Definition of a unified methodology for the simulation of rupture in collision and grounding of ships

J.N. Marinatos & M.S. Samuelides

ABSTRACT

The object of the present study, is the definition of a numerical procedure to simulate the response of ship structures under accidental loading conditions, which suffer various different modes of failure, such as tension, bending, shear, and crushing and in particular to investigate the effect of material modeling, i.e. material curve and rupture criterion as well as mesh size on the results. To this end, medium and small scale indentation experiments conducted by different research groups, are simulated using the explicit finite element code ABAQUS 6.10-2. The tests refer to the quasi-static transverse loading of various thin walled structures which represent parts of a ship structure, such as an un-stiffened plate, stiffened plates and a double hull model. Three rupture criteria are incorporated into VUMAT subroutine, which interacts with the explicit finite element code and refers to an isotropic hardening plane stress J2 material, in order to investigate the prediction of rupture. The focus is on investigating whether it is possible to define a unified methodology, which is appropriate for the simulation of all different tests.

INTRODUCTION

The Finite Element simulation of strongly non-linear response of structures, which results in large strains, heavily depends on the material model that is chosen by the user to represent the actual material behaviour. Finite element codes require as input the true Mises stress-strain relation of the material in the plastic domain, which commonly the user determines from the measurements of the force and the elongation acquired during standard tensile tests. However, there is more than one procedure to determine the required relationship that the user inputs to the code, from the measured parameters.

In the present investigation three different types of true stress-strain curves beyond neck were assumed and applied in the simulations, i.e. the experimental, the powerlaw and the tangent type, (Marinatos et al. 2013b), Figure 1. Also three rupture criteria were implemented inside VUMAT subroutine given in the ABAQUS explicit finite element code, in order to investigate fracture prediction. These are referred in the literature as the critical equivalent plastic strain criterion or SHEAR criterion, the BWH instability criterion (Alsos et al. 2008) and the RTCL damage criterion (Törnqvist 2003), respectively. It is noted that, two forms of the RTCL and SHEAR damage criteria were implemented in the simulations, the unscaled (RTCL, SHEAR) and the scaled (RTCLS, SHEARS) form. According to the selected form, the critical equivalent plastic strain was dependent or not on the element length, (Marinatos et al. 2013b), Figure 1.

The effect of the aforementioned modeling parameters on the simulation results has been investigated, by comparing the experimental force and absorbed energy-penetration curves with those that had been derived from the numerical analysis. Representation of damage has also been examined.

