THE CONCEPT AND CALCULUS OF 'REFLOATING A SHIP' APPLIED TO GROUNDED SHIPS

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ABSTRACT

Grounding has been representing an important topic in the maritime industry because it is almost always connected to a catastrophic pollution of the marine environment. It is really important for the shipping industry to manage to obtain such a ship's construction with respect to the grounding events but this problem has been only partially solved. Another important matter is represented by the refloating methods that should be applied on these ships that are grounded in order to minimize the effects of the pollution that could arise from this operation. There is a need for a basic understanding of the geometry, stability and strength of intact ships before trying to refloat a damaged, grounded or sunken ship. Understanding these, the refloating operation can be evaluated in accordance with the ship's properties that vary during the grounding event.

Keywords: *ship, grounding, refloat, pollution, marine.*

1. INTRODUCTION

It is really vital to have a well thought-out and organized refloating plan in order to apply a certain refloating operation.

In order to have such a refloating plan it is necessary to investigate properly the ship's site and gather the appropriate information.

To develop a workable refloating plan, the position and condition of the ship must be evaluated, understand the complexities of the given situation and conceptualize the work and methods necessary to accomplish the aims of the operation.

Planning must proceed from broadly based tactics covering entire operations to detailed plans for specific ships or other portions of an operation.

In all cases, the plan must serve the purpose of the operation; then balance the work to be done with the resources available and the schedule required.

Ships' groundings can have devastating effects on the marine environment.

Cleaning up after a major grounding event could lead to enormous amounts of money and even then there is no certainty that the cleaning process has the best results or even the wanted results.

The society needed such events to truly admit that there is an increased need for safer ships and also for new requirements in ships' construction so that this kind of unfortunate events would not be met again in the future in the maritime business.

It is not a good thing that these requirements are triggered only when there is an appropriate media attention given to these events.

This kind of requirements should first of all come from the shipbuilders and afterwards from the ship-owners but due to the high costs involved that arise from these safety measurements it can be easily understood that it is not in their interest to raise the expenses in the process of building a ship.

Also, when talking about refloating a grounded ship, it is first of all necessary to fully understand the event that lead the ship into that position so that the best method for refloating is applied. It is an important demand to establish the appropriate method of refloating so that the risk of pollution is reduced to minimum.

2. GROUNDING ISSUES

A grounded ship is subject to very different forces and conditions than when in normal service. Part of a grounded ship's weight is supported by the surrounding water, part by the ground.

The portion of the ship's weight supported by the ground is *ground reaction* (Φ), or *tons aground*; it is equal to the lost buoyancy. The ground reaction distribution is uneven and unpredictable. There are four major effects of ground reaction:

- The loss of buoyancy alters hydrostatic characteristics and hull girder loading.
- The upward force of ground reaction at the keel causes a virtual rise in the centre of gravity.
- Extremely high local loading with damage or penetration of the hull can occur, particularly on rocky bottoms.
- Ground reaction holds the ship stationary; she cannot respond to or fall away from disturbing forces, such as waves, as she does when afloat.

The conditions of a grounding event are seldom fully defined in the beginning and often are not completely defined during the refloating operation.

The grounding condition and the environment are the principal sources of forces on a grounded ship.

Ship's refloating is time-critical because environmental conditions may improve or worsen with time, but the condition of a grounded ship steadily deteriorates.

The way the ship lies on the ground and her position relative to the seafloor and coastline influence the casualty in two ways:

- The way the ship lies on, and is supported by, the ground is a principal indicator of the effort required to free her.

- Distribution of the ship's weight between residual buoyancy and ground reaction affects stability and strength.

The ship's position relative to the shore and underwater features can either intensify or mitigate environmental effects. Specific considerations are:

- Magnitude and distribution of ground reaction.
- Changes in list and trim caused by the stranding.
- The area of the ship in contact with the bottom.
- Depth of water under and around the ship.

An overall view on groundings categorizes the accidents in two major groups:

- Grounding on soft sea beds, so-called Light Groundings. The damage to the hull in terms of crushing at the point of ground contact is limited but the hull girder may fail in a global mode due to shear force and bending moment exceeding the hull girder capacity.
- Grounding on hard bottoms, so-called Hard Groundings. The primary concern here is the local crushing and tearing of the ship bottom due to a cutting rock.

The force required to move a casualty over its strand is the sum of the forces required to:

- Overcome friction between the ship and seafloor.
- Move loose seafloor material that may be pushed ahead of the ship.
- Break or crush obstructions or impalements, such as rock outcroppings, coral heads, etc.
- Overcome suction on soft bottoms.
- Friction is a function of ground reaction as modified by other factors, such as the coefficient of friction of the bottom, the area of the hull in contact with the bottom, and the casualty's list and trim. Freeing force is reduced by decreasing the effects of these factors, as well as by decreasing ground reaction.

