

The Literature Study on Corrosion Rate in Mooring Chain for Tropical Seawaters – Class Rules Review

Hasan Ikhwani¹, Sista Mutya Atikanta², Wimala L. Dhanistha³

(Received: 02 March 2021 / Revised: 09 March 2021 / Accepted: 13 March 2021)

Abstract—many design codes for structures in tropical waters are still based on the code for the North Sea, even though both have different environmental conditions. This research was conducted to assess the influence parameters of the tropical water environments and to determine the empirical estimates of the parameters that have a major effect on the corrosion that occurs in tropical waters. The result of this study will produce a practical equation function to estimate the corrosion loss based on the parameters of temperature, current velocity, and dissolve Nitrogen (DIN) for two different levels, low concentration level DIN, and high concentration level DIN. The function can analyze the estimation of corrosion that occurs in two different locations in the chain, the splash zone area, and immersed area. The corrosion rate (mm / year) obtained from the empirical estimation is then validated with the actual measurement data from the field obtained from the available literature. The empirical estimation results show a good fit when compared with data from existing actual measurements. Furthermore, the validated estimation results and actual data are compared with the existing class/code rules wear allowance. The corrosion rate results in particular conditions that exceed the corrosion wear allowances in the rules for data on tropical waters.

Keywords— corrosion, model, mooring chain, tropical seawaters.

I. INTRODUCTION

Corrosion due to the marine environment, both uniform corrosion and pitting corrosion, combined with mechanical loading is one of the main reasons for the failure of a mooring system [1]. Corrosion will also contribute indirectly to a series of other failures so that the actual design life cannot cover up to the end of the operating service life [2]. Various design codes have different ranges to determine the corrosion rate of various specific locations. The range that guides the design of the structure is quite wide, so there is a possibility that the designer will choose the smallest corrosion rate value with the main consideration that the investment value is small. Meanwhile, a conservative designer will choose the value of the greatest corrosion rate with the consideration of getting better safety assurance. However, due to the large investment costs, in many cases, the smallest estimated value of the corrosion rate is chosen for the mooring system design. If there is a failure in the mooring system because the selected estimation for corrosion rate factor is too small, it will require a very large repair cost due to the accident. Not to mention the possibility of fatality and environmental damage caused by the vigilance of this mooring system. Therefore, a more in-depth study of the estimated corrosion rate is necessary.

Mooring integrity is an important concern in the offshore industry. However, some failures of the mooring system due to corrosion of the chain resulted in the actual design life of the mooring system is lower than the operating service life [2]. Most of these incidents occurred in tropical waters. Until now, many design codes for structures in tropical waters are still sticking to the codes designed for the North Sea, even though both have different environmental conditions [3].

Robert E. Melchers [4] proposed a method for estimating and modeling chain corrosion that occurs in an environment that is always / almost always submerged in corrosive media for low alloy steels. Extensive research is being carried out further by SCORCH JIP (Seawater Corrosion of Rope and Chain Joint Research Industry), or a multi-stakeholder joint project that examines corrosion of chains and mooring ropes in tropical waters in various overseas locations. In their journal [4][5][6], it is known that water temperature, current velocity, and DIN greatly influence the corrosion of the chain in seawater, especially in tropical seawaters. This research was conducted to determine the influences of the tropical environment and to seek empirical estimates of the parameters that are thought to have a major effect on corrosion that occurs in tropical waters.

II. METHOD

A. Melcher's Model

To model the corrosion that occurs in the mooring chain, the method proposed by Melchers [4][5][6] is used. This model can be used to analyze uniform corrosion (uniform corrosion), by dividing corrosion into two phases, namely the short term phase and the long term phase. These two phases can be used to create

Hasan Ikhwani is with Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, 60111, Indonesia. E-mail: hikhwani@oe.its.ac.id

Sista Mutya Atikanta is with Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, 60111, Indonesia. E-mail: sista.atikanta@gmail.com

Wimala L. Dhanistha is with Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, 60111, Indonesia. E-mail: wimala.danistha@gmail.com

functional trends in corrosion for metals submerged in seawater.

