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To cite this article: S Komariyah *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **557** 012038

IOP Conf. Series: Earth and Environmental Science **557** (2020) 012038 doi:10.1088/1755-1315/557/1/012038

Structural Degradation of Oil Tanker Operating in Indonesian Waterways

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Abstract. Corrosion is one of the significant factors for decreasing strength in floating marine structures. In general, rules of classification society use the North Atlantic Ocean located in the sub-tropical region as a reference area in the formulation of the structural strength. If the sub-tropical area compare with tropical region such as Indonesia waterway, Indonesia waterway has high salinity and humidity. This makes marine environment in Indonesia more corrosive. One example of the effects of corrosion is the reduction in plate thickness. This leads to decrease in ship strength. Using measured thickness data collected from 25-thickness measurement reports from 24 Oil Tankers that sailing in Indonesian waterways, the diminution of ship structural thickness has been analysed. The age of Oil Tankers, whose data was taken, ranges from 5 to 23 years. Data analysis was carried out by using statistical approach based on Weibull distribution. Using 95% cumulative probability, it was found that the thickness diminution of Oil Tanker with design life of 20 years is 2,07 mm for deck plate, the side plate is 2,06 mm, the bottom plate is 1,81 mm and the inner bottom plate is 1,53 mm.

1. Introduction

Corrosion is an important factor that affects the degradation in strength of ship and other floating steel structures. Generally, corrosion is influenced by environmental factors such as humidity, temperature and salinity. In the design stage, the effect of corrosion on the ship structure is compensated by adding thickness named corrosion addition. The thickness of corrosion addition is a compensation value of the amount of plate thickness reduction during its design life. Herewith, the required plate thickness is the thickness of corrosion addition and the minimum requirement of plate thickness of structural member [1].

During the ship in operation, the condition of ship structure must be ensured through periodic surveys and inspections. Thickness measurement of ship structure members will be conducted during periodic survey. This is to ensure that the thickness diminution of structural member does not exceed the wastage allowance.

Corrosion rate is conventional estimated by using the amount of reduction in plate thickness divided by the age of the ship at a given time. Those are simple and easy, however, they are considered unrealistic estimation since the method is not taking into account the phenomenon of corrosion that may occurs [2][3]. Yamamoto [2] proposed a probabilistic model that takes into account the process of corrosion generation and corrosion progress in structural members in order to define the permissible corrosion level. He divided the corrosion process into 3 sequent processes, namely the deterioration process of anti-corrosion paint, the process of forming a pitting point followed by the progress of the pitting point. Wang [4] [5] and Paik [6] created a mathematical model that described the statistical characteristics of corrosion wastage as a function of the time at which the corrosion rate was described using the Weibull distribution. Figure 1 shows a progress corrosion scheme, where three curves are plotted, namely convex, concave and straight line. The convex curve indicates that the corrosion rate increases at the beginning of the progress and then decreases as the corrosion progresses. Concave curves indicate accelerating corrosion in line with the ongoing corrosion process. Straight lines show constant-rate corrosion progress.

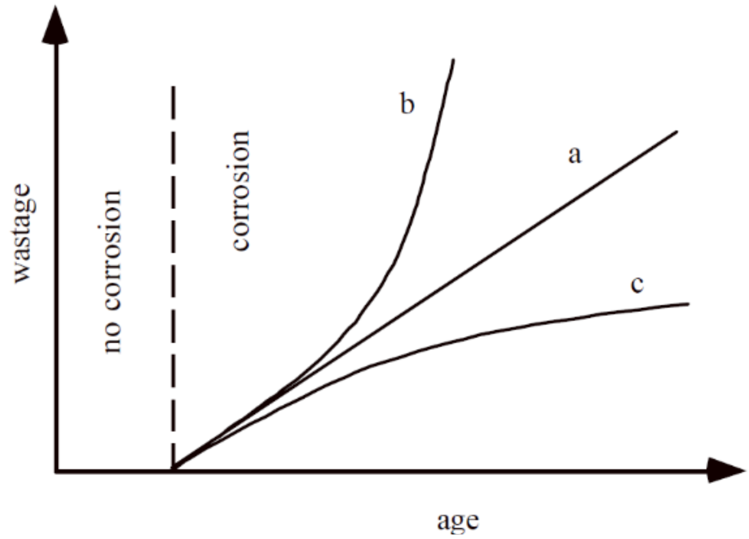

Figure 1. Corrosion progress [4][6]

Garbatov [7] made a nonlinear model of corrosion wastage for deck plates. Zayed [8] proposed a simplified method for predicting corrosion in different structural panels for different corrosion types. The reduction plate thickness of the FPSO hull has carried out by Larangeira [9] and it is estimated using several non-linear approximation methods. Meanwhile, IACS has issued Technical Background in determining corrosion addition and wastage allowance that be used in the CSR Rules [10]. Many studies on the evaluation of corrosion wastage have been carried out including its effect on the ultimate strength of ships, e.g., [11] [12] [13] [14] [15].

