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Ultimate Strength Analysis of Roro Passenger Ship under Combined Global and Local Load Using Nonlinear Finite Element Method

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Abstract

Since roro passenger ships have specific characteristics in handling cargo with the roll-on-roll-off loading and unloading system that must be equipped with a ramp door. Therefore, it is important to conduct the ultimate strength analysis by considering local loads and global loads to ensure the level of safety and reliability of the ship structure. The aim of this research is focused on the investigation of the structural response and the ultimate strength of the roro passenger ship using the non-linear finite element method. The dynamic explicit method is conducted to estimate the large displacement of the deformed structures such as the hull girders, deck girders and plates. In the structural response analysis, the results shows that maximum stress was occurred on the deck girders due to the sagging bending moment load. In the ultimate strength analysis, it is identified that hydrostatic load have reduced the ultimate strength about 33 %. Otherwise, the ultimate strength is increased about 1 %, in the sagging condition.

Keywords: Ultimate hull girder strength, Nonlinear finite element method, Roro passenger ship, Local and global loads, Ultimate global bending load

Introduction

In the maritime sector, environmental conditions greatly affect the worthiness of ships while sailing and for offshore buildings that are operating. These environmental conditions cannot be separated from the geographical location of a country. This geographical location makes each country have different aquatic environmental conditions from one another. Like in Indonesia, with a geographic location that can be said to be strategic, which is flanked by 2 continents, namely the continents of Asia and Australia and between 2 oceans, namely the Indian Ocean and the Pacific Ocean, making the condition of the waters in Indonesia have its own characteristics.

Water transportation is an important means of connecting the islands of Indonesia. The vessels used include large container ships, roro passenger ships, passenger ships, sailing ships, and small motor boats. The roro passenger ship serves the straits between adjacent islands, such as Sumatra and Java, Java and Bali or other islands. On congested routes, the crossing between Sumatra-Java and Java-Bali, ferries carrying vehicles and passengers are operated 24 h per day. There are also several international ferries serving the Malacca Strait between Sumatra-Malaysia and Singapore.

The roro passenger ship has specific characteristics in handling cargo when compared to ordinary passenger ships, **Figure 1**. This is because the cargo on the main deck (vehicle deck) uses a loading and unloading process with a roll on-roll off system which must be equipped with a ramp door. Based on this condition, it is necessary to conduct a study of the ultimate strength of the roro passenger ship structure by considering local loads and global loads to ensure the level of safety and reliability of the ship structure in supporting operations.

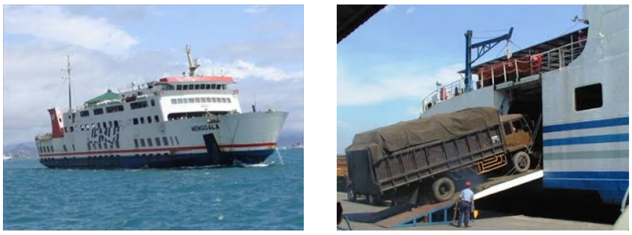


Figure 1 Roro passenger ship with a ramp door as the loading-unloading system equipment.

An accurate assessment of the ultimate strength of a ship involving progressive collapse of the hull girder is very important in assessing the safety and reliability of the ship's structure. In recent decades, various methods have been used and developed by researchers to estimate, predict and predict the ultimate strength of the hull girder ultimate strength. Hull girder strength is commonly known as longitudinal strength. The method commonly used to calculate longitudinal strength is a method that uses basic beam theory to determine the magnitude of the distribution of shear forces and bending moments. Along with the development of computer technology, a non-linear finite element method has been developed to estimate the ultimate strength of the hull girder.

The aims of this study is to implement the non-linear finite element method to predict and estimate the ultimate hull girder strength of the roro passenger ship. The application of non-linear finite element analysis as a method for estimating ultimate strength is one of the alternative methods in predicting the response of structures with large deformation and plastic deformations to structural failure. The study of the ultimate hull support strength is expected to be a reference in assessing the level of safety and reliability of the roro passenger, especially for the ship which is operated in Indonesia. Otherwise, this study are also expected to contribute positively to the development of roro ship construction design and marine transportation technology in Indonesia.

The layout of this paper is as follow: The literature review of the ultimate strength of ship structure are covered in section 2. The application nonlinear finite element method in ship structure analysis are outlined in section 3. Section 4 presented the development of FE model which include material modeling, load and boundary condition definition. Section 5 presented the results and discussion of the obtained structural response. Section 6 presents the conclusion of the analysis result.

Materials and methods

Literature review

In this study of the ultimate hull support study, the majority of articles reviewed relate to the calculation procedure and ultimate strength analysis of the ship structure. Tatsumi [1] conducted a study on the ultimate hull support strength on container ships which are subjected to combined loads, namely hogging moment and local load on the bottom of the ship (bottom local) using the nonlinear finite element method. The results show that the main factors that can reduce the ultimate strength in hogging conditions are increased longitudinal compression on the outer bottom and decreased effectiveness of the inner bottom, namely on the side of the local bending stress in the double bottom area.

Wang [2] investigated the ultimate strength of the ultra large container ship (ULCS). Experimental studies and the nonlinear finite element method were used to evaluate the ultimate strength behavior of the ULCS hull support. The initial stage, the experiment was carried out using a similar model to examine the characteristics of the ultimate longitudinal strength of the ULCS. This model test is designed to represent the actual progressive collapsed behavior in the bending moment of hogging. The next step is to conduct a study using the nonlinear finite element method. The results of the numerical analysis are then compared with the experimental results. The results show that the nonlinear numerical analysis of the finite element method is in accordance with the results of experimental studies. In this study, the nonlinear finite element method is also used to assess the ultimate strength of ULCS with a capacity of 4000 TEU, 10000 TEU, and 20000 TEU by considering the effect of nonlinearity of material and geometry, as well as conditions for initial imperfections. In another article, Wang [3] conducted a study on the ultimate strength at a capacity of 10000 TEU ULCS with a combination of longitudinal bending loads and punter loads. The results show that the estimation of the numerical analysis is consistent with the experimental measurements in the elastic and plastic conditions when failure occurs.

