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Mathematical Model Development to Estimate Gross Tonnage of Ro-Ro Ferry

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***Abstract*— This paper introduces an approach to estimate gross tonnage of Ro-Ro Ferry. The approach was formulated from the analysis result of data of tonnage and main dimensions of Ro-Ro Ferries which operated in Indonesia in 2012. The result obtained is a mathematical model to estimate gross tonnage of Ro-Ro Ferry as a function of the tonnage volume. Tonnage volume consists of hull and superstructure volume. The volume of hull was formulated as a function of main dimensions and form coefficient of ship hull while volume of superstructure was formulated as a function of length between perpendiculars (LBP), breadth (B), and cumulative height of superstructure (HS). This equation can be used to estimate the gross tonnage of Ro-Ro Ferry in the preliminary design stage as well as an initial reference to the ship measurement by ship surveyors.**

Keywords— Mathematical Model; Ro-Ro Ferries; Tonnage

I. INTRODUCTION

Indonesian government has organized ferry transport service by placing the ships to be operated regularly at some certain routes. As a rule, the ship type to be used is Ro-Ro Ferry for transporting passengers, vehicles and their cargo. In a Decree of Minister of Transportation of Republic of Indonesia Number KM 53 of 2002 on the National Order of Port Affairs [1]; Article 22, regarding Ferry Port class, Ro-Ro Ferry was classified into three groups of gross tonnage (GT). The first port class for the ships with tonnage less than 500 GT, the 2nd port class for ship with tonnage between 500 GT and 1000 GT, and the 3rd port class for ship with tonnage more than 1000 GT until 1500 GT.

Under the terms of Article 2 of the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 8 Year 2013 about Ship Measurement [2], any ship prior to be operated must be measured to determine the length, breadth, height, and its tonnage. Tonnage is the volume of the ship expressed in (gross tonnage (GT) and net tonnage (NT).

Prior to the enactment of legislation of the Regulation of the Minister of Transportation of the Republic of Indonesia Number PM 8 Year 2013, ship tonnage measurement in Indonesia is based on the Regulation of the Minister of Transportation of the Republic of Indonesia Number KM 6 of 2005. Before 2005, the measurement of ships tonnage is based on a number of regulations about ships tonnage. For ships with a length of 24 meters or more, its tonnage determined based on the international measurement method which recommended in International Convention on Tonnage Measurement of Ships, 1969.

Based on the data of Ro-Ro Ferries tonnage which is operated in Indonesia in 2012, there are several ships which have the same main dimension but different tonnages. In addition, there are some other ships with smaller main dimensions but have a greater tonnage than the other ships that have larger main dimensions.

In principle, the amount of ship tonnage is the result of multiplying factor K_1 with the tonnage volume (V_T). Factor K_1 is expressed as a logarithmic function of the tonnage volume. Tonnage volume consists of hull volume and superstructure volume. This paper has developed a mathematical model to estimate the gross tonnage of Ro-Ro Ferry based on tonnage volume (V_T) information. The equation of tonnage volume is formulated as a function of its main dimensions. This equation can be used to estimate the gross tonnage of Ro-Ro Ferry in the preliminary design stage as well as an initial reference to the ship measurement by ship surveyors.

II. RESEARCH METHODS

The number of ships to be observed in this research was 206 ships of 219 Ro-Ro Ferry which operated to serve ferry transport in Indonesia in 2012. The data of tonnage and main dimensions of sample ships were collected from document of The Map of Ferry Route [3]. There are varying sample ships with different main dimension and tonnage.

The development of mathematical model to estimate the gross tonnage of Ro-Ro Ferry was based on the tonnage and main dimension of ships sample. The development was divided into four steps which are determination of tonnage volume, determination of ship hull volume, determination of superstructure volume, and formulation of ship gross tonnage estimation.

According to the terms of Rule 22 in Annex I of the Regulation of the Minister of Transportation of the Republic of Indonesia, PP No. 8 Year 2013 about The Ships Measurement [2], ships gross tonnage (GT) can be obtained by multiplying factor K_1 to the tonnage volume (V_T). Tonnage volume consists of volume of submerged hull and volume of superstructure including deck house volume.

