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Strength Behavior Analysis of Insert Plate for Placing Corner Fitting due to Container Load

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Abstract. Currently, the ship container generation has allowed for the carriage of containers on deck up to four tiers high. The container loads in tiers high affect on deck structure. Consequently, an insert plate is used and located on the top of the ship deck structure for placing the container corner fitting. Sometimes container fitting is placed between longitudinal deck beams under without supporting construction such as pillar or carling. Therefore, this matter should be analyzed to obtain the strength behavior of the insert plate. This study describes the strength analysis using the finite element method (FEM) through ANSYS software. Based on the simulation results, the maximum Von Mises stress of the insert plate was obtained exceeds 181 N/mm² and 235 N/mm² in the initial condition, whereas the insert plate could support only 15% loads per corner fitting (three tiers high). Then, the thickness addition of the insert plate until 24 mm reduced the stress, however, the reduction was a small magnitude. By adding two carling construction is similar to the size of a transverse deck beam, under the insert plate, the stress was obtained 138.54 N/mm².

1. Introduction

Local stress on an element of container ship construction is a very interesting topic to be studied, mainly the main deck. Some studies related to stresses on container deck member structure have been carried out because the stresses at deck level are typically large such as the deck longitudinal [1]. In a previous study, Rosmani et al. [2] studied about the response of the container deck structure due to laying all container on deck. This study found out that ship construction experiences the greatest stress on the deck precisely on the deck beam. Another element of ship structure components that must be considered is the deck plate. The deck plate is one of the structural components of the ship that first receives a loading response before being forwarded to the deck beam. For certain types of ships, the deck plate must withstand considerable loads. As happened in container ships whose cargo is on the deck. Containers as a unit of load on a ship have treads at each angle. Container tread is a component that directly supports containers. Containable containers at each corner make the container load concentrated at each corner of the base.

Then, some container ships have decks with different plate thicknesses. Thickness differences occur in each area at the bottom of the container shoes. Thickening of the deck plate is not caused by a doubling plate but a whole plate without doubling or called an insert plate. Insert plate has the size or dimensions specified following the plan. In this research, insert plate thickness is estimated to have a major effect on the strength of the insert plate under the container tread.

2. Literatur Review

2.1 Container Ship

Container ships are freighter designed for the transportation of goods inside the container. The engine room and accommodation are usually in the rear to maximize container storage, see Figure 1 [3].

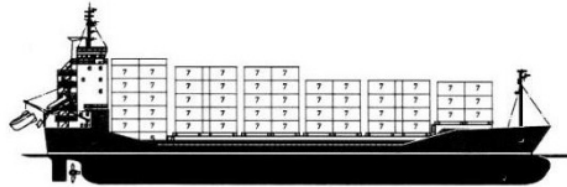


Figure 1. Container ship

Container ships are designed to meet the needs, including the desired speed, and the number of containers arranged according to the size, type and weight of the calculated cargo. The maximum number of containers is calculated according to the capacity available on the ship. Supporting features or equipment is provided to increase port productivity by enabling rapid loading and unloading. If cranes are not available at some of the ports to be visited, the ship must be equipped with equipment capable of being used for loading and unloading. Meanwhile, container loading and unloading equipment are very important, where competition requires ships to be reliable, operated efficiently and constructed and operated economically [4].

2.2 Insert Plate

Insert plates on the deck of the container ship are distributed according to the planned placement of the container holder. Planning for ship container placement is arranged horizontally and vertically with the number of piles from front to back is not the same. For the part in front of the ship's midship, there are two piles of containers and for the parts behind the midship, there are three piles of containers, see figure 2. The under deck construction component for each Insert plate has a different position and type. Some insert plates are placed with a container holder just above the deck girder, web beam, or bulkhead with their respective position differences. There is also the placement of the Insert plate with a container holder that is not right above the web beam or girders. Placement of the Insert plate and container ship deck construction can be seen in Figures 2 and 3.

