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Fatigue Analysis Of 5000 GT Ferry Ro-Ro′ s Car Deck Using Finite Element Method

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Abstract

Ro-Ro Passenger Ship type crossing ship is a ship that is operated to connect 2 (two) ports. On the Ro-Ro ship there is a car deck as one of the vital construction structures, because it is used to support the vehicle load on it. This study aims to determine the value of fatigue life in car deck construction by reviewing hot spot stress areas that are prone to cracking. The value of the fatigue analysis is taken from the greatest stress value and the shortest cycle is taken at each plate thickness variation. The method used is the Finite Element Method (FEM). By varying the thickness of the car deck plate assisted by using finite element based software. The results showed the highest maximum stress was found on car deck 1 with a thickness of 80% (9.6 mm) which was 241.16 MPa, while the lowest minimum stress was found on car deck 2 with a thickness of 110% (13 mm) which was 103.07 MPa. The highest value of fatigue life is found in car deck 2 with a plate thickness of 110% (13 mm) of 74.23 years with a stress cycle of 1350,000 times, while the lowest fatigue life value is found in car deck 1 with a plate thickness of 80% (9.6 mm) of 7.63 years with a stress cycle of 220,000 times.

1. Introduction

Sea transportation is part of the national transportation system that plays an essential role in the regional and national economy of the maritime country. In the context of Indonesia, sea transportation plays a vital role in development. In this regard, efforts should be made to provide sufficient infrastructures and facilities. Thus, It will trigger sea transportation modes, including Ro-Ro Ferries. For example, a port located in Merak, Banten Province, is one of the crossing ports between the islands of Java and Sumatra. The mobility and occupation rate of the Ro-Ro ferry is high [1].

The KMP Legundi 5000 GT is a Ro-Ro ferry that operates in the Sunda Strait on the Port of Merak - Bakauheni. This busy shipping route, which takes approximately two and a half hours, requires that the ship is always in the best performance, particularly in its construction. In shipbuilding, the ship construction should be designed with maximum stress smaller than allowable stress, and the structure can still withstand a certain load [2].

In the study of the technological development of ro-ro ferries, most reviewed articles are related to safety because the ro-ro ferry is more vulnerable than other merchant ships due to the following issues : (a) stability issue (b) low freeboard, (c) cargo access doors, (d) lack of bulkheads, (e) access to life-saving appliances (f) vulnerability of adverse weather, (g) vehicle lashing and (h) loading processes with respect to weight distribution[3].

The ferry decks are occupied with different loads; for example, a lower deck accommodates vehicles and cargo [4]. Loading and unloading the vehicles use the Ramp Door with Ro-Ro (Roll On - Roll Off) system, which is designed at the bow or stern of the ship [5]. Then the vehicles are accommodated in the lower deck or car deck. The car deck is subject to vehicle loads and should withstand heavy and repetitive loads. It should be ensured that stress working on the car deck comply with rules and requirements.

The number of Ro-Ro ferry service users is growing and the increase in population and transportation. At a specific time, a load spike occurs because the number of passengers and vehicles transported by the ship is dramatically increased [6]. At this time, the ship's car deck is subject to heavy loads and prone to structural fatigue due to the repeated loads. It will impact the durability of the deck and the lifetime of the ship. Considering that, A study on the fatigue life of the KMP Legundi's car deck will be performed in the present study [7].

2. Methods

The research stage is generally described in the flow diagram shown in Figure 1 and will be explained comprehensively step by step.

