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STUDY ON THE ALTERATION OF GEOMETRICAL DIMENSIONS OF TEE STIFFENERS CONCERNING THE ULTIMATE STRENGTH CHARACTERISTICS UNDER A VERTICAL BENDING LOAD

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ABSTRACT

The midship section in oil tankers has become a major concern for the maximum bending moment during operational conditions. The section is assembled by a top deck structure, side structure, and bottom structure, which is usually supported by a stiffened panel, that is, a panel with an attached stiffener. This study elaborated on the conventional tee stiffener profile on the midship section of an oil tanker structure. Ultimate strength analysis was carried out using the finite element method for all the stiffeners with various geometrical dimensions according to the International Association of Classification Societies. This included the calculation of the section's modulus and mass as related variables, using an analytical approach. The results showed that the ultimate strength, section modulus, and mass were influenced by the alteration of web length and plate thickness. For example, an increase of 10 mm in web length gave an additional value of 2.22% for the ultimate strength, 2.8% for the section modulus, and 0.61% for the mass. In contrast, 1 mm of additional plate thickness increased the ultimate strength by 48.57%, section modulus by 6.91%, and mass by 3.68%.

Keywords: Conventional stiffeners; Finite element method; Ultimate strength; Vertical bending load

1. INTRODUCTION

A ship consists of multidimensional structures because it must contend with static loading, in terms of cargo, and dynamic loading, such as waves working on the ship during the operational conditions on the ocean, which generate various types of loads (Hughes & Paik, 2010). Therefore, the structural performance of oil tankers is a major concern associated with the safety of the operations. Especially for the midship structure, which is supported by substructures like stiffened plates, the stiffener on a panel plays an important role in distributing the bending moment over the plate. There are various types of stiffener profiles in the midship sections of oil tankers, such as flat bar, angle bar, and tee bar stiffeners (Leheta et al., 2015). The different characteristics of loading working on the midship structure, for example, the top deck, side, and bottom, during operational conditions, mean that the stiffener profile has specific geometrical dimension variables. For example, on carriers like bulk carriers and oil tankers, a tee stiffener profile is present on the bottom structure, while a bulb stiffener profile is found on the side structure (Amlashi & Moan, 2008). Different geometrical dimensions on the top deck, side, and bottom structures for various types of stiffener profiles have been proposed

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to strengthen the midship structure.

In accordance with such circumstances, the structural performance of stiffener profiles is crucial in terms of the ultimate strength characteristics. Ultimate strength gives the best description of the load-displacement relationship, elaborating the endurance of the stiffener profile under a specific type of loading (Committee III.1., 2015). The loading can stem from a combination of cargo and various wave heights on the ocean; such conditions produce vertical bending moment, torsional load, axial compression, and lateral pressure. Accordingly, the vertical bending load, represented by sagging and hogging conditions, represents a major concern, because the specific circumstances of the stiffener give different characteristics of elastic–plastic deformation conditions. Therefore, an elaboration regarding the ultimate strength characteristics and their correlation with the geometrical dimensions, related section modulus, and mass has prospective value as a foundation for the geometrical development of stiffeners.

Related studies have been carried out in terms of various types of geometry on the stiffened panel; for example, researchers have compared calculations in experiments on the ultimate strength on wide stiffened panels (Xu & Soares, 2013b), as well as investigating the residual ultimate strength under compressive loads on the dented wide and narrow stiffened panels (Xu & Soares, 2013a; Xu & Soares, 2015). In addition, research on the ultimate strength under torsional loading under various dimensional conditions of box girders has also been conducted (Shi & Wang, 2012; Ao & Wang, 2016). Related to the implementation of the finite element method on the substructure, an investigation has been carried out on the nonlinear finite element method models for ultimate strength analysis of stiffened-plate structures under combined biaxial compression and lateral pressure actions—Part I: plate element, and Part II: Stiffened panels (Seo & Paik, 2009; Paik & Seo, 2009). Paik (2009) also examined the residual ultimate strength of plates with longitudinal cracks under axial compression in a nonlinear finite element method investigation. Another study was carried out by Do et al. (2013) on the ultimate limit state assessment of stiffened panel structures for extremely large ore carriers. The alternative hybrid structural panel was elaborated on by Fajrin et al. (2017) in terms of its structural behavior under a pure bending load. Finally, an analytical model is developed by Benbouras et al. (2017) under three-point bending for symmetric laminated beams.