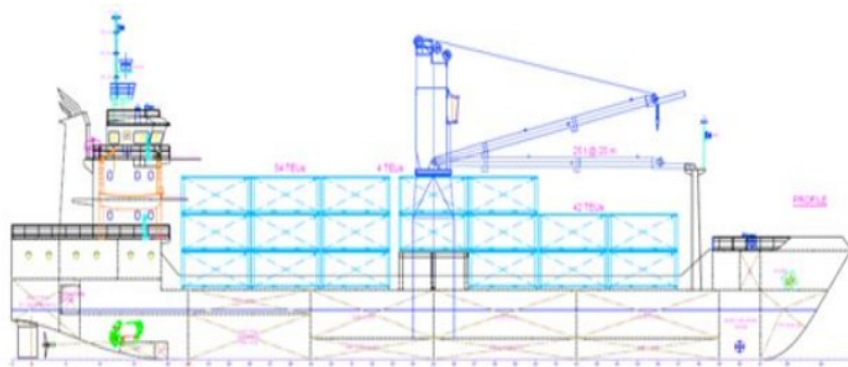


Figure 2. Container formation

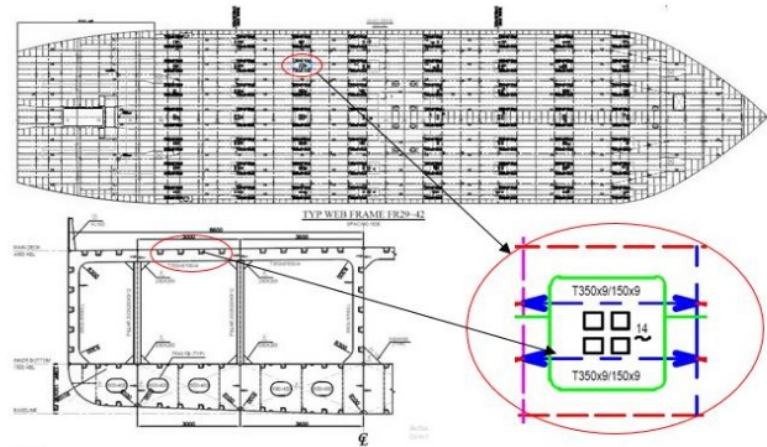


Figure 3. Construction profile and midship section

2.3 Container pad

Containers are reusable boxes made of steel or aluminum. Containers come in various types and sizes. Details can be obtained from the website of one of the manufacturers. Nominal dimensions have lengths of 20, 40 and 45 feet, the width of 8 feet and a height of 8.5 or 9.5 feet. The inner volume and weight of items that can be carried vary according to the material. For general purpose steel containers, it has a size of 20 ft with an internal capacity of around 33 m³, an empty weight of around 2.3 tons and a maximum load of around 21.7 tons. The 40 ft container has an internal capacity of around 68 m³, an empty weight of around 3.8 tons and a maximum load of around 26.7 tons. Aluminum containers have the same volume but are lighter in weight and capable of carrying larger loads than steel containers. Containers can be used for transportation of general goods and liquids [5]. Container dimension are accordance with ISO (International Organization for Standardization) standart, namely containers 10 ft, 20 ft, 30 ft and 40 ft, see Figure 4.

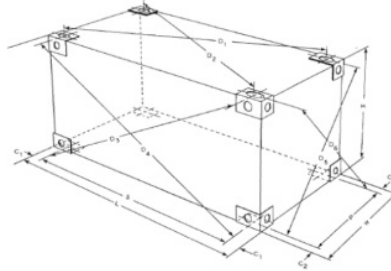


Figure 4. ISO standard of container dimension [6]

2.4 Stress

Stress is defined as the amount of force acting per unit area. There are two types of stress: normal stress and shear stress. Normal stress (σ) is a measure of normal force or axial force per unit area [7]. Mathematically the definition can be written as:

$$\sigma = \frac{F}{A} \quad (1)$$

defining:

- σ = Stress (N/mm²)
- F = Force (N)
- A = Sectional Area (mm²)

