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Longitudinal strength problems in design of ships for loading nodules at sea

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Abstract
The naval architect has to tackle many of the problems, while designing ships for the loading, storage and transport of polymetallic or other nodules, this article focuses on how to assure appropriate hull strength. This author proposes mathematical relationships and operational and design solutions allowing to more effectively reduce shear forces and bending moments during the loading of nodules in the open sea. The suggested solutions may be used in the design of ships intended for such or other functions.

Introduction

As stated in [1], work is in progress on developing a system for mining nodules from the ocean floor. A key element of such system is a ship designed for loading, storage and transport of nodules to the shore. The mentioned publication presents theoretical considerations on design problems relating to ships for the carriage of nodules.

The density of nodules varies depending on their form, and ranges from 2 to 3.5 t/m^3. Loading a ship with cargo of such density creates structural problems similar to those characteristic of bulk carriers intended for heavy cargoes, ore carriers in particular. Due to the high density of cargo, most essential problems include the appropriate hull strength, particularly in the loaded condition [2] and counteracting excessive stability. Another design problem related to the conditions of bringing nodules to the ocean surface is to keep the vessel in position on the waves.

To satisfy the requirement of sufficient hull strength, naval architects seek adequate design solutions and, additionally, develop operational guidelines.

Design solutions implemented in ore carriers include [2]:

– selection of main dimensions, particularly the length/moulded depth L/H ratio;
– hull space division: number and location of transverse and longitudinal bulkheads;
– hold shape;
– increased depth of the double bottom in the area of holds;
– increased capacities of ballast tanks relative to holds capacity.

Operational solutions used in carrying heavy cargo include an optimal loading program ensuring that in all stages of loading the internal forces do not exceed maximum values. The requirement is generally fulfilled by loading heavy cargo in two stages.

This article presents considerations referring to problems of assuring the proper hull strength of a ship loading high density nodules in the open sea.

Design problems of adequate hull strength of a ship loading nodules in the open sea

Naval architects designing ships for carriage of high-density bulk cargo take into account the loading condition prior to departure, given that cargo handling operations are carried out in harbour where waves do not affect the ship. If we adopt such conditions in design guidelines, we do not take account of the distribution of internal forces occurring in instantaneous loading states in a port. The designer only takes into consideration distributions of internal forces acting in loading states of the ship setting out on a voyage. Such assumption greatly facilitates the designing process, because in such conditions (smooth sea) internal forces do not reach maximum values. The problem of negative distribution of internal forces during loading operations in a harbour is solved by implementing adequate operational procedures.

We should assume that the loading of nodule-carrying ship will take place in the open sea in varying hydrometeorological conditions. This means that naval architects should take into account internal forces occurring in all temporary loading stages of the ship in waves. This is an issue, because in such conditions internal forces may reach high values. To solve the problem, we should use additional operational or design solutions implemented in typical bulk carriers taking high-density cargo.

Proposed methods of reducing internal forces

Values of internal forces present in loading operations of typical bulk carriers carrying heavy cargo are reduced thanks to special loading instructions developed for such ships. The instructions recommend that during loading the load distribution should be changed to a minimum extent. This is achieved through:

- placing cargo in special holds;
- appropriate sequence of holds to be loaded;
- two-stage loading of selected holds;
- balancing the weight of cargo with the weight of ballast water;
- limited trim maintained during loading.

One operation reducing the impact of internal forces in a ship being loaded with nodules may be the loading, in which the weight distribution balances the buoyancy distribution to a greater degree than it happens in typical ships. This means that in the area of holds the distribution of ship weight $p(x)$ should be maximally balanced by the buoyancy distribution $w(x)$ (Fig. 1):

$$p(x) - w(x) \approx 0 \qquad (1)$$

where:

$p(x)$ – values of weight distribution;
$w(x)$ – values of buoyancy distribution.

We can define the parameter dp on the basis of the above relation (Fig. 1):

$$dp = p(x) - w(x) \qquad (2)$$

According to the relations (1) and (2), the condition for reducing shear forces and bending moments may be a method of loading such that for the possibly longest range of ship's length the value dp is minimum:

$$dp \to 0 \qquad (3)$$

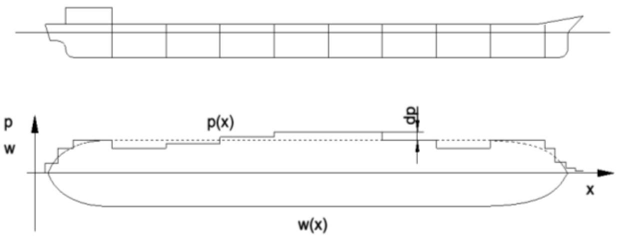

Fig. 1. Distributions of the weight $p(x)$ and buoyancy $w(x)$

The condition (3) in case of operational procedure may be satisfied through:

- simultaneous loading of nodules into all holds (Fig. 2);
- multi-stage loading into holds of small portions of nodules.