The unshaded part describes the short-time general corrosion loss function, the layer formed due to corrosion (c_d) increases with increasing corrosion rate (r_0) with time (t_d). In phase 0-1, the corrosion that occurs will be greatly influenced by temperature. The

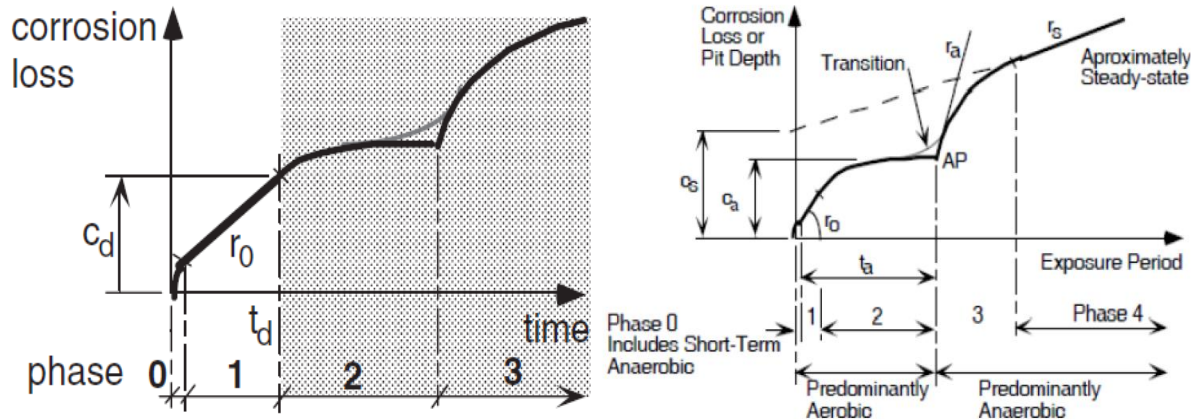


Figure 1. Melcher's Model [4-6].

B. Required Data and Case Identification

There are two kinds of data needed, namely corrosion data on the mooring system itself and environmental data. the data required includes:

Mooring system corrosion data

- Mooring system failure and its causes
- Field measurement data
- Data from experimental tests in the laboratory

Environmental data

- Temperature
- DIN / MIC
- Water current Velocity

From the existing data, it will be studied to determine the characteristics, trends, and tendencies of chain corrosion in the mooring system.

C. Locations along the line

In the method proposed by Melchers [4], the value of the uniform corrosion that occurs per different depth is considered the same. However, the Scorch findings [7], stated that the uniform corrosion that occurs will differ according to the location of the chain and the depth of the mooring chain. For this reason, the Modified Melchers Method is used, where the method proposed by Melchers will be further defined according to the location of the chain where the corrosion occurs, which will be divided into:

1) Splash Zone

Corrosion occurs mostly in areas that are close to surface level.

2) Immersed Zone

Corrosion in submerged water will be affected by DIN, oxygen and nitrogen decomposition, and current velocity.

corrosion rate will continue to increase until dissolved oxygen in the water near the surface of the metal controls the corrosion depending on the remaining oxygen concentration, the process is called a "concentration control". Factors that can affect this phase include water temperature, dissolved oxygen content, salinity, and water velocity.

D. Empirical Estimation for Corrosion Loss

Using the Melchers empirical model [4], the involved parameters will be inputted into a function to find corrosion loss estimates, namely:

$$r(T, D, V, L) = r_0 \cdot f(T) \cdot f(D) \cdot f(V) \cdot f(L) \quad (1)$$

With,

$f(T)$ = Function for seawater temperature

$f(D)$ = Function for DIN level

$f(V)$ = Function for water current velocity

$f(L)$ = Function for location factors

r_0 = Initial corrosion rate (mm/year/side)

r = Corrosion rate affected by parameters above (mm/year/side)

E. Validation and Analysis and Comparison





The empirical estimates were validated with actual corrosion allowance (c_a) data, and The results will be compared with those from the existing rules and standards, especially for tropical waters.

