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Special Issue, 2005

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The papers published in this issue have been reviewed by :
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Assoc. Prof. J. P. Michalski ; Assoc. Prof. J. Naumczyk
Prof. K. Rosochowicz ; Assoc. Prof. K. Skalmowski

Editorial

POLISH MARITIME RESEARCH is a scientific journal of worldwide circulation. The journal appears as a quarterly four times a year. The first issue of it was published in September 1994. Its main aim is to present original, innovative scientific ideas and Research & Development achievements in the field of :

Engineering, **Computing & Technology**, **Mechanical Engineering**,

which could find applications in the broad domain of maritime economy. Hence there are published papers which concern methods of the designing, manufacturing and operating processes of such technical objects and devices as : ships, port equipment, ocean engineering units, underwater vehicles and equipment as well as harbour facilities, with accounting for marine environment protection.
The Editors of POLISH MARITIME RESEARCH make also efforts to present problems dealing with education of engineers and scientific and teaching personnel. As a rule, the basic papers are supplemented by information on conferences , important scientific events as well as cooperation in carrying out international scientific research projects.

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Editor's message

This is the second special issue of Polish Maritime Research quarterly, devoted to results of the research on design, manufacture and operation of a new generation of ecological floating dock. The research was carried out in the frame of the EU-supported EUREKA projects aimed at creating new ideas of shipping and ship repairing processes, and satisfying the conceptual requirements of Baltic Sea status as a Sensitive Sea Area. For that reason great importance has been attached to ecological problems in this project. We hope that initiative of the Editors and the Principal Coordinator of the project will meet with kind acceptance.

Editor-in-Chief

NEW GENERATION OF ECOLOGICAL SHIPYARD INSTALLATIONS IN THE EUROPEAN EUREKA RESEARCH PROJECTS

Project E!2968
Environmentally Friendly Floating Docks

Chief executor and coordinator of the whole project :

Gdańsk University of Technology
Faculty of Ocean Engineering and Ship Technology

Gdańsk 2005

Ecological floating dock

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ABSTRACT

This paper presents final results of E!2968 EUREKA – ECOLOGICAL DOCK project sponsored by the Polish State Scientific Research Committee. The consortium established for realization of the project is presented, ecological hazards are characterized, the most important legal regulations are specified, as well the design of the ecological floating dock SINE 212CD and a concept of conversion of the existing dock SINE 126CD to the class CLEAN is characterized. The paper also contains the complete bibliography of the elaborations done within the project. More information can be found on the web page www.oce.pg.gda.pl/oce2/eureka *. This paper opens the series of the selected publications on various problems solved in the frame of the project, which are presented below.*

Keywords : EUREKA – ECOLOGICAL DOCK project,
structural strength, construction, technology, designing, ecological problems

INTRODUCTION

Environment safety problems begin to play more and more important role in the world economy. The tendency is also reflected in paying attention to designing the environment-friendly transport means including those for sea and inland waterways shipping, as well as to creating technical infrastructure suitable for their production and operation, and relevant legal background.

The widely spread status of environment-friendly short--voyage ships operating on relatively short shipping coastal routes or in restricted waters, is accompanied with the necessity of developing such technical infrastructure for building and repairing these ships, which could satisfy contemporary demands for environmental protection. This paper deals with the above mentioned problem in the frame of which is presented a design proposal for the medium- size ecological floating dock as well as a design concept of such conversion of one of the floating docks operated in Poland to fulfil ring the ecological „cleanness" requirements. Both the proposals are recommended to the readers' attention as a possible alternative of building a launching facility both for the shipyards having problems with building, repairing and launching the ships (as a result of lack of terrains or progressing decapitalization) and for currently organized enterprises of shipbuilding industry, not having at their disposal any ship launching facility.

AIM OF THE PROJECT

In order to create a design vision of an ecological floating dock for the Baltic Sea the European project called „Environment Friendly Floating Dock" E!2968 has been established within EUREKA group. Apart from the preliminary design of floating dock, based on broad topical studies, it was also necessary to elaborate the design concept of conversion of one of the existing docks to assign the class *Environmental Clean* to it. Moreover some measurements on the state of environmental pollution in the area of operation of the floating dock in question had to be performed in shipyard, environment-friendly engineering processes to be selected, as well as mechanisms and systems which could ensure environmentally safe operation of the floating dock to be analysed.

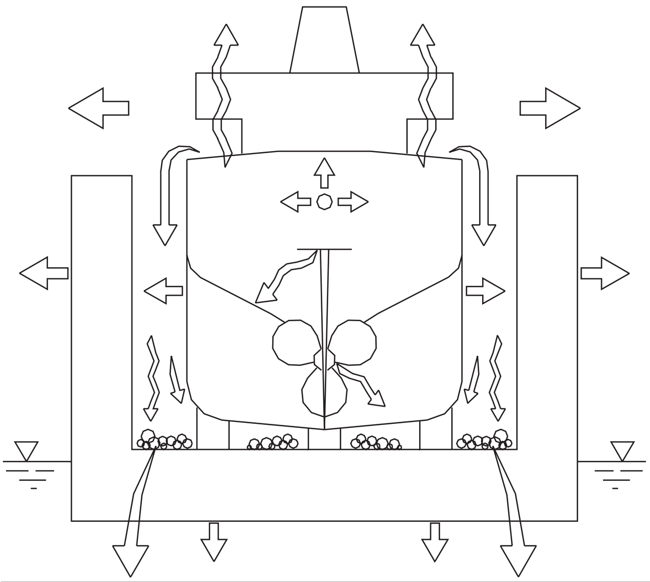
STRUCTURE OF THE PROJECT

The realization consortium has been set up as follows :

- Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology was assigned the coordinator of the whole project and executor of : design assumptions for the dock, technical studies concerning structure, strength, reliability and safety, technological feasibility assessment, and design of special systems for the ecological dock.
- Faculty of Environment Engineering, Warsaw University of Technology – the executor of : studies on technical and physical problems of environmental protection associated with operation of floating docks.
- SINUS Design Office, Co Ltd – the author of technical solutions for the ecological floating dock, as well as of the design concept of conversion of existing floating dock.
- Gdynia Naval Shipyard – a participant of an ecological monitoring task.
- Gdańsk Maritime Shipyard – a participant of an ecological monitoring task.
- Innowative Fertigung Infert (a German company) – a consultant.
- Polish Register of Shipping – a consultant and the author of a draft proposal for classification rules for ecological docks.

ECOLOGICAL HAZARDS GENERATED BY FLOATING DOCKS

Floating dock's operation creates significant hazards to environment. They generally amount to various emissions and pollutions (Fig. 1) or production of solid wastes resulting from engineering processes of repair work, moreover a part of the substances or their components is cumulated in water bed sediments in the area of dock's operation and their rest dispose to the atmosphere or water, and is thus spread over a greater area. Docked ship is also a source of hazards as it generates threat of non-controlled discharge and emission of e.g. liquid working media (fuels, oils, lubricants, contaminated ballast water, sewage, cooling liquids, cargo residues) or gaseous substances remaining in empty holds, tanks and installations. The threat significantly grows especially in the case of docking the floating units of failed hull structure or functional systems. Hazards generated by the ship itself depend on its kind and size. At last, the floating dock itself may be a source of environmental pollution e.g. due to discharged ballast water, leakage from its systems and connecting pipe lines, operational materials used in its facilities and systems, its own paint coatings, scrap materials or residues from operation of the dock's systems.



Possible environmental pollution produced by floating dock

Emission of :	
dust of abrasive materials	
paint particles	
vapours	welding gases
chemical compounds	

Discharge or leakage of :	
sewage	solutions
emulsions	mixtures
oil products	synthetic oils

Solid wastes :
biological
abrasive materials
paint flakes
corrosion products
welding materials

Fig.1. *Schematic diagram of non-controlled hazards to environment resulting from ship's hull repair operations carried out on the dock .*

The hazardous phenomena resulting from floating dock operations are not subjected to systematic control, they have not been so far precisely defined and have found only a limited relation to legal and technical regulations. It mainly results from an aversion of industrial circles to reveal the ecologically unfavourable side effects of their activity. Generally, the greatest attention should be paid to effects of carried-out engineering processes and produced scrap materials. Penetration of noxious substances to environment may be reduced by :

1. covering (sheltering) the whole dock by means of a mobile roof structure
2. applying local modular stiff paravans to protect ship hull fragments or even the entire hull
3. temporary sheltering the ship by canvas or plastic covers
4. applying, when running some engineering processes, special systems and/or machines with closed circulation of working media and gathering wastes in a system of containers being an integral replaceable part of the machine or a separate unit
5. removal of production wastes with the use of separate special floating units adjusted to recycling them on board or carrying to land-based waste stations equipped with recycling and utilizing systems
6. limitation of development of new independent, waste-generating dock systems in which only a few emergency systems are left and most of working media used on the dock are taken out through special service lines belonging to land stations
7. arrangement of special local stations to prevent from propagation pollutions occurred in emergency situations.

Effectiveness of application of the means 1,2 and 3 depends on effective isolation (separation) of working spaces. It is automatically associated with the necessity of application of additional ventilating, filtering and warning systems to eliminate possible appearance of dangerous concentration of gases inside dock's protective encasings, as well as application of systems for gathering and removal other liquid, semi-liquid and solid wastes (items 4,5 and 6).

General complex application of the means effectively preventing the environment against pollution may appear too expensive for operators of only one dock as in the case of small shipyards able to apply only simple temporary means of a low effectiveness. In the areas of concentration of ship repair and shipbuilding industry it seems justified to arrange special common centres for collection, transport, processing and utilization of waste substances hazardous for water, land and air environment, that obviously could ensure a professional, high-level effectiveness of their activity.

Out of the engineering processes which are specially hazardous to environment the following may be distinguished :

- ✓ initial washing
- ✓ removal from construction of fouling, old coating flakes and corrosion products
- ✓ washing the construction in advance of painting
- ✓ painting the construction
- ✓ welding, thermal cutting and straightening
- ✓ luting and grinding
- ✓ insulating.

The processes may be carried out with the use of various techniques and methods and should be selected with accounting for their as-low – as-possible harmfulness to the environment, that may appear expensive. Hence it is clear that it cannot be an immediate narrow-ranging activity but it must be a result of complex long-ranging actions often involving investment outlays.

HARMFUL SUBSTANCES

A few measurement series have been performed for the project's purposes because any systematic data on monitoring the state of ecological hazards in the areas of operation of floating docks, are lacking. They have served for qualitative and quantitative determination of sewage and waste streams generated in the course of repair work on ships of three different types.

a) In the range of emission to the atmosphere:
- dust of abrasive materials (uncontrolled discharge) – content of compounds of the metals: zinc, iron, copper, lead
- volatile components of paints and solvents (uncontrolled discharge) – content of : xylene, aliphatic hydrocarbons, butyl acetate, ethylic benzene, phenol
- gas emission resulting from operation of dock's energy systems – content of : NO_x , SO_x
- emission resulting from welding processes – content of : CO , NO_2 , dust containing Fe_2O_3 and MnO.

In the case of the sheltered working space of the dock, disposal and utilization of xylene vapours as well as dust and smoke is especially important.

b) In the range of pollution of water around the docks – after completion of repair work: the increase of content of the metals : cadmium (4 times), zinc (2 times), nickel, copper, chromium, cobalt and manganese (2 times each).

c) In the range of water bed sediments of abt 30 cm in depth – in the area of dock's basin a large content of mineral substances and significant contamination with heavy metals (zinc, copper, lead, nickel, manganese) and iron has been observed. Also, aromatic hydrocarbons and tin organic compounds have been found.

d) In the range of liquid wastes due to:
- preliminary washing – high content of suspended matter, dry residues and COD (Chemical Oxygen Demend) organic nitrogen and phosphor, chlorides and sulphides
- bilge water – high content of oil derivatives as well as COD, tin organic compounds and heavy metals (cobalt, zinc, copper) and iron.

e) In the range of solid wastes:
- after washing – oil derivatives, heavy metals (copper, zinc, lead) which in principle belong to the category of harmful wastes
- after abrasive jet working – high content of iron, lead, zinc, copper; which in principle belong to the category of harmful wastes.

LEGAL REGULATIONS

In the considered case are in force the legal regulations concerning shipping and ports such as : MARPOL 1974/78 International Convention, the Convention on Prevention of Marine Pollution by Dumping of Wastes and Other Matter (1972), London Convention OPRC (1990), Helsinki Convention on Prevention of Baltic Sea Environment (1992), IMO Act for the Prevention of Pollution from Ships (1995), Rules of the classification societies such as DNV, LR, ABS and GL, relating to the requirements for ecological ships, Polish State Act on Prevention of Environment (2000), the Decree of Ministry of Infrastructure relating to port plans on managing the wastes (2002), as well as that on reporting about functioning the port facilities for picking-up the wastes (2002), European Union Directives on the Limitation of Volatile Organic Compounds (VOC) (valid from 1.06.2001) limiting the application of paints containing harmful solvents, IMO Resolution A 895 which fully prohibits the application of paints based on TBT compounds (valid from 1.01.2008). From the above given specification it results that special ecological problems of floating docks should be covered by one uniform legal act.

