International Journal of Impact Engineering 62 (2013) 88–98

Contents lists available at SciVerse ScienceDirect

International Journal of Impact Engineering

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

Ship structure steel plate failure under near-field air-blast loading: Numerical simulations vs experiment

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ARTICLE INFO

Article history:
Received 7 December 2012
Received in revised form
12 June 2013
Accepted 14 June 2013
Available online 29 June 2013

Keywords:
Air-blasted plate
Ductile fracture
Viscoplastic material
Parametric study
Numerical simulation

ABSTRACT

This paper deals with the numerical simulation of the dynamic failure of a ship structure steel plate under near-field air-blast loading. Various energetic levels of air-blast loading, involving variable explosive mass and charge-plate distance, were tested leading to the bulge of the loaded plate for the lowest energy level and to the failure of the loaded plate for the highest level. A modified version of the Gurson–Tvergaard–Needleman potential was used to reproduce the response of the material along the damage-plasticity process at stake. The 3D constitutive equations were implemented as user material in the engineering finite element computation code ABAQUS®, and numerical simulations were conducted and compared with experiments considering air-blast loaded plates. Several crucial numerical issues are addressed concerning notably the use of ABAQUS® conwep function, the hourglass control and the influence of the model constants. Numerical results clearly show the interest of the adopted modelling for the description of salient stages of dynamic structural failure.

1. Introduction

This paper addresses the numerical simulation of the dynamic failure of a ship structure steel under near-field air-blast loading.

Air-blast tests belong to the experiments devoted to study the vunerability of ship hulls regarding explosion loading. Depending on the energetic conditions – induced by both explosive mass and charge-plate distance – one can typically observe the bulge of the structure for the lowest and the failure of the structure for the highest. Many experimental and numerical studies are available in literature aiming to reproduce the deflection of a plate (bulge) under low to moderate air-blast loading induced energy, see e.g. Refs. [1–4]. Conversely, works regarding numerical modelling attempting to describe all the air-blast post-loaded states, i.e. passing from the bulge to the ultimate failure, are scarce. This work aims at reproducing numerically the failure mechanisms of a ship structure constitutive material when submitted to air-blast loading.

To qualify the high-purity, ferritic–pearlitic mild steel employed as structural material in panels of naval structures under consideration regarding explosion loading, air-blast experiments were carried out. The samples were machined in the form of square thin plates, see Fig. 1a. The steel plate was held down by two frames fixed to the underlying structure. The plastic explosive charge was spherical, hung on a post and braces, see Fig. 1b. The mass of the charge and the distance between the charge and the plate are controlled parameters. The reader may refer to Ref. [5] for an extensive experimental investigation of the air-blast test.

Depending on the mass C of the charge, and on the distance D between the charge and the plate, one can typically observe three states resulting from the explosion loading: the deflection of the plate (Fig. 2.1), the macrocracks incipience and growth (Fig. 2.2–2.3), and the propagation of macrockacks resulting in the so-called petalling failure (Fig. 2.4). The maximum residual deflection of the plate is reported in Fig. 3 for variable charge mass and variable charge/plate distance. One can coarsely distinguish two domains: the first domain, covering long distance, for which the plate is able to consume the explosion induced energy by plastic deformation; the second domain, covering short distance, for which the explosion leads to the catastrophic failure of the plate. It must be noted that the notion of long distance and associated 'far' field is very

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0734-743X/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijimpeng.2013.06.009