III. RESULTS AND DISCUSSION

A. Data grouping and investigation: Corrosion Survey according to SCORCH JIP-Field observations of mooring chains

Chevron contributed mooring data to the SCORCH JIP about floating production facilities in West Africa (2010), and FPU in Indonesia (2010) [8][7], with a summary, listed as follows:

TABLE 1.
 CONDITION OF THE WEST AFRICAN AND INDONESIAN MOORING CHAINS [8][7]

Condition of mooring chains	
Chevron West Africa	Chevron Indonesia
 <p>Figure 2. Above waterline [7].</p>	 <p>Figure 3. Above Waterline [7].</p>
 <p>Figure 4. Immersed part [8].</p>	 <p>Figure 5. Immersed part [8].</p>

From there, 2 depth categories can be obtained which are the parameters for determining each corrosion rate, namely splash zone and immersed zone.

- B. The factors that influence the corrosion of the mooring system
- 1) Temperature

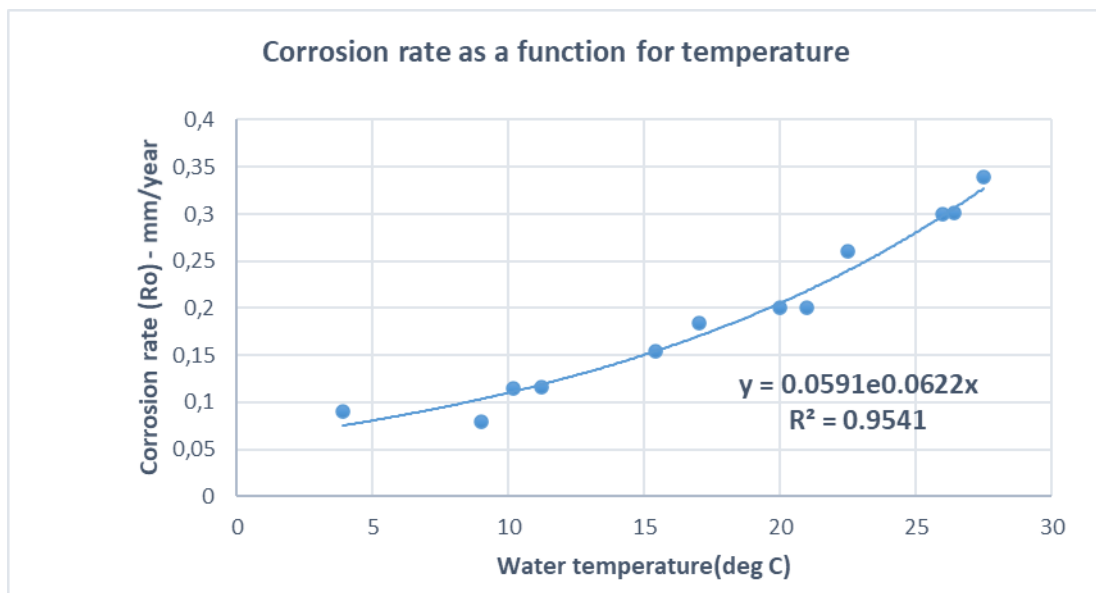


Figure 6. Corrosion rate (r_0) o the function of mean sea water temperature (T) based on data from references Melchers et al. [6]