Although several inline studies have been carried out, there are still prospective potential studies on the effect of the dimensional variables of the stiffener profile on structural performance in terms of ultimate strength under various types of loading. For instance, the maximum load carried by various types of stiffener profiles that can be withstood can be investigated using the finite element method. In addition, the research can be advanced considering the comparison of the structural performance effectiveness of a novel Y stiffener profile with the conventional one. It has been found that an additional close section in terms of that on the Y stiffener profile has merits for the torsional rigidity and strength-to-weight ratio; that is, the section modulus of the Y stiffener profile on the plate is larger compared with an as-built stiffened panel with the conventional tee profile, and the mass is reduced for the Y stiffener profile compared with the tee stiffener profile. This condition reduces the number of stiffeners by increasing the stiffener spacing. Therefore, in the present work, several stiffeners with various types of geometrical dimensions in the midship section structure of an oil tanker are analyzed using licensed ANSYS finite element software to give a clear description of the ultimate strength under a vertical bending load and related variables, for example, the section modulus and mass.

2. METHODS AND THE REFERENCED OIL TANKER

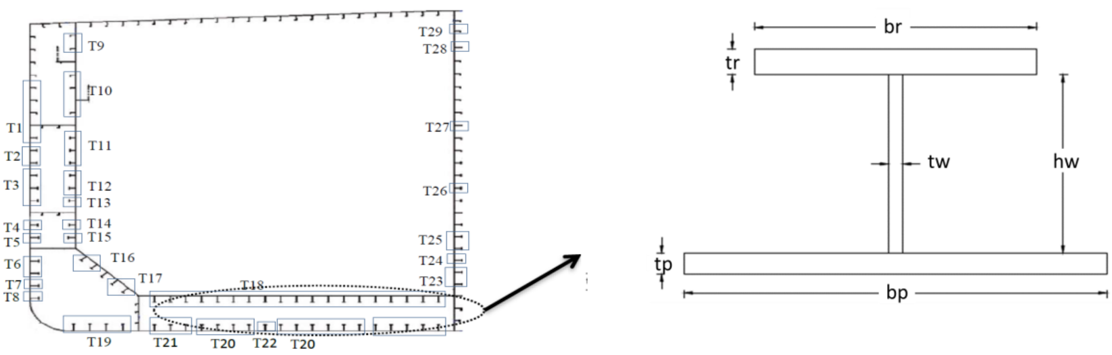
2.1. The Midship Section of the Oil Tanker Structure

The subject of the present work is tee stiffeners on the midship structure of an oil tanker classed by the International Association of Classification Societies (IACS), which has common, standardized structural rules, as stated in Badran et al. (2013). The principle dimensions of the double-hull oil tanker are listed in Table 1, and Figure 1 describes the stiffeners on the bottom, side, and top deck structures of the midship section, focusing on the geometrical characteristics and dimensions of each tee stiffener profile. Accordingly, variations in thickness are considered in terms of the optimum design of the moment of inertia in all stiffener dimension variable configurations. This means that there is a correlation between the section and the geometrical properties of a given cross-section of stiffeners, that is, the ratio of bending stress to bending moment. Therefore, in the present work, the value of the section modulus is calculated using an analytical approach referring to the dimensional characteristic difference of the stiffeners.

The differences in the tee stiffeners' geometrical dimension profiles relate to various positions, for example, the main deck, side structure, and bottom structure. Figure 1 shows the inner and outer side and bottom structures, on which the tee stiffener profile is attached, and refers to the IACS. Figure 2 describes the tee stiffener profile, where the geometrical design refers to that of the IACS. The tee stiffener profile is understood as the major stiffener on the midship structure. Badran et al. (2013) mapped the 29 conventional tee stiffener profiles with various types of geometrical dimensions on the midship section of a double-hull oil tanker in terms of the plate breadth, plate thickness, web length, web thickness, flange breadth, and flange thickness. The sequence of stiffener positions starts from the top outer side structure to the bilge structure at the corner of the bottom structure, and this is repeated from the top of the inner side structure to the bottom and continues to the inner part of the bottom of the structure transversely and the outer bottom of the structure. The last stiffener is on the longitudinal centerline of the midship section.

Table 1 Principle dimension of referred oil tanker

Length between perpendiculars (LBP)	238 m
Molded breadth (B)	43 m
Molded depth (D)	21 m
Scantling draught (T)	14.3 m
Deadweight (DWT)	97,000 tons



(a) (b)

Figure 1 Midship section of a double-hull oil tanker (a) and cross-section of tee stiffener profiles (b)

