} fatigue crack threshold.

The process is thus assumed fatigue controlled, if the calculated fatigue crack growth is faster than the corrosion growth. The assumption is based on no interaction between the chemical (corrosion) and the mechanical (stress ranges) deterioration process.

Jacket platform components exposure to several hazards determines the structure risk level. A corroded component without fatigue crack is less vulnerable to failure than the corroded component with fatigue cracks [2].

Therefore, jacket platform structural safety will not be sufficiently established if the risk assessment with regards to corrosion and fatigue hazards is not undertaken with the appropriate risk reduced or prevention measures. However, risk prevention measure is seen as the most proper solution in hierarchy of risk control measure.

Risk Assessment Matrix (RAM) is recommended to be the appropriate expression for risk evaluation that gives support for decision-making [3]. Based on this technique, the risk assessment for offshore jacket platform was performed with regards to corrosion and fatigue hazards.

2. THEORETICAL ANALYSIS

2.1 Risk based assessment model

Risk is exposure to hazards while the risk level is determined by the severity of the consequences and the probability of the incident occurring. A general expression of risk "R" is described in Equation (2) [4].

$$R = \sum f(p, C) \qquad (2)$$

where: p and C denote frequency and consequence of incident, respectively.

The flow chart in Figure-1 summarily explains how risk based assessment is to be performed with recommendation provided to mitigate the risks, essentially for the scenarios with unacceptable risk levels.

In this study, in order to adequately account for offshore jacket platform structural damage manners, inspection was carried out on three jacket platforms and the outcome of the exercise was reported below. Based on this result, the marine structural damage scenarios were developed and applied in subsequent sections of the study.

2.2 Field analysis

The three jacket platform structures inspected in the course of the study were built in Niger Delta. The structural components show general corrosion and fatigue cracks were developed in certain joints of the structures. In summarily, the anomaly criteria found on the platforms during the inspection were presented in Table-1.

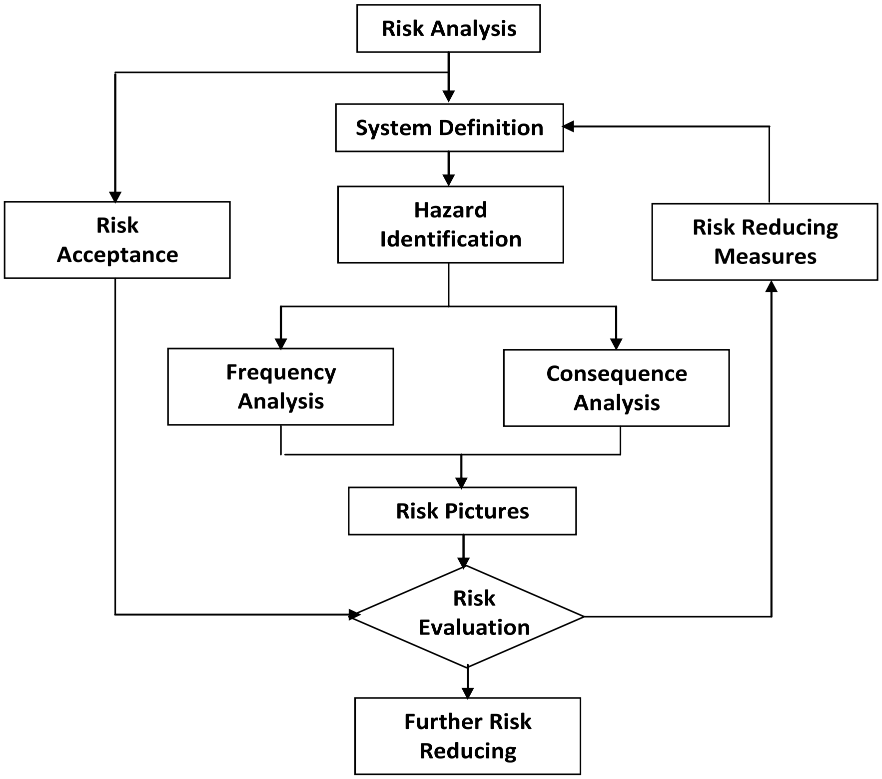
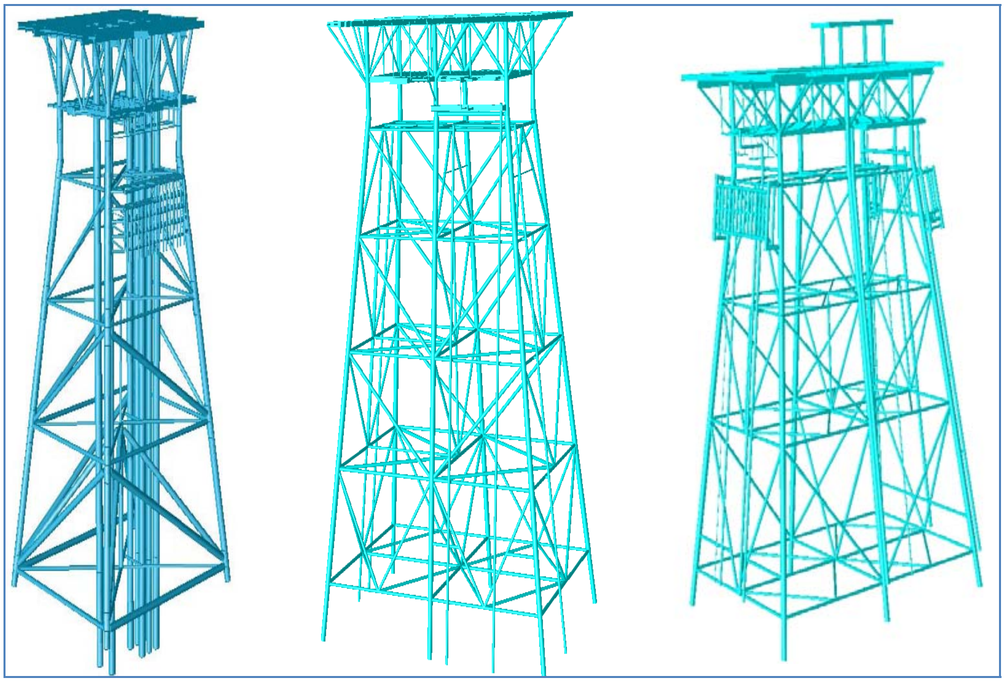


