**COPINAVAL - 2009**

# TECHNICAL ASPECTS OF REFLOATING OPERATIONS FOR GROUNDED VESSELS

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**ABSTRACT**

Despite all improvements and electronic developments relating to the safety of navigation and associated with crew training nowadays, accidents occur and will always occur for a variety of reasons. Groundings happen for different reasons, ranging from a main engine breakdown to an inadequate medicine ingested by the bridge duty officer or assisting pilot or ingestion of alcohol.

Upon grounding, immediate assistance is required in order to mitigate damages to the vessel and to the environment and related costs. Prompt assistance given to a casualty may boost one's chances of performing a salvage operation rather than a wreck removal operation: the situation of grounded vessels deteriorate quickly due to different factors such as weather and the nature of the bottom where the vessel is standing.

Additionally, considering the updated worldwide rules and regulations for environmental protection, bunkers removal from grounded vessels is fast becoming mandatory in order to mitigate hydrocarbon environmental damages, thus avoiding heavy penalties and lawsuits from different parties. In addition to bunkers removal, in case of constructive or actual total loss, it is often also necessary to proceed with the wreck removal because of visual pollution and, in some cases, lest the vessel becomes a peril to navigation.

Today, the idea that a powerful tug will solve all problems related to a grounded vessel is technically unsound. Together with a skilled salvage master and salvage team, a good shore-based technical and scientific team must be available for support in a 24-hour/day regime.

This paper highlights the main technical aspects related to salvage operations as inspection of the casualty, including cargo and flooding, inspection of the site, including weather conditions, availability of material and equipment, stability and strength calculations, grounding reaction calculation, cargo transshipment or jettisoning, patching and dewatering, pulling with usage of beach gear or tugboats and dewatering and assisted refloating. Examples and case studies are included and new research areas indicated.

## 1.0 Introduction

The objective of this work is to approach statistical and technical studies related to shipping accidents, including, but not limited to groundings, whether in rivers or at sea, both within a Brazilian and worldwide scenario. Initially, so that we can better understand the dynamics of the parties involved in grounding occurrences, it is necessary to go back in time and learn a little about the oldest modes of insurance, the formation of today's largest world insurance market and the technical and commercial developments of the different salvage operations of vessels and other crafts.

Marine salvage is the process of rescuing a ship, her cargo and in some cases her crew from a danger. Salvage operations includes rescuing by means of a tugboat, refloating a grounded or sunken vessel, patching or repairing a vessel. Nowadays, protecting and preserving the environment from cargoes like oil and other contaminants is considered more important and with a higher priority in relation to saving the ship and recovering her cargo.

For the carrying out of salvage operations, cranes, floating docks, diving teams and tugboats are used; all with the aim of refloating, lifting, repairing and towing a vessel under safe conditions.

In marine salvage, there are different interests represented by their "*Experts*". The parties involved do not always show compatibility in their attributions and in the development of their services inherent to that salvage operations. Normally, shipowners, cargo owners, insurers and the rescuers of the goods or thing have a legal and common interest in preserving the value of the goods in danger. However, there are other interests that may think that the cargo or even the ship could be a source of pollution, and simply ignore any value that the goods may have in view of getting rid of the problem as soon as possible.

The salvage coordinator, also known as the project manager or salvage master, is the technician who is in charge of the whole salvage operation. The salvage team to be chosen should be such that they have all the qualifications and skills necessary and should be of the least number possible.

The salvage team, composed of different professionals, such as divers, mechanics operators, welders, blowtorch operators and electricians, is responsible for the whole execution of the salvage plan prepared by the salvage engineer together with the salvage coordinator.

The shipowners are those who have the greatest interest in the goods or thing in danger and their prime interest is to have these goods or thing back to normality and generating the cash flow necessary to their business.

Hull and machinery underwriters, civil liability underwriters, cargo underwriters and others will always be present at the salvage operation and each of them will defend their interests, including in the declaration of general average.

During the development of a salvage operation, it is common that only the hull and machinery underwriters and the vessel's owners'civil liability underwriters (P&I Club) have access to the ship and the information relative to the development of the operation by the vessel salvors.