The normal stress equation for the three-dimensional plane is as follows :

$$\sigma_x = \frac{E}{(1+\nu)(1-2\nu)} [\varepsilon_x(1-\nu) + \nu(\varepsilon_y + \varepsilon_z)] \quad (2)$$

$$\sigma_y = \frac{E}{(1+\nu)(1-2\nu)} [\varepsilon_y(1-\nu) + \nu(\varepsilon_x + \varepsilon_z)] \quad (3)$$

$$\sigma_z = \frac{E}{(1+\nu)(1-2\nu)} [\varepsilon_z(1-\nu) + \nu(\varepsilon_x + \varepsilon_y)] \quad (4)$$

Finite element software analysis usually has the advantage of being able to produce Von Mises stress values or equivalent stresses, that is the type of stress that results in failure of the material structure formulated by its inventor named Von Mises. To determine the Von Mises stress, the main stress acting on the structure with equation (3–4) is calculated first, after the main stresses are found, the Von Mises stress can be obtained by the equation:

$$\sigma = \left\{ \frac{[\sigma_1 - \sigma_2]^2 + [\sigma_2 - \sigma_3]^2 + [\sigma_3 - \sigma_1]^2}{2} \right\}^{1/2} \quad (5)$$

2.5 Permissible Stress

Permit stress is the stress that results in a construction experiencing a large deflection where the deflection is the limit of construction is still safe in overcoming the burden that occurs or who works on it. If the permissible stress from the construction concerned is less than the maximum stress that occurs, then the construction is not safe.

The normal strength of the hull steel structure is the hull steel structure having a minimum yield point of REH 235 N/mm² and tensile strength of Rm 400 – 520 N/mm² [8]. Tension in the area of ship structure and substructure for containers as well as the cell guide system and lashing device on the hatch cover of the cargo deck not to exceed the following values:

$$\sigma_b = \frac{ReH}{1.5} \text{ [N/mm}^2\text{]} \quad (6)$$

$$\sigma = \frac{ReH}{2.3} \text{ [N/mm}^2\text{]} \quad (7)$$

$$\sigma_v = \sqrt{\sigma_b^2 + 3\tau^2} \leq \frac{ReH}{1.3} \text{ [N/mm}^2\text{]} \quad (8)$$

defining,

- σ_b = bending stress [N/mm²]
- σ = shear stress [N/mm²]
- σ_v = equivalent stress [N/mm²]
- ReH = yielding minimum limit of material

2.6 Finite Element Method

Finite element analysis is a numerical technique. In this method, all the complexity of the problem, such as various forms, boundary conditions and loads are maintained but the solution obtained is an estimate. Because of its diversity and flexibility as an analytical tool, it receives a lot of attention in the engineering field. Rapid improvements in computer hardware technology and reduced computer costs have pushed this method because computers are the basic requirement for implementing this method. Using this package, one can analyze several complex structures [9].

The new method based on virtual displacement is the last solution in the world. Applied mathematical problems and solutions are still being developed along with the development of computer science [4]. Types of structural problems include [10]:

- a. Stress analysis, including Truss and frame analysis
- b. Buckling
- c. Vibration analysis.

In problems involving complex geometry, such as the problem of imposing complex structures, it is generally difficult to solve through mathematical analysis. This is because mathematical analysis requires quantities or prices that must be known at each point in the structure under study. Completion of the analysis of a differential equation of complex geometry, complex loading, is not easy to obtain, the formulation of the finite element method can be used to overcome this problem [10].

3. Research Methodology

3.1 Ship Container Data

The ship has a frame distance of 600 mm and using a longitudinal construction system. Container loads are placed on the main deck of the ship. The ship does not have a container load hole in the hull and the ship is not equipped with a torsion box. The data needed for this research is the main dimensions of the ship, as follow:

Ship Type	: Container Ship
LOA	: 74.05 m
LBP	: 69.20 m
B	: 17.20 m
H	: 4.90 m
T	: 3.50 m

Plate material on ships using grade A normal strength steel base on BKI Class.

3.2 Structure Modeling

Data in structural modeling is obtained through profile construction data and midship construction, as shown in Figure 5. Construction components that are modeled with the Insert plate include deck plates, longitudinal deck beams, and Intercostal beams. The dimensions of the structural components being modeled such as Insert plate, deck plate, Intercostal deck beam, and longitudinal deck beam are as follows:

- a. Intercostal beam with profile size T 350 mm × 9 mm / 150 mm × 9 mm.
- b. Longitudinal deck beam with profile size L 120 mm × 120 mm × 11 mm.
- c. Deck plate with a thickness of 10 mm.
- d. Insert plate with a thickness of 14 mm and the area of A is 1.44 m².

