External ice reinforcements for ships in operation

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Abstract. The subject of the proposed article is the external ice reinforcements of the ship hull. Ice reinforcements for the Russian commercial fleet are an urgent topic, but the traditional measures of such matter (replacement of the shell plating, installation of an intermediate frame) are expensive and require a large amount of preparatory work. External reinforcement are an alternative, which is much cheaper than their installation. As a rule, it is performed in the form of a rolling profile of various shapes (most often a semicircle) welded to the outer skin. In addition to the lower cost, they have a number of other advantages.

1. Introduction
The relevance of ice hull reinforcement for already operating vessels is due to several reasons. First, the renovation of the domestic commercial fleet is usually through the purchase of foreign vessels that already have significant service lives. These ships are generally not designed for navigation in ice conditions, and therefore for full navigation in the Russian seas (and they all belong to the freezing), their hulls needs reinforcements. For example, in the FESCO group, the share of foreign-built vessels is 75%, mainly ships without ice categories, i.e. their navigation will be difficult in the winter-spring period, even in the water area of the Amur Bay. Other paragraphs are indented (BodytextIndented style).

The second reason is connected with the expansion of Arctic navigation due to the activation of domestic cargo transportation along the Northern Sea Route, the development of mineral deposits and hydrocarbons in high latitudes. The increase in cargo traffic according to the FGUU "Administration of the Northern Sea Route" and FSUE "Atomflot" from 2011 to 2017 was from 3111 thousand tons to 10,691 tons, i.e. for 7 years the freight traffic increased by 343.7%, on average by 19.3% per year. The increased number of transportations on Arctic routes requires a greater number of vessels of high ice categories. For this, it is possible to build new vessels or (which is much cheaper) to modernize existing ones.

Traditionally, the following measures are used to increase ice hull strength:
- installation of intermediate set - frames, stringer;
- replacement of the outer shell plating with thicker ones;
- complete modernization of the sections of the ship (as a rule, the fore end);
- a combination of several methods.

The installation of the intermediate set represents a reliable and the most frequently used method of improving the ice qualities of the vessel. In this case, the strength of not only the set but also of the outer shell increases, due to the reduction in the dimensions of the plate. However, most often the installation of additional frames is required in the area of bulbous fore end contours. Here the
The execution of such work has technological difficulties, since the fore area of the hull is a cramped space, installation works in which it is difficult and requires a large amount of preparatory work.

Increasing the thickness of the outer shell plates is advisable to be used in combination with other measures of reinforcement of the shell or to increase the strength of the shell due to considerable wear. This is just a laborious and expensive method.

Modernization of the bow (cutting of the bulb) consists in the complete replacement of part of the underwater hull of the ship in the fore area. This is the most expensive measure, the use of which is justified only in rare cases. With an increase in ice hull strength and patency, this worsens the running and seaworthiness of the vessel on free water.

As a result of a brief review of traditional ice reinforcements, the following shortcomings should be noted:

- high cost of installation work because of the need to conduct them in cramped bow rooms;
- to achieve high levels of ice hull strength it is necessary to combine activities, as a rule, it is not enough just to install an intermediate set or change the shell plating.

Thus, there is a need for an alternative to traditional measures.

One option for this alternative is external ice hull reinforcement. They are rolled segments welded from the outside to the lining in parallel or at an angle to the waterline (figure 1 and 2).

![Figure 1. External ice reinforcements in the bow of the ship.](image1)

![Figure 2. External ice reinforcements.](image2)

In Russia, the concept of external reinforcements was developed at the Faculty of ship design of FENU (since 2012 it is part of FEFU) in 2008. Employees of the department developed projects of external amplification for the tanker-bunker "Flagman" and the refrigerator "Gulf of Raduga". Later, such gains were applied to other vessels.

In [1] the merits of this reinforcement method were called:

- in contrast to the internal set, the distance between the outer weld segments can vary over a wider range, which allows achieving the required strength level of the structure;
- such reinforcements are less labor intensive and the cost of installation is lower than that of traditional options, in addition, it requires considerably less preparatory work;
- welded segments serve as the protection of the outer shell plating, selecting some of the contact interactions with the medium.

Some aspects of this technology will be discussed below.

2. Effect of segments on the strength of the shell

The effect of segments on the strength of the hull was analyzed in [3]. As the object of analysis, a semicircular segment is taken (figure 3). The effect of segments on the strength of the skin was evaluated by two criteria: fiber yield and ultimate strength.

To assess the increase in the strength of the shell plating, the following indicators are proposed:

$k_{min}$ - coefficient of reinforcement by the criterion of fiber yield,
$k_0$ - is the reinforcement coefficient by the criterion of ultimate strength.

Both coefficients represent the ratio of the moment of resistance of the shell plating to the reinforcement at the moment of the resistance of the shell plating without reinforcements, calculated according to the corresponding strength criteria. Below are the formulas for determining them.

$$k_{\text{min}} = W_{RS} / W_S = \frac{\bar{C} - \bar{B} / \bar{A}}{R_s - B / A},$$

(1)

where $W_{RS}$ - the minimum moment of resistance of the shell plating with the reinforcements installed;

$W_S$ - the minimum moment of resistance of the shell plating without reinforcements;

$$\bar{A} = A / s b_s = 0.5\pi R_s R_b + 1; \bar{B} = 2R_b^3 / 3 - 0.5; \bar{C} = C / s^3 b_s = R_s^3 R_b / 8\pi + 1 / 3; R_b = R / b; R_e = R / s;$$

R - radius of the reinforcement segment;

b - segmentation interval;

s - shell plating thickness.

$$k_0 = \frac{W_{ORS}}{W_{OS}} = 2\pi R_s R_b (4R_b^3 / 3\pi - \bar{e}) + 2\bar{e}^2 + 2(1 + \bar{e})^2,$$

(2)

where $W_{ORS}$ - the limiting moment of the resistance of the shell plating with the reinforcements installed; $W_{OS}$ is the limiting resistance moment of the shell plating without reinforcements, $\bar{e} = 0.25R_s R_b - 0.5$.

