INVESTIGATION ON HULL GIRDER ULTIMATE BENDING MOMENT OF CATAMARAN STRUCTURES

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Abstract: *The ultimate strength of a ship hull girder depends on geometric, material characteristics, boundary and load conditions as well as initial imperfections of plate and stiffeners. The ultimate bending moments of amid ship cross section are obtained from nonlinear finite element analysis (NFEA). A comparison between these results with tested box girder models under pure bending loading is also performed. As the small errors and they show that the advantage of model simulation, the NFEA can determine rapidly the ultimate limit state when laboratory cannot set up the experiments. This paper focus on the assessment of the ultimate bending moment of MST-3 box with various length of tested models and the effect of lateral pressures are also applied to catamaran hull structures. These results contributes the input data for catamaran structural optimization analysis.*

Keywords: MST-3, NFEA, catamaran, hull girder, ultimate strength, ultimate bending moment.

Classification number: *2.1*

1. Introduction

Ultimate strength is a critical and fundamental assessment in ship and offshore structures design. The global ultimate strength plays an important role in ship structural design assessment. Linear and nonlinear buckling in elasto - plastic collapse dominate the strength for the slender members in compression, not similar to the yielding strength of members in tension.

The first evaluation of ultimate strength of ship structures was performed by Caldwell in 1965 with the influence of buckling stress which reduced the yielding strength of material [1]. In the early decade 1970's the elasto - plastic with large deflection analysis was performed by using finite element method (FEM) and computation time met the big problem [2]. Nishihara carried out experiments by using nine box girder models under pure bending loading, in which two closed boxes such as the MST-3 and MST-4 with thickness is 3.05mm and 4.35mm, respectively [3]. The ultimate strength of various structures and materials was evaluated by Oliveira [4]. Direct assessment methods were developed by Paik and Mansour, however these methods cannot take into account for strength in compression in post-collapse reduction [5]. Since the rapid development of informatics technology, the CPU time could be improved for increasing of the performances of NFEA applied to complicated models. According the obtained results, a limit state is defined by Paik and Thayamballi, it includes four types such as ultimate limit state (ULS), serviceability limit state (SLS), fatigue limit state (FLS) and accidental limit state (ALS), respectively [6]. Gordo performed the benchmark the hull girder ultimate strength of bulk carrier with the consideration of initial imperfection and lateral loadings [7]. The direct assessment methods were also improved by Paik et al. [8], the modified methods were applied to double hull oil tanker with grounding behaviour and compared the obtained results with NFEA, ISFEM, and Smith's method [9]. A hull girder reliability assessment with Monte Carlo based simulation method was performed by Gaspar and Guedes Soares [10], this study assessed full reliability section. An experiment ultimate strength for SWATH (small water plane area twin hull) structural model with one-eight scaled real ship was carried out. In the comparison of tested model with NFEA and the effects of hydrodynamic wave pressure distribution on the ship ultimate strength were considered [11].

This paper focus on the tested MST-3 with NFEA performed by ANSYS codes. The obtained results show that, the deviations of bending moment from experiments by Nishihara and NFEA models are insignificant.

Otherwise, this method proposed the application to catamaran structures in order to determine ultimate bending moment, which contributes the input data to optimization structure analysis. The models are analysed by technique with various length and thickness of box as well as meshing strategy.

2. Methodology

The ultimate bending moments achieved at the experiment by Nishihara and NFEA models are performed by ANSYS codes. This method propose an application to a catamaran structural model.

2.1. Nishihara tested models

MST-3 with the principal properties are shown in Table 1, the setup model in Figure 1, and cross section model in Figure 2.