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$$GT = K_1 V_T \text{ and } K_1 = 0.2 + 0.02 \log_{10} V_T \quad (1)$$

The first step of this research is to determine tonnage volume of ships sample. Based on equation (1), tonnage volume (V_T) for each ships sample can be interpolated using equation (2) as follows.

$$V_T = [\{(GT_D\text{-}GT_B)/(GT_U\text{-}GT_B)\}(V_{TU}\text{-}V_{TB})]+V_{TB} \quad (2)$$

Here, V_{TU} is tonnage volume which generated randomly to calculate G_{TU} using equation (1) until the generated value of GTU is more than GT_D while V_{TB} is tonnage volume which generated randomly as well to calculate GT_B using equation (1) until the generated value of GT_B is less than GT_D. GT_D is gross tonnage data (ship sample), GT_U is gross tonnage value which is greater but almost the same with GT_D while GTB is gross tonnage value which smaller but almost the same with GT_D.

Determination of hull volume of ships sample is the second step of the mathematical model development. According to Taggart, 1980 [4], the volume of ship hull (V_H) can be calculated using equation (3) as follow.

$$V_H = V_C\,(1.25\ H/T - 0.115) \quad (3)$$

VC is volume of submerged hull while H and T are height and draught of ship respectively in meter.

The equation (3) is the equation of the submerged hull volume (V_C) together with the freeboard volume (V_{FB}). Separately, the equation for VC and VFB respectively are:

$$V_C = 1.04\ L_{BP}\ B\ T\ C_B \quad (4)$$

$$V_{FB} = 1.04\ L_{BP}\ B\ (H - T)\ C_{BF} \quad (5)$$

L_{BP}, B, H, and T respectively are length between perpendiculars, breadth, height, and draught of ship in meter. C_B and C_{BF} are block coefficient of submerged hull and block coefficient of freeboard. If the freeboard volume is compared to submerged hull volume, then the equation of freeboard volume (V_{FB}) can be expressed as a function of submerged hull volume (V_C) as follow.

$$V_{FB} = V_C\,(C_{BF}/C_B\ H/T - C_{BF}/C_B) \quad (6)$$

Furthermore, the hull volume (VH) can be expressed as the sum of the submerged hull volume (VC) according to the equation (4) and freeboard volume (VFB) according to the equation (6) as follow.

$$V_H = V_C\,(1 + C_{BF}/C_B\ H/T - C_{BF}/C_B) \quad (7)$$

The constant value of 1.25 in the equation (3) is actually the ratio between block coefficient of freeboard with block coefficient of submerged hull (C_{BF}/CB). Therefore, the equation to determine the hull volume (VH) that is used in this research can be expressed as follow.

$$V_H = 1.04\ L_{BP}\ B\ T\ C_B\ (1.25\ H/T - 0.25) \quad (8)$$

The third step is the determination of superstructure volume. The formula to calculate the superstructure volume was developed in four steps:

1) Determine superstructure volume (V_{SD}) of each ship sample using the following equation:

$$V_{SD} = V_T - V_H \quad (9)$$

Where, VT and VH are tonnage volume and hull volume (eq. 2 and eq. 8).

2) Determine superstructure cumulative height (HSD) of each ship sample with the following equation:

$$H_{SD} = V_{SD} / (L_{BP}\ B) \quad (10)$$

Where, VSD is data of superstructure volume from eq. 9.

3) Superstructure cumulative height (H_{SC}) was formulated as a function of L_{BP} and B. The formulation use regression method of the H_{SD} dependent variable data of each ship sample (eq. 10).

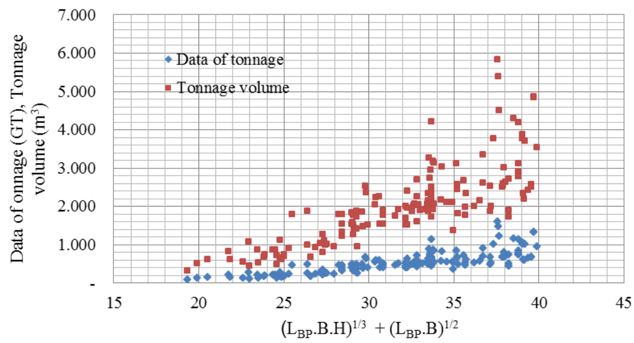
4) Estimation of superstructure volume (V_S) was formulated in the form of multiplication of L_{BP} with B and H_{SC}.

