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Ultimate Strength Analysis of FPSO Hull Girder Under Longitudinal Bending

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Abstract. Ship and offshore structures have become the key for the development of the offshore world. Production and processing equipment can be placed on a platform, ship and/or barge structure called FPSO (floating, production, storage, and offloading units). The FPSO's hull works like a beam and deforms in the vertical plane. In this case, weight and bouyancy are not normally distributed and wave loading. The most important aspect of FPSO structure is the materials and structural strength used in the design. The critical condition of FPSO is when the structure is under the operation so that the structure needs to be analysed for the design requirement. In the present study, the ultimate strength of FPSO hull girder under longitudinal bending moment is analysed using numerical approach. The nonlinear finite element analysis is adopted to handle the calculation. For the simple case, the one-frame space and the fully cross section of FPSO are modeled. The quadrilateral shell element of the nonlinear method is used for meshing. By performing the boundary condition with the Multi Point Constraint (MPC) is applied where the neutral axis located. The vertical bending moment is also placed at this point (MPC) and it is connected to the all nodes at both sides of the cross sections. The ultimate strength of FPSO is calculated only for intact in hogging and sagging conditions. The ultimate strength analysis is represented in terms of the moment-curvature relationship for hogging and sagging. The result obtained the nonlinear finite element analysis is compared with Smith's method including their collapse behavior. It is found that the comparison result of the ultimate strength is about 8.9% and 10.1% in hogging and sagging condition, respectively. It is shown that the nonlinear finite element analysis is in good aggrement with the analytical solution performed by Smith's method.

1. Introduction

The FPSO's system has become the principle method in offshore oil and gas production sites in the world. Offshore units in the form of ships having a variety of benefits when compared to other types of structures in terms of sufficient work areas, deck load, high storage capability, structural strengths, shorter waiting times, building costs, and suitability for conversion and reuse. However, similar to other floating platform types, the replacement volume below the water line is relatively large, and the response and structural failures under extreme environmental conditions are associated with waves, winds, and significant problems to consider in design and operation. These items must considered for the requirement of strucutral design.

The ultimate strength analysis of ship's hull has been done by many researchers. The asymmetrically damaged ship under sagging condition was investigated by Muis Alie [1]. A plate and/or stiffened plate element at the specified location so-called "critical element" reached its ultimate strength which represent that the hull girder strength also attained the ultimate strength. Tekgoz et al. [2] analyzed a container ship under asymmetrical bending taking the influence of structural damage and associated neutral axis translation and rotation of the residual load carrying capacity. The FE analysis was used and a formulation based on the Common Structural Rules (CSR). The ship was analyzed in intact and damaged condition. The assessment of the ultimate strength for Ro-Ro ship after damage was conducted by Muis Alie et al. [3]. The example of the calculation focused on the cross section. The side shell of the hull and bottom part were assumed to be damaged by simply removing those elements on that part. The result of analytical solution was compared for intact and damage under hogging and sagging conditions.

Kim and Paik [4] expanded a full automated method to optimize design for hull structural scantling of merchant cargo ships and the plate-shell were used for modelling. To minimize the structural weight and maximize structural safety, the technique for full optimization with multi-objectives was used based on the design constraint related to the ultimate limit states of the plate panels, support members and hull girders. The procedure of development was implemented to the hull structure of VLCC, the procedure's capacity is shown by this test for requirement of common structural rules. Gaspar et al. [5] evaluated the influence of the nonlinear vertical wave-induced bending moments on the ship hull girder reliability. A chemical tanker for which the nonlinearity of the vertical wave-induced bending moments was found to be significant was adopted as case study.

Muis Alie et al. [6] used Finite Element Method to analyze the ultimate strength of asymmetrically damaged ships. The collision damage was simply created and remove the elements on that part. The comparison between FE analysis and analytical solution was done including their collapse behavior of ship's hull. Ultimate limit state-based ultimate longitudinal strength analysis was performed by Park et al. [7] to identify the operability of aged non-ice class ships in the Arctic Ocean considering aging. The hull girder ultimate strength was verified by Garbatov et. al. [8] based on the class society and the result obtained by experiment and dimensional theory.

