Stress analysis on passenger deck due to modification from passenger ship to vehicle-carrying ship

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Abstract. Stress is a basic concept in learning about material mechanism. The main focus that needs to be brought to attention in analyzing stress is strength, which is the structural capacity to carry or distribute loads. The structural capacity not only measured by comparing the maximum stress with the material’s yield strength but also with the permissible stress required by the Indonesian Classification Bureau (BKI), which certainly makes it much safer. This final project analyzes stress in passenger deck that experiences modification due to load changes, from passenger load to vehicle one, carrying: 6-wheels truck with maximum weight of 14 tons, a passenger car with maximum weight of 3.5 tons, and a motorcycle with maximum weight of 0.4 tons. The deck structure is modelled using finite element software. The boundary conditions given to the structural model are fix and simple constraint. The load that works on this deck is the deck load which comes from the vehicles on deck with three vehicles’ arrangement plans. After that, software modelling is conducted for analysis purpose. Analysis result shows a variation of maximum stress that occurs i.e. 135 N/mm\textsuperscript{2}, 133 N/mm\textsuperscript{2}, and 152 N/mm\textsuperscript{2}. Those maximum stresses will not affect the structure of passenger deck’s because the maximum stress that occurs indicates smaller value compared to the Indonesian Classification Bureau’s permissible stress (175 N/mm\textsuperscript{2}) as well as the material’s yield strength (235 N/mm\textsuperscript{2}). Thus, the structural strength of passenger deck is shown to be capable of carrying the weight of vehicles in accordance with the three vehicles’ arrangement plans.

1. Introduction

Engineering may be freely defined as knowledge application for general purpose in life. In order to fulfill such mission, engineers design quite an amount of objects to serve the society’s needs. Factors that need to be reviewed in design mentioned above covers several aspects such as usage, strength, appearance, economy, and environment protection. In learning the material mechanism, the main design that needs to be brought to attention is strength, which is an object’s capacity to carry or distribute loads. The example of objects which need to be able to carry weight are building, machine, containers, truck, airplane, ship, etc. For simpler explanation, we will refer to all those objects as structure. A structure is each and every object that has to be able to withstand, carry, or distribute loads. In order to review such principle, a basic concept of material mechanism (stress and strain) is necessary.

Stress is defined as a comparison between the working force on a structure with the structure’s cross-sectional area. Stress also shows the force strength that can cause shape changes in a structure. Changes in the structure’s shape, when compared to the initial size of that object, can be concluded as strain. So, the relationship between stress and strain is quite closely related, illustrated in a stress-strain curve. That
curve indicates the nature of a structure’s: elastic or plastic. Then, the difference between elastic and plastic is characterized by yield strength with the value of 235 \( \text{N/mm}^2 \) for structure with normal steel material.

Ship owner who wants to modified their ship from the passenger ship become the vehicle-carrying ship should considering the structural strength of the deck against the changing of the load. The modification of the passenger ship become the vehicle-carrying ship would affect on the deck structural strength. Therefore, in this research would be analyzed the deck strength against passenger loads and vehicle loads [1].

2. Ship Structural Strength

Ship, as a thin-walled building, is a three-dimensional object which is bounded by plane or curved fields. Ship, other than being a building, is also a transportation that carries passengers and stuffs across the sea or river (like boat or other smaller ships). Big ship usually provides smaller ship such as lifeboat. Meanwhile, in English terms, the definition is separated between larger ships and smaller boats [2].

Construction system is a combination of several constructions which are connected to one another, forming one unity to withhold the received force in accordance to the main purpose of building such system. Construction system in this ship deck which becomes the object in this research covers the longitudinal framing system where the majority of construction system consists of profile and plat.

Meanwhile, in ship’s structure known as ship construction that has a construction system. Framing system is divided into 2 (two) main types: transverse framing system and longitudinal framing system. From these 2 (two) main framing systems, another type of framing system is also known, called mixed framing system [2].

2.1. Normal stress and strain

The most basic concept in material mechanism is stress and strain. The effects of force and moment that occurs on block is providing deflection that is perpendicular to the longitudinal axis of the stem, resulting in normal stress as well as friction in each cross-section of stem perpendicular to the stem axis [2].

The amount of average stress in a plane can be defined as the force intensity which occurs in that plane. Thus, systematically-speaking, average normal stress can be declared in the following equation:

\[
\sigma = \frac{P}{A}
\]  

(1)

where:
\( \sigma \) = Average Normal Stress (N/m²)
\( P \) = Occurring Force (N)
\( A \) = Area of Object (m²)

A straight rod will experience length change if it’s axially burdened, becoming longer if it experiences pull/drag and shorter if it experiences pressure. In accordance with this concept, extension per length unit is called strain [2].