2.2. Finite Element Analyses on the Tee Stiffener Profile

2.2.1. Finite element model

Several studies have shown a well précised on the results of nonlinear finite element analysis. In accordance with the specific circumstances, it is thought that ANSYS nonlinear finite element analysis is the most suitable refined method for giving an accurate solution in this work. The applied modeling technique must represent the actual structural behavior associated with geometrical nonlinearity, material nonlinearity, boundary conditions, mesh size, and loading conditions (Paik, 2009; Ao & Wang, 2016). In addition, the modeling of material stress-strain properties is considered in terms of elastic–plastic deformation. The elastic–plastic deformation model is adopted by neglecting the effect of strain hardening, on which the elastic–plastic large deflection behavior is considered before and after the ultimate strength is reached (Ao & Wang, 2016). Mesh refinement is important for controlling the accuracy of the finite element method. Thus, coarse and fine meshes are considered for this work; it should be recalled that the fine mesh is 30% denser than the coarse mesh is, and thus, the mesh density is relative. Regarding the mesh size, a convergence study is considered to determine the best size of the finite element mesh based on an adjustment between computational cost and accuracy. Although fine mesh modelling is understood to provide more accurate solutions, the best practice considers that a similar degree of accuracy can be achieved with coarser mesh modelling. The various elements' mesh sizes are adjusted to find the largest size with a sufficient accuracy level. A mesh size of 24×24 mm is chosen, referring to the verification of Badran et al. (2013) on achieving the critical moment for a simply supported beam under uniform load. Here, the verification is on a simple supported beam with a flat web under a uniform moment using the coarser mesh, as conducted by Saddek (2006; see Table 2). Accordingly, the results obtained from the numerical solution compared with the analytical studied beams are in the range of 1.0003–1.008%.

Table 2 Verification of supported beams under using the coarser mesh (Saddek, 2006)

Beam No.	Section dim (mm)	b_f (cm)	t_f (cm)	d_w (cm)	t_w (cm)	Uniform moment		
						Timoshenko Theor. value	ANSYS result Value	ANSYS result Error
1	200×18/600×11	20	1.8	60	1.1	70.45	70.95	0.007
2	300×27/800×15	30	2.7	80	1.5	324.25	324.30	3E-04
3	300×10/600×15	30	1.0	60	1.5	90.08	89.93	0.002
4	350×15/500×15	35	1.5	50	1.5	179.25	179.70	0.003
5	180×6/500×18	18	0.6	50	1.8	13.50	13.40	0.008
6	400×16/550×20	40	1.6	55	2.0	313.32	313.70	0.002

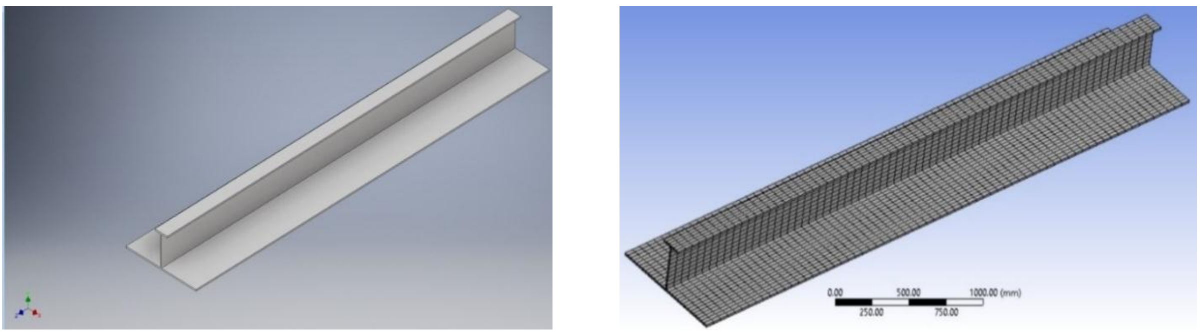
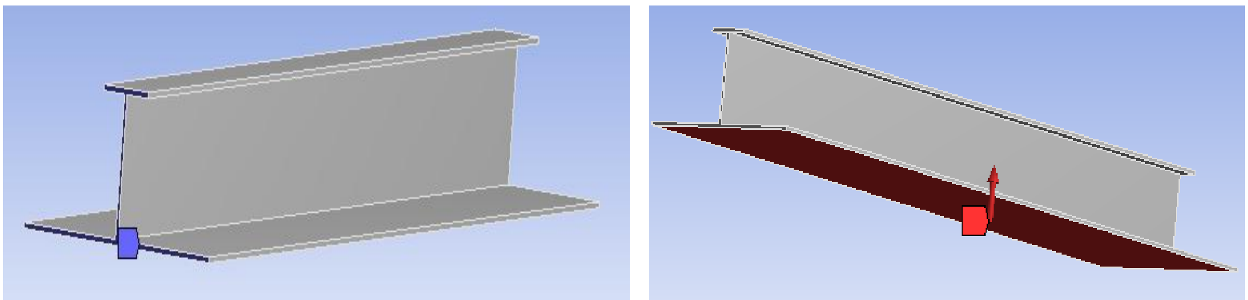


Figure 2 Design of tee stiffener profile (a) and meshed tee stiffener profile (b)

