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# The Ultimate Strength of Double Hull Oil Tanker Due to Grounding and Collision

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**Abstract.** The damaged tanker by grounding and collision may totally collapse if loss its buoyancy, stability and suffer structural failure. The objective of the present study is to investigate the ultimate strength of double hull oil tanker under vertical bending moments due to grounding and collision. The damages are modelled by removing the elements consist of stiffened and unstiffened plates from the damages part. One-frame space of the double hull oil tanker is taken to be analysed. Two damages cases are considered in the analyses those are grounding and collision. The transversal damage extent for grounding are 10%, 25%, 40% and 55%. The groundings are placed at symmetric position on the outer bottom part. For the case of collision, the vertical damage extent are taken as 10%, 20%, 40% and 60%. The transversal damages extent is taken to be B/16 and it is constant for all collision damages. The investigation of the ultimate strength is performed by the Non-Linear Finite Element Analysis method under moment control. The boundary condition is applied with fully constrained on all nodes at the aft-end, while the rigid linked on all nodes is attached at the fore-end with respect to the reference point on the neutral axis. The initial imperfection, welding residual stress and crack are not considered in the analyses. The results obtained by Non-Linear Finite Element Analyses for the ultimate strength are compared with the in-house program using Smith's method implemented in HULLST. The stress distribution and deformation for every case of damages including intact are also discussed in the present study.

## 1. Introduction

The grounding and collisions experienced by the ships are the two biggest contributing factors of the 12591 maritime incidents occurring in 2011-2015 [1]. The ships damaged may experience the total collapse if lose stability and buoyancy and constructional failure. Based on constructional failure, it is important to investigate the ultimate strength of bending moment of the ship. The Non-Linear Finite Element Analysis (NLFEA) method is very accurately and recommended by the classification and many researchers to calculate the ultimate strength of ships were complex structures.

Many researches have been done regarding to ultimate strength analysis of ships damaged by grounding and collision. Jiang *et al* [2] performed finite element analysis to investigate the residual strength of ship hulls due to collisions and grounding, with comparing two models of damage. The first form of damage is a hole with adjacent plastic deformation and the second by removing the damaged frames. Luis *et al* [3] analyzed the reliability of double hull Suezmax tankers damaged by grounding. The damage is assumed to occur in the middle of the keel and simulated by removing damaged elements. Various measures of damage were analyzed and linked to reliability indices related



to bilge ultimate strength. Muis-Alie [6] analyzed the residual strength of unsymmetrical damaged bilge hulls in the effect of longitudinal bending using a beam method adopted for testing of residual strength of two bulk carriers (Ship B1 and Ship B4) and a three-hold-model bulk carrier with a single hull Panamax type under hogging and sagging conditions. Muis-Alie *et al* [8] used Smith's method to analyze the residual strength of bulk carrier and tankers who suffered collision damage. Paik *et al* [9] developed a procedure for identifying the possibility of hull girder failure after collision and grounding based on the closed-form formulae of hull girder strength and cross-sectional modulus after damage. Muis-Alie [7] analyzed the effect of asymmetric damage on a bulk carrier type Panamax using finite-element analysis of DYTRAN.

Based on the background, as a follow-up of the Muis-Alie [8] research, this study aims to investigate the ultimate strength of damaged tanker by grounding and collisions using the NLFEA method. The results from this study will be compared with the Smith's method.

### Method of Analysis

In the present study, The Non-Linear Finite Element Analysis is used coded by ANSYS [10]. The double hull oil tanker [8] which is 114 m in length, 44 m of breadth and 22.1 m in depth. The cross sectional and material properties of double hull oil tanker as shown in Figure 1.