Figure-1. Risk analysis and evaluation flow chart (Yong Bai, 2003).

Table-1. Jacket structural data and anomaly criteria of non conformity.

Jackets	Platform-A	Platform-B	Platform-C
Length (m)	44	55	57.7
Leg number (Qty)	4	6	6
Water depth (m)	32	43	49
Structure age (yr)	24	31	36
Vintage	Early-RP2A	Early-RP2A	Early-RP2A
Platform type	Wellhead	Production	Production
Conductor quantity	12	None	None
Coating damage	Bare metal	Bare metal	Bare metal
Marine growth (mm)	79	82	85
CP devices	Impressed current	Impressed current	Impressed current
Anodes conditions (%)	≥ 40%	≥ 45%	≥ 50%
Max member thickness loss (%)	17.32	16.74	18.25
Min member thickness loss (%)	4.31	4.85	7.47
Abrasion scars	Damage	Damage	Damage
Weld defects	Joints undercut with weld loss and cracks	Joints undercut with weld loss	Joints undercut with weld loss and cracks
Flooded member (Qty)	1	None	2
Member damage	Buckled and dented	Buckled and dented	Buckled and dented
Jacket bottom condition	Scour	Build-up	Scour



Platform A Platform B Platform C

Figure-2. 3D Jacket models.

2.3 Risk analysis frame work

Hazard probability of occurrence is presented in Table-2 with regards to risk evaluation as it is applicable to offshore jacket platform structural damage. The rate of failure occurrence increases from E to A and the event frequency is developed in accordance with the basic failure data applicable in petroleum industry [6].

The working definition of severity and potential impact is provided in Table-3. The outcome of risk evaluation based on events probability and damage frequency with associated risk level was reported on Risk Assessment Matrix in Table-4. This table is divided into three major regions, namely, unacceptable risk (A and B), acceptable risk (E) and region between acceptable and unacceptable or medium are (C and D). Table-5 described several hazard combination scenarios which was proposed for use in the study based on characteristics of the structural damage found during the field inspection exercise.