Shi [4] conducted a comparative study of the ultimate strength requirements on the newly modified common structural rules of bulk carrier and oil tanker (CSR-H) with the common structural rules of oil tanker (CSR-OT) or common structural rules of bulk carrier (CSR-BC). The ultimate strength of the hull supports is analyzed using the SMITH method in accordance with the requirements for a stable and fast calculation. The non-linear finite element (NFEM) method was also used in this study, to explain the factors that influence the ultimate hull girder strength on regulatory requirements.

Van [5] conducted a study on the effect of initial imperfections and corrosion losses on the strength degradation of bulk carrier ships. Initial imperfections are referred to as initial distortion and residual stress. The corrosion loss is modeled by considering the amount of reduction in construction thickness due to corrosion. The results show that the highest initial imperfection can reduce the ultimate bending moment strength by 10 %, while the largest due to corrosion loss is 30 %. The decrease due to the combination of these 2 factors can increase the magnitude of the reduction by 1.5 times for cases of average corrosion level (moderate) and 2.4 times for high corrosion loss (severe corrosion wastage).

Xu [6], conducted a study on finite element modeling using explicit methods that can produce accurate and reliable outputs with acceptable computational resources. Several factors influence the failure behavior of the hull supports, such as boundary conditions, geometric range of the finite element model, element type, loading method and loading time. The estimation results using this explicit method are then compared with the analytical and experimental methods. In another study, Xu [7] conducted a numerical study of the ultimate strength experiment of stiffened panels. The reinforced panels are numerically simulated with a uniaxial compressive load until failure occurs and post failure. The simulation results are then compared with the tests that have been made to investigate the effect of stiffener geometry and boundary conditions. The geometrical non-linearity of the material is also taken into account in the simulation process. Two types of stiffener are made of mild steel and high tensile steel for the bar stiffener and 2 are the L model and the U model, each of which is made of mild steel. The 4 stiffeners were used to investigate different geometry and material configurations with the 4 boundary conditions defined in the analysis process.

Benson [8] performed a comparison of computational methods to predict the progressive failure of a box beam. The finite element method and the simplified progressive collapse method were compared and used to analyze 3 small box supports. The outputs of these different computational approaches are then compared to determine their relative performance to each other. This study also discusses the effect of residual stress which is defined in the simulation of a damaged condition as a differentiating assumption in the computational method comparison process.

Shu [9] conducted a study on the ultimate hull support strength on bulk carrier vessels with global and local combined loads in hogging and alternate hold loading conditions using non-linear finite element analysis. The effect of scantling modification by multiplying the plate thickness by the design modification factor (DMF) was also studied in this study. The results show that there is a practical interaction equation developed between the bending capacity of global hogging and the average outside sea pressure at the bottom area.

Gordo [10] conducted an experimental study of the failure of 3 box girders when subjected to pure moment bending. The construction is made of high tensile steel material with a nominal yield stress of 690 MPa and is reinforced by a bar stiffener made of the same material. The failure modes of each box girder are discussed taking into account the slenderness variations of the panels. This concept is very useful for identifying the parameter drop that affects the ultimate strength of 3D structures when subjected to a major bending moment.

Paik [11] conducted a study on methods for evaluating the ultimate strength limit on ships and ship-shaped offshore structures. In this paper, the study focuses on the analysis of the progressive failure of the hull supports due to bending moment loads. An AFRAMAX class double hull tanker structure is designed using the IACS common structural rule (IACS-CSR) regulation as an example. The ultimate bending moment capacity of the hull structure was analyzed using ANSYS-FEA, ALPS / HULL and IACS CSR and comparisons were made on the numerical computation results.

Qi [12] conducted a comparative study of the ultimate hull support strength on large double hull tankers. Integrated framework from element analysis to non-linear (NLFEM), locally improved idealized structural unit method (ISUM), simplified method (SM) which states the stress-strain relationship according to beam-column theory, as well as advanced analytical method (AM) coupled with The elastic-plastic method (EPM, which is a combination of large elastic deflection analysis and rigid plastic analysis) of ultimate buckling strength and according to biaxial bending and non-symmetrical structure of the damaged hull was used for a comparative study of ultimate strength on a 300,000 DWT double hull tanker. The results of the calculation will be compared with the common structural rules (CSR) procedure for double hull tankers.

The application nonlinear finite element method in ultimate strength analysis

Ship structure is a complex construction which is consist of block structures that was made from the assembly any kind of components such as: plates, profiles, flat stiffened panels and curved stiffened panels. Therefore, the evaluation of ship structure response using the numerical analysis such as finite element method should be supported by the powerful computer resources with high computation performance specification. Because of the high specification hardware requirements, the studies of ship structure analysis using finite element methods usually presented on the time when the development of computer hardware technology is progressively established. Recently, the nonlinear finite element method (NFEM) have been capable to conduct analysis on the ultimate strength and the structural response of the ship construction which involved the nonlinearity behavior in geometry and material mechanical properties such as large displacement analysis, post buckling analysis and collision crash analysis.

During the computational process to find the solution, the nonlinear finite element method probably presented an unstable numerical analysis. The numerical calculation instability commonly occurred because of the nature of geometrical deformation and the nature of material properties that can be found on the buckling and yielding strength analysis. In the case of ultimate strength of the ship construction, the instability in FE analysis can be localized through the strain energy transfer of the component to the adjacent structure parts. As regards to the computational behavior, the ultimate strength analysis can be solved as a dynamic problem formulation.

The NLFEM simulation which is adopted for the ultimate hull girder strength should be capable to take into account of the initiated of local failures of the hull construction component. Otherwise, the plastic deformation of the structure during the buckling and yielding phase also should be presented. Therefore, the plasticity properties of the selected material should be determined. Furthermore, the damping factor was considered to maintain the stability of computational and achieved the convergent solution. To determine the magnitude of the damping factor, the trial and error procedure was adopted until the convergent computational results is obtained.

The modeling of roro passenger ship structure for nonlinear finite element analysis

As an archipelago country, Indonesia should be supported by a reliable marine transportation system. The roro passenger vessel usually have been used as the coastal shipping and to cross the strait between the main islands such as Sunda strait, Bali Strait, Lombok Strait and the others. In 2014, there are 225 crossing route which is contain of 44 commercial routes and 181 pioneer routes that was serviced by 306 units of roro vessel, [13]. The roro passenger vessel in the present study is selected from the population of the roro passenger vessels as a representation of the existing vessels. The selected roro design have been adopted because of the availability of structure dimension data for the roro vessel that was operating in Indonesia seaways. The principal dimension of the roro passenger vessel can be seen in **Table 1**, while the midship section design and the longitudinal structure members are presented on **Figure 2** and **Table 2**, respectively.