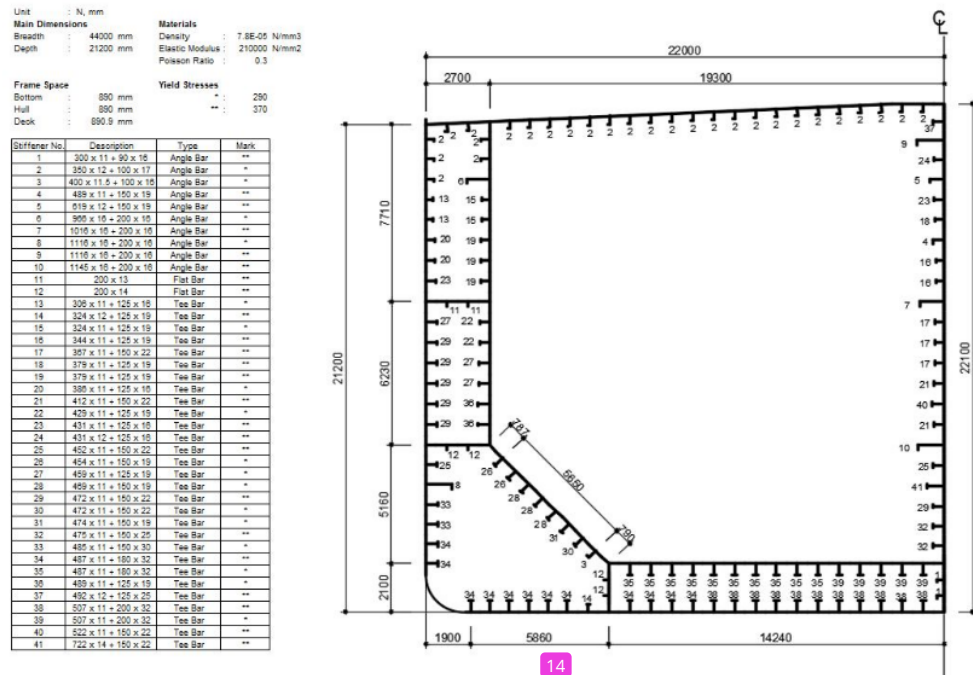
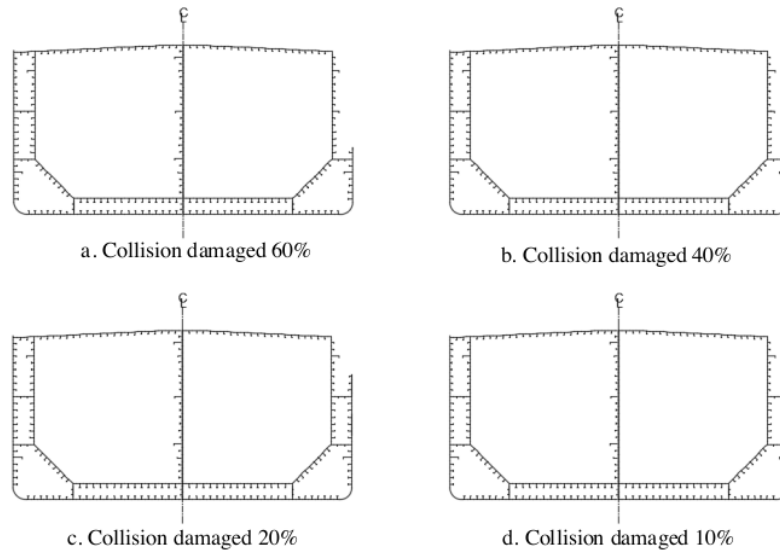


Figure 1. The cross sectional of double hull oil tanker.

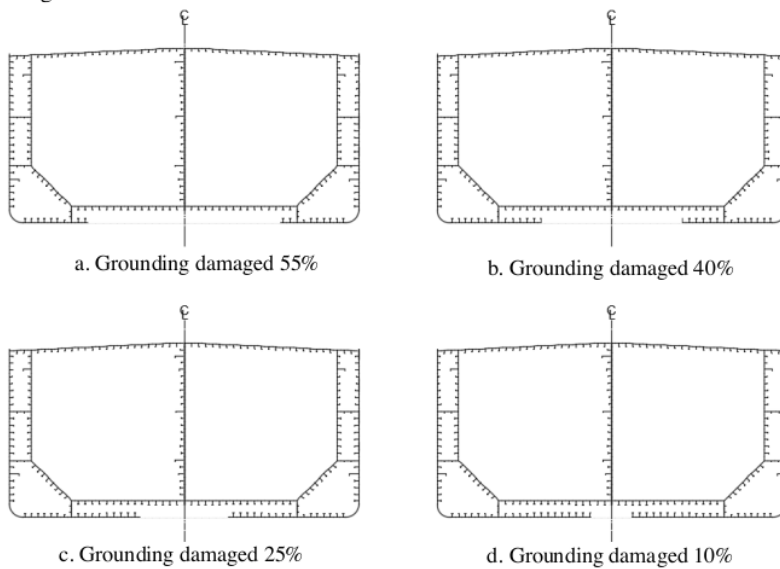
The grounding and collision damages are assessed for the ultimate strength of bending moment using ANSYS [3].