In this research, a statistical analysis of the plate thickness reduction was conducted. The reduction rate of structural members was determined by using cumulative probability simulation model. The results were compared with the previous study and finally, reasonable corrosion margin for oil tanker ships operating in Indonesia waterways based on thickness data measurement was proposed.

2. Thickness Measurement Data

Plate thickness measurements data were collected from Ultrasonic Thickness measurement (UT) Reports. UT measurement was carried out when the ship conducted a periodical inspection. 25 UT reports that measured in 24 Oil Tankers were used in this research. The selected ships have the size larger than 500 GT and only sail in Indonesian domestic waters.

The age of selected ships is figured in Figure 2. The age of selected ships varies from 5 years to 23 years. The distribution of ship's age shows that the major contribution is 20.83% with 22 years old. Figures 3 and 4 show the distribution of ship length and ship size in GT. The selected ships have major distribution of length between 65 meter to 70 meter and is also majorly distributed between 1400 GT to 1500 GT in ship size.

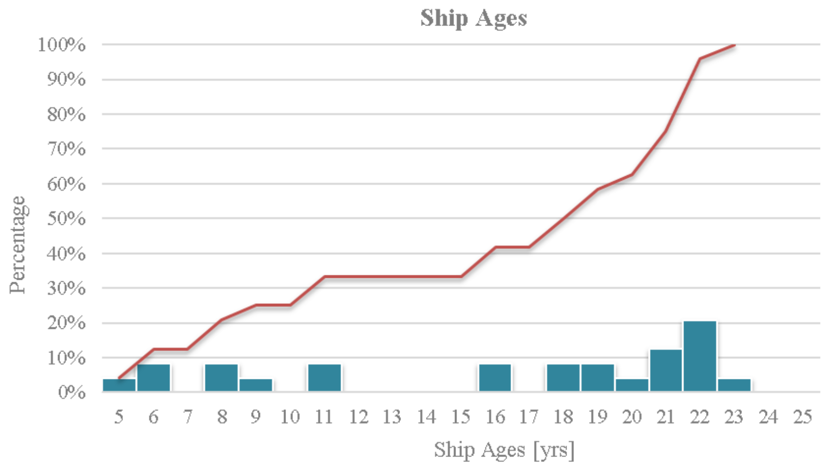

Figure 2. Ages distribution of oil tanker ships

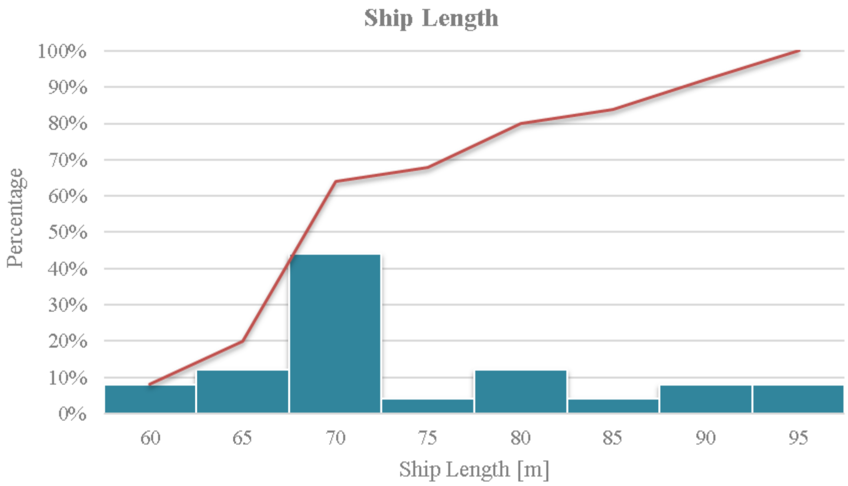

Figure 3. Length distribution of oil tanker ships

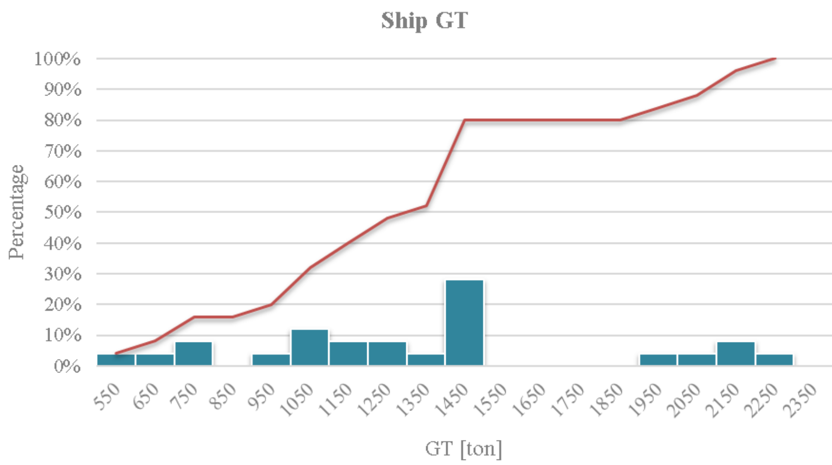

Figure 4. GT distribution of oil tanker ships

The number of UT points used in this research was 16814 points. The points were obtained from four area of plate thickness measurement. There were 4288 points in the deck plating, 6328 points in the bottom plating and 2687 points in inner bottom plating and 3511 points for side plating.

Based on aforementioned data, the differences between original thickness and measured thickness of plate were determined. Furthermore, filtering system was applied on the data where the measured thickness plate was larger than original thickness. We assumed that ship structure had replating which the thickness of new plating was difference from the original ones. The addition filtering was when the diminution of plate thickness was equal to zero.