Table 1. *Principal property of tested models.*

Model	t mm	σ_Y kg/mm^2	E kg/mm^2	ν
MST-3	3.05	29.3	2.11E4	0.277

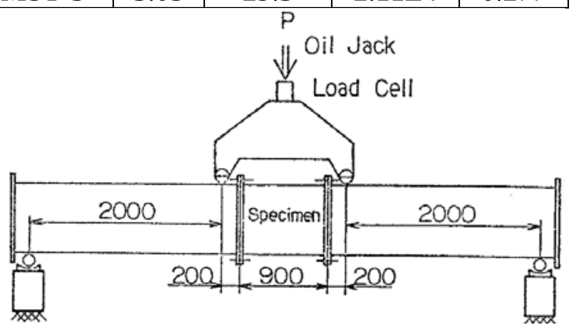

Figure 1. *Nishihara tested model setup.*

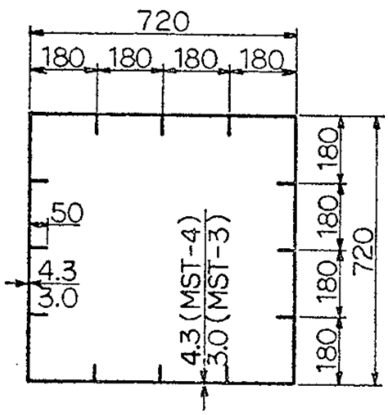

Figure 2. *Nishihara tested model cross section.*

2.2. Simulation models

The simulation models are coded by ANSYS for MST-3. Firstly, MST-3 with length of 900mm is evaluated, in order to determining converge of NFEA in three mesh strategies which is LSIZE of 18, 36 and 54 mm. Secondly, MST-3 models are investigated with various length of 540, 720, 900, 1080, 1260, 1440 and 1620 mm, respectively. Finally, according to the good obtained results, this study proposes the application to catamaran structure analysis in determining the ultimate bending moment with and without pressure. It plays important role in assessment of ultimate strength of ship structures when laboratory cannot carried out an experiment.

The initial imperfection is also taken into account to these models, there are three types of initial distortions are considered, which can be shown as follows [12]:

- Buckling mode initial deflection of plating:

$$w_{opl} = A_0.\sin\frac{m\pi x}{a}\sin\frac{\pi y}{b} \tag{1}$$

- Column type distortion of stiffeners:

$$w_{oc} = B_0\sin\frac{\pi x}{a}\sin\frac{\pi y}{b} \tag{2}$$

- Sideways initial distortion of stiffener:

$$w_{os} = C_0\frac{z}{h_w}\sin\frac{\pi x}{a} \tag{3}$$

Where, a and b is the length of long edge and short edge of plate, respectively; h_w = 50 mm – height of web stiffener, m = buckling mode of the plate is determined by the first integer which satisfying, figure 3:

$$\frac{a}{b} \le \sqrt{m(m+1)} \tag{4}$$

A_0, B_0 and C_0 are coefficients depend on the plate thickness - t_p, length of long edge plates - a, as follows:

$$\left.\begin{aligned} A_0 &= 0.1\beta^2 t_p \\ B_0 &= 0.0015a \\ C_0 &= 0.0015a \end{aligned}\right\} \tag{5}$$

$\beta = \frac{b}{t_p}\sqrt{\frac{\sigma_Y}{E}}$ – Slenderness ratio

In the first case, b = 180 mm, a = 900 mm, t_p = 3.05 mm, σ_Y = 29.3 kg/mm^2, E = 2.11x10^4 kg/mm^2, thus: β = 2.2, A_0 = 1.475, B_0 = 1.35

and C_0 = 1.35, take m = 5 is satisfied Equation (4).

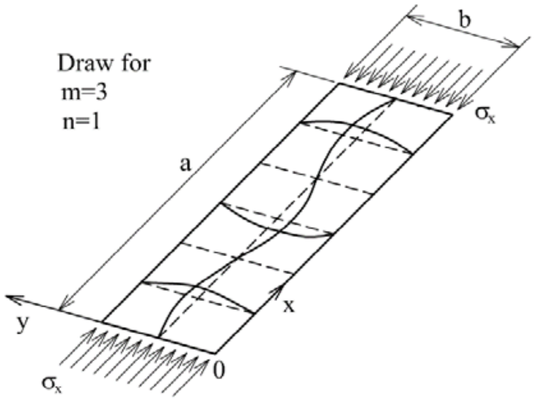

Figure 3. *Initial deflection of plates.*

2.3. Meshed models

There are three strategies for meshing models shown in Figure 4, as follows:

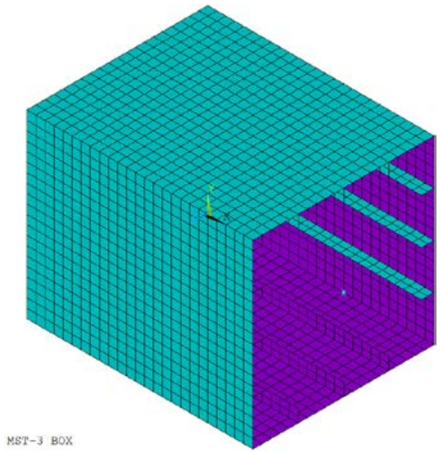

Figure 4. *Medium mesh: Element size of b/5.*

For fine meshes of 9802 elements, medium mesh of 2602 elements and coarse mesh of 1294 elements. The SHELL 181 element type is also applied to these models, with four nodes, four edges and 6 DOFs.

