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Prediction of hull girder moment-carrying capacity using kinematic displacement theory

Gökhan Tansel Tayyar [a], Ji-Myung Nam [b], Joonmo Choung [b,*]

[a] Department of Naval Architecture and Marine Engineering, Istanbul Technical University, Istanbul, Turkey

[b] Department of Naval Architecture and Ocean Engineering, Inha University, Republic of Korea

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A B S T R A C T

The hull girder moment capacity of a very large crude oil carrier (VLCC) called *Energy Concentration* (EC), for which many benchmark studies have been carried out using the simple progressive collapse method (SPCM), is predicted. In this study, three approaches are used to represent the load-shortening behavior, so-called average compressive strength, of a stiffened panel, comprising the hull section: 1) kinematic displacement theory (KDT); 2) nonlinear finite element analysis (FEA); and 3) simple formulas in the common structural rule (CSR) for tankers. Load-shortening curves for various kinds of stiffened panels in EC are compared for five different scenarios with variations of load-shortening approaches and initial imperfections. In order to verify the effect of load-shortening on the prediction accuracy of the hull girder moment-carrying capacity, load-shortening curves are imported into an SPCM-based in-house program called Ultimate Moment Analysis of Damaged Ships (UMADS). Comparison of the hull girder ultimate strength for general heeling conditions, including hogging and sagging conditions, reveals that the load-shortening curves significantly affect the hull girder moment-carrying capacities. Based on our comparison of these capacities with other benchmark results, it is concluded that nonlinear FEA provided the most conservative results, KDT provided the second most conservative results, and the CSR formulas predicted the upper bound.

* Corresponding author. Tel.: +82 32 860 7346; fax: +82 10 8604 7346.
E-mail address: jmchoung@inha.ac.kr (J. Choung).

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Nomenclature

a	frame spacing or length of the stiffened panel
a_p	magnitude of initial deflection in the attached plate
a_s	magnitude of initial deflection in the plate-web intersection line
a_w	magnitude of initial deflection in the stiffener web
A_e	effective cross-section area of the stiffened panel
A_p	section area of the attached plate
A_{pe}	effective section area of the attached plate
A_s	section area of the attached stiffener
b	longitudinal stiffener spacing
$b(z)$	$\begin{cases} t_w & \text{for stiffener web} \\ b_p & \text{for attached plate} \\ b_f & \text{for stiffener flange} \end{cases}$
b_f	width of the stiffener flange
b_p	width of the attached plate
b_{pe}	effective width of the attached plate
b_w	width of the stiffener web
b_{we}	effective width of the stiffener web
B	breadth of ship
C	initial centroid of the cross section of the stiffened panel
C_e	effective centroid of the stiffened panel
dc_i	magnitude of incrementa displacement vector between ith and $i+1$th nodes
dl_i	shortening of ith element
dL	axial shortening
ds_i	element length between ith and $i+1$th nodes
du_i	incremental displacement component in longitudinal direction between ith and $i+1$th nodes
dw_i	incremental displacement component in vertical direction between ith and $i+1$th nodes
$d\theta_i$	incremental arc angle between ith and $i+1$th nodes
D	depth of ship
E	elastic modulus
I	second moment of area
i	number of element or node
j	number of iteration step
L	half span length of the stiffened panel
L_{OA}	length overall of ship
L_{BP}	length between perpendiculars of ship
M_i	moment at ith node
$M(\phi)$	hull girder moment capacity at heeling angle or angle of moment plane ϕ
$M_u(\phi)$	ultimate hull girder strength at heeling angle or angle of moment plane ϕ
$M_p(\phi)$	fully plastic moment at heeling angle or angle of moment plane ϕ
N_i	force component in longitudinal direction at ith node
n	the number of discretized elements
P	axial shortening load
r_i	radius of curvature at ith node $(= \lvert 1/\kappa_i \rvert)$
R	rotational displacement
t_f	thickness of the stiffener flange
t_p	thickness of the attached plate
t_w	thickness of the stiffener web
T	translational displacement
u_i	displacement component in longitudinal direction at ith node