The grounding and collision damages are simulated based on DNV [5]. The percentage of collision damage are taken as 10%, 20%, 40% and 60%. The transversal damage extent is considered to be  $B/16$  and it is constant for collision damages. The element composed of plates and stiffened plates for the damage part are removed as illustrated in Figure 2.



**Figure 2.** Tanker's cross sectional configuration due to collision.

For the case of grounding, the damages are taken as 10%, 25%, 40% and 55%. The damages are placed at symmetric position at the outer bottom part. The vertical damage extent is 1/20 of the width of the vessel or two meters (whichever is smaller) and damage breadth by 10% of the breadth of the ship. Similarly, all the elements consists of plates and stiffened plates of the damage part are also removed as shown in Figure 3.



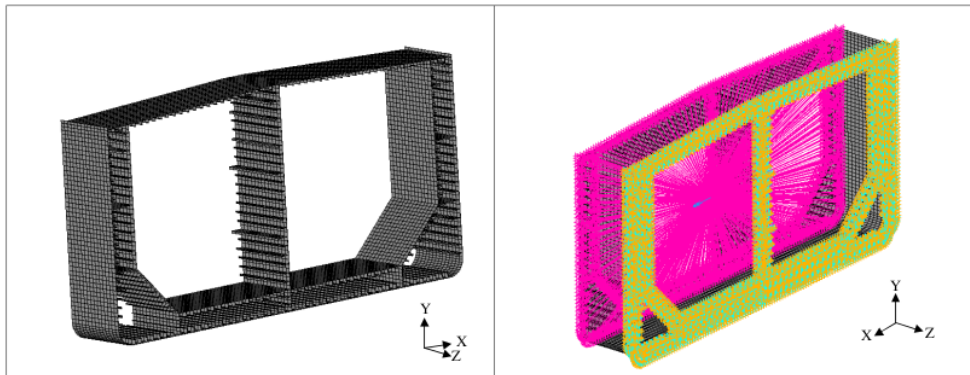
**Figure 3.** Tanker's cross sectional configuration due to grounding.

The 3D of the finite element model is created by using shell element type 181 with configuration and material specifications for each element as shown in Figure 4. After that, the material properties value for each element is included in Table 1. The size of mesh is 500 mm and it is applied for whole model.

**Table 1.** Material properties.

Material Properties	Type of Materials	
	AH27	AH36
Density (kg/m <sup>3</sup> )	7850	7850
Modulus Young (N/mm <sup>2</sup> )	210000	210000
Poisson's Ratio	0.3	0.3
Yield Strength	290	370
Tangent Modulus	625	675

In the present study, the ultimate strength is analysed under moment control process in order to know the progressive collapse of double hull oil tanker before and after damage. The boundary condition is applied to the overall end point of the back model is a full constraint. There is no loading applied at the reference point. The fore end of section model at the neutral axis reference point, the bending moment of  $1.6 \times 10^{13}$  Nmm is given. Then, all nodes at the fore-end are rigidly linked to the neutral axis reference point. The illustration of boundary condition and loading as shown in Figure 4.



**Figure 4.** Modelling and boundary condition of double hull oil tanker hull girder by NLFEA.

The Non-Linear Finite Element Analysis (NLFEA) used static analysis by arc length method to get the ultimate buckling and post buckling value from the structure. The ultimate bending strength then evaluated and compared using previous research conducted by Muis-Alie *et al* (2012).

### 3. Results And Discussion

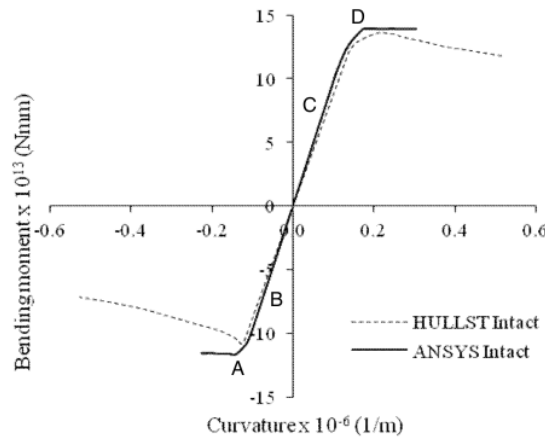
Table 2 shows result of the ultimate bending moment strength calculated at each percentage of damage in both sagging and hogging conditions using NLFEA. Prior to the damage, the ultimate strength of double hull oil tanker's obtained as  $1.38983 \times 10^{13}$  Nmm under hogging conditions and  $-1.17019 \times 10^{13}$  Nmm under sagging conditions.