The assumption made in the study for detecting components damage and survival of jacket platform structures prior to failure were based on the following probability factors: (1) Susceptibility of structural members to corrosion; (2) Structural element inspections; (3) Operator surveillance; (4) Simultaneous action of corrosion and fatigue hazards, and (5) Redundancy member prevent structural failures.

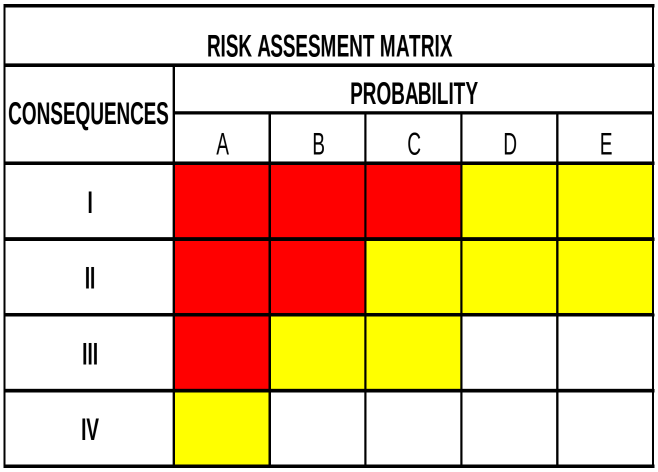
Table-2. Hazards probability for platform operations (Damir and Hinko, 2005).

Probability category	Definition	Interpretation
A	Possibility of repeated incidents	Offshore platform with current conditions that indicate repeated future occurrences are possible
B	Possibility of isolated incidents	Offshore platform with current conditions indicate several future occurrences are possible
C	Possibility of occurring sometime	Offshore platform with current conditions indicate occasional future occurrences are possible
D	Not likely to occur	Offshore platform with current conditions indicate future occurrences are not likely to occur
E	Practically impossible	Offshore platform with current conditions indicate future occurrences are practically impossible

Table-3. Damage potential for offshore platform structures (Dagmar, 1998).

Consequence category	Health/safety	Public disruption	Financial impact	Environmental impact
I	Fatalities or serious health impact on public	Evacuation of the whole personnel from the platform and continuing national or international attention	Corporate	Potential wide spread, long term, significant adverse effects
II	Permanently disabling injury and serious lost time	Evacuation of the whole personnel from the platform and continuing regional attention	Business	Potential localised, medium term, significant adverse effects
III	Minor lost time injury with medical aid	Evacuation of some personnel and one time regional attention	Field	Potential short term, minor adverse effects
IV	First aid	No evacuations, minor inconveniences to a few personnel	Others	Confined to lease or close proximity

Table-4. Risk assessment matrix (Yong Bai, 2003)



RISK ASSESMENT MATRIX					
CONSEQUENCES	PROBABILITY				
	A	B	C	D	E
I	🟥	🟥	🟥	🟨	🟨
II	🟥	🟥	🟨	🟨	🟨
III	🟥	🟨	🟨		
IV	🟨				

Table-5. Corrosion and fatigue damage scenarios.

Scenarios	Descriptions
Scenario - 1	Joint and member uniform corrosion + Little fatigue
Scenario - 2	Joint and member uniform corrosion + No fatigue
Scenario - 3	Joint localised corrosion + Little fatigue
Scenario - 4	Member localised corrosion + Little fatigue
Scenario - 5	Member localised corrosion + Medium fatigue
Scenario - 6	Member localised corrosion + No fatigue
Scenario - 7	Joint localised corrosion + Medium fatigue
Scenario - 8	Joint localised corrosion + No fatigue
Scenario - 9	No impact

- Little fatigue- Nucleation period;
- Medium fatigue- Fatigue growth period;
- Localised Corrosion- Pitting Corrosion
- Uniform Corrosion- General Corrosion

2.4 Risk analysis

The risk evaluation was performed with the following parameters: (1) Scenarios consequences (Figure-3); (2) Qualitative probability (Figure-4) and (3) Quantitative probability (Figure-5). The risk estimation process commenced with scenarios consequence followed by qualitative and quantitative probabilities, respectively. In the case of scenarios consequence estimation, the process was simulated by specifying "Yes" or "No" and the numbers of yes or no along the scenario part determine the event consequences to be either, I, II, III or IV.