The roro passenger vessel construction using the combined framing system, with the longitudinal system on the deck and bottom construction and the transverse system on the side shell construction. The spacing of longitudinal stiffeners is 600 mm and the distance between solid floors is 2,400 mm which is 4 times of the main frame spacing.

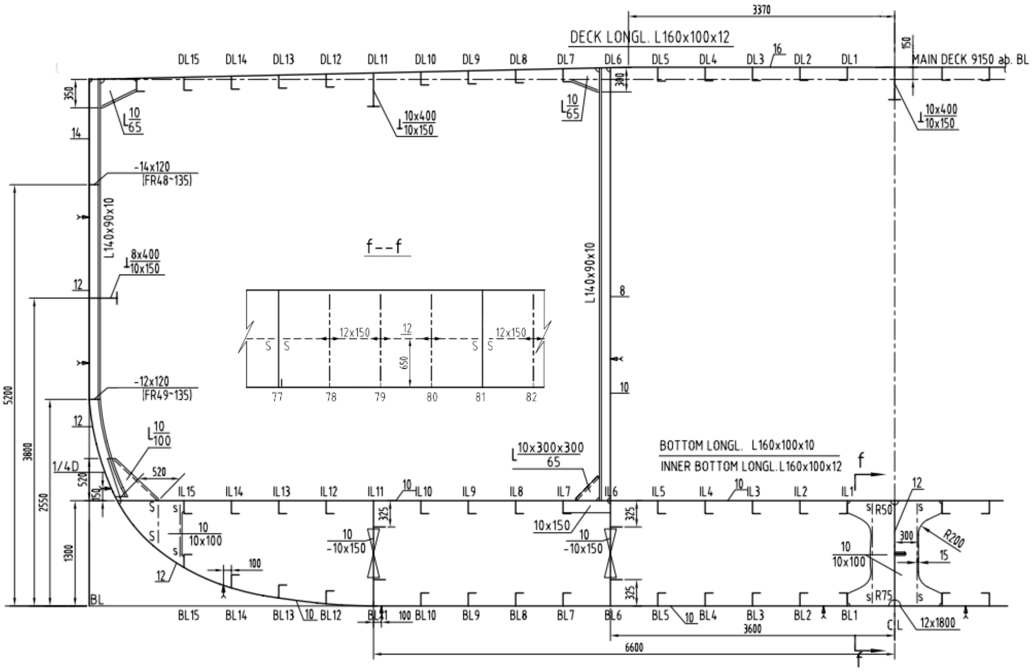


Figure 2 The midship section of the roro passenger ship.

Table 1 The principal dimensions of the roro passenger vessel.

Length over all (m)	106.25
Length between perpendicular (m)	99.20
Breadth molded (m)	20.40
Depth molded (m)	6.50
Design draught	4.20

Table 2 The longitudinal structure members of the roro passenger ship.

No	Component Name	Dimensions (mm)	Type
1.	Bottom longitudinal	160×100×10	Angle-bar
2.	Inner bottom longitudinal	160×100×12	Angle-bar
3.	Center girder	1,300×12	Flat-bar
4.	Side girder 1	1,300×10	Flat-bar
5.	Side girder 2	1,300×10	Flat-bar
6.	Side stringer	8×400 + 10×150	Tee-bar
7.	Deck longitudinal	160×100×12	Angle-bar
8.	Deck girder	10×400 + 10×150	Tee-bar
9.	Center deck girder	10×400 + 10×150	Tee-bar

The FE model was defined on the midship part of the roro passenger structure. The midship section FE model is appropriate to represent the structural response of the roro passenger due to the global load and the local load. The defined global load is the vertical bending moment while the local load are the hydrostatic pressure and internal cargo pressure. To determine the global load, the longitudinal weight distribution and the buoyancy was calculated. The calculation procedure is usually adopted as the longitudinal strength calculation. The detailed calculation procedure can be found on reference, [14]. The longitudinal bending moment of the vessel have been calculated on the still water, sagging and hogging condition, **Figures 3** - **5**.

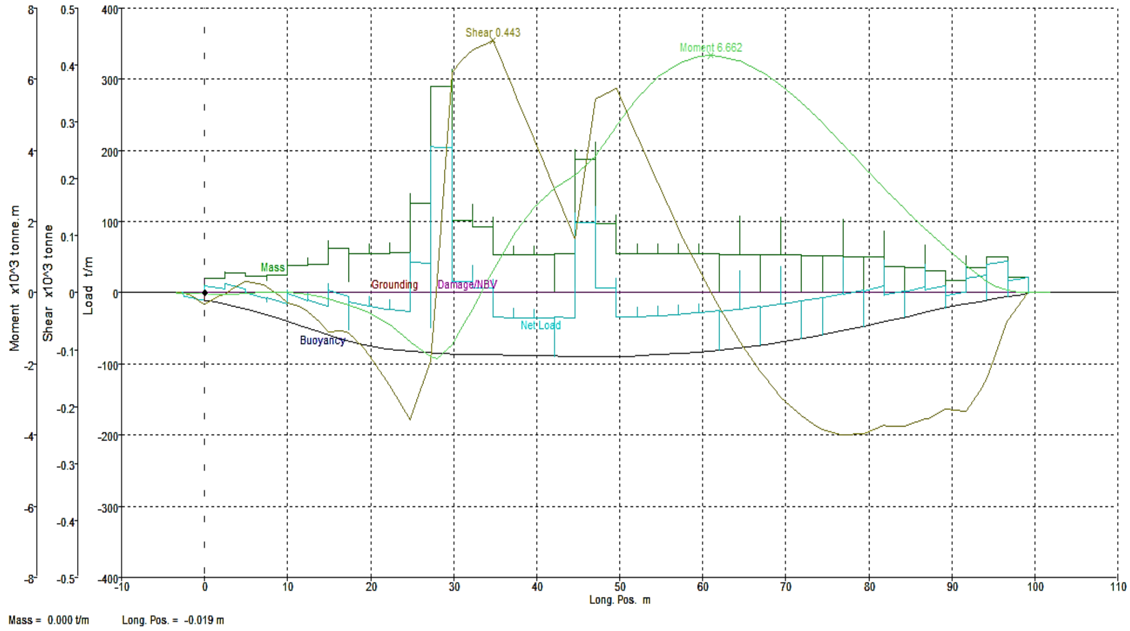


Figure 3 The longitudinal bending moment in still water condition.