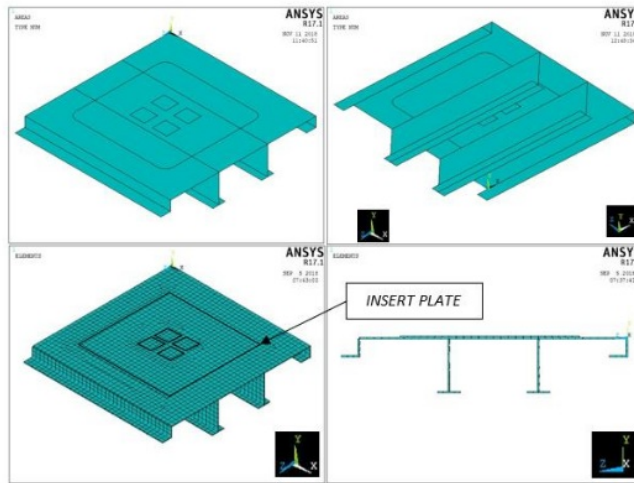


Figure 5. Insert plate model on the container deck

3.3 Loading Variation

The load is given to the model in the form of a uniform load (pressure). The evenly distributed load is obtained from the division between point P load and the area of loading. P point load is obtained from the calculation of deck load with a container load, while the loading area is the container tread area at each corner (container corner fitting). Container loads on deck are determined based on the following equation:

$$P = P_E (1 + a_v) \quad [\text{kN}]$$

where,

$$\begin{aligned} P_E &= \text{maximum container load} \times G \text{ m/s}^2 \\ G &= \text{gravitational acceleration} (9.81 \text{ m/s}^2) \\ P_E &= 24 \text{ ton} \times 9.81 \text{ m/s}^2 \\ &= 235.44 \text{ kN} \\ G &= \text{gravitational acceleration} (9.81 \text{ m/s}^2) \\ v_o &= 12 \text{ knot} \\ F &= 0.11 [12 / 69.20^{0.5}] \\ &= 0.159 \\ m &= 1.0 \quad \text{for } 0.2 < x/L \leq 0.7 \\ a_v &= 0.159 \times 1.0 \\ &= 0.159 \\ P &= 235.44 \text{ kN} (1 + 0.159) \\ &= 272.8 \text{ kN} \end{aligned}$$

The container load is then divided by four according to the number of corners (corner fittings) at the bottom of the container, which the calculation is as follows :

$$\begin{aligned} P &= 272.8 \text{ kN} && \text{(load of one container)} \\ \frac{1}{4} P &= 272.8 \text{ kN} \times \frac{1}{4} && \text{(for each corner fitting)} \\ &= 68.2 \text{ kN} \end{aligned}$$

There are three piles of containers above the Insert plate. Thus, the total load for one container site (corner fitting) is the accumulated load of the three piles. The total load for one tread container (corner fitting) as follows:

$$\begin{aligned} \frac{1}{4} P \text{ total} &= \frac{1}{4} P \times 3 = 68.2 \text{ kN} \times 3 \\ &= 204.6 \text{ kN} \quad \sim 204600 \text{ N} \end{aligned}$$

The total container load for one container site (corner fitting) is then converted to a pressure load according to the container tread area (the dimensions of the container site can be seen in Figure 6. Pressure load calculation for one tread container (corner fitting) as follows:

$$\text{pressure } q = \frac{1}{4} P_{\text{total}} / \text{Load Area}$$

The loading area is the container tread area (corner fitting). From Figure 6, the container tread size (corner fitting) is 178 mm x 162 mm so that the loading area (A) and pressure load (q) can be calculated as follows:

$$\begin{aligned} \text{Loading Area (A)} &= 178 \text{ mm} \times 162 \text{ mm} \\ &= 28836 \text{ mm}^2. \\ \text{Pressure Load (q)} &= \frac{1}{4} P_{\text{total}} / A \\ &= 204600 \text{ N} / 28836 \text{ mm}^2 = 7.0953 \text{ N/mm}^2 \end{aligned}$$

From the calculation above the pressure load applied to each container site (corner fitting) for three stacks is 7.0953 N/mm². Meanwhile, the value of the pressure load based on the percentage load of 3 piles of containers can be seen in Table 1.