Table 1 presents tabulation of the occurrence number of deck plate thickness diminution ranges for various vessel ages. The maximum thickness diminution of deck plating is 4.36 mm which occurs at the 22 years old of selected ship.

In details, the data are divided into four ranges of ship ages. For ships between 5 to 10 year old, the maximum occurrence of thickness diminution is between 0.0 mm to 0.5 mm with the average of thickness diminution at this age's range is 0.3 mm. The maximum thickness diminution occurs at ship of age 5 years olds that is 1.30 mm. For ships between 11 to 15 year old, the average of thickness diminution is 0.41 mm while the maximum diminution is 2.4 mm. For ship ages 16 to 20 years old, the maximum thickness diminution is 1.80 mm at ship ages 20 years old. At this range, the average of diminution is 0.55 mm. The last ranges is ships between 21 to 25 years old, the average of thickness diminution is 0.69 mm which located in range between 0 to 0.5 mm depth of corrosion with number of occurrence is 690.

Table 1. Thickness loss due to corrosion in deck plate

Depth of corrosion	Ship ages [years]			
[mm]	5 - 10	11 - 15	16 - 20	21 - 25
$0 < h \leq 0{,}5$	1132	363	456	690
$0{,}5 < h \leq 1{,}0$	43	70	159	287
$1{,}0 < h \leq 1{,}5$	2	21	70	341
$1{,}5 < h \leq 2{,}0$	0	7	22	44
$2{,}0 < h \leq 2{,}5$	0	2	0	6
$2{,}5 < h \leq 3{,}0$	0	0	0	3
$3{,}0 < h \leq 3{,}5$	0	0	0	9
$3{,}5 < h \leq 4{,}0$	0	0	0	0
$4{,}0 < h \leq 4{,}5$	0	0	0	1

The distribution of occurrence number for thickness diminution of bottom plate is shown in Table 2. The maximum diminution occurs on ships aged 11 years old, which is 2.5 mm. For ship age 5 to 10 years old, the average of thickness diminution is 0.35 mm with the maximum diminution is 1.8 mm. The maximum number of occurrence is 1192 for depth of corrosion between 0 to 0.5 mm.

In the range of 11 to 15 years old, the maximum thickness diminution of bottom plate is 2.5 mm and the average is 0.49 mm. For ship ages 16 to 20 years old, the maximum and average diminution is 2.3 mm and 0.72 mm. For ship ages between 21 to 25 years old, the maximum number of occurrence is 1547 for depth of corrosion between 0 to 0.5 mm. The average of thickness diminution for this range of ship's age is 0.51 mm with the 2.2 mm for maximum diminution at ship age 21 years.