CHARACTERISTICS OF THE DOCK

The designed dock SINE 212CD (Fig.2 and 3) consists of an integral box structure composed of pontoon and two continuous side walls. The dock is fitted with 6 ballast compartments of 4 ballast tanks each. In the dock's structure has been provided 3 longitudinal watertight bulkheads (of 13 mm plate thickness), 5 transverse watertight bulkheads (of 10 , 12 and 14 mm plate thickness, respectively) as well as 28 transverse non – watertight bulkheads (of 10 and 14 mm thickness, respectively). In the pontoon is located the transverse cable duct (having gabarites of 1780x1940x10 mm) which connects relevant casings in the side walls, the bottom (of 10, 11, 12 and 13 mm plate thickness) and the deck (of 10 , 12 and 14 mm plate thickness). Each of the dock's side pontoons (of the dimensions of 170000x4000x9750 and shell plating thickness 8 or 10 mm have 2 decks: the upper deck (of 24 mm plating) and safety deck (of 9 mm plating), 5 transverse bulkheads (of 10 mm plating), tanks, inspection and cable casings, gangways, 1 outer and 2 inner fenders, overflow and access recesses. In order to improve the dock's stability, the sponsons (of 10 mm plating) have been provided on the outer side structure at the pontoon's deck height. On the dock's side walls a continuous framework has been assembled, on which 6 movable roof segments sheltering the dock are placed. The segments were so designed as to obtain the units of two different depths and breaths, that makes it possible to slide one over another (to change windage area or to enable transport of elements to the dock working space). The segment roofing and side coverings of framework as well as shutter-like coverings of end roof segments are aimed at limitation of emission of harmful substances to the atmosphere and effective improvement of working conditions. On the framework a 160 kN lifting capacity gantry crane operates. The side pontoons have the so called *coastings* (10 m long and of 10 mm plating thickness and the dock's end platforms (10 m long and of 12 mm shell plating, aft, and 5.725 m long and of 12 mm plating, fore) are fixed to the pontoon. The side pontoons are connected together by means of a two-wing passageway.

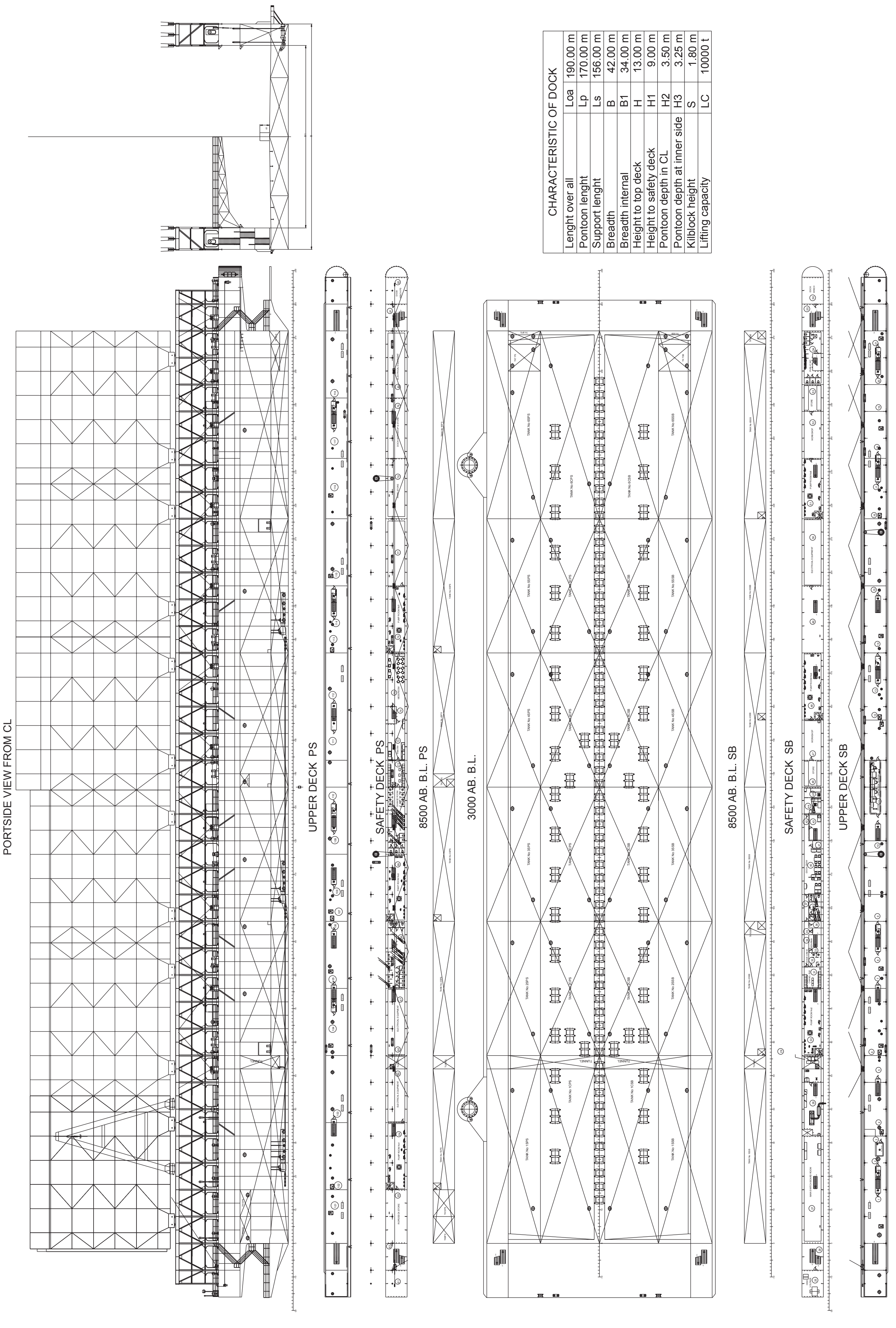
Particulars of the dock :

total length	L_c	= 190.0 m
pontoon length	L_p	= 170.0 m
outer breadth	B_z	= 42.0 m
inner breadth	B_w	= 34.0 m
pontoon depth	H_{ps}	= 3.5 m
pontoon depth at side wall	H_{bs}	= 3.25 m
depth to safety deck		– 9.0 m
depth to upper deck		– 13.0 m
height of keelblocks		– 1.8 m

dock's load-carrying capacity : 10 000 t

dock's load – carrying capacity at the draught T = 3.06 m : 13 715 t

- The minimum freeboard of the immersed dock : >1.5 m; and the freeboard of the emerged dock (pontoon) measured at the inner side wall plating : ≥0.2 m
- The maximum values of dimensions of docked objects :
  - total length L_c = 169.0 m under full roofing, and
  - L = 185 m at slid-over end roof segments
  - maximum draught T_{max} = 5.8 m
  - maximum mass – 10 000 t



CHARACTERISTIC OF DOCK		
Lenght over all	Loa	190.00 m
Pontoon lenght	Lp	170.00 m
Support lenght	Ls	156.00 m
Breadth	B	42.00 m
Breadth internal	B1	34.00 m
Height to top deck	H	13.00 m
Height to safety deck	H1	9.00 m
Pontoon depth in CL	H2	3.50 m
Pontoon depth at inner side	H3	3.25 m
Kilblock height	S	1.80 m
Lifting capacity	LC	10000 t

***Fig.2.** Simplified general arrangement plan of the SINE 212CD dock .*

- The dock is moored to 2 dolphins on PS
- Deck equipment : four 80 kN capstans, two mobile pulling cars, on PS and SB, together with 100 kN warping winches for leading the ship into the dock, put-in personnel & load elevator (PS) of 10 kN hoisting capacity, fenders, mooring bollards and fairleads
- Three options of electric energy supply have been provided (2 from land sources, and 1 from own electric generating set)
- Dock's power plant: one electric generating set of 140 kW at 1500 rpm, oil fuel tank, cooling water surge tank
- Pump stations: 3 in each of the side pontoons, fitted with a mechanical intake ventilating system. The pump stations are equipped with a motor driving ballast pump, drives of the main and controllable gate valves for ballast water and its residues, bilge pump of the capacity Q = 6 m^3/h, at the pumping pressure H = 0.2 MPa
- Mechanical workshop: locksmith and welding equipment.

Functional systems :

- Ballast system – 6 ballast pumps of 2400 m^3/h capacity each, at H = 0,07 MPa, 2 residual water deep-well pumps of 90 m^3/h capacity, at H = 0.2 MPa, which may operate as 60m^3/h fire pumps, at H = 0.8 MPa
- Water fire main system intended also to support a froth--smoothering system
- Froth-smoothering system : frothing agent tank of the capacity V = 5m^3, two 9.5 m^3/h water pumps
- CO_2 fire-extinguishing system : the station of five CO_2 cylinders, of the capacity V = 67 l
- Steam system – supplied from a land source
- Sanitary system – fresh water supply piping from a land source, sterilizer, electric heater, 2 circulation pumps of 1.8 m^3/h and 3.6 m^3/h capacity, respectively
- Sewerage system – sewage is pumped away from TK9PS tank to a land-based tank
- Compressed air system – supplied from a land-based compressed air station
- Acetylene pipeline system : supplied from a land-based acetylene station
- Oxygen pipeline system : supplied from a land-based oxygen station
- Light water system : supplied from a land source
- Bilge water system – 7 bilge water pumps of 6 m^3/h capacity each, located in pump stations and pumping the water to a dock's tank and from here away to a land- based tank
- Drainage system – taking water from the framed upper deck and pontoon deck – through catch gates and piping to the pontoon deck and further to oily-water and non-oily water tanks. The tanks are emptied with the use of pumps bringing the water away to land
- Electric generating set's cooling system – of two stages : with fresh water (closed) and overboard water (open)
- Fuel oil system – through a service tank
- Exhaust gas system – through an insulated pipeline to the atmosphere, behind the dock's structure
- Ventilating system (servicing the accommodations) : a mechanical supply-exhaust system with outlet to the dock chamber space and from here by using fans (14 units of 11.3 m^3/h capacity each) and special filters – overboard to the atmosphere
- Electric power system – the main supply from a land-based electric station of 3x15 kV at 50 Hz frequency, and 3x400 V. The maximum power output of 15 kV network : 640 kW (800 kVA), the maximum power output of devices fed from 400 V land-based electric network : 80 kW (10 kVA). Simultaneous supply from both the networks is not provided for. On the dock a 15 kV connection switchboard and 0.4 kV transformer feeding 400 V main switching station, are installed. The 3x230 V/50 Hz network is fed from a 200 kVA main transformer as well as from 40kVA emergency transformer.

