CMD 2026 Conference

The 3rd International Online Conference on Corrosion and Materials Degradation

In Memoriam of Prof. Dr. Digby Macdonald

30 June – 2 July 2026 Online

MDPI

Remaining Useful Life Estimation of SPM and FPSO Mooring Chains Under Corrosion Effects

[1*]Chigozie Ebunuoha [1]Ebigenibo G. Saturday [2]Celestine E. Ebieto

1. Offshore Technology Institute, University of Port Harcourt, Rivers State, Nigeria.

2. Department of Mechanical Engineering, University of Port Harcourt, Rivers State, Nigeria.

*Corresponding author: chigozie_ebunuoha@uniport.edu.ng

CMD 2026 – SCIFORUM - 176510

INTRODUCTION & AIM

Floating production storage and offloading (FPSO) vessels and single point mooring (SPM) calm buoy are critical infrastructures in both upstream and downstream oil and gas businesses. The floating platforms represents a new technology with a promising future for the upstream oil and gas sector . However, several issues came up which are of both industry and academic interest. Historically, fatigue damage has been identified as the primary focus of remaining useful life (RUL) evaluations, localized and uniform/general corrosion wastages have emerged as dominant degradation and deterioration mechanisms that significantly accelerate mooring chains strength reductions. Mooring chains are single point of failure on FPSOs. Recent estimation methods often treat marine corrosion wastages as a static safety factor rather than a time-variant stochastic process, leading to premature mooring chains replacement or undetected risk exposure. An accurate RUL estimation for floaters remains a significant industrial challenge to local and international operators for the integrity management of SPM and FPSO mooring systems and other floaters that utilizes mooring chains. Although, global performance assessments assume that the unavoidable gradual and predictable thickness reductions, with empirical evidence from both in-service and recovered mooring chains indicates that corrosion especially uniform/general/pitting corrosion on mooring chains of FPSO and SPM calm buoy is often the true driver of premature failure. However, other silent drivers exist such as design, fatigue, installation, manufacturing defects, and mechanical causes of failure cannot be over emphasized. It was observed that due to scarcity of field data, most of the research works in structural health monitoring, structural reliability, fatigue assessments and life extensions of FPSO and SPM mooring chains relied on data obtained from corrosion coupon in laboratory and apply it to life extension studies. This is an empirical research gap. Such data are unreliable because they are under control unlike data from the field locations in marine environment, where corrosion wastages occurs naturally. Moreover, the Offshore West Africa is a temperate region. Previously operators usually recover the mooring chains on dive vessels for surveys/data collection and re-install it, this approach is time consuming and expensive. This is a methodological gap. Hence, use of in-situ approach and field data were recommended for subsequent mooring chains corrosion wastage evaluations. However, quantifying remains challenging for existing prognostic models on how area/sectional thickness loss and surface roughness evolve dynamically under continuously fluctuating marine environmental conditions and varying cathodic protection states. This research paper presents a coupled degradation linear models that integrates time-variant corrosion wastage progression with structural health capacity degradation. The model utilizes mooring chains grade factor to simulate uniform/general corrosion wastages of selected chain links. The mooring chains area reductions/thickness losses (geometric defects) which represents the uniform corrosion wastages were subsequently inputted into mooring chains minimum breaking strength (MBS) analytical models to assess MBS reduction over time. The result is a probabilistic RUL output that reflects the extremely variability of marine corrosion wastage damage. The proposed framework is validated against chain samples in-situ data obtained from operational FPSO/SPM units in offshore West Africa, demonstrating a significant marked improvement in prediction accuracy for life extension programs over traditional S-N curve approaches. To bridge the gap between condition monitoring/surveillance data and predictive maintenance planning and scheduling, ultimately enhancing structural reliability and structural health monitoring decision making, the safety and cost-efficiency of offshore terminal operations mooring chains replacement. This approach will help operators move from a time-based replacement philosophy to a corrosion-informed remaining useful life prognosis. In addition, it will provide operators with tools to optimize data interpretations, plan for chains replacement and avoid being cut by multiple chain failure, domino effects and ultimately systems failure. The approach aim to carry out the remaining useful life estimation of FPSO and SPM calm buoy mooring chains under corrosion effects.