The ultimate strength of the conventional tee stiffener profile is assessed using ANSYS 15.0, student version. The geometrical and material nonlinearities are considered with large elastic–plastic deflection on the design model of the tee stiffener profile, as shown in Figure 2. A bilinear isotropic elastic–plastic material model with no consideration of the stain rate effects is considered in the finite element analysis. In this study, the properties of the material consisted of the following: Young's modulus, E = 206 GPa; Poisson ratio, m = 0.3, yield stress, Y = 235 N/mm^2; and stiffener length, 4,500 mm. A Solid45 or tetrahedral element is utilized for modelling the stiffener in the finite element analysis. The element has eight nodes, and every node has 3 degrees of freedom, that is, translation in the nodal x-, y-, and z-directions. Solid 45 was selected for its large deflection, plasticity and strain capabilities. The accuracy can be representatively achieved for the yielding behavior and actual spread of plasticity of the tee stiffener model. The total stress range is considered equal to double the yield stress, and the nonlinear stress–strain model is bilinear kinematic hardening, that is, rate independent plasticity. The behavior model utilized a simple bilinear stress–strain curve; this is appropriate for the relatively small strain used for steel material, in line with the von Mises yield criterion. The solid 45 of the Finite Element model can give relatively accurate and precise results with proportional effort and computation time savings.

2.2.2. Boundary condition and loading

It is crucial to model the stiffener edge condition precisely for the description of the boundary condition, since the boundary of the tee stiffener profile is supported by the transverse frame and longitudinal girder. The boundary condition consists of the tee [x, y, z], indicating the translational constraints, and the R [x, y, z], indicating the rotational constraints in the x-, y-, and z-coordinates, respectively; a value of "0" indicates constraint, while "1" indicates no constraint (Paik, 2009). Figure 3 shows that the uniform load on the bottom area of the tee stiffener profile is implemented vertically, representing the vertical bending load on the ship under operational conditions, and the cross-sectional areas on both transversal sides act as fixed supports. The given uniform load of 6,000 kN is applied to investigate the longitudinal displacement of the tee stiffener's profile. This represents the global load applied on the ship structure in terms of sagging and hogging conditions, on which the maximum vertical wave–induced bending moment is on the midship section. A major classification provides guidelines for generating rule based global loads, that is, IACS CSR section 10 on the buckling and ultimate strength of the local and primary support members. It is utilized to determine the minimum scantling of structural components, on which the resulting stress must be less than the material's permissible stress. Therefore, the geometrical difference on the tee stiffeners, affecting the section modulus, mass, and ultimate strength can be elucidated further.



(a) (b)

Figure 3 Fixed support (a) and uniform vertical bending load (b)

2.3. Section Modulus and Mass

The affected physical variable toward the geometrical dimension variable of the tee stiffener profile is the section modulus. This is a beam's capability to resist the form alteration of the given load. The calculation of the section modulus referred to Badran et al. (2013), explaining the geometrical dimensions of 29 tee stiffener profiles. Figure 4 describes the variables of the geometrical dimensions, where all the tee stiffener profiles have different geometries in terms of plate breadth (Pb), plate thickness (Pt), web length (Wl), web thickness (Wt), flange breadth (Fb), and flange thickness (Ft). The analytical approach was used in this work to calculate the section modulus values of all 29 tee stiffeners profile, that is, T1 to T29.

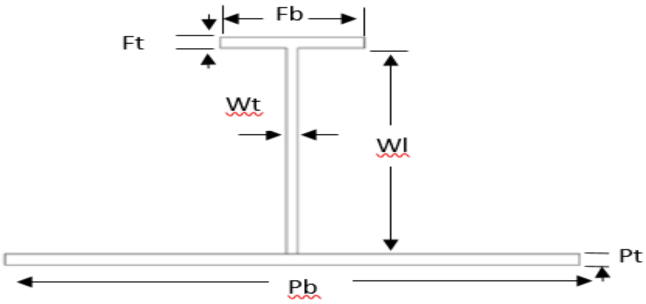


Figure 4 Geometrical dimension variables of tee stiffeners

The formula of section modulus is defined as follows:

$$Z = \frac{I}{y} \tag{1}$$

with the sample formulas of moment inertia (second moment):

$$I = \frac{1}{12} bh^3 \tag{2}$$

and the formula of mass:

$$M = (FbxFt) + (WtxWi) + (PbxPt)\,xLstiffener \tag{3}$$

3. RESULTS AND DISCUSSION

3.1. Section Modulus

Figure 5 shows the fluctuation of the section modulus of 29 tee stiffeners in sorted sequence, affected by various positions of the stiffener on the side and bottom structures. Such different positions are influenced by the various types of loadings, for example, the wave-induced, static, and impact loads; these affect the geometrical dimensions of each stiffener and the section modulus. The figure shows the relationship between the section modulus and the 29 tee stiffener profiles, on which there are several tee stiffeners categorized as the lowest values of the section modulus, that is, T10, T1, and T11. In contrast, the three largest values of the section modulus belonged to the stiffeners of T29, T28, and T9, and the highest one was T29. The different magnitudes of the section moduli on the 29 stiffeners was affected by the positions of the stiffener, that is, top deck, side, and bottom structure, including the type and magnitude of loading during operational conditions on the ocean. In addition, the geometrical dimension variables of the tee stiffeners in terms of flange breadth, flange thickness, web length, and plate thickness are different for each position. Therefore, in the present work, mapping was carried out on the influence of dimensional variables toward the value of the section modulus and the ultimate strength on each stiffener. The mechanism involved grouping the flange thicknesses into two categories in sequence, that is, 15 mm and 18 mm; following this, each group was regrouped in reference to the other dimensional variables and sorted from the largest to the smallest value for the 29 tee stiffeners.

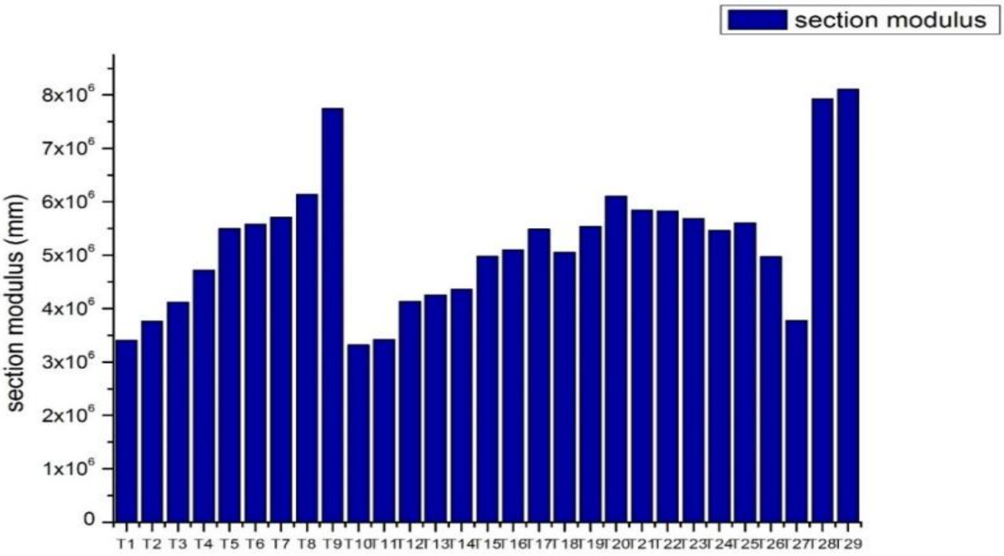


Figure 5 Section modulus of 29 tee stiffeners' profiles

3.2. Load-displacement Curve

During the operational conditions when the ship is on the ocean, sagging and hogging become common phenomena causing various types of loading, such as vertical bending load, and the stiffener detains such loading. The stiffener's ability to resist the load can be elaborated on in relation to the load-displacement curve. The vertical bending load working on the stiffener is considered on the elastic–plastic region of the stress–strain curve, and the contour of stress deformation is described in Figure 6a, representing an elastic deformation for the given uniform vertical loading direction. This includes the total deformation and its boundary condition, that is, the fixed support is on both sides of the longitudinal cross-sectional area, and the bottom of the tee stiffener becomes the area of the attached vertical bending load. This represents the global loads in terms of vertical wave–induced bending moment, that is, sagging and hogging conditions working on the midship section of the ship structure.