The last step of this research is the formulation of mathematical model to estimate the gross tonnage of Ro-Ro Ferry.

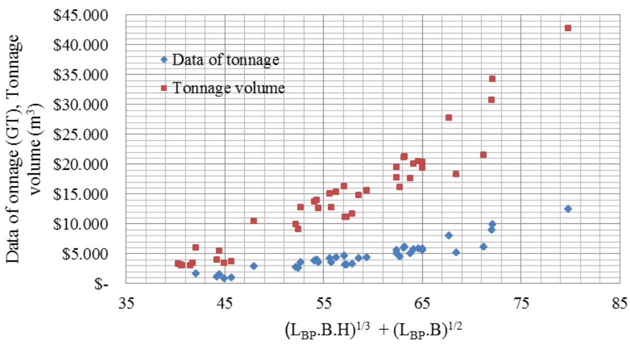
III. RESULTS AND DISCUSSION

A. Tonnage Volume

The distribution of tonnage data of Ro-Ro Ferry sample in this research is illustrated in Figure 1. Tonnage is illustrated as a function of the tonnage volume factor. The factor is the cube root of the L_{BP} multiplied by B and H $\{(L_{BP}\ B\ H)^{1/3}\}$ and the square root of the L_{BP} multiplied by B $\{(L_{BP}\ B)^{1/2}\}$. The range of sample ships dimensions are: L_{BP} between 19.50 m. and 131.67 m.; B between 7.00 m. and 22.00 m.; H between 2.00 m. and 6.60 m.; and T between 1.00 m. and 5.15 m. The tonnage range of these sample ships is between 83 GT and 12498 GT.



a. Tonnage volume factor between 19.32 and 39.89



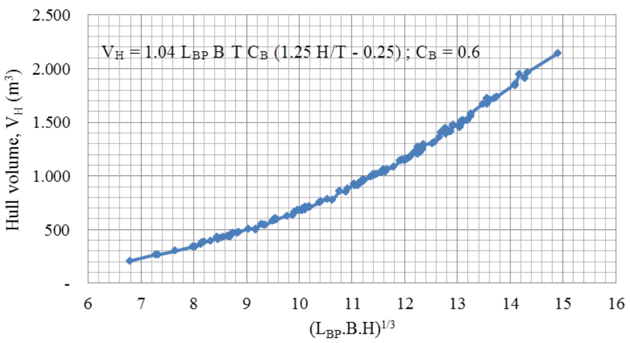
b. Tonnage volume factor between 40.25 and 79.78

Figure 1. Tonnage data and tonnage volume of ro-ro ferries

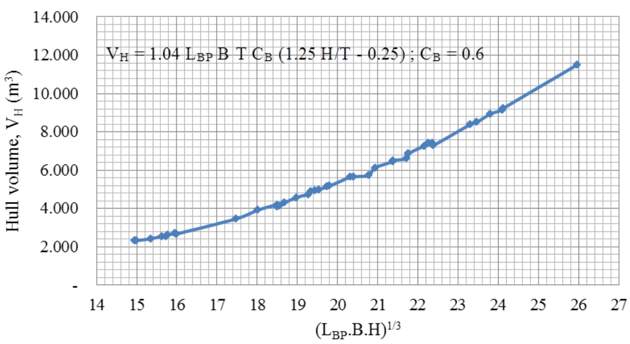
The tonnage volume which illustrated in Figure 1 represents hull volume and superstructure volume. Separately, hull volume was illustrated in Figure 2. Hull volume of each ships sample was calculated using equation (8). Note, block coefficient (CB) was determined to be 0.6 for all the sample ships.

B. Hull Volume

The tonnage volume which illustrated in Figure 1 represents hull volume and superstructure volume. Separately, hull volume was illustrated in Figure 2. Hull volume of each ships sample was calculated using equation (8). Note, block coefficient (CB) was determined to be 0.6 for all the sample ships.



a. Hull volume factor between 6.79 and 14.91



b. Hull volume factor between 14.96 and 25.96

Figure 2. Hull volume of ro-ro ferries

C. Formulation to Estimate Superstructure Volume

Figure 3 below shows the data of superstructure cumulative height (H_{SD}) of all ships sample which were calculated using equation (10).