**Table 2.** The ultimate bending strength of double hull oil tanker (in Nmm).

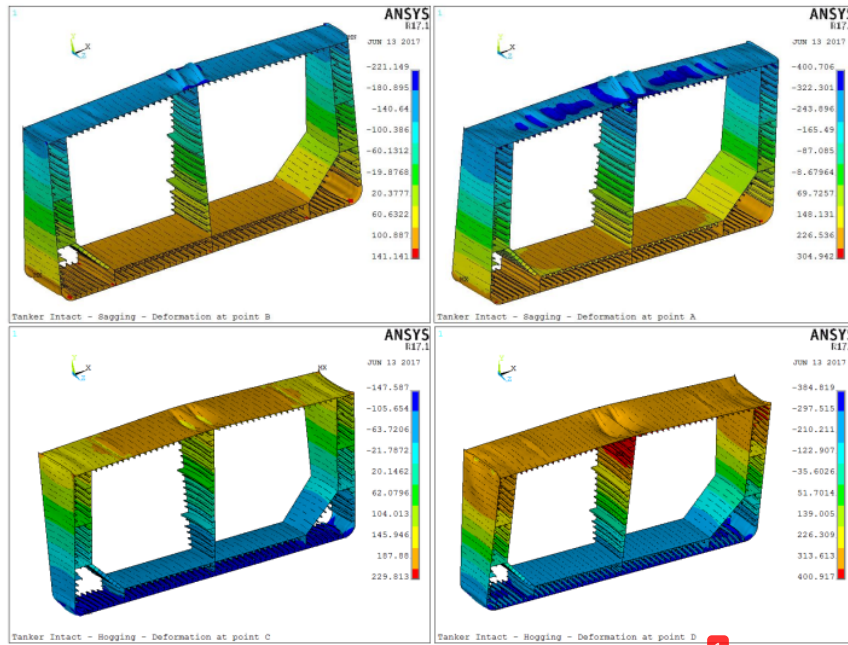
Condition of tanker		Ultimate bending strength x 10 <sup>13</sup>		Ratio
		Smith's Method	NLFEA	
Intact	M <sub>u</sub> - Hogging	1.3632	1.38983	1.0195
	M <sub>u</sub> - Sagging	-1.07898	-1.17019	1.0845
Collision 10%	M <sub>u</sub> - Hogging	1.3181	1.3879	1.053
	M <sub>u</sub> - Sagging	-1.0212	-1.0513	1.029
Collision 20%	M <sub>u</sub> - Hogging	1.2956	1.3243	1.022
	M <sub>u</sub> - Sagging	-0.99470	-1.04204	1.048
Collision 40%	M <sub>u</sub> - Hogging	1.2789	1.3214	1.033
	M <sub>u</sub> - Sagging	-0.97931	-0.98724	1.008
Collision 60%	M <sub>u</sub> - Hogging	1.2701	1.2723	1.002
	M <sub>u</sub> - Sagging	-0.97285	-0.98190	1.009
Grounding 10%	M <sub>u</sub> - Hogging	1.3181	1.3864	1.052
	M <sub>u</sub> - Sagging	-1.0672	-1.1521	1.079
Grounding 25%	M <sub>u</sub> - Hogging	1.2524	1.3532	1.080
	M <sub>u</sub> - Sagging	-1.0486	-1.1256	1.073
Grounding 40%	M <sub>u</sub> - Hogging	1.2025	1.2561	1.045
	M <sub>u</sub> - Sagging	-1.0319	-1.0635	1.031
Grounding 55%	M <sub>u</sub> - Hogging	1.1309	1.1563	1.022
	M <sub>u</sub> - Sagging	-1.0065	-1.0123	1.006

In hogging conditions, the ultimate strength of damages due to grounding is significantly decreased. This occurs because the breakdown of the element in the bottom causes the compression force on the bottom not to be massively supported by the bottom structure. At grounding with 60% of damage, the ultimate strength decreases from 16.8% to 1.1563 x 10<sup>13</sup> Nmm, whereas at 55% collision damage, the ultimate bending strength decreases from 8.46% with 1.2723 x 10<sup>13</sup> Nmm.