Thus, the average temperature function is:

$$r_0 = 0.0591e^{0.0622T} \quad (2)$$

- 2) Water Velocity

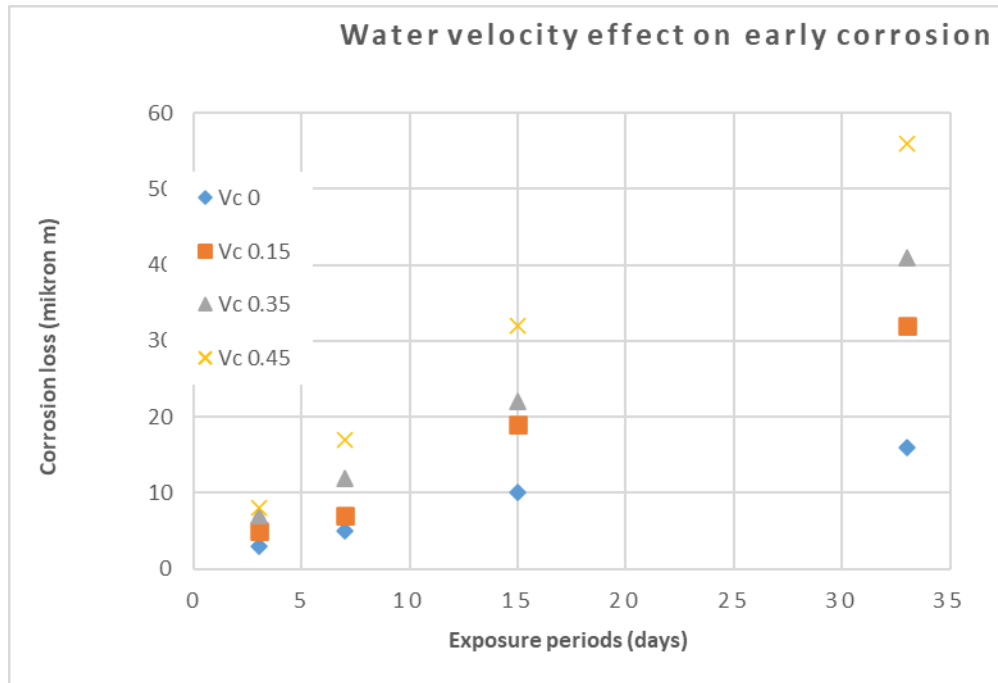


Figure 7. Linear effect of average current velocity on short-term corrosion modeling according to the Melchers and Jeffery model in Rosen [8].

From these results, a new equation for the combined average current velocity that follows the empirical relation is obtained by adding the V_c data (current velocity data) as follows:

$$r_v = r_0 \times (1 + 1.42 \times V_c) \quad (3)$$

with,

r_v : r_0 affected by V (mm/year)

r_0 : initial corrosion loss at $V_c = 0$ (mm/year)

V_c : velocity current data (m/s)

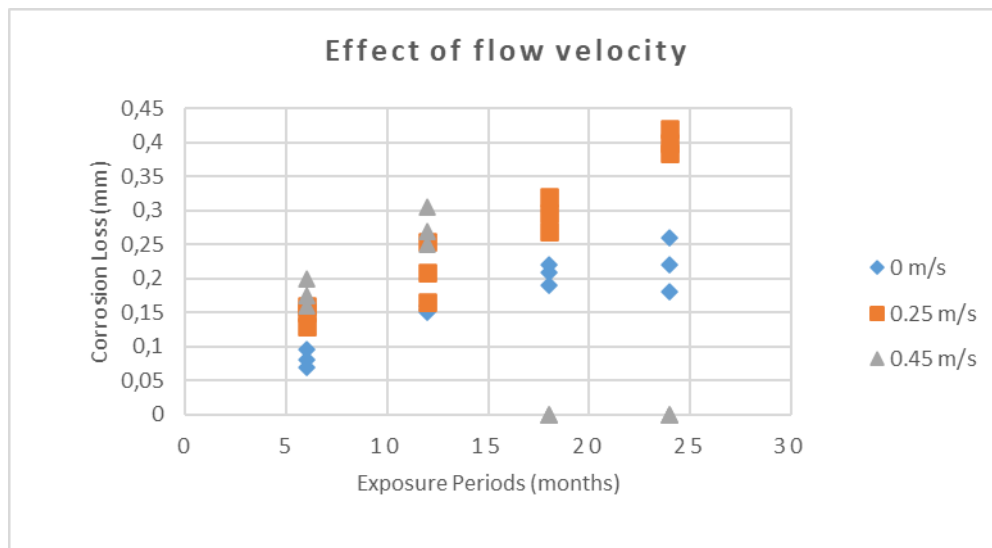


Figure 8. Effect of exposure period and velocity current on corrosion loss [6].

