

Overview of the Safety Operations in a Floating – Graving Dry Docking System

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ABSTRACT

In this paper, a critical review of floating-graving dock is conducted to determine the current status of docking problems. A background study is carried out on a floating-graving docking system, highlighting its layout, trends, and factors affecting the selection of a dry dock system. The ship docking specification is also reviewed and the corresponding standards and regulations of floating-graving docks are presented.

Key Words: *Floating dry docks, Graving dry docks, Safety standards.*

1. INTRODUCTION

Operating shipping fleets requires professional organisations to execute the various processes in terms of administrative, technical, and operational matters [1]. Performing docking operations – which are the biggest logistical and planning issue in the content of planned ship maintenance programmes – is one of the critical processes for ship managers under the control of technical and operational divisions [1].

In general, shipyards have specialised workshops and spaces such as mechanical, electrical, steel sandblasting, docking, painting, and others. Routine docking works such as washing, grit blasting, coating, sea chest cleaning, proper dismantling, polishing, controlling of tail shaft and stern tube seals can be listed as the main facilities during a docking period [2]. The shipping firms' roles in the docking process begins with planning the time, period and concept of the work and finishes with the trial voyage and completing the required tests of the systems at the end of the whole process.

The selection of a suitable shipyard with respect to many criteria such as ship position, reputability of shipyard organisation, previous experiences of yards, size of required work, limitations of shipyard, equipment capacity of yard, etc., is needed, and a wide range of market surveys and a detailed analysis are required to make the final decision [3].

A shipyard organisation with a well-designed docking system and which adapts the required technology into the whole process can manage to perform this process in both a safe and efficient manner. From the viewpoint of shipyard organisational safety, the facilities of design, construction, and docking process should be well organised for the application of formal safety assessment (FSA) to satisfy customer expectations and prevent conflicts after unexpected accidents [4].

An important change in the dry docking industry is the application of FSA. In the middle of the 1990s, in order to promote and improve maritime safety, the International Maritime Organisation (IMO) adopted FSA, which was initially put forward by the Maritime and Coastguard Agency (MCA) at the 62nd meeting of the Maritime Safety Committee (MSC), which introduced FSA to the marine industry and put it into use, and asked its members to be actively involved in the research on ship safety [4]. FSA is a systematic formal and integral assessment approach.

The purpose of the application of this method in safe management of dry docking evolution, ship design, and shipping is to use the five-step procedure of FSA to make an overall analysis of dry dock design, inspection, operation, and maintenance, etc., thus enhancing maritime safety. FSA can be used as a tool to improve the measures and regulations or to make new ones on the basis

of analysis of current dry dock designs and engineering techniques, of docking ships' operation and control, standards and regulations of safe management, together with the combination of realistic needs [5]. FSA has changed the traditional reactive regulatory framework towards a risk-based and goal-setting regime. Risk assessment and cost-benefit analysis are carried out to complete FSA.

The application of traditional methods of risk assessment may prove difficult when faced with new hazards and uncertainty. Novel approaches and techniques towards risk assessment may be required in order to deal with such problems.

2. REVIEW OF FAILURE IN FLOATING – GRAVING DOCKING SYSTEM

Dry or *graving docks* are used to enable the ship's bottom and underwater fittings to be inspected and worked on (Tupper, 2013). They normally consist of a basin dug into the shore of a body of water and provided with a watertight gate on the waterside, used for major repairs and overhaul of vessels. When a ship is to be docked, the dry dock is flooded, and the gate opened. After the vessel is brought in, positioned properly and guyed, the gate is closed and the dock is pumped dry, bringing the craft gradually to rest on supporting keel and bilge blocks anchored to the floor [6]. A floating dock on the other hand usually takes the form of a U-shaped box structure with side walls mounted on a base pontoon. A large part of the structure is devoted to ballast tanks which are free flooded to sink the dock [6].