The relation above if written into equation (2) is as following:

\[
\varepsilon = \frac{\delta}{L}
\]

(2)

where:
\( \varepsilon \) = Strain
\( \delta \) = Extension of object’s length (m)
\( L \) = Length of object (m)
2.2. Stress and strain on elastic object

Nearly all engineering materials have certain nature, which is elasticity. If a material is subjected to an external force, then that material will experience a shape change, known as deformation. As long as the applied force does not exceed certain boundary, when the external force is lifted then the material will back to its initial shape.

In this particular research, objects subjected to external force are always considered as perfectly elastic, meaning the object will always go back to its initial shape when the external force is removed [3]. In finite method formulation, analyzing stress and the relation between strain and displacement is very essential. Displacement, which is denoted by “u” and “v” is function of “u” coordinate = u (x,y,z), v = v (x,y,z), w = w (x,y,z) [3].

The relation between strain – displacement can be generally defined in the following equation (3):

\[
\varepsilon_x = \frac{\partial u}{\partial x}; \quad \varepsilon_y = \frac{\partial v}{\partial y}; \quad \varepsilon_z = \frac{\partial w}{\partial z}
\]

(3)

Where u, v, and w are translation in the direction of x, y, and z. Shear strain of \(\gamma_{xy}\), \(\gamma_{xy}\), etc is declared in the following equation (4), (5), and (6), respectively:

\[
\gamma_{xy} = \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} = \gamma_{yx}
\]

(4)

\[
\gamma_{yz} = \frac{\partial v}{\partial z} + \frac{\partial w}{\partial y} = \gamma_{zy}
\]

(5)

\[
\gamma_{zx} = \frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} = \gamma_{xz}
\]

(6)

The relation between stress – strain for isotropic material, which is derived from theory of elasticity, is as written in the following equation:

\[
\varepsilon_x = \frac{\sigma_x - \nu \sigma_y - \nu \sigma_z}{E}, \quad \gamma_{xy} = \frac{\tau_{xy}}{G}
\]

(7)

\[
\varepsilon_y = \frac{-\nu \sigma_x + \sigma_y - \nu \sigma_z}{E}, \quad \gamma_{yz} = \frac{\tau_{yz}}{G}
\]

(8)

\[
\varepsilon_z = \frac{-\nu \sigma_x - \nu \sigma_y + \sigma_z}{E}, \quad \gamma_{zx} = \frac{\tau_{zx}}{G}
\]

(9)

with

\[
G = \frac{E}{2 (1+\nu)}
\]

(10)

Where:
E = young modulus,
G = shear modulus,
\(\nu\) = poison ratios.
3. Finite Element Analysis
The ship used as a reference in this research is a passenger ship that was particularly modified due to changes in the passenger load into a vehicle. One particular dock that got to be the material for this research is the freeboard deck. This freeboard deck is located under the upper deck. The vessel data required for modeling are the main measurements of the said vessel consist of a multitude of terms and definitions specifically related to ships, which includes the length between perpendiculars (LBP/LPP), width (B), draft (T), height (H), and speed. The principal dimension of ship is the following:

|                         |       |
|-------------------------|-------|
| Length Overall          | 134.86 m |
| Length Construction     | 125.00 m |
| Breadth (moulded)       | 20.00 m  |
| Depth (moulded)         | 14.09 m  |
| Draft (moulded)         | 6.95 m   |
| Service speed           | 17.00 knots |

3.1. Modeling of passenger deck construction
The ship’s passenger deck construction modeling use finite element software. The modeling of a construction must be done in such a way that the model can actually represent the real condition. In general, the modeling of a construction consists of several stages [4].

a. Creating Ship Geometry
Platform and profile modeling can be done using two approaches: Bottom-Up (modeling a progression from the start point to volume) and Top-Up (a combination of various small and large entities into a single model).

b. Giving Material Properties
Once the stage for geometry is done then the next step is defining the material properties. The aim for this is to create a model that looks like it is made from material that is close to the material in reality. This modeling is done with the premise that the ship is made with grade A steel 36 with a modulus of 20 Gpa elasticity and that the position ratio is 0.3.

c. Meshing
Generally, meshing is a stage to discredit the geometry model into elements up to and nodal points that are to be analyzed, shown as in Error! Reference source not found..

3.2. Model constraint
The assumption of constraints in finite element calculations should be arranged in such a way that can be as closely as possible with the real conditions. This way the structure model can really represent the real conditions that occur.

The constraints used in this calculation are simple and fix constraint. The constraint at the end of longitudinals and plates are assumed to use fix constraint, while the area of the bulkhead is assumed to use a simple constraint. The course of the binding is according to Table 1 as follows [5]:

Figure 1. Finite Element (FE) model of deck construction.
### Table 1. Constraint on FE model.

| Constraint          | Translation | Rotation |
|---------------------|-------------|----------|
|                     | Dx         | Dy       | Dz | Rx | Ry | Rz |
| All DOF (fix)       | fix        | fix      | fix | fix | fix | fix |
| Dy (Simple)         | fix        |          |     |     |     |     |

### 3.3. Loading

In this part of the deck construction analysis, the applied load type is pressure load. The load occurring on the deck is the vehicle load resulting from the weight of the vehicle that is distributed in accordance to the design of vehicle’s location.