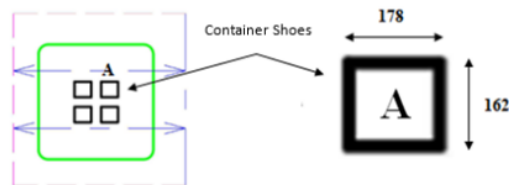


Figure 6. Loading area

Table 1. Pressure load on container shoes base on percentration of container weighth

Percentage Container Load	Container Weigth (w) [ton]	PE = (w x 9.81 m/s ²) [kN]	P = {PE (1 + av)} [kN]	¼ P = (¼ P x 1000) [N]	Pressure Load [N/mm ²]
100 %	72	706.32	818.62	204600	7.0953
80 %	57.6	565.06	654.90	163700	5.6769
60 %	43.2	423.79	491.17	122700	4.2551
40 %	28.8	282.53	327.45	81800	2.8367
20 %	14.4	141.26	163.72	40900	1.4184
15 %	10.8	105.95	122.79	30600	1.0611
14 %	10.1	32.96	38.20	9500	0.3294
13 %	9.4	30.61	35.47	8800	0.3051
12 %	8.6	84.76	98.23	24500	0.8496
11 %	7.9	77.70	90.05	22500	0.7802
10 %	7.2	70.63	81.86	20400	0.7074

3.4 Boundary Condition

Restraints or supports are given based on the identification of the meeting between the construction components that are modeled with the construction components that border with it. Translational or rotational restraints are given in accordance with the shape of the modeled construction cut. The translation is divided into three namely x, y, and z translations. The rotation has 3 degrees of freedom, namely rotation x, y, and z. Each degree of freedom is used according to the shape of the construction cut being modeled.

All deck construction components bordering the transverse bulkhead are fix supported (see Figure 7), i.e., translation x, y, and z are not free or equal to 0 so that translational motion does not occur. Meanwhile, x, y, and z rotations are 0 (not free), so the model cannot rotate. Then at the end of the intercostal beam, which borders frame 30, a pinch is also provided. For longitudinal deck beams and deck plates bordering frame 30 (see Figure 7) a support is placed where translation $x = 0$, translation $y = 0$, and rotation $z = 0$. Then for deck plates lengthwise (see Figure 7) given a support where translation $y = 0$, translation $z = 0$, and rotation $x = 0$. A value of 0 (zero) indicates that part of the structure is not given the freedom to make movements according to the shape of the movement (translation or rotation) and in accordance with the direction of movement (x, y, or z).

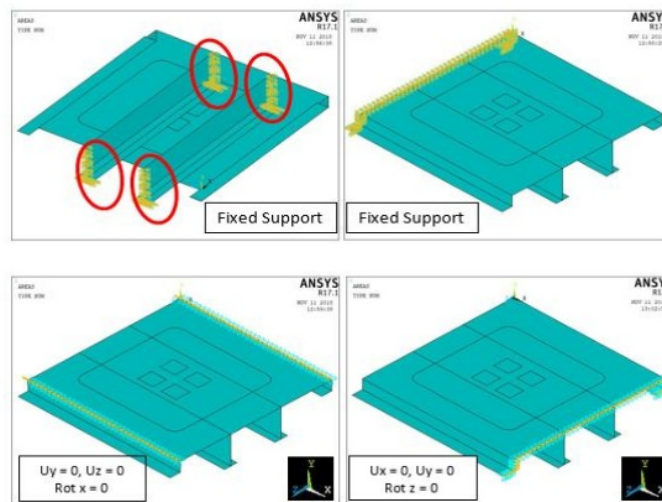


Figure 7. Restraint on insert plate model

4. Numerical Results

4.1 Initial Condition

Structural analysis in the initial conditions is analysis without adding other construction components such as carlings and so on. At this stage, the analysis is carried out based on the displacement value and the stress value that occurs on the Insert plate.

