Design and finite element analysis of gondola construction for multibeam echosounder (MBES) installation on RV Baruna Jaya III - BPPT

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Abstract. The revitalization of hydrographic equipment at the Research Vessel (RV) Baruna Jaya III has been carried out by the Technology Center for Marine Survey (BTSK) – BPPT to improve its service capabilities. A Multi-Beam Echosounder (MBES) for the deep-sea mapping up to 8000 meters depth has been chosen to replace the existing equipment which only has a mapping capability of 3000 meters depth. MBES requires a support construction mounted on the vessel hulls as its housing, considering the installation principle from both the shipowner and MBES maker. In this research, a gondola installation principle has been agreed to develop. The gondola construction has been designed in consideration of actual vessel conditions and several requirements by the MBES maker. The design construction is further analyzed using the finite element method (FEM) to ensure its strength and safety and meet Indonesian Classification Society (BKI) minimum requirements. The analysis conditions are divided into 3; hydrostatic load (A), sensors load (B), and the combination of hydrostatic and sensor load (C). The von Mises stress was obtained from finite element analysis for conditions A, B, and C, respectively, 164 MPa, 1.552 MPa, and 160.8 MPa. The analysis results in all loading conditions have met the minimum allowable stress required by Indonesia Classification Society rules, which is 180 MPa. In conclusion, the design of the gondola construction for MBES installation on RV Baruna Jaya III has good structural strength and safety, so it is feasible to use.

1. Introduction
Technology Center for Marine Survey (BTSK) is one of the work units of the Agency for the Assessment and Application of Technology (BPPT) with the mission of providing services, increasing innovation, and developing research capacity and competence in the field of marine observation and surveys. To achieve this mission, BTSK carries out functions including the management of 4 (four) national research vessels (RV Baruna Jaya I, II, III, and IV), marine survey equipment, and supporting

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facilities as well as data and information management of survey results and marine observation. BTSK continues to develop national and international/global cooperation networks between central/regional government agencies, universities, research institutions, and the marine industry to achieve its mission.

Taking into account these tasks and missions, BTSK currently has marine survey equipment that is quite old and out of technology, and some of them are damaged so that BTSK has many obstacles to carry out marine survey activities. The existing equipment does not support the research activities to be carried out. For this reason, with the government support and the availability of an existing fund, BTSK intends to do a revitalization by purchasing new equipment to be installed on the Baruna Jaya III Research Vessel (R/V), namely Multi-Beam Echosounder (MBES). MBES is a technology for mapping the seabed using the principle of acoustic waves. In its use, the MBES cannot be deployed separately, but the device is integrated with other components that are systemically interrelated, therefore the device will later be installed on the RV Baruna Jaya III.

However, in order to obtain proper advantages of MBES, it is necessary to construct and install an auxiliary system on the R/V Baruna Jaya III. Careful planning is required before the installation begins to ensure the work process can be carried out properly. One of the most important steps at the planning stages is the design and structural analysis of the MBES mounting construction to meet the qualifications and requirements given by the Indonesia Classification Society (BKI) and the MBES manufacturer.

The purpose of this study presented in this paper is to design a gondola construction for MBES mounting. Furthermore, the strength of the design of gondola construction was analyzed by using the Finite Element Method (FEM) in this study to comply with the BKI rules, focused on the minimum strength requirements.

The scope of this study is to design the gondola construction based on the requirements of the transducer’s maker and owner, creates gondola geometry by using CAD software and performing finite element calculations by using finite element analysis software. In the end, analyze the results of calculations regarding the criteria from the Indonesia Classification Society rules.

2. Literature Review

In conducting research related to this paper, the authors study the previous papers on gondola construction, protective structures, MBES support mounting, and finite element methods. The transducer system is generally installed in two possible ways namely shipside portable installation and bottom fixed installation. Shipside portable installation is mainly used for shallow-water MBES systems with small transducers [1]. Bottom fixed installation, in which the transducer is installed in a fixed manner on the bottom of the vessel, offers the advantages of improving the safety of the transducer and providing long-term posture stability, and can also improve the efficiency of the investigation work.