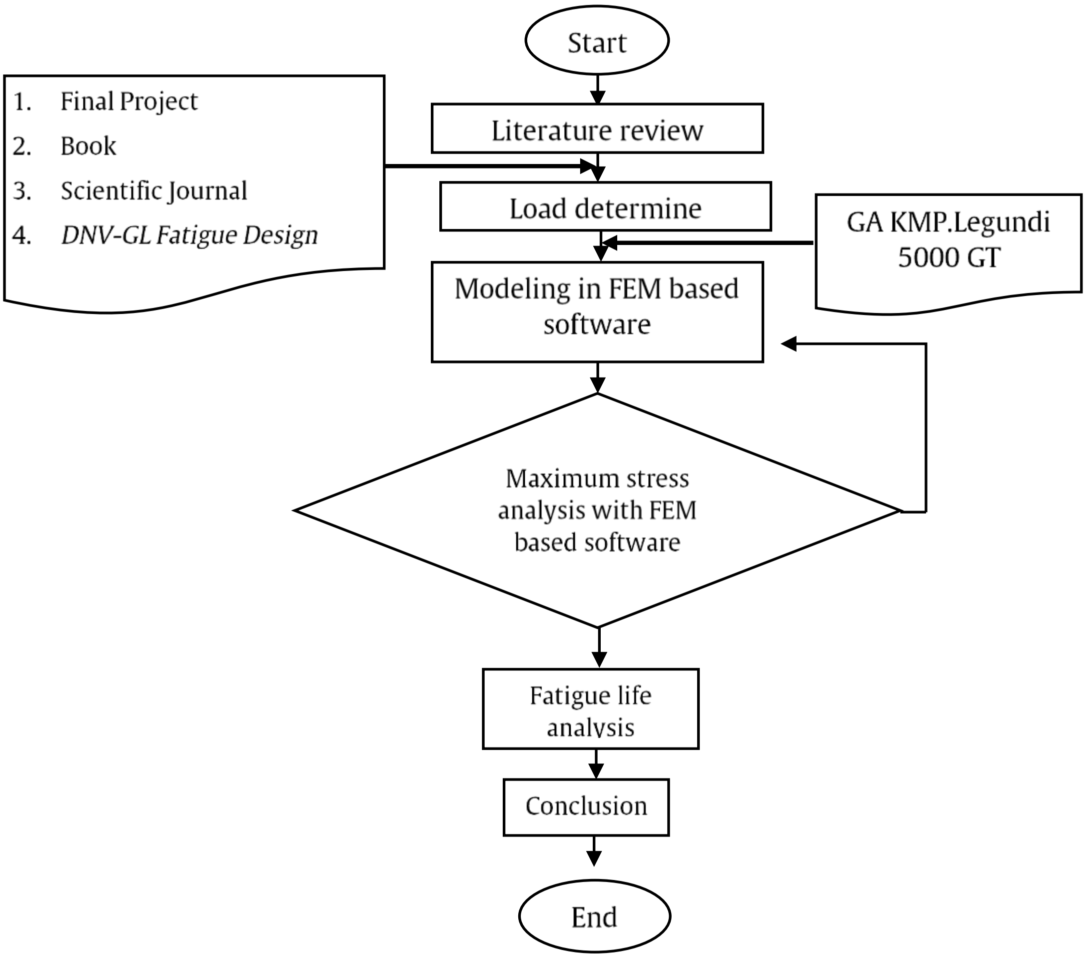
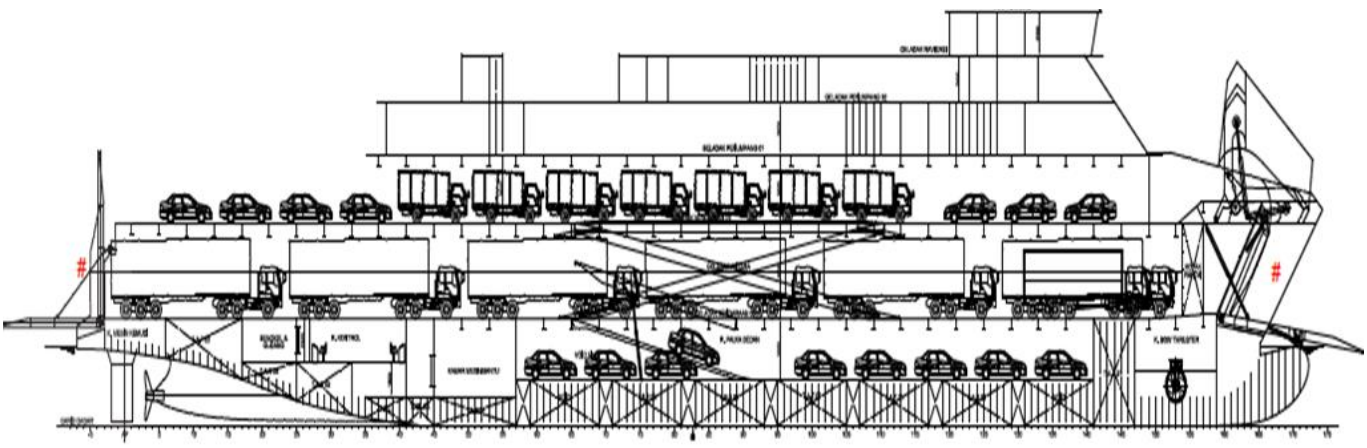
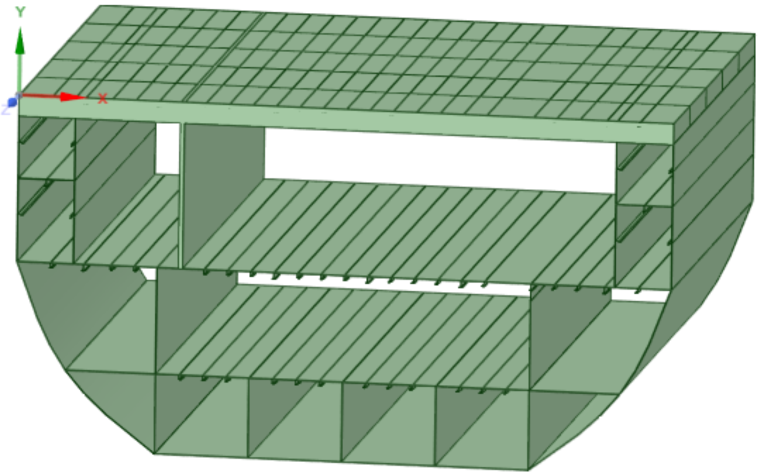


Figure 1. Research Flow Chart Diagram

In the present study, the finite element method is used by applying finite element-based applications. The thickness of the car deck plate is varied with a thickness of 110%, 100%, 90%, and 80%. For analysis purposes, the model data is needed. The model data are obtained from DITLASDP 2012. KMP Legundi's car deck model in the midship with frames 70 to 95 is shown in Figure 2.