4.1.1 Displacement

Some parts of the structure being modeled will experience displacement (Displacement) when a load is working on it. Displacement is a displacement or deflection that occurs in several parts of the structure. Caused by the forces acting on the structure. The maximum displacement of the modeled structure occurs around the encumbered area. To prove that the maximum displacement occurs around the loading area can be seen in Figure 8.

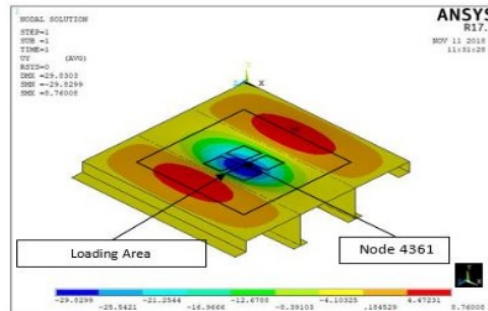


Figure 8. Displacement maximum on y-direction

Based on figure 8, the Displacement of the maximum y-direction occurs at node 4361. Node 4361 is in the meeting area of the four container sites. The maximum displacement value of y-direction for the initial conditions of the Insert plate is -29.83 mm.

4.1.2 Stress

Figure 9 shows the stress gradation that occurs in the initial conditions of the structure. When the foundation container under the container corner fittings is evenly loaded with maximum load, the maximum Von Mises stress occurs in the area of the plate is loaded. This can be seen from the gradation of red, shown in Figure 9. The red gradation in the Von Mises voltage contour represents the maximum stress experienced by the structure. The maximum stress value that occurs is 1306.82 N/mm² at node 5639. This value exceeds the limit of the REH material, yielding, which is 235 N/mm².

Then a load reduction simulation is performed to determine the load value by obtaining stress less than the yielding material limit and the BKI permit stress.

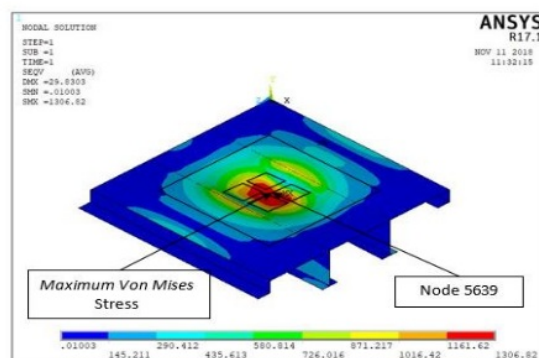


Figure 9. Stress gradation on initial condition

The stress values obtained through the results of the simulation of load reduction can be seen in Table 2.

Table 2. Von Mises stress maximum base on container load percentage

Container Load Percentage	Weigth of 3 Container (ton)	Node	σv_{max} (N/mm ²)
100 %	72	5639	1306
80 %	57.6	5639	1045
60 %	43.2	5639	783
40 %	28.8	5639	522
20 %	14.4	5639	261
15 %	10.8	5639	195
14 %	10.1	5639	182
13 %	9.4	5639	169
12 %	8.6	5639	156
11 %	7.9	5639	143
10 %	7.2	5639	130

Based on Table 2, yelling material limits can be met when a given load <15% of the maximum load of the container (load and construction). Then the BKI permissible stress of 181 N/mm² can be met when the weight of the container and its load is less than <14% of the maximum load of the container (load and construction). To meet the BKI permit stress with a load of 100%, one way to reduce the stress experienced by the structure is to increase the thickness of the Insert plate or add carlings under the deck plate.

4.2 First Solution: Added Thickness of Insert plate

The addition of a thick Insert plate is done to increase the strength of the deck structure so that the stresses experienced can be reduced, and the stress values obtained below the BKI permissible stress. To find out the amount of the addition of insert plate thickness with a stress value less than the BKI permissible stress, a simulation of adding thickness with a difference of 2 mm is carried out. The stress values obtained from the simulation results can be seen in Table 3.

Table 3. Maximum Von Mises stress causes an added thickness of the *insert plate*.