An analytical method was proposed by Gao et. al. [9] for rapidly predicting response of FPSO side structures in case of being struck by a ship with rigid bulbous bow. The proposed was developed by combining several primary failure models of major double shell members, including the plate punching model, the plate perforating model, the plate denting model, the plate tearing model and the X-shaped structure crushing model. The residual strength analysis of ship with bottom damage was conducted by Muis Alie [10] taking the fully cross section into consideration and using the nonlinear finite element method.

In the present study, the ultimate strength analysis of FPSO hull girder is conducted using the nonlinear finite element method. The cross section and one-frame space of the FPSO are taken for the calculation, and those are modeled by 3D finite element method. The model is created by using shell element. Both two sides of the cross section are attached Multi Point Constraint (MPC) and at this point the moment is applied. The result obtained by nonlinear finite element analysis is compared to the analytical solution.

2. Method of Analysis

The shape configuration and properties of the FPSO' cross section are summarized in Table 1, Table 2 and Figure 1, respectively, as follow:

Table 1. Sections properties of FPSO

Items	Unit (N,mm)
Breadth	49987,2
Depth	15849,6
Density	780000

Items	Unit (N,mm)
Yield Strength (*)	315
Elastic Modulus	210000
Poisson Ratio	0,3

Table 2. Stiffener dimensions of FPSO's cross section

Stiffener no.	Dimension	Type	Mark
1	125 x 75 x10	Flat Bar	*
2	250 x 90 + 12 x 16	Flat Bar	*
3	350 x 100 + 12 x 17	Flat Bar	*
4	300 x 90 + 11 x 16	Flat Bar	*
5	1524 x 304,8 + 15,875 x 25,4	Tee Bar	*
6	1270 x 203,2 + 14,288 x 25,4	Tee Bar	*
7	1524 x 304,8 + 15,875 x 25,4	Tee Bar	*