METHOD

Approximately 20 years in service an operator is replacing the top chains of its FPSO mooring chains twice, originally selected for 20-year service life. Firstly, after the first 10 years and secondly after the second 10 years due to the excessive corrosion wastages on the FPSO and SPM mooring chains in West Africa. These decisions were reached through detailed mooring chains surveys, measurements and assessments using class society equations. In this research work, field data were obtained from a field in offshore West Africa. The sample mooring chains data were collected across the 6 legs of the mooring legs of an external turret FPSO splash zone which served as a case study. A total of 76 mooring chains links were analyzed based on in-situ field data. The data collected were multiple thickness measurements across the mooring chains straight and side bars using Vernier calipers. The in-situ method of data collection was used while the tools used in cleaning the chain links before measurements are: wire brush, chipping hammer, needle gun, grit blasting and high pressure water jet. The data collected were collated and analyzed using linear mooring chains analytical models. The mooring chain is R3 grade studless top/upper chains with original design thickness of 76 mm and life of 10 years. For ultrasonic thickness measurement (UTM) gauging of the interlink, side and straight bars, the average reading is expressed as;

$$\text{Average gauged thickness} = \frac{U_1 + U_2 + \ldots + U_n}{U_n} \quad (1)$$

$$\text{Reduction in thickness (wastage)} = (\text{design thickness} - \text{avg gauged thickness}) \quad (2)$$

As per class societies guidelines and recommendations, this assessment calculates the minimum breaking strengths of new chains based on the diameter:

$$\text{MBS}_{\text{new}} = \text{f x d}^2\text{x}(44 - 0.08 \text{ x d}) \quad (3)$$

$$\text{MBS}_{\text{corroded}} = \text{MBS}_{\text{new}} \text{ x } \frac{\text{Area corroded}}{\text{Area new}} \quad (4)$$

Where,
MBS_{new} is the minimum breaking strength in kN
The chain grade factor. For R3 chain, f= 0.0223 kN/mm^2
Breaking strength of new 76mm chain is therefore 4884.28kN
$MBS_{corroded}$ is the estimated corroded breaking strength in kN
$Area_{corroded}$ is the corroded chain cross-sectional area of the chain mm2
$Area_{new}$ is the cross-sectional area of the chain in mm2

RESULTS & DISCUSSION

The outcome of the evaluations predicted that among the 76 mooring chains links sampled for assessments in 2023 after 8 years of installation, the weakest link lost 10.10 mm of materials. This loss resulted to MBS reduction of 24.81% and residual or remaining strength of 75.19%. All other links strength parameter falls within the range of 75 – 94% residual strength. While those of other links fall within 80-90%. The results of the assessments showed that there was diminished MBS when the values obtained for new and corroded chains where compared. The weakest link on chain link number 24 of mooring leg 1 which has an MBS of 3672.35kN as against the design value of 4884.28kN. Of course, this was due to material loss of 10.10 mm which showed up in chains diameter/thickness and area reduction. Therefore, with average corrosion rate of 1.26 mm/year, by 1Q 2026 the mooring chains profile/configuration would likely not be in compliance with minimum factor of safety as established by class societies requirements. The mooring chains condition survey had shown excessive corrosion in the top chains segments. The results of 10-20% strength reduction is in line with previous projects from sea water corrosion of steel wire rope and chains joint industry project (SCORCH JIP).