In the sagging condition, the greatest the ultimate strength occurs under the collision damage condition. The ship wall damages due to collision resulted neutral axis position becomes not symmetrical. Unsymmetrical neutral axis makes the distance of the point of damage to the neutral axis becomes greater. This causes the working stress on the damaged part becomes greater. At grounding 60%, there was a decrease of the ultimate strength value of 13.49% to -1.0123x10<sup>13</sup> Nmm whereas at collision 55%, there was a decrease of the ultimate bending strength value of 16.09% to 0.9819x10<sup>13</sup> Nmm.

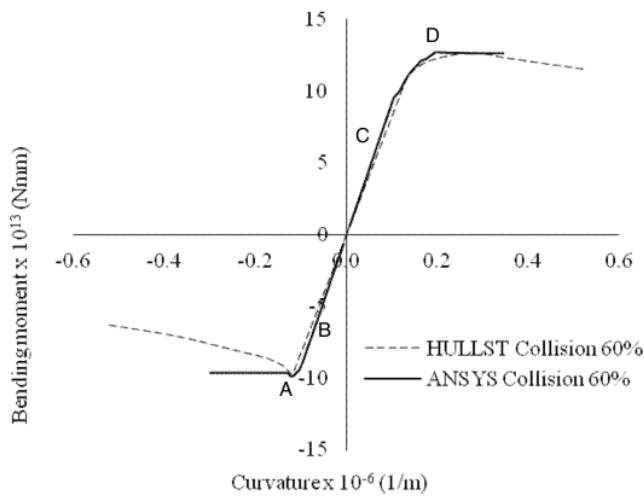


**Figure 5.** Moment curvature in intact condition

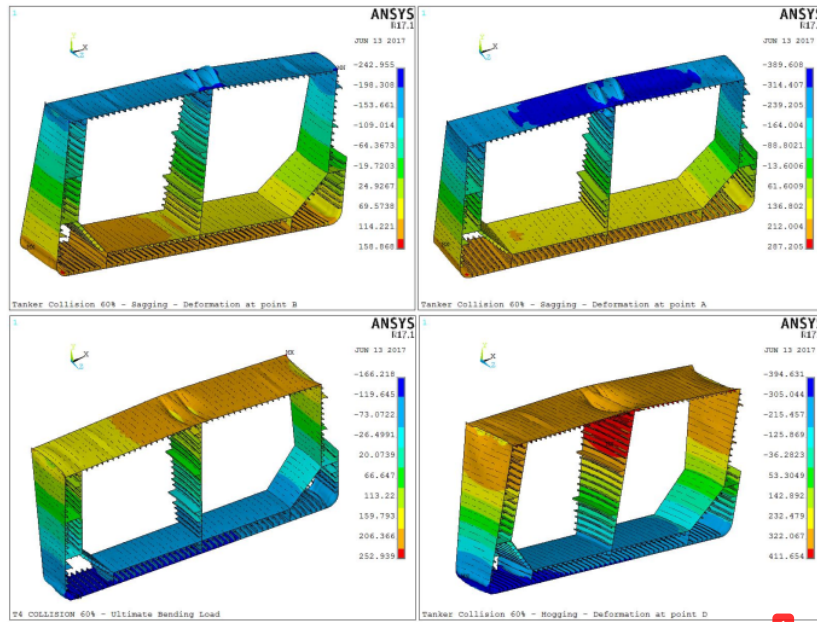


**Figure 6.** The behaviour and stress distribution of intact tanker structure at the ultimate bending strength in sagging and hogging condition.

Figure 5 shows the comparison of the ultimate strength obtained by Smith’s method (HULLST) and NLFEA methods in intact condition. The ultimate strength obtained by NLFEA is greater as 1.95% for hogging and 8.45% in sagging conditions rather than the Smith’s method. The stress distribution at the ultimate bending strength of double hull oil tanker for intact is showed in Figure 6.