In different salvage operations government agencies also may take part in the salvage process of a vessel by force of the law. Their participation is quite broad in the world scope and is aimed at the preservation of the environment and maintenance of the existing goods. Their tasks are developed with the help of the personnel involved with the salvage operation and through their representatives who are placed on board for technical and operational accompaniment.

Construction plans and drawings should be studied and all the technical and operational information available should be stored for future use, while the salvage plan takes shape. Such information is also necessary during the development of the salvage operation.

## 2. Salvage Operations

Salvage operations are generally classified into the following categories:

### a) Grounding

There are the most varied causes for grounding: winds, currents, sea conditions, tides, etc. A ship grounds due to human error or mechanical failure. The development of one grounding is never identical to another similar one. It is possible to state with technical reasonability that the results of groundings are always different. Navigation errors, navigation close to the coast, winds, bad weather, unknown currents and mechanical problems are contributing factors to groundings.

A refloating operation can be done by applying different methodologies or a combination of pumping ballast in or out and handling anchors.

Pumping ballast into empty water, fuel and cargo tanks so that a positive grounding reaction is obtained thus avoiding the adverse effects of buoyancy caused by tide variations or waves (surfing). The amount of ballast to be pumped should be determined based on the buoyancy characteristics of the vessel. Excess ballast should be avoided, since this may cause excessive stresses on the hull which may aggravate the damage.

Sea conditions permitting, anchors may be dropped as soon as possible after the vessel runs aground. Positions and distances must be calculated so as to maintain the grounded vessel in a fixed position and in such a way that ropes or chains may be tightened from time to time, as necessary.

**b) Sinking**

A ship sinks when she loses its reserve of buoyancy and some of the causes of sinking may be:

i. Flooding because of a failure of a valve, piping, hull plating, etc.
ii. Collision with a submerged object causing water to enter.
iii. Collision with another ship or floating or fixed structure.
iv. Bad weather causing capsizing or rupture of the hull plating.

The methods for removal of a ship from the bottom are:

**Pumping**

The vessel cannot be under more than 10.00 meters of water, as building cofferdams for depths greater than this would be difficult and costly, due to pressures imposed to the same.

**Compressed Air**

This method is the fastest for the removal of a small size vessel from the bottom. The organization of a salvage operation with the use of compressed air requires experience by the person responsible so that it is done successfully.

The use of compressed air in refloating operations requires that any patching or repairs done to the hull of the vessel are complete and waterproof, which is not required for pumping operations. Extensive work is necessary by the divers, whether for patching the hull or stabilizing the craft, and this type of work can be expensive, in terms of material, labor and time.

Regardless of the factors above, and before deciding for the use of compressed air, one should consider:

i. Size and number of openings in the hull;
ii. Number of patching-ups required and necessary;
iii. Cost of the operation;
iv. Pumping rate of the compressors
v. Stability calculations required during the de-watering operation using compressed air.

**Lifting**

This method requires a lot of seamanship with cables and tackles and the size of the ship to be saved is directly related to the lifting capacity available on the market.

Currently on the world market, the largest floating crane in operation has a capacity to lift 14,000.00 tons when using its two booms in parallel. Also available in the market, and easier to find, are floating cranes, selfpropelled or otherwise, with lifting capacity ranging from 600.00 up to 3,600.00 tons

**Towing**

Towing operations are much less complicated than salvage operations of grounded or sunken ships. Salvage by towing consists in simply towing a vessel or craft, helping a ship that is adrift due to problems resulting from mechanical defects, bad weather or collision with submerged objects or other ships or floating or fixed structures. It can also be employed where light groundings have occurred in muddy or sandy bottoms and in which the calculation of the grounding reaction results in a force such that the jettisoning of cargo or liquids is not needed, and that the pull of the ship associated with the tide variations or increase in the level of a river gives clear indications of a safe operation which will not cause any damages to the environment.

For the success of a rescue operation on the high seas, the following requirements are basic:

i. Tugboat, equipment and crew suited to the operation to be carried out.
ii. Knowledge of navigation for the fast location of the vessel in danger.
iii. Crew qualified for high seas approach for passing ropes and making connections.
iv. Knowledge and experience of trip-in-tow.

## 3.0 The Environment

Coastal damage caused by storms or bad weather is made worse by the consequences that these phenomena cause to ships, and fixed or floating structures. Pollution by hydrocarbons and / or chemical products caused by navigation accidents (groundings, shipwrecks, collisions) or simply the visual pollution caused by the abandonment in some cases cause problems to navigation channels.

