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Ship Ballast Tank Sediment Reduction Methods

ABSTRACT

Steel ships constructed after the beginning of the twentieth century are provided with tanks for the storage of ballast water (BW). Together with the water, sediments are also collected. The solid sediments accumulated in ballast tanks contribute, when discharged in other locations, as much as the BW itself, since they contain living species that are alien to the discharge areas and are, therefore, likely to contaminate their new "habitat". The accumulation of sediments derives from the obstruction of the scallops in the tanks' structures, and by the non-direction of sediments towards the BW suction bell. To minimize this problem, this paper proposes modifications in the deballasting systems of ships that can be implemented in either existing ships or incorporated in new construction. The proposed alterations ensure the structural and operational integrity of ships, as well as facilitating the flow and subsequent removal of sediments from within the ballast tanks.

KEYWORDS
ballast water
sediments
environmental impact
ship construction
pollution and invasive species

Introduction

As a consequence of the impact caused by the discharge of ballast water (BW) in various places around the world, several studies are in progress to develop methods and procedures to control this problem (Bolch and Hallegraeff, 1993; Carlton, 1995; Endresen et al., 2004). In spite of these numerous studies and attempts to eliminate the introduction and transfer of invasive (i.e., "exotic") marine species transported by ships (Carlton, 1995), in compliance with regulations of the International Maritime Organizations (IMO), emphasis has been focused on ballast water treatment in compliance with these international requirements through the exchange or treatment of ballast water (Carney et al., 2011). Few studies have been conducted on the organisms that are found in sediment on the bottom of the ballast tanks of ships (Johengen et al., 2005; Hallegraeff and Bolch, 1992).

The types of sediment normally found deposited on the bottom of ballast tanks of ships are solid substances (sand, silt, clay, et al.). They are admitted with BW during the ballasting of a ship, along with native species existing in the area of the BW uptake (National Research Council, 1996).

Therefore, The Non Ballast On Board (NOBOB) ships also present a considerable risk to the environment, since even a residual amount of BW can allow the survival of benthic and planktonic organisms on the bottom of tanks (Drake et al., 2005). Such organisms were the responsible for a series of invasions in both the Chesapeake Bay and the Great Lakes in the 1980s, when no effective regulations existed for residual sediments on the bottom of tanks (Drake et al., 2007).

Conversely, systematic removal of sediments only occurs during mandatory dry docking. This complies with the Rules and Regulations of the respective Classification Societies. The tanks must be empty and totally clean for the inspection of the internal structure and thickness gauging. In general, tanks are constructed with metallic components (e.g., plates and profiles), followed by repairs (when needed) and anti-corrosion treatment. Drake et al. (2005) explain that tens of tons of sediments are accumulated in the ballast tanks of ships. Johengen et al. (2005) state that it is possible to find up to 200 tons of sediment on the bottom of merchant vessel ballast tanks. These authors have examined 103 foreign ships that called at ports of Canada and the USA between 2000 and 2002, and verified that approximately 68% of these ships contained residues of ballast in the tanks.

It is not uncommon for a layer of sediment in a ballast tank to reach 10-15 centimeters, which must be manually removed during dry docking. This happens normally in tanks that are not easily accessible, and are subdivided by athwartship floors and bottom longitudinals. These structures are called "egg crates" and they lack natural lighting and ventilation, which makes the cleaning process of these tanks slow and difficult. The consequence is expensive manual labour, since all residue inside the tanks must be removed ashore preceding final destination.

For example, a Panamax-type bulk carrier, with a LOA of 220 m and a breadth of 32.20 m, contains ballast tanks that encompass a joint area of about 150 m length by about 30 m width, rendering an area of approximately 4,500 m^2. A layer of 0.10 m of sediment over this bottom would result in a mean volume of 450 m^3.

With an estimated average density of 1.5 kg/dm^3, this sediment would amount to 675 tons. It creates a habitat for numerous exotic organisms and is transported across oceans, and it detrimentally affects the full dead weight of the ship. Naturally, there are logistical problems that surround the removal of sediment from tanks during dry docking. For these reasons, sediment is an enormous problem.

From an economic perspective of maximizing the ship capacity, the transportation of sediment over five years not only results in loss of cargo capacity, but also the loss of tens of thousands of dollars in freight revenue.