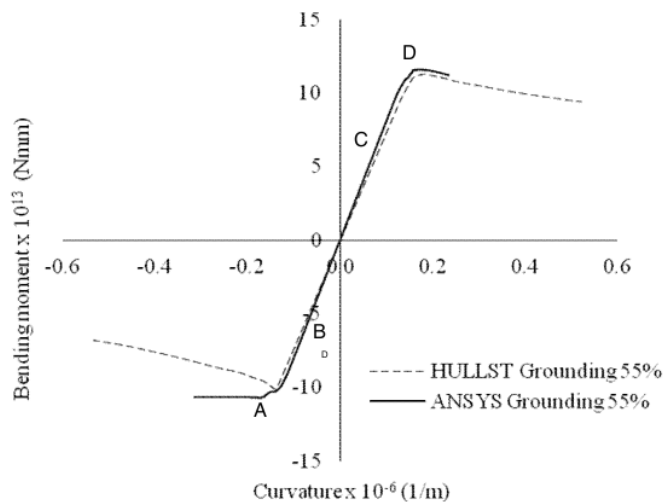


**Figure 7.** Moment curvature in collision 60% condition.

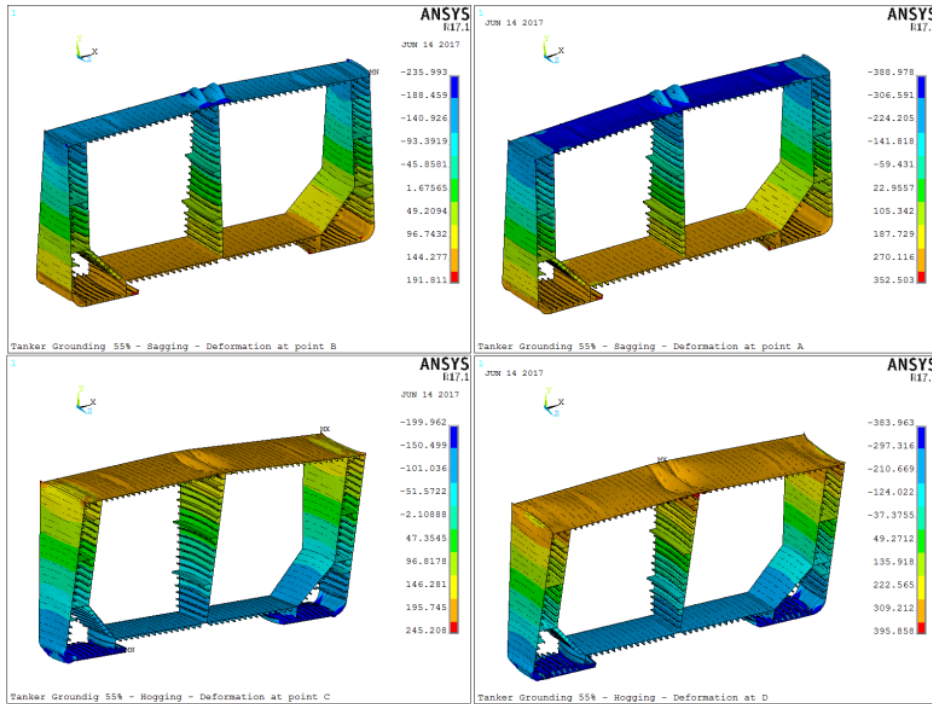


**Figure 8.** The behaviour and stress distribution of collision tanker structure at the ultimate bending strength in sagging and hogging condition.

Figure 7 shows the comparison of the ultimate strength obtained by Smith's method and NLFEA methods at 60% collision damage condition, the ultimate strength obtained by NLFEA is greater 0.2% in hogging condition and 0.9% in sagging condition than Smith's method. The stress distribution at the ultimate bending strength of double hull oil tanker for collision tanker is shown in Figure 8.