The bottom fixed installation method that mainly uses for deep-water MBES systems with the large transducer is the gondola installation. The advantage of this approach is that the transducer is located far away from the hull, thus allowing it to effectively avoid the hull noise and bubbles that are generated during navigation, and other acoustic equipment (such as an Acoustic Doppler Current Profiler (ADCP) or a sub-bottom profiler) can be installed in the fairing [1]. The disadvantage of this installation is that the attachment resistance will increase strongly (up to or more than 20% of the bare hull resistance), which in turn affects the speed of the vessel and increases the installation cost [1]. In addition, a protruding fairing is more likely to cause the vessel to be stranded at the bottom, to tow fishing net cables, and to have difficulty in docking.

To ensure that the design of the gondola construction can be installed firmly and safely, it is necessary to calculate the strength of the structure. The strength of the gondola construction must be taken into account in various loading conditions, and the construction must produce strength following the criteria of the BKI. As in the paper written by Arfis, et al. [2] which developed the mounting on the ship's hull for the MBES installation process. In his study, the fairing structure design for MBES installation that has been developed must meet the construction strength criteria based on the BKI.
rules using the Finite Element Method (FEM). The evaluation was carried out for 3 (three) loading conditions in FEM Modeling, namely hydrostatic loading, sensor loading, and the combination of hydrostatic and sensor loading. FEM modeling in this study resulted in von Mises stresses for loading conditions A, B, and C, respectively 63.20, 3.39, and 63.9 MPa. All of which is lower than the allowable stress required by the BKI rules, which is 180 MPa. The results of the analysis show that the design of the fairing structure as an MBES installation will be safe when installed in the hull of the Baruna Jaya I RV.

Invalidating a design, it is necessary to have numerical analysis and experiments. However, for fast needs with minimal costs, the experiment can be ruled out because the results of the numerical analysis method will be close to the results of the experimental method. The paper written by Abu Bakar and Dow [3] discusses the comparison between experimental data and penetration that causes damage. This paper also compares numerical simulations and direct investigations when the ship is docked. Numerical simulations were carried out using the FEM ABAQUS software to model what it would look like during a direct investigation into the ship. There are three levels of complexity used in modeling the double bottom structure which is concentrated on the inside and outside, namely longitudinal reinforcement on the shell plate and structures with longitudinal reinforcement on the floor. The result of this paper is that the simulation of finite element analysis is acceptable when compared to direct observation. Numerical simulation is cheaper to do when compared to experimental studies, but it is better to still compare the results of numerical simulations with experimental studies so that the results are more convincing.

Nugroho and Pitoyo [4] also discussed a numerical modeling study based on the finite element method of aluminum hull EN AC-43100. From the results of this modeling in the form of normal stress distribution for the entire hull under conditions of wave induction. Verification of the results of numerical modeling is done by calculating the longitudinal strength of the ship. The calculation results with numerical simulations are 19.6 MPa, while the analytical calculations for the basic construction are 20.1 MPa, while on the main deck the numerical simulation results are 17.5 MPa and the analytical calculations are 18.1 MPa.

3. Gondola Design Construction

3.1. Design requirement
Multi-Beam Echosounder (MBES) is a tool that converts electrical and sound energy into usable energy. The type of MBES is quite varied depending on the capabilities and range of power owned. The type of MBES that will be installed in the RV Baruna Jaya III is the EM 304 produced by Kongsberg Marine. EM 304 uses 2 (two) transducer arrangements for Transmitting and Receiving. The two transducers can be assembled using more than 1 module mounted on the mounting frame. The two transducer arrays are normally mounted as “T” or “L” configurations under the vessel's hull (Mills Cross configuration) [5]. The array transmitter must be installed in the direction of the ship's keel, while the receiver must be 90o from the ship's keel. The two transducer arrays shall be mounted horizontally on a plane mounted on the ship's moon (see Figure 1).
Transducers can be installed using different mounting methods. EM Transducer in principle must be installed based on the design of the ship, especially the shape of the hull. In addition, several other factors related to ship design must also be considered during installation planning, including at the design stage.

The EM transducer arrangement (Multibeam/MBES) can be installed on ships using the following mounting construction methods/types [5]:

- Gondola
- Blisters
- Flush mounted
- Fairings
- Box keel
- Portable mounting
- Hull units
- Drop keel

Not all types of installation methods mentioned above are compatible with the EM transducer model that will be installed in the RV Baruna Jaya III. From the results of discussions conducted by ship owners and equipment manufacturers, the type of installation that will be installed and constructed is the type or method of installation using a gondola. The requirements for this type of gondola installation are as follows:

- A gondola is a construction mount that is mounted under the ship, connected to the hull using welding or bolting joining methods (see Figure 2). This construction based on information from the manufacturer is a type of stand that is very compatible with the MBES EM 304 system.