In the world the preoccupation and the scenario are not different. In the great majority of oil spills in the sea, the quantity of oil spilled is less than 7 metric tons and details and figures are incomplete, according to data available through the ITOPF – International Tanker Owners Pollution Federation, that is a non profit technical organization based in London, and involved with all aspects relative to the preparation and response to spillages of oils, chemicals and any other substances into the marine environment.

Relative to the spills of oil and damages to the marine environment, ITOPF maintains a world database of the quantities of oil spillages caused by accidents at sea. The graphs in figure 1 and 2 show the results obtained by an analysis of the data obtained in the ITOPF.

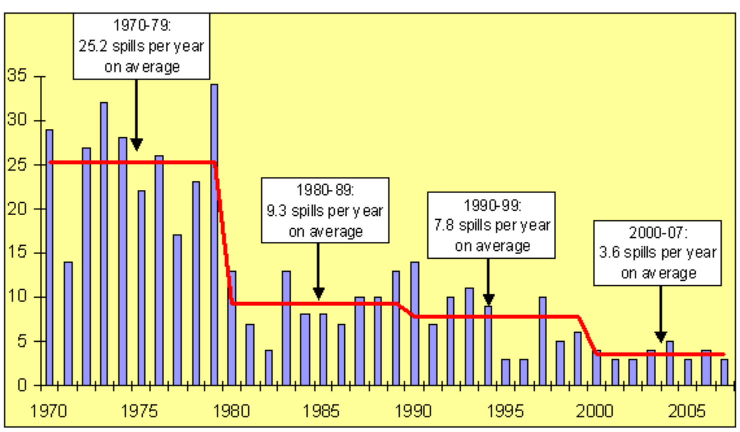


Figure 1: Number of spillages above 700.00 tm (1970→ 2005) (Ref.32)

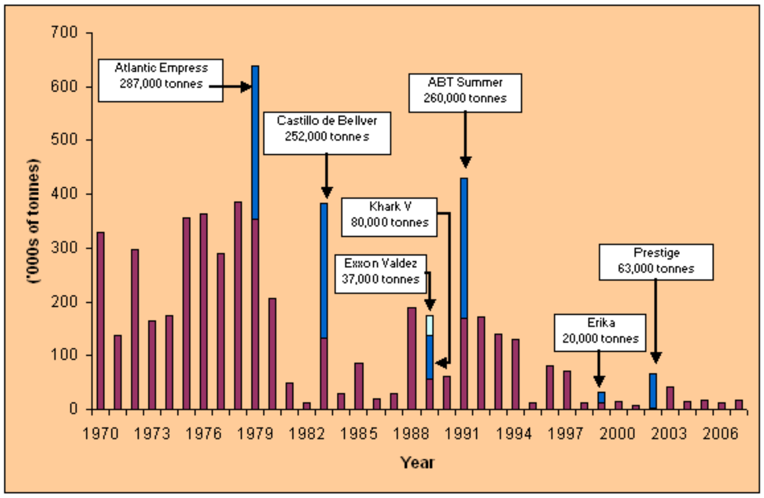


Figure 2: Amount of oil dumped into the sea (Ref. 32)

In Brazil, the last large spillage of oil by a ship in the marine enviroment occurred on 15 November 2004 due to an explosion and fire on board the Chilean flag vessel "Vicuna" of Sociedad Naviera UltraGás de Santiago – Chile, while she was berthed at Cattalini Marine Terminal, in the port of Paranaguá. .

**4.0 Aspects in the Grounding of Vessels**

When grounded, a vessel is subject to adverse loads that are not present when she is sailing. Associated to this, there are the damages resulting from the grounding, which will affect her structural strength. In this way, it is important that the salvage coordinator *(Salvage Master)* or salvage engineer has knowledge of and understands the movements and loads imposed on the vessel or craft after grounding.

Stabilization of the grounded vessel can be obtained by dropping her anchors at previously calculated positions and distances, by using a *beach gear* or simply by adding weight through a ballast operation.