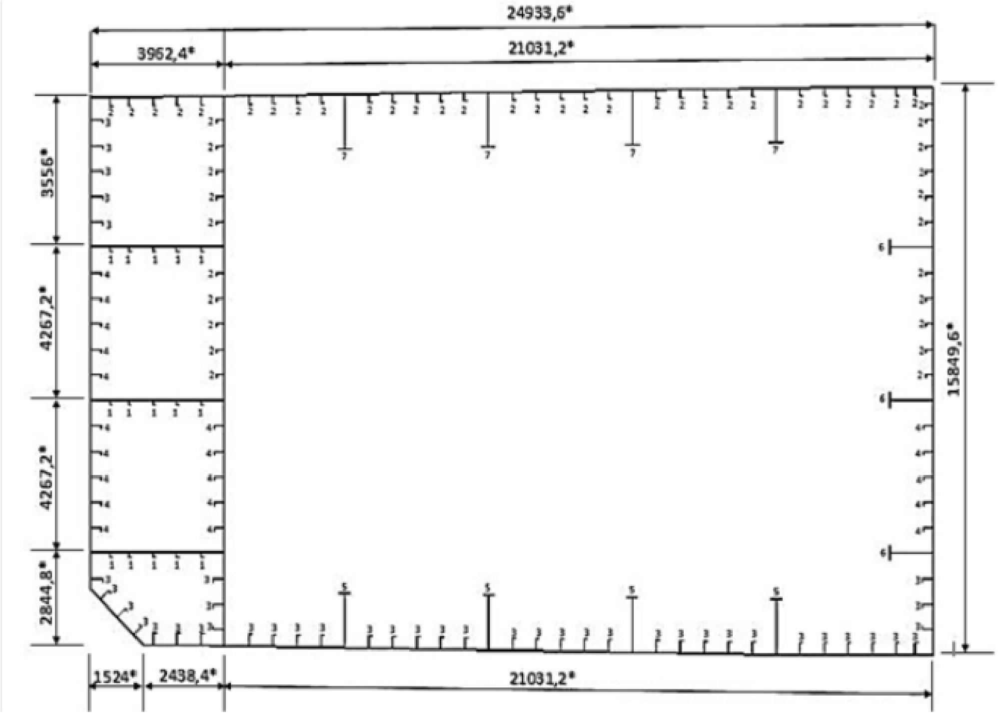

Figure 1. Cross section of FPSO

3. Finite Element Model

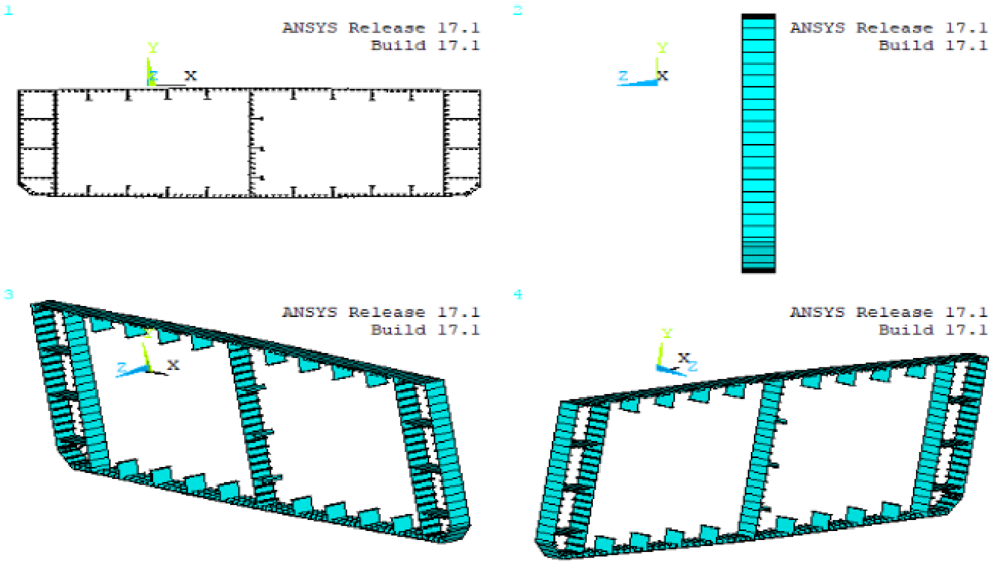

Figure 2. Finite element modeling

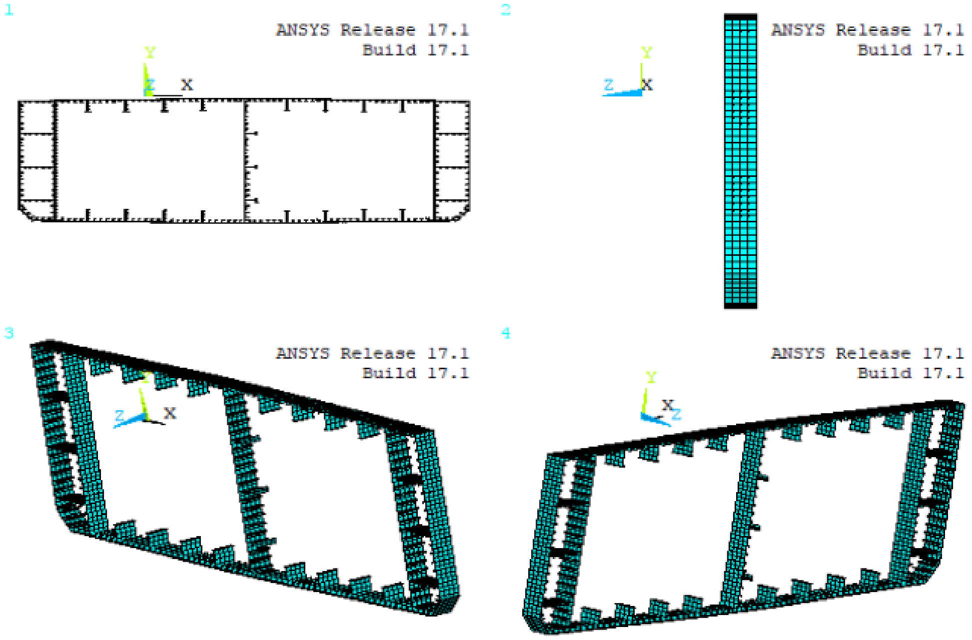

Figure 3. Meshing size

Figures 2 and 3 show the finite element modelling and meshing size together with their coordinate systems. In this model, the shell element type is used and generated to all area. The application of Multi Point Constraint (MPC) can be seen in Figure 4 as follow,