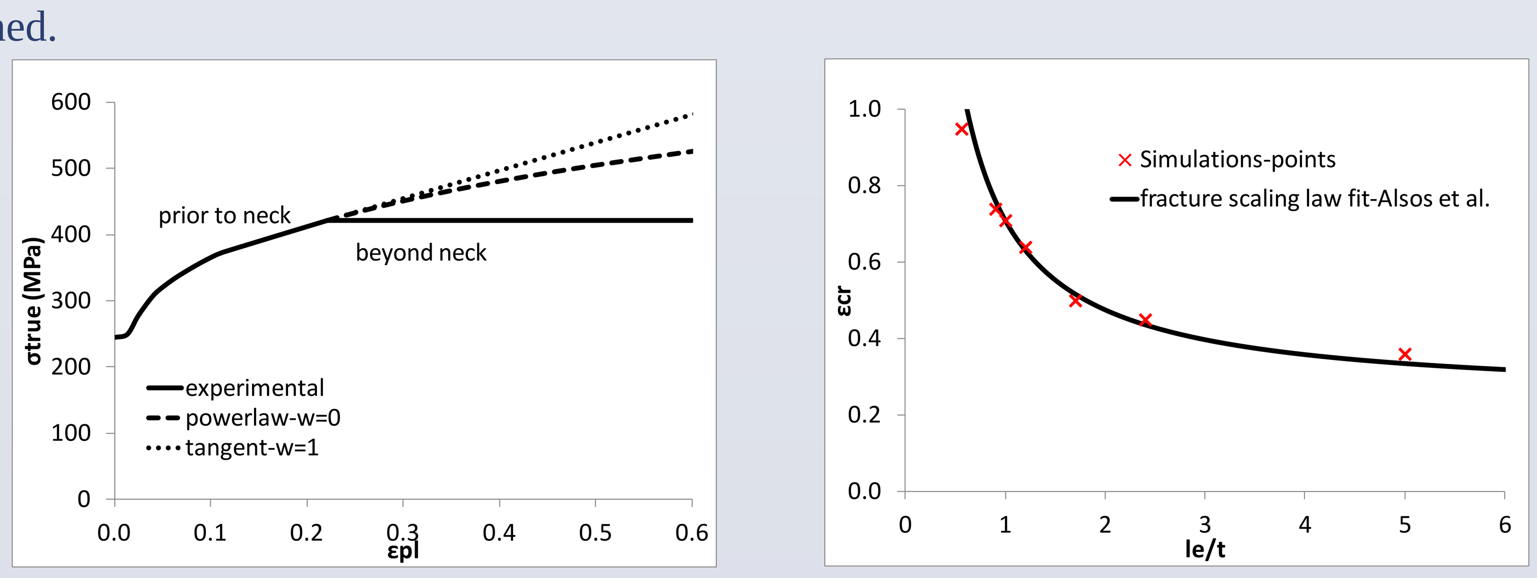


Figure 1. Different types of true equivalent stress-plastic strain curves beyond neck and equivalent plastic failure strain for different element sizes (uniaxial tension), Alsos et al. (2009)

OBJECTIVE

The scope of indentation experiments is to investigate the structural crashworthiness of the collided vessels in stranding, when the ship settles on the sea floor without being subjected to sway or surge motions and also in collision events. In the case of such events, damaged hull and cargo tanks may have severe environmental consequences and could even result in serious injury even loss of life. Thus, focus through this experimental procedure is placed on the investigation of the resistance of the struck structure under transverse loading, including the response of the structure after ultimate load is reached. Furthermore valuable data is attained, which then can be used for the verification of the rupture criteria that are applied in numerical simulations.

INDENTATION EXPERIMENTS

Different tests of extreme loading on thin walled structures that were performed by independent research groups have been simulated. In particular, the tests which are presented in Alsos & Amdahl (2009) and Paik et al. (1999) refer the former to quasi-static transverse loading of an un-stiffened (US) and two stiffened plates, one with one flat bar (1-FB) and the other with two flat bar (2-FB) stiffeners, and the latter to quasi-static indentation tests of a double hull model, where the impact location of the cone shape indenter on the outer skin plating was varied between webs and on webs, (ST-3-BW) and (ST-3-OW) respectively. In all experiments a rigid, bulbous, bow shape indenter was forced upon the thin walled structures. The configuration of each test and the form of the rigid indenters are illustrated in Figure 2.