2.4. Boundary condition

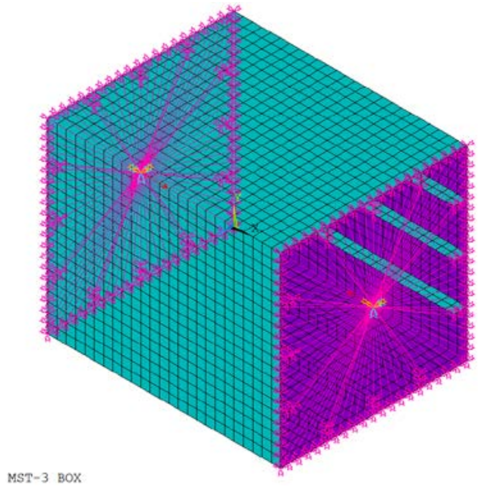

Figure 5. *Boundary with coupling conditions.*

The boundary conditions are applied to analytical models, by using coupling with rigid region depends on the referenced nodes at neutral axis of cross section, figure 5.

- At the Master node (X = 0): UX, UY, UZ, ROTX, ROTZ;

- At the Slaver node (X = 900): UY, UZ, ROTX, ROTZ;

2.5. Buckling and nonlinear analysis of models

- Firstly, for determining the eigenvalue in order to achieve the minimum force value can apply to model in buckling behavior.

- Secondly, applying the initial imperfections to plate and stiffeners of model. Then analyzing with large deflection by Newton Raphson nonlinear method.

3. Comparison of experiment and NFEA models

3.1. Ultimate bending moment with the length of 900 mm model

Ultimate bending moment is obtained from experiment by MST-3 model, M_{max} = 57.5 T.m and 60.0 T.m. By using NFEA, the MST-3 is simulated, the results are M_u = 59.06 T.m, 60.39 T.m, and 62.12 T.m appropriate fine mesh, medium mesh and coarse mesh, respectively. Von-Mises stress distributions (amplified scale of 25) are shown in figure 7 -9. The ultimate bending moment is obtained from medium mesh with good agreement as M_{max}/M_U = 0.99, for this mesh strategy is applied as catamaran structural analysis. These are shown in table 2 and figure 6, as follows:

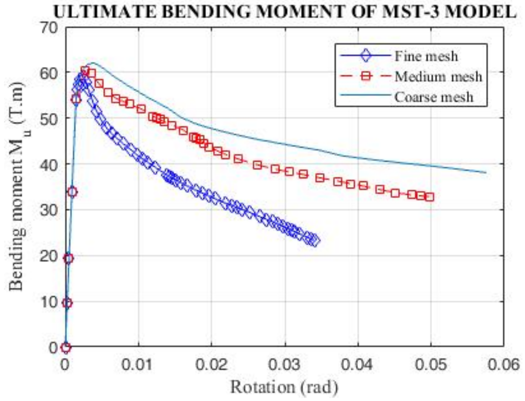

Figure 6. *Bending moment of three mesh sizes.*

Table 2. *Comparison of bending moment (T.m) between experiment and NFEA models.*

Experiment M_{max}	M_u of NFEA mesh models		
	Fine	Medium	Coarse
57.5-60.0	59.06	60.39	62.12
M_{max}/M_U	1.02	0.99	0.97