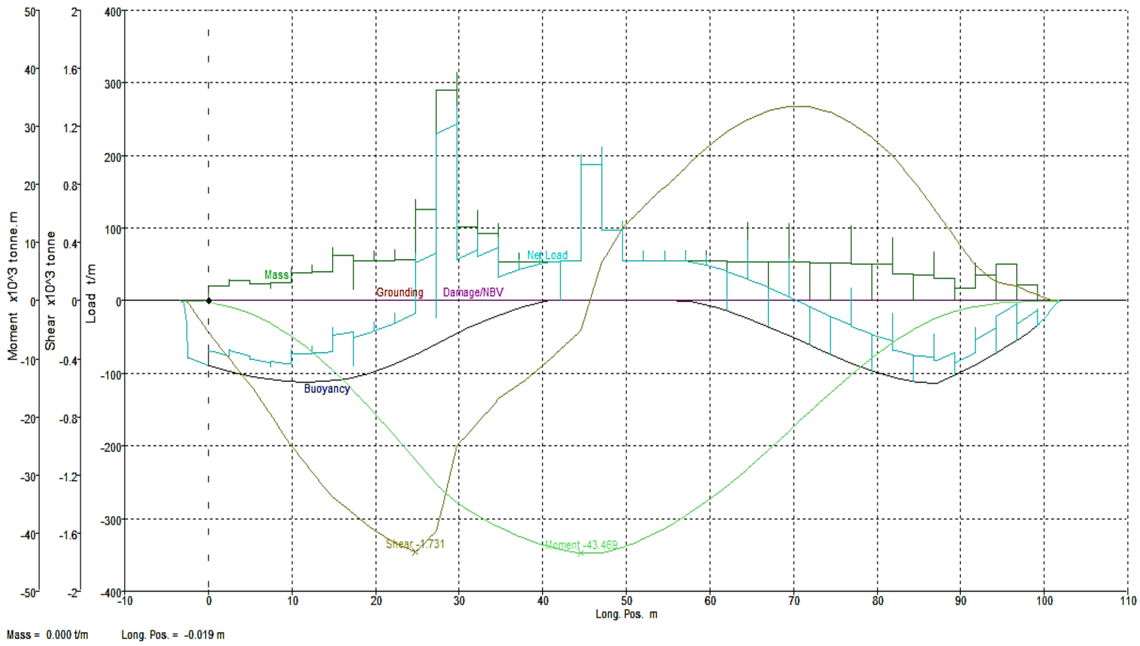


Figure 4 The longitudinal bending moment in sagging condition.

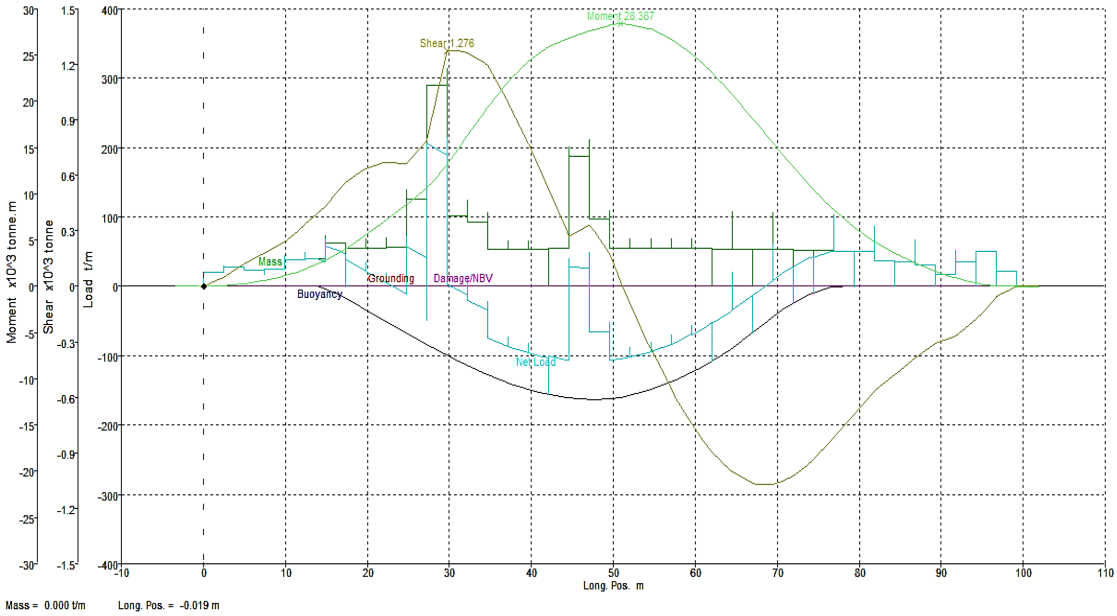


Figure 5 The longitudinal bending moment in hogging condition.

The developed FE model do not adopted the 1-frame-space model, [15], because the model is not suitable for the combined global and local loads. The 1-frame-space model do not present significantly the bending behavior on the bottom structure area. The other study have presented a ½ + 1 + ½ holds FE model, [16], however this FE model also cannot be applied on the roro vessel because of the roro hold compartment is significantly different with the bulk carrier. Therefore, the FE model was defined on the parallel middle body of the vessel hull that is equivalent with the ½ + 1 + ½ model. The parallel middle body model represented a similar region with the ½ + 1 + ½ model which is the maximum and ultimate hull girder stress is occurred.