(a)



(b)

Figure 2. (a) Car Deck on ferry ro-ro 5000 GT (b) Car Deck model design

From Figure 1, the length of the car deck is the distance of frame 70 to 95, which is 15 m. Each car deck is subject to different loads, car deck 2 is loaded down with 435.6 tons consisting of 41 sedans and 37 trucks, car deck is loaded down with 800 tons composed of 20 trailers, and in the sedan space, it is loaded with 57.6 tons which consist of 36 sedans. After getting value on the ship, simulation is carried out using software based on the finite element method [8]. It will be analyzed to know the maximum and minimum stress [9,10]. Maximum stress will use to find the fatigue life for the ship. We did not calculate wave spectrum and RAO but only calculated every deck's maximum load [11,12].

The type of data used in this research is primary data. Primary data is the data used in the modeling process to carry out the problem analysis process in the final project. The data is sourced from the Ministry of Transportation, Directorate General of Land Transportation (DITLASDP). The primary data collected, among others, are in Table 1.

Table 1. Dimension Car Deck of Ferry ro-ro 5000 GT

Dimension	value	unit
Length Overall	109,40	*m*
B Deck	19,60	*m*
L deck Palka room	50,4	*m*
L car deck 1	94,8	*m*
L car deck 2	90,6	*m*
H	5,60	*m*
T	4,10	*m*
Trailer load	40	*ton*
medium truck load	10	*ton*
Sedan load	1,6	*ton*

The load value is the actual load received by each area of the existing deck length. Meanwhile, in this paper, the area to be analyzed is only an area of a predetermined model, so that the next step is to calculate the load acting on the car deck model [13,14]. The load experienced by the car deck model is determined using Eq. 1.

$$\frac{Car\ load\ deck}{Car\ deck\ area} = \frac{Car\ deck\ model\ load}{Car\ deck\ model\ area} \tag{1}$$

From equation 1 above, the load value for each car deck model is obtained. The load values experienced for each car deck model are shown in Table 2.

Table 2. Deck loads on the KMP legundi 5000 GT model

Load Location	Rated Load (Ton)
Car deck 2 model	72,1192053
Car deck 1 model	126,5822785
model hatch space of the sedan	9,781924198

After the load value is obtained, then the calculation of working force is carried out for each unit area of the model (pressure) with Eq. 2 [15].

$$\frac{Car\ deck\ model\ load}{Car\ deck\ model\ area} \tag{2}$$

From equation 2 above, the pressure value for each car deck design model is obtained. The load values received for each car deck design model are shown in Table 3.

Table 3. Data of force acting per unit area

Load Location	Pressure (Mpa)
Car deck 2 model	0,00244420311104435
Car deck 1 model	0,0042900271821
Palka Room model	0,00580991831334656

3. Results and Discussion

In the next stage, after the pressure value is obtained, meshing process the car deck construction model and running on a finite element based application to find the maximum stress value that works on the car deck construction, as to the results of running on element-based software [16]. The meshing result of the car deck construction model is shown in Figure 2, and the result for 110% plate thickness variations is shown in Figure 3.

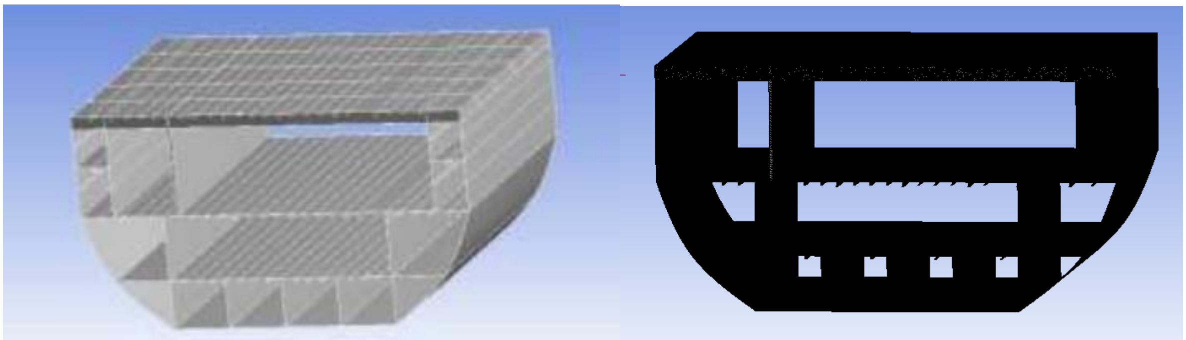


Figure 3. Meshing process car deck construction model ferry ro-ro 5000 GT.

The meshing process sets the distance between the elements that must be carried out using finite element-based software to go through the pre-processing stages before doing the analysis. One aspect that must be arranged in the meshing process is managing these aspects, i.e., mesh size. Mesh size is the set distance between model elements. If the input distance is close to 0 or relatively small, then the number of elements appears to be many and small in size. If the input distance is large, the number of elements that will appear will be few and have a large size. After the meshing process is complete, as shown in Figure 3, the model will look like small parts or call nodes and elements. After determining the meshing Size and getting the number of elements and nodes in this modeling, do solve. If the solving process runs smoothly [17]. If there is a failure in the finishing process, you can process to the next step, namely the analysis step in finite element-based software, to find out the stress value resulting from applying the load to each car deck [18].