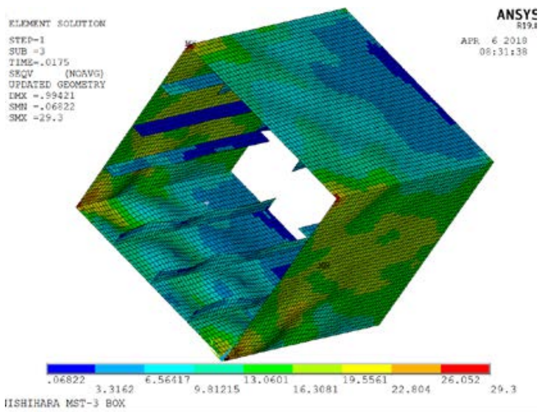

Figure 7. *Von-Mises stress: fine mesh model.*

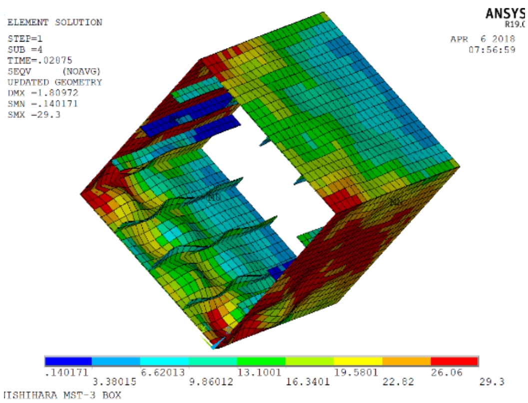

Figure 8. *Von-Mises stress: medium mesh model.*

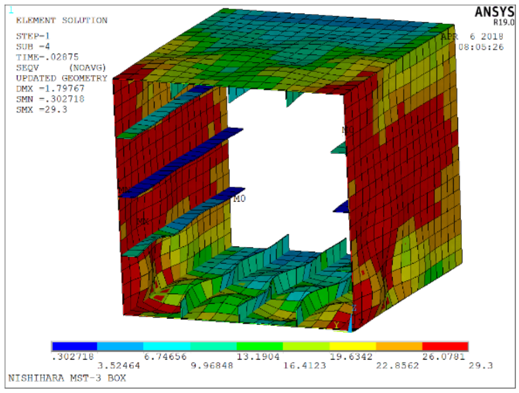

Figure 9. *Von-Mises stress: coarse mesh model.*

3.2. The length effect of tested box

The model MST-3 is investigated on varying of lengths. These derived results are shown in Figure 10 and the details in Table 3, with the same cross section, the ultimate bending moment increase appropriate for length of models.

Table 3. *The length effect to ultimate bending moments M_u (T.m).*

L (mm)	a/b	N_E	M_u	deviation
540	3	1562	40.59	-33%
720	4	2082	52.31	-13%
900	5	2602	60.39	0%
1080	6	3122	64.47	7%
1260	7	3642	67.89	12%
1440	8	4162	68.67	14%
1620	9	4682	66.19	10%

Where: L (m) – Length of box, a/b – Ratio of long edge to short edge, N_E – Number of elements.

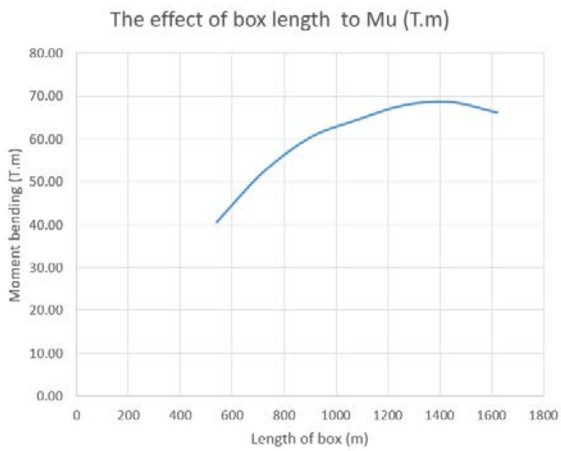

Figure 10. *Bending moment of various length.*

In figure 10, when the length of MST-3 increase from 540 mm to 1620 mm, the ultimate bending moment reaches the maximum value at *L* = 1440 mm, it appropriate *a/b* = 8 and *m* = 8. When the length greater than 1440 mm the ultimate bending moment is reduced. In table 3, the high of *Mu* is increased in the range of ratio a/b from 5 to 8.

4. Application of NFEA for catamaran hull structures

The catamaran ultimate strength is analysed by nonlinear finite element method. In order to improving the calculation time, the symmetry boundary condition is applied to an half geometries model, the ratio of *a/b* is 6.

Principal characteristic of catamaran ship structures are shown in table 4, with the SHELL 181 and BEAM 188 are applied to plates and longitudinal stiffeners. Where the deck plate thickness is 7mm, side and bottom plate thickness is 6mm, the web plate thickness is 8mm, the longitudinal stiffeners are angle bar L75x75x6 and L90x90x8, Figure 11. The model is analysed in two cases: Only the uniaxial compression load without pressure on plates, and another one with hydrostatic pressure as well as pressure on deck which is determined by rules.

