Analytical Model of a Bulb Flat

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Abstract. The computer based analytical model of a bulb flat is a component of a larger project where an analytical model of a ship hull is developed. The calculus domain of a bulb flat is defined starting from its main dimensions and it is discretized in polygons. We used notions of computer aided analytical geometry in order to define the boundary of the domain. The number of inner points along the fillets is parameterized. The output values of the model are the geometrical characteristics and they are compared with the values found in the manufacturers’ data sheets. In order to have an effective solution we developed a software consisting of more than 2000 computer code lines. The original program is flexible, being possible to add new bulb flat dimensions. After extensive tests for various dimensions of the bulb flats and inner points in which a fillet is discretized we draw the conclusion that the results are accurate. Moreover, for fillets’ discretization angles larger than 10° there is a very slight improvement of the accuracy. This computer aided analytical model is important because it offers the product moment of area, value that cannot be found in the manufacturers’ brochures where are also missing some bulb flats dimensional variants. The analytical model may be included in upper level of complexity models or in computer aided hybrid models. The solution may be considered an inspirational environment in order to conceive other analytical models.

1. Introduction

Computer based analytical models are reliable components of upper level complexity models. Moreover, there may be created libraries of computer based analytical models that are reused in several subsequent projects. The instruments used to develop analytical models are based on a wide range of various concepts provided by a series of academic disciplines such as: analytical geometry, algebra, equations, numerical methods, computer aided design, mechanics, strength of materials, theory of elasticity and others. The context that integrates all the concepts is created using computer programming which offers speed and accuracy of the resulting software instruments. An important issue in any model regards the calculus domain that may be defined in several ways. One of the most flexible methods is the division of the domain in subdomains which are either simpler from a geometrical point of view, or they represent standardized parts whose according metadata may be found in tables.

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2. Problem formulation
The analytical model of a ship hull is conceived by the use of the so-called classic approach by dividing the ship with a series of transversal planes. For each cross section there must be computed the geometrical characteristics that are used at a later stage to calculate the stresses and the displacements along the hull. According to the methodology presented in the previous section, the cross sections are divided in subdomains, some of them being the bulb flats which are important for the overall strength of the ship hull and for the calculus of its mass. The values of the geometrical characteristics for common sizes may be found in the product data brochures provided by the manufacturers, such as BRITISH STEEL, [1], TATA STEEL, [2], DE JONG & LAVINO BV - IJER & STAAL, [3] or JFE Steel Corporation, [4]. There are sizes of the bulb flats that are used in ship manufacturing for which the geometrical characteristics cannot be found, in the brochures being given only the dimensions.

![Diagram of bulb flats dimensions](image)

**Figure 1.** Bulb flats’ dimensions for BRITISH STELL, [1] and TATA STEEL, [2].

There may be also noticed some inconsistencies regarding some values of the dimensions in the datasheets. For instance, for the 200x10 bulb flat in the BRITISH STEEL, [1] and TATA STEEL, [2], documentations we find $b = 200 \text{ mm}$, $t = 10.0 \text{ mm}$, $c = 28.0 \text{ mm}$, $d_y = 8.7 \text{ mm}$, figure 1, while in
the JFE Steel Corporation, [4], the values are $A = 200\, mm$, $t = 10\, mm$, $d = 26.5\, mm$, $c_y = 8.34\, mm$ and we calculate $e_y = t + d - c_y = 10 + 26.5 - 8.34 = 28.16\, mm$, figure 2.

![Figure 2. Bulb flats’ dimensions from JFE Steel corporation, [4].](image)

The geometrical characteristics of the bulb flats cannot be found in tables for all the sizes and variants, and, moreover, by comparing the values of the geometrical characteristics from various brochures, slight variations were noticed for the same size of the common used bulb flats.

The conclusion is that we must conceive a method to compute the geometrical characteristics.

3. Discussion

To solve the problem of the geometrical characteristics there must be followed the stages: analytical definition of the calculus domain, implementation of the analytical definition and of the calculus relations and various tests whose results must be cross checked.