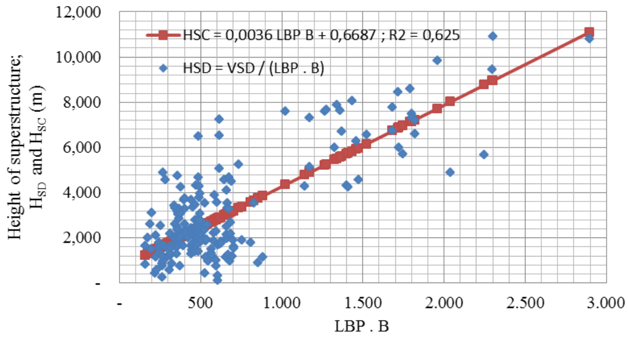


Figure 3. Superstructure cumulative height of ro-ro ferries

Based on the data of H_{SD}, the H_{SC} was formulated as a function of L_{BP} and B (Fig. 3). The equation to determine H_{SC} is as follows.

$$H_{SC} = 0.0036\ L_{BP}\ B + 0.6687;\ R^2 = 0,625 \qquad (11)$$

The equation for calculating the volume of the superstructure can be expressed as follows.

$$V_S = L_{BP}\ B\ (0.0036\ L_{BP}\ B + 0.6687) \qquad (12)$$

Equation 12 can be used to calculate superstructure volume (V_S). The result is shown in Figure 4 below.

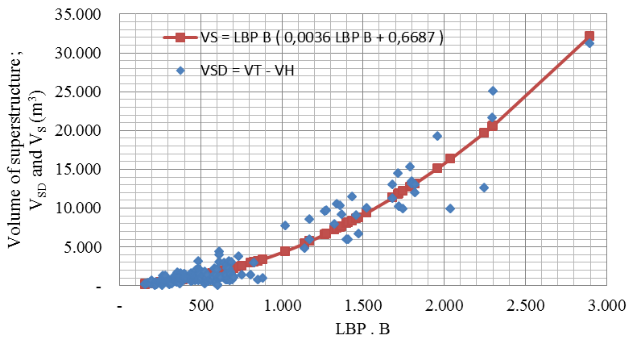


Figure 4. Superstructure volume of ro-ro ferries

As a comparison, Figure 4 also shows the data of superstructure volume of sample ship which calculated using equation (9).

D. Formulation to Estimate Gross Tonnage

As can be seen in equation 1, the gross tonnage of ship is the result of multiplying factor of K_1 with the tonnage volume (V_T). Factor K_1 is expressed as a logarithmic function of the tonnage volume. Tonnage volume consists of hull volume and superstructure volume. The equation to determine the hull

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volume (V_H) can be found in Equation 8. Equation to determine superstructure volume (V_S) had been formulated as shown in equation 12. As a result of this research, a mathematical model to estimate the gross tonnage of Ferry Ro Ro is proposed as follows.

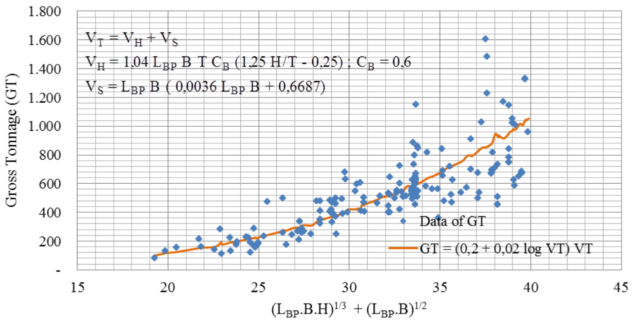
$$V_H = 1.04\ L_{BP}\ B\ T\ C_B\ (\ 1.25\ H/T - 0.25\ ) \quad (8)$$