The dock, with the ship, is then raised by carefully controlled pumping-out of the ballast tanks. The sequence of pumping is such as to limit the longitudinal deflection of the dock (and hence the ship in it) to avoid undue longitudinal bending moments [7]. Besides undue longitudinal bending moment is the positioning and stiffness allocation of docking blocks, which are important decisions when docking a ship because mis-positioning or mis-allocation of docking blocks may give rise to unreasonably large block reactions and consequently serious damage to both the docked ship and blocks. Docking block failures may also cause the disruption of docking schedules and an extension of ship downtime. Any failure may lead to the loss of lives [6].

Marine dry docks have been subject to study and research from several points of view such as environmental, hydrodynamics design and construction [8]. Likewise, docking analysis has attracted the attention of various researchers. Jiang *et al.* [9] developed a reliable, efficient computer program for predicting block reactions in both graving and floating docking analyses. Cheng and Zeng [10] proposed a mathematical model for optimising the positioning and allocation of docking blocks which ignored potential uncertainties in their design. Two-level optimisation techniques were employed to solve the optimal solution in their study. Cheng *et al.* [6] proposed the convex model (mathematical model) in which the indeterminacy about the uncertainty variables in designing docking blocks is presented. Numerical examples were used to show that uncertainties affecting the optimal solution can lead to an increase in volume of blocks compared to deterministic optimisation.

Technical considerations and investigations on docking facilities are discussed within various studies in the literature such as strength analysis of floating docks [11], robust design of docking blocks [6], predicting dry dock block reactions [12], and other related research. On the other hand, computer integrated supply chain management [13], integrating lean model for repair and maintenance [14] and work flow cost model of repairing activities [15] are seen in the literature as ongoing research regarding the planning and implementation process of docking facilities in shipyards.

A fuzzy axiomatic design-based performance evaluation model for docking facilities was proposed by [2], with the goal of overcoming the selection problem with respect to several criteria to find the most suitable shipyards. The effects of dry docks on marine hydrodynamics are mainly related to the significant amounts of pollutants which build up over dry dock surfaces because of intensive industry activity [16, 17].

Another concern in the design of dry docks is the total time required to fill them with water [18]. The filling time depends mainly on the specifications of a flooding system which is generally operated by gravity. The main components of the flooding system such as an intake channel and guide walls are generally extremely complex. Also, the interaction of dry docks and marine hydrodynamics and sedimentation is also a major issue in design [19]. Najafi-Jilani and Naghavi [8] insisted on the necessity to investigate the hydrodynamic behaviours of dry docks, the flow patterns, and the efficiencies of flooding system using the numerical method as a proposed method to analyse the flow through the flooding system.

The maintenance and safety certification of graving dry docks is essential in supporting fleet operation and readiness. Wu *et al.* [20] proposed stability analysis and displacement measures of graving dry dock walls using distance measuring instruction. Periodic docking facilities can be recognised as the biggest logistical issue in the content of ship maintenance programmes and are the critical process from the viewpoint of ship-owners. Since the relationship between ship management and shipyard continues during the life cycle of operating ships, it is required to have a well-planned and organised system [2]. In this new era, new safety rules place new demands on ship operators and dry dock operators to increase the quality of floating-graving dry dock operations and improve safety [21].

Docking ships are potentially hazardous operations as the ship passes between the dry and waterborne conditions. A ship may run aground either due to human errors in navigation, due to obstacles not recorded on charts, or due to the failure of the ship's control systems [7]. It is therefore important that they are studied in some depth [7]. Although docking is now less frequent because hull coatings to reduce corrosion remain for longer, and although more can be achieved in the way of repairs with a vessel still afloat, the docking industry remains vital in the economy of the shipping industry [7].