This paper proposes alterations to the current deballasting system that would minimize the deposit of sediments. These proposed alterations can be implemented individually, or can be integrated into existing ships and into the design and construction of new vessels.

Ballast water tanks and deposit of sediments

The shape and arrangement of ballast tanks has been the subject of study by various authors for many years. Parsons and Kotinis (2002) focused on a typical section of a bulk carrier. These authors studied the overall shape of the vessel to alter the arrangement of tanks, which allowed the exchange of BW as well as the removal of sediments from within the tanks. This developed system was called Ballast-Free. Although this system has been proven efficient, it is not applicable to all types of vessels.

New methods can be used in the design of new ships to minimize the accumulation of sediment, and to increase management and treatment options for a higher level of efficiency. For existing ships, adaptations or modifications of piping and equipment would be necessary (Taylor and Rigby, 2001).

Resolution MEPC.150 (55) of the Marine Environment Protection Committee (MEPC-2006) supplies directives for design and construction that facilitate the control of sediment, and give some parameters for the construction of ballast tanks that minimize the accumulation of sediment on the bottom of ballast water tanks.

The National Academy of Sciences (1996) performed a study on ballast water, addressing such topics as the transportation of species inside the ballast tanks of ships and the processes and projects of ships' tanks, focussing on the control of BW.

It is not unusual to find 5 cm of residual water on the bottom of tanks after a deballasting operation (Stocks, 2002). Together with the water that remains inside a tank, the presence of accumulated sediments is confirmed after every voyage. In the National Academy study, the author evaluated the use of using sodium hypochlorite inside the tank to eliminate the presence of microorganisms in the sediment. However, the author verified that the sediment inside the tank might inhibit the application of the treatment, since the sediment itself prevents the elimination of the microorganisms that are located below the deposits.

Therefore, it is evident that treatment alternatives for the accumulation of sediments inside ballast tanks need to be further explored. This paper presents slight modifications in the arrangement of ballast water tanks that may reduce the accumulation of sediments inside those tanks, with no impact on the structural resistance of the ship.

Ballast Water Tanks

The vast majority of ballast tanks of merchant ships belong, normally, to three main categories: a) Collision Tanks, b) Side Tanks, and c) Double Bottom Tanks (DBT). Collision Tanks are located at the extremities of the hull (bows and stern), and possess configurations that taper down toward the keel of the ship, with intermediate structures of non-integral platforms that allow the concentrated draining of sediment toward the bottom of the tank, where they can be easily removed.

Side Tanks, especially in tanker ships, are situated vertically between cargo tanks (or holds) and the side shells, located symmetrically, extend from the bottom of the structure up to the exposed (strength) deck. Their cavernous size allows easy cleaning.

Double Bottom Tanks (DBTs) are situated between the bottom of the cargo holds (tank-tops) and the bottom plating of the ship, varying in height between 1.6 m and 1.9 m.

Structurally, there are significant differences amongst the three types of tanks, as a result of the function that each type has to carry out during the lifespan of the vessel. On one hand, the Collision Tanks situated at the extremities of the ship contain structures that are specially reinforced to sustain frontal impacts, either from the sea itself or from another ship. The Side Tanks, notably the “designated tanks” (solely employed for BW), are fitted with well-spaced web-frames to absorb lateral impacts, therefore establishing the so-called “double hull” now required for all new tankers.

Double Bottom Tanks, however, especially in dry cargo ships (e.g., bulk carriers and general cargo ships), are meant to support and distribute the weight of the cargo loaded into the holds above them. It is not uncommon for the weight loaded into the hold of a bulk carrier to exceed the weight of 10,000 tons, exerting a pressure in excess of 10-ton/m^2 on the structure of the adjacent DBT. As a consequence, the internal structure of a DBT is constructed of many components, across and lengthwise which, after being united, result in an “egg crate” configuration within a frame spacing that normally is not in excess of 1.0 m.

In the case of all three types of tanks, jointing of structural components is performed by electric welding (MIG, TIG, slag), as opposed to ancient ships in which the jointing was carried out by riveting. This newer system avoids the concentration of residual tensions during welding in the so-called “hard spots”. Small apertures opened in the upper and lower corners of the used profiles in the shape of quarter circles (i.e., “scallops”), prevent the meeting of several welding seams at any one point.