The basic techniques used nowadays for refloating of a vessel or craft are:

i. Reduction of the static grounding reaction;
ii. Static traction applied in the direction of deep waters;
iii. Increase in the depth of the water in the site of the grounding;
iv. Combination of some of the items above.

In some cases of partial grounding, success in refloating is obtained by maneuvers associated with changes in the positioning of weights on board, adjustment of ballast and consequent changes in trim. A change in the position of the grounding reaction is altered along the body making the efficacy and yield of the force applied to the grounded vessel to be greater.

The application of static traction, whether pulling or pushing, requires force in an amount sufficient to overcome the forces of friction, suction and bottom elevations resulting from the grounding. The force of friction in the mud is the result of the product of the sheering force and the area in contact with the bottom; removing the mud from around the hull will help in the refloating operation. The force of suction can be minimized with fore and aft movements of the grounded vessel or by the scouring effect that may increase the flow of water past the hull. The use of dragging and scouring may increase the depth of the water in the site of the grounding. Tides also cause an increase in the depth in the site of the grounding, but in a temporary manner.

Grounding is treated as an event with little probability and large consequences, which is the reason why every grounding should be conducted under a regime of urgency, under all and any aspect.

An inspection of the state of the vessel after grounding is fundamental for the strategy to be adopted in the salvage. The submerged parts of the hull should be checked as to their general state and operationality, including seachests , the rudder and tailshaft sealing system. In cases where an underwater inspection is not possible or is limited due to meteorological conditions or characteristics of the site of the grounding, all the conclusions on the general conditions of the hull will have to be made by an observation of the internal part.

The underwater inspection, when done, should cover the following items:

i. The area of the hull in contact with the bed of the sea or river;
ii. The existence and location of rocks;
iii. The existence and location of penetrations in the hull;
iv. Location and dimensions of cracks and openings in the hull;
v. Type of soil in the grounding location and existence of an accumulation of material or the effect scouring.

The salvage plan defines all the work to be done covering the availability of equipment and stating dates and times for the different events; sets out the responsibilities of each member of the team or participating company; and is the instrument for coordinating all the salvage work so that the dates and times stipulated in the project can be complied with.

A good salvage plan should consider, contain and include the following topics:

i. The safety of the personnel involved;
ii. Safety of navigation in the region of the grounding;
iii. Time schedule for the work;
iv. Estimates of the costs involved;
v. Locates and makes available, as necessary, the resources required;
vi. Considers the dynamics of the accident due to the constant changes;
vii. Identifies the areas of risk and weaknesses.

The principal evaluations to be done by the salvage coordinator *(salvage master)* or salvage engineer should include:

i. Grounding reaction (static)
ii. Refloating effort
iii. Location of the neutral point of the loading (if applicable)
iv. Stability while grounded and while floating
v. Strength of the hull, damaged areas and points for application of forces and lifting
vi. Summary of the technique applied during refloating
vii. Hydrographic studies

Any technician who is involved with works relative to the salvage of vessels or any other type of craft should be familiarized with the geometry, stability and structural strength of these vessels when intact, which will allow them to:

i. Make approximations in the calculations and make technical decisions which will always be on the conservative and safe side of the project being handled,
ii. Understand the behavior of the grounded vessel, and

iii. Have a greater technical capacity as salvage coordinator *(salvage master)* or salvage engineer.

In the cases of vessels aground or during the refloating, control of weights should be even greater, and their effect on the displacement, trim and stability should be known before performing it. The removal of weights from the wrong areas or the excess removal of weights may result in a condition with precarious stability resulting in danger when refloating the vessel. The same happens as to the placement on board of salvage equipment, the placement of such weights should be avoided in high positions.

Flooding represents one of the greatest dangers to any vessel because it may result in its loss by:

- Sinking because of a loss of her buoyancy reserve, or
- Capsizing because of a loss of stability.

The flooding of a vessel may be the result of the water used in firefighting, open sea, collisions, explosions, damages to the cargo transfer systems, and any other damages that allow the entrance of liquids through the vessel's hull.

A compartment that is partially full of liquid will have this same liquid moving from one side to another according to the movements of the vessel and reducing its stability.

The combined effects of flooding are:

- Increase in displacement;
- Movement of the center of gravity position;
- Free surface effect;
- Effect of free communications (open hull and bulkheads).