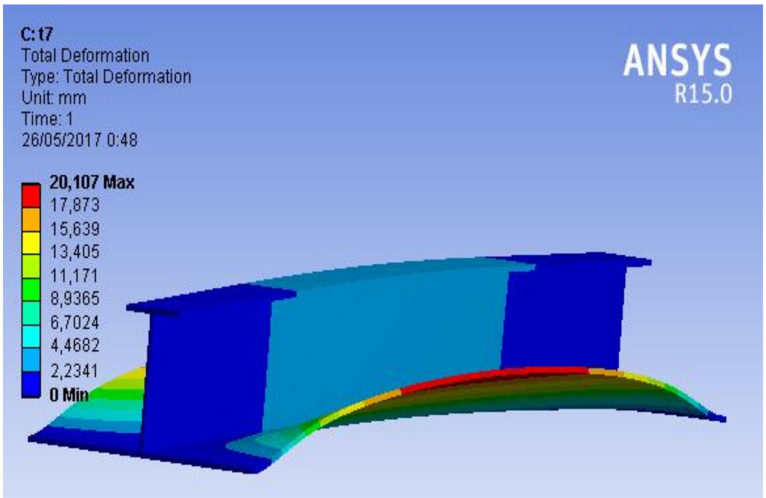


Figure 6 Contour stress distribution

ANSYS finite element method software was utilized to investigate the 29 stiffeners' profiles with various geometrical dimension variables to elaborate on the characteristics of the ultimate strength in terms of load-displacement, as shown in Figure 7. The elastic and plastic area of deformation on the load-displacement curve is related to the applied vertical bending load. The increasing value of the vertical bending load makes the deformation enter the elastic–plastic zone and continue with fully plastic deformation. Referring to Figure 7, several typical tee stiffener profiles, such as T11, T27, and T12, have similar deformation characteristics; that is, T11 has the largest plastic deformation area in terms of the elastic, elastic–plastic, and plastic areas of deformation. The other tee stiffeners' profiles, such as T22, T20, and T8, only reached the elastic deformation area before rupture; that is, they had large values of vertical bending load with small plastic deformation areas. This was affected by various types of geometrical dimension variables on the tee stiffener profiles in terms of plate breadth (Pb), plate thickness (Pt), web length (Wl), web thickness (Wt), flange breadth (Fb), and flange thickness (Ft), thereby indirectly influencing the ultimate strength characteristics and section modulus. However, in the practical operational conditions of the ship, the vertical bending load working on the classed tee stiffener profile is below the yield strength of the material because the required large vertical load and the cargo loading, which has reverse direction to the vertical load, strengthened the stiffener. The large value of the vertical bending load is required to give a clear comprehension of the elastic and plastic deformation of the tee stiffener profile under vertical bending load.

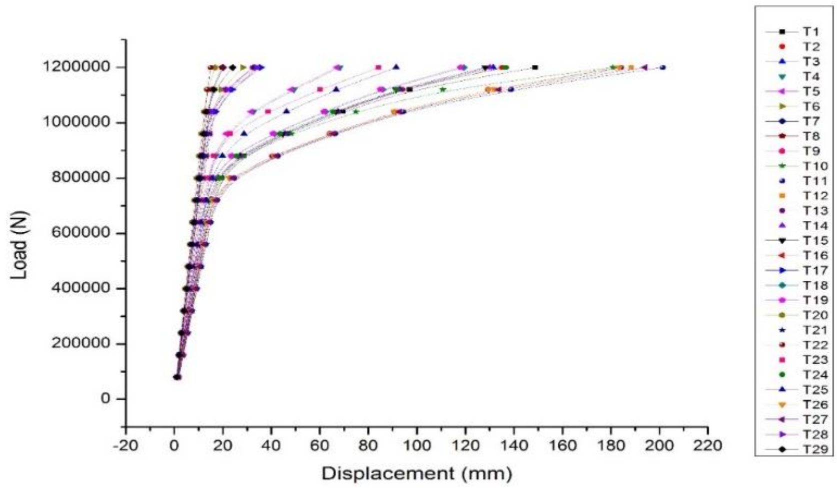


Figure 7 Load displacement of 29 tee stiffeners

After implementing a continuous increase of the vertical bending load, the displacement shifted. In Fig. 7, the first region of deformation is the elastic area, and in line with the increase in the magnitude of the vertical bending load, the stiffeners with small section modulus values, for example, T10, T11, and T27, had specific characteristics when entering the elastic–plastic and plastic regions. In contrast, the stiffeners with relatively large section modulus values, such as T29, T28, and T9, remained in the elastic region with increases of the vertical bending load. For the specific magnitude of the vertical bending load, each stiffener started to enter the plastic region, on which the magnitude of the vertical bending load working on the stiffener with a small section modulus value was lower compared with that associated with a higher section modulus value. The continued rise of the vertical bending load made T10, T27, and T11, which had small section modulus magnitudes, enter the elastic–plastic zone, followed by the plastic zone. In contrast, T29, T28, and T9 remained in the elastic regions until the highest vertical bending load was given with a small plastic deformation area, as shown in Figure 7. The general understanding of the section modulus is that, in the elastic–plastic region, a higher magnitude of vertical bending load is required to shift from the elastic region into the plastic regions due to the higher value of the section modulus. In addition, this is correlated to the capacity of the stiffener in adsorbing the energy of the vertical bending load.