Thickness (mm)	Node	σv_{max} (N/mm ²)
14	5639	1306.70
16	5639	1035.50
18	5639	844.68
20	5639	705.22
22	5639	599.89
24	5639	518.04

Based on Table 3, the value of the stress that meets the BKI permissible stress is at the thickness of the 46 mm insert plate. While the initial thickness of the insert plate in Table 3 is 14 mm. Thus, the addition of an insert plate thickness from the initial thickness is 32 mm.

For linear analysis, the pattern of stress changes due to the addition of insert plate thickness in accordance with the given thickness variation can only be reviewed if the structural stress is less than the yielding material (REH) limit of 235 N/mm². The load value for the stress is less than the yielding material limit of 1.0611 N/mm². The stress value for each variation of thickness addition can be seen in the following Table 4.

Table 4. Maximum Von Mises stress on every added thickness of the insert plate

Thickness (mm)	Node	$\sigma v \text{ max}$ (N/mm ²)
14	5639	195.43
16	5639	154.90
18	5639	126.39
20	5639	105.56
22	5639	89.84
24	5639	77.61

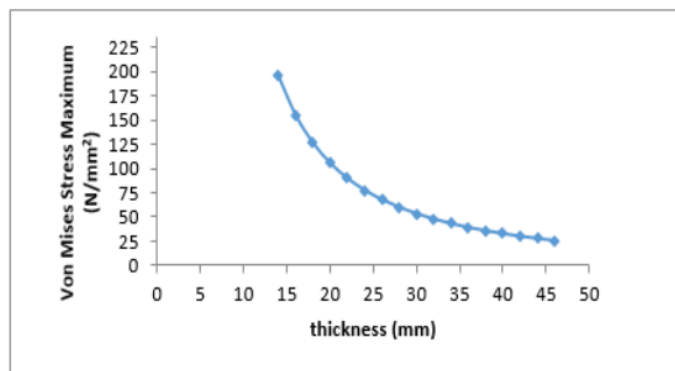


Figure 10. Von Mises Stress maximum base on the addition of insert plate thickness

The graph of the influence of the addition of carlings accompanied by the addition of thick insert plates to changes in stress that occurs in the structure can be seen in Fig. 10. Based on the curve in figure 10 shows that with the addition of thickness to the Insert plate, the stress can be reduced. The greater the thickness value is given, the smaller the stress obtained.

4.3 Second Solution: Added Carlings Construction

At the bottom of the deck plate, which is loaded with containers, structural components such as carlings are added to add strength to the deck vessels, see Figure 11. Carlings are blocks that are placed transversely below the deck of a ship. Carlings connects one deck beam to another deck beam. In this case, carlings are placed under the Insert plate.

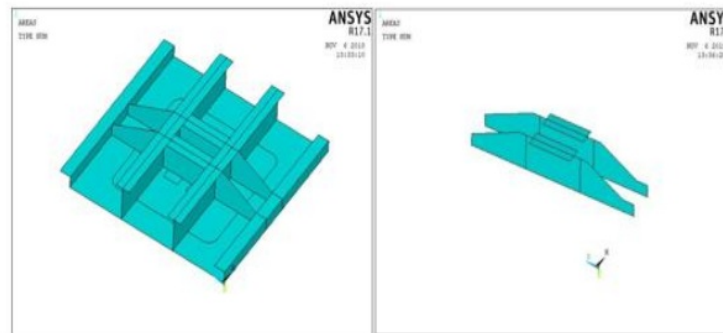


Figure 11. Addition carlings construction under the insert plate

Carlings connect between the two intercostal beams under the Insert plate. The dimensions of the carlings are determined following the dimensions of the intercostal beam with a profile size of 350 mm × 150 mm × 9 mm. The number of carlings installed is 2 (two) carlings transversely.