The analysis is carried out when the required data has been obtained, such as: have obtained stress values on models with several plate thickness variations. In this analysis, the Boundary condition is the Fixed Support option, which functions as a pinch force or makes the field have no effect when receiving style from within the construction itself [19]. After using Fixed Support, then use pressure, which functions as a working pressure obtained from the previous pressure calculations. Then use pressure, which functions as a working pressure obtained from the last calculation pressure.

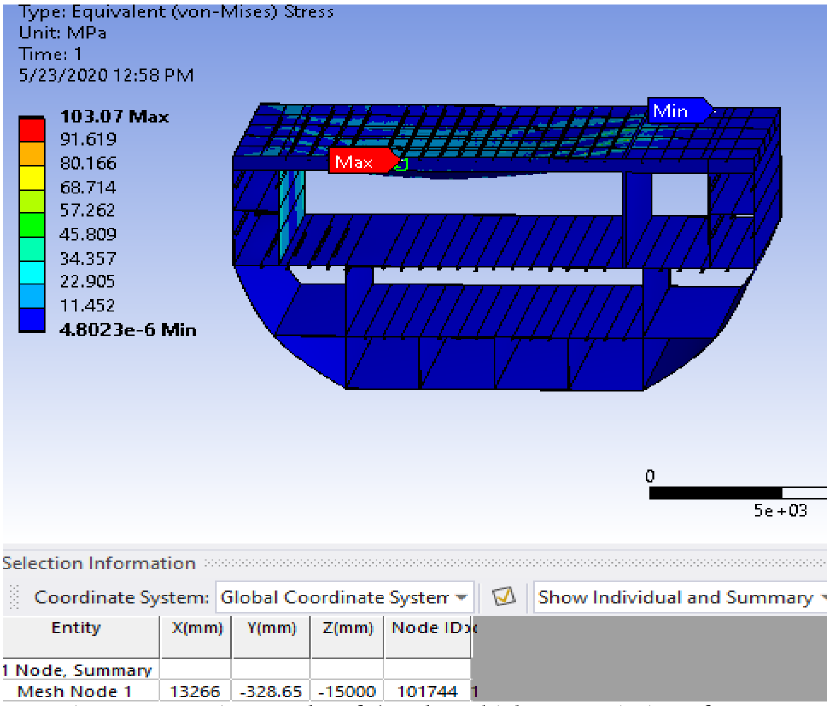


Figure 4. Running results of the plate thickness variation of 110%

The value of the working stress in the Y direction that occurs in variations in thickness 110% plate to car deck 1 is 231.61 MPa, for the stress value. The X and Z direction work has a small value, so it does not affect the ship's structure. Stress at plate thickness 110% is located at Node 3812, while the smallest stress is 0 Min MPa. The value of the Y-direction working strain that occurs in thickness variations 110% plate to car deck 1 is 36,638 mm, for the value of strain. The X and Z direction work that occurs has a small value, so it is considered not to have too much effect on the ship's structure. Strain at 110% plate thickness is located at Node 368928, while the smallest strain is 0 mm.

The value of the working stress in the Y direction that occurs in variations in thickness plate 100% to the car deck 2 is 103.73 MPa. The stress value The X and Z direction work that occurs has a small value, so it does not affect the ship's structure. Stress at 100% plate thickness is located at Node 99000, while the smallest Stress is 0.000010215 MPa. The value of the Y-direction working strain that occurs in thickness variations 110% plate to car deck 2 is 7,1023 mm, for the value of strain. The X and Z direction work that occurs has a small value, so it is considered not to have too much effect on the ship's structure. Strain at 110% plate thickness is located at Node 243278, while the smallest strain is 0 mm.