Table 2. Thickness loss due to corrosion in bottom plate

Depth of corrosion	Ship ages [years]			
[mm]	5 - 10	11 - 15	16 - 20	21 - 25
$0 < h \leq 0{,}5$	1192	484	540	1547
$0{,}5 < h \leq 1{,}0$	249	138	304	444
$1{,}0 < h \leq 1{,}5$	5	47	248	291
$1{,}5 < h \leq 2{,}0$	1	18	27	19
$2{,}0 < h \leq 2{,}5$	0	9	6	1

Table 3 and Table 4 are the tabulation of number occurrence of thickness diminution for side plate and inner bottom plate. For thickness diminution of side plate, the maximum diminution is 2.7 mm that occur at the ship's age 11 years. The average of thickness diminution for ship ages 5 to 10 years, 11 to 15 years, 16 to 20 years and 21 to 25 years are 0.34 mm, 0.44 mm, 0.63 mm and 0.39 mm with the maximum diminution in sequence are 1.8 mm, 2.7 mm, 2.0 mm and 1.7 mm. For inner bottom plate, the maximum thickness diminution is 2.4 mm, which occur at ship 21 years old.

Table 3. Thickness loss due to corrosion in side plate

Depth of corrosion [mm]	Ship ages [years]			
	5 - 10	11 - 15	16 - 20	21 - 25
0 < h ≤ 0,5	683	368	269	1079
0,5 < h ≤ 1,0	101	61	166	174
1,0 < h ≤ 1,5	9	27	49	60
1,5 < h ≤ 2,0	1	21	28	3
2,0 < h ≤ 2,5	0	2	0	0
2,5 < h ≤ 3,0	0	1	0	0

Table 4. Thickness loss due to corrosion in inner bottom plate

Depth of corrosion [mm]	Ship ages [years]			
	5 - 10	11 - 15	16 - 20	21 - 25
0 < h ≤ 0,5	787	303	262	671
0,5 < h ≤ 1,0	108	45	42	127
1,0 < h ≤ 1,5	0	28	1	42
1,5 < h ≤ 2,0	0	11	5	4
2,0 < h ≤ 2 ,5	0	0	0	1

3. Evaluation of Thickness Diminution

Evaluation of plate thickness data was performed using a probabilistic model. The nonlinear corrosion model was estimated by processing data of structural plate thickness measurements and it was assumed to follow a Weibull distribution. In this study, corrosion is assumed to occur in the fifth year of the ship life or when the ship conducts a survey of the first class renewal because the corrosion protection system is still considered effective, so the data used was the UT data of ships aged 5 years and over.

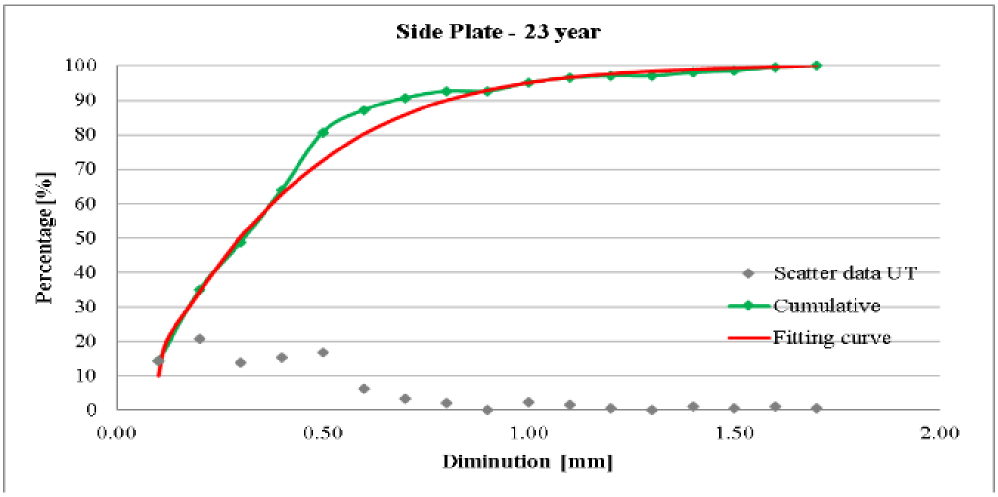

Figure 5. Probability density at structural member at various ship's age. Side plate is shown.