3. CALCULUS FOR A GROUNDED SHIP

A ship is considered to be grounded if there is contact between the keel and the bottom of the sea.

Grounding affects the initial equilibrium adding to the weight and pressure a third force, Φ, called grounding reaction, as a result of elementary reactions in contact points.

We have P_0 and η_0 the weight and pressure before grounding. After grounding, the ship is subjected in her new position of equilibrium to forces $P=P_0$ (unchanged weight), η (new pressure) and Φ grounding reaction. Reaction Φ is therefore necessarily vertical having a value:

$$\Phi = P - \varpi W \qquad (1)$$

Reading the draught of the grounded ship defines the keel, resulting W and Φ, P so that the position of **G** is calculated starting from a standard situation considering the real situation of the cargo and perishable cargoes at grounding. The vertical of Φ is established through the annulment condition of the resulting moment. The application point E on this vertical is usually deducted with an excellent approximation of the position of the contact area.

We can compare grounding with removing a weight Φ in E. E having a very low position and Φ being relatively high, it results in an important reduction of the stability which we can appreciate by diminishing the module P (r – a) which becomes $P\left(r-a\right)-\Phi e$, where e is the vertical distance separating E from the differential meta-centre reported at transversal canting, or easier at floatability.

A grounded ship is seldom in danger of listing, given that groundings frequently cause ruptures on the ship's hull and invasions leading to water holes which negatively influence stability. Meanwhile the contact area resulted could be sandy blocking the ship's hull and preventing the ship from listing.

If several particular classical situations are accepted (grounding in the centre of sternpost) the issue arising when the ship is grounded is obviously that of refloating the ship.

If grounding is an easy one, meaning that the grounding reaction is weak, the ship may be refloated by her own means, putting the engine full astern for example, or by using tugs.

In some cases, the tides' help could be waited for and then refloating comes naturally: if grounded in shallow waters, the ship could refloat at high tide.

On the contrary, groundings at high tide are more dangerous as the grounding reaction increases once the sea level decreases leading to a higher risk of listing.

In serious situations, efforts should be made for vertical refloating which could be done in different ways: relieving weight by unloading weights (the simplest method), auxiliary floatation means, lifting machineries (lifting craft, crane), etc.

The method for calculating these efforts (values and target points) depends on the nature of grounding.

We shall limit our exemplification to the case of the ship grounded in point E of the keel (figure 1) considering the adding or elimination of some weights. Using some simplified results, we shall only get an approximation, but this would be usually enough for defining a way of action even if the weights loaded and unloaded from the ship are really small when compared to P.

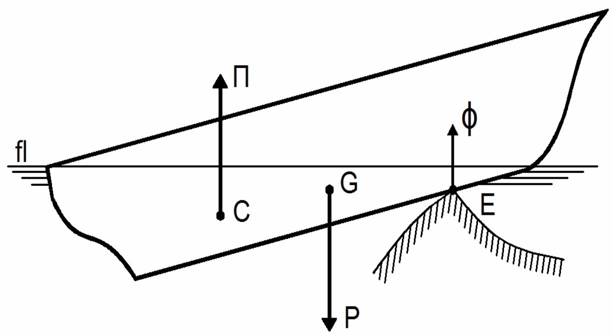

Figure 1 A ship grounded in point E

3.1 Example of a calculus of refloating efforts

Let it be t_E the draught of the grounded ship in section E; t_E is a datum of the problem representing the riprap or rock filling immersion at contact. If the free ship had in this section an inferior draught compared to t_E, grounding in E wouldn't have happened. We should consider the efforts which, applied on the ship before grounding, would have led to a draught equal to t_E (limit condition). Applying these efforts on the grounded ship should refloat point E, and consequently liberate the ship astern if trimming is positive and headways if it's negative.

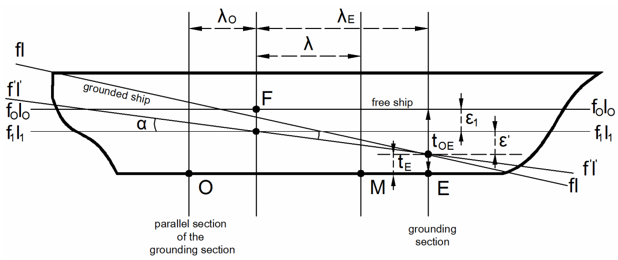

Figure 2 Forces acting on a grounded ship

The vertical of M is applied on the free ship before grounding (floatation f_0l_0) an effort Φ directed upwards and the value of Φ is determined in such way that the variation of the section's draught E should be: $\Delta t = t_{OE} - t_E$. We can write Φ' being considered to be positive upwards and λ positive in front of F:

- applying Φ' in section F:

$$f_0 l_0 \to f_1 l_1, \quad with \quad \varepsilon_1 = \frac{\Phi'}{\varpi\Sigma} \tag{2}$$

- transfer of **Φ'** from section F in section M:

$$f_1 l_1 \to f'l', \quad cu \;\; tg\alpha = \frac{\Phi'\lambda}{P(R-a)} = \frac{\varepsilon'}{\lambda_E}$$

$$resulting \quad \Delta t = \varepsilon_1 + \varepsilon' = \frac{\Phi'}{\varpi\Sigma} + \frac{\Phi'\lambda\lambda_E}{P(R-a)} \tag{3}$$

$$and \quad \Delta t = \frac{\Phi'}{\varpi\Sigma}\left[1 + \frac{\varpi\Sigma}{P(R-a)}\lambda\lambda_E\right] = \frac{\Phi'}{\varpi\Sigma}\left(1 - \frac{\lambda}{\lambda_0}\right)$$

O being the conjugated point of E in the equilibrium position f_0l_0.

The refloating effort on the vertical of point E ($\lambda = \lambda_E$) is of course equal to the grounding reaction, Φ:

$$\Phi = \varpi S\Delta t \frac{\lambda_0}{\lambda_0 - \lambda_E} = P - \varpi W \tag{4}$$

Resulting in the expression of Φ':

$$\Phi' = \Phi\frac{\lambda_0 - \lambda_E}{\lambda_0 - \lambda} \tag{5}$$

The refloating effort on the vertical of the floatation centre is:

$$\Phi'_F = \varpi S\Delta t \tag{6}$$

And we can also write:

$$\Phi' = \Phi'_F \frac{\lambda_0}{\lambda_0 - \lambda} \tag{7}$$

Φ' is infinite for $\lambda = \lambda_0$. Any effort applied on the vertical of **O** cannot lead to a variation of the draught in E (definition of the conjugated points).

The curve Φ' (λ) is in the shape represented by figure 3.

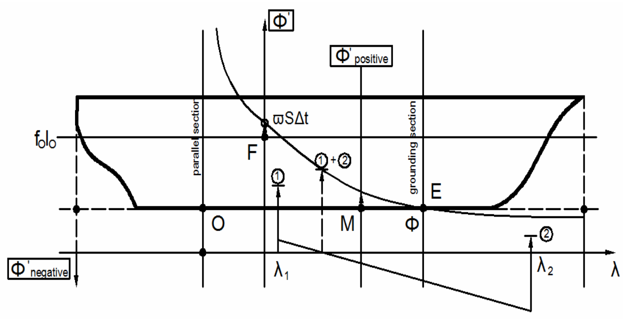

Figure 3 The curve Φ' (λ)

It represents particularly the value of the refloating effort which must be applied right forward (minimum effort).

It also allows the definition of efforts' combinations, such as:

(effort 1 in λ_1 (floatation gears)
(
(+ effort 2 in λ_2 (lifting craft)
(
(= refloating effort 1 + 2 sufficient.

Corresponding characteristics at f_0l_0 are not known in advance but, as previously mentioned, they are accessible through calculus starting from well known standard situations. After grounding, the usual actions are relieving the ship by unloading all possible weights, especially in high areas (improving stability) as well as the starting situation f_0l_0 which is already an attenuating situation.

The action of the tide is simply introduced in the calculi above through the variation of t_E meaning Δt**,** resulting in several curves Φ' (low tide, high tide, medium level sea). The refloating operation is of course performed at high tide as the efforts are minimal then.

3.2 Stability calculi

We shouldn't omit a close pursue of the evolution of transversal stability from the grounding moment calculating the consequences of every operation.

Considering only one module of the initial stability and the calculus approached by the initial formulas are generally not enough; therefore we shall be led towards establishing some stability diagrams complete for a certain number of intermediary situations. If there are any keels near the right ones, the calculi are simple, but it rarely happens so when it comes to grounding.

In any case, the next resultants should always be present (applicable of course to weights or important forces):

- weights on board (forces working downwards) above the floating line
- weights unloaded (forces working upwards) above the floating line
- mobile weights, especially topsides

All three of them represent danger to the grounded ship.

4. CONCLUSIONS

During maritime transport it happens many times for ships to run aground. There are various causes for this, combining usually human error with unfavourable meteorological conditions.

In most cases, crews try and usually succeed to refloat the ship by her own means. The procedure is a relatively simple one consisting in moving weights from bow to stern if possible and putting the main engine astern in different rudder angles, but there are several cases when the ship severely runs aground and there is an urgent need for a calculus type in order to help the crew and the rescue team establish the most efficient method for refloating.

This paper presented an alternative for this particular calculus.

The need for immediate refloating is time critical

because there is always a risk for the grounding event to determine a catastrophe for the marine environment.

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