3.1. Analytical definition of the calculus domain

The calculus scheme is presented in the following figure, the notation of the dimensions being inspired by [1] and [2], figure 1. We consider a right-hand system of axes with axis $Z$ downwards and axis $Y$ to the right.

The concept used to analytically define the calculus domain must firstly consider a solution regarding the calculus of the geometrical characteristics. In [5] we presented a solution based on the approximation of the boundary with spline functions and in [6] we presented a solution based on the discretization of a domain in polygons. The solution based on spline functions is appropriate for boundaries having a general and complex shape. The implementation of this solution is more complicated because it leads to large exponents, i.e. 20 for the second moment of area with respect to the horizontal axis. The resulting large values require the use of some extended precision libraries, in
this case being used the GMP arbitrary precision library. The solution based on polygons is simpler, but we must discretize the arcs using angles lower than 10° in order to have a high accuracy solution. To conclude, according to our studies, the solution based on polygons is the most appropriate one for the bulb flats problem.

Figure 3. Calculus scheme used to analytically define the calculus domain.

We notice that the boundary of the calculus domain is a set of line segments and arcs. The discretization is presented in the following figure where we have the following subdomains:

1. \(C_1\)-A-B-C_1;
2. \(C_1\)-B-D-C_2-C_1;
3. \(C_2\)-D-E-C_2;
4. A-E-F-M-A;
5. M-F-H-N-M;
6. H-I-C_3-C_4-L-N-H;
7. C_4-I-J-C_4;
8. C_4-J-K-C_5-C_4;
9. C_5-K-L-C_5.

Figure 4. Division of the domain in a set of solid subdomains.

The arcs of the fillet regions are approximated using a set of line segments. The discretization process of these subdomains starts with the calculus of the points of reference, i.e. the centre of the arc’s circle and the points at the ends of the arc. The coordinates of the relevant points are computed in the \texttt{set_the_coordinates()} void. Because between two lines there are four possibilities to create fillets, this problem is solved separately. This is an analytical geometry simple problem, in this field the authors having a long run expertise, [7], [8], [9]. The coordinate along the horizontal axis of the C3 centre point is computed using the \texttt{get_XC_Fillet_Geometry()} void which calls the \texttt{point_of_tangency_coordinates_2()} function. Finally, it is accepted only that centre which is in the same semi-plane as a reference point, i.e. the product of the equation of a line in the reference point,
multiplied by the equation of the same line in the centre to be tested must be greater or equal to zero. The equation of the line is computed in the f() function and the selection of the appropriate centre is solved in the accepted_solution() function which returns the index of the centre which fulfils all the conditions. Last two functions are presented in the following figure.

Figure 5. The original C++ computer code in the Eclipse environment.

Once we have all the coordinates we are able to compute the geometrical characteristics for each subdomain and finally for the entire bulb flat by the use of the algorithm presented in reference [6].

3.2. Implementation of the analytical definition of the calculus domain
Using the previously presented concepts we developed a software consisting of more than 2000 computer code lines.

The software considers as input data an index, i_dataset, which symbolizes the bulb flat whose dimensions are assigned in order to generate the geometry of the calculus domain. New dimensions of the bulb flats may be defined in the Load_Bulb_Flat_Data() void, therefore the application is flexible, allowing the analyst to extend it by adding new cross sections.

The calculi are performed using some original general libraries previously developed, based on the calculus relations presented in [6] and on the general concepts presented in [10].

The figure above presents a sequence of the computer code and some of the functions used to generate the calculus domain.

3.3. Results and interpretation
The original software was run several times for various dimensions of the bulb flats in order to identify the possible flaws and to evaluate the accuracy of the method.

The rounded corners of the bulb flat, i.e. the fillets, were modelled as a set of line segments. It was interesting to evaluate the sensitivity of the output values with respect to the number of inner points in which the fillet is divided.

The output values of the software were compared to the values of the geometrical characteristics provided by the manufacturers’ data sheets. The following tables present the values and the relative error for the 200x10 bulb flat whose fillets are discretized with N=1, N=9 and N=89 inner points. In
the calculus of the relative errors the value of reference is considered the output data computed using the analytical model.