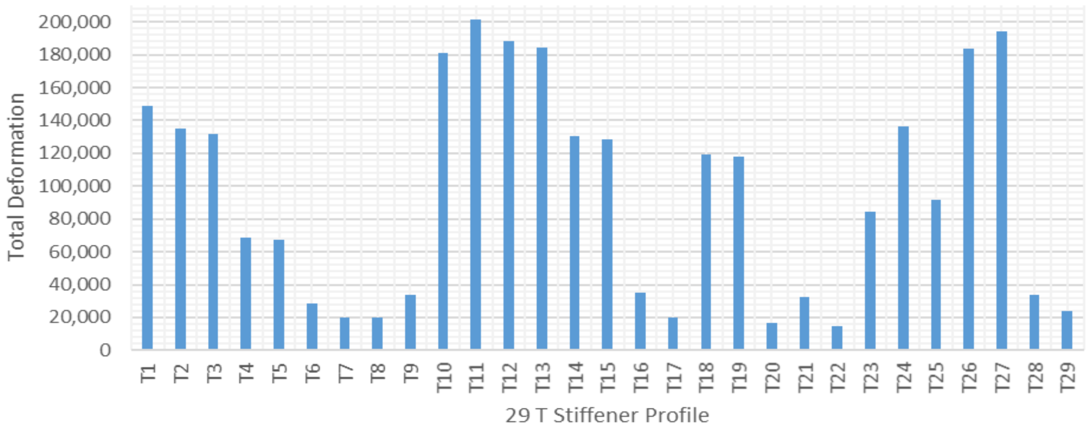


Figure 8 Total deformation of 29 stiffeners

Regarding the correlation between the section modulus and total deformation, a sample of a stiffener was taken, that is, T11. After being given a vertical load, the stiffener of T11 included the three lowest section modulus values referred to Figure 5; it also had the largest total deformation, as shown in Figure 8. In line with this finding, the stiffeners T29, T28, T9, and T22 with the four highest section modulus values, had the smallest respective total deformation values. The similarities of the small total deformation values were affected by specific geometrical dimension variables, which were diverse for each tee stiffener profile, namely plate breadth (Pb), plate thickness (Pt), web length (Wl), web thickness (Wt), flange breadth (Fb), and flange thickness (Ft). Furthermore, the relation between section modulus and total deformation is shown in Figure 9, and the general pattern of the 29 stiffeners for the section modulus and total deformation was that a larger section modulus value of the stiffener resulted in a smaller magnitude of total deformation. Nevertheless, the increased magnitude of the section modulus resulted in differences in the ultimate strength; as shown in Figure 9, for example, the section modulus of stiffener T12 was larger than that of T3, but the ultimate strength of stiffener T12 was lower. This phenomenon happened repeatedly on several different stiffeners, for example, T4 versus T26, T15, and T18; T16 versus T24; T17 versus T15 and T19; T6 versus T25 and T23; T6 versus T25 and T23; and T22 versus T21, T20, T8, and T9. Similar section modulus values had different total deformation values, and vice versa. The positioning of the stiffeners on the midship section structure in terms of the top deck, side and bottom structures affected the findings in a nonlinear pattern for the 29 stiffeners. In addition, the difference of the geometrical dimension variable was found for each stiffener, in reference to the IACS guidelines.

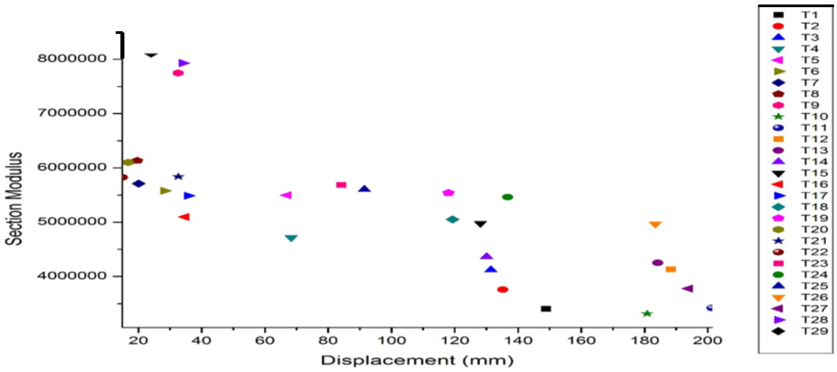


Figure 9 Total deformation and section modulus

3.3. Effect of the Geometrical Variables' Dimensions on Section Modulus, Ultimate Strength, and Mass

An elaboration on the factors playing important roles in increasing the section modulus value, where the specific circumstances have no linear correlation to the increasing ultimate strength, was conducted by mapping the geometrical characteristics of each of the 29 stiffeners to the ultimate strength. An evaluation of the efficiency of the implementation of the IACS rules can be conducted by establishing a comprehensive understanding of the patterns of alteration of the variables' dimensional characteristics affecting the section modulus and ultimate strength. The tee stiffeners and their dimensional variables, such as plate breadth, plate thickness, web length, web thickness, flange breadth, and flange thickness, were sorted in accordance with the section modulus, total deformation, and mass. Some tee stiffeners were selected and sorted from the smallest section modulus value to the highest one, as shown in Table 3, which describes the geometrical dimensions, that is, the effect of web length (Wl) shifting on the ultimate strength and section modulus (Z) in terms of Δ, illustrating the rise in the deformation and section modulus. T10 and T1 had similar values in all the dimensional variables; nevertheless, a rise in plate thickness gave increasing section modulus and ultimate strength values. In the other cases, as shown in Table 4, there was plate thickness (Pt) difference, and this affected the ultimate strength and mass (m) in terms of Δ; that is, there was a rise in the deformation and mass, and ultimately, a similar situation occurred in several stiffeners, including T13 and T14, as well as T15 and T17. This was also valid for several stiffeners in terms of flange thickness, such as T10 and T11, as well as T2 and T27, and web length, as in T1 and T2, T14 and T15, and T27.