A relationship is sought between corrosion losses that are not affected by current velocity (C_s) and corrosion losses that are already influenced by current velocity (C_s'). So, from the result above, the formulation can be concluded as follows:

$$F(v) = 1 + \alpha \times V_c \quad (4)$$

$$F(v) = 1 + 1.9 \times V_c C_s' = C_s \times F(v)$$

with,

$F(v)$ = Corrosion rate-controlling factor

α = Current velocity factor = 1.9

V_c = Average current velocity (m/s)

C_s = Corrosion loss at $V_c = 0$ (mm)

C_s' = Corrosion loss at V_c when not 0 (mm)

3) DIN/MIC

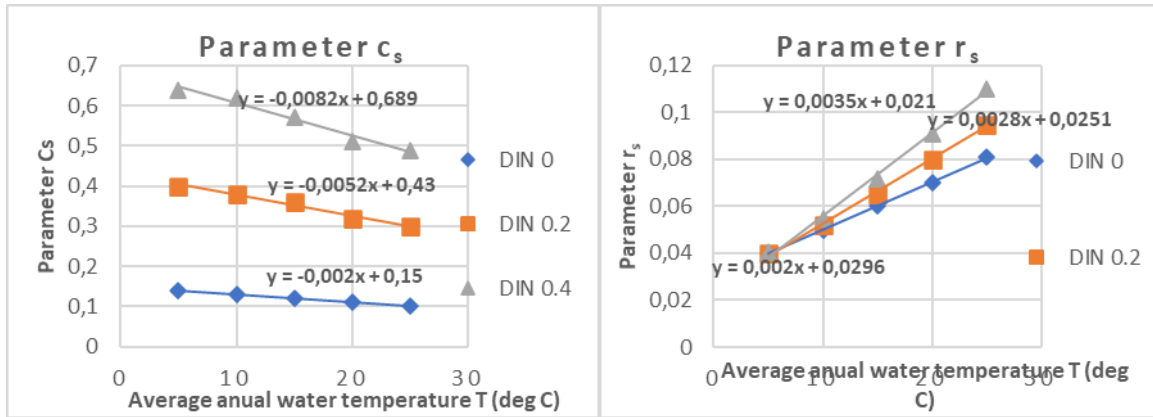


Figure 9. Parameter c_s (left) and r_s (right) as function of T and DIN.

TABLE 2.
 AVERAGE ANNUAL CORROSION LOSS (MM/YEAR) AT HIGH CONCENTRATION DIN (DIN > 1 MGN/L), IN TEMPERATE WATER (TROPICS = 25°C) [6]

Type	Exposure Condition	DIN = 2 mgN/L		DIN = 4 mgN/L		DIN = 6 mgN/L	
		10 years	20 years	10 years	20 years	10 years	20 years
Chain	Immersed still water	0.67	0.58	0.9	0.74	1.15	0.91

From the corrosion coefficient estimation table, the trendline that can be estimated is the following equation:
 $c_s = 0.75x(DIN) + 0.25$ (5)

$$r_s = -0.0008x(DIN^4) + 0.0133x(DIN^3) - 0.0742x(DIN^2) + 0.2117x(DIN) - 0.02 \quad (6)$$

