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Simplified analytical method for evaluating web girder crushing during ship collision and grounding

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A B S T R A C T

The paper presents a simplified analytical method to examine the crushing resistance of web girders subjected to local static or dynamic in-plane loads. A new theoretical model, inspired by existing simplified approaches, is developed to describe the progressive plastic deformation behaviour of web girders. It is of considerable practical importance to estimate the extent of structural deformation within ship web girders during collision and grounding accidents. In this paper, new formulae to evaluate this crushing force are proposed on the basis of a new folding deformation mode. The folding deformation of web girders is divided into two parts, plastic deformation and elastic buckling zones, which are not taken into account for in the existing models. Thus, the proposed formulae can well express the crushing deformation behaviour of the first and subsequent folds. They are validated with experimental results of web girder found in literature and actual numerical simulations performed by the explicit LS-DYNA finite element solver. The elastic buckling zone, which absorbs almost zero energy, is captured and confirmed by the numerical results. In addition, the analytical method derives expressions to estimate the average strain rate of the web girders during the impact process and evaluates the material strain rate sensitivity with the Cowper-Symonds constitutive model. These adopted formulae, validated with an existing drop weight impact test, can well capture the dynamic effect of web girders.

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Nomenclature

a	half width of web flange
b	half span of web girder
b_1	one side of web girder
b_2	another side of web girder, $b_2 = 2b - b_1$
E	total energy dissipation
E_b	bending energy dissipation
E_m	membrane energy dissipation
$E_{b,sub}$	bending energy dissipation of the second fold
$E_{m,sub}$	membrane energy dissipation of the second fold
$E_{1,b}$	energy dissipation of the first folded web due to bending
$\dot{E}$	total energy rate
$\dot{E}_b$	bending energy rate
$\dot{E}_{b,sub}$	bending energy rate during second folding
$\dot{E}_m$	membrane energy rate
$\dot{E}_{m,sub}$	membrane energy rate during second folding
$\dot{E}_{1,m}$	membrane energy rate of the first folded web
$F_{b,sub}$	resistance force of the second folding due to bending
F_m	mean crushing force of web girder
$F_{m,sub}$	mean crushing force in the second fold
$F_{1,b}$	resistance force of the first folded web due to bending
$F_{1,m}$	resistance force of the first folded web due to membrane straining
$F(\delta)$	instantaneous crushing force of web girder
$F_1(\delta)$	total resistance force of the first folded web
$F_{sub}(\delta)$	instantaneous crushing force in the second fold
H	folding wavelength of web girder
H_w	web girder height
M_0	fully plastic bending moment per unit angle
P	girder in-plane load
$P(\delta)$	resistance force of web flange
t	plate thickness of web girder
t_f	plate thickness of web flange
v	impact velocity
α	instantaneous rotation angle of web girder
$\dot{\alpha}$	angular velocity of rotational web girder
δ	instantaneous indentation
$\dot{\delta}$	indentation velocity
σ_y	yield stress of the material
σ_u	ultimate stress of the material
σ_0	flow stress, $\sigma_0 = (\sigma_y + \sigma_u)/2$
$\sigma_{0,dyn}$	dynamic flow stress
$\dot{\varepsilon}_{av}$	average tensile strain rate

1. Introduction

Increased attention has being paid to investigate the response mechanisms of ship collision and grounding accidents, to reduce the risk of structural impact damage [1,2]. In the event of a collision or grounding, the double hull structure of the collided/stranded ship can experience a large plastic deformation and fracture. In order to prevent ship flooding with severe economic loss and casualty, the rupture of the inner hull should be avoided until all the incident energy is dissipated. Thus, it is