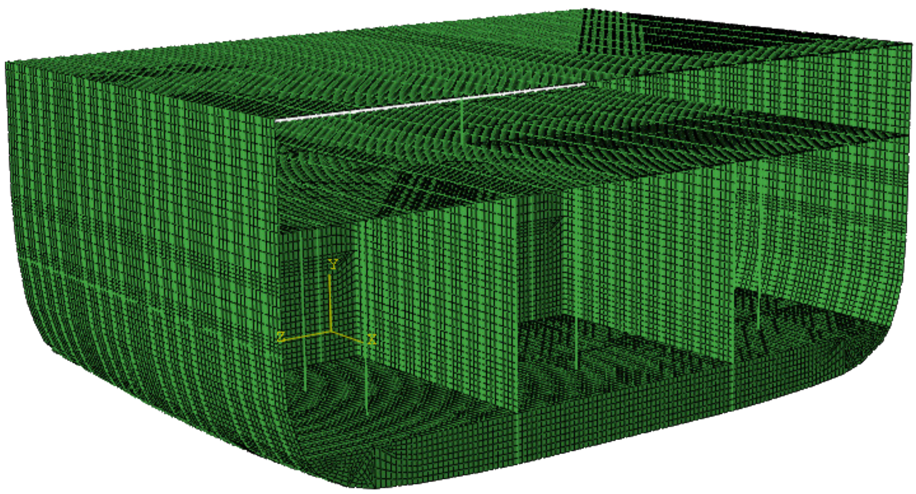


Figure 6 The FE model of the roro passenger ship.

The element type is defined as the quadrilateral shell element and the beam element for the plate and beam structure, respectively. The mesh size is defined with the uniform fine mesh which is considered sufficiently capable to capture the structural members buckling. During the ultimate strength assessment of the roro construction, the combined load of global bending moment and local hydrostatic pressure have conducted buckling under compression load at the bottom structure (hogging condition). Otherwise in the sagging condition, the buckling phenomena can be occurred at the deck structure. Since the very fine mesh model might cause the larger memory consumption and computational time, therefore the sufficiently fine mesh model was adopted. The total number of elements is 82,768 elements and 70,530 nodes. The initial imperfections such as weld induced geometrical imperfections and the residual stress was not defined. The illustration of the FE model can be found on the **Figure 6**.

Table 3 The material properties of the FE model.

Young modulus (GPa)	2.1
Poisson ratio	0.3
Yielding stress (MPa)	310
Density (Kg/m^3)	7850
Fracture Strain	0.25
Stress Triaxiality	1.35
Strain rate	1
Damage evolution	Type Displacement, Softening Linear, Degradation Maximum
Displacement at Failure	0.65

Table 4 The boundary condition of the FE model.

Rigid link definition						
Nodes on longitudinal members	Translation			Rotation		
	Dx	*Dy*	*Dz*	*Rx*	*Ry*	*Rz*
All longitudinal members	Rigid link	Rigid link	Rigid link	-	-	-
Boundary condition definition of independent points						
Location of independent point	Translation			Rotation		
	Dx	*Dy*	*Dz*	*Rx*	*Ry*	*Rz*
Afterwards point	-	Fix	Fix	-	-	-
Forewords point	Fix	Fix	Fix	Fix	-	-

The material model was defined as bilinear elastoplastic material with the mechanical properties that can be seen on the **Table 3**. The boundary condition was adopted from the common structural rules for bulk carrier and oil tanker, **Table 4**, [17]. The node of the longitudinal members should be rigidly connected (RL) with the independent point which is located at the neutral axis on the centerline. The independent point was determined as a simply supports therefore the longitudinal direction of one independent point should be free. In the case of the load condition, the vertical global bending moment load was defined on the both independent point. The hydrostatic and the cargo load pressure was determined as the local load of the FE model. The investigation of the structural response and ultimate strength of the roro vessel have been conducted on the still water, sagging and hogging condition. During the structural response analysis the vertical global bending moment load was determined through the longitudinal strength calculation. Otherwise, the global moment load was defined exceeding the maximum value for the ultimate strength analysis.

Results and discussion

Structural response analysis due to still water and wave condition

The structural response for the combined global and local load have been conducted for 3 kind of loading conditions namely still water, sagging and hogging condition. The defined load was determined as the representation of the operational load on the environment of the Indonesia seaways with the wave height of 3.75 m, [18]. Therefore, the results of the analysis is presented the behavior of the structural response during the operational activities.

In the still water condition, the maximum effective stress of 79.77 MPa have been occurred on the bottom plate. It can be explained that the global bending moment load have positive value so that the structure have similar response with the hogging condition. Otherwise, the local hydrostatic load also increased the effective stress, especially on the bottom part of the ship structure. The stress distribution of the still water condition can be seen on the **Figure 7**.

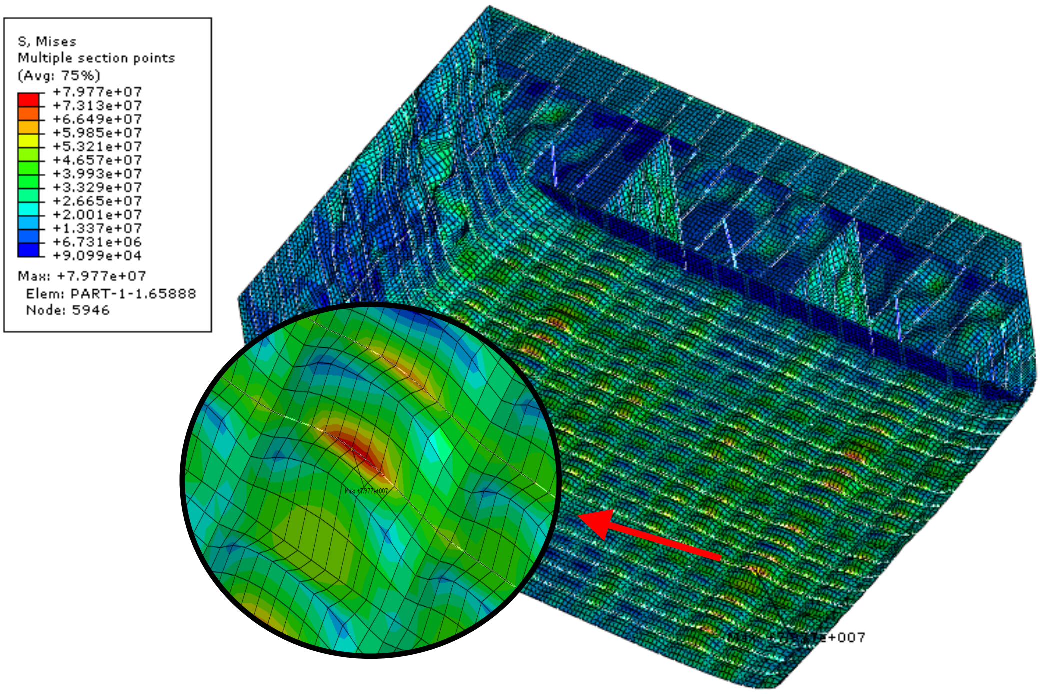


Figure 7 The stress distribution on the still water condition.