C. The location along the line

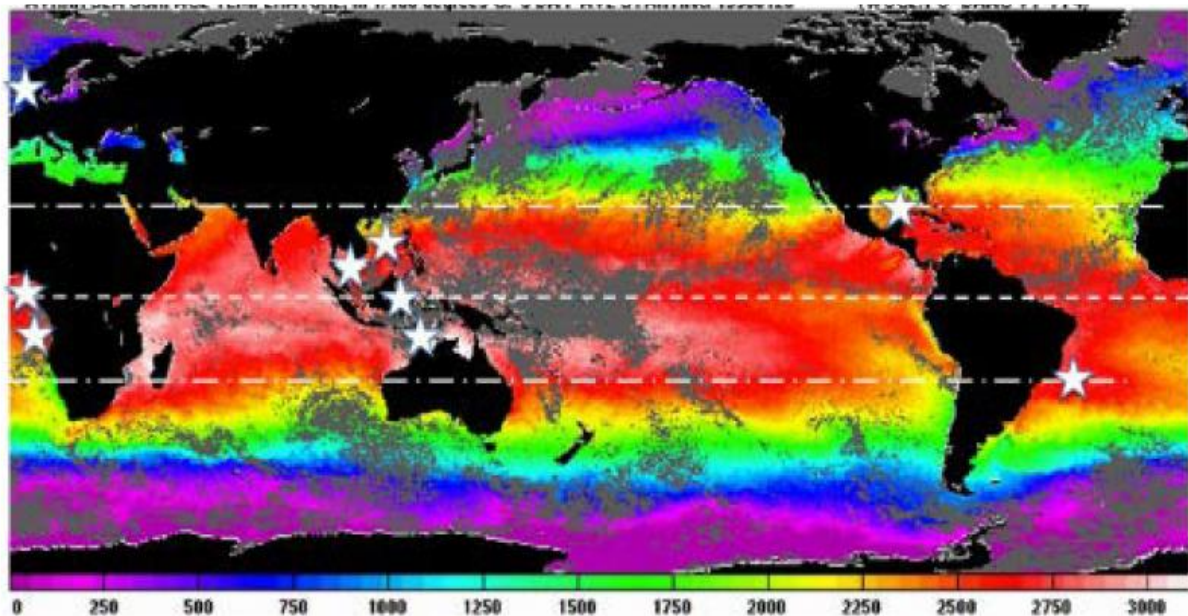


Figure 10. The location of the data source for the corrosion rate observation in the field [8].

Splash Zone is an uncertain area that is sometimes exposed to water and sometimes exposed to air, so defining which part is more exposed is hard. Therefore, a

location factor (F_z) is needed which is used to approach the corrosion location.

TABLE 3.
 LOCATION FACTOR (FZ) FOR *SPLASH ZONE*

Descriptions	Splash Zone / Submerged
FPSO 1	1.519
FPSO 2	1.225
FPU 1	1.387
FPU 2	1.119
Average	1.312

Location factor (fz) for immersed and splash zone is:

$$\begin{aligned} \text{Immersed / submerged} &= 1 \\ \text{Splash Zone} &= 1.312 \end{aligned}$$

- fz : Location factor (immersed or splash zone)
- fv : Velocity factor
- cs : Intercept Gradient cs
- rs : Intercept Gradient rs
- ro : Initial corrosion rate (mm/year)
- t : Period (year)
- T : Temperature (°C)

D. Empirical estimation of corrosion loss

From the parameters of location, temperature, current velocity, and DIN previously analyzed, an empirical estimate is obtained for calculating corrosion loss due to uniform corrosion as follows:

$$\begin{aligned} r_0 &= 0.059 \exp(0.062 \times T) \\ C &= f_z \times (f_v \times c_s + r_s \times t + f_v \times r_0 \times t) \end{aligned} \quad (4)$$

with,

C : Total Diameter Loss (mm)

E. Comparison of estimates with field data for validation

If the corrosion loss value obtained from the empirical estimation calculation results is compared with the corrosion loss value from the actual data, the percentage error ratio is as follow:

TABLE 4.
 COMPARISON OF THE CORROSION LOSS VALUES CALCULATED WITH THE DATA

Data	Location in Chain	Comparison of Corrosion Loss		
		data mm/year	estimation mm/year	Margin error %
Check 1	immersed	1.750	1.718	1.824
Check 2	immersed	1.130	1.284	-13.648
Check 3-A	immersed	0.750	0.771	-2.859
Check 3-B	Splash Zone	1.040	1.012	2.679
Check 4	immersed	0.400	0.387	3.256
Check 5	immersed	0.640	0.665	-3.954
Check 6	immersed	0.420	0.402	4.291
Check 7	immersed	0.670	0.695	-3.665

It can be seen that the estimation method has a fairly small margin error, which means that the estimation results have an accuracy good enough to be considered practically.

The mid-catenary zone and touch-down zone are treated the same as the immersed zone in this study because they have the same value, and the biggest value will be taken per the rule that includes the criteria for tropical waters per location.

F. Comparison of Estimates with Existing Rules

TABLE 5.
 COMPARISON OF RULES [3][9][10]

Codes/Standards	Chain Corrosion-Wear Allowance (mm/year in chain diameter)		
	Splash Zone	Mid-Catenary Zone	Touch-down Zone
API RP 2SK	0.2-0.4	0.1-0.2	0.2-0.4
ISO 19907-1	0.2-0.8	0.1-0.2	0.2-0.8
BS 6349-1	Tropical Seas	0.16-0.34	0.08-0.26 ²
	Without Inspection	0.4	0.3
DNV OS-E301	Regular Inspection	0.2	0.3
	Norwegian Regulations	0.8	0.2
	Tropical Seas	1	0.3
BV NI 493	Ratio per ISO 19907-1 or API RP 2SK		

TABLE 6.
 COMPARISON OF CALCULATED CORROSION LOSS VALUES AND DATA WITH RULES [3][9][10]

Check no.	Location Along the Chain	Actual Data mm/year	Result from Calculation mm/year	a = DNV OS-E301		b = BS 6349-1		Description
				Splash zone	Immersed	Splash zone	Immersed	
Check 1	immersed	1.750	1.718	-	0.4	-	0.26	Estimation and Data has the value bigger than in the code a and b
Check 2	immersed	1.130	1.284	-	0.4	-	0.26	Estimation and Data has the value bigger than in the code a and b
Check 3-A	immersed	0.75	0.771	-	0.4	-	-	Estimation and Data has the value bigger than in the code a and b
Check 3-B	Splash zone	1.040	1.012	1	-	0.34	-	Estimation and Data has the value bigger than in the code a and b
Check 4	immersed	0.4	0.387	-	0.4	-	0.26	value obtained from estimation is bigger than code b, actual data is bigger than in the code a and b
Check 5	immersed	0.64	0.665	-	0.4	-	0.26	Estimation and Data has the value bigger than in the code a and b
Check 6	immersed	0.42	0.402	-	0.4	-	0.26	Estimation and Data has the value bigger than in the code a and b
Check 7	immersed	0.67	0.695	-	0.4	-	0.26	Estimation and Data has the value bigger than in the code a and b

Most of the results of corrosion loss checks exceed the corrosion wear allowances in the rules for tropical waters. This indicates that corrosion in certain areas in tropical waters is occurring more rapidly than predicted by existing rules.

The data with the largest diameter loss is in check 1, which is 1,750 mm / year in the immersed zone, with the diameter of the loss from the modeling results closer to the field data, namely 1,718 mm / year.