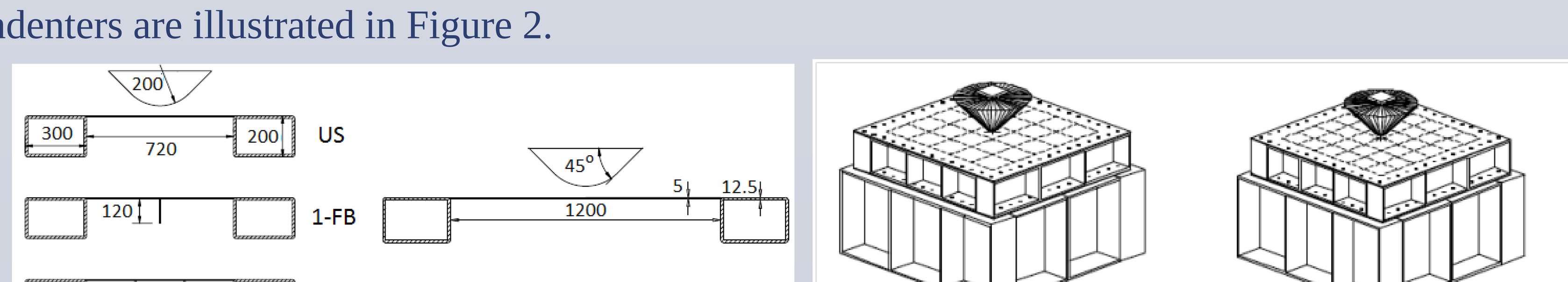
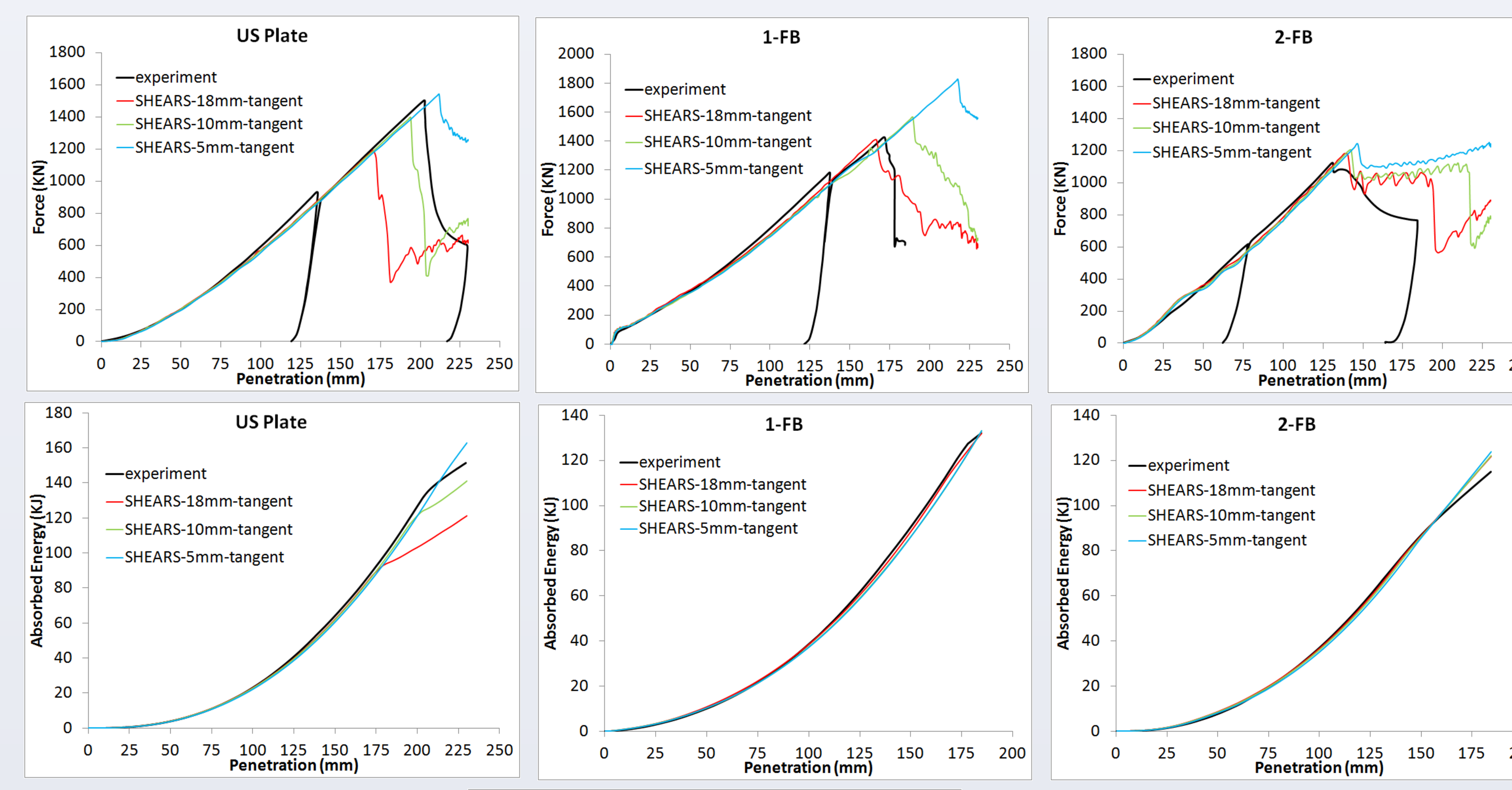