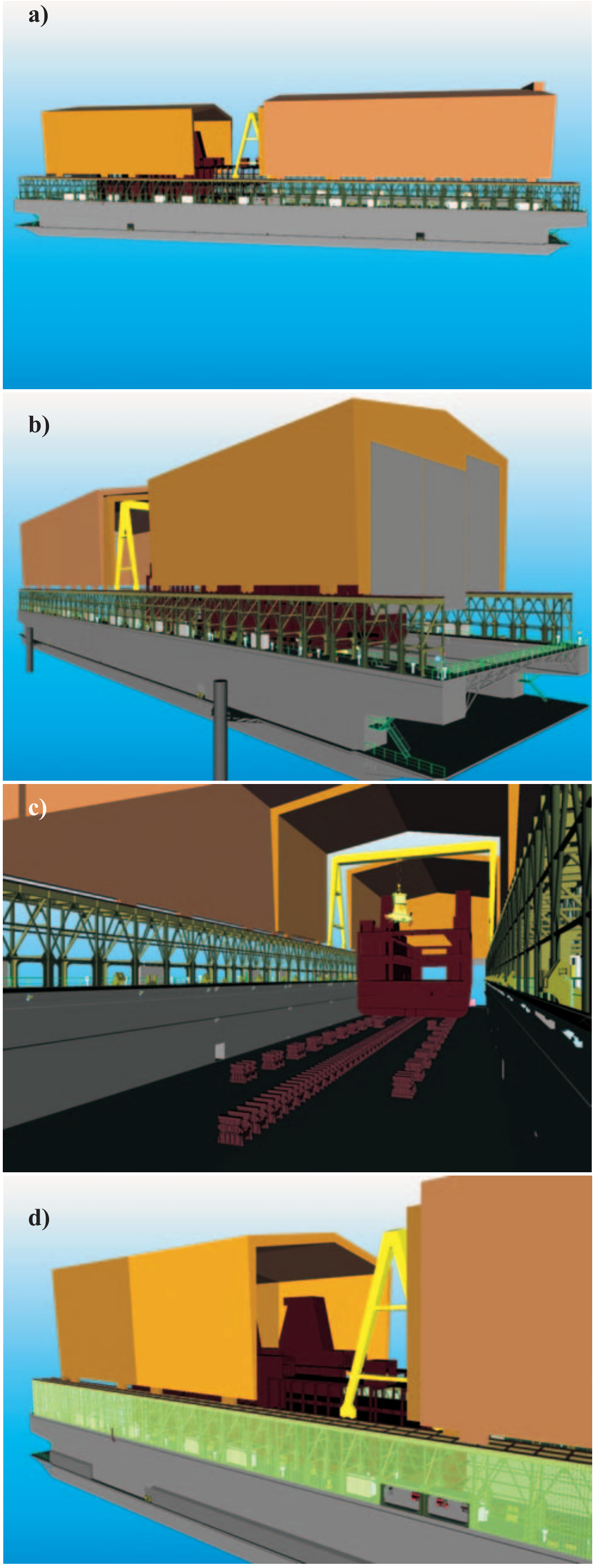
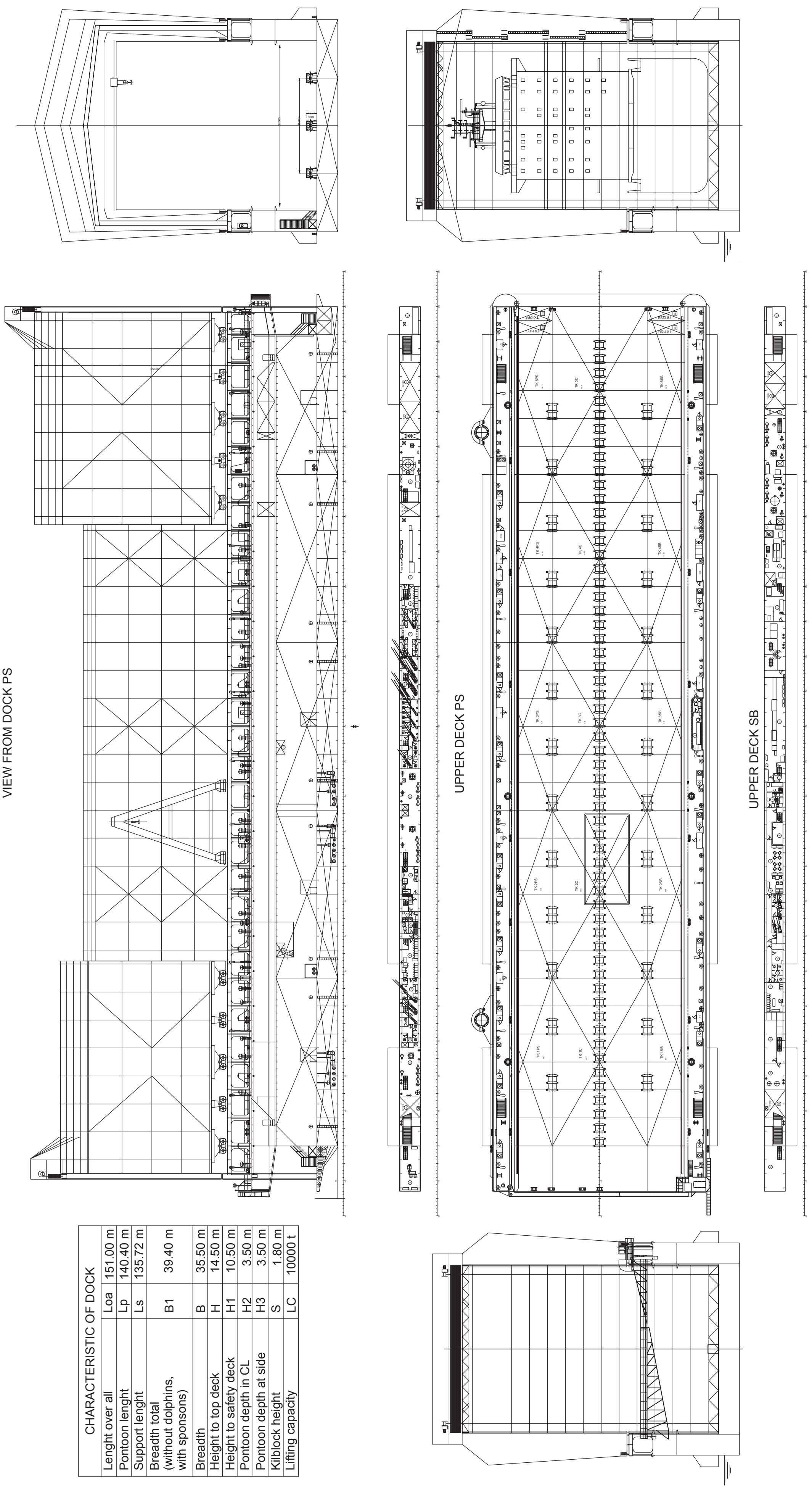


Fig.3. *Selected examples of virtual visualisation of the SINE 212CD dock :* ***a)*** *general view;* ***b)*** *shutter-like coverings of end roof segments;* ***c)*** *the framework assembled on the dock's side walls;* ***d)*** *sponsons and the light passing through framework covers .*



CHARACTERISTIC OF DOCK		
Lenght over all	Loa	151.00 m
Pontoon lenght	Lp	140.40 m
Support lenght	Ls	135.72 m
Breadth total (without dolphins, with sponsons)	B1	39.40 m
Breadth	B	35.50 m
Height to top deck	H	14.50 m
Height to safety deck	H1	10.50 m
Pontoon depth in CL	H2	3.50 m
Pontoon depth at side	H3	3.50 m
Kilblock height	S	1.80 m
Lifting capacity	LC	10000 t

Fig.4. *Characteristics of the converted dock .*

CHARACTERISTICS OF THE CONVERTED DOCK

The design concept of pro-ecological modernization of the SINE 126CD dock (Fig.4) concerns the existing unit of the following particulars :

total length L_c = 151.0 m
outer breadth B_z = 35.5 m
max. draught T_{max} = 13.3 m
inner breadth (between sides pontoons) – B_K – 28.5 m
height of side pontoons – 14.5 m
height to safety deck – 10.5 m
load-carrying capacity – 8000 t
hoisting service – 2 cranes.

The design concept of the dock's modernisation amounts to :

- assembling 4 m deep continuous frameworks on the upper decks of side walls
- adding three blocks of segments of dock's roofing, two end segments of which fitted with shutter-like coverings are movable and have different heights so as to make it possible to slide them over the main, middle part of the roofing
- introduction of the side wall sponsons to improve the dock's stability
- adding 4 tanks for sewage and waste water, of 35 m^3 each
- adding one 160 kN gantry crane
- adding the ship pulling-in devices moving along the side walls
- modification of run of some stairs
- adding the mechanisms to move the roof segments
- adding the framing of side wall main decks, and pontoon deck
- introduction of a separate ventilating system consisted of 16 ventilating units fitted with special filters against xylene vapour lingering in under-roof space
- adding a biological sewage treatment station
- installation, in the region of the added sewage tanks, a local piping system to discharge their content into sewage tender cars, with the use of a mobile pneumatic pump.

It has been proposed to gather solid wastes mechanically and discharge them to land for further processing. Suspension waters and mixtures should be in advance processed in the additional tanks from where the cleaned-up water flows down to overboard waters, and the sluge is delivered to land. As a result of the proposed changes the PRS class **dk dok ekologiczny* can be assigned to the dock in question. Also, the dock obtains the following new main particulars :

- total breadth including sponsons – 39.4 m
- breadth of dock's roofing – 38.9 m
- maximum side height above waterline – 52.6 m
- load-carrying capacity of the dock
- elimination of to-be-docked ships of about 80 m length and 8000 t mass in order to satisfy longitudinal strength criteria for the dock.

The following factors may limit safe working conditions of the dock :

- necessity of strengthening the upper deck of side walls by means of girders
- necessity of strengthening the pontoon's longitudinal structure
- limitation of possible docking operation of the ships to the wind force less than 17.8 m/s for ships 80 m long and of 8000 t mass (to satisfy the longitudinal strength criteria).

SUMMARY

Conclusions concerning SINE 212CD dock

The movable roofing of the floating dock, proposed in the design as a permanent structural element to prevent the atmosphere from emission of harmful substances, has its advantages and disadvantages. To the advantages one should count stable conditions for realization of engineering processes, and making them independent of atmospheric exposures. A disadvantage is a significant rise of the centre of lateral pressure of the dock and its centre of gravity, as well as an increase of the docks deadweight by the weight of roof structure and an additional casual weight of snow (stability), that results in the necessity of application of sponsons to broaden dock's waterplane, and simultaneously limits the effective load-carrying capacity of the dock. The problems involved by roofing the dock may be omitted by applying modular structural paravans to be used only during the operations especially harmful to the environment. However, even if any mode of sheltering is applied, the most effective way is to reduce emission of dust and paint particles to the atmosphere. The problem of concentration of solvents and paint particles within the enclosed space of the dock becomes more and more observable. Concentration of xylene may be a problem as it occurs close to the pontoon deck and its removing requires additional ventilating ducts located in lower parts of the side wall inner plating and the expensive mobile ventilating and filtering stations. The problem can be effectively solved by replacing harmful paints with paints containing solvents based on water or carbon dioxide, in compliance with European Union directives. As far as the paints which pollute surrounding waters are concerned a far-reaching solution would be to resign from application of TBT paints and replace them either with less noxious copper paints, coverings of high smoothness or future paints containing biocides. It seems reasonable to widen the use of methods of paint hydrodynamic spraying with air support or HVLP (low pressure) spraying, which lead to significant limitation of paint spattering by over 80% and 75%, respectively, and to a reduced emission of solvents. In the range of noxious emission due to welding the „low-smoking" and gas-shielded welding techniques accompanied by local mobile ventilating systems should be decidedly introduced. It seems essential to introduce systems for monitoring harmful concentration and emission to the atmosphere**.**

The problem of solid wastes of different origins seems to require a comprehensive solution, outside the dock's working area. In general, to this end the currently used solution based on the floating or wheeled waste removal units may be further applied on the condition that the problem of mechanical gathering the wastes from the dock's working space associated with successive washing both ship's structures and dock's working surfaces, is effectively solved with accounting for that the resulting liquid and suspension sewage would be collected in the bilge-tank system and then discharged to land. It seems also reasonable to elaborate a design concept of a facility for storing and processing ecologically harmful wastes, common for a greater number of shipyards.

Conclusions concerning the conversion of the existing dock

To protect the environment against emission of harmful substances from the dock in question is possible by applying :

- total structural roofing of the dock
- absorption and utilization of harmful gases, dusts and solid substances.

The application of the movable end parts of dock's covering would make it possible :

- to significantly reduce lateral windage area during ship's docking operation
- to ease free access to end parts of the dock (repaired ship) from the side of water area
- to bring the ships having high aft superstructures into the dock.

The reduction of lateral windage area by sliding the movable roofing parts over the middle ones and the addition of sponsons prevents the dock from exceeding the heel angle of 1.5° under the wind pressure p = 490 Pa (abt. 20 m/s wind force), permissible for the considered dock acc. to PRS rules. Docking the ships of abt. 80 m in length and the nominal weight of abt. 8000 t may be permitted at the wind pressure not greater than 413 Pa (abt. 17.8 m/s wind force). Control calculations have confirmed that the elaborated dock roofing design is feasible. However the design should be further developed with a view of the following problems :

- moving and fixing, at given positions, the movable roof segments
- a way of removing snow layer from the dock's roofing, especially from its middle part, since an excessive snow layer could prevent the movable roof segments from motion.

Provisionally the two ways were considered :

- to provide for a heating system located just under the roofing
- to direct heat air flow towards the roofing.

The first way is easy in use but expensive, whereas the second is characterized by a large heat dissipation and lower effectiveness, but in return it rises temperature within the whole space (compartment).

However the structural analysis of the dock, performed on the basis of spatial beam model, consisting in longitudinal, transverse and local strength calculations (acc. PRS rules) leads to the following conclusions :

- In the analysed loading conditions of the dock the pontoon's centre girder and plate floors in its vicinity show a great overloading over almost the whole length of the dock
- The longitudinal strength of the dock is ensured for docking the ships less than 80 m long and of the weight equal to the nominal load – carrying capacity of the dock but decreased by the weight of roofing and coverings.

In order to maintain the current range of operation of the dock its hull should be strengthened. The two following methods of rebuilding (strengthening) the dock may be effective :

a) to cut the dock close to its plane of symmetry and add the next centre girder together with neighbouring parts of plate floors

b) to design a new pontoon with making use of the existing side walls of the dock.