With regards to qualitative probability analysis, the scenario was described by superlative degree words such as very low, low, medium and high. Based on these words strength (low, medium or high) along the scenario part, the event probability was established to be either very low, low, medium or high.

In the same way, the quantitative probability for the scenario was also computed using percentage as a means of determining the likelihood of event occurrences as follows: 70% - 90% was adopted for highly likely scenarios and 1% - 30% for low likely scenarios. These calculations continued in Table-6 by multiplying all the percentages (90%, 70%, 30%, 20% or 10%) which were established along every scenario part that results to event quantitative probability. The risk analysis was summarized in Table-7 ready for final plotting into RAM in Table-8.

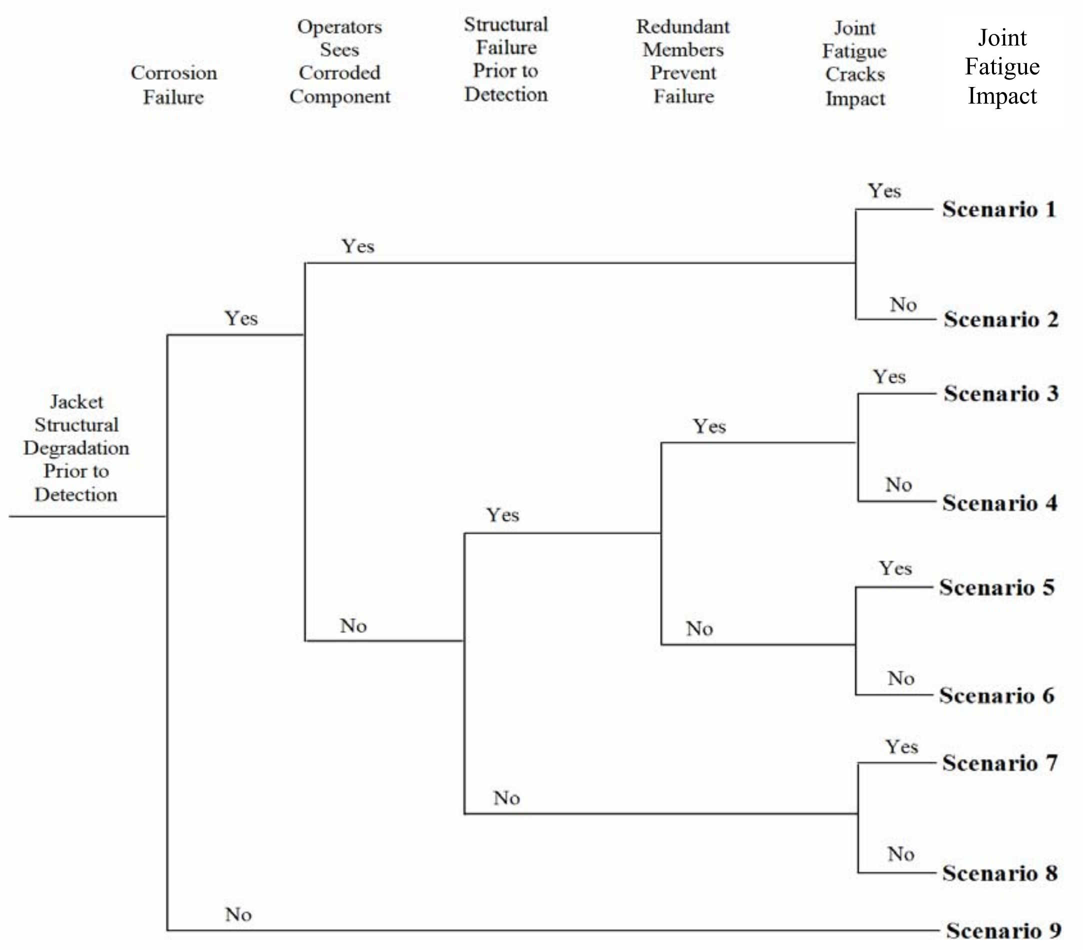
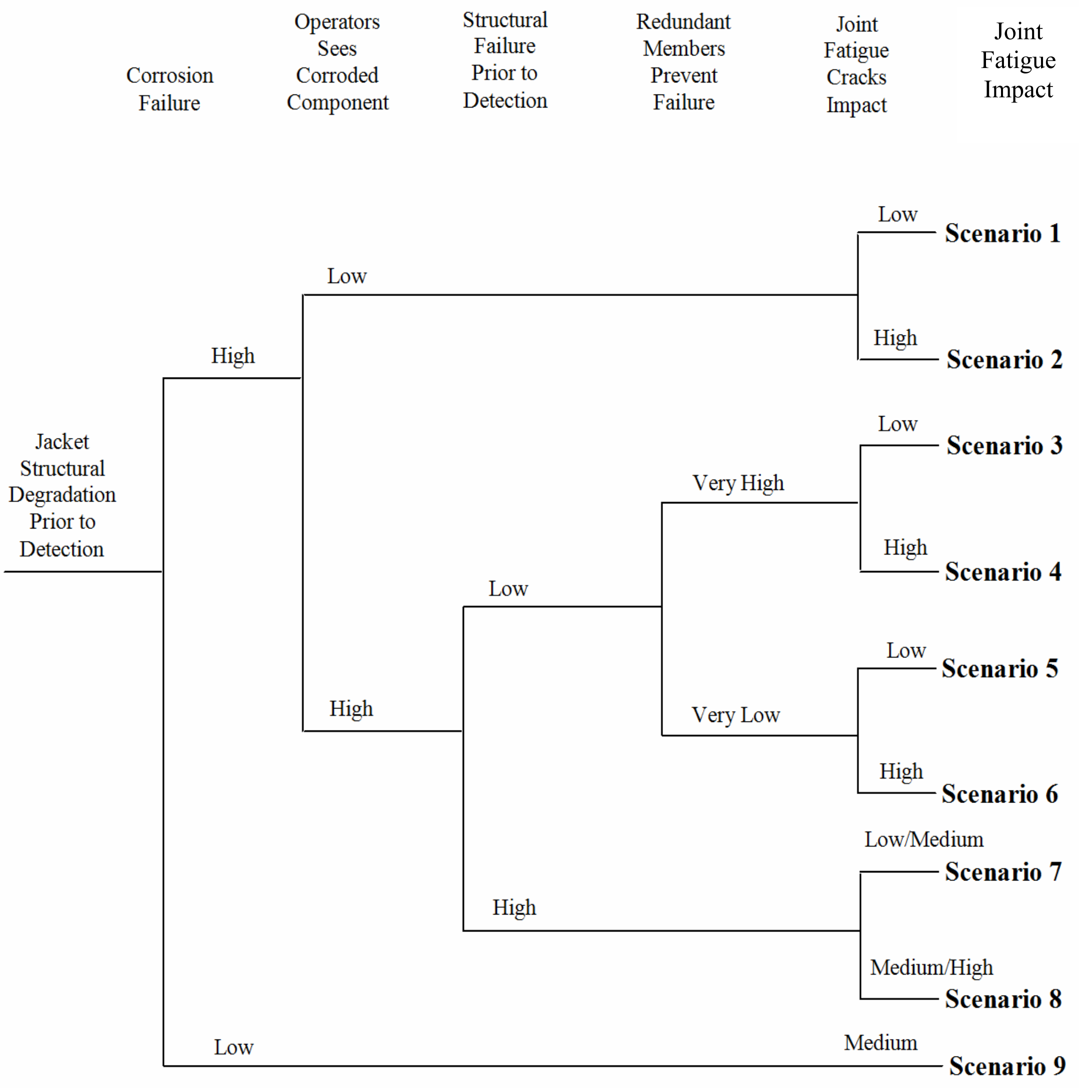