Figure 5 and Figure 6 show the example of probability density for side plating, and inner bottom plating of Oil Tankers at a stipulated ship age. The grey point is the scatter data of UT Reports while the green line is the graph for each cumulative probability. The red line is plotting the results of a proposed probabilistic model. It is shown that the fitness of the proposed probabilistic model and that of cumulative probability density are still acceptable. The other probability density of deck plating and bottom plating area are also determined.

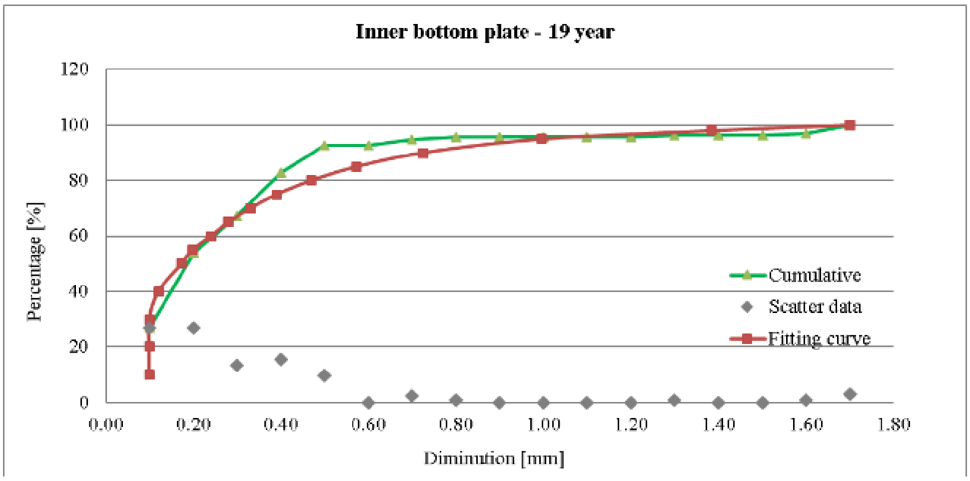

Figure 6. Probability density at structural member at various ship's age. Inner bottom plate is shown.

4. Results & Discussion

The number of plate thickness diminution is determined and is obtained by using probability model. This diminution could illustrate the actual value of plate thickness reduction of Oil Tanker that has voyage in Indonesian waterway. The results are used as corrosion margins.

The amount of corrosion margin is varying depending on cumulative probability. 5(five) values of cumulative probability levels are chosen in this works. There are 80%, 85%, 90%, 95% and 98%. Figure 7 displays the cumulative probability values of 80%, 85%, 90%, 95% and 98% on the deck plating. Figures 8-10 are for the side plating, bottom plating and inner bottom plating. The scatter of data UT are also plotted in those figure based on the ship ages. The selected cumulative probability is a value where the average and the maximum diminution are not greater than the value for both the entire population and for each age of Oil Tankers.