Table 3 Effect of web length (Wl) alteration on the ultimate strength and section modulus (Z)

T	Fb	Ft	Wl	Wt	Pb	Pt	Z	Mass	Deformation	%Δ of Def	%Δ of Z
T1	150	15	300	12	850	15.5	3402081.66	642.19	148.88	9.22	9.52
T2	150	15	330	12	850	15.5	3760164.15	654.34	135.15		
T4	150	18	380	12	850	16.5	4717603.40	718.48	68.28	1.76	14.16
T5	150	18	440	12	850	16.5	5495753.88	742.78	67.08		
T7	200	18	420	12	850	17.5	5711393.04	793.75	35.66	44.87	6.91
T8	200	18	450	12	850	17.5	6135085.77	805.90	19.66		
T12	150	18	360	12	850	15.0	4132737.75	667.34	188.38	2.22	2.80
T13	150	18	370	12	850	15.0	4251736.57	671.39	184.19		
T18	150	18	430	12	840	15.5	5051101.88	704.80	119.34	1.12	8.85
T19	150	18	470	12	840	15.5	5541659.68	721.01	118.01		
T27	150	18	330	12	850	15.0	3776638.11	655.19	194.07	5.48	24.00
T28	150	18	430	12	850	15.0	4969323.92	763.37	183.43		

Table 4 Effect of plate thickness (Pt) alteration on the ultimate strength and mass (m)

T	Fb	Ft	Wl	Wt	Pb	Pt	Z	Mass	Deformation	%Δ of Def	%Δ of m
T13	150	18	370	12	850	15.0	4251736.57	671.4	184.19	29.38	2.14
T14	150	18	370	12	850	15.5	4365117.58	685.7	130.07		
T15	150	18	420	12	850	15.5	4979208.21	706.0	128.11	84.30	8.13
T17	150	18	420	12	850	17.5	5487622.82	763.4	20.11		
T21	150	18	450	12	840	17.5	5838213.56	769.6	32.63	48.57	3.68
T20	150	18	450	12	840	18.5	6102524.34	798.0	16.78		
T24	175	18	450	12	850	15.5	5461632.16	733.3	136.37	32.94	1.96
T25	175	18	450	12	850	16.0	5604103.13	747.7	91.45		

4. CONCLUSION

The aim of this study was elucidating the influence of geometrical dimension characteristics of tee stiffeners' profiles on the ultimate strength under operational conditions using numerical and analytical approaches. This represents the global load working on the ship structure, that is, the sagging and hogging conditions, whereas the maximum wave–induced bending moment is evident on the midship section of the ship. Accordingly, a series of finite element method computations was carried out on stiffeners for various specific circumstances, and the variables were geometrical dimensions of the tee stiffeners, the section modulus, mass, and ultimate strength. The results of the study will be used as a foundation for further advanced research on the comparison of the structural performance effectiveness between the conventional tee profile and novel Y stiffener profile, which has merits in terms of its promising strength-to-weight ratio.

According to the results obtained from the present study, the conclusions can be described as follows: (1) The shifting in the magnitude of the section modulus has no significant influence on the stiffeners' strength; that is, the increase of the section modulus value is not followed by increasing stiffener strength. The strength of the stiffener is partially affected by the geometrical dimensions on some variables; (2) Under a vertical bending load, the geometrical dimension strongly affects the stiffener strength. In terms of the geometrical dimension variables, the plate thickness and web length give a strong contribution to the strength of the stiffeners; the thicker the plate and longer the web, the stronger the stiffener becomes; (3) The increase of the plate thickness and web length magnitude affect the ultimate strength and section modulus in terms of a fluctuation of percentage increases of the ultimate strength and section modulus; (4) Regarding the mass, the greater the mass, the higher the ultimate strength value of the tee stiffener in terms of the vertical bending load; and (5) The geometrical dimensions are strongly related to the profile of the stiffener; that is, other forms of stiffeners, such as the bulb, I, and L bar forms, will increase the mass for a constant section modulus and ultimate strength.

5. REFERENCES

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