Figure-3. Scenarios consequences schematic.

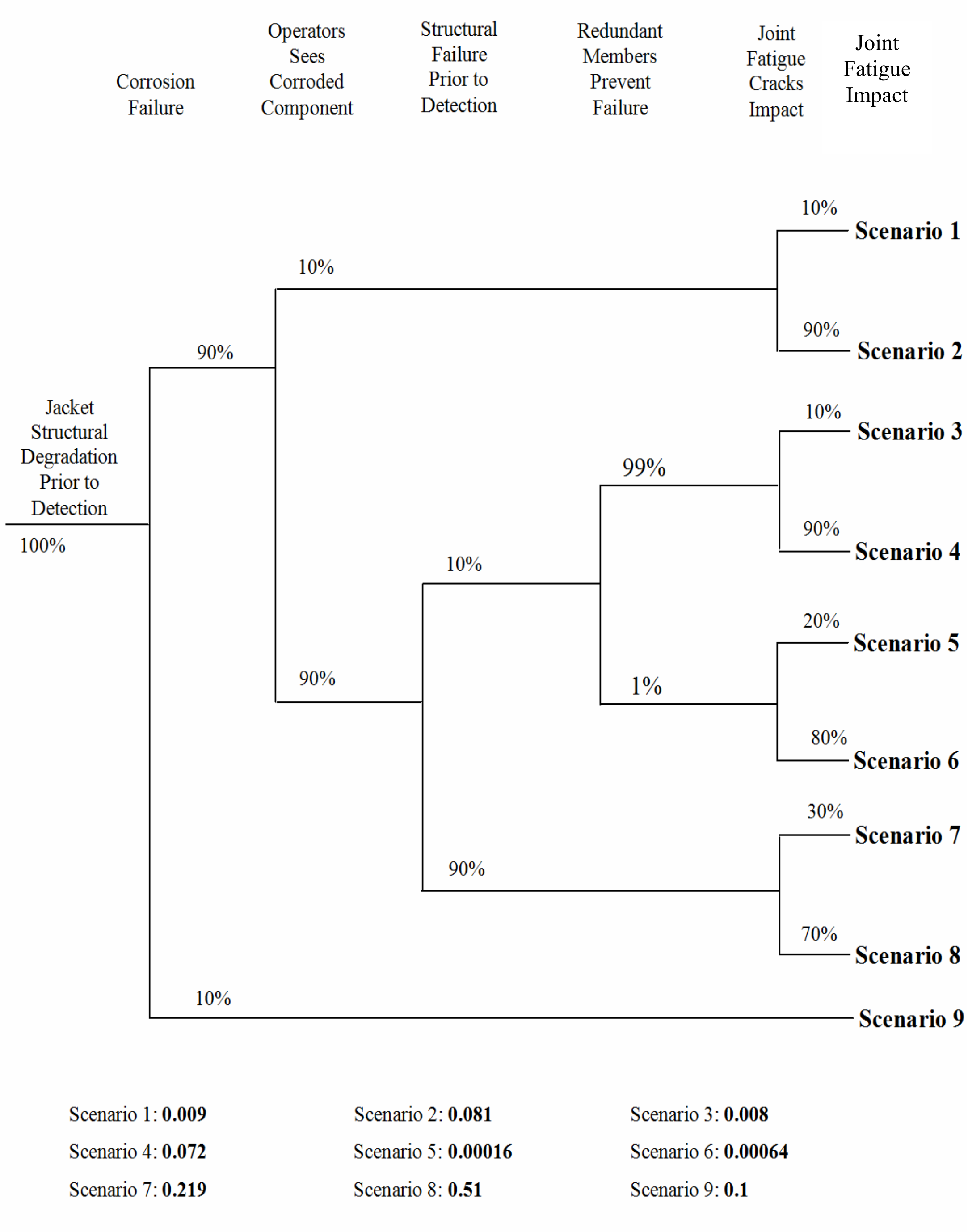
Consequences summary

Scenario 1: Joint and member uniform corrosion + little fatigue (III)
Scenario 2: Joint and member uniform corrosion + no fatigue (IV)
Scenario 3: Joint localised corrosion + little fatigue (II)
Scenario 4: Member localised corrosion + little fatigue (III)
Scenario 5: Member localised corrosion + medium fatigue (II)
Scenario 6: Member localised corrosion + no fatigue (III)
Scenario 7: Joint localised corrosion + medium fatigue (II)
Scenario 8: Joint localised corrosion + no fatigue (III)
Scenario 9: No impact, not applicable.



Scenario 1: **Low**
Scenario 2: **Medium**
Scenario 3: **Low**
Scenario 4: **Medium**
Scenario 5: **Very Low**
Scenario 6: **Low /Very Low**
Scenario 7: **High**
Scenario 8: **High**
Scenario 9: **Medium**

Figure-4. Qualitative probability schematic.