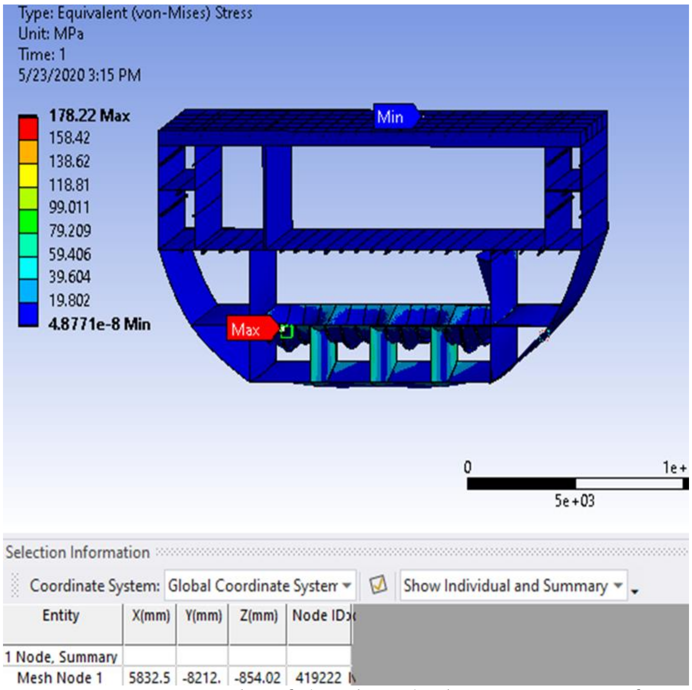


Figure 5. Running results of the plate thickness variation of 100%

The value of the working stress in the Y direction that occurs in variations in thickness plate 100% against car deck 1 is 236.37 Mpa (see Figure 5). The X and Z direction work has a small value, so it is considered not to have too much effect on the ship's structure. Stress at 100% plate thickness is located at Node 1,123,999, while the smallest stress is 0 Min MPa. the value of the Y-direction working strain that occurs in thickness variations plate 100% against car deck 1 is 38,162 mm, for the value of strain. The X and Z direction work has a small value, so it is considered not to have too much effect on the ship's structure. Strain at 100% plate thickness is located at Node 210706, while the smallest strain is 0 mm.

The result for 100% plate thickness variations is shown in Figure 5. The value of the working stress in the Y direction that occurs in variations in thickness plate 100% to the car deck 2 is 103.73 MPa. For the stress value, the X and Z direction work that occurs has a small value, so it does not affect the ship's structure. Stress at 100% plate thickness is located at Node 99,000, while the smallest Stress is 0.000010215 MPa the value of the Y-direction working strain that occurs in thickness variations plate 100% of the car deck 2 is equal to 7.1931 mm, for the value of strain. The X and Z direction work has a small value, so it is considered not to have too much effect on the ship's structure. Strain at 100% plate thickness is located at Node 255191, while the smallest strain is 0 mm.

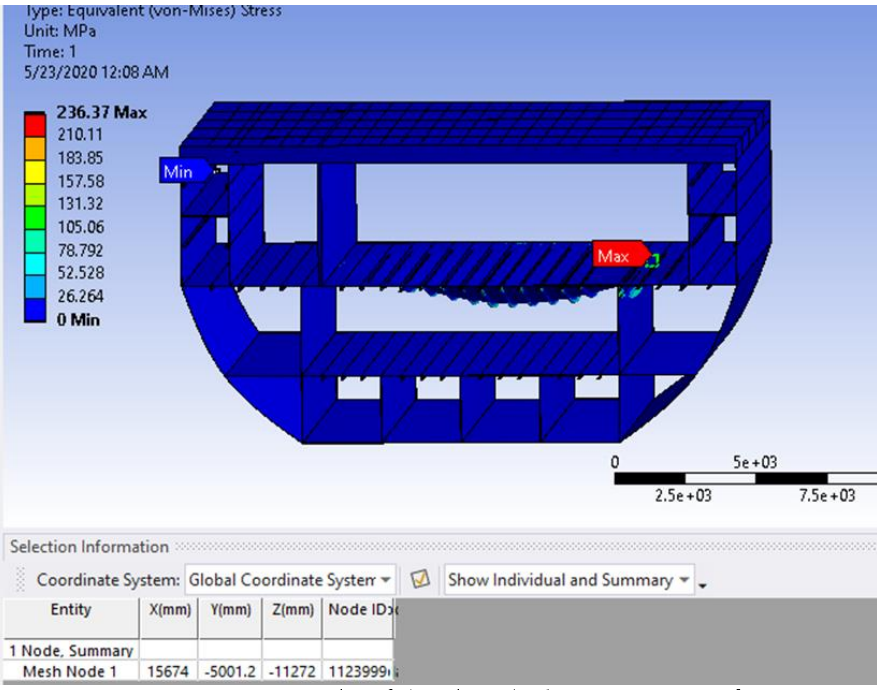


Figure 6. Running results of the plate thickness variation of 90%

The value of the working stress in the Y direction that occurs in variations in thickness plate 90% against car deck 2 is 240.08 Mpa (see Figure 6). The X and Z directions that occur have a small value, so they do not affect the ship's structure. At 90% plate thickness, stress is located at Node 1196521, while the smallest stress is 0.00000010205 MPa. The value of the Y-direction working strain that occurs in thickness variations plate 90% against car deck 1 is 39,979 mm, for the value of strain. The X and Z direction work that occurs has a small value, so it does not affect the ship's structure. Strain at 100% plate thickness is located at Node 23,767, while the smallest strain is 0 mm.

The value of the working stress in the Y direction in variations in thickness Plate 90% against car deck 2 is 104.29 MPa. The X and Z directions that occur have a small value for the value of working stress, so they are considered not to affect the ship's structure. The stress at 90% plate thickness is located at Node 94915. In comparison, the smallest stress is 0 MPa. The value of the Y-direction working strain that occurs in thickness variation plate 90% against car deck 2 is 7.4686 mm. For the value of strain, the X and Z direction work that occurs has a small value, so it is considered not too much effect on the ship's structure. Strain at 100% plate thickness is located at Node 478779, while the smallest strain is 0 mm.