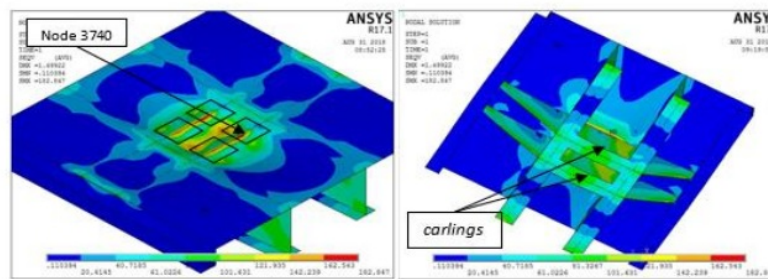


Figure 12. Stress gradation with addition carlings

Based on Figure 12, the maximum Von Mises stress experienced by the structure after the addition of carlings under the deck of the container holder occurs at node 3470. At the node 3470 is the meeting between the Insert plate and the carlings below. The maximum stress value that occurs at node 3470 is 185.24 N/mm². The addition of carlings causes the stress experienced by the structure to decrease to close to the BKI permissible stress. BKI permit stress is 181 N/mm² has a difference of 4.24 N/mm² from the stress experienced by the structure with the addition of carlings. To fulfill the permitted stress of BKI, which is 181 N/mm², the addition of thickness insert plates or longitudinal carlings are added.

Addition of Insert Plate Thickness

Based on the first simulation at point 4.1 and the second simulation at point 4.2, it can be seen that the addition of thick Insert plate and the addition of carlings causes the structural stress to decrease. Both simulations at points 4.1 and 4.2 can be used as a basis for the implementation of the next simulation by adding carlings and adding thick Insert plates. From the test results in this simulation, it is known that the stress experienced by the structure decreases after the addition of carlings accompanied by the addition of thick Insert plates. The stress values obtained based on the addition of carlings and variations in the thickness of the Insert plate can be seen in Table 5.

Table 5. Maximum Von Mises cause added carlings and thickness of the insert plate

Thickness (mm)	Node	$\sigma v \text{ max (N/mm}^2\text{)}$
14	3470	185.24
16	3469	138.54
18	3566	125.22
20	3566	122.90
22	3566	120.50

The graph of the influence of the addition of carlings accompanied by the addition of thick insert plates to changes in stress that occurs in the structure as follows.

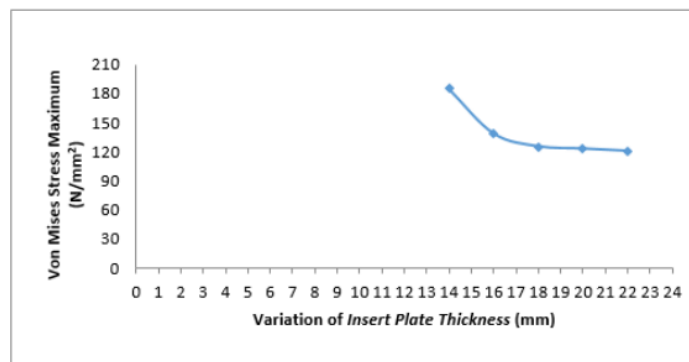


Figure 13. Von Mises stress maximum base on addition carlings and insert plate thickness

5. Conclusion

This research conducted using ANSYS 17.1 software and analysis by using the Finite Element Method. Based on the result of this research can be concluded as below:

- 1). The maximum Von Mises stress obtained in the initial condition by maximum loading exceeds 181 N/mm² (BKI permit stress) and 235 N/mm² (REH material yelling limit). The yelling material limit can be met when the load is given less than 15% of loading for three container layers (load and construction). Meanwhile, the BKI permit stress can be fulfilled when the burden is less than 14% of loading for three container layers (load and construction).
- 2). The addition of insert plate thickness affects the stress reduction experienced by the structure. The greater the thickness that is added, the stresses obtained and the percentage of stress reduction is smaller.
- 3). The BKI permit stress (181 N/mm²) can be fulfilled when adding 2 Carlings transversely under the Insert Plate with the addition of 2 mm thick Insert Plate or with the addition of 2 Carlings longitudinally. The dimensions of Carlings follow the dimensions of intercostal beams with profile sizes of 350 mm × 150 mm × 9 mm. The stress obtained after the addition of 2 transverse Carlings accompanied by the addition of Insert Plate thickness is 138.54 N/mm². Meanwhile, the stress obtained after the addition of transverse and longitudinal Carlings is carried out at 141.38 N/mm².

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