Scenario 1: **0.009**
Scenario 2: **0.081**
Scenario 3: **0.008**
Scenario 4: **0.072**
Scenario 5: **0.00016**
Scenario 6: **0.00064**
Scenario 7: **0.219**
Scenario 8: **0.51**
Scenario 9: **0.1**

Figure-5. Quantitative probability schematic.

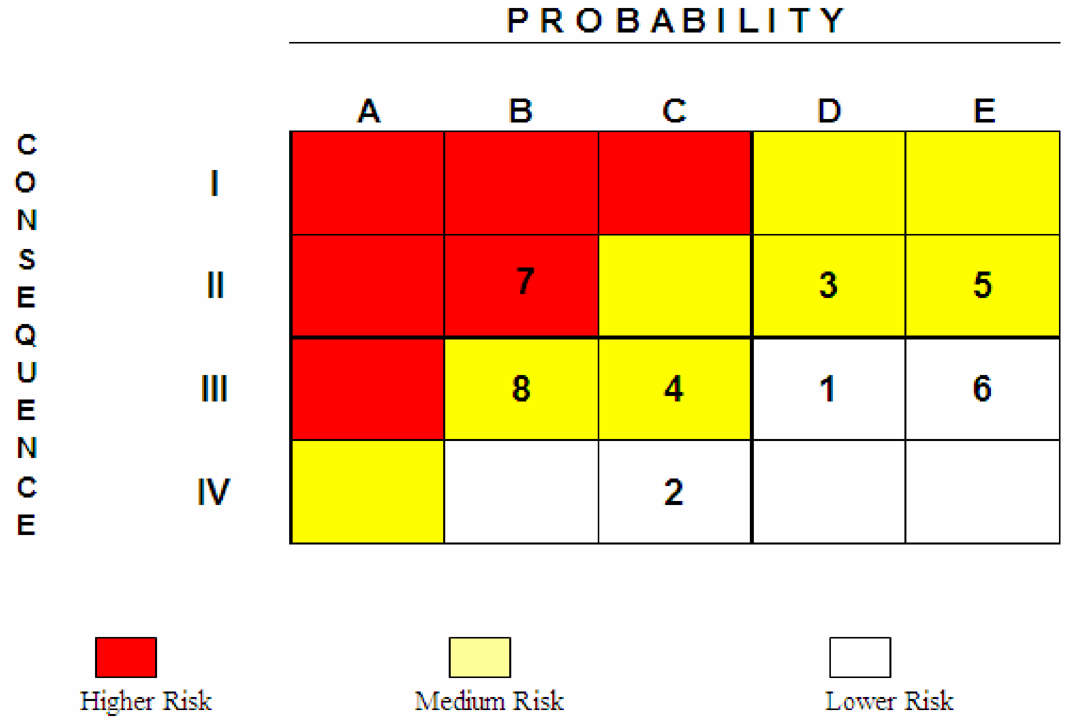
Table-6. Quantitative probability estimation.

Probability factors	**Scenarios**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Corrosion failure	90%	90%	90%	90%	90%	90%	90%	90%	10%
Operators sees Corroded members	10%	10%	90%	90%	90%	90%	90%	90%	N/A
Structural failure prior to detection	N/A	N/A	10%	10%	90%	90%	90%	90%	N/A
Redundant members prevent failure	N/A	N/A	99%	99%	1%	1%	N/A	N/A	N/A
Joint fatigue cracks impact	10%	90%	10%	90%	20%	80%	30%	70%	N/A
SUM	0.009	0.081	0.008	0.072	0.0002	0.0006	0.219	0.51	0.10

Table-7. Risk estimation results.

Risk measuring parameters	**Scenarios**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Scenario consequence	III	IV	II	III	II	III	II	III	N/A
Qualitative probability	Low	Med	Low	Med	Very low	Low/very low	High	High	Med
Quantitative probability	0.009	0.081	0.008	0.072	0.0002	0.0006	0.0219	0.51	0.10

Table-8. Plotting risk scenarios on assessment matrix.



CONSEQUENCE	PROBABILITY				
	A	B	C	D	E
I	🟥	🟥	🟥	🟨	🟨
II	🟥	🟥 7	🟨	🟨 3	🟨 5
III	🟥	🟨 8	🟨 4	⬜ 1	⬜ 6
IV	🟨	⬜	⬜ 2	⬜	⬜

🟥 Higher Risk
🟨 Medium Risk
⬜ Lower Risk

Table-9. Scenario -7 risks ranking.