These apertures normally possess a radius of 5 cm (2"), sufficient to allow a weld fillet to return to the opposite side of the same metallic profile without connecting to the other welds of the jointed profiles. Figure 1 demonstrates a use of scallops in the joining of athwartship floors to bottom longitudinals on the bottom plates of a tank.

These small apertures were originally conceived to allow the flow-to-aft of BW, toward its removal by the ship’s ballast pumps located in the engine room. These openings, however, are soon obstructed by sediment contained in the tank, as well as by the rust scales that are produced over the time by the steel construction and ballast piping when not regularly treated. Consequently, the sediment cannot be carried aft by BW when drained at the aft end of a tank, since the apertures are either too small or are obstructed. As result, the natural sediment in the BW is not eliminated from the tank, with the corresponding expenses and problems already outlined.

Proposal of change in the tanks

We propose the following solution to the matter of sediment retention on board with minor alterations in the structural design of new ships, which can also be made on existing ships. We developed three alternatives to changes of tanks.

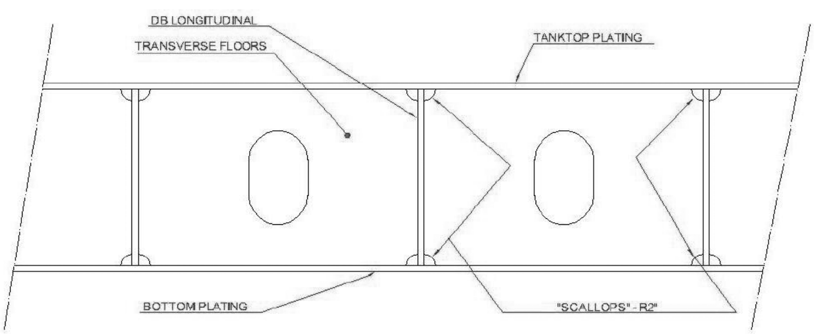

FIGURE 1. Schematic of typical scallops.

ALTERNATIVE 1

As a solution to the matter of sediment retention, the following minor alterations are proposed in the structural design of new ships, which can also be made on existing ships:

a) The increase of the radius of the scallops from 5 cm to 7.5 cm at the joining of the several profiles.
b) The opening of additional scallops along the lower edges of the transverse elements of the bottom structure, in the shape of half moons, with the same radius of 7.5 cm, in a spacing not greater than 1.5 m between adjacent scallops, as demonstrated in Figure 2.
c) The opening of identical scallops on the lower edges of longitudinal profiles, at the rate of one scallop for each frame space.
d) Installation of water jets against the bottom of the tanks, for the stirring of the accumulated sediments on the bottoms.

In this proposed system, only a very small reduction will occur in the Section Modulus of the ships, either longitudinally or athwart ships, easily accomplished when the Scantling Plan of the ship is prepared.

It must be noted that the scantlings of the intended metallic profiles already predict a reduction in the original thickness that may reach up to 20%, depending upon the region in the hull. This permitted thickness reduction is, in fact, much greater than the reduction in strength imposed by the opening of the additional scallops.

It is worth mentioning, at this point, that the structural elements of a DBT are also systematically fitted with lightening holes (openings of elliptic shape with average size of 600 mm by 400 mm). These elements are designed for the passage of people during construction as well as throughout the life cycle of the ship, and also decrease the rigidity of the aforementioned elements. If care is taken to not place the proposed new scallops immediately below the lightening holes, the rigidity of the structural element remains integral.

ALTERNATIVE 2: MODIFICATION OF THE DEBALLASTING SYSTEM

The most commonly used deballasting system, employed around the world, is based upon the fitting of one suction mouth close to the bottom plates at the aft end of the tank, as close as possible to the ship's centerline, and connects to the ballast pump in the engine room through a manifold. This suction mouth, in the shape of a bell, is located above a striking plate (disk), welded against the bottom plating as protection against erosion and/or corrosion during the pumping operations.

The operation of deballasting a ship is normally carried out from fore to aft of the ballast tanks, thus obtaining a trim-by-stern of the ship, favouring the flow of the BW towards the suction bells, and allowing an almost complete "stripping" of the tanks.

