Marine Structures 23 (2010) 462–474

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

The influence of the material relation on the accuracy of collision simulations

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ARTICLE INFO

Article history:
Received 10 September 2010
Accepted 27 December 2010

Keywords:
Collision simulation
Material relation
Non-linear FEA

ABSTRACT

The non-linear finite element method is widely used to simulate marine structures subjected to collisions. Furthermore, common to all non-linear finite element simulations is the need to implement the non-linear material behaviour including failure. However, the influence of the material relation on the accuracy of numerical results is not presented in detail in the present literature even though different material relations are used. Additionally, the material relation needs to include an appropriate criterion for treating the occurrence of fracture within the marine structure. Thereby, the crash resistance until inner hull failure should be predicted reliable and realistic. Therefore, this article seeks to describe the common choice of a material relation and compares this with a recent finite element-length dependent material relation based on optical measurements. As a result, this comparison gives an insight into the influence of the material relation on the accuracy of non-linear finite element simulations. Hence, this comparison can support the future use of an appropriate material relation for collision simulations.

1. Introduction

Numerical collision simulations are carried out widely and are already used to influence the conceptual ship design, see for example the proceedings of the 5th International Conference on

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0951-8339/$ – see front matter © 2010 Published by Elsevier Ltd.
doi:10.1016/j.marstruc.2010.12.002

Collision and Grounding of Ship Structures [1]. Furthermore, all numerical simulations need to account for the non-linear behaviour of the material utilised to build the marine structure in question. In other words an appropriate material relation has to be chosen as a basis of the simulation. Hence, the choice to be made when selecting a material relation for non-linear finite element simulations concerns the strain and stress relation and a failure criterion. Furthermore, these selected material parameters are often adjusted until some experimental compliance for the chosen mesh size is obtained; see for example [2]. However, this adjustment may not account for the actual material behaviour. Additionally, the mesh size may be changed without re-adjustments of the material parameters.

Commonly, the strain and stress relation is determined with a tensile experiment according to an agreed standard; see, for example, ASM [3] or DNV [4]. Therein, the general procedure of the experiment is described. Furthermore, DNV defines that the breadth of flat specimens with a thickness above 3 mm is supposed to be 25 mm. Only the effective length of the specimen, respectively gauge length, is adjusted according to the initial effective cross-sectional area of the specimen. Therefore, one has to keep in mind that such alleged material test results in a structural response of the tested specimen, namely the engineering strain and stress measure. Hence, the 'true' or 'local' stress versus strain can be obtained from this engineering strain and stress measured in the form of a power law fit, see [5–8]. In this paper the difference in strain and stress measures will be indicated with the addition 'global' or 'local'. Global measures refer to the overall effective dimensions of the tensile specimen, whereas local measures refer to the localised behaviour of the material.

However, whether or not a chosen finite element length corresponds to the local strain and stress relation obtained remains questionable. For one selected finite element length, agreement between the numerical simulation and the tensile experiment may be achieved by an iterative procedure. Here the local strain and stress relation, i.e. the power material law, used as input for the simulation is changed until compliance with the corresponding tensile experiment is achieved [8,9]. However, this iterative procedure can lead to wrong structural behaviour if the element length is changed, in which case the procedure needs to be repeated for each mesh size selected until compliance is reached. Hence, the proper material relation until failure is of considerable importance, as it directly influences the accuracy of non-linear finite element simulations until fracture, such as collision simulations.

Furthermore, the determination of the material relation alone does not necessarily suffice, as the failure strain, i.e. the end point of the stress versus strain curve, depends in turn on the material relation. However, a significant amount of research has been conducted to describe criteria to determine the failure strain, for example by [5,10,11] and to present their applicability [12,13]. However, all of these papers use a standard or modified power law to describe the material behaviour, and none of these papers identifies a clear relation between the local strain and stress relation and the element length. Relations to obtain an element length-dependent failure strain value are given by [5,10–12]. These curve-fitting relations, known as Barba's relations, are obtained on the basis of experimental measurements. However, they define only the end point of the standard or modified power law.

Therefore, Ehlers and Varsta [14] and Ehlers [15] presented a novel procedure to obtain the material's strain and stress relation including failure with respect to the choice of element length using optical measurements. Therein, they introduced the strain reference length, l_{ref}, indicated as A and B in Fig. 1, as a measure to relate the element length to the material relation including failure.

Ehlers [17] utilises this strain reference based material relation to simulate a tanker collision and obtains significantly better correspondence in results for changing element sizes when compared with the standard power material relation. However, he does not present if this difference in correspondence arises from the choice of material relation alone, or from the choice of failure criterion. Therefore, this article seeks to give an insight into the influence of the material relation on the accuracy of collision simulations. Furthermore, the different contributions arising from the material relation and failure criterion will be presented for different non-linear finite element simulations. In detail, this paper presents a comparison of a tensile-, plate punching- and collision simulation using both, the strain reference length based material relation and the power law based material relation for mild steel.