3. FLOATING – GRAVING DOCKING SYSTEM

Dry docks are structures that allow complete dry access to a vessel for maintenance, overhaul, and repairs, or for new construction and launching. They are the workhorses of ship repair facilities and may be used in lieu of traditional building ways at shipyards devoted to new construction. There are various types of dry docks, including those that physically lift the ship from the water such as floating dry docks, marine railways, and vertical-lift systems, and traditional basin dry docks that dewater an enclosed space around the vessel [22]. Only floating and graving dry docks are considered in this research. This section is intended as an introduction to floating and graving dry docks and their basic principles of design and operation.

3.1 Shipbuilding and Ship Repair Yard

Shipyards are industrial plants located in suitable water areas such as a harbour basin, a bay or a river, for building, repair and maintenance of ships. They are generally classified as shipbuilding yards, which produce new ships, and ship repair yards, which are mainly involved in the repair and maintenance of ships. There are also shipyards for both production and repair of ships [23]. Their equipment will depend on the prevailing type of production. Thus, in ship repair yards, shipbuilding will be of secondary importance, simply providing work for production units during less intensive work periods. Only the ship repair yard is included in this research. In ship repair, the main criteria are the size and the type of ships repaired, whether large, medium or small [24].

3.2 Background on Graving Dock

The name ‘graving dock’ derives from the dock’s original action, to permit the cleaning of a ship’s bottom, a process known as graving. Graving docks are large, fixed bases built into the ground at the water’s edge [22]. A watertight gate is closed after a vessel is floated into the dry dock and positioned above the blocking that will support it in the dry condition. Once the gate and vessel are in position, the water is pumped from the basin, causing the ship to settle on the blocks, exposing the underbody for dry dock [25].

Many construction techniques are used for building graving docks: sheet pile cells filled with sand, caissons of re-enforced concrete, and monolithic cast concrete, to name a few. The factors involved in deciding upon a construction technique include initial cost (often traded off against life expectancy), designer’s or owner’s preference, local influences such as the conditions, and available materials and skills [25]. When the fixed basin is dewatered, hydrostatic uplift tends to lift the entire structure from its foundation, causing it to tilt. In the early days of graving dock design, this tendency was countered by providing an enormous mass of concrete for its construction.

Today’s modern approach uses a relieved floor, whereby uplift is avoided by installing a draining area system beneath the floor of the dry dock and pumping water away from contact with the boundaries of the dock [12]. The dry dock is structurally divided into five parts: the portside walls, the starboard and head walls, the pump room, the entrance, and the dock bottom. All these parts seal off water [26]. There are three categories that relate to the means used to resist the buoyancy force on the dock resulting from the displacement of water volume of the dock, i.e. [27]: full hydrostatic graving dock – relies on its own weight or an anchorage system to resist the hydrostatic forces acting on the dock; full relieved graving dock does not have sufficient weight to resist forces acting on the dock, but relies on a drainage system to remove the surrounding water behind the walls and beneath the slab to alleviate the hydrostatic pressure; partially relieved graving dock. Thus it requires relief of the hydrostatic force under the floor slab only.

3.3 Background on Floating Dry Dock

Floating dry docks are barge-like floating structures with sufficient displacement, dimension, and stability for physically lifting a vessel from the water. Wing walls are provided on either side of the barge-like pontoon structure. They provide stability during docking operations and add to the sectional strength of the dock. They exist in a wide variety of sizes and designs. Large docks are very complex systems and are designed by professionals who intend to build structure, utilities, mechanical equipment, blocking and crane configuration [23]. They are also operated with list and trim to reduce block loading and reduce or eliminate vessel stability problems when docking or undocking [24].

Floating dry docks are composed of a pontoon and wing walls. The pontoon is the main structural component that must be designed to distribute the concentrated blocking loads from the vessel to the dock and ultimately to the uniform buoyant force on the hull. The pontoon provides the transverse strength for the dock as well as contributing to the longitudinal strength (Harren, 2012). Additionally, the pontoon must have sufficient volume to provide displacement to lift the vessel and dock out of the water with buoyancy. The wing walls provide stability when the pontoon is submerged, and the longitudinal strength to distribute the ship’s weight to the uniform buoyancy support [22]. These docks are used mainly for ship repair work but they can also be used for launching new ships. In modern layouts, floating dry docks are also equipped with gantry cranes, ensuring greater flexibility during repair or exchange of large parts of the ship under repair [25].

3.4 Layout of Ship Repair Yards

In floating-graving dock ship repair yards the division of organisational units and their location on the shipyard area are different from those of shipbuilding yards because of the different technological processes involved. Generally one can have the following

main production workshops in a repair shipyard: hull repair shops, maintenance and paint shops and repair shops for ship machinery. All these workshops are usually located close to the quays and docks [26]. Hence, four kinds of ship repair yard layout exist: (pier arrangement), around a basin, on an island, and on a peninsula. Pier arrangement is very useful because it gives a relatively narrow quay front and very short transport lines. The basin layout results in the least efficient arrangement of workshops because of the extended transport routes and the necessity for dividing equipment repair shops and machine repair shops into two separate centres [23].

Ship repair yards cannot afford the simplicity of single purpose equipment or layout but must be able to cope with any problem and be prepared for any repair job, day and night, from replacing a hull plate to rebuilding a main engine. The rapid growth in ship dimensions in recent years has brought about the reorganisation of ship repair facilities and the constant modification of the layout, mainly as regards size. This has led to the elongation of existing berths but, at the same time, mooring and docking devices that were too small to use. Existing cranes were too weak for the increased loads, such as ship engines, while the individual workshops required a larger area, and larger machine tools and overhead cranes. As a consequence, ship repairs yards on their original sites were not able to keep pace with demand [23].

3.5 Trends in the ship repairing industry

The dynamic development of the world economy has naturally resulted in the growth of international and ocean trade; the latter characterised by continuous quality and quantity changes [23]. This means that the rate of the world merchant fleet development is a function of the risk in cargo turnover in ocean trade and of the changes in the fleet structure (at least in the technical sense) as a direct consequence of the changes in the structure of international trade. It is quite possible that a certain decline in repair will occur in the immediate future [26].

This does not mean, however, a complete slowdown in the development of international ocean trade. Technical progress in ship repair will lead to new techniques of cargo handling, and new freight systems characterised by the increasing efficiency of ships and by decreasing unit costs for cargo [23]. By analysis of trends in international ocean cargo trade and the future economic development of individual geographical regions and their populations, it is possible to estimate the sea cargo turnover. Analysis of the world cargo fleet development finds the following kinds of ships have been distinguished [23]: (a) general cargo ships, container ships, ferries, hover-craft, etc.; (b) ships for dry cargo including the oil-bulk-ore (OBO) carriers and ore-tankers; (c) tankers for crude oil and oil products and special tankers for liquefied gas, liquid sulphur carriers, etc.

3.6 Factors making ship repairing more efficient

Some characteristics and features are desirable for efficient operation of a dry dock regardless of type and facility chosen [23]: (1) adequate space is necessary in and around the dry dock for both the people and material move to and from a vessel in the dock; (2) fast and efficient access is needed to and from the dry dock and the vessel in the dry dock. Access for vehicular traffic is very desirable. The introduction of travelling staging or dock arms for use in basin and floating dry docks has helped to make ship repairing more efficient; (3) adequate light and ventilation are necessary to ensure good working conditions; (4) an efficient method should be provided for moving a vessel in and out of dry dock.

Docks often are equipped with tensioning winches, capstans, and other line-handling hardware, which allow the dry dock crew to control the vessel as it enters the dock and position it correctly over the blocks. Electric or electrohydraulic capstans are most often used to handle the lines; (5) a proper blocking system must be provided. Blocks are used to support the weight of the ship while positioning it at a convenient height to provide work access underneath and leave much of the bottom area free for cleaning, repair, and painting. They also provide stability to prevent the ship from tipping over due to high winds or earthquake forces. The blocking can be considered as a mattress that provides support yet yields elastically to account for irregularities in the fit of the ship.

3.7 Factors affecting the selection of a dry dock system

The management of nearly every shipyard at one time or another considers an investment in a new or enlarged dry docking capability. Sometimes the choice of system is easy, as only one type of dry dock will meet the shipyard's need. More often, however, management must evaluate several systems and decide between them [23]. Selection of the appropriate type of dry docking facility will be influenced by many factors including [26]: (1) the dimensions, weight characteristics, and general features of the vessels to be serviced by the dry dock; (2) conditions at the site of the dry dock and the associated land facilities, including available land area, available area in the water, proximity to navigable channels or open water, tides, currents, topography, and soil conditions; (4) the near- and far-term goals of the shipyard and the potential future extension of the dry docking facilities. The most vital factor is the size of vessel and size of dry dock. A summary of factors to be considered in the selection of a floating-graving dock system is presented in Table 1 [25].

Table 1: Summary of factors to be considered in the selection of a dry dock system

	Graving Dock	Floating Drydock
Vessel size	Virtually unlimited, the largest docks handle vessels, in excess of 1 million deadweight tons	Recent docks have been built to handle vessel in excess of 350,000 deadweight tons
Sitting restrictions	Local extremes of soil conditions can create extreme variations in initial cost	None
Speed of operation	Dependent on pumping capacity. Typical installations utilize rates of between 6 to 10 hours	Dependent on pumping capacity. Typically 1 to 3 hours
Dredging/ Siltation	Adjacent bottom level must be maintained below sill of gate elevation	Must maintain adequate depth in area of dry dock to permit nominal clearance beneath baseline at submerged elevation
Maintenance	<i>Gate-Periodic drydocking for vessel-like maintenance. Machinery-Preventative maintenance and occasional overhaul. Basin- In-place corrosion control and repair. Protection-Impressed current cathodic protection systems and sacrificial zincs are usually provided for underwater steel elements.</i>	Machinery-Preventative maintenance and occasional overhaul. Dock structures- Floating dry docks are usually designed to be self-docking vessel-like maintenance. Protection-Cathodic protection and sacrificial zincs are usually provided.
Guideline, Annual reserve for maintenance	<i>1-2% of initial cost</i>	1-4% of initial cost
Capital Recovery Potential	None	About 90% of appraised value (less towing and insurance expenses)
Land Area Required	Usually a graving dock is inset into a shipyard site and therefore requires an amount of real estate equal to the footprint of the dock plus access	Requires only frontage on the property line. Can often be moored outside of the harbour's bulkhead line.
Compatibility with transfer to land berths	Graving docks are very seldom used in conjunction with land berths.	Often utilizes a full or partial grounding mat to stabilize the dock's level during transfer. Ballasting control is possible and has been used without grounding mass but requires a highly trained dockmaster.
Material flow to vessels in drydock	All material must be removed from area prior to docking and undocking. Cranes are usually installed on dock walls to facilitate handling. New docks are sometimes provided with a vehicle ramp to remedy this traditional shortcoming.	Wing-walls limit access to the end of the dock. Material must be removed prior to docking and undocking. Cranes are often provided on wing-walls to assist.
Earthquake resistance	Special design criteria must be considered for docks to be installed in earthquake prone areas. Ships blocking must also be considered in these areas.	Tsunamis accompanying earthquakes are the major consideration for floating drydocks.
Special features available	Intermediate gates permits subdivision of graving docks for more than one vessel at a time. Double ended docks with intermediate gates are sometimes used to permit a long dock to function as two docks.	Floating dry docks can be designed to be separated into two independent units. Special adaptations and designs have been developed to permit limited access without full drydocking.
Simplicity of drydocking	Winches and centering guides are used to assist in positioning ships. The crew size is a function of the vessel size. Operations are carried out in the relative calm of a protected basin.	Vertical control is maintained by the pumping of water. A certain amount of dock and vessel motion must be contended with to assure safe operation. A skilful docking master is required.

3.8 Regulations and Standards on Floating-Graving Dry docks

IMO stands for International Maritime Organisation formed as a specialized UN-agency that sets standards in IMO conventions, codes and other instruments, which are developed following proposals made by member flag states that are both users and providers of international shipping services, and are generally adopted on a consensual basis [28]. These are internationally agreed minimum standards. They are not the highest possible or conceivable standards, but the highest practicable [28].

The major aims of IMO are as follows: (1) To provide effective machinery for technical, legal and scientific cooperation among flag states in the field of the protection of the marine environment from pollution from ships and relative activities; (2) To adopt the highest practicable standards in matters concerning maritime safety and the prevention and control of marine pollution from

ships and related activities; (3) To encourage the widest possible acceptance and effective implementation of these standards at the global level [28].

Is a new body which developed important instruments and guidelines to facilitate flag states in fulfilling their obligations under the applicable conventions but the core of the problem still remains unresolved. For the time being, there continues to be widespread resistance to granting the IMO any enforcement authority of this kind. A number of ports have adopted the Port State Control (PSC), but their authority is limited and their inspections generally superficial, with insufficient depth and detail [28], hence many flag states turn to have delegated their responsibility to classification societies.

The main function is to lay down standards for the construction and subsequent maintenance of ships and to ensure that these standards are fully implemented. These standards are published in the form of Rules and Regulations and Procedures. According to the rules for classifications of floating docks [29] rules are based on assumptions that the floating dock will be properly handled at all times, and it is assumed that all loading and ballasting will be in compliance with the approved operating manual. ABS [30] and KR [31] also provides similar rules for building and classing steel floating dry docks. Class can only attend periodical surveys as defined in their Regulations and only at the request of the Owner/Operator/Manager. Periodic surveys are carried out on annual, intermediate (2 to 3 years) or special survey (5 years' cycles). Class cannot maintain safety of ships under all circumstances due mainly to the following [28]: Class dependence on the ship-owners or for new building on shipyards: (b) Conflict in interest as Class is often carrying out statutory surveys and issuing certificates on behalf of flag state (c) Classification rules and regulations and procedures are the absolute minimum standards: (d) Class has no or at least very limited authority to implement and enforce regulations; (e) Class in fact does not have direct responsibility.

4. CONCLUSION

A floating-graving structure is a complex and expensive engineering structure composed of many systems and is usually unique with its own operational characteristics [32]. These structures need to adopt new approaches, new technology, and to new hazardous situations, and each element brings with it a new hazard in one form or another. Therefore, safety assessment should cover all possible areas including those where it is difficult to apply traditional safety assessment techniques. Such traditional safety assessment techniques are considered to be mature in many applications.

Depending on the uncertainty level/the availability of failure data, appropriate methods can be applied individually or in combination to deal with the situation. All such techniques can be integrated in the sense that they formulate a general structure to facilitate risk assessment and FSA [33]. When dealing with floating-graving system risk analysis, it is clear that Fault tree analysis, HAZOP, Failure Mode Effects Analysis, Petrin nets and Monte Carlos Simulation techniques cannot be easily implemented since such techniques need the frequencies of hazardous situations to be usually estimated based on historical failure data. Almost invariably, failures are assumed to be random in time; that is, the obtained number of failures is divided by an exposure period to give a failure rate and this is assumed to be age-dependent [34].

Since it is planned to make an evaluation from the viewpoint of shipyard-owners, this paper focuses on expectations and execution activities of the technical and operational departments of ship management companies regarding the docking process by implementing FSA. However, uncertainties in material, geometric properties, loads etc., are unavoidable in the design of engineering structures such as floating-graving docks.

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