Notwithstanding, as result of the eventual obstruction of the small scallops in the structure of the DBT, sediment contained within a tank can not find a clear path to be dragged and drained to aft, remaining confined in the various pockets of the "egg crate".

This modification recommends that the ballast piping inside a DBT be subdivided into branches

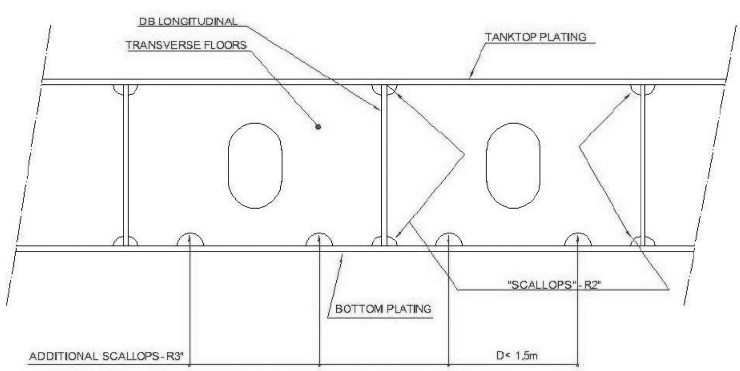

FIGURE 2. Schematic change in section of DB tank.

that reach each and every interval between adjacent bottom longitudinals. All are connected to the same main suction line, and terminate in suction mouths that resemble the mouth of a vacuum cleaner (rectangular and wide) close to the bottom of the tank. Figure 3 shows an example of this application.

Therefore, with the opening of scallops on the lower edges of the structural elements of a DBT and with the suggested branching-out of the suction piping, it is extremely likely that the sediment on the bottom of a DBT will be eliminated during deballasting operations.

ALTERNATIVE 3: INJECTION OF WATER AGAINST THE BOTTOM OF TANKS

Although the aforementioned proposed alterations may result in a substantial increase in the efficiency of eliminating sediment existing in ballast tanks, it must be stressed that the mandatory cleaning and removal of sediment is only carried out at five-year intervals. This means that, basically, the clayish sediment will have had a long period to agglutinate and compact against the bottom plating of the tanks.

Like a hydraulic cannon normally found assembled in suction dredges, the compacted layer of sediment could be stirred and agitated by using a piping system provided with sprinkler nozzles directed against the bottom plates at each frame spacing interval.

This suggested system should be employed on every deballasting operation for more efficient sediment removal, and employed until air is sucked into the suction bell of the deballasting system. It is suggested that the proposed piping system be 3" in diameter, with a working pressure of not less that 3 kg/cm^2.

Discussion

These presented alternatives to traditional ballasting methods would reduce the deposit of sediment within ballast tanks of ships without compromising operation or safety. The amount of sediment could be reduced with an increase in the diameter and number of scallops. Although this increase in scallop diameter is only 50% when compared to the current size, it would allow the flow of BW to carry the sediment from tank to aft during deballasting operations more efficiently. With more scallops distributed along the same sections, the flow of BW would increase and, consequently, the amount of sediment removed during the deballasting operation would also increase. These proposed alterations would not alter the resistance of the structural elements of the ship.

Distribution of an auxiliary deballasting piping system within the tanks would allow a greater collection capacity of the sediment deposited inside the tanks. The conventionally used central piping system concentrates only on the collection operation of the sediment.

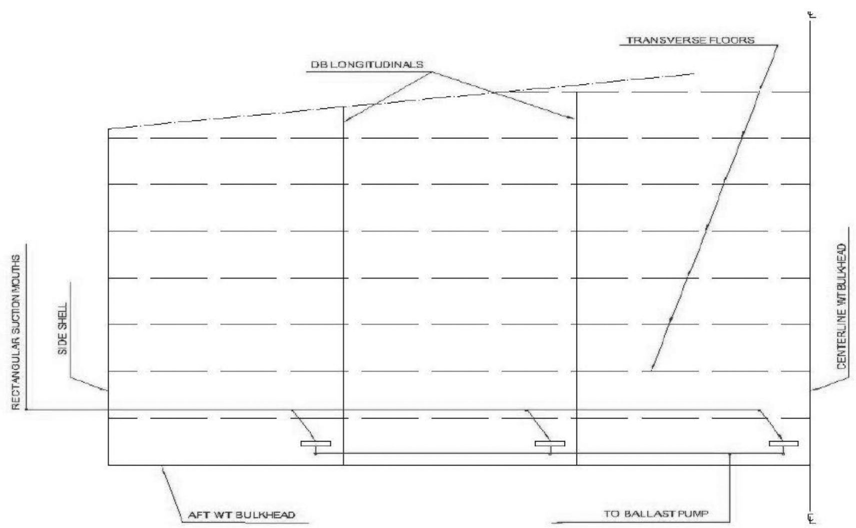

FIGURE 3. Schematic of ballast water system change.