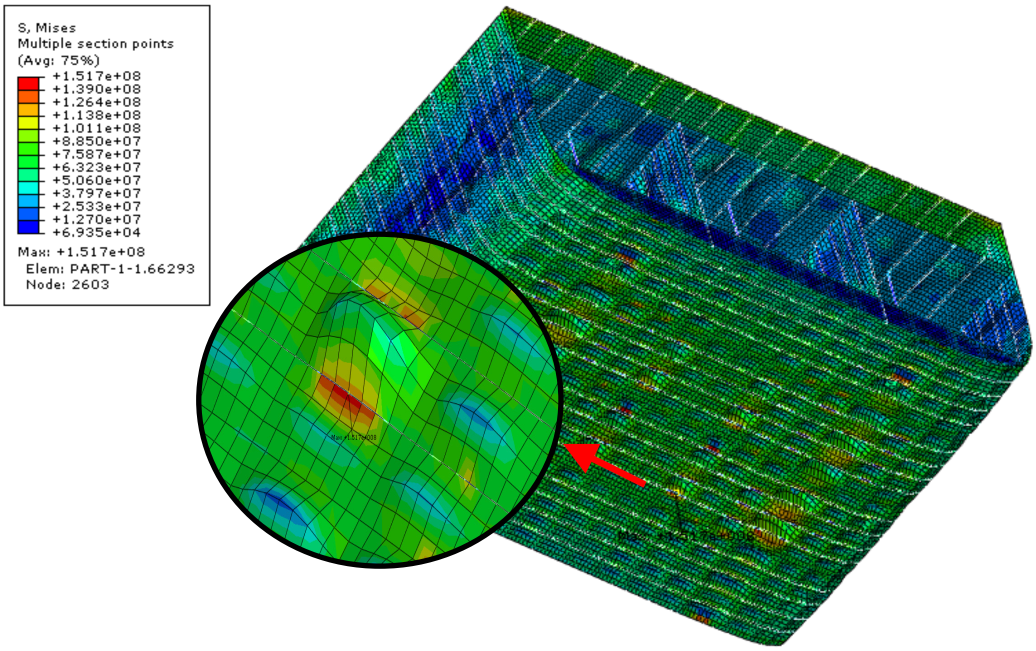


Figure 8 The stress distribution on the hogging condition.

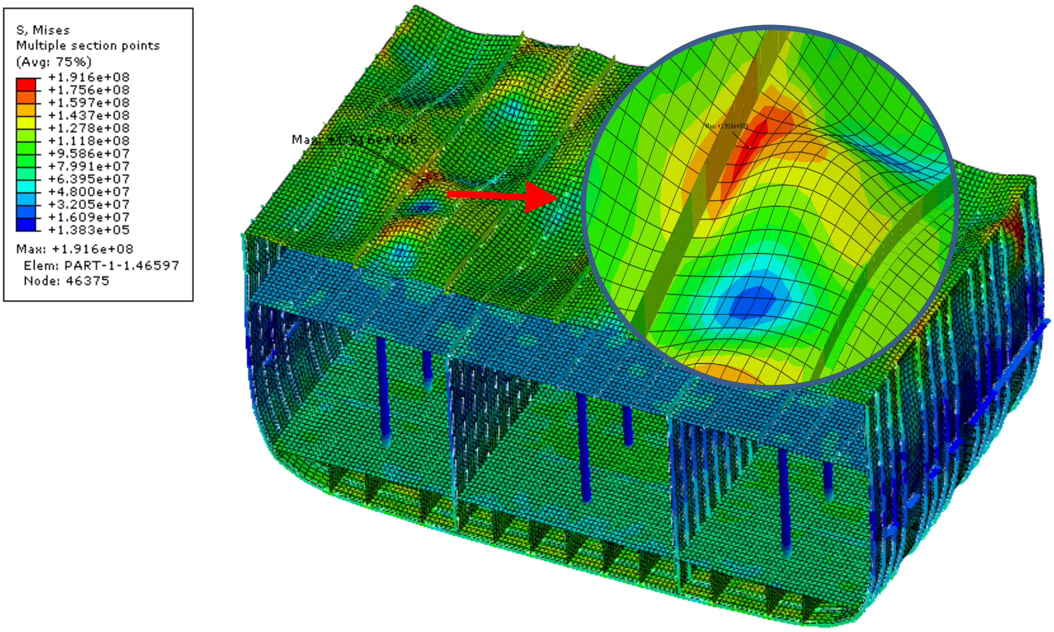


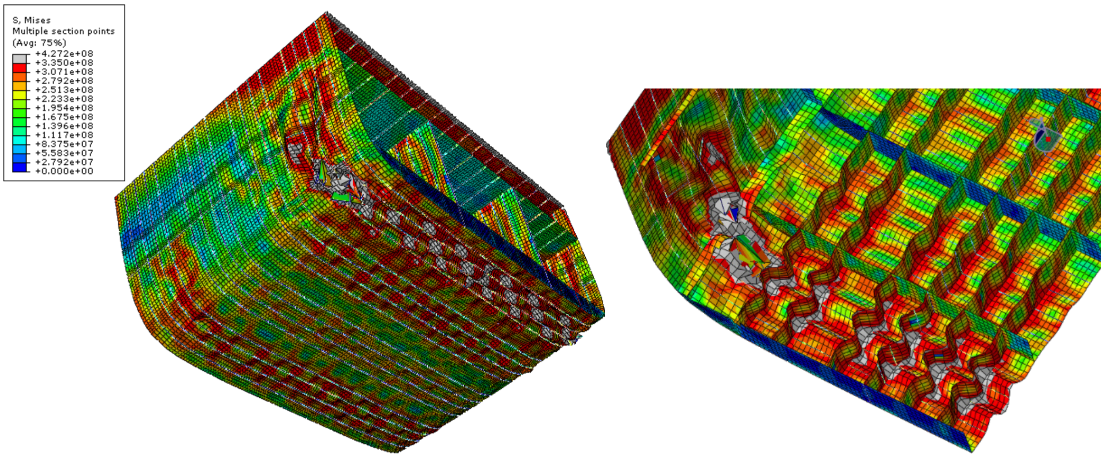
Figure 9 The stress distribution on the sagging condition.