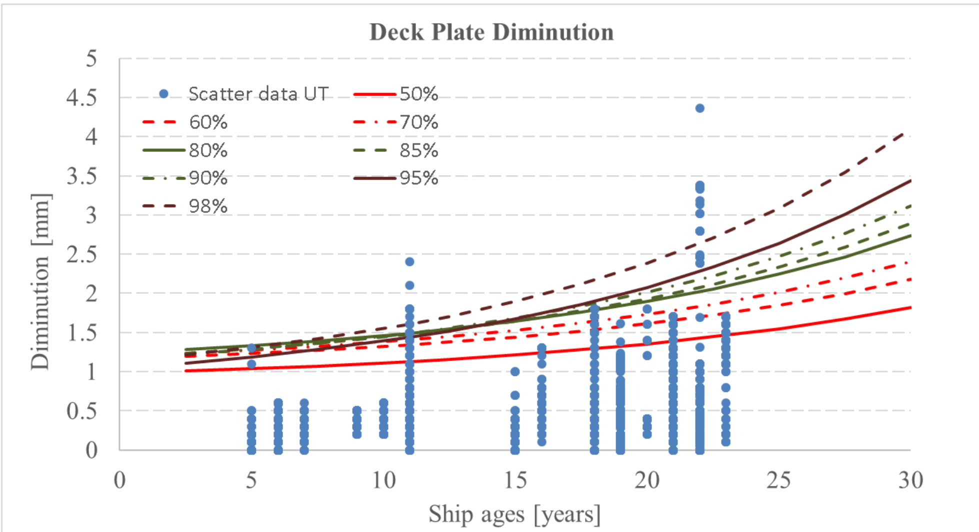

Figure 7. Probability cumulative for deck plate

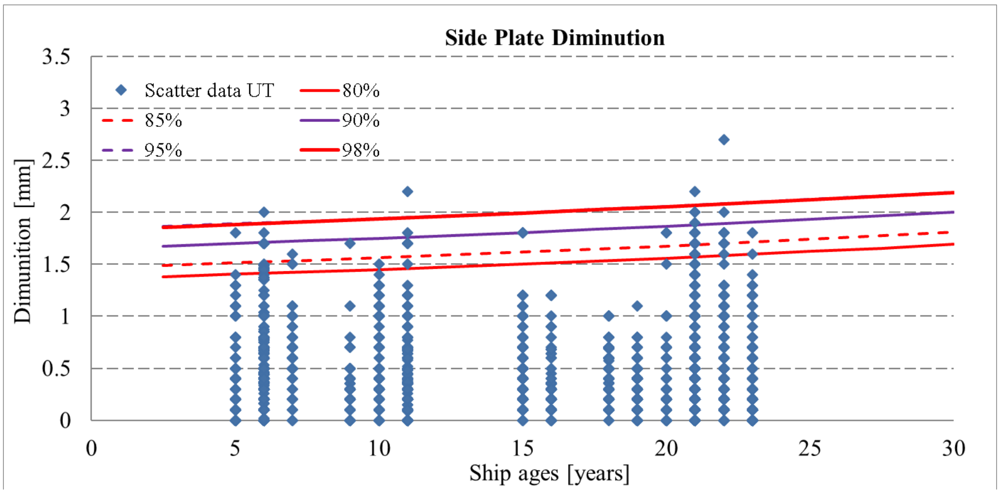

Figure 8. Probability cumulative for side plate

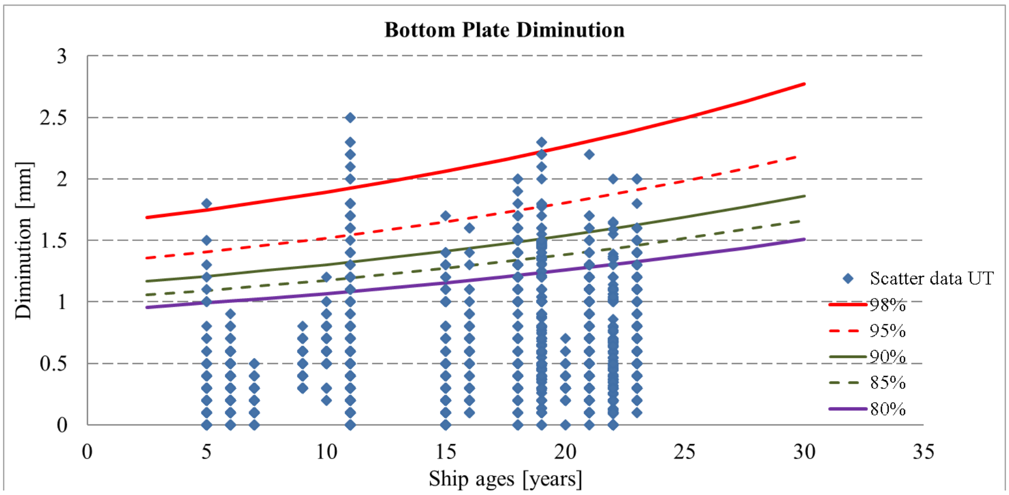

Figure 9. Probability cumulative for bottom plate

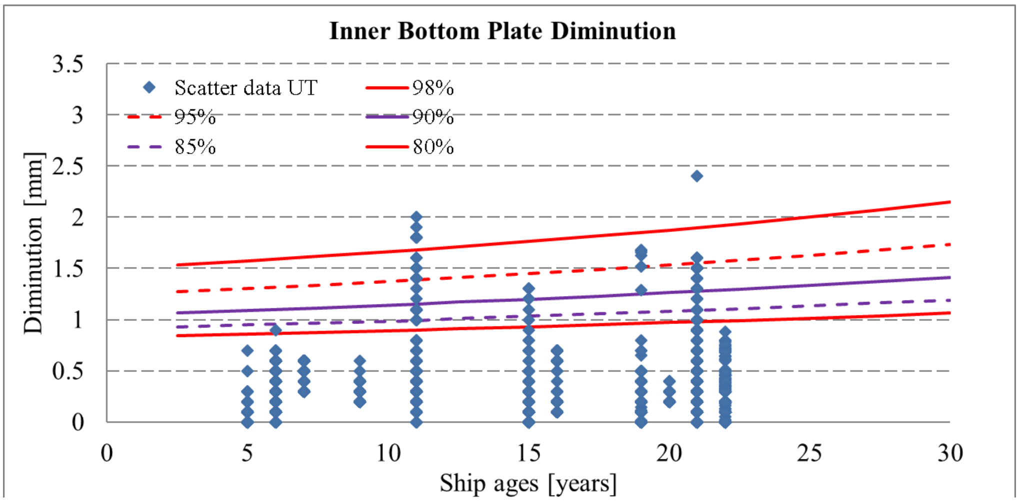

Figure 10. Probability cumulative for inner bottom plate

Table 5. Thickness diminution for each structural member in mm

Structural member	Max.	Mean	Deviation	Cumulative Probability				
				80 %	85 %	90 %	95 %	98 %
Deck plate	4.36	0.51	0.42	1.89	1.93	2.01	2.07	2.38
Side plate	2.7	0.24	0.34	1.56	1.68	1.87	2.06	2.05
Bottom plate	2.5	0.51	0.38	1.26	1.39	1.54	1.81	2.26
Inner bottom plate	2.4	0.38	0.28	0.97	1.08	1.26	1.53	1.87

Table 5 is the thickness diminution for structural plating applying for design life 20 year resulted from this study. Using 95% cumulative probability, it is found that the predicted thickness dimunition of deck is 2.07mm. 2.06 is for side plate, 1.81mm is for bottom plate and inner bottom plate is 2.4mm. Thus, those results are compared to the previous study conducted by other researcher [3,5,10] that already published, as shown in Table 6 and Table 7.

Three areas are selected, deck plate, side plate and bottom plate in comparison phase. For design life 20 year, thickness diminution of structural plating for Oil Tanker ships operated in Indonesia waterways is smaller than in ocean going, except for the side plate. It is assumed that the side plate area has almost identical thickness dimunition for Ocean Going route and Indonesian waterways only route because side plate area effects to changing wet and dry condition also affect to the corrosion rate of plate thickness area. The thickness dimunition for others area (deck plate and bottom plate) of Indonesian waterways shows that the effect of salinitas on the tropic area such as Indonesia, did not give any substantial additional corrosion to the plate. It is also caused by additional corrotion protection that be applied in the both deck plate and bottom plate, such as coating application. Furthermore, effect of corrotion protection is not taken into account in this report.