The movement of the positioning of the center of gravity may improve or worsen the stability conditions of a vessel depending on the location of the shifted weight. The free surface and free communications effects always worsen stability. Each one of these effects occurs separately and should be calculated in an independent manner.

Heeling or listing is a symptom and not a cause of a reduction of stability, and its probable causes are:

- Placement of weights outside the center line
- Negative metacentric height (GM)
- A combination of the two items above.

Whenever there is heeling or listing, it is of vital importance to determine the cause before any correction, because improper corrective actions may aggravate the situation.

The longitudinal strength of a vessel is defined as the capacity that it has to support the forces imposed by its loading and the sea, including a percentage of uncertainties for other conditions, including salvage.

Two conditions common during salvage require that the force levels be calculated:

i. The vessel may have a loading not forecast in its original design.

This can happen due to flooding, grounding or another unusual loading condition making its maximum bending moment to be at another point that is not close to the midship section (amidships). The same happens with the location of sheer forces.

ii. Damage that alters the distribution of forces on a section making the maximum bending moment and maximum sheer forces occur in sections other than those above.

Damage, even in a small length, interrupts the continuity of the longitudinal elements and reduces the section module at any distance from one of the sides of the damaged section.

During a salvage operation, an analysis of the structural strength is used to determine:

i. The structural strength of the grounded vessel at the first moment;
ii. The effects of the salvage plan;
iii. The capacity of the grounded vessel to support loads.

## 5.0 The Grounding reaction

The involuntary grounding of vessels is the most common cause of accidents involving salvage operations. The vessel aground finds herself in a position that her designers, constructors and operators never intended her to be.

When a vessel runs aground, whether by a navigation error or by mechanical failure, the momentum will take her to the beach or reefs where she will remain partially supported partially by its buoyancy and partially by grounding. The amount of buoyancy lost is equal to the weight supported by the ground.

**Weight = Buoyancy + Grounding reaction**

The tides and their variations are of great importance in cases of grounding, because their variation makes the grounding reaction increase or reduce, that is:

| | | | |
|---|---|---|---|
| Incoming | → | Buoyancy > | Grounding reaction< |
| Outgoing | → | Buoyancy < | Grounding> |

During the development of refloating operations, it is important to know the heights of the sea during the tidal variations. In case such values are not tabulated, and assuming that between high tides the sea follows a cosine graph, we can obtain a good approximation of the values by using the expression (1)

$$Hn = \frac{R}{2} x \cos \Theta + \left(\frac{R}{2} + Hlw\right) \quad (1)$$

Where:

| | | |
|---|---|---|
| Hn | → | Height of tide at an hour “n” before or after high tide |
| n | → | Hours before or after high tide |
| Ǿ | → | Phase angle of the sea for one hour ( 180/T Degrees or π/T radians, where T is the duration of the ebbing or rising tide) |
| Hlw | → | Height of the ebbing tide in relation to the datum |

Two qualities are important for the grounding reaction: size and distribution. The size of the grounding reaction is calculated by mathematical formulas considering the fundamental aspects of naval architecture while its distribution is difficult to estimate. There are not methods for estimates for the distribution of the grounding reaction that have been verified empirically. However, there are two approximations that can be found in practice:

1$^{st}$ Considering the distribution of the grounding reaction uniform along the length of the grounding and assuming its point of application to be the geometric center (Figure 3)

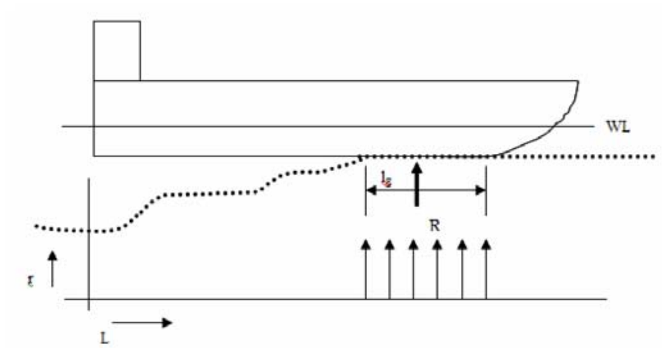

Figure 3: Grounding reaction approximation 1(Ref. 25)

2nd Considering the distribution of the grounding reaction triangularly due to the inclination (*slope*) with irregularities on the bottom, considering it to be zero at the end of the grounding reaction and the maximum at the fore part considered in the grounding reaction (assuming the bow aground or in that direction). In this case, the center of the grounding reaction will be at $^1/_3$ of the grounded length, counted from the fore part. In this theory, and considering the hull in a cave, we will probably have a trapezoidal distribution and the center of the grounding reaction will be between $^1/_3$ and ½ of the grounded length, counted as from the fore. The exact location will depend of the proportionality of the parts.