Figure 1. Example of EM 304 transducer mounting configuration
3.2. Gondola Construction

The position of placing the gondola under the hull is based on the considerations of the shipowner and MBES manufacturer as shown in Figure 3.

- There is sufficient distance between the hull and the top of the gondola so that the water flow mixed with air (bubble water effect) will pass through this section and not hit the bottom side of the gondola where there is an MBES sensor on the bottom. So the MBES sensor will be safe from bubble water interference when operating.
- Gondola construction can be designed according to the shape of the hull.
- The manufacturer (Kongsberg Maritime) recommends placing a “debris knife” on the front end of the gondola.
- Gondola construction will be completely filled with water.
- Sensors other than EM 304 can also be mounted on the gondola construction.
- The surface around the transducer must be flat to get the best results from the MBES system to be installed.
- The interior of the gondola must use anti-corrosion paint protection and have sacrificial anodes installed for longer construction durability.
- Construction design must get approval (approval) from the Classification Bureau to ensure construction safety[6].
Figure 3. The position of placing the gondola at RV Baruna Jaya III

From Figure 3, it can be seen that the position of the gondola is 1.3 meters below the hull at a distance of Fr.77 to Fr. 87. Based on the requirements of the shipowner, the sensors that will be installed in the construction of the gondola are as follows:

- Multibeam Echosounder (MBES) EM 304 – TX and RX
- Sub Bottom Profiler (SBP) Knudsen
- Sound Velocity Sensor (SVS)

The plan for placing sensors (Gondola Arrangement) on the gondola can be seen in Figure 4:

Figure 4. Gondola sensor arrangement
Based on this arrangement, a construction design that has strength is made using the standard regulations of the Indonesia Classification Society. Some of the main parts of the detailed construction drawings can be seen in Figure 5:

![Figure 5](image)

**Figure 5.** Gondola detail construction drawings; (a) gondola main plate top view; (b) gondola main plate bottom view; (c) gondola side view; (d) gondola cross-section (Fr.80 – typical) and welding details

From the figure above, it can be seen the main size of the gondola (principal particular) as described in Table 1.

| Table 1. Gondola dimensions |
|----------------------------|
| Dimension (m)              |
| Overall Length             | 5.560 |
| Maximum Width              | 4.240 |
| Height to Keel             | 1.243 |

Sensors that will be installed on the gondola require a holder (casing) that is integrated with the main construction of the gondola. The casing of the transducer EM304 TX and RX is a package provided by the manufacturer, so the gondola construction design must accommodate this.
4. Finite Element Method

The finite element method is a numerical procedure that can be used to obtain solutions to a large class of engineering problems involving stress analysis, heat transfer, electromagnetism, and fluid flow [7]. For structural analysis, the value sought is the value of the displacement of the nodes which will later be translated into stress values or others. What is meant by the displacement of nodes is the displacement of points due to the loading experienced by the structure.

The continuum or object (structure) is divided into several smaller parts, so these small elements are called finite elements. It is called a finite element because the size of this small element is finite (rather than infinitely small) and generally has a simpler geometric shape than the continuum. In general, the elements in the finite element method are divided into three, namely 1D, 2D, and 3D.

The finite element analysis of the gondola design construction aims to get an overview of the strength of the gondola structure. Analysis of the strength of the structure is carried out, in addition to knowing the strength and reliability of the design, it is also one of the requirements for obtaining certification from Indonesia Classification Society. In this regard, the things that were carried out in the structural analysis of the gondola design construction were as follows:

- Modeling the construction of the gondola;
- Provide loading conditions;
- Perform finite element calculations (FEM);
- Analyzing the calculation results based on the Indonesia Classification Society rules criteria.