Table 1. Comparison between the results of the analytical model for various values of the inner points in which an arc is divided, $N$, and the values in the datasheets.

| $200x10$ | Bulb flat | $d_y$ | $\varepsilon_y$ | $d_z$ | $\varepsilon_z$ | $A$ | $\varepsilon_A$ | $I_x$ | $\varepsilon_{I_x}$ | $I_y$ | $\varepsilon_{I_y}$ | $I_{YZ}$ | $\varepsilon_{I_{YZ}}$ |
|----------|-----------|-------|-----------------|-------|-----------------|-----|-----------------|------|----------------|------|-----------------|--------|-----------------|
|          | Analytical model, $N=1$ | 8.4646 | 0 | 119.1 | 0 | 2537.6 | 0 | 9963660 | 0 | 155933 | 0 | -615428 | 0 |
|          | References [1] and [2] | 8.7 | 2.7805 | 119.7 | 0.47004 | 2560 | 0.88471 | 10104700 | 1.4155 | 171800 | 10.1755 | - | - |
|          | Reference [3] | - | - | 119 | -0.11751 | 2566 | 1.12116 | 10200000 | 2.372 | - | - | - | - |
|          | Reference [4] | 8.34 | -1.4725 | 118.4 | -0.62112 | 2523 | -0.5734 | 9970000 | 0.0636 | 1510000 | -3.1635 | - | - |

| $200x10$ | Bulb flat | $d_y$ | $\varepsilon_y$ | $d_z$ | $\varepsilon_z$ | $A$ | $\varepsilon_A$ | $I_x$ | $\varepsilon_{I_x}$ | $I_y$ | $\varepsilon_{I_y}$ | $I_{YZ}$ | $\varepsilon_{I_{YZ}}$ |
|----------|-----------|-------|-----------------|-------|-----------------|-----|-----------------|------|----------------|------|-----------------|--------|-----------------|
|          | Analytical model, $N=9$ | 8.6799 | 0 | 119 | 0 | 2559.1 | 0 | 10098600 | 0 | 171134 | 0 | -657104 | 0 |
|          | References [1] and [2] | 8.7 | 0.2313 | 119.7 | 0.01755 | 2560 | 0.034 | 10104700 | 0.0604 | 171800 | 0.38917 | - | - |
|          | Reference [3] | - | - | 119 | -0.56735 | 2566 | 0.26845 | 10200000 | 1.0041 | - | - | - | - |
|          | Reference [4] | 8.34 | -3.9162 | 118.4 | -1.06869 | 2523 | -1.4118 | 9970000 | -1.273 | 1510000 | -1.765 | - | - |

Generally, the geometrical characteristics computed using the analytical model are accurate. However, as it can be noticed the accuracy of the results depends on the number of inner points in which a fillet is discretized. If we consider a right angle, for $N=1$ we have an angle of $45^\circ$, for $N=9$ it results an angle of $9^\circ$ and for $N=89$ the angle is $1^\circ$. As it can be noticed from the previous tables, for $N=9$ the relative errors are smaller than 0.4%. Using a larger number of inner points doesn’t improve the accuracy in a significant way.

4. Conclusions
The paper presents a study that is included in a wider strategy to conceive computer aided analytical models.

The analytical model of a bulb flat presented in the paper has some important features:
1. the results are accurate, conclusion drawn after the comparison with the values of the geometrical characteristics from the manufacturers’ datasheets;
2. it offers the value of the product moment of area, value that cannot be found in the brochures; the product moment of area is useful for the calculus of the normal stress in a beam with no symmetry;
3. it is the only method which may be used for the calculus of the bulb flats’ geometrical characteristics which are not listed in the datasheets;
4. being a computer aided method, the program may be included in upper level complexity models, such as the analytical model of a ship hull, or in hybrid models.

The study presented in the paper may be considered as an inspiring environment for other mechanical parts whose geometrical characteristics must be computed.

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Acknowledgement
This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-04-04/31PCCDI/2018, acronym HORESEC, within PNCDI III, [11].