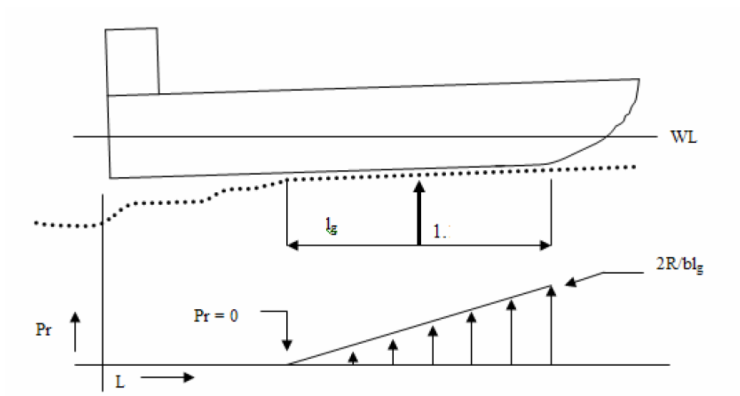

Figure 4: Grounding reaction approximation 2 (Ref. 25)

In figure 4 the nomenclature follows the description below.

$P_{max} = 2R / l_g b_{avg}$ (2)
r = Pr b (3)

| | | |
|---|---|---|
| $P_{max}$ | → | Maximum grounding pressure (Mton/ m$^2$ or Lton/pé$^2$) |
| R | → | Grounding reaction (Mton or Lton) |
| $l_g$ | → | Length of the grounding (m or feet) |
| $b_{avg}$ | → | Average breadth of the area of contact in the grounded length (m or feet) |
| b | → | Breadth of the contact area (m or feet) |

The center of pressure, or simply the center of the grounding reaction, is the point at which the grounding reaction would act if it was concentrated. The determination of this point is necessary due to changes in the location of weights and their effects on the grounding reaction. This center is also the point at which the vessel will pivot.
The grounding reaction, for the large majority of cases, assumes that the distribution is uniform throughout the whole grounded length. An exception applies when groundings occur on sharp rocks and similar. In these cases a small area of the hull will be in contact with the ground and the distribution of the grounding reaction cannot be determined with accuracy, in spite of considering for such a uniform distribution over the area of the rocks.

**The Neutral Loading Point - NP**

The neutral loading point is the point at which the sum of the weights causes sinking parallel at the effecting point of the grounding that is exactly balanced by an alteration of the; or that is:

Parallel sinking– Alteration of trim = Zero

The concept of the neutral loading point applies to groundings that occur on rocks, being less precise in other cases. Generally, in the cases in which the center of the grounding reaction is less than "L/8" measured from the center of floating, the neutral point will be located outside the grounded area and then it should be considered as being grounded throughout its whole length.

The addition or removal of weights from the neutral loading point will not cause alterations in the grounding reaction.

The location of the neutral loading point is given by the expression 2.

$$dn = \frac{(MT1\ x\ L)}{TPI\ x\ dr} \quad (4)$$

Where:

| | | |
|---|---|---|
| dn | → | Distance of the LCF to the neutral loading point |
| MT1 | → | Moment to trim 1 |
| L | → | Length between perpendiculars |
| TPI | → | Tons per inch of immersion |
| dr | → | Distance from the center of the LCF grounding reaction |

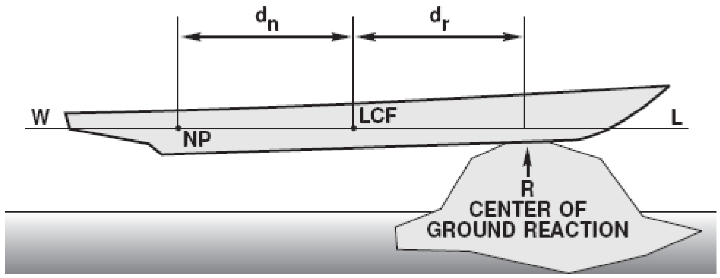


Figure 5: Neutral loading point NP (Ref. 31)