Table (1): Combined Corrosion Wastage and Remaining Thickness

Sn	CALM 1			CALM 2			CALM 3			CALM 4			CALM 5			CALM 6		
Chain links ID	Average UTM Gauging	Corrosion Wastage	Remaining thickness %	Average UTM Gauging	Corrosion Wastage	Remaining thickness %	Average UTM Gauging	Corrosion Wastage	Remaining thickness %	Average UTM Gauging	Corrosion Wastage	Remaining thickness %	Average UTM Gauging	Corrosion Wastage	Remaining thickness %	Average UTM Gauging	Corrosion Wastage	Remaining thickness %
20	70.80	5.20	93.16	72.70	3.30	95.66	68.10	7.90	89.61									
21	71.40	4.60	93.95	71.10	4.90	93.55	70.00	6.00	92.11	70.80	3.90	94.87	72.00	4.00	94.74	72.00	4.00	94.74
22	68.50	7.50	90.13	70.15	5.85	92.30	68.20	7.80	89.74	71.40	6.30	91.71	69.70	6.30	91.71	69.80	6.20	91.84
23	68.90	7.10	90.65	69.00	7.00	90.79	67.90	8.10	89.34	68.50	6.20	91.84	69.80	6.20	91.84	69.80	6.20	91.84
24	65.90	10.10	86.71	69.40	6.60	91.32	67.50	8.50	88.82	68.90	8.20	89.21	67.80	8.20	89.21	67.60	8.40	88.95
25	68.00	8.00	89.47	69.80	6.20	91.84	68.90	7.10	90.66	65.90	8.10	89.34	67.90	8.10	89.34	67.90	8.10	89.34
26	68.90	7.10	90.66	72.10	3.90	94.87	69.20	6.80	91.05	68.00	6.80	91.05	69.20	6.80	91.05	69.20	6.80	91.05
27	70.70	5.30	93.03	70.90	5.10	93.29	70.90	5.10	93.29	68.90	6.70	91.18	69.30	6.70	91.18	69.30	6.70	91.18
28	68.50	7.50	90.13	73.20	2.80	96.32	70.00	6.00	92.11	70.70	5.90	92.24	70.10	5.90	92.24	70.10	5.90	92.24
29	70.23	5.78	92.40	71.40	4.60	93.95	71.10	4.90	93.55	68.50	4.00	94.74	72.00	4.00	94.74	72.00	4.00	94.74
30	68.80	7.20	90.53	73.00	3.00	96.05	73.70	2.30	96.97	70.23	5.20	93.16	70.80	5.20	93.16	70.80	5.20	93.16
31	71.20	4.80	93.68							68.80	4.80	93.68	71.20	4.80	93.68	71.20	4.80	93.68
32										71.20	3.80	95.00	72.20	3.80	95.00	72.20	3.80	95.00
33										71.20	3.90	94.87	72.10	3.90	94.87	72.10	3.90	94.87
34										71.20	2.40	96.84	73.60	2.40	96.84	73.50	2.50	96.71

Table (2): Combined MBS Corroded and MBS Reduction Percentage

Sn	New chain Data			CALM 1			CALM 2			CALM 3			CALM 4			CALM 5			CALM 6		
Chain links ID	Selected chain links ID	Original thickness	MBSnew	Selected chain links ID	MBScorroded	MBS Reduction (%)	Selected chain links ID	MBScorroded	MBS Reduction (%)	Selected chain links ID	MBScorroded	MBS Reduction (%)	Selected chain links ID	MBScorroded	MBS Reduction (%)	Selected chain links ID	MBScorroded	MBS Reduction (%)	Selected chain links ID	MBScorroded	MBS Reduction (%)
20	20	76.00	4884.28	20	4239.07	13.21	20	4469.33	8.50	20	3921.64	19.71									
21	21	76.00	4884.28	21	4311.22	11.73	21	4274.77	12.48	21	4143.52	15.17	21	4239.07	13.21	21	4383.68	10.25	21	4383.68	10.25
22	22	76.00	4884.28	22	3968.13	18.76	22	4161.30	14.80	22	3933.16	19.47	22	4311.22	11.73	22	4108.08	15.89	22	4119.88	15.65
23	23	76.00	4884.28	23	4014.03	17.82	23	4025.98	17.57	23	3898.64	20.18	23	3968.13	18.76	23	4119.88	15.65	23	4119.88	15.65
24	24	76.00	4884.28	24	3672.35	24.81	24	4072.79	16.61	24	3852.84	21.12	24	4014.03	17.82	24	3887.16	20.41	24	3864.26	20.88
25	25	76.00	4884.28	25	3910.13	19.94	25	4119.88	15.65	25	4014.32	17.81	25	3672.35	24.81	25	3898.64	20.18	25	3898.64	20.18
26	26	76.00	4884.28	26	4014.32	17.81	26	4395.86	10.00	26	4049.35	17.09	26	3910.13	19.94	26	4049.35	17.09	26	4049.35	17.09
27	27	76.00	4884.28	27	4227.10	13.45	27	4250.75	12.97	27	4250.75	12.97	27	4014.32	17.81	27	4061.06	16.85	27	4061.06	16.85
28	28	76.00	4884.28	28	3967.84	18.76	28	4531.02	7.23	28	4143.52	15.17	28	4227.10	13.45	28	4155.37	14.92	28	4155.37	14.92
29	29	76.00	4884.28	29	4170.20	14.62	29	4310.92	11.74	29	4274.77	12.48	29	3967.84	18.76	29	4383.68	10.25	29	4383.68	10.25
30	30	76.00	4884.28	30	4002.67	18.05	30	4506.29	7.74	30	4593.13	5.96	30	4170.20	14.62	30	4238.77	13.22	30	4238.77	13.22
31	31	76.00	4884.28	31	4286.80	12.23							31	4002.67	18.05	31	4286.80	12.23	31	4286.80	12.23
32	32	76.00	4884.28										32	4286.80	12.23	32	4408.06	9.75	32	4408.06	9.75
33	33	76.00	4884.28										33	4286.80	12.23	33	4395.86	10.00	33	4395.86	10.00
34	34	76.00	4884.28										34	4286.80	12.23	34	4580.67	6.22	34	4568.23	6.47

