Marine Structures 54 (2017) 167–187

Contents lists available at ScienceDirect

Marine Structures

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

Simulating transverse icebreaking process considering both crushing and bending failures

Li Zhou [a,*], Kaj Riska [b], Chunyan Ji [a]

[a] School of Naval Architecture and Ocean Engineering, Jiangsu University of Science and Technology, Zhenjiang 212003, China
[b] TOTAL S.A. - DGEP/DEV/TEC/GEO - Tour Coupole, 2, Place Jean Millier, La Défense 6 - Cedex 45, 92078 Paris La Défense, France

ARTICLE INFO

Article history:
Received 15 December 2016
Received in revised form 6 April 2017
Accepted 26 April 2017

Keywords:
Level ice
Crushing
Bending
Model test
Icebreaking vessels

ABSTRACT

The present numerical model simulates ice actions on marine structures in the vicinity of the waterline caused by breaking of intact ice. Intact ice mainly fail in bending or/and crushing mode on the interaction surface between ice and the hull. In this paper, a new method has been proposed to simulate non-simultaneous crushing failure in time domain based on previous research on simulations of bending failure. The simulated results are also compared with model test results. It shows that the simulated ice loads are in good agreement with the experimental results in terms of mean value, standard deviation, maximum and extreme force distributions, though there are some deviations between predicted and measured results for certain cases.

1. Introduction

As hydrocarbon exploration and exploitation in ice-covered waters increases, marine operations under ice impact are gaining more and more concern. For station keeping operations, prediction of ice actions poses a substantial challenge for design and safe use of marine structures in ice covered waters.

As a basic component, level ice exists in all ice interactions. Therefore, investigation of station keeping in ice should start from level ice. So far, a lot of researchers have studied the level ice–structure interaction process. [4,5]; and Riska et al. [16] proposed some semi-analytical and empirical performance models which are helpful to the early stage of designing an icebreaker [10]. developed a 3D numerical model by dividing the ice-hull interaction process into four phases: breaking, rotating, sliding and clearing [12]. also developed a method for simulating the interaction between moving level ice and a fixed conical structure. Later [9], refined the ice-ship contact procedure to simulate ship manoeuvres in level ice, where the coupling between continuous ice forces and ship motions in horizontal plane was included [15]. extended this method to simulate the performance of a moored ship in the horizontal plane under more complex conditions. However, there are some limitations with this method. This method only includes bending failure due to localized crushing initiated between ice and structure. If the slope of structure is large, crushing failure may occur non-simultaneously along the interaction surface. Therefore, some modifications have to be proposed to make it more suitable for structures with steep slope.

In this paper, a new method to simulate ice breaking force resulted from non-simultaneous crushing failure is developed as a compensation to the existing method for bending failure. Two ice breaking failure modes are assumed to be dependent on

* Corresponding author.
E-mail address: zhouli209@hotmail.com (L. Zhou).

http://dx.doi.org/10.1016/j.marstruc.2017.04.004
0951-8339/

the slope of structure where ice intrudes. If the slope is large or above a specified limitation, non-simultaneous crushing will occur. Otherwise, bending failure occurs. Both failure modes may occur along a wide structure with varying slope and simulated for an icebreaking vessel in the paper. Sensitivity study has been done to find which parameters have large influence on the simulated results. Finally, the simulated results are analysed and compared to the model test data from Ref. [13].

2. Overview of the existing numerical method

The action of drifting level ice on a station-kept structure is complex in that several ice failure patterns occur, primarily crushing and bending. The corresponding physical phenomena during the process are difficult to reproduce in a numerical way. Therefore, some assumptions have to be made to simplify the problem. It is assumed that the ice drift speed is low and thus ventilation and slamming are neglected. The ice loads acting on a moored ship in unbroken ice or large level ice floes depends significantly on the interaction process by which the hull breaks and displaces the ice. Once the ice contacts the hull, ice is being crushed locally. The localized crushing force then increases with increasing contact area until failure of intact ice sheet. The ice may fail in bending or crushing [9]. simulated ice breaking force due to bending failure.

The basic geometric model for ice–hull interaction includes the full-size waterline of the ship and the edge of the ice. As shown in Fig. 1, the waterline of the ship is discretized into a number of nodes as a closed polygon and the edge of the ice is discretized into a poly line in the established simulation program. At each time step, the simulation program is set to detect the ice nodes which are inside the hull polygon. Then, each contact zone can be found. To check whether the ice node is inside the hull polygon, geometric tools from computer graphics are adopted.

At each contact zone shown in Fig. 2, it is assumed that the contact surface between ice and hull is flat, and the contact area is simply determined by contact length and indentation depth. The contact length is calculated from the distance between adjacent hull nodes, and the indentation depth is calculated from the perpendicular distance from the cusp of ice nodes to the contact surface.

The ice wedges formed in the ice breaking process were determined by bending cracks, which were idealized and described by a very important parameter, namely the icebreaking radius. The icebreaking radius R was derived from the expression given in Ref. [12] (based on information from Enkvist (1972) and [11]:

$$R = C_l l \left(1.0 + C_v v_n^{rel}\right) \tag{1}$$

where $v^{rel}{}_n$ is the relative normal velocity between the ice and the hull node, C_l and C_v are two empirical parameters, C_l having a positive value and C_v is a negative value, l is the characteristic length of the ice:

$$l = \left(\frac{Eh_i^3}{12(1-\nu^2)\rho_w g}\right)^{1/4} \tag{2}$$

The ice wedge is determined by the interpolation of the icebreaking radius at the first and last contact nodes (i.e., R_f and R_l). The opening angle of the ice wedge is denoted as θ.

Ice pressure on the contact surface is assumed to be uniform and equal to the effective crushing strength. The ice force and velocity is shown in Fig. 3. It is true that the crushing pressure will decrease as nominal contact area between ice and structures increase. For the design of larger structures where they are needed to design shell plate, stiffeners, scantlings etc, local loads or pressures must be considered. Pressure-area curve is always involved, which is often obtained from ice standards based on an upper limit of measured data. Herein, the focus in on the global loads, it would be too conservative if pressure-area curve is used. Therefore, a constant pressure is assumed and used [9,10]; Lubbad, 2011). The localized crushing force F_{cr} which is normal to the contact surface is calculated as

$$F_{cr} = A_c\, \sigma_c \tag{3}$$

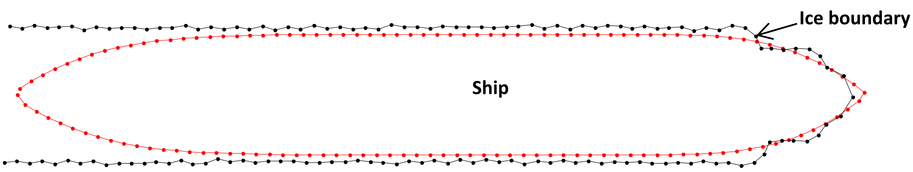

Fig. 1. Discretization of the ship hull and the edge of the ice.