$$V_S = L_{BP}\ B\ (0.0036\ L_{BP}\ B + 0.6687) \quad (12)$$

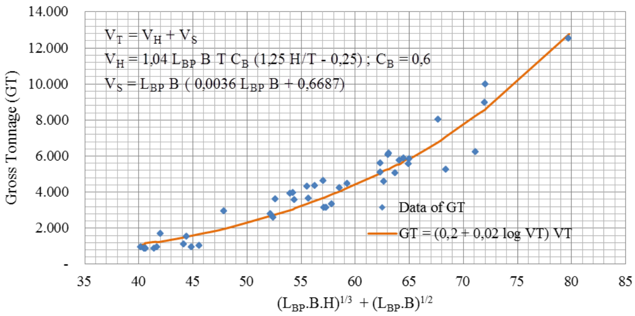
$$V_T = V_H + V_S \quad (2)$$

$$GT = K_1\ V_T \text{ and } K_1 = 0.2 + 0.02 \log_{10} V_T \quad (1)$$

The gross tonnage (GT) which illustrated in Figure 5 below is gross tonnage of each ships sample which was calculated using the developed mathematical model above.



a. Tonnage volume factor between 19.32 and 39.89



b. Tonnage volume factor between 40.25 and 79.78

Figure 5. Gross tonnage of ro-ro ferries

The difference rate between gross tonnages which calculated using the developed mathematical model with tonnage data is 6.79% in average. The difference was caused by the differences of data of tonnage between the ships which have exactly the same dimensions. There are some ships which have the same main dimensions but have significantly different of tonnage data. As an addition, the tonnage data of sample ships are also shown in Figure 5.

C. Discussions

Block coefficient is one of the variables of the submerged hull. Hence, submerged hull volume for each ship should be calculated according to its block coefficient. In Taggart (1980), in order to calculate the whole ship hull volume (including freeboard volume) the ratio of freeboard block coefficient to submerged hull block coefficient (C_{BF}/C_B) must be 1.25. In fact, with the same C_B value, some ship has significantly different C_{BF} value. Hence, the formula of Taggart (1980) cannot be applied to calculate any ship hull volume. If data of C_{BF} and C_B are available, then the hull volume should be calculated using equation (7).

In this study, the determination of the superstructure volume was formulated as shown in equation (12). Superstructure volume is a function of the L_{BP}, B, and H_{SC}. The superstructure cumulative height is also formulated as a function of L_{BP} and B (see equation 11). However, a study of the cumulative height of superstructure still needs to be done based on the actual data of dimensions and characteristics of the superstructure and deck house of Ro-Ro Ferry.

IV. CO NCLUSIONS

This paper introduces mathematical model to estimate gross tonnage of Ro-Ro Ferry. In accordance with the analysis and discussion in the previous section, the tonnage volume of Ro-Ro Ferry can be estimated using mathematical models in the following steps:

1) Determination of the hull volume as a function of the main dimensions of ship and its hull form coefficient. The main dimensions which used as the variables are length between perpendiculars, breadth, height, and draught. The form coefficients of hull are block coefficient of submerged hull and block coefficient of freeboard.

2) Determination of the superstructure volume as a function of length between perpendiculars, breadth, and cumulative height of superstructure. The cumulative height of superstructure is a function of length between perpendiculars and breadth.

3) Finally, determination of tonnage volume, which is the sum of the hull volume with superstructure volume.

REFERENCES

[1] Decree of Minister of Transportation of Republic of Indonesia Number KM 53 of 2002 on the National Order of Port Affairs (in Indonesia).

[2] Regulation of Transportation Ministry of Republic of Indonesia Number PM 8of 2013 on Ship Measurement (in Indonesia).

[3] General Directorate of Land Transportation, Directorate of LLASDP, 2012, The Map of Ferry Routes, The Ministry of Transportation of the Republic of Indonesia, Jakarta (in Indonesia).

[4] Taggart, R., 1980, Ship Design and Construction, The Society of Naval Architects and Marine Engineers (SNAME), New York.

[5] Biran, A.B., 2003, Ships Hydrostatics and Stability, Butterworth-Heinemann An imprint of Elsevier Linacre House, Jordan Hill, Oxford OX2 8DP 200 Wheeler Road, Burlington, MA 01803

[6] Edward V. Lewis (Ed.), 1988, Principle of Naval Architecture, Volume I. Stability and Strength, The Society of Naval Architects and Marine Engineers, 601 PavoniaAvenue, Jersey City, NJ