A comparison of 95% cumulative probabability level for 25 years design life and the results study by IACS[10] is tabled in Table 7. The comparable between two datas shows that predicted thickness dimunition of side plate area are still almost identical. It could conclude that the 20 years and 25 years design life give the almost identical prediction results.

Table 6. Thickness diminution for design life 20 year

Structural member	Sonne [3]	Wang [5]	Result
Deck plate	3.11	3.500	2.07
Side plate	1.91	2.000	2.06
Bottom plate	4.35	5.600	1.81

Table 7: Thickness diminution for design life 25 year

Structural member	IACS [10]	Result
Deck plate	3.540	2.64
Side plate	2.180	2.12
Bottom plate	3.660	1.98

Based on the above results and discussion, the above results could as used as references in determining the corrotion addition and/ or wastage allowance for Oil Tankers that sail in the Indonesian waterways. The adjusment corrosion addition of typical Oil Tankers could be reduced to 50% for deck plate area and 30% for bottom plate area.

5. Conclusion

Reduction in the thickness of the hull plates namely on the deck, sides, bottom and inner bottom were estimated. Analysis based on UT report data for 16814 points using the Weibull distribution function.

Average values and standard deviations for each structure were obtained using the entire population data and for each age of the ship.

By using 95% probability density obtained for the design life 20 years of the ship the thickness diminution of deck plating is 2,07 mm, the side plating is 2,06 mm, the bottom plating is 1,81 mm and the inner bottom plating is 1,53. This estimate values can be used as a reference in determining corrosion addition and wastage allowance for Oil Tankers sailing in the Indonesian waterways.

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