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Impact Damage of Long Plastic Cylinders

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ABSTRACT

The objective of the paper is to assess the local damage of long tubular members and pipes caused by the impact of a rigid mass. The formulation is general and covers a wide range of events: low velocity-large mass impacts, as encountered in collisions; medium velocity impacts caused by dropped objects; and projectile and missile impacts. By making assumptions on the cross-sectional deformed shape of the cylinder, the two-dimensional shell problem was reduced to a one-dimensional problem of a plastic string resting on a rigid-plastic foundation. It was shown that the deformation propagates away from the point of disturbance with a constant plastic wave speed and diminishing amplitude. Calculated were the instantaneous velocity and deflection profiles, the final deformed shape of the shell, and the maximum deflection attainable under impact. A parametric study was performed by changing the mass and velocity of the impacting object over several orders of magnitude. An approximation to the dynamic solution was also obtained by using the static solution of the shell under "knife" loading and comparing the plastic work of the deformation process to the kinetic energy of the impacting mass. This approximation was compared to the dynamic solution and good agreement was shown for a range of masses and impact velocities encountered in offshore applications. Finally, use of the proposed methodology was illustrated by predicting the local damage caused by a drill-collar accidentally falling on one of the brace tubular members of an offshore platform.

NOMENCLATURE

c	: transverse wave speed
h	: shell thickness
m	: mass per unit surface area
$\overline{m}_u$	: equivalent mass in axial direction
$\overline{m}_w$	: equivalent mass in transverse direction
$m_{\alpha\beta}$	: normalized bending moment tensor
$n_{\alpha\beta}$	: normalized membrane force tensor
p	: pressure load
$\overline{p}$	: equivalent line load
$\overline{q}$	: equivalent foundation constant
t	: time
t_f	: response time
$\overline{t}$	: normalized time
u	: axial displacements
V	: velocity of deformed region
w	: transverse deflections
w_f	: final transverse deflections
x	: axial coordinate
$\overline{x}$	: normalized axial coordinate
$\dot{E}_{ext}$	: rate of external work
$\dot{E}_{int}$	: rate of internal dissipation of energy
F	: axial load
H	: drop height
$\dot{I}_2$	: second invariant of strain rate tensor
M_o	: impacting mass
M_{pl}	: fully plastic bending moment per unit length
$M_{\alpha\beta}$	: bending moment tensor
$\overline{N}$	: equivalent axial force
N_{pl}	: fully plastic membrane force per unit length
$N_{\alpha\beta}$	: membrane force tensor
P	: "knife" load
Q	: shear load
R	: radius of cylinder
S_o	: shell surface area
V_o	: impact velocity
δ	: maximum or central deflection of shell
δ_f	: final central deflection of shell
$\dot{\varepsilon}_{\alpha\beta}$	: strain rate tensor
η	: mass ratio
θ	: circumferential coordinate
$\dot{\kappa}_{\alpha\beta}$	: curvature rate tensor
$\dot{\lambda}$	: proportionality constant
μ	: relative mass and velocity ratio
v	: velocity ratio
ξ	: length of deformed zone
ξ_f	: final length of deformed zone
ρ	: density
σ_o	: flow stress
f	: yield function
$\cdot$	: $\frac{d}{dt}$
$'$	: $\frac{d}{dx}$
$]$	: jump discontinuity

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KEY WORDS: Cylindrical shell, impact, local damage.

INTRODUCTION

Structural impact is of relatively frequent occurrence in offshore construction, drilling and production activities. Collisions of offshore platforms with supply vessels, for example, can be classified as large mass and low velocity impacts. An intermediate range of impact scenarios is covered by dropped objects hitting parts of the protective or load-carrying structure. Small mass and high velocity impacts may be caused by projectile impacts.