Table 4. *The material of plates and stiffeners in catamaran structures.*

Item	t mm	σ_Y N/mm^2	E N/mm^2	ν
SHELL 181	6 ; 7 & 8	355	205800	0.3
BEAM 188	L75x75x6 L90x90x8	355	205800	0.3

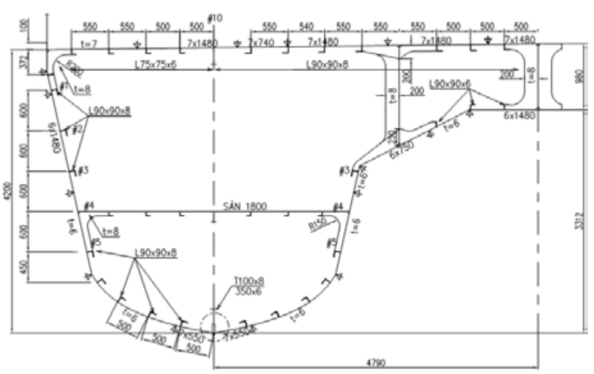

Figure 11*. Mid ship section - Catamaran structure.*

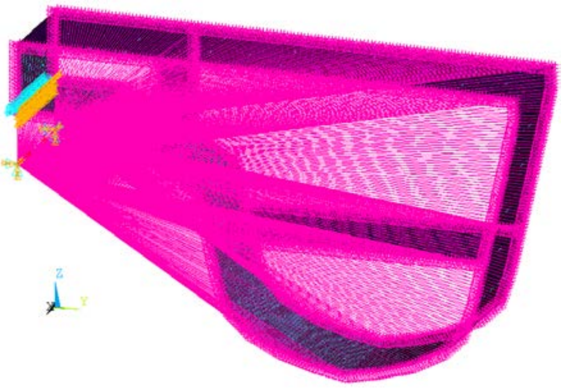

Figure 12. *Symmetry boundary conditions.*

Boundary condition different from sub section 2.4 with symmetry UY = 0 at the centre line, the mesh strategy is medium size, these are shown in figure 12.

