A compared study of the shape's plate behaviour under the impact load

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Abstract. A major stage in the naval design is to establish the structural resistance of the ship body. Non-linear FE analysis methods are used for determination the hull’s structural capacity. The plates and the beams are important constructive elements of the ship structure. This paper presents a compared study of the impact analysis of the plates with different curvature. Both non-linear static and dynamic analysis are made to understand the structural behaviours of the plates. It deals with determining the deformations and stresses obtained from implicit static and explicit dynamic analysis. In order to evaluate the influence of shape plate on structural behaviour, the energy dissipation is observed by calculating the absorbed energy. The main results will be used in the process of optimisation the ship body’s shell shape.

1. Introduction

Recently, more attention has been given to a vessel’s structural resistance to an accident Many international codes, as DNVGL one, included structural analysis in their requirements and that is the reason why this modern design become more attractive against experimental one, that is more expensive due its financial costs. Mathematical model that describe physical model, as stress-strain curve that simulate material behavior, are develop for computational purpose and improving design process.

Sadowski et al [1] shows in his paper on structural carbon steel, that tangent modulus is an important parameter that has influence on analysis results. Also geometrical shape is important and Sadowski et al [2] observed in his experiments that tangent modulus of curve specimen is greater than the flat one. The characterisation of material model allows obtaining data that are used, as parameters, in non-linear FE analysis from important fields, as shipbuilding design. Shape analysis is important subject both in hull and propeller design as mentioned by Nechita et al [3]. Energy calculation method is used for predicting hull’s structure damages. In shipbuilding design impact problems considers external and inner dynamics analysis of the ship structure. Mechanical tests are done for modelling inner impact mechanism, as Alsos and Amdahl [4]. They presented in their paper results and discussion of experimental impact analysis on the resistance to penetration of stiffened flat plates. Elastic-plastic steel material with kinematic hardening is used in Kajaste-Rudnitski et al [5] paper for modeling of plate’s shell behavior.

Our study develops a research that uses non-linear FE analysis on curve plates with a simple curvature. The material behaviour was modelled with piecewise material model. The non-linear explicit transient analysis described the dynamic impact process. The results are analysed against
experimental one, mentioned by Balan et al [6]. Simulation and pre-post processing are made with Nastran NX and Femap 11.4.2 FE software. A non-linear static analysis is done for calibrating the model against DNV-RP-C208 code [7]. Conclusions of our compared study shows that piecewise material model can describe process at low forces and the curvature of the plate effects on its dynamic response under impact loads. A compared analysis of the models’ string energies shows that curvature influences on the analysis values. During FE simulations was observed that tangent modulus directly influences on the stress value and this phenomenon will be analysed in our future research.

2. Theoretical aspects
Sadowski et al [1] argues in his paper that knowledge about yield plateau and tangent modulus is important for a safe characterisation of the post-yield material behaviour. A modern design includes tangent modulus, $E_h$, as an input parameter, and structural analyst have to consider it in his particular choice of material behaviour for a rigorous analysis.

Three distinct regions are observed in figure 1 and figure 2, which described the engineering stress-curve for structural carbon steel, in qualitative and idealised manner [2].

![Figure 1](image1.png) Qualitative characterisation of a typical engineering stress-strain curve for structural carbon steel (after Sadowski et al [2]).

![Figure 2](image2.png) Idealisation of stress-strain curve including strain hardening for design and computational purpose (after Sadowski et al [2]).

In our paper we use S235 steel and calculate tangent modulus, $E_{pl}$, as a value of 0.1% of the nominal elastic modulus, $E$, in respect with European Standards EN 10025 mentioned in DNV-RP-C208 code [7], valid for marine structure made from structural steel with a yield strength up to 500 MPa.

3. Non-linear FE analysis
The analysis of internal mechanism of impact event can be done with simple formulae, simplified analytical approach, simplified FEM and non-linear FEM simulation. Kujala and Pedersen [8] summarized the advantages and disadvantages of these methods.

The aim of our study is to describe the impact effect on curve plate using non-linear FE analysis, build on knowledge that is experimentally based on models with a geometry presented in figure 3. We consider, as data input for our analysis, the results obtained in experiment shown in figure 4. It is seen the experimental stand that contains model of steel plate and steel ball. Aramis HS optical tool was
used for measuring deformation and displacements during the impact test. An impact force was
detected by the accelerometer with value of 1950 N, as mentioned Balan et al. [6]. The tests results are
recorded in table 1.

Figure 3. Axial sections of the models 1 and 2 (after Nechita et al [3]).

Figure 4. Aramis HS GOM (after Balan et al [6]).

Table 1. Displacements experimental values under impact with F=1950 N.

| Model | Displacements (mm) |
|-------|--------------------|
| 1     | 5.01               |
| 2     | 4.22               |

Analyses are made with NX Nastran Femap 11.4.2 FE software, which includes non-linear material
behaviour and non-linear geometry.

A non-linear static analysis was made, in a preliminary phase of this design, for defining material
model and mesh density of the structure, and calibrates the computational model against DNV-RP-C208 [7], that mentioned the parameters characteristic to stress-strain curve, as is seen in figure 5.

The dynamic response of the model’s structure analysis was obtained as output of non-linear explicit
transient analyses.
The material properties used both in experimental tests and numerical analyses are shown in table 2.

![Diagram of stress-strain curve]

Figure 5. Parameters to define stress-strain curve (after DNV-RP-C208 [7]).