In [3], it was concluded that the segments had an ambiguous effect on the strength of the skin: profiles with a sufficiently low value of the minimum moment of resistance could reduce the strength of the shell plating. Those to have a positive effect on the strength, the moment of resistance of the segment to be installed must be at least a certain value.

3. Influence of the outer segments on the wear of the outer shell plating

In this area, certain results have also been achieved - based on theoretical consideration of the problem, the calculated dependences for determining the wear of the reinforced shell plating are proposed.

It should be said that there is no operational data on the wear of the outer segments. Therefore, all the results obtained in this area are purely theoretical and require verification by practice.

Two theoretical approaches can be distinguished in considering a plate with reinforcements. The first relates to the case of installing reinforcements in parallel to the waterlines and assumes uniform wear of the segment (see Figure 3). According to him the following assumptions are proposed:

- the total weight wear of the shell with reinforcements does not exceed the wear of the shell without reinforcements; their equality is the most dangerous case, from which the calculation should be based;
- the reduction in the cross-sectional area is calculated from the allowance for wear set in the classification survey rules.

Figure 3. Symmetrical wear pattern of the segment.

Figure 4. The asymmetric diagram of segment wear.
To show the effect of segments on the wear of the shell plating, the reinforcement factor is used, representing the ratio of the wear of the shell with the established segments to the wear of the shell without them. Taking into account the accepted assumptions, the following formulas were obtained:

\[ k_s = \frac{\Delta S_s}{\Delta S} \]

where

- \( k_s \) - reinforcement factor,
- \( \Delta S_s \) - surcharge for reinforced plating,
- \( \Delta S \) - surcharge for the shell plating without reinforcement;

\[ k_s = 1 - \frac{m_s}{m_0} \left( 1 - \frac{R}{b} \right) \geq 0, \]  

where \( m_s \) is the coefficient of the allowed residual sectional area of the segment; \( m_0 \) - coefficient of allowable residual thickness of the outer skin according to the Rules.

\( R_0 = R / S_0 \), \( b_0 = b / S_0 \),

\( S_0 \) - the initial or required thickness of the outer shell plating, without taking into account the reinforcements.

The disadvantage of this approach is that wear depends on the thickness of the shell. For general reasons, it must depend on the intensity of the external loads.

Another approach is built for the case of the segment at an angle to the waterlines and assumes an asymmetrical wear (see Fig. 4). He proposes the following assumptions:

- reducing the thickness of the reinforcing segment does not exceed the reduction of the thickness of the shell without reinforcement as a result of wear;
- segment wear is uneven, resulting in a parabolic segment.

These assumptions made it possible to obtain the following formulas:

\[ k_s = \frac{1}{1 - 2R} \left( 1 - \frac{4}{3} \frac{R^2}{b^2} - 0.238 \frac{b}{\Delta S} \right) \geq 0, \]  

where \( \frac{R}{b} \). Table 1 shows the coefficient values for some combinations of \( R \) and \( b \).

**Table 1.** The values of the skin gain factor for \( \Delta S = 5 \) mm and for various \( R \) and \( b \).

| \( R, \) mm | \( b, \) mm |
|-----------|-----------|
| 250       | 300       | 350       | 400       | 450       |
| 30        | 0.88      | 0.90      | 0.92      | 0.93      | 0.94      |
| 35        | 0.81      | 0.85      | 0.88      | 0.89      | 0.91      |
| 40        | 0.71      | 0.78      | 0.82      | 0.85      | 0.87      |
| 45        | 0.59      | 0.68      | 0.74      | 0.79      | 0.82      |
| 50        | 0.43      | 0.57      | 0.66      | 0.71      | 0.76      |
| 55        | 0.23      | 0.44      | 0.55      | 0.63      | 0.68      |
| 60        | 0.00      | 0.27      | 0.43      | 0.53      | 0.60      |

As a rule, when installing reinforcements, \( b \) is selected in the range 250 ... 350 mm, \( R \) - 40-60 mm. The average value of the coefficient in this case is 0.67. Those. the amount of the wear allowance for the reinforced plating can be reduced by 30%.

**4. Conclusion**

The features of external ice reinforcement described above make it possible to consider them as a very effective and relatively inexpensive tool for reinforcing the hull. The advantages of this method were listed above. However, it is necessary to note some points that hinder the wide spread of this technology:
there is no regulation on the part of the Register, and therefore the development of a reinforcement scheme and the rationale for increasing the ice class is a non-trivial task requiring high qualification of the performer;

- there is no systematic study of the impact of such reinforcements on the strength of the hull;
- there is insufficient operational information on the operation of the skin with such enhancements in ice conditions

In general, the wide spread of external amplifications is hindered by the poor knowledge of this method. The accumulation of experience in the realization of such amplifications, given thickness gauges on vessels with realized reinforcements and theoretical studies should accelerate its popularization.

References
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