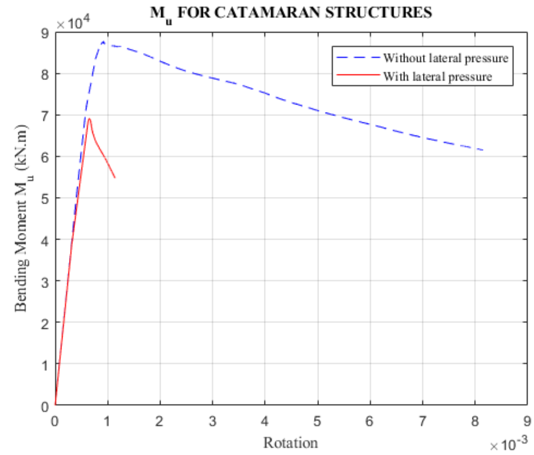

Figure 13. *Ultimate bending moment of catamaran hull structure.*

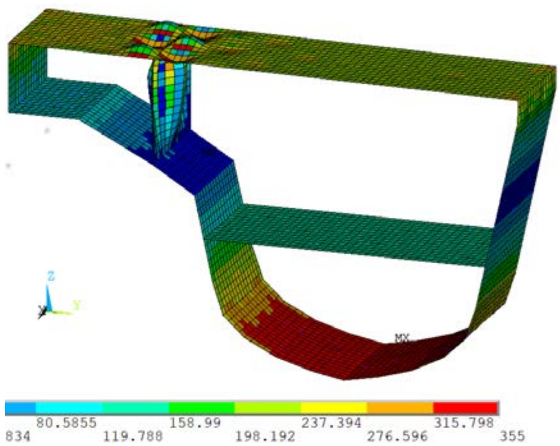

Figure 14. *von-Mises stress distribution without lateral pressure.*

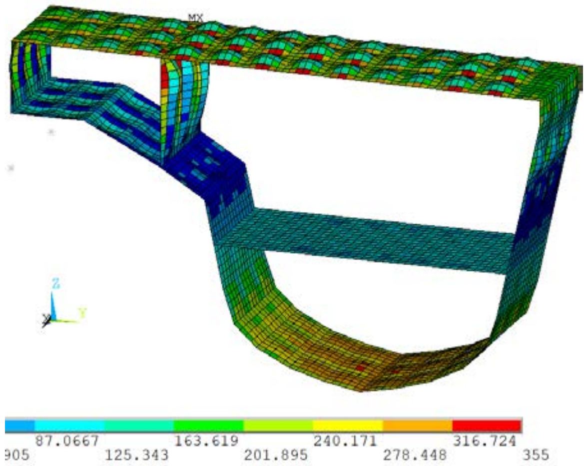

Figure 15. *von-Mises stress distribution with lateral pressure.*

The obtained results from model just under uniaxial without lateral pressure and with pressure, the ultimate bending moment *Mu* in figure 13 is 87746.5 kN.m and 69147.1 kN.m, respectively. The reduction is 21.2% when apply hydrostatic pressure to hull structure in which appropriate to draft of 1900 mm and pressure on deck is 0.005 kN/m^2 derived from the structure rules.

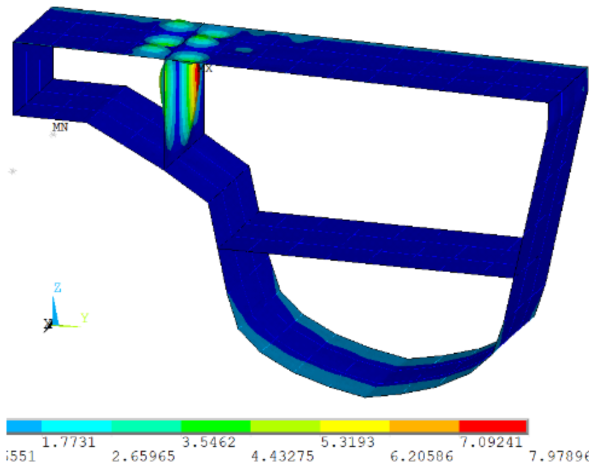

Figure 16. *Deformation distribution without lateral pressure.*

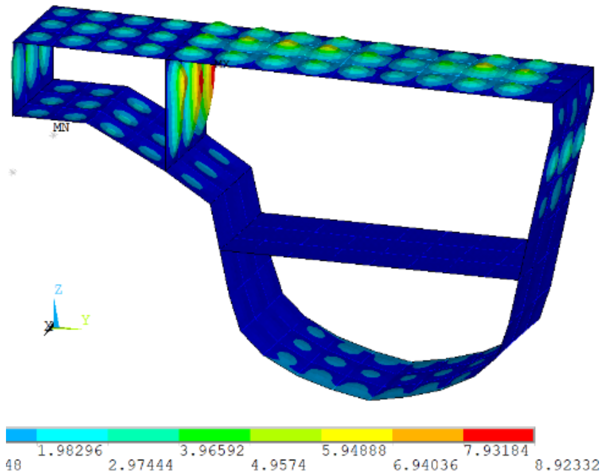

Figure 17. *Deformation distribution with lateral pressure.*

The distribution of von-Mises stress is shown in Figure 14 and Figure 15, ultimate bending stress reach maximum values at bottom and deck. Displacement in case of model under lateral pressure is higher than the other one in case of without lateral pressure, however with the small deviation of 0.944 mm, is shown in Figure 16 and Figure 17. Additionally, in two cases, the maximum values of deformation of model is appeared on the cross deck where are paid attention to by many structural designer. The high deformation is also distributed on deck in case of with the lateral pressure, thus the shearing stress and twisted body are taken into account.

From analysis of two kinds of hull girder model, the lateral pressure and ratio of a/b play an important role in hull girder ultimate strength.

5. Conclusion

Ultimate bending moment are investigated on box girder and catamaran hull structures, as the effect of various frame spacing and lateral pressures. This paper reached two important conclusions, as follows:

-The box girder under uniaxial compressive load, value of ultimate bending moment increasing when ratio of a/b from 3 to 8, and reducing as ratio of a/b greater than 8.

- Ultimate bending stress is reduced when the lateral pressure includes of hydrostatic and deck pressure are applied to catamaran hull structures, with the deviation of 21.2%.

The reliability method is performed by comparison between experiment and NFEA with three meshed strategies, the error is 1%. Particularly, ultimate bending moment is also important input data for the assessment of ship strength as well as optimization of hull structures❑

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