IV. CONCLUSION

- 1) The temperature, DIN, and current velocity have a significant effect on corrosion loss in the mooring chain. The greater the temperature, the larger the uniform corrosion rate, especially in the splash zone area, is greater than the immersed zone. Meanwhile, for current velocity, the greater the corrosion loss, the greater the uniform corrosion rate in the immersed area. The DIN will show a big impact when it is above 8mgN / L. The empirical estimation obtained for corrosion loss due to the influence of DIN, temperature, and current velocity is influenced by location factors. For tropical waters, the fz value for the splash zone is 1.312, and immersed is 1. Thus, the empirical estimation that can be obtained from This research is $C (T,D,V,L)=r_{0.t} f(T) f(D) f(V)f(L)$. The formula has fv component which represents the velocity factor $F (v) = 1 + 1.9 \times Vc$, cs and rs, which represents the gradient intercept factor for DIN function, $ta = 6.1492 \exp (-0.08T)$ and $ca = 0.344 \exp (-0.048 T)$.
- 2) The empirical estimation obtained can be used as a practical aid formula in determining corrosion wear allowances, because the results have a close value compared to the actual data with small errors on validation, which means that they have fairly high accuracy. Most of the data have corrosion loss which exceeds the corrosion wear allowance values provided by codes specified for tropical waters. 6 out of 7 data exceed corrosion wear allowance provided by existing codes, where the corrosion allowance value in tropical waters is 1.0 mm / year for splash zone and 0.4 mm / year for immersed according to DNV OS-301 and 0.26 mm/year for the immersed zone and 0.34 mm/year for splash zone according to BS 6349-1.

ACKNOWLEDGMENTS

The completion of this research is inseparable from the help and support of many parties who have assisted in terms of knowledge, experience, and supporting facilities for this research. The author would like to thank the parents and all parties involved in carrying out this research either directly or indirectly so that this research can be completed.

REFERENCES

- [1] E. Fontaine, J. Rosen, A. E. Potts, K. T. Ma, and R. E. Melchers, "SCORCH JIP – Feedback on MIC and Pitting Corrosion from Field Recovered Mooring Chain Links". Presented at Proceedings of the Offshore Technology Conference, Houston, Texas, US, 5-8 May 2014, pp. 4-9.
- [2] R. D'Souza and S. Majhi, "Application of Lessons Learned from Field Experience to Design, Installation, and Maintenance of FPS Moorings", presented at Offshore Technology Conference, Houston, Texas, US, 6-9 May 2014, pp. 2-7.
- [3] API (2011), "Specification for Wire Rope". API Specification 9A, 26th Edition, May 2011.
- [4] R. E. Melchers, "Modelling of Marine Immersion Corrosion for Mild and Low-Alloy Steels Part1: Phenomenological Model". Corrosion, 2003, 59:319–334.
- [5] R. E. Melchers, "The Effect of Corrosion on the Structural Reliability of Steel Offshore Structures", Corrosion science 47, The University of Newcastle, Australia, 2005, pp.2397-2408.
- [6] R. E. Melchers, R. J. Jeffery. "Long-term Corrosion of steels and Steel Piling in Seawaters with Elevated Nutrient Concentration", presented at The European Corrosion Congress, Pisa, Italy, 9 September 2014, pp. 1-7.
- [7] J. Rosen, K. Jayasinghe, A.E. Potts, R.E. Melchers, and C. R. Chaplin, "SCORCH JIP - Findings from Investigations into Mooring Chain and Wire Rope Corrosion in Warm Waters", presented at Offshore Technology Conference, Houston, Texas, US, 4-7 May 2015, pp. 3-10.
- [8] J. Rosen, A. E. Potts, E. Fontaine, K. T. Ma, C. R. Chaplin, and W. Storesund, "SCORCH JIP – Feedback from Field Recovered Mooring Wire Ropes", presented at Proceedings of the Offshore Technology Conference, Houston, Texas, US, 5-8 May 2014, pp. 16-27.
- [9] BV (2008), "Classification of Mooring Systems for Permanent Offshore Units". Guidance Note NI 493 DTM RO1 E, July 2008.

- [10] DNV (2013), "Position Mooring". Offshore Standard DNV-OS-E301, October 2013.