The allowable stress is the stress that occurs due to the loading that lasts indefinitely on the machine or construction element, without causing fracture or deformation that leads to damage. The choice of allowable stress is very decisive for calculating and re-checking the size of the machine and construction elements. According to the Indonesia Classification Society rules, the allowable stresses for the plates are as follows:

\[ \sigma_{\text{perm}} = \text{permissible design stress} \ [N/m^2] \]
\[ = \left( 0.8 + \frac{L}{450} \right) \cdot \frac{230}{k} \ [N/m^2] \text{ for } L < 90 \ m \] \hspace{1cm} (1)
\[ = \frac{230}{k} \ [N/m^2] \text{ for } L > 90 \ m \] \hspace{1cm} (2)

while the allowable stresses for other stiffeners are as follows:

\[ \sigma_b^{\text{bending stress}} = \frac{150}{k} \ [N/mm^2] \] \hspace{1cm} (3)
\[ \tau^{\text{shear stress}} = \frac{100}{k} \ [N/mm^2] \] \hspace{1cm} (4)
\[ \sigma_v^{\text{equivalent stress}} = \sqrt{\frac{\sigma_b^2}{k} + \tau^2} = \frac{180}{k} \ [N/mm^2] \] \hspace{1cm} (5)

The type of material used in this gondola construction structure is A36 steel (mild steel). A36 material is steel material with the following properties:

- Density: 7860 kg/m3
- Yield stress (yield): 235 MPa (36 psi)
- Modulus of elasticity: 207 GPa
- Poisson ratio: 0.3

The gondola construction model is made in 3D (see Figure 6) based on the top view, bottom view, side view, cross-section, and per frame view of the 2D gondola structure.
The 3D model is arranged into elements with parameters of thickness of wrang 8 mm and thickness of leather plate 10 mm. In the finite element method, the arrangement of elements in the construction modeling must represent the properties of the structure, and the selection of elements depends on the mathematical properties of the elements. In this analysis, only one type of element is used, namely solid elements.

The next stage is to discrete the geometric model into an arrangement of finite elements and nodal points to be analyzed or called meshing. The results of the meshing are shown in Figure 7.

Another parameter that must be specified in finite element modeling is the boundary conditions. Boundary conditions are conditions where support must be given to the structure which is a modeling of the relationship of the structure being reviewed with the surrounding structure. The gondola, which will be installed at the bottom of the ship, is designed to use the type of welding connection, for that the type of boundary condition that is appropriate to use is the type of fixed geometry at the top of the pillar, as shown in Figure 8, the green color part is the constrain as a fixed geometry.
After the parameters in this finite element have been determined, the loading test is carried out. In this analysis of the structure of the gondola construction, three loading conditions were carried out, namely hydrostatic loading (condition A), sensor loading (condition B), and the combination between hydrostatic and sensors loading (condition C).

In Condition A, the hydrostatic load is calculated by using equation (6), and the loading conditions that occur due to the hydrostatic loading as shown in Figure 9.

\[
P_{\text{hydrostatic}} = \rho_{\text{seawater}} \cdot T \cdot g
\]

where:
- \( P_{\text{hydrostatic}} \) = hydrostatic force
- \( \rho_{\text{seawater}} \) = density of seawater
- \( T \) = ship laden
- \( g \) = gravity

The value of hydrostatic loading on the model obtained is:

\[
P_{\text{hydrostatic}} = 1025 \text{ kg/m}^3 \cdot 5.5 \text{ m} \cdot 9.81 \text{ m/s}^2
\]
\[
= 55303.875 \text{ N/m}^2
\]
In Condition B, the load that occurs is the weight of the transducer sensors attached to the gondola structure. The calculation of the weight of the transducer sensors on the gondola structure can be seen in Table 2.

Table 2. Calculation of the weight of sensors - transducer sensors on the gondola

| No | Item                  | Quantity | Unit Weight (kg) | Total Weight (kg) |
|----|-----------------------|----------|------------------|-------------------|
| 1  | Transmitter TX Module | 8        | 37               | 296               |
| 2  | Receiver RX Module    | 8        | 19               | 152               |
| 3  | TX Mounting frame     | 1        | 600              | 600               |
| 4  | RX Mounting frame     | 1        | 600              | 600               |
| 5  | SBP Knudsen           | 16       | 11.3             | 180.8             |

Subtotal (Kg) 1828.8
Component weight margin 10% 182.88
Total (Kg) 2011.68

The loading conditions that occur due to the weight of the transducer sensors can be seen in Figure 10.
Figure 10. Loading conditions due to the weight of the sensors on the gondola

Loading for condition C is a combination of hydrostatic loading and loading due to the weight of the transducer sensors. The loading conditions are a combination of the loading conditions in conditions B and C.