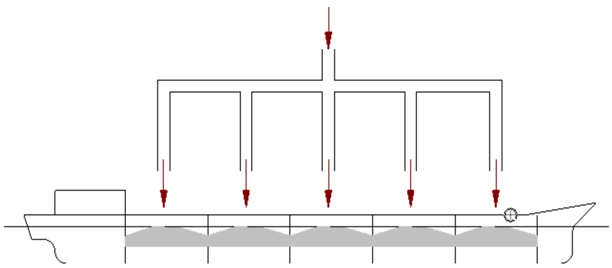

Fig. 2. Simultaneous loading of nodules into all holds

The major advantage of the former solution is fast loading operation, while the disadvantage consists in the need to separate the flow of nodules into a few streams, which requires a complex system of cargo transfer. The positive aspect of the latter solution is that a typical system of loading can be used, while long loading time is its disadvantage.

On the other hand, the condition for balancing the weight of nodules during loading is skillful handling of ship's ballast. Due to the high density of nodules the proportion of ballast tanks volume relative to the volume of holds should be larger than in typical ore carriers.

To allow for the impact of waves on internal forces, operational guidelines should be provided, specifying the maximum sea state at which loading operations can be conducted, and the parameters allowing for the suspension of loading. This can be done by using the methods described in [3, 4, 5].

Other design solutions aimed at the assurance of required hull strength of a ship transporting nodules include:

1) determination of the length / moulded depth ratio L/H, for given spatial arrangements, so that we obtain an acceptable level of internal forces in specific wave conditions;

2) increase in the volume of ballast tanks to facilitate the balance of the buoyancy curve.

To determine the value of L/H ratio at which internal forces will reach an acceptable level, we should define the relation between the indicator IF describing the level of internal forces and ship's length L, irregular wave parameters, such as significant height H_S and characteristic period T:

$$IF = f(L, H_S, T) \tag{4}$$

where:
IF – indicator describing the value of internal forces;
L – ship's length;
H_S – significant height of wave;
T – characteristic period of wave;
f – searched-for approximating function.

The function f can be calculated through statistical analysis of internal forces occurring in ship hulls:

- of various lengths (Fig. 3);
- with assumed hold configuration;
- at various states of hold filling;
- sailing in various wave conditions.

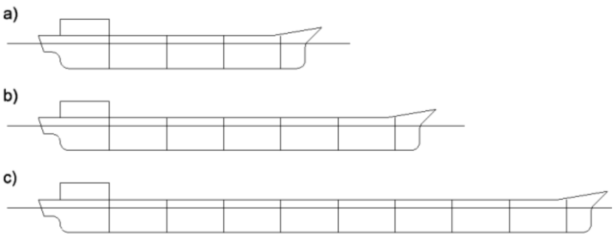

Fig. 3. Selected configurations of holds in ships of various lengths, constant hold length

Relation (4) can be used as a limiting function in the preliminary design of a nodule carrier. For this purpose one should adopt a certain IF value and assume wave conditions generally prevailing in the ship's operating area.

For better balancing of the buoyancy curve by ship's ballasting, we should increase the volume of ballast tanks in relation to the volume of holds. The proportion can be represented by the ratio of cross-section area of ballast tanks Fb to the cross-section area of holds containing the cargo of nodules Fk at a given location of the ship (Fig. 4):

$$\mu = \frac{Fb}{Fk} \tag{5}$$

where:
μ – coefficient;
Fb – ballast tank cross-section area (Fig. 4);
Fk – cross-section area of a hold with nodules.

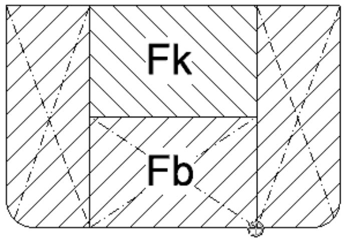

Fig. 4. Cross-section area of ballast tanks Fb in relation to cross-section area of a hold loaded with nodules Fk at a given frame

Considering the relations (1), (2), (3), (5) we can reach a design solution by determining a value of μ at which the parameter dp will reach the minimum with:

- assumed geometry of a hold described by the area Fk;
- assumed specific gravity of nodules,

that is

$$dp = \left(\mu \cdot Fk(x) \cdot \gamma_b + Fk(x) \cdot \gamma_k + p_{sp}(x)\right) - w(x) \rightarrow 0 \tag{6}$$

where:
γ_b – specific gravity of ballast water;
γ_k – specific gravity of nodules;
p_{sp} – weight distribution of a light ship.

Note that the determination of μ via the relation (5) is only possible through iteration, because when the value μ changes, the buoyancy distribution $w(x)$ may also change.

From the relation (5) we can calculate the volumes of ballast tanks to allow for more effective ballasting of the ship during the loading and discharge of nodules.

Conclusions

Operational and design solutions suggested in this article may permit to more effectively balance the internal forces during the loading of nodules in the open sea. The proposed methods may constitute a basis for further research and design analysis aimed at assuring proper strength of a ship for the carriage of nodules. The presented relations may be used for working out design guidelines allowing to reduce internal forces on nodule carriers.

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