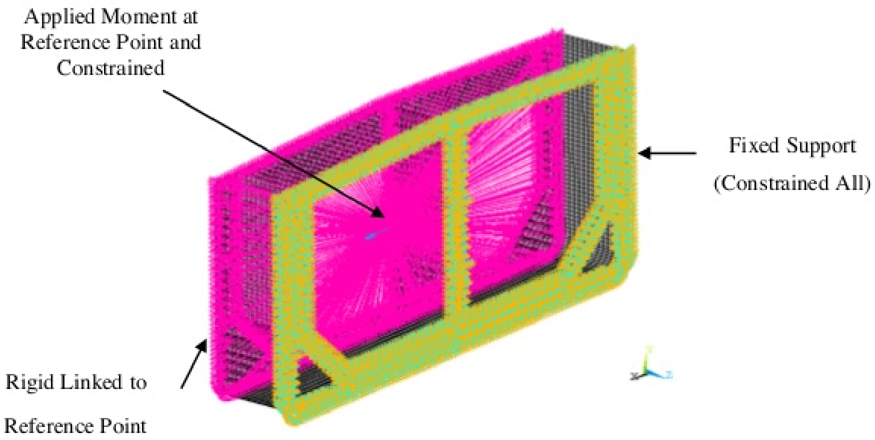

Figure 4. Boundary condition

4. Results and Discussions

Figures 5 and 6 show the stress distributions on the ultimate strength in hogging and sagging conditions, respectively. Tension occurs on deck part when the cross section is under hogging condition. While compression is placed on the bottom part when the cross section is under sagging. MX symbol indicates that value is maximum on that part.

