DEVELOPMENT OF A FIRST-YEAR RIDGE KEEL LOAD MODEL

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By

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ABSTRACT

This thesis documents the development of a new modelling approach for first-year ridge keel loads. The development involves a detailed review of previous and new ice rubble indentation and shear strength experiments. A systematic regression analysis of compiled laboratory data sets is used to establish a basic approach to keel load modelling, analogous to that for soil retaining problems. Experiments pioneering the modelling of first-year ridge keels with sand are also described. The dry sand tests afforded a high degree of control which led to the development of a new sand force prediction model that was adapted and calibrated for ice keel modelling.

The advantage of the new first-year ridge keel load model is that new effective structure width and keel shape models are utilized, ridge width is factored in and surcharge effects are considered. The model shows excellent agreement with a large body of new experimental data and the best field data available. Also, it is closed-form, has been successfully applied to both vertical and conical structures, and is based on fundamental earth pressure equilibrium mechanics as are other approaches already in the literature. A further advantage is that ice rubble shear strength yield criteria used in the model have been thoroughly examined so that associated parametric uncertainties are quantified and reduced. An *in situ* technique for testing the shear strength of ridge keels is developed and direction for future field work and modelling efforts is given.

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NOMENCLATURE

A	specified cross-sectional area
A_c	acceleration
A_p	projected area
A_r	aspect ratio
a	keel angle
B	specified length dimension
b	limit sail height exponent
C	limit sail height constant
C_d	drag coefficient
C_m	inertia coefficient
c	cohesion
c_i	specific heat of ice
D	diameter/width of a structure
D_b	cone base diameter
D_{eff}	effective structure width
D_f	furrow width
D_s	neck diameter
d	vessel depth
E	modulus of elasticity
e	porosity
F	specified force
F_c	crushing force
F_{keel}	keel failure force
F_l	level ice failure force
F_n	normal force
F_r	ridge failure force
F_s	shear force
F_{sail}	sail failure force
f	specified function
f_c	contact factor
g	gravitational constant
H	keel depth
H_f	furrow depth
H_{ks}	total ridge thickness ($H+H_s$)
H_p	depth at point of peak load
H_s	sail height
H_{sur}	surcharge height
H_t	total height of sand at structure
h	level ice thickness
I	indentation coefficient
K_a	active earth pressure coefficient
K_p	passive earth pressure coefficient
K_o	at rest earth pressure coefficient
k	thermal conductivity
L	latent heat of fusion
L_i	ice blocks: thickness (minimum dimension)
L_x	ice blocks: median of maximum dimension
M	mass
Ma	added mass
m	rupture distance for cone
m_c	shape factor
n	void ratio
P	specified pressure
P_{en}	penetration distance
q	Dolgopolov *et al.* (1975) shape factor
R	radial distance
R_f	ridge factor
r	forward rupture distance
r^2	regression correlation coefficient
r_a	radius
S	salinity
s	side rupture distance
T	temperature
T_f	freezing point temperature
T_i	ice surface temperature
t	duration
U_o	far field velocity
u	longitudinal velocity component
V	specified speed or velocity quantity
v	lateral velocity component
W	ridge or keel width
W_s	sail width
w	specified weight
x	specified quantity
x_m, x_{sd}	mean, standard dev. of quantity
Z_h	Weaver inertia force
z	specified vertical position

Nomenclature continued

α	structure angle from vertical
β	flare angle
β'	apex angle
β''	half-apex angle
γ	specified unit weight
δ	surcharge angle from horizontal
θ	specified angle
λ	Weaver added mass factor
ν	dynamic viscosity
ν_p	Poisson's ratio
ξ	$= 90 - \alpha + \phi_1$
π	3.1415926
ρ	specified density
ρ_i	density of ice
ρ_w	density of water
σ	specified stress
$\sigma_1 \sigma_2 \sigma_3$	principal stresses: major, intermediate, minor
σ_{fl}	flexural strength
σ_h	horizontal stress
σ_{max}	maximum confinement stress
σ_n	normal stress
σ_v	vertical stress
τ	shear stress or strength as specified
ϕ	internal friction angle
ϕ_1	soil or ice against structure friction
ψ	Keinonen bow flare angle
$\psi 2$	Keinonen stem angle
$\psi 3$	Keinonen entrance angle
ω	rupture angle