RISK RANKING							
BEFORE RECOMMENDATIONS				AFTER RECOMMENDATIONS			
S_b	P_b	E_b	F_b	S_a	P_a	E_a	F_a
B-II		D-II	C-II	E-II		E-III	E-III

S = Safety; P = Public disruption; E = Environmental; F = Financial
b = before recommendations; a = after recommendations

2.5 Risk evaluation summary

The risk evaluation was adequately completed for the nine scenarios with the result summarized in Table-7. The risk level for each of the scenario was established using RAM in Table-8. Scenario-7 (localised corrosion and medium fatigue) falls within highest risky zone and therefore, makes the risk level for the scenario unacceptable and consequently required mitigation safeguards to reduce the risk level. After the mitigation measures suggested in section 3 of this study assumed to be implemented, the risk level for scenario-7 was re-evaluated as illustrated in Table-9 with considerable risk level reduction as shown in before and after recommendation columns.

3. RESULTS AND DISCUSSIONS

The outcome of offshore platform inspection in the Niger Delta region indicates that structural components may be subjected to corrosion and fatigue hazards concurrently. The field data shows that significant damage to jacket platform structures and integrity issues may be attributed to corrosion and fatigue hazards. Corrosion damage has been found in the generally isolated to known vulnerable details such as spider deck, grating, tertiary members, conductor bays and appurtenance connections. The common mitigation safeguard in place against corrosion and fatigue hazards for jacket platform in Niger Delta is cathodic protection. However, several number of anodes installed on the jacket structures have been depleted as some of the platforms have been operated beyond the design life.

The major causes of marine component damage have been established and attributed to effect of several corrosion agents, incessant action of seawater wave and winds in offshore environment. The facilities operator cannot be left out in this matter, because these structures have been in operation for long time without renewal of the existing corrosion protection devices.

The risk assessment carried out in this study involved group discussion, consultation with senior colleagues and field engineers regarding corrosion and fatigue damage scenarios. Hazards associated with platform failures were discussed with specific reference to risk probability, consequences and mitigations. Several risk factors were considered during the group debate as it is applicable to marine structures damage with due consideration to human error and important of jacket redundancy members for structural failure prevention.

The following mitigation measures were proposed for implementation in the study to reduce jacket platform risk levels due to corrosion and fatigue hazards. (1) Sufficient inspection program; (2) Well-timed components repair/replacement; (3) Cathodic protection system renewal; (4) Good quality welds and (5) Provision of corrosion allowance.

The risk evaluation results presented in Tables 8 and 9 demonstrated that Scenario-7 (localised corrosion and medium fatigue) is associated with high risk level of B-II, which was unacceptable. The outcome of the study show that jacket platform structures subjected to corrosion and fatigue hazards exhibit high risk mostly when the structure continue to be operated without implementation appropriate mitigation measures.

Jacket platform structures guarantees safety, necessitate that the structural system meets design requirements with great consideration for planned inspection program and repair. Corrosion and fatigue hazards identified in this study provided understanding of the mechanisms that may leads to offshore platform failure and appropriate preventive measures.

The result of the risk evaluation carried out in this study demonstrates that jacket platform requires survey rules to control structural component corrosion and fatigue damages in support of API RP 2A recommendations. Marine structural components with limited access are noted for corrosion and fatigue damage and they are recommended to be designed for higher fatigue safety factors and effective corrosion protection. Combination of localised corrosion and fatigue hazards on marine structures demonstrate unacceptable risk level that threatening integrity of jacket structures. Consequently, this manner of damage should be watched out for during offshore structures survey and considered as a limiting damage scenario that is appropriate for marine structures underwater inspection.

4. CONCLUSIONS

The risk based assessment presented in this study was performed with due consideration to several possible damage scenarios that might occur during the operational life time of an offshore jacket platform structures. The study established that the key factors that determine jacket platform risk levels that might lead to structural failures are hazard severity and probability.

Offshore platform structures subjected to corrosion and fatigue hazards was established to fall within high risk zone and consequently prone to failure, particularly when the structure is operated continuously without sufficient risks mitigation measures.

The effort presented in this paper has practical application on hazard control for the structures built in hostile marine environment that constantly threatening by corrosion and fatigue hazards.

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