It contains S235 steels values for elastic modulus, $E$, shear modulus, $G$, coefficient for calculating tangent modulus, $E_{pl}$, from elastic modulus, Poisson coefficient, $\nu$, yield strength, $\sigma_{yield}$, ultimate strength, $\sigma_{ult}$, material density, $\rho$, in respect with DNV-RP-C208 code [7]. The software calculated the plastic modulus.

Table 2. S235 steels non-linear properties.

| E (MPa) | G (MPa) | $E_{pl}$ | $\nu$ | $\sigma_{yield}$ (MPa) | $\sigma_{ult}$ (MPa) | $\rho$ (kg/m$^3$) |
|---------|---------|---------|-------|------------------------|----------------------|-------------------|
| 210     | 79      | 0.001   | 0.3   | 235                    | 360                  | 7850              |

3.1. Non-linear static analysis
In a non-linear static analysis, the applied load is incremented in a static solution, using implicit Newton Raphson method. Plate element type with 3 mm thickness and Kirchhoff's shell plate formulation is set. Mesh size was 4-8 times greater than the thickness of the plate and its value was taking into account the model's geometries from Nechita et al [3]. The analysis results recorded in table 3 show that the concordance with experimental analysis is satisfactory for the value of the impact point displacement. The Von Mises stress obtained are in respect with DNV-RP-C208 code [7].

Table 3. Models static responses under impact with F=1950 N.

| Model | Displacements (mm) | Von Mises stress (MPa) |
|-------|--------------------|------------------------|
| 1     | 4.88               | 235                    |
| 2     | 4.65               | 235                    |

3.2. Non-linear explicit transient analysis
The explicit solution is stable if the analysis time step is sufficiently small to catch the impact moment. For shells it depends on element size and the speed of sound in the material.
4. Results and discussion

The numerical dynamic analysis results are studied against experimental analysis output. It is seen in table 5 that displacements of impact point from numerical values are very close with the experimental one, in an acceptable range, as 4.39 for model no.1 and 8.05 for model no. 2.

Table 5. Comparison of experimental and numerical displacements (mm).

| Model | Experimental | Numerical | Dif. (%) |
|-------|--------------|-----------|----------|
| 1     | 5.01         | 4.79      | -4.39    |
| 2     | 4.22         | 4.56      | 8.05     |

The influence of plate’s shape on structural analysis is observed in table 6. We can see that the model no. 2 with a small curvature diminishes the Von Mises stress and the displacement in impact point.

Table 6. Dynamic responses of model 2 against model 1 under impact load.

| Dynamic response | Model 1 | Model 2 | Dif. (%) |
|------------------|---------|---------|----------|
| Displacements (mm) | 4.79    | 4.56    | -4.80    |
| Von Mises stress (MPa) | 225.377 | 203.294 | -9.79    |

The dynamic response of model no.2 against model no.1 under impact load is presented in figure 6 where is observed that percentages for Von Mises stress are greater than the displacement one and its dynamic have influence on displacements trend line.

Energies values are important reference in impact assessment. Elastic energy was ignored and string energy for both models was calculated and presented with its trendline in figure 7. It shows that model...
no.2 receives more string energy (5.006 J) than model no.1 (4.851 J) under impact load, being a strengthen structure.

Figure 7. Comparative analysis of the string energy during impact.

5. Conclusions
The paper focuses on structural analysis of curve plate behaviour under impact. The results of the numerical analysis against experimental analysis shows that piecewise material model offers a good description of impact mechanism under low forces, the numerical values being near to experimental ones. In numerical analysis the mesh size and the time step values assures simulations accuracy.

The shape of curve plate has influence on material behaviour. Increasing the design radius with 6% reduces the Von Mises stress and displacement, with 9.79% respectively 4.80%. The Von Mises stress varies more quickly that the displacement ones.

It is observed that tangent modulus influences Von Mises stress values and our future work will deal on influence of different geometries on strain values under impact load.

6. References
[1]  Sadowski A J, Rotter J M, Stafford P J, Reinke T and Ummenhofer T 2017 On the gradient of the yield plate in structural carbon steel J. of Constructional Steel Research 130 120
[2]  Sadowski A J, Rotter J M, Stafford P J, Reinke T and Ummenhofer T 2015 Statistical analysis of the material properties of selected structural carbon steel Structural Safety 53C 26-35
[3]  Nechita M, Mocanu C I and Popescu G 2013 Constanta Maritime University Annals 19 125-7
[4]  Alsos S H and Amdahl J 2009 On the resistance to penetration of stiffened plates, Part 1-Experiments Int. J. Impact Eng. 36 799
[5]  Kajaste-Rudnitski J, Varsta PM and Matusiak J E 2005 Some finite element estimates of ship collision event Int. Congress of Int. Maritime Assoc. of the Mediterranean (Lisboa, Portugal, 26-30 September 2005) 447-453
[6]  Balan M, Lavrente D, Nechita M, Muscalu A and Mocanu C I 2012 Proc. of the 16th Int. Conf. Modern Technologies Quality and Innovation (Sinaia, Romania, 24–26 May 2012 2) (Iasi: ModTech Publishing House) 69–72
[7]  DNV 2013 Recommended Practice-Determination of structural capacity by non-linear FE analysis methods (Hovik: Det Norske Veritas AS) p 19
[8]  Wang G and Spong R 2003 Experience based data for FPSO’s structural design Offshore Technology Conference (Houston, USA, 5-8 May 2003) (Offshore Technology Conference) 15068