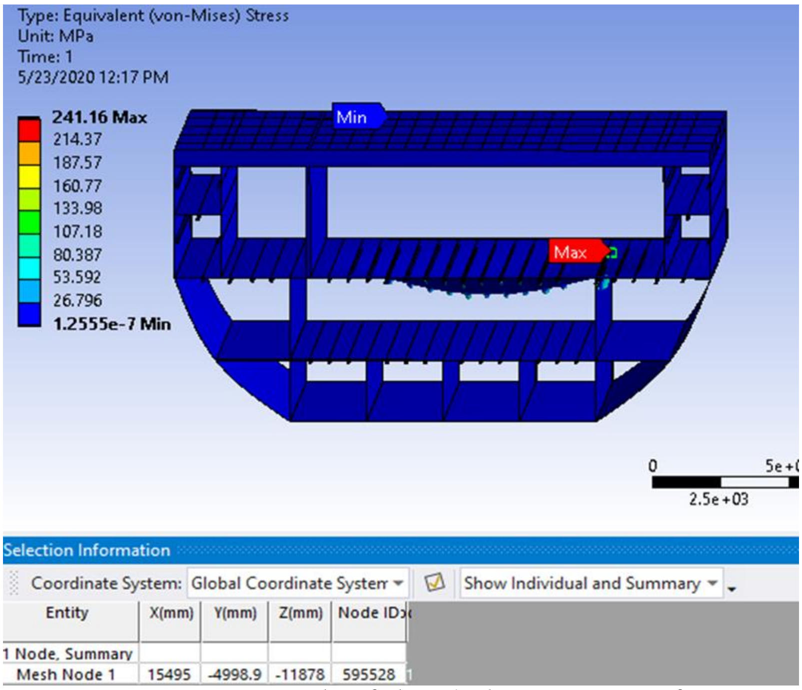


Figure 7. Running results of plate thickness variation of 80 %

The value of the working stress in the Y direction that occurs in the variation of 80% plate thickness against cardeck 1 is 241.16 Mpa (see Figure 7), for the value of the working stress in the X and Z directions that occurs has a small value so that considered not to have much effect on the structure of the ship. Stress on 80% plate thickness is located at Node 595528, while the smallest stress of 0.00000012555 MPa. The value of the Y-direction working strain that occurs in thickness variations 80% plate against car deck 1 is 40,814 mm, for the value of strain. The X and Z direction work that occurs has a small value so it is considered not too much effect on the structure of the ship. Strain at 80% plate thickness is located at Node 1219419, while the smallest strain is 0 mm.

The value of the working stress in the Y direction that occurs at variations in thickness plate 80% against cardeck 2 is 109.47 MPa, for the value of working stress. The X and Z directions that occur have a small value so they are considered not too effect on the structure of the ship. Stress at plate thickness 80% is located at Node 805528, while the smallest stress is 0 Min MPa. the value of the Y-direction working strain that occurs in thickness variations plate 80% of the sedan hatch space is 8.2811 mm, for the value of the working strain in the X and Z directions that occur has a small value so that considered not to have much effect on the structure of the ship. Strain on 80% plate thickness is located at Node 212404, while the smallest strainof 0 mm.

After the stress value is obtained, the last step is calculating the fatigue life of the car deck construction [20]. To obtain fatigue life, the value of fatigue damage is determined using the simplified fatigue analysis equation in accordance with the equation DNVGL-RP-0005: 2014-06, the simplified fatigue analysis equation is shown in Eq. 3.

$$D = \frac{v_0 T_d}{a} q^m \Gamma\left(1 + \frac{m}{h}\right)1 \quad (3)$$

where
D = Accumulated Fatigue Demage
r(1+m/h) = Gamma fuction
v_0 = Average zero up-crossing frequency
q = Weibull stress range scale distribution parameter
T_d = Design life of ship in seconds
a ̅ = intercept of the design S-N curve with the log N axis

After the fatigue damage is obtained, then the value is inputted into the fatigue life equation, the fatigue life equation can be seen in Eq. 4. The result of the analysis on car deck 2 is shown in Table 4.

$$Fatigue\ life = \frac{Design\ life}{D} year \quad (4)$$

where
Fatigue life = Age of fatigue
Design life = The operating life of ship, normally taken as 20 years
Year = 1 Year

Table 4. Analysis results of car deck 2

Variation of plate thickness	Stress (Mpa)	*Number of Cycles*	*Fatigue Damage*	*Fatigue life* (year)
110 %	0,00244420 311104435	1350,000	0,27	74,23
100 %	0,00244420 311104435	1100,000	0,29	70,00
90 %	0,00244420 311104435	980,000	0,30	67,34
80 %	0,00244420 311104435	950,000	0,35	57,87