The injection of water against the bottom of a tank tends to stir upward the accumulated sediment on the bottom of the tank during a deballasting operation. Therefore, the sediment is in suspension and is mixed with the water, and is therefore sucked by the discharge bell along with BW. On the other hand, the suspension of sediments in the ballast water during the deballasting operation could affect the efficiency of the ballast water treatment. Treatment based on UV radiation is very sensitive to the presence of suspended sediment since this alters UV efficiency (Mebashi, 2004). In this sense, the proposed agitation tends to be most feasible during the ballast exchange operation in open sea, because this would not compromise the efficiency of treatment for the elimination of exotic species.

If the proposed alterations were jointly implemented, there would be a greater efficiency in the discharge ballasting system of water and sediment. For new ships (new construction), the number of scallops and their size are currently defined by a computer-aided design program and manufacturer (CAD-CAM), and could be altered with virtually little or no additional construction costs, since this work is performed by machine. For the fitting of more enlarged scallops in existing ships, the work could be carried out during a scheduled dry docking, employing small templates for use by shipyard labourers after the required cleaning of the DB tanks and prior to the surface treatment of the steel profiles. The additional scallops and the increased size of the scallops at the jointing of bottom profiles would not alter or invalidate class requirements for the applicable welding procedures.

This work could be completed within 2-3 days, and would not substantially increase the total cost of docking a ship, which normally lasts for about two weeks if no other major repairs are scheduled. Therefore, the cost could be diluted into the total cost, and would have a positive environmental impact as well.

From an operational perspective, the transport of sediment becomes accompanying fauna, and as such it impacts the cargo capacity of the vessel and creates unnecessary problems for the cleaning of tanks during dry docking.

For future research work, the authors are developing a computer simulation model using Moving Particle Semi-implicit (MPS) (Pan et al., 2008; Arai and Cheng, 2004). This MPS model will assess the impact of the proposed scallops' increasing number and diameter against the residual volume of sediment at the tank bottom. The MPS allows the separation of the particles of water and the sediment. Thus, it would be possible to verify the BW and sediment residual volume in the tank after it has been deballasted. Moreover, it would be possible to evaluate the fluid flow through the scallops. This would allow the calculation of the optimal number of scallops needed to minimize sediment deposit in the BW tanks.

Ship designers should focus more on new systems that are more efficient for the removal of sediment from within ballast tanks. Lately, many studies have been focused on the development of BW treatment systems for the elimination of exotic species transported on ships, but these systems do not address the removal of sediment from ballast tanks.

Final considerations

Since a dry cargo vessel, as well as a tanker, needs to eliminate BW before or during loading operations, several or many times per year, the elimination of sediment from ballast tanks could be carried out systematically at every mandatory exchange of BW in ocean waters (IMO – MEPC-868/A), instead of only during the statutory dry docking of the vessels.

Another important consideration in doing so is that ships transport sediment within ballast tanks unintentionally through the course of years, creating columns of sediments that may reach 30 cm (Hamer et al., 2001). These proposed alterations would significantly reduce this highly-polluting material. The accumulation of bacteria and viruses inside the sediment can effect BW treatment, mainly in the treatment systems that are applied during deballasting operations.

Finally, this paper presents simple modifications in ballast tanks that would result in a positive impact in the reduction of sediment. Further laboratory, or even on real scale studies that can be implemented on docked ships, are needed. Once original configurations are updated, they will require continuous assessment to evaluate the efficacy of the proposed method.

This paper has attempted to start a precedent for new alternatives to be tested based on our proposals. The intention is to demonstrate that simple and inexpensive solutions can efficiently improve the management of sediment on ships.

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