**Alteration of the Grounding Reaction Caused by Change of Weights**

Any change in the weights within the vessel should always reflect an equal change in the sum of the buoyancy and grounding reaction. In case a grounded vessel does not trim in response to the movement of weights, the submerged volume of the hull and its buoyancy will be unchanged. Alteration by the removal or addition of weights will reflect directly on the calculated grounding reaction (ΔR = +/- W).

In case the grounded vessel trims out at any other point that is not the center of buoyancy, as should occur in groundings, then we have an alteration in buoyancy and consequently in the grounding reaction.

Assuming that the ship pivots on the center of the grounding reaction and that alteration will occur in the grounding reaction, we can state that:

a. Weights added or removed at the pivoting point (center of grounding reaction) will cause an alteration in the grounding reaction equal to the weight moved and will not alter its buoyancy;

b. Weights added to or removed at the neutral loading point (NP) cause an alteration in buoyancy equal to the weight moved without altering the grounding reaction;

c. The proportion in the variation of weights by alteration of the grounding reaction may be assumed as a linear variation having 0% at the neutral loading point and 100% at the center of the grounding reaction, as in the figure below.

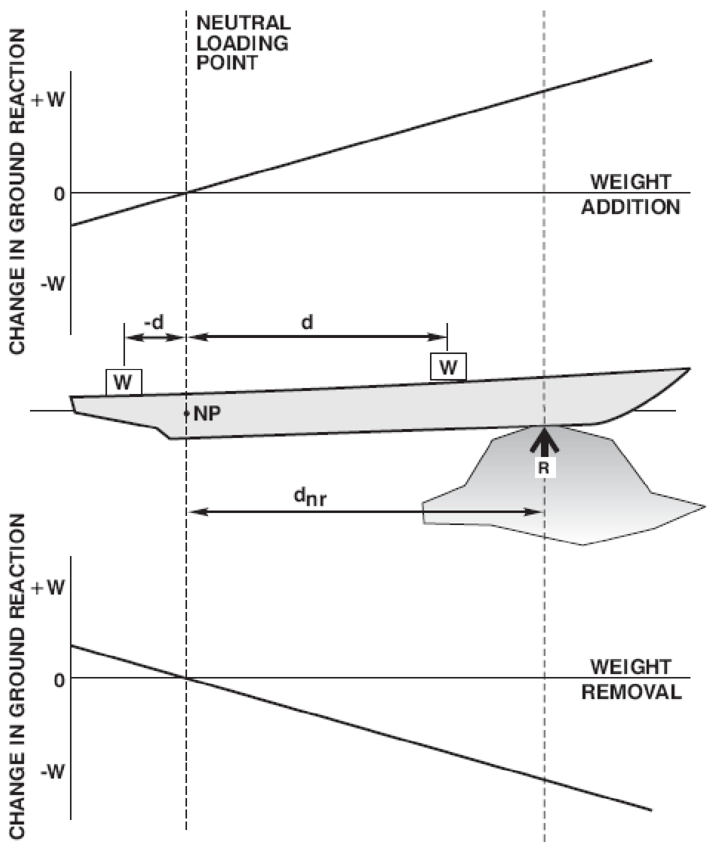


Figure 6: Changes of reaction with variations in weights (Ref. 31)

The alteration of the grounding reaction (δR) resulting from movement of weights at any point along the length of the grounded vessel may be obtained by the following mathematical relation:

$$\delta R = w \times \frac{d}{d_{nr}} \quad (5)$$

Where:

| | | |
|---|---|---|
| $\delta R$ | → | Variation in the grounding reaction |
| w | → | Weight added or removed |
| d | → | Distance of the weight removed or added to the neutral loading point |
| $d_{nr}$ | → | Distance of the neutral loading point from the center of the grounding reaction |
| $d_{nr}$ | → | $d_n + d_r$ |