The types of vehicles in this study are consisting of freight cars in the form of six-wheeled trucks, four-wheeled passenger cars, and motorcycles. In accordance to the data described in the previous subsection, the weight of deck load can be obtained using equation (11) as explained below:

\[ W = m \cdot g \quad \text{(kN)} \]  

where:
- \( W \) = weight of vehicle
- \( m \) = mass of vehicles
- \( g \) = gravitys acceleration

From the equation (11) the value of \( W \) from each vehicles can be obtained. The next part is to find out the unity load of each vehicle using the following equation (12):

\[ P = \frac{W}{A} \quad \text{(kN/m}^2\text{)} \]  

where:
- \( P \) = pressure on area
- \( W \) = weight of vehicle
- \( A \) = cross-sectional area

There will be 3 (three) variations of the vehicle’s arrangement plan as the loading scenario, all being done on the deck. The vehicle’s arrangement plan is to be explained in Table 2.

### Table 2. Vehicle Arrangement plan on the deck.

| Variations of Vehicle Arrangement Plan | Vehicle Arrangement |
|---------------------------------------|---------------------|
|                                       | Rear  | Middle | Front    |
| 1                                     | Truck | Car    | Motorcycle |
| 2                                     | Motorcycle | Truck | Car    |
| 3                                     | Car    | Motorcycle | Truck |

The load on the deck of this ship consists of 6-wheeled trucks load, in which the weight varies from 10.605 tons, 9.99 tons and 9.147 tons, passenger cars with maximum weight of 3.5 tons and motorcycles with a maximum weight of 0.4 tons. In accordance with the calculations performed, then the loading value is obtained as shown in Table 3 and Table 4, respectively.

### Table 3. Loading.

| Vehicle      | Maximum mass (ton) | Gravitation (m/s²) | Load (kN) | \( P \times 1 \) (m²) |
|--------------|---------------------|--------------------|-----------|----------------------|
| Truck        | 14                  | 9.81               | 137.34    | 6.1 x 2              |
| Car          | 3.5                 | 9.81               | 34.335    | 5 x 2                |
| Motorcycle   | 0.4                 | 9.81               | 3.924     | 2 x 0.8              |
Table 4. Load per area.

| Vehicle   | Load (kN) | Area (m²) | Load per area (kN/m²) |
|-----------|-----------|-----------|-----------------------|
| Truck     | 137,34    | 12.2      | 11,257377             |
| Car       | 34.335    | 10        | 3,4335                |
| Motorcycle| 3.924     | 1.6       | 2,4525                |

4. Result and Discussion

The analysis of deck structure uses static analysis. The analysis stage is applied to the model in the form of elements in accordance with the loading and constraining that is given to the model. At this stage finite element software runs the process of analyzing the model that has been generated in the form of finite element and has been given certain limit and load conditions.

Once the analysis process is done, the output obtained is the maximum stress value that occurs in each and every vehicle arrangement plan. Figure 2 shows example of one of the results of the deck construction analysis.

Based on the analysis results, the maximum stress that occurs in each vehicle arrangement plan will be reviewed and examined. The following results of the maximum stress that occurs are shown in Table 5 and Table 6.

Table 5. The comparison between maximum stress and permissible stress.

| Vehicle Arrangement Plan | Maximum Stress $\sigma_{maks} (N/mm^2)$ | Permissible Stress $\sigma_{perm} (N/mm^2)$ | $\sigma_{maks} < \sigma_{perm}$ |
|--------------------------|----------------------------------------|------------------------------------------|-------------------------------|
| 1                        | 135                                    | 175                                      | Accepted                      |
| 2                        | 133                                    | 175                                      | Accepted                      |
| 3                        | 152                                    | 175                                      | Accepted                      |

Table 6 The Comparison Between Maximum Stress and Yield Strength

| Vehicle Arrangement Plan | Maximum Stress $\sigma_{maks} (N/mm^2)$ | Yield Strength $Y_{yield} (N/mm^2)$ | $\sigma_{maks} < Y_{yield}$ Strength |
|--------------------------|----------------------------------------|---------------------------------|------------------------------------|
| 1                        | 135                                    | 235                             | Accepted                           |
| 2                        | 133                                    | 235                             | Accepted                           |
| 3                        | 152                                    | 235                             | Accepted                           |
5. Conclusion

Based on the analysis results shown in Table 5 and Table 6, it can be concluded that the maximum stresses occur in deck structure are less than both permissible stress and yield strength of material. Therefore, it can be assumed that the strength of the passenger deck structure is capable for vehicle loads in accordance to vehicle arrangement plan.

References

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