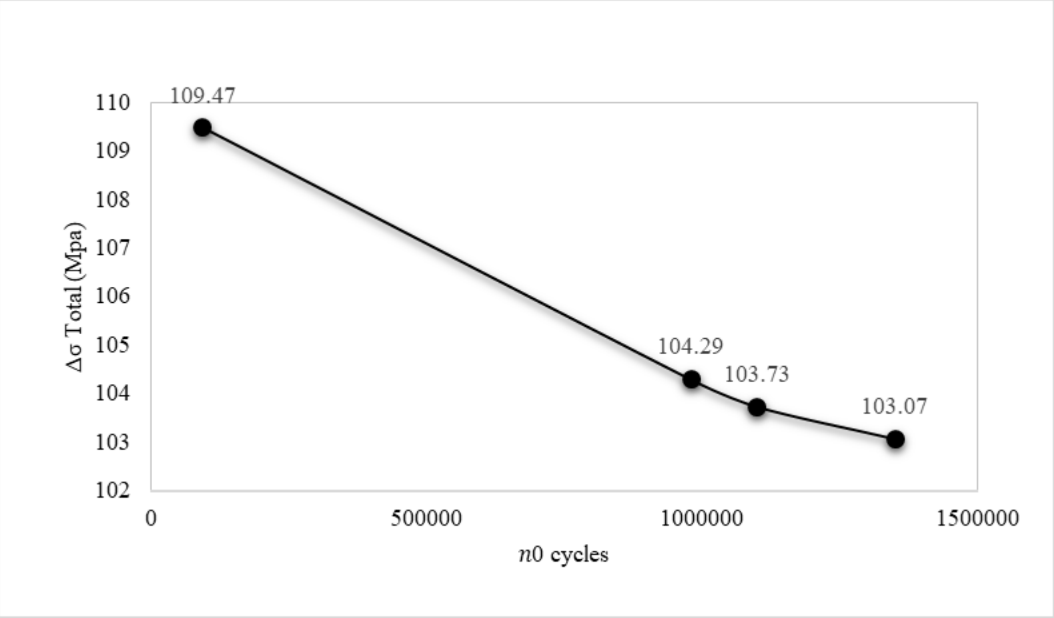


Figure 8. S-N curve on Car Deck 2

Based on Table 3, it is found that the fatigue life of plate thickness with variations 110%, 100%, 90%, and 80% respectively as follows; the fatigue damage is 0.27 with 74.23 years for 110%, 0.29 with 70 years for 100%, 0.30 with 67.34 years for 90%, and 0.35 is 57.87 years for 80%. Based on the analysis result of four plate thickness variations on Cardeck 2, the S-N Curve is obtained in Figure 8.

Based on Figure 8. it can be concluded that the cycle value at a stress of 103.07 MPa is 1350,000 times, the stress of 103.73 MPa is 1,100,000 times, the stress of 104.29 MPa is 980,000 times, and the stress of 109.47 MPa is 95,000 times. From the obtained results, it can be concluded that the stress is inversely proportional to the cycle value. The analysis results on car deck 1 are shown in Table 5.

Table 5. Analysis results of car deck 1

Plate thickness variations	stress (Mpa)	*Number of Cycles*	*Fatigue Damage*	*Fatigue life* (years)
110 %	0,004290 0271821	213.000	1,17	17,10
100 %	0,004290 0271821	208.000	1,25	16,00
90 %	0,004290 0271821	200.000	1,32	15,14
80 %	0,004290 0271821	198.000	2,62	7,63

Table 5 shows that the fatigue life of plate thickness with variations 110%, 100%, 90%, and 80% respectively as follows: the fatigue damage is 1.17 with 17.10 years for 110%, 1.25 with 16 years for 100%, 1.32 with 15.14 years for 90%, 2.62 is 7.63 years for 80%. Based on the results, the S-N Curve is obtained, which is shown in Figure 8.

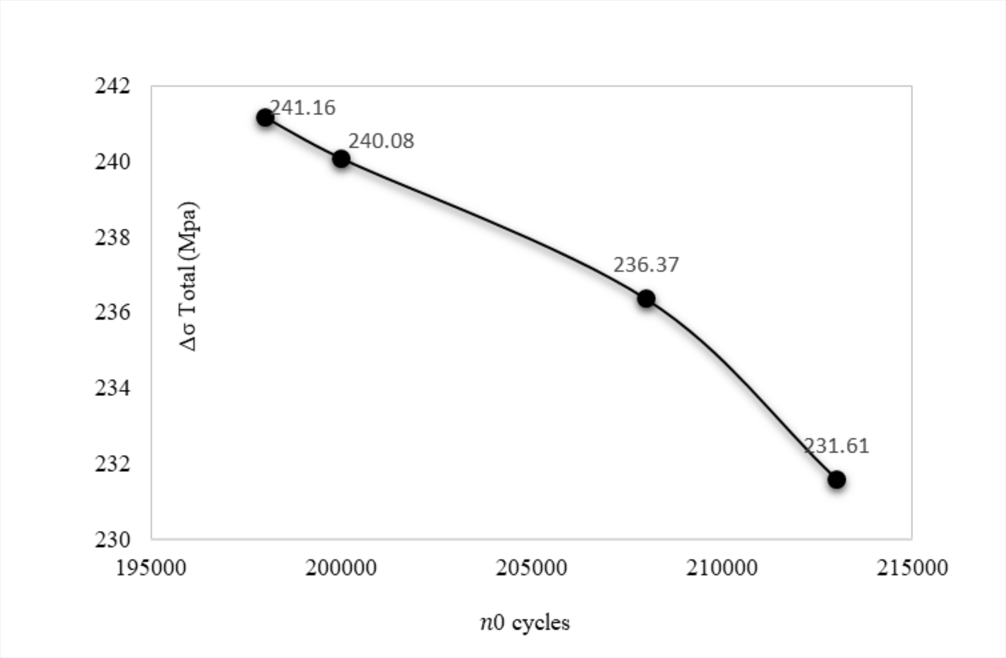


Figure 9. S-N curve on Car Deck 1

From Figure 9, it can be concluded that the value of the cycle at a stress of 231.61 MPa is 213,000 times, the stress of 236.37 MPa is 208,000 times, the stress of 240.08 MPa is 200,000 times, and the stress of 241.16 is 198,000 times. From the obtained results, it can be concluded that the stress is inversely proportional to the cycle value. The analysis results of the sedan space are shown in Table 6.