In the wave conditions, the structural analysis have been conducted on the hogging and sagging conditions. The global hogging bending moment have generated the maximum effective stress of 152 MPa. Since the hogging condition generated the maximum positive bending moment load, therefore the maximum effective stress was occurred on the bottom area of the ship, **Figure 8**. Otherwise, the global sagging moment have generated the maximum effective stress of 192 MPa at the upper deck of the ship. **Figure 9** presented that the maximum stress was occurred on the deck plate which is located near to the side deck girder. It is indicated that the high stiffness of the deck girder structure generate the stress concentration while directly connected with the low stiffness plate structure. The additional structure member such as deck transverse, deck beam and deck longitudinal on the connection area can reduce the stress concentration effect. Nevertheless, all of the load condition is still accepted because the acceptance requirement should be below 235 MPa.

Ultimate strength analysis of the roro passenger structure

The primary goal of this research is to investigate the ultimate strength of the roro passenger ship under the combined load in the sagging and hogging condition. The dynamic explicit solver was adopted for the numerical calculation of the progressive collapse of the parallel middle body roro ship structure FE model. The dynamic explicit nonlinear FE analysis was running on the Intel Core™ i7-3770 3.40 Ghz (8 CPUs) and 8 GB RAM. The computational time commonly spend about 10 h on the workstation. To present the effect of the hydrostatic local load on the ultimate strength behavior of the roro passenger. Two kind of load condition have been defined which is with hydrostatic and no hydrostatic pressure. Furthermore, the result of the simulation have been presented on the **Figures 10 - 12**.

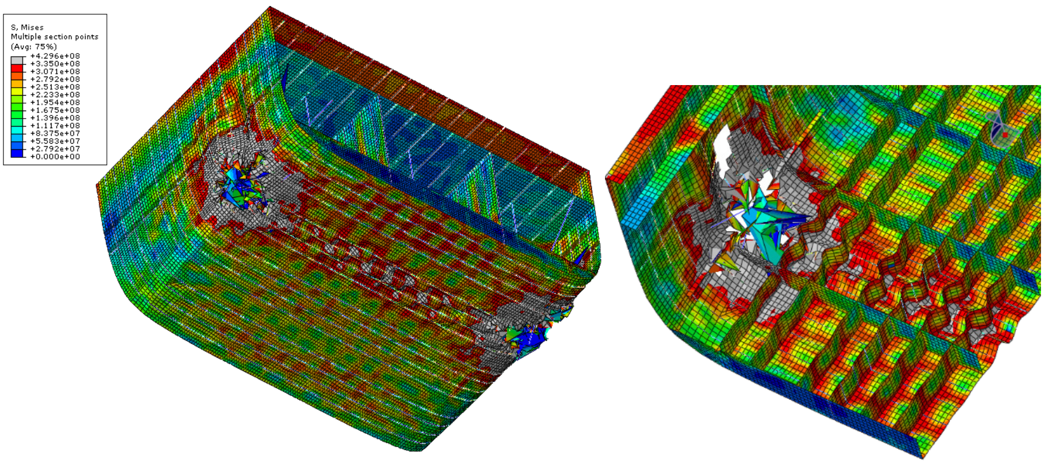
The result presented the deformation of the midship section due to the vertical global bending moment with hydrostatic and no hydrostatic pressure at the ultimate strength load level. All of the simulation have shown that the maximum effective stress have achieved the defined ultimate failure stress around 430 MPa, while the effective stress achieved the maximum limit, the element was deleted by the simulation program. Therefore, it can be found some deleted elements on the simulation model because of the element stress was over the limit of failure stress. Instead of the deleted element, the blue color broken mesh also can be found as the failure element due to the excessive ultimate load.



(a) (b)

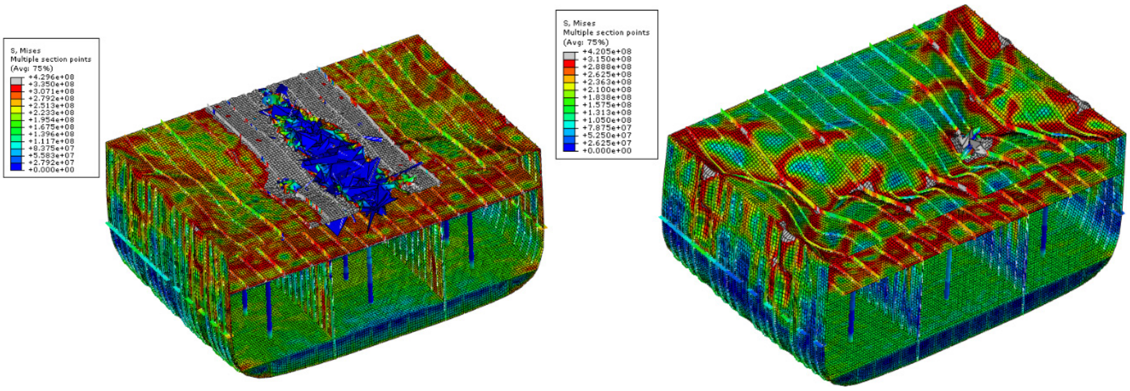
Figure 10 The structural deformation and effective stress distribution on the hogging condition with no hydrostatic pressure at the ultimate strength load level: (a) parallel middle body; (b) girder and bottom structure.

Figure 10 present the severe deformation was occurred on the bottom plate, the bilge streak and the bottom girder. Since the primary structure member have failed, the roro passenger structure have lost its structural strength integrity. The magnitude of the ultimate bending moment load without hydrostatic pressure load have been estimated as large as 817 MNm. As regards to the influence of the hydrostatic load to the ultimate strength, **Figure 11** have presented the deformation of the midship structure due to the global ultimate bending moment and the local hydrostatic pressure. It can be seen that the location of the damage region similar with the no hydrostatic condition. However, the damage area is larger than the no hydrostatic condition. The maximum ultimate bending load have been achieved on 790 MNm.