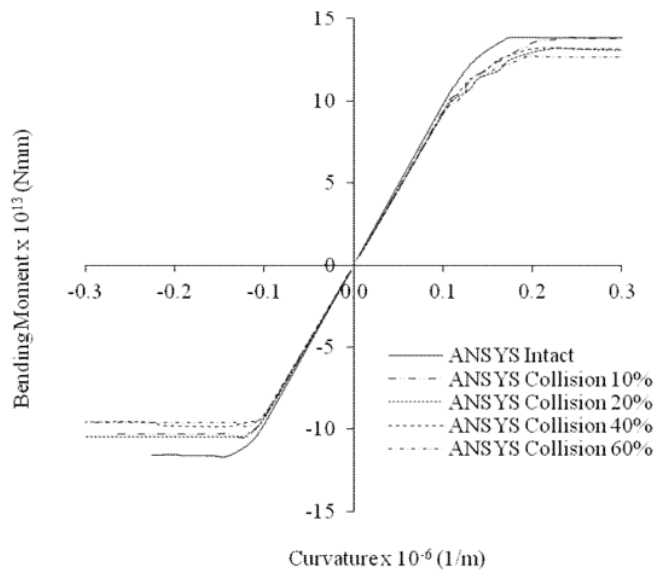
**Figure 9.** Moment curvature in grounding 55% condition.



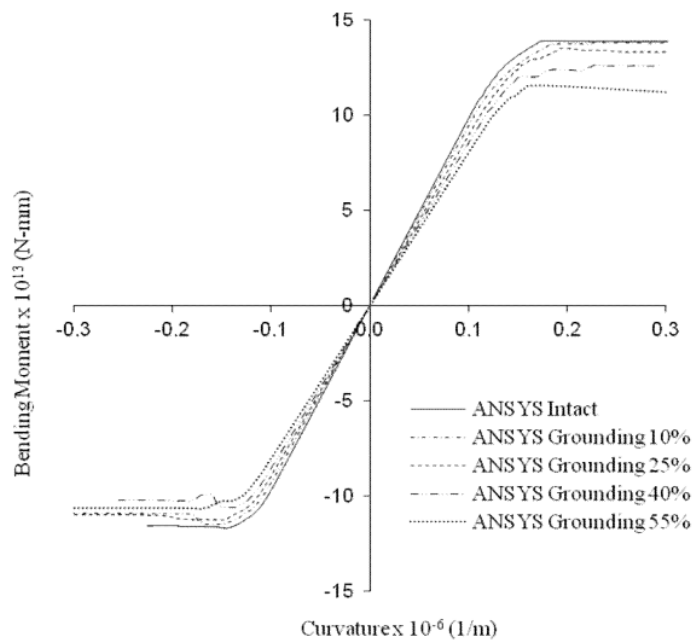
**Figure 10.** The behaviour and stress distribution of grounding tanker structure at the ultimate bending strength in sagging and hogging condition.

Figure 9 shows the comparison of the ultimate strength obtained by Smith's method and NLFEA methods for 55% damage conditions, the ultimate strength obtained by NLFEA is greater 2.2% in hogging conditions and 0.6% in sagging conditions than in the Smith's method. The stress distribution at the ultimate bending strength of double hull oil tanker for grounding is illustrated in Figure 10.

Figures 11 and 12 show the accumulation of the ultimate strength of bending moment-curvature relationship for damages conditions due to grounding and collision for hogging and sagging. The ultimate strength of double hull oil tanker decreased by the increasing the percentage of damage. The ultimate strength of double hull oil tanker is larger in hogging conditions because the bottom has a massive structural configuration that can withstand compressive forces better than structural configurations in the deck part. After the structure reaches the peak of the ultimate strength, the trend of the moment-curvature relationship tends to decrease until it reaches the point of collapse because the structure has become plastic, so that when buckling takes place the structure cannot return to its original shape.



**Figure 11.** Moment curvature in intact and collision tanker.



**Figure 12.** Moment curvature in intact and grounding tanker.

#### 16 4. Conclusions

The Nonlinear Finite Element Analysis (NLFEA) method<sup>15</sup> investigate the ultimate bending strength of a double hull oil tanker due to grounding and collision under vertical bending moment is conducted in the present study. The following conclusions can be drawn:

- a. The increased of damaged percentage of the hull girder effects on the increase of working stress and decreased for the ultimate bending strength of the hull girder.
- b. Damage caused by grounding and collision indicates that the structure still has a bending moment strength greater than the external bending moment. Based on this, the ship is totally collapsed on 55% and 60% of grounding and collision, respectively.
- c. The result obtained by NLFEA for the ultimate strength is in good agreement with the Smith's method implemented in HULLST.

The behaviour of double hull oil tanker obtained for this research can be developed for future works such as: ship strength analysis due to weld cracking at critical part in ship structure, analysis of ship's residual strength due to grounding and collision and ship strength analysis due to torsion load and load combination.

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