CONCLUSIONS

The study presents a technically significant study addressing corrosion-driven deterioration in FPSO and SPM mooring chains, highlighting an important gap in conventional RUL estimation methods. The use of in-situ data from 76 chain samples adds strong empirical grounding and enhances the reliability of the proposed methodology. This study develops a corrosion-informed remaining useful life estimation methodology for FPSO and SPM calm buoy mooring chains, addressing the growing incidence of chain failures in offshore operations. Based on in-situ data from 76 R3-grade chain samples, the research characterizes localized corrosion patterns, particularly in splash zone segments, and quantifies their impact on residual strength. The analysis of corrosion rate distributions and their impact on cross-sectional loss and minimum breaking strength (MBS) is well-articulated and practically relevant. The study effectively demonstrates the limitations of traditional uniform corrosion assumptions and advocates for a more realistic, data-driven approach. The integration of field observations with engineering assessment provides valuable insights for offshore asset integrity management. The discussion on regional variations, particularly in West Africa, strengthens the contextual applicability of the findings. Results indicate MBS of 3672.35kN from the weakest link against a catalogue value of 4884.28Kn. All MBS reductions fell within of 10–20%, with severe thickness losses leading to significant structural degradation beyond conventional linear corrosion assumptions. The findings demonstrate that traditional uniform corrosion allowances underestimate actual deterioration rates observed in West African offshore environments. The proposed model supports a shift from time-based replacement strategies to condition-based, corrosion-driven RUL assessment. Practical recommendations include upgrading chain grade or size in splash zones and applying protective coatings such as thermally sprayed carbide (TSC) or thermally spread aluminium (TSA) to enhance long-term mooring integrity. This in-situ approach to data collection eliminates the old trend of retrieval of mooring chains to DSV deck for data collections and re-installation (high cost & time consuming).

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

Future works: Future works should take more case studies and leverage on field data at different regions of the world and offshore locations which is more realistic in mooring chains corrosion wastage and MBS analysis rather than data from corrosion coupon in laboratory .

References:

Ma, K.T., O'Driscoll, M., Stemmler, P., & Yan, H., (2016). Replacement of Corroded Mooring Chain on an FPSO. Chevron Energy Technology Company. *SNAME-SMC-2016-045. Paper presented at the SNAME Maritime Convention, Bellevue, Washington, USA, November 2016*. Pp. 1-9.

Karkori. F. (2025). Offshore Mooring Chain: Introduction to Classification Requirements. Synthesis Lectures on Ocean System Engineering, Springer Publications. P.42

Acknowledgment:

The authors wishes to acknowledge MDPI publishers and organizers of CMD 2026 conference for giving us the opportunity to present our research work.