The alteration in the draft can be advanced by the relation between the changes in buoyancy and the corresponding change in the average draft by the following expressions:

$$\delta Tm = \frac{\delta B}{TPI} \quad (6)$$

$$\delta Ta = \delta Tm \, x \, \frac{da + dr}{dr} \quad (7)$$

$$\delta Tf = \delta Tm \, x \, \frac{-df}{dr} \quad (8)$$

Where:

| | | |
|---|---|---|
| $\delta T_m$ | → | Variation in the average draft |
| TPI | → | Tons per inch of immersion |
| $\delta B$ | → | Change in buoyancy = w - $\delta R$ |
| $\delta T_a$ | → | Alteration in the stern draft |
| $\delta T_f$ | → | Alteration in the bow draft |
| $d_r$ | → | Distance of the LCF to the center of the grounding reaction |
| $d_a$ | → | Distance of the LCF to the stern perpendicular |
| $d_f$ | → | Distance of the center of the grounding reaction to the perpendicular of the bow |

## 6.0 The Mechanics of Grounding and its Prognostics

An evaluation of the existing bibliography, shows that grounding of vessels has been a little unexplored as far as research goes. The initial experimental research work in what concerns the mechanics of grounding and its prognostics were, initially, based on empirical methods and developed in experimental investigations. In the large majority, these studies were developed by Minorsky (1959).

Subsequently, in 1975, a statistical study relative to double bottom tanks and segregated ballast tanks in oil tankers was published by J.C. Card. He studied, between 1969 and 1973, a total of 30 groundings in American territorial waters, and he concluded that in 27 of the 30 cases the length of the damage to the hull in the vertical direction was a number smaller than B/15 (the breadth measurement divided by 15). With this analysis, we had an indication, based on statistics, that a vessel with a double bottom with a height equivalent to the number above would have prevented the spillage of the oil load into the water in 90% of the cases.

Later, since the 90s until today, several other scientific works were developed in so far as what refers to groundings of high bottoms with substrates of a varied nature, including but not limited to soft mud or rock, thanks to computational technology. Associated to this and in response to the preservation and conservation of the oceans and rivers, the International Maritime Organization *(IMO)*, that is the international organism which regulates the designs of tanker vessels and others affecting the preservation and conservation of the environment, introduced into the world market the probabilistic procedures for the regulation of the stability of vessels in damaged conditions. Initially, the regulations were applied to passenger vessels and later to cargo ships. The methodology of the probabilistic procedures was used for the first time in response to the OPA 90 *(US Oil Pollution Act)* that had as a result requiring ships to have double hull or equivalent. The equivalence is determined based on the probabilistic calculations of an oil spillage and is defined in annex I of MARPOL 73/78 –Alternative design and construction for tanker vessels. The construction of new oil tankers that have the height of the double bottom tanks greater than 2.00 meters will also apply the calculation of the height of the double bottom by the formula or 1/15 of the breadth, and the smaller result will apply.

Based on actual statistical data, groundings occur on different types of bottom substrates, which are classified as sand, tabatinga *(like clay)* or mud, smooth rock and coral rock, and hard rock, causing different kinds of damage to the vessel structure.

## 7.0 Conclusion

Groundings always are and should be treated as an event of low probability and large consequences, a reason why every grounding should be conducted under a regime of urgency, under all and any aspect. A vessel, when grounded, is subject to movements and loadings for which she was not designed, like limited hydro-dynamic movements and bottom reactions in the grounding site.

The abilities of vessels and other crafts salvors to stabilize the grounded ship immediately after the accident will always be of large relevance in the success or not of the operation. The inability to mobilize personnel and equipment may cause the loss of an opportunity with favorable weather conditions or even cause the deterioration and aggravation of the grounded vessel that may cause damages of such a magnitude that results in her total loss, as well as almost irreparable damages to the environment. The management and choice of adequate technical personnel appears to be the principal aspect to be followed in salvage operations.

Technical studies based on statistical data are restricted to a certain extent due to the non-availability of data or incomplete information like vessel speed, extent of the damage to the hull and structures, and the conformity of the submerged obstacle in the case of grounding on rocks. Such information and other details are commonly treated as confidential and the prerogatives of the ship owners or simply treated as confidential due to judicial disputes.

Various techniques have been developed for the scientific treatment of the operations of refloating vessels. In this text, we point out the need to extend these developments with the inclusion of experimental tests that validate numerical applications.

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