Figure 2. The transverse and longitudinal cross section with and without stiffeners. Alsos & Amdahl (2009), (left) and schematic view of the test set-up for initial colliding BW and OW. Paik et al. (1999), (right)

CONCLUSIONS

Through this investigation it has been concluded that, SHEARS rupture criterion in combination with the 'tangent type' true stress-strain curve, corresponds fairly well in all cases of the examined models. Moreover a length element over thickness ratio which varies between $1.5 \leq 3$ yields good results in all of the examined cases, (Marinatos et al. 2013a,b).

The numerical results of the examined tests are illustrated in Figure 3, while Figure 4 illustrates the representation of damage in the use of SHEARS rupture criterion in combination with the 'tangent type' true stress-strain curve for three mesh sizes.



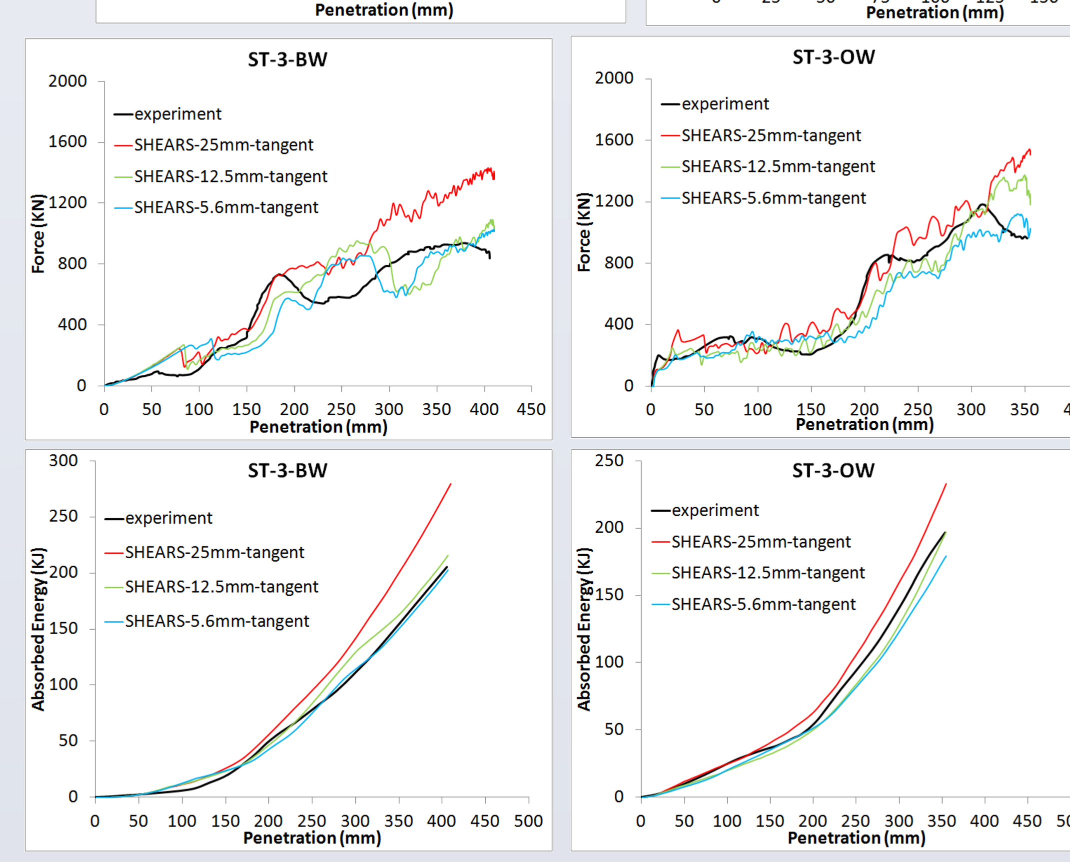
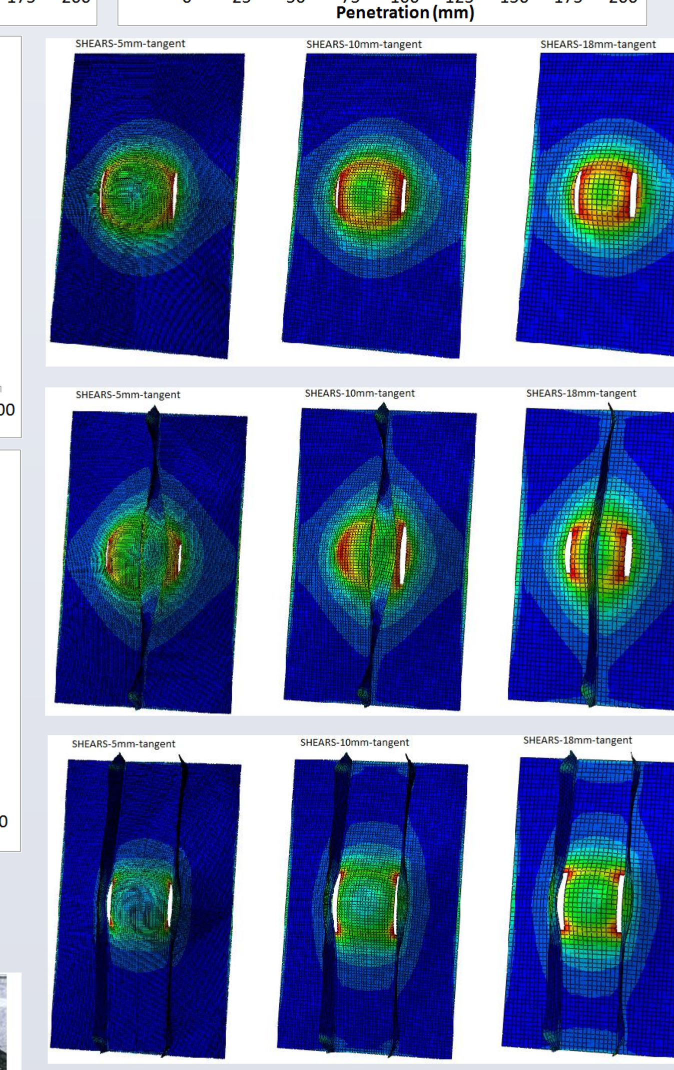
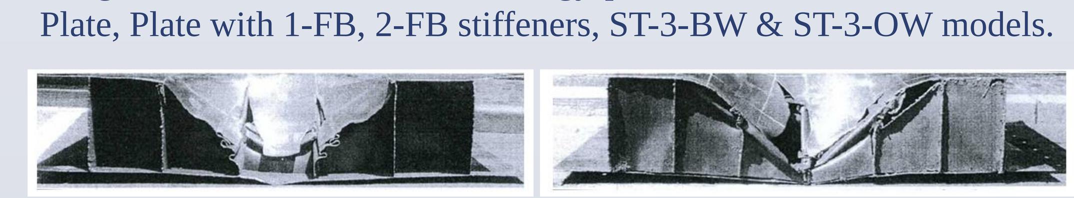
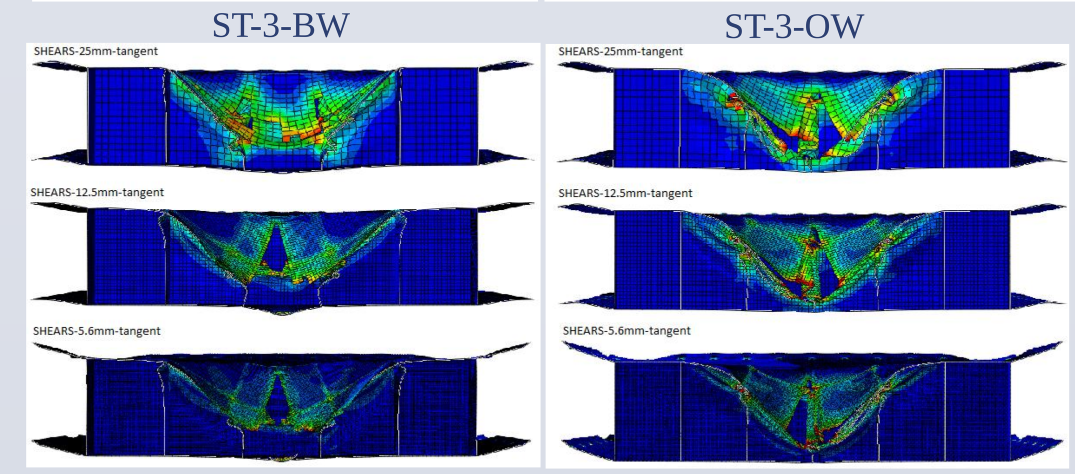