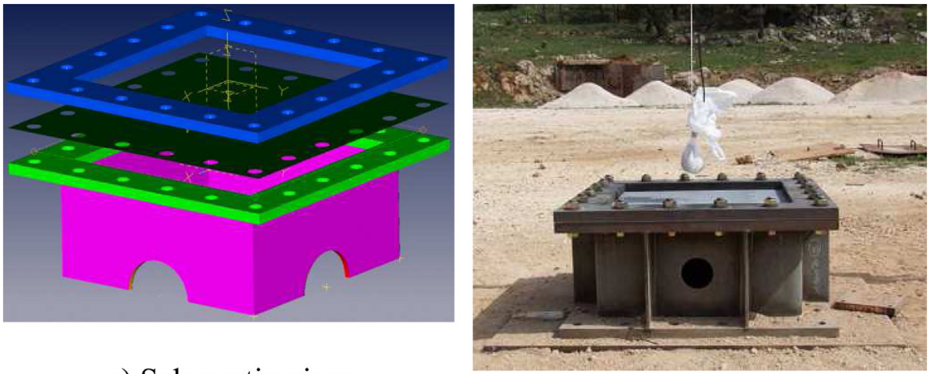
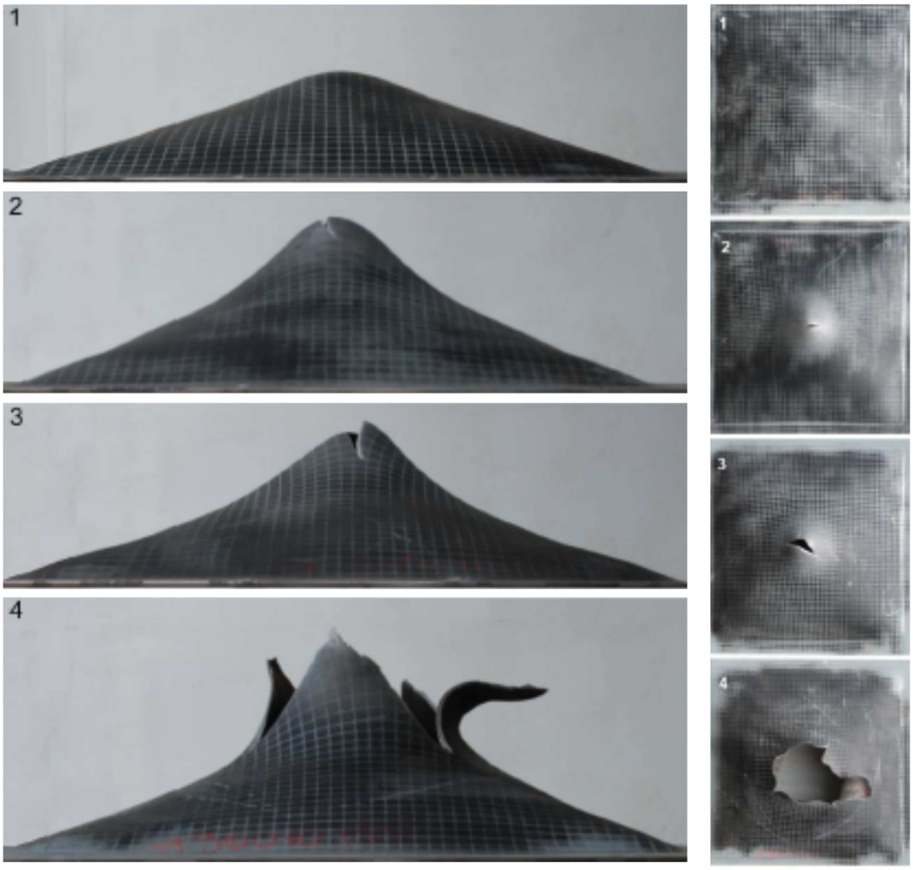

a) Schematic view
b) Real view

Fig. 1. Air-blast experimental set-up. (a) Schematic view. (b) Real view.

relative, as shown in Fig. 1b. The distance values on both sides of the transition, corresponding to the cracking initiation in Fig. 3, separating the domains of whole consumption of the explosion induced energy by plastic deformation (bulge) and catastrophic failure, are consequently very close.

Predicting loading range and mode of ultimate structural failure implies identifying the underlying damage mechanisms at stake and describing their consequences. In the material at stake, damage has been seen to proceed from void initiation, growth and coalescence and to occur late in the deformation process. The consequences of void growth induced damage are generally double: a progressive degradation of the overall properties of the bulk material and the appearance, in addition to the isochoric plastic deformation due to dislocation glide in the matrix material, of an inelastic dilatancy due to void growth. Gurson [6] microporous model is a micromechanics based model widely used for dealing with ductile fracture, see, e.g. Refs. [7,8]. Recently, Longere et al. [9] proposed an extended version of Gurson's model in order to reproduce the delay experimentally observed between plastic deformation occurrence and hole nucleation, on one hand, and hole



a) Side views
b) Rear views

Fig. 2. Final state of the plate after air-blast loading for various loading configurations (DCNS-DGA): constant charge mass *C* and decreasing distance *D* from 1 (far) to 4 (close).