(a) (b)

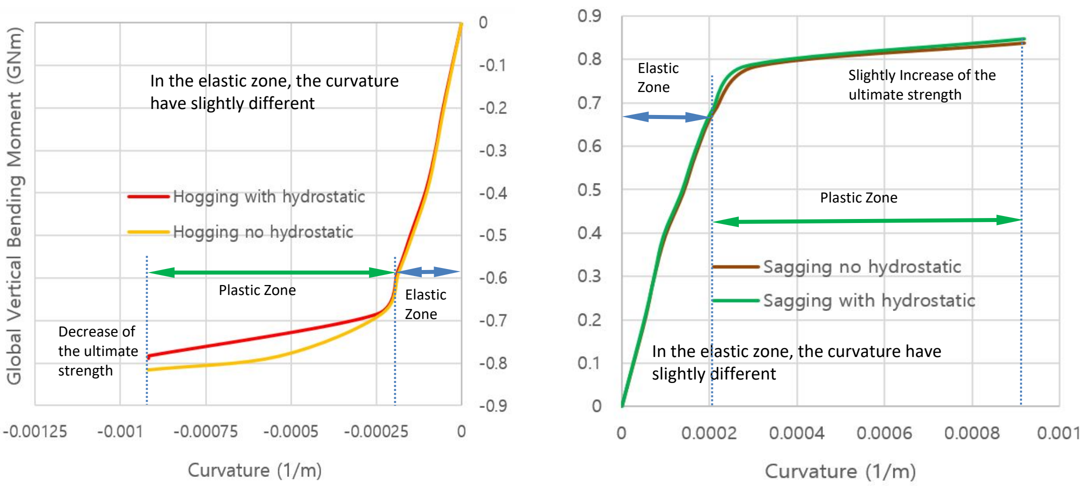
Figure 11 The structural deformation and effective stress distribution on the hogging condition with hydrostatic pressure at the ultimate strength load level: (a) parallel middle body; (b) girder and bottom structure.



(a) (b)

Figure 12 The structural deformation and effective stress distribution on the sagging condition at the ultimate strength load level: (a) no hydrostatic; (b) with hydrostatic.

In the case of sagging condition, the severe deformation can be found on the deck plate, deck girder and deck longitudinals, **Figure 12**. The structural integrity have been lost because of the failure of the deck girder and longitudinals. The magnitude of the ultimate bending moment load without the hydrostatic pressure is 838 MNm. The ultimate bending moment load have been increased as 846 MNm, once the hydrostatic pressure was provided as the local load. Furthermore, the no hydrostatic condition, **Figure 12(a)**, have presented a larger damage area compare to the model with the hydrostatic pressure, **Figure 12(b)**. This behavior can be explained that the hydrostatic pressure have generated the opposite bending moment (hogging direction) of the global bending moment, therefore the hydrostatic have positive contribution on the ultimate strength due to the sagging bending moment.



(a) (b)

Figure 13 The relation of the midship section curvature and the global bending moment: (a) hogging; (b) sagging.

The nonlinear simulation result also presented the relation between the bending moment loads with the midship FE model curvature, **Figure 13**. It can be found that the nonlinear method have capability to capture the plastic zone when the global bending load generated stress over the yield limit. Firstly, the midship model have the linear elastic response. On the hogging condition, the influence of the hydrostatic load do not significantly recognized on the change of model curvature at the elastic zone. After the global bending moment generates the effective stress over the yield limit, the hydrostatic pressure significantly reduced the ultimate strength of the midship model. It is obtained that the ultimate strength have decreased around 33 % than without hydrostatic pressure. The hogging yield limit have been achieved on the global bending moment of 593 and 589 MNm for no hydrostatic and with hydrostatic conditions, respectively.

On the sagging condition, even though the similar structural response was shown on the elastic zone, however it still can be recognized that the hydrostatic pressure have slightly reduced the magnitude of model curvature on the same global bending moment load. The influence of the hydrostatic pressure became apparently recognized on the plastic zone. The ultimate strength have increased about 1 % than without hydrostatic pressure. The sagging yield limit are 687 and 691 MNm for no hydrostatic and with hydrostatic conditions, respectively.

According to the simulation result it can be concluded that the hydrostatic pressure have reduced the ultimate strength on the hogging conditions, otherwise the roro passenger structure have shown similar response with no hydrostatic pressure condition, especially on the elastic zone (below the yield limit). Furthermore, the hydrostatic pressure have slightly increased the ultimate strength on the sagging condition. As regard to the yield limit, it is obtained that the structural response analysis on the still water, hogging and sagging condition still can be identified as the elastic response. Therefore, the structural design of the roro passenger ship is reliable to withstand the global and the local load on the selected sea environment.

Conclusions

The ultimate hull girder strength analysis of the roro passenger ship using nonlinear finite element method has been made. The parallel middle body part of the roro ship structure was selected as finite element model to investigate the structural response and the ultimate strength behavior. The variation of load cases such as still water, sagging, hogging, global, local and combined load were determined during the dynamic explicit simulation analysis. The nonlinear FE analysis of the roro structures presented the results that can be concluded as follow:

The nonlinear FE analysis with the dynamic explicit method is capable to estimate the nonlinear behavior of the roro structures response due to the combined global and local load. The large displacement of the deformed structures as the representation of the geometry nonlinearity, such as the damage of bottom plate and bottom side girder, can be estimated appropriately. The material nonlinearity behavior also can be captured, therefore the elastic and the plastic response due to the incremental combined load can be identified effectively.

The structural response analysis results shows that the maximum effective stress of the roro structural was occurred on the sagging load condition. It is identified that the high stiffness deck girder is directly connected to the low stiffness deck plate might cause a stress concentration that magnify the mean stress level. However, the maximum effective stress still can be accepted by the regulation requirements criteria. Furthermore, the maximum effective stress have been identified as the elastic deformation response on the ultimate strength analysis.

The ultimate strength analysis results shows that the influence of the local load (hydrostatic pressure) have been significantly recognized when the structural response have exceeded the yield limit point (plastic zone). Furthermore, it is also can be found that the ultimate strength have been reduced around 33 % compare to the pure global ultimate bending load, on the hogging condition. Otherwise, the hydrostatic pressure have slightly increased the ultimate strength around 1 % on the sagging condition. This behavior is can be theoretically explained that the hydrostatic pressure have generated the contradictory bending moment to the global bending moment load. Therefore, the hydrostatic pressure have positive contribution on the sagging condition.

The accuracy of nonlinear finite element have been influenced by some factors which is include mesh size, element type, material type model such as the plasticity behavior, damage evolution, fracture strain and displacement at failure. Therefore, the appropriate selection and definition of the factors is very important to conduct an accurate ultimate strength analysis using nonlinear finite element method.

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