5. Results and Discussion

5.1. Static Structural Analysis Result

From the results of Finite Element Analysis (FEA), the maximum Stress von Mises at condition A (hydrostatic loading) is 164 MPa (see Figure 11 (a)) with the maximum displacement is 4.794e-001mm (see Figure 11 (b)). The maximum stress occurs at the connection of the left side pillar with the top plate.

While in condition B, the maximum Stress von Mises that occurs due to the weight of the transducer sensors is 1.552 MPa (see Figure 11 (c)) with the maximum displacement is 9.397e-003mm (see Figure 11 (d)). The maximum stress occurs in the RM304TX cover amplifier section.

And in condition C, the maximum value of Stress von Mises caused by a combination of hydrostatic loading and loading due to the weight of the transducer sensors is 160.8 MPa (see Figure 11 (e)), with the maximum displacement is 3.970e-001mm (see Figure 11 (f)). The maximum stress occurs at the front side shell connection with the top plate.
Condition A

Figure 11. Static structural analysis results for gondola construction in conditions A, B, and C

5.2. Discussion
From the results of the static structural analysis of the gondola construction mentioned above, to make it easier and clearer in comparing the results of the analysis of the three loading conditions with the requirement from the Indonesia Classification Society rules, a table is made as shown in Table 3.

|                  | Max Stress von Mises (MPa) | Allowable Stress (MPa) | Max Displacement (mm) |
|------------------|-----------------------------|------------------------|-----------------------|
| Condition A      | 164                         | 180                    | 4.794e-001            |
| Condition B      | 1.552                       | 180                    | 9.397e-003            |
| Condition C      | 160.8                       | 180                    | 3.970e-001            |

Table 3. The results of the analysis of the static structure of the gondola under loading conditions A, B, and C
From the results of the analysis of the static structure of the gondola construction in Table 3, it can be seen that under the three loading conditions, namely hydrostatic loading (condition A), sensors loading (condition B), and a combination of hydrostatic and sensors loading (condition C), the resulting maximum stress von Mises are 164 MPa, 1,552 MPa, 160.8 MPa, respectively. The three values of maximum stress von Mises are below the allowable stress required by the Indonesia Classification Society rules. With this, it can be said that the design of this gondola construction meets the requirements of the Indonesia Classification Society rules. From Table 3, it can also be seen that the maximum displacement values that occur when the maximum stress occurs due to conditions A, B, and C are 4.794e-001 mm, 9.397e-003 mm, and 3.970e-001 mm.

6. Conclusion and Future Works
The allowable stress for the construction of the gondola with A36 steel material required by the Indonesia Classification Society is 180 MPa. From the results of modeling using FEM, it is known that the von Mises stresses generated for loading conditions A, B, C on the gondola construction are 164, 1,552, and 160.8 MPA, respectively. These results indicate that the stress values generated from the FEM modeling are all smaller than the allowable stresses required by Indonesia Classification Society. So, it can be concluded that the design structure of the gondola construction meets the Indonesia Classification Society rules.

As the author realizes that the maximum stress obtained from FEM calculation is too narrow with the BKI maximum allowable stress, however, to obtain more strength of the construction, the author suggested to install more stiffener inside the gondola construction during manufacture process. Further calculation regarding this adjustment needs to be conducted in order to ensure more construction safety.

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Reference
[1] Wu Z, Yang F and Tang Y 2021 High-resolution Seafloor Survey and Applications, ed Z Wu, et al. (Singapore: Springer Singapore) pp 21–76
[2] Putra A, Handoyo T and Priohutomo K 2019 Desain dan Analisa Struktur Konstruksi Fairing Multibeam Echosounder (MBES) di Kapal Riset Baruna Jaya I BPPT menggunakan Metode Elemen Hingga (FEM) Wave: Jurnal Ilmiah Teknologi Maritim 13
[3] Abubakar A and Dow R 2013 Simulation of ship grounding damage using the finite element method International Journal of Solids and Structures 50 623–36
[4] Wibowo Harso N and Pitoyo P 2012 Study Numerik Distribusi Tegangan Badan Kapal Berbahan Aluminum Wave 6 1–6
[5] Maritime A K 2019 Kongsberg EM 304 Multibeam echo sounder, Installation manual (United States: Kongsberg Maritime AS)
[6] BKI 2021 Rules For Hull Volume II. (Jakarta: Biro Klasifikasi Indonesia)
[7] Moaveni S 1999 Finite Element Analysis: Theory and Application with ANSYS: Prentice Hall