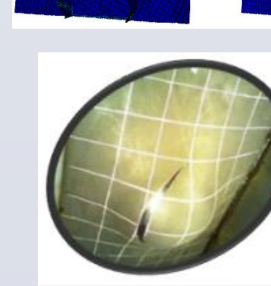
Figure 3. Force and absorbed energy-penetration curves for the US Plate, Plate with 1-FB, 2-FB stiffeners, ST-3-BW & ST-3-OW models.

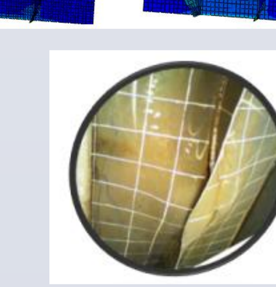




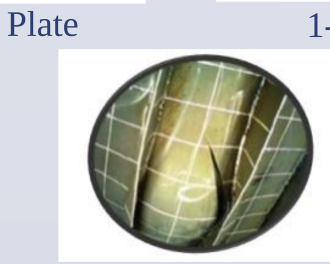
ST-3-BW ST-3-OW







US Plate 1-FB



2-FB

Figure 4. Representation of damage according to SHEARS rupture criterion for each model in combination with the tangent type material true curve and three element lengths.

ACKNOWLEDGEMENTS

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Heracleitus II. Investing in knowledge society through the European Social Fund.

REFERENCES

ABAQUS 6.10-2. 2010. Documentation.

Alsos, H.S., Hopperstad, O.S., Tornqvist, R., Amdahl, J. 2008. Analytical and numerical analysis of local necking using a stress based instability criterion. *International Journal of Solids and Structures* 45(7-8): 2042–2055.

Alsos, H.S. & Amdahl, J. 2009. On the resistance to penetration of stiffened plates, part I: experiments. *International Journal of Impact Engineering* 36(6): 799-807.

Alsos, H.S., Amdahl, J., Hopperstad, O.S. 2009. On the resistance to penetration of stiffened plates, part II: numerical analysis. *International Journal of Impact Engineering* 36(7): 875-887.

Ling, Z. 1996. Uniaxial true stress-strain after necking. *AMP Journal of Technology* 5:37–48.

Marinatos, J.N. & Samuelides, M. 2013a. Material modeling for Finite-Element simulation of ship impacts. *4th International Conference on Marine Structures* , Espoo, Finland.

Marinatos, J.N. & Samuelides, M. 2013b. Material characterization and implementation of the RTCL, BWH and SHEAR failure criteria to finite element codes for the simulation of impacts on ship structures. *6th International Conference of Collision and Grounding of Ships*, Trondheim, Norway.

Paik, J.K., Chung, J.Y., Choe, I.H., Thayamballi, A.K., Pedersen, P.T., Wang, G. 1999. On rational design of double hull tanker structures against collision. *Transactions of the Society of Naval Architects and Marine Engineers*, Vol. 107:323-363.

Törnqvist, R. 2003. Design of crashworthy ship structures. Ph.D. thesis, DTU, Lyngby, Denmark.

European Union European Social Fund
OPERATIONAL PROGRAMME EDUCATION AND LIFELONG LEARNING investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS MANAGING AUTHORITY
NSRF 2007-2013 EUROPEAN SOCIAL FUND
Co-financed by Greece and the European Union