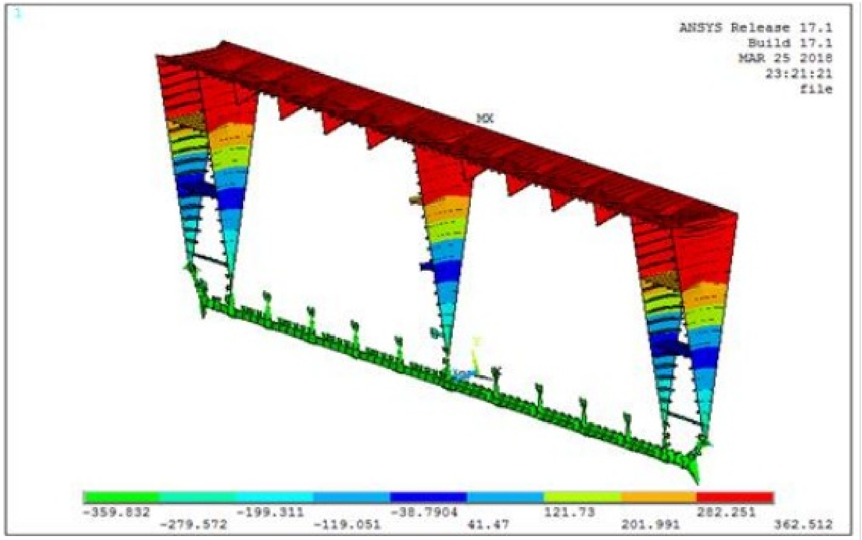

Figure 5. Ultimate strength in hogging condition

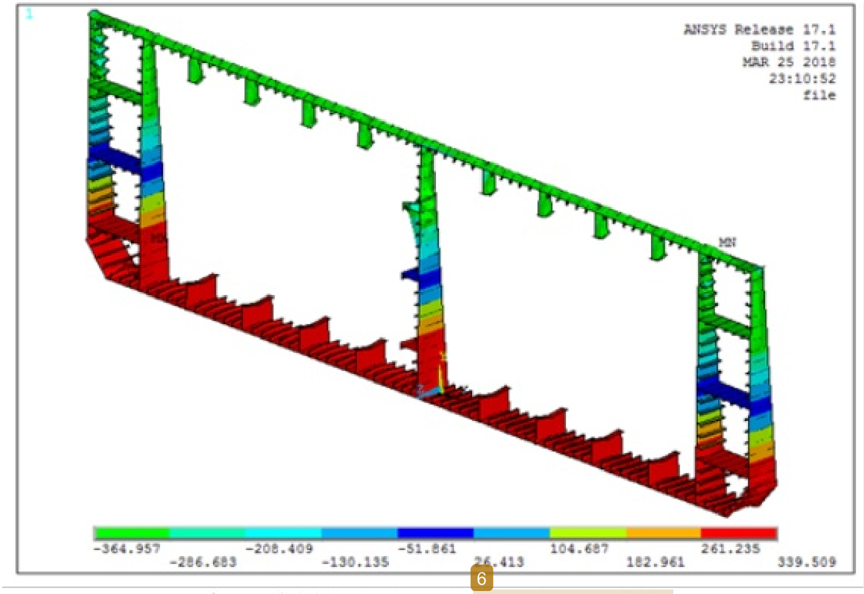

Figure 6. Ultimate strength in sagging condition

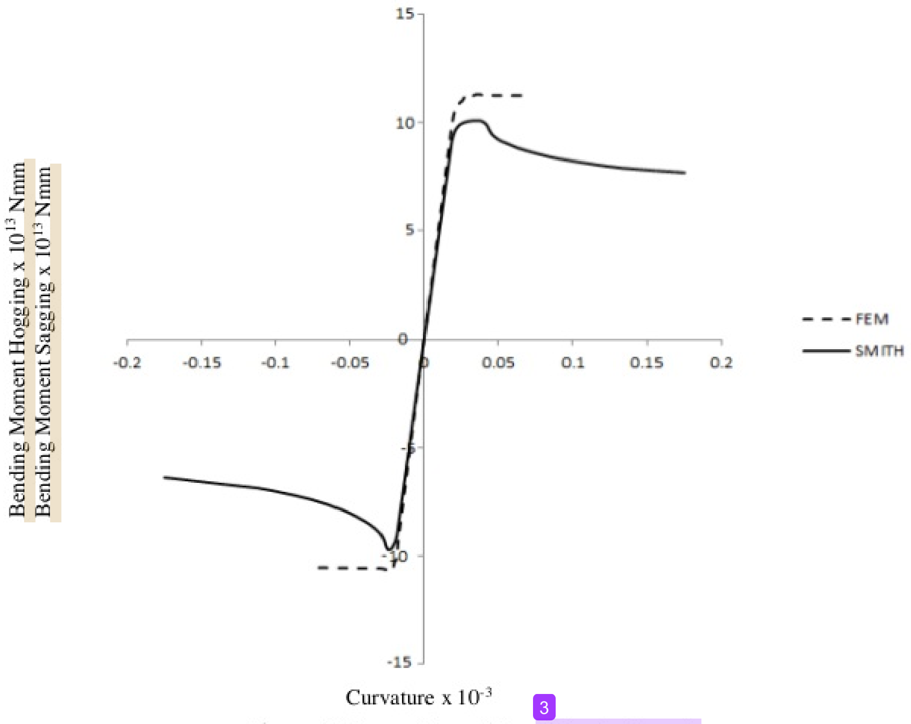

Figure 7. Comparison of the ultimate strength

Figure 7 shows the comparison of the ultimate strength obtained by nonlinear finite element analysis and Smith's method. The ultimate strength for the nonlinear finite element method is represented by the dot line and the solid line for Smith's method. It should be noted that the FE analysis considers many elements to construct the model. Therefore, the stress distribution spreads to all the elements. However, the bending stiffness both two methos are identic. The section modulus between deck and bottom is also different. This is marked by the distance from the neutral axis to deck and bottom. Therefore, generally, this behavior where the ultimate strength in hogging condition is always larger than sagging condition. It is also observed that the ultimate strength in hogging and sagging condition are different due to the redistribution of the stress concentration in the FE model.

5. Conclusion

The ultimate strength analysis of FPSO has been conducted using the nonlinear finite element method, the following conclusion is that the ultimate strength in terms of the moment-curvature relationship obtained by using nonlinear finite element analysis is in good aggrement with the analytical solution performed by Smith's method.

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PRIMARY SOURCES

1	M. Tekgoz, Y. Garbatov, C. Guedes Soares. "Strength assessment of an intact and damaged container ship subjected to asymmetrical bending loadings", Marine Structures, 2018 Publication	%3
2	www.kosori.org Internet Source	%2
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