**Stresses and Forces Under Ice Compacting**

V.A. Nikitin and S.A. Kolesov  
Arctic and Antarctic Research Institute, St. Petersburg, Russia

**ABSTRACT**

Calculated and measured values of stresses and ice forces under ice compacting leading to the ridging of the ice floes are presented in this paper. The calculated stresses were obtained using the knowledge of the ice strength characteristics. For the ice thickness exceeding 1 m, the ice forces can reach the order of severalMN·m⁻¹. Some evaluations of the ice forces obtained by calculations based on the mathematical modeling of the ice compacting processes are also presented. The critical values of the calculated stresses are close to the measured stresses, when dimensions of compacting zones are of the order of hundreds of kilometers.

**INTRODUCTION**

Of all the dynamic processes in the sea ice cover, ice compacting is most dangerous for ships and hydrotechnical structures. Ice compression usually reveals itself in ice fracture of different types and ice ridging, and it is the last stage of the ice cover compacting.

The ice-floe drift irregularities due to nonuniformity of the external forces, and the influence of the sea coast are the direct cause of the appearance of stresses in the sea ice. The spatial nonuniformity of the ice compacting affects, in its turn, the adverse influence on the drift velocity; it is known that in the compacting sea ice cover, the stresses can be transferred for a substantial distance of the order of hundreds of kilometers.

A normative document (Bushuev et al., "Scale of the ice compacting," 1981) takes into account the dynamic state of the ice cover, in which the gradations of 0, 1, 2, 3 numbers are determined on the grounds of the qualitative visual indications. The users, however, need the specific indications in the numerical form of stresses and ice forces.

Results of the direct stress measurements in the ice cover were presented earlier, by Sackinger and Nelson (1979), and Comfort and Ritch (1990). Existing sea ice models which take into account the internal interaction of the ice floes allow us to calculate a stress distribution in the ice cover (e.g., Coon et al., 1974; Hibler, 1979, Timokhov and Kheisin, 1987; and Kolesov, 1991).

The method of calculation of stresses and ice forces under ice compacting is presented in this paper. The method is based on the knowledge of strength characteristics of the sea ice. Here two types of ice-floe fracture are considered. The first occurs due to the loss of stability in the case of thin ice. The second is stipulated by the confined compression mechanism.

The obtained results are compared with calculations using the mathematical models and also with the field measurements.

**ICE FORCE CALCULATIONS BASED ON ICE STRENGTH CHARACTERISTICS**

Table 1 demonstrates possible values of stresses and ice forces due to compacting, leading to the ridging of the ice floes. The age categories of the ice evolution and their thickness limit are presented according to Krutskikh (1984). The calculations rest on the principle that the compressive stress cannot exceed breaking stresses in ice floes.

The obtained results are compared with calculations using the mathematical models and also with the field measurements.

**ABSTRACT**

Calculated and measured values of stresses and ice forces under ice compacting leading to the ridging of the ice floes are presented in this paper. The calculated stresses were obtained using the knowledge of the ice strength characteristics. For the ice thickness exceeding 1 m, the ice forces can reach the order of severalMN·m⁻¹. Some evaluations of the ice forces obtained by calculations based on the mathematical modeling of the ice compacting processes are also presented. The critical values of the calculated stresses are close to the measured stresses, when dimensions of compacting zones are of the order of hundreds of kilometers.

<table>
<thead>
<tr>
<th>Age categories, thickness limit, m</th>
<th>Calculated values of stresses σT, MPa</th>
<th>Measured values of stresses σm, MPa</th>
<th>Calculated ice forces, qT, MN/m</th>
<th>Ice forces on shipboard, qh, MN/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>grey-white ice, 0.3</td>
<td>0.5-0.6</td>
<td>0.30 h=0.12m</td>
<td>0.15-0.18</td>
<td>0.13-0.18</td>
</tr>
<tr>
<td>thin first-year ice, 0.7</td>
<td>0.7-0.8</td>
<td>&gt;0.32 h=0.35m</td>
<td>0.49-0.56</td>
<td>0.47-0.64</td>
</tr>
<tr>
<td>medium first-year ice, 1.2</td>
<td>0.8-1.1</td>
<td></td>
<td>0.96-1.32</td>
<td>0.72-0.96</td>
</tr>
<tr>
<td>second-year ice, 2.5</td>
<td>0.8-1.6</td>
<td>&gt;1.72</td>
<td>2.00-4.00</td>
<td>1.50-2.00</td>
</tr>
</tbody>
</table>

Table 1 Stresses in ice floes and ice forces by compacting

In order to decrease the influence of the scale effect, the value σp0.05 is recalculated for the specimen with the side L equal to the ice thickness, using the formulas:

\[ \sigma_p = \bar{\sigma}_p(T,S) \cdot a \cdot b \cdot c \cdot d \cdot f \]

\[ \sigma_p \cdot L = \bar{\sigma}_p(T,S) \cdot a \cdot b \cdot c \cdot d \cdot f \]

\[ \sigma_p = \bar{\sigma}_p(T,S) \cdot a \cdot b \cdot c \cdot d \cdot f \]

by \( L = 0.3 \) m:

\[ \sigma_{p,0.3} = \sigma_{p,0.05} \cdot 0.45 \cdot 0.25 \cdot 0.30 = 0.42 \cdot \sigma_{p,0.05} \]

by \( L = 0.7 \) m; 1.2 m; 2.5 m:

\[ \sigma_{p,0.7} = \sigma_{p,0.05} \cdot 0.36 \cdot 0.50 \cdot 0.70 = 0.33 \cdot \sigma_{p,0.05} \]

\[ \sigma_{p,1.2} = 0.29 \cdot \sigma_{p,0.05} ; \sigma_{p,2.5} = 0.24 \cdot \sigma_{p,0.05} \]