Table 6. Analysis results of the sedan space

Plate thickness variations	stress (Mpa)	*Number of Cycles*	*Fatigue Damage*	*Fatigue life* (years)
110 %	0,004290 0271821	408,000	0,64	31,05
100 %	0,004290 0271821	400,000	0,69	28,89
90 %	0,004290 0271821	360,000	1,10	18,28
80 %	0,004290 0271821	220,000	1,11	18,10

From Table 6, it is found that the fatigue life of plate thickness with variations 110%, 100%, 90%, and 80% respectively as follows; the fatigue damage is 0.64 with 31.05 years for 110%, 0.69 with 28.89 years 100%, 1.10 with 18.28 years for 90%, and 1.11 with 18.10 years for 80%. Based on the results, it is obtained the S-N Curve as shown in Figure 10.

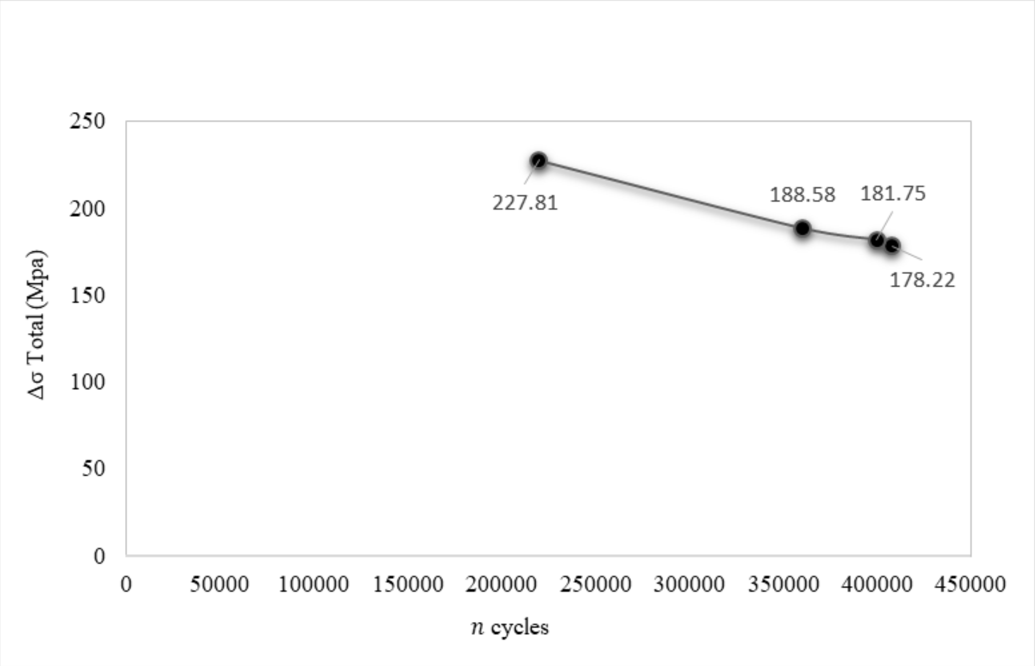


Figure 10. S-N curve on the sedan space

From Figure 10, it can be concluded that the cycle value at a stress of 178.22 MPa is 40,800 times, the stress of 181.75 MPa is 400,000 times, the stress of 188.58 MPa is 360,000 times, and the stress of 227.81 is 220,000 times. Based on the obtained results, the stress is inversely proportional to the cycle value.

4. Conclusion

The fatigue life of car deck 2 in plate thickness with variations 110%, 100%, 90%, 80% respectively are shown as follows the estimated lifetime is 74.23 years with the stress of 103.07 MPa for 110%, 70 years with the stress of 103.73 MPa for 100%, 67.34 years with the stress of 104.29 MPa for 90%, and 14.13 years with the stress of 109.47 MPa for 80%. As for the fatigue life in the car deck as follows: 17.10 years with a stress value of 231.61 Mpa for 110%. Sixteen years with a stress value of 236.37 MPa for 100%, 15.14 years with a stress value of 240.08 MPa for 90%, 7.63 years with a stress value of 241,16 MPa for 80%. The fatigue life of the sedan space is as follows:

- 31.05 years with a stress value of 178.22 MPa for 110%
- 28.89 years with a stress value of 181.75 MPa for 100%
- 18.28 years with a stress value of 188.58 MPa for 90%
- 18.10 years with a stress value of 227.81 MPa for 80%

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