Perhaps, the method **a)** is less expensive and labour--consuming in realization but it does not guarantee any long service-time for the dock because of the developed corrosion process of its structure. An additional transverse strength analysis of the dock could provide indications on by how much it would be possible to broaden the dock and if it would be sufficient to satisfy stability criteria for the dock without adding the sponsons, that is rather doubtful. Furthermore any increase of the pontoon's breadth would result in an increased breadth of dock's roofing, and in consequence, in an increase of scantlings of its structural members and thus also its weight etc.

The method **b)** makes it possible to design the pontoon in an optimum way, that could provide the dock with an appropriate service range.

Also, effectiveness of the method of dock's mooring to dolphins should be checked, and the problem of uniform distribution of weight of the movable part of the dock's roofing (by making its side walls more flexible and increasing the number of driving car units), as well as the problem of leading the tractive wheel units of roof segments in the condition of transverse deformations of the dock's hull, should be solved.

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175. Sinus: Pontoon tanks venting SINE 126-I CD 5310-2. Gdańsk, 2005
176. Sinus: Deck scuppers SINE 126-I CD 5320-1. Gdańsk, 2005
177. Sinus: Dock ventilation layout SINE 126-I CD 5600-2. Gdańsk, 2005.

Management of liquid wastes on floating docks in the aspect of its impact on the environment

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ABSTRACT

State of environment pollution in the area of operation of a floating dock was investigated. In the taken samples of liquid wastes, outboard water and bed sediments were determined values of their basic physical and chemical parameters as well as concentration of poly-cyclic aromatic hydrocarbons, butyl tin compounds ($(Bt)_3SnCl$, $(Bt)_2SnCl_2$, $BtSnCl_3$, $(Bt)_4Sn$), polychlorinated biphenyls (PCB 28, PCB 52, PCB 101, PCB 138, PCB 153, PCB 180) as well as heavy metals (Zn, Cd, Pb, Cu, Ni, Cr, Co, Fe, Mn, As, Hg).

Key words : dock, liquid wastes, bed sediments, environment investigations, GC/MS

INTRODUCTION

Management of liquid wastes on the dock is a complex problem. Two main groups of liquid wastes can be distinguished : liquid wastes associated with service of the dock considered as an autonomous floating unit, and liquid wastes resulting from repair operations carried out on it.

In the first group liquid industrial wastes and sewage associated with permanent stay of dock's crew and additional personnel on the dock can be distinguished. The sewage are usually discharged to the quay and further transported to a municipal sewage treatment plant. Qualitative content of dock sewage does not much differ form that of typical living sewage [1,2].

Liquid industrial wastes from the dock are collected in dock's bilge wells and tanks. They comes from leakage of such systems as : main drainage, fire fighting, fuel oil pumping between the dock and floating unit under repair, industrial water supply, power plant, sanitary water supply. They are to a large extent contaminated with oil and subject to deoiling process. The separated organic fraction is pumped out and collected in tanks outside the dock [3,4].

It is extremely difficult to define liquid industrial wastes associated with repair work carried out on a docked floating unit. To this end it is necessary to recognize the object from the point of view of its location, construction and realization of operations carried out on it. Repair operations can be performed with the use of various engineering processes. And, the following characteristics of the unit under repair are also important :

- type of a unit, which influences a way of it use (region of operation, kind and amount of shipped cargo, operations carried out on board, e.g. fish processing on fishing trawlers)
- its construction
- hull and outfit materials as well as kinds of paints used during the preceding repair
- scope of repair work [2,5].

The criteria contained in [6] have to be accounted for in determining noxious substances and those of potentially harmful impact on the environment.

In the case of floating dock the substances of both the kinds may :

- be generated as a result of repair and modernization work
- be components of materials used for repair of floating units
- be removed as waste materials, out of the repaired unit
- find their way to the environment due to a failure, incorrect work of the dock, or the carrying out of operations against the criteria of the Best Ecological Practice [6,7].

In the tested liquid wastes, concentrations of poly-cyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCBs) as well as butyl tin compounds were determined. PCBs and butyl tin compounds are the group of compounds prohibited for application, but they are contained in many ship elements removed in the course of ship repair. PCBs have found their application in a.o. heat exchangers, condensers, hydraulic devices. And, tin organic compounds, first of all tri-butyl tin (TBT), are used as components of antifouling paints. Such paint coverings have been continuously improved and self-polishing paints appeared in 1980s. It has been demonstrated that though TBT has liquidated organisms fouling ship hulls it has detrimentally influenced the aquatic life (oysters, dolphins and whales). During 21st session of IMO General Assembly was adopted A 895 Resolution ordering to introduce a legal act to ban application of TBT beginning from January 1, 2003.

It was agreed that the systems containing TBT are allowed to be used until January 1, 2008. In the presently manufactured antifouling paints the compounds are not applied at all. However from the point of view of impact on the environment around floating docks it is important whether there is no tributyl tin compounds contained in removed old paint coverings laid during previously carried out repair work [5,8].

OBJECT OF THE INVESTIGATIONS

The investigations dealing with influence on the environment of the repair processes carried out on the dock were realized in three cycles: in January 2004 , May / June 2004, and December 2004 / January 2005.

The investigated object was a ship repair dock of Gdynia Naval Shipyard. Its main parameters were as follows :

- lifting capacity : 8000 t
- overall length : 151 m
- overall breadth : 35.5 m
- breadth between side walls : 28.5 m
- depth of side walls : 14.5 m
- distance between keelblock lines : 27 m
- maximum draught : 13.3 m.

Characteristics of repaired or modernized ship as well as scope of operations were accounted for. In compliance with the earlier made assumption the dock and the ship docked on it were considered as one object of the investigations. Measurements were connected with the stay of the three ships on the dock, namely :

- the GR 6-50 fishing trawler *Polar Siglir* of 3000 DWT, built in 1975
- the bulk carrier *Ziemia Suwalska* of 26605 DWT, built in 1984
- the bulk carrier *Ziemia Chełmińska* of 26700 DWT, built in 1984.

MATERIALS AND METHODS

The points of sampling the dock surrounding water and bed sediments (Fig.1) were chosen with taking into account : the dock's construction, ship docking procedure, location of the dock within the dock's basin, and bathymetry of the basin. The samples were taken in four points located at the edge of the dock's basin. Two sampling points were located at starboard hawse holes, one at dock's bow and one in the starboard mid-length. Points 1, 2 and 4 (Fig.1) were located at a distance of 15 m from dock's side walls. Point 3 was placed on the dock's longitudinal axis, before its bow at a distance of 20 m from the arranged oil boom. The samples of outboard water and bed sediments were taken and their physical and chemical characteristics determined. The sampling procedure was in compliance with PN-EN 25667 and PN-ISO 5667 standards.

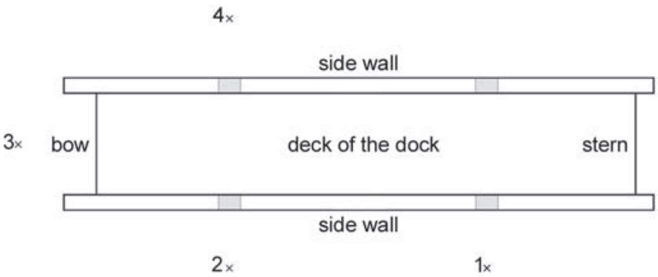

Fig. 1. *Arrangement of sampling points for outboard water and bed sediments around the dock.*

The sampling procedure of the bed sediments was in accordance with [9]. During the investigations were taken the samples of : preliminary washdown waste water, bilge water and ballast water. The preliminary wash-down waste water comes from washing hull's surface by means of fresh water under high pressure to remove salt deposits, corrosion products, living organisms and other contaminations from the hull surface before commencing removal of old paint coverings. For the ship's hull wash-down process the amount of water, ranging from 70 to 290 m^3 , is used. Because of the very large amount of waste water it was necessary to carry out the sampling in such a way as to make averaging the waste water sample from the preliminary washing-down carried out on a greater hull surface area, possible. It was assumed that qualitative and quantitative contents of the taken samples should reflect the contents of real waste water produced during the preliminary washing - down of separated hull surface areas. Three such areas were distinguished: above-water zone, changeable draught zone and underwater zone which distinctly differed to each other. (Fig.2).

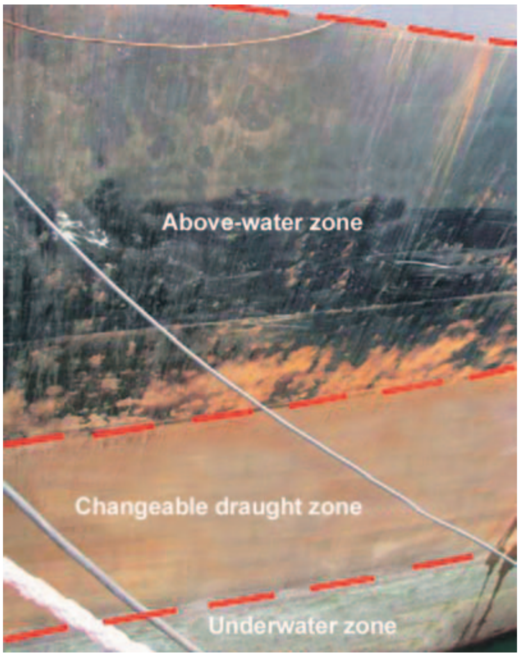

Fig. 2. *Ship side surface with distinctly seen above-water, changeable draught and underwater zone.*

The greatest amount of micro-organisms overgrew the bottom and sides of the ship up to its waterline. Moreover, the surface was to a great extent corroded. The next distinguished hull zone ranging from the waterline up to the Plimsol's Mark (Fig. 2), was characterized by a much smaller amount of fouling organisms than the underwater zone but its corrosion wastage was much greater. The last distinguished hull zone was the above-water hull side above the Plimsol's Mark.

In Fig.3. range of the distinguished zones of hull surface was presented with the bulk carrier *Ziemia Chełmińska* as an example.

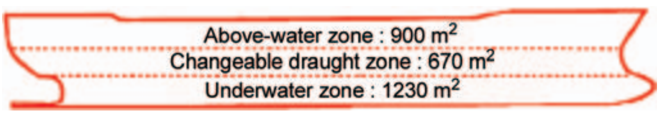

Fig. 3. *The distinguished zones of the ship's hull surface.*

Samples of bilge and ballast water were taken from the places in which they have been collected on the repaired ship.

Determination of values :

- of physical and chemical properties of the samples of the sediments obtained from liquid wastes, and of bed sediments, namely reaction, density, hydration of residues, total nitrogen and phosphor, was performed by means of the method described in [6],
- of polychlorinated biphenyls (PCBs) – by means of the authors' own method [11] and
- of tin organic compounds and poly-cyclic aromatic hydrocarbons (PAH) – with the use of the authors' own method [2].

RESULTS

The samples of water taken from the dock basin were clear and of natural colour. Its high conductivity should be considered as a natural feature of such sea water as that of the Baltic Sea having 7 ‰ salinity. The determined values of concentration of cations and anions (chlorides, sulphates, bicarbonates, magnesium, calcium) were on the level of concentration of those ions in the Baltic Sea waters. On the basis of values of COD, permanganate index and BOD the tested waters may be numbered among medium-contaminated sea waters of coastal zone. Values of the basic physical and chemical parameters of the sea water taken in the course of repair work during both campaigns, did not significantly differ from the results of the analysis of the water taken at the same sampling points, before commencement of the ship's repair work on the dock. Their qualitative and quantitative contents corresponded with those of sea water. Comparing the results of determination of content of heavy metals in the water samples taken before commencement of repair work on the dock and during carrying out the work, one can observe a significant rise of concentration of the following substances :

- cadmium – four times
- zinc – over three times
- copper, nickel, chromium, cobalt, manganese – over two times.

Determined concentration values of the remaining heavy metals contained in two samples taken from the same places are similar.

The bed sediment samples taken in the point 1 and 2 consisted of a black silt of a loose uniform consistence free from any thick fractions (stones, residues of aquatic macrophytes). The samples emitted distinct smell of hydrogen sulphide and oil products. The bed sediment sample taken in the point 3 consisted of a dark-grey silt containing an amount of a deep red-olive green sand of medium-size grainage. In the sample taking place, below 30 cm of sediment depth, a distinct boundary was found between the surface layer of silt and lower, neighbouring layer of sand. The bed sediment sample taken in the point 4 consisted of a grey watery silt having distinct smell of hydrogen sulphide. The sample was uniform, without any coarse - grain components. In the case of the samples taken in the point 1 and 2, depth values of the silt layer, its macroscopic description and values of its basic parameters were similar to each other. Results of analysis of the bed sediment sample taken in the point 3 only slightly differed from those of the remaining bed sediment samples. The tested bed sediment samples were characterized by a large degree of watering and large content of mineral substances in dry sediment mass (87.9%-93.35%). The performed tests indicate that the taken samples have been highly contaminated by heavy metals. Out of the all determined metals, iron was of the highest content (2% do 3.3%) relative to dry sediment mass. Attention should be paid also to the significant content of zinc, copper, lead, nickel and manganese. Results of determination of content of specific organic pollutants in bed sediment showed that it was highly contaminated. To a large extent the degradation of bed sediment is due to poly-cyclic aromatic hydrocarbons and tin organic compounds, and to a smaller extent - polychlorinated biphenyls. The high content of the PAH and tin organic compounds, especially of tri-butyl tin, determined in bed sediment, indicates that repair activity, in particular the processes of preliminary washing - down the hull surface and removing the old paint coverings, could contribute to the bed sediment degradation within the dock basin.

The physical chemical properties of the waste water samples taken during preliminary washing-down operations carried out on successive ships under repair, significantly differed from each other. The samples showed a specific colour whose kind and intensity depended on a degree of corrosion wastage of cleaned hull surface, amount of micro-organisms removed by water stream from hull surface, effectiveness of washing devices per unit area of washed down surface. The large quantity of ordinary suspended matter, dry residues and COD as well as degree of turbidity was equivalent to the amount of removed corrosion products together with residues of loosely bounded paints and amount of hull fouling micro-organisms. In the case of some samples the great share of losses , amounting to 37- 42% , during roasting the dry residues, as well as the high concentration of organic nitrogen and general phosphor, may indicate that the content of residues of organisms removed from hull surface in the total amount of removed material, was high (Fig.4). In single samples of waste water from the preliminary washing-down, an increase of COD accompanied with that of concentration of oil products was observed. The situation took place in relation to the sample coming from the preliminary washing-down of oily surfaces.

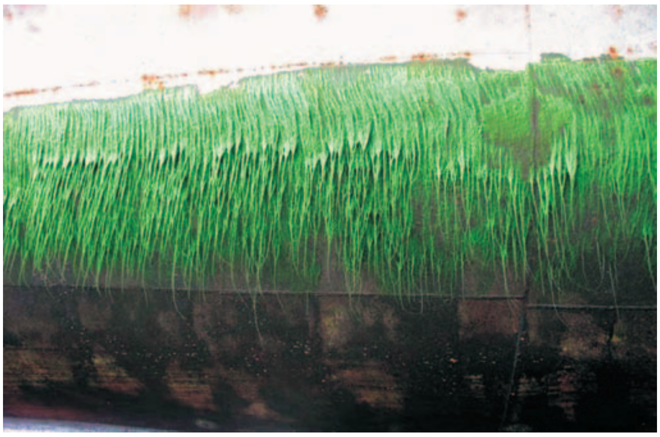

Fig. 4. *Algae fouling the ship hull .*

The waste water samples were also characterized by high conductivity, large amount of dry residues as well as high concentration of chlorides sulphates. It was amounts of the sea salt washed out from hull surface, which influenced such properties of waste water.

During the preliminary hull wash-down process significant amounts of material were removed, namely more than 2 g per litre of waste water , in which mineral substances amounted to 55% . High quantities of COD in waste water tell about its significant contamination. Very high ratio of COD and BOD contents in some samples indicates that the collected material contains substances which are hard to be disintegrated in a biochemical way, or noxious substances. Results of content determination of organic tin compounds and poly-cyclic hydrocarbons confirm that observation. In the hull wash-down waste water samples was found a high concentration of organic tin compounds, among which tri-butyl tin dominated, whose concentration was from a few to several hundred times greater than that of the remaining organic tin compounds, Fig.5 and 6. Significant amounts of tri-butyl tin, both in dissolved and suspended form, were determined in the waste water samples taken in the course of preliminary hull washing-down. Whereas PAH were first of all present in suspension fraction of the waste water samples, as compared with their vestigial amounts found in the filtered samples, Fig.7.

The waste water sample taken in the course of washing - - down the first, new-laid paint layer, was characterized by its natural colour, oil-product like smell as well as by a small amount of the well-settling sediment of maroon colour. Surprisingly high was the amount of the dry residue, in which the content of mineral substances was about 92%. From comparison of the ratio of COD and BOD contents it results that the dissolved substances may subject to biodegradation.

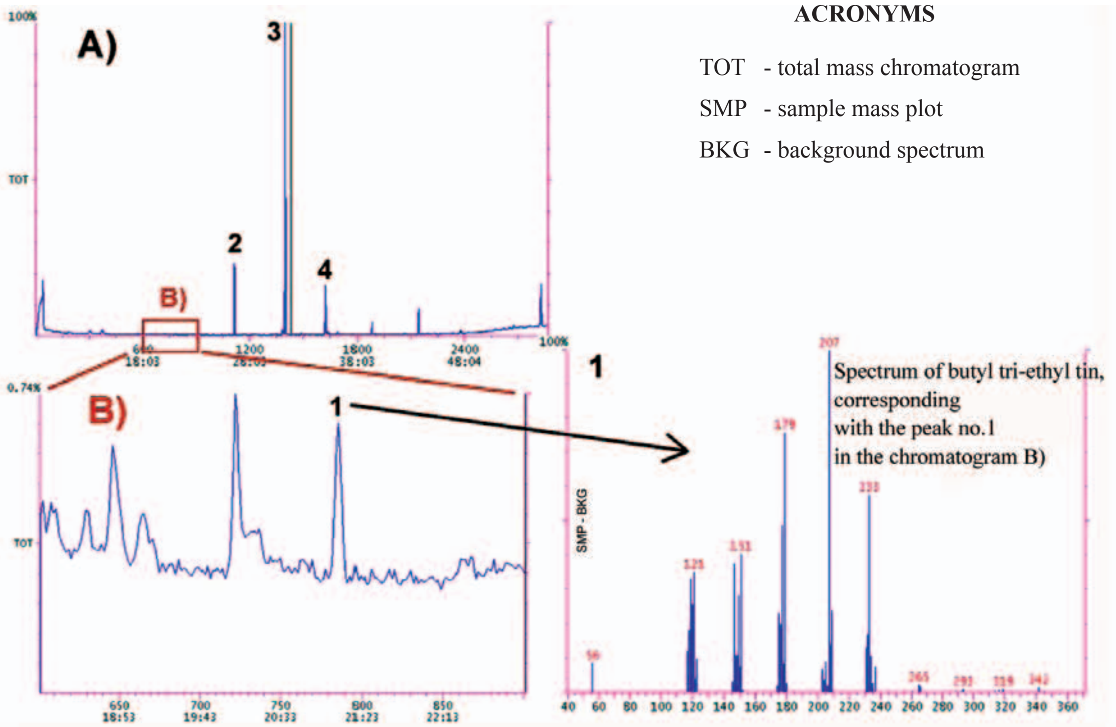

***Fig. 5.** Examples of chromatograms showing spectra of organic tin compounds found in a sample of filtered waste water .*

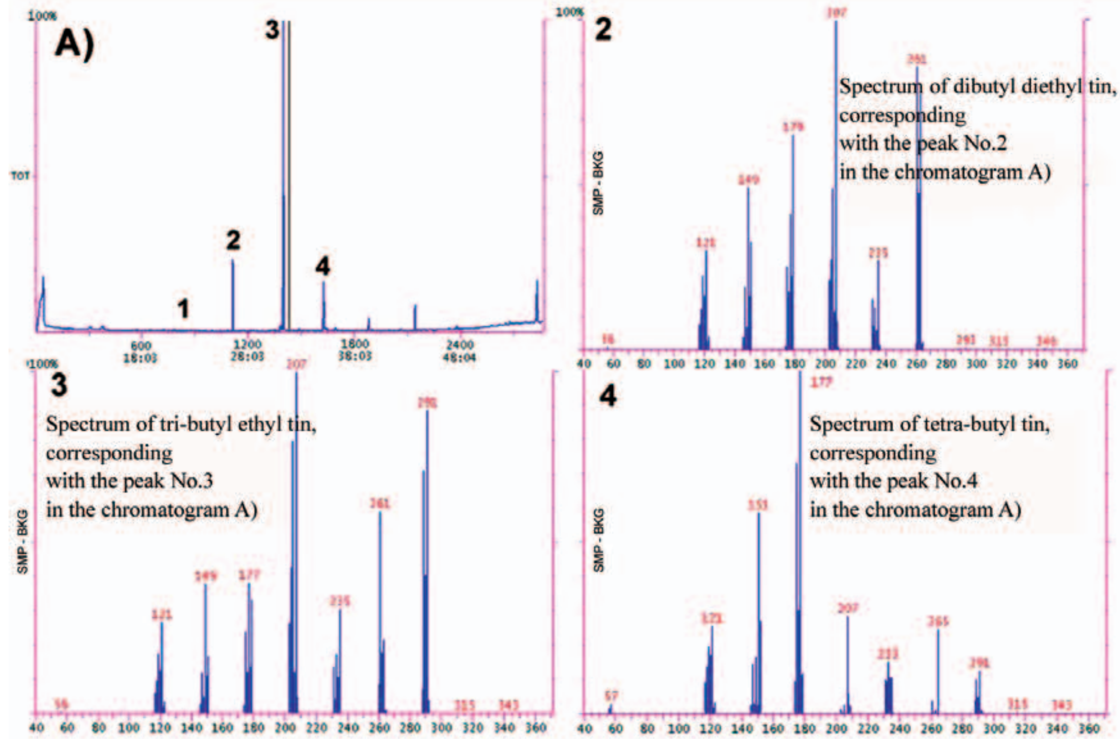

***Fig. 6.** Examples of chromatograms showing spectra of organic tin compounds found in a sample of filtered waste water – the next part .*

SUMMARY

The liquid wastes produced on the dock in the course of ship repair work can detrimentally impact the environment. Effective methods should be implemented to prevent the environment from their influence by separating the spaces where repair work is usually carried out on the dock. It seems rational to design and realize a system for collecting the produced liquid wastes. Waste water from preliminary hull washing-down and ship bilge water (after releasing bottom drain plugs) may be collected in dock's deck drainage wells and then discharged through drainage ducts to a trimming tank. Application of such a solution requires rebuilding the dock [8]. Another solution may be to force waste water to flow gravitationally along the pontoon deck, by trimming the dock by stern. The liquid wastes collected aft may be further processed. Information found in the subject-matter literature does not allow to indicate which method of treatment of preliminary hull wash-down waste water is the only best. On the basis of the obtained results of determination of the properties of suspended matter and easily settling suspension, as well as turbidity and colour, it can be assumed that to preliminarily purify the waste water will be necessary. The preliminary purification should be performed just after collection of the waste water. The

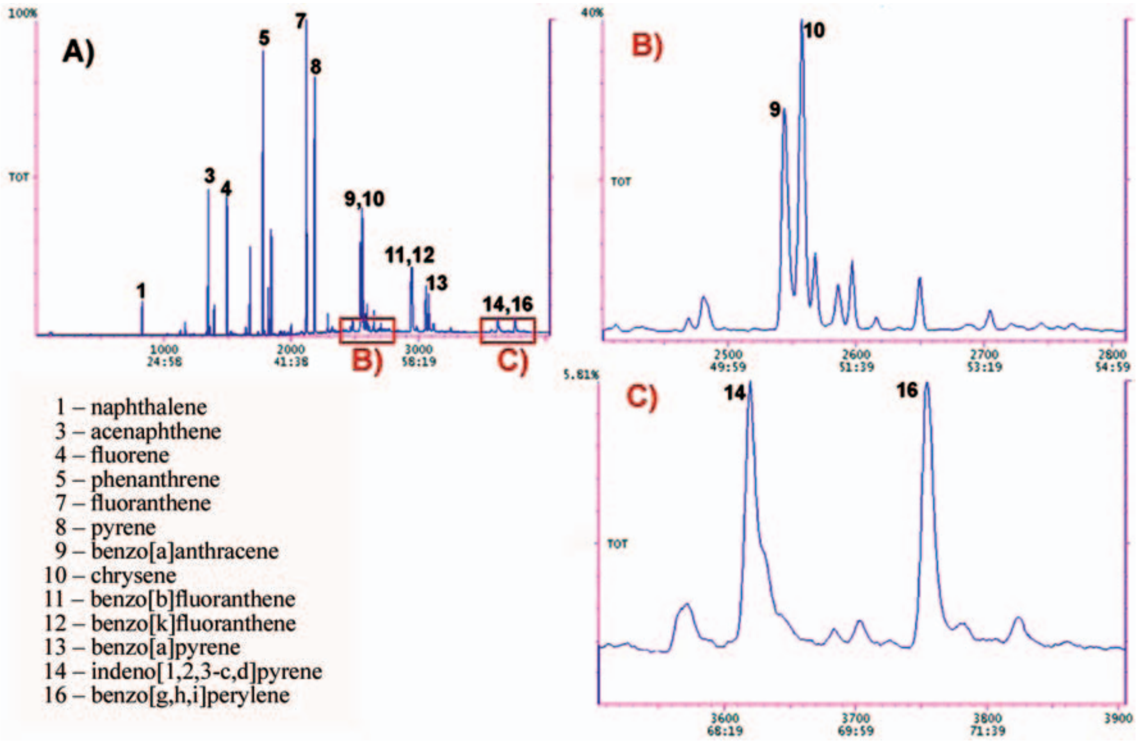

Fig. 7. *Examples of chromatograms of PAH in the form of suspension, found in a sample of waste water from ship hull washing-down .*

separated suspension should be considered as a waste. After preliminary purification the waste water should be subjected to a coagulation process in view of the results of determination of turbidity, colour, content of heavy metals and tri-butyl tin in filtered samples. It can be assumed that the coagulation process will require correcting pH value of the liquid wastes free from a thick suspension layer removed in advance. The sediment obtained from coagulation should be considered as a waste. On the basis of scarce literature data it can be expected that to apply aluminium salts as a coagulant, at pH = 6, would be most effective [12].

Some researchers indicate that after coagulation additional purification would be necessary. The task can be realized by removing dissolved wastes with the use of the activated - - carbon adsorption method. The carbon bed can be cleaned by applying the extraction method with the use of appropriate solvents dosed to water stream, or utilized together with absorbed contaminations, by means of the high-temperature combustion process [13].

Without performing some technological tests it is not possible to decide which method of purification of the waste water from preliminary hull washing-down is the best.

Moreover in particular cases, when the content of highly oiled bilge water in whole amount of liquid wastes discharged from the dock is large, all technological procedures can be applied only after separation of organic fraction. The separation of oil products should be performed by using a flow oil separator. The collected oil products should be taken as a waste; additional research on their possible utilization and classification should be arranged.

Resigning from actions aimed at improvement of waste water management will lead to further degradation of the environment. However actions aimed at making changes in ship repair technology realized on the dock, and at improving waste water and garbage management may not suffice to improve state of environment in the surrounding of dock's basin because of a secondary release of noxious substances to surrounding water from highly contaminated bed sediments which will be a source of secondary pollution even for many years.

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Some environmental aspects of ship repair work on floating docks – management of wastes

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ABSTRACT

This paper contains summary of investigations and analyses performed by Institute of Environment Engineering Systems, Warsaw University of Technology, in the area of management of the wastes produced in the course of ship repair work on floating docks. During the investigations carried out in Gdynia Naval Shipyard, were determined substances which qualitatively characterize selected wastes (in their original form as well as their water extracts), and amount of the wastes of basic groups, produced during floating dock service and repair and modernization work carried out on it, was estimated. Recommendations for waste managing on floating docks are presented, including possible ways of utilization of the wastes as well as their final usage (recovery and/or neutralization).

Key words : waste management, quantitative and qualitative characteristics of wastes, waste utilization (recovery and/or neutralization).

INTRODUCTION

Governmental authorities are forced, because of increasing environmental pollution, to establish more and more severe legal acts aimed at stopping the degradation process of environment. It particularly concerns the well-developed countries in which such legislation process is advanced most. Every new investment undertaking must – already in its design stage – account for several requirements aimed at limiting – as much as possible – its detrimental impact on the environment. Such requirements have been established also for shipbuilding and ship repair industry. It means that the engineering processes used in building and repair of ships must comply with the standards for emission of harmful substances, comprised in legal regulations; moreover all materials and devices used in the processes are recommended to be manufactured, selected and used in accordance with the principles of *the best available technology*.

In this paper selected investigations and analyses in the area of management of the wastes produced in the course of ship repair work on floating docks are summed up and presented together with relevant recommendations which – if obeyed – can make the environment protecting possible.

INVESTIGATIONS ON WASTES

The investigations in question were aimed at determination of selected indices of wastes, which characterize properties of samples of the wastes from repair work carried out on the dock.

In the scope of the investigations carried out in Gdynia Naval Shipyard the substances qualitatively characterizing the selected wastes (in their original form as well their water extracts) were determined, and amount of the wastes of basic groups produced during floating dock service and repair and modernization work carried out on it, was estimated.

The preliminary investigations made it possible :

- to determine environmental hazards resulting from carrying out repair work
- to determine qualitative and quantitative characteristics of contaminations contained in the wastes
- to classify the wastes from the point of view of their impact to the environment
- to determine possible utilization of the wastes including ways for their final usage.

During the research cycles (two measuring campaigns realized in 2004) the authors were focused on the kinds of produced wastes most important from the point of view of their qualitative and quantitative characteristics. Specificity of repair work on floating dock was also accounted for. The tested wastes came from the following operations :

- **preliminary cleaning** – fouling and paint residues washed-down by using water jet technique
- **actual cleaning** (the wastes resulting from abrasive blasting), and determination of characteristics of the used abrasive material, i.e. copper slag).

Samples were taken in compliance with a Branch Standard (BN) with accounting for specificity of the produced wastes, including the sample taking scheme for loose and granulated materials, adopted by *the Association of Official Analytical Chemists*. The wastes taken from particular repair work operations, assumed to be an original sample, were collected in a specially arranged place, from where an average laboratory sample was taken. In the laboratory the sample was prepared for physical and chemical tests in compliance with requirements of Polish Standards (PN).

In the course of the waste testing the following contamination indices were determined :

- selected parameters characterizing combustion properties (humidity, losses in roasting at 500°C)

- content of reducing substances (by using the bi-chromate method)
- content of non-polar organic substances
- content of substances extracted with the use of petroleum benzine
- content of phosphor
- content of some heavy metals
- content of some specific substances (some organic tin compounds, PAH, PCB)

The tests of solid waste samples were carried out by using the test methods given in Polish Standards (PN) and Branch Standards (BN) [1].

The tests of water extracts, necessary to assess environmental impact of the wastes and their possible final usage, covered the following items :

- pH value
- COD (by using the bi-chromate method)
- content of dissolved substances
- content of dissolved mineral substances
- content of non-polar organic substances
- content of substances extracted with the use of petroleum benzine
- content of chlorides
- content of sulfates
- content of phosphates
- content of some heavy metals
- content of some specific substances (some organic tin compounds, PAH, PCB)

Tests of water extracts were carried out by using the sewage testing methods given in Polish Standards (PN) [2].

DISCUSSION OF RESULTS OF TESTING THE WASTES

The research report [3] contains all results of the tests in the form of the tables supplemented with comments and interpretation of the results. In this chapter only a general discussion of the test results is given.

Wastes from preliminary hull washing-down

The tested samples are characterized by a very small content of organic substances, which shows that amount of fouling and paint residues with high content of metallic oxides, has been small. The sample from ship's deck washing-down (no. 2) is characterized by a high content of iron and relatively low humidity. The sample from ship's hull washing-down (no. 3) is characterized by a high content of oil products and substances extracted with the use of petroleum benzine, a lower content of iron and much higher content of heavy metals (copper, zinc, lead). Another sample from ship's hull washing-down (no. 6) is characterized by a high content of iron and, like the sample no. 3, much higher content of heavy metals (copper, zinc, lead).

Because of the high content of the specific substances (numbered among those highly noxious) the wastes in question should be considered dangerous [4]. However it should be stressed that in view of the fact resulting from the performed tests, that the allowable level of total concentration of highly noxious substances has not been exceeded, it will be possible to qualify the wastes as different from dangerous if only the full procedure determined in [5] is performed.

Wastes from ballast tanks

The tested sample (no. 7) is characterized by a very low content of organic substances, which shows that amount of fouling and paint residues with high content of metallic oxides, has been small. The sample is characterized by a high content of iron, humidity higher than the preceding samples, as well as a relatively low content of heavy metals.

Wastes from abrasive blasting

All tested samples are characterized by a vestigal content of organic substances and very low humidity, which shows that the content of metallic oxides, paint residues and used abrasive material, has prevailed. For all the tested samples high content of iron is characteristic. The samples of the copper slag containing wastes from abrasive blasting (no. 5, 9 and 10) are characterized by a little higher content of heavy metals than that of the control copper slag samples (no. 4 and 8).

The wastes in question should be considered dangerous [4] because of the high content of the specific substances (numbered among those highly noxious. However it should be stressed that in view of the fact resulting from the performed tests, that the allowable level of total concentration of highly noxious substances has not been exceeded, it will be possible to qualify the wastes as different from dangerous if only the full procedure determined in [5] is performed.

Water extracts from wastes produced during preliminary washing-down

All the tested water extracts are characterized by a similar (low-alkaline) value of pH reaction. The pH reaction value of the water extract sample from the wastes produced during ship's deck washing-down (no. 2a) exceeds that permissible for discharging the liquid wastes to waters or ground [6]. Moreover the sample is characterized by a relatively high content of dissolved substances (mainly mineral ones). Except from an insignificant surpass of pH reaction value the sample satisfies the requirements for liquid wastes discharged to waters or ground.

The water extract sample of the wastes from ship's hull washing-down (no. 3a) is characterized by a relatively high value of COD (slightly exceeding the concentration level permissible for discharging such wastes to waters or ground) and a lower content of dissolved substances. Except from the slight surpass of COD the sample in question does not comply with the requirements for discharging such wastes to waters or ground, as far as zinc and copper content is concerned.

The water extract sample of the wastes from ship's hull washing-down (no. 6a) is characterized by a relatively high content of dissolved substances (mainly mineral ones). Besides, it shows contents of chlorides and copper slightly surpassing their allowable levels, hence it does not comply with the requirements for discharging the wastes to waters or ground.

On the basis of comparison of the test results of water extracts and the criteria for accepting the wastes for storage in storage facilities of particular types, determined in [7] and reflecting the decisions [8], it should be concluded that the wastes produced during ship's deck washing-down should be stored in the storage areas for the wastes different from dangerous and neutral ones. The sample no. 2a does not comply with the requirements for the wastes allowed to be stored in the storage areas for neutral wastes (because the contents of dissolved chlorides and sulfates surpass their allowable levels). And, the sample no. 3a does not comply with the requirements for the wastes stored in the storage areas for wastes different from dangerous and neutral, as far as zinc content is concerned. Hence in view of the surpass (however only slight), the material should be stored in the dangerous waste storage areas, or after an appropriate physical and chemical treatment and resulting change of its washing-out properties (so as to comply with the requirements) – in the storage areas for the wastes different from dangerous and neutral.

The sample no. 6a does not comply with the requirements for the wastes stored in the neutral waste storage areas (because the contents of dissolved chlorides, zinc, copper, lead, and of sulfates a little surpass their allowable levels).

Water extracts from the wastes formed in ballast tanks

The water extracts from the wastes taken from ballast tanks (the sample no. 7a) are characterized by a low-alkaline value of pH reaction, a little surpassing the allowable level for discharging the liquid wastes to waters or ground. Except from the surpass of the allowable pH value, the sample no. 7a complies with the requirements for liquid wastes discharged to waters or ground.

On the basis of comparison of the test results of the water extracts and the criteria for acceptance of the wastes for storage in appropriate facilities it should be concluded that the wastes formed in ballast tanks should be stored in the storage areas for the wastes different from dangerous and neutral ones, as they do not fulfill the requirements for the wastes allowed to be stored in the neutral waste storage areas because the contents of dissolved chlorides and sulfates exceed their allowable limits.

Water extracts from wastes produced during abrasive blasting

Both water extracts from the samples taken during the first measurement campaign, (no. 4a and 5a) are characterized by low concentrations of pollutants hence they fulfill the requirements for the liquid wastes discharged to waters or ground. The low concentration of heavy metals in the water extracts (against that in initial wastes) goes to show that the metals have the form of oxides, in the wastes.

The water extract sample from the copper slag prior to blasting process (the control sample no. 4a) fulfills the requirements for the wastes allowed to be stored in the storage areas for neutral wastes and does not endanger the environment in the case of its storage or use as a building material for application without any treatment e.g. for road foundation hardening. The water extract sample taken from the copper slag mixed with after blasting wastes (no. 5a) is characterized by a little greater content of pollutants, and in the range of chromium content it does not comply with the requirements for the wastes allowed to be stored in the storage areas for neutral wastes. The small surpass makes that the wastes in question should be stored in the storage areas for wastes different from dangerous and neutral, or after an appropriate physical and chemical treatment and a resulting change of their washing-out properties (so as to comply with the requirements) – in the storage areas for neutral wastes.

All the water extracts from the samples taken during the second measurement campaign (no. 8a, 9a and 10a) do not satisfy the requirements for the liquid wastes discharged to waters or ground, as far as their pH value is concerned. Except from the surpass of pH value, they are characterized by low concentration values of pollutants, which satisfy the requirements for liquid wastes discharged to waters or ground.

All the samples comply with the requirements for the wastes allowed to be stored in the storage areas for neutral wastes and they do not endanger the environment in the case of its storage or use as a building material for application without any treatment, e.g. for road foundation hardening.

CLASSIFICATION OF WASTES

According to [4] the tested wastes should be classified into the following groups, subgroups and kinds:

- wastes from preliminary washing-down (removal of fouling and paint residues) COD (tested by the bi-chromate method)
- copper slag (prior to abrasive blasting process) – control sample
- copper slag mixed with the removed wastes (after abrasive blasting process)
- wastes from ballast tank cleaning .

BALANCE OF AMOUNTS OF PRODUCED WASTES

On the basis of [9] and made estimations the following yearly balance of some materials consumed by the shipyard in question, is presented :

Ship surface cleaning prior to painting :

- total yearly consumption of copper slag 3900 Mg/year
- including that for ship repair dock 1800 Mg/year

Welding :

- total yearly consumption of welding electrodes 63000 kg/year
- including that for ship repair dock 3500 kg/year

Painting :

- total yearly consumption of paints 112000 kg/year
- including that for ship repair dock 71000 kg/year

In the course of repair work carried out on the ship „*Polar Siglir*" (GR 6-50) the following amounts of the wastes of the main groups, were produced :

- copper slag 320 Mg
- bilge oils 24 Mg

Detail data on amount of wastes of the remaining kinds, are lacking.

In the course of repair work carried out on the ship „*Ziemia Suwalska*" the following amounts of the wastes of the main groups, were produced :

- copper slag 425 Mg
- bilge oils 20 Mg
- wastes from ballast tanks 35 Mg
- mixed municipal wastes (200399) 33.7 Mg
- paint package 250 x 20 l tins
- abrasive materials 313 Mg

Detail data on amount of wastes of the remaining kinds, are lacking.

PRINCIPLES OF MANAGEMENT OF THE SELECTED GROUPS OF WASTES

In determining the management principles for the selected groups of wastes the following items were taken into account :

- the present way of dealing with wastes
- the results of performed tests on the wastes in question (those concerning environmental impact of the wastes as well as their technological properties characterizing possible recovery/ neutralization of the wastes with taking into account such total concentration of highly noxious substances, which, after performing the complete procedure determined in [5], would not exceed the allowable level)
- the recommended methods of dealing with the wastes (including both the domestic ones and those established by EU)
- possible ways of recovery/ neutralization of the wastes, resulting from the performed investigations.

In Tab. 1 are presented the recommended ways of dealing with the selected – as the most characteristic for the applied engineering processes – wastes produced in the course of ship repair work on floating docks.

***Tab. 1.** The recommended ways of dealing with the selected wastes produced in the course of ship repair work on floating docks .*

No.	Name of waste	Recommended way of dealing with the wastes			Comments
		Collection	Transport	Recovery / neutralization	
1	Wastes from preliminary washing- -down (removal of fouling and paint residues by means of hydraulic monitor), sludge [4]	After collection to store - temporarily and selectively - the wastes in tight and appropriately marked containers.	By special transport means - to quay area and farther to a waste storage area. Selective storage and successive transfer for recovery / neutralization.	After solidification the wastes could be used as a material for road foundation. They may be also used e.g. as a material for intermediate insulation layer in waste storage areas, or in the case of the wastes from ship's deck washing-down - to undergo recycling process. The wastes from ship washing-down should be stored in the storage areas for dangerous wastes,or after an appropriate treatment and resulting changes of their washing-out properties - in the storage areas for the wastes different from dangerous or neutral.	Possible recovery/ neutralization of the wastes depends on their properties associated with specificity of used paints as well as quality and quantity of fouling organisms. In the case of a greater concentration of organic substances - application of the thermal processing of the wastes may be considered.
2	Copper slag (prior to abrasive blasting process)	In tight and properly marked containers	By railway or road transport	Copper slag materials prior to blasting process comply with the requirements for the wastes allowed to be stored in the storage areas for neutral wastes, hence they do not endanger the environment both in the case of their storage or use as an untreated building material.	The waste is applied as an abrasive material for cleaning hull surface of ships under repair.
3	Wastes from abrasive blasting process (copper slag mixed with residues after the blasting), sludge [4]	As in No. 1.	As in No. 1.	Usage: for filling void spaces in copper mines, road building – as a filler in manufacturing building materials. The waste should be used as an intermediate insulating layer or stored in the storage areas for the wastes different from dangerous and neutral[1]. After physical and chemical treatment and change of its washing-out properties it may be used as a building material.	Main action should be focused on minimization of its production e.g. by applying the abrasive blasting process operating in closed systems, or by using the high-pressure water cleaning processes operating in closed systems.
4	Wastes from cleaning the ballast tanks	As in No. 2.	Selective storage and successive transfer for recovery / neutralization.	The waste should be used as an intermediate insulating layer or stored in the storage areas for the wastes different from dangerous and neutral. Because of a high concentration of iron the waste may be subjected to recycling process. After solidification the waste may be used as a building material and /or for ground hardening.	Possible recovery / neutralization of the waste depends on its properties associated with specificity of paints used in the tanks as well as quality and quantity of sediments and fouling organisms.

[1] The waste does not comply with the requirements for the wastes allowed to be stored in the neutral waste storage areas.

RECAPITULATION

- The engineering processes used for the construction and repair of ships must fulfill legal standards for limitation of waste emission. It is recommended the materials and devices used for the processes to be manufactured, selected and applied in compliance with the principles of *the best available technology* (BAT). It should be stressed that floating docks are not numbered among the facilities required to be granted with an integral approval, however according to [15] technical solutions applied to new or significantly rebuilt facilities should satisfy the BAT principles (par. 143 of the above mentioned Act).

- An effective method to limit environmental emission of the wastes produced during ship repair work on the dock, is to separate the areas in which such engineering processes are carried out, from the surrounding. This can be reached by placing the repaired ship in a „closed" dock or by applying suitably tight coverings to isolate from the surrounding only that part of the ship in which operations associated with waste emission would be carried out.
- Used materials should contain as small amount of compounds harmful or dangerous to the environment, as possible. Applied devices and processes should allow to minimize amount of produced wastes, and the management of wastes from ship repair work on the dock should be highly effective in selective collecting and processing (recovery / neutralization) the wastes, at acceptable cost.
- A main activity aimed at effective managing the wastes should be to minimize their production (e.g. by applying abrasive blasting technique realized in closed systems or by substituting a high-pressure water - cleaning technique realized in closed system for traditional technology.
- If use of an open-cycle abrasive - blasting technique is necessary then application of copper slag as an abrasive material should be avoided and a less noxious material (e.g. ARMEX® means) used instead, applied a sheltered water-blasting technique and/or special coverings (fitted with an air cleaning system) to separate working areas from the surrounding, or to substitute water jet cleaning for abrasive blasting technique.
- In the case of application of the traditional way of ship surface cleaning as large amount of the wastes as possible should be subjected to recovery processes (selective collecting the wastes and their recovery - see Tab. 1).

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Photo : Cezary Spigarski

Assessment of ecological hazards to atmosphere and waters around floating docks in service by using an index method

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ABSTRACT

Identification of ecological hazards was performed on the example of analysis of operational conditions of a floating dock in a ship repair yard. The following issues were described and discussed :

- ✦ *classification and valorization of repair work operations*
- ✦ *alternative ecological engineering processes*
- ✦ *guidelines for designing new environment-friendly docks*
- ✦ *model of environment-friendly dock.*

Keywords : dock designing, engineering processes, environment protection

INTRODUCTION

Activity of ship repair yards generates significant hazards to the environment. Environment protection should be a main obligation strictly integrated with shipyard's manufacturing activity. As long as it is not the fact relevant rules and standards partially regulating the problem must be implemented by order.

An important factor are engineering processes applied to operations carried out on the dock, and their appropriate ecological organization.

In the work in question was performed an analysis of present state of hazards to environment on the example of service of a standard dock used in a selected shipyard. Its scope contained the following problems :

- ➢ identification and valorization of operations and engineering processes which generate hazards to the environment
- ➢ assessment of used docking procedures
- ➢ assessment of dock's technical solutions and equipment intended for environmental protection.

On this basis the proposals of alternative, environment-friendly engineering processes were elaborated. The analysis of existing design solutions was the basis for elaboration of modernization proposals and next the guidelines for designing a new ecological dock.

ESSENCE OF ECOLOGICAL HAZARDS ASSOCIATED WITH SHIP REPAIR WORK ON FLOATING DOCK

A degree of influence of a dock in operation on the environment results from the technical state of the art of its design and engineering processes carried out on it, especially the following issues :

- ⇨ dock's construction
- ⇨ scope and kind of its outfit with devices and systems protecting against environmental pollution
- ⇨ type of operations carried out on the dock
- ⇨ applied engineering processes.

The above mentioned technical and technological problems decide on real effectiveness of pro-ecological activities. In the case of domestic ship repair yards such factors as standards and regulations for environment protection or activity of authorities responsible for environment protection have a very small influence on environment protection effects.

From the complex analysis of hazards to the environment it results that investing in sophisticated environment protecting devices and systems appears very low effective and the outlay of efforts and means appear inadequate to the obtained results, because of a still present unsatisfactory culture of work and a low level of abiding the standards and procedures for environmental protection.

Hence attention should be today paid first of all to applied engineering processes and correct technical state of environment protecting systems and devices installed on existing docks.

The problems associated with environment-friendly course of dock's service should be mainly considered in the aspect of kind of work carried out on docked ship. The dock can be used for :

- ➔ repair of floating units
- ➔ conversion of floating units
- ➔ building new floating units.

The dock itself generates rather low hazard to the environment if it satisfies basic conditions (appropriate construction and equipment) for environment protection as well as if it operates in a way compliant with relevant regulations being in force.

It is important to correctly carry out water and sewage management, to protect against spilling oil products (coming from the dock's internal systems) as well as correct collecting and discharging wastes and garbage produced by the dock's crew.

The currently operating docks much differ to each other in the range of their impact to the environment. The docks built at the turn of 19^{th} and 20th century are scarcely equipped with devices and systems for environment protection. A level of their equipment results from rebuilding its construction and systems in order to comply with relevant standards to a minimum required extent.

On the docks built to operate in the conditions of full cooperation with shipyard's infrastructure as regards their supply with energy media and electric energy from land sources, a degree of their saturation with devices and systems which may have detrimental influence on the environment is lower than in the case of autonomous docks being self-sufficient in maintaining operative and carrying out production.

Main factors which influence the environment around the docks integrated with shipyard's infrastructure, are the following :

- a way in which water and sewage management is carried out
- a degree of protection of waters and atmosphere against pollutants coming from production processes
- environment protection against pollution which may occur in special emergency cases.

Use of the docks for production purposes entails hazards to the environment, which result mainly from realization of engineering processes and operations carried out on a docked object.

To assess the hazards and elaborate appropriate actions aimed at prevention against or reduction of factors harmful for the environment one should define the carried out operations and classify them from the point of view of their harmfulness to the environment. To this end, identification of the repair operations carried out on several ships docked in the selected dock, was performed. The selected dock was assumed representative for the medium class of floating docks as regards their construction (built in 1987) and scope of equipment. An index method for assessment of relative level of hazards was elaborated for purposes of identification of environmental hazards and determination of appropriate preventive actions.

As an environmental hazard measure the following synthetic index was assumed :

$$s = ki$$

where :

k – hazard class expressed in the point scale ranging from 1 to 10 according to the criteria presented in Tab.1

i – three-level hazard intensity factor given in Tab.2.

Tab. 1.

Hazard intensity	Hazard class [in points]
low	1 ÷ 3
medium	4 ÷ 5
high	6 ÷ 8
very high	9 ÷ 10

Tab. 2.

Frequency of occurrence in a process	Hazard intensity factor
sporadically, rarely	1.0
often	1.5
intensively, permanently	2.0

The relative environmental hazard indices for realization of repair operations on the selected dock, are presented in Tab.3.

Tab.3. *Valorization of relative hazard levels for the group of operations most hazardous to the environment .*

No.	Most hazardous engineering processes and operations	Description of operations and processes	Description of hazards to the environment	Hazard class and intensity [points]		Hazard index [points]
				k	i	s
1	Emergency docking of a damaged ship	Sporadically occurring but intensively running	Spill of oil from damaged ship tanks	10	2.0	20
2	Discharge of ballast water from ship tanks	Impossible to be replaced in an other way; it occurs almost always	Contaminations contained in sludge sedimentation or in oiled water	8	1.5	12
3	Ship hull cleaning by using hydraulic monitor	Rather not replaceable by other means; share of several percent	Flow of contaminated water onto the dock's deck and next to surrounding waters	6	1.5	9
4	Removal of paint covering	On the above water part of hull it may be realized beyond the dock; 5 ÷ 15 % share in the entire cycle of work on the dock	Flow of contaminated water out of the dock's deck; dust over water area	7	1.5	10.5
5	Jet painting	On the above water part of hull it may be realized beyond the dock; 15 ÷ 25 % share in the entire cycle of work on the dock	Flow of contaminations from the deck ; paint spreading	6	1.5	9
6	Dock immersion to dock out the ship	Proposals of changes are given; The operation is performed once a docking cycle.	Flow of contaminations from the dock's working deck to surrounding waters	7	1.5	10.5
7	Cleaning of fuel oil tanks	The operation may be carried out beyond the dock; Slight share in the entire amount of work	Spills of oil product pollutants; utilization of wastes	5	2.0	10
8	Fuel oil pumping- over	Sporadically performed to tank the fuel or to discharge it for storing	Spills of oil products on the dock and to surrounding waters	8	2.0	16
9	Propeller shaft disassembling	The operation is performed only on the dock; Several percent share in the dock cycle	Spills of oil product pollutants	3	1.0	3
10	Structure scrapping	Necessary for carrying out hull repair work ; several percent share	Dock's deck contamination, as well as emission of smoke and dust to the atmosphere	3	1.5	4.5
11	Bilge water pumping from the dock	Necessary during service of the dock; sporadically performed	Possible spill of oil product pollutants to the surrounding waters	8	1.0	8
12	Current service of the dock and cleaning its working deck	Current maintenance and repair, and cleaning the dock's deck	Paints, oils, garbage, cleaning materials and wastes, wastes from engineering processes	2	1.5	3

Comparison of the relative hazard levels in the group of most hazardous operations realized on an usual dock and on ecological one are presented in Tab.4.

Tab. 4. *Comparison of relative hazard levels for the group of operations most hazardous to the environment, carried out on an ecological dock and standard one*

No.	Most hazardous engineering processes and operations	Description of hazard lowering factors	Class and intensity of hazards [points]		Hazard index s [points]	
			k	i	ecological dock	standard dock
1	Emergency docking of a damaged ship	Effective barriers around the dock, and environment-protecting bilge water system of the dock	2	2.0	4	20
2	Discharge of ballast water from ship tanks	Effective barriers around the dock, and environment protecting bilge water system of the dock	2	1.5	3	12
3	Ship hull cleaning by using hydraulic monitor	Environment protecting bilge water system of the dock	1	1.5	1.5	9
4	Removal of paint covering	Roofing of the dock, fitted with intake/exhaust ventilation system	2	1.5	3	10.5
5	Jet painting	Roofing of the dock, fitted with in/out flow ventilation system	1	1.5	1.5	9
6	Dock immersion to dock out the ship	Appropriate devices to remove contaminations from the deck of dock	2	1.5	3	10.5
7	Cleaning of fuel oil tanks	Appropriate devices for handling fuel and heavy oil	1	2.0	2	10
8	Fuel oil pumping - over	Appropriate devices for handling fuel and heavy oil	2	2.0	4	16
9	Propeller shaft disassembling	Devices for removing oil spills, environment protecting bilge water system of the dock	1	1.0	1	3
10	Structure scrapping	Roofing of the dock, fitted with intake/exhaust ventilation system	2	1.5	3	4.5
11	Bilge water pumping from the dock	Environment protecting bilge water system of the dock	2	1.0	2	8
12	Current service of the dock and cleaning its working deck	Roofing of the dock, environment protecting bilge water system of the dock	1	1.0	1	3
		Total :	**19**	**18**	**29**	**115.5**

ALTERNATIVE ENGINEERING PROCESSES

Identification of operations having the highest relative hazard level is the basis for determining the hierarchy of preventive actions, namely :

- ★ moving such operations beyond the dock, to a workshop
- ★ applying alternative engineering processes and materials
- ★ assessing rationality of investment undertakings (purchase of new equipment, modernization of dock's facilities etc.).

The problem of replacement of troublesome engineering processes by alternative, environment-friendly ones, becomes especially important because of high cost of devices for neutralization of contaminations. In present it deals first of all with a way of carrying out preventive painting operations on docked ship's hull. Great attention should be paid to application of environment-friendly working materials (appropriate abrasive materials, paints based on non-noxious solvents and components).

The engineering processes so far applied to such operations should be replaced by more ecological ones and less troublesome for their direct executors. Instead of the traditional way of removing old paint coverings by means of the dry grinding method with the use of portable grinding tools or open-cycle sand, electro-corundum or copper slag blasting, the closed-cycle blast cleaning processes, e.g. by using special facilities or closed chambers, as well as „wet sand" blasting should be applied. In this process only the final stage of hull cleaning is allowed to be performed by using an open-cycle „dry" jet in the case if the high cleanness class of surface prepared for painting (SA 2.5 class) is required. In 2003 the open-cycle dry sand blasting was banned in Poland, like in neighbouring countries.

Ship equipment elements which can be disassembled (e.g. hatch covers) as well as other steel structures made on the dock itself or shipyard's quay , should be cleaned and preserved in closed chambers. Despite the associated increase of direct manufacturing cost it is possible to obtain a positive economical result due to accounting for an improvement of workmanship quality of operations, their prompt realization as well as a decrease of environment pollution penalties.

For ship hull cleaning the „hydroblasting" method by using water jet under a very high pressure (over 2500 bar) is recommended , which substantially lowers a range of further dry jet blasting, or even entirely eliminates it in the case if a high cleanness class of surface preparation prior painting is required.

Amount of water consumed in the UHP (Ultra High Pressure) cleaning process is much smaller, accompanied with much higher effectiveness of the process, than the amount consumed in the traditional use of hydraulic monitors installed on the dock.

The modern high pressure devices are fitted with their own system for collecting used water as well as for separating solid wastes (paints , corrosion products) produced during hull cleaning. The wastes are collected in a separator by means of an under-pressure system. The UHP process is friendly for the environment and direct operators as well, and much more effective than an open dry-jet cleaning process. It is also favourable for quality and durability of a new paint covering as it effectively removes sea salt deposits from cleaned hull surface.

GENERAL GUIDELINES FOR DESIGNING NEW ENVIRONMENT - FRIENDLY DOCKS

In real investment conditions the problem of choice of a type and size of a dock is dependent on natural conditions and hydraulic engineering possibilities of building such technical facility, and it results from a type and size of floating units intended to be dominating in profile of production or repair work carried out by a given shipyard. The crucial choice is to determine a type of dock : whether dry or floating one.

For the dry dock it is easier to provide working conditions similar to those prevailing in workshops. Full roofing and sheltering the floating dock is technically difficult and costly. Moreover such covering is to fulfill strength conditions under strong wind and snow loads, as well as requirements for dock's stability and lifting capability. Even though in the existing shipyards there is no floating dock with full roofing , and equipped with facilities satisfying all environment protection criteria, it can be stated that to build a relatively small-size, environment-friendly floating dock is possible. Because of technical difficulties and financial costs connected with building or full modernization of an ecological floating dock its optimum lifting capacity and size may be determined as follows :

➡ lifting capacity of the dock – a few thousand tons
➡ length of ships to be docked – up to a hundred meters.

General assumptions

A new dock should comply
with the following conditions :

❖ As far as its construction and equipment is concerned it has to comply with the criteria given in regulations of international institutions (IMO) and classification societies, „Marpol" 73/78 International Convention, as well as home port regulations.

❖ Procedures and manuals binding in carrying out work on the dock and its current service have to be elaborated on the basis of the above mentioned regulations and in compliance with the principles of work safety and environment protection.

❖ A monolithic structure of the dock is recommended as tightness of its working deck is required for the reason of control of purity of the water flowing from the deck to the surrounding waters.

❖ Length of the dock should be greater than the overall length of to-be-docked ships so as to make sheltering the dock by means of closed aft and fore curtains effective.

❖ Equipment of the dock with combustion devices (electric generating sets, compressors) and other ones (boilers) which increase hazards to the environment, should be reduced to a minimum. It may be obtained e.g. by connecting the dock with shipyard's energy infrastructure, to possibly largest extent.

❖ Such dock's system of supply from land sources should satisfy whole energy demand for carrying out production operations and current service of the dock. The emergency lighting network of the dock should have an additional supply source from an accumulator battery.

The following media should be supplied
from land sources :

⅄ electric energy
⅄ heat energy
⅄ compressed air
⅄ oxygen and acetylene
(or another combustible gas)
⅄ fresh and tap water
⅄ working water
(for ship ballasting)

❖ A range of outfit of the dock with sanitary and living systems is determined during its design phase, depending on shipyard's conditions. If in the shipyard in question the infrastructure for sewage and waste collecting and treatment is well developed then to double it on the dock is unnecessary. In such case the dock's systems of the kind should be reduced to a minimum reflecting only the needs of crews of the dock and docked ship. In the case if possible discharging of sewage and waste water to a land-based system is limited then the dock is to be fully equipped with relevant systems complying with the rules binding for sea-going ships.

❖ The dock is to be fitted with an environment protecting bilge water system as well as it should be capable of developing an oil boom.

❖ The dock should be adjusted to installing, in the future, its full roofing and sheltering by means of front and side curtains, or dismantleable roof segments.

Moreover a new ecological dock should have :

✓ properly secured outlets and terminals of fuel oil and sanitary liquid systems
✓ alarm systems for signalling excessive emission of gas pollutants, discharge of oily water and oil itself
✓ gear for ship's hull high-pressure washing
✓ tanks and containers for collecting wastes, as well as a gear for neutralization and removal of oil and chemical pollutants.

During designing a new dock it is possible to account
for the following additional design solutions :

◈ installing the dock's systems in dry, easily accessible ducts placed above or between ballast tanks of the dock
◈ full heating the working compartments and insulating their walls to reduce failures possible in winter conditions as a result of freezing and cracking the piping systems
◈ applying the gantry cranes instead of typical dock cranes
◈ applying the dust and gas exhaust ventilation systems installed in dock's side walls and under its roofing.

MODEL OF ENVIRONMENT-FRIENDLY DOCK

The problem of rational limitations for design solutions of ecological docks should be solved by introduction of the notion of ***a model of ecological dock***. And, two its models should be distinguished :

✪ **IDEAL ONE**

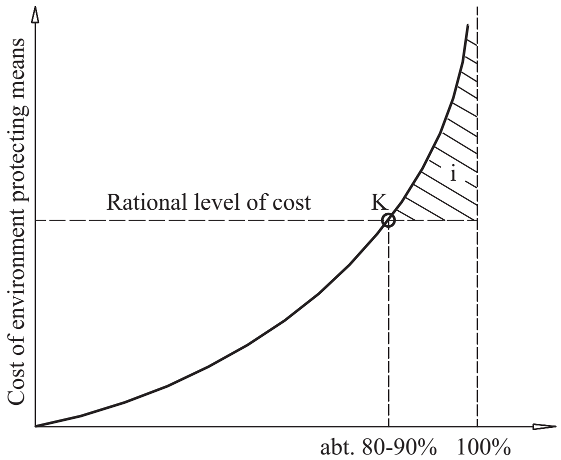
✪ **REAL ONE**

The models are defined as follows :

- ☆ **IDEAL MODEL** – an independent design solution which contains about all environment protective means against full set of dock's operational hazards
- ☆ **REAL (RATIONAL) MODEL** – a dependent design solution tailored to meet conditions of a given shipyard with accounting for rational technical and economical limitations. It has to cover a rational scope of environment protecting means for real (rational) set of dock's operational hazards.

The ideal model forms a model space for design solutions which may serve as a reference space for real designs.

The graphical illustration of the proposed design idea of ecological dock is presented in Figure.



Graphical illustration of the ecological model idea.
***Notes** : **K** – critical point for rational design solutions;*
***i** – area of irrational actions .*

FINAL REMARKS

- Scientific research work on an ***ideal model of ecological dock*** should be continued as it presents a design solution independent of technical and economical limitations existing in today ship repair yards. Such solution free from the present limitations will be a proper reference space for real dock designs.
- Apart from the above mentioned work similar research should be carried out on the ***real models*** to reveal sources of existing problems and barriers against their solving.
- The area of irrational design activity, shown as the area „i" in Figure, should be practically removed by technical organizational actions aimed at eliminating unwanted hazards.
- In the conditions of today ship repair yards, any investment into tools and gear for realization of engineering processes should be accompanied with „investment" into process management technology. The process management system should be fully integrated with comprehensive activity aimed at environment protection, in all realization phases of ship repair undertaking (i.e. offering, contracting, designing dock's construction and technology, realization of repair work and evaluation of its processes).

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Photo : Cezary Spigarski

A general concept of design procedure for floating docks regarding their reliability, safety and ecological aspects

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ABSTRACT

In this paper is presented a concept of design procedure, and problems resulting from it, for floating docks with a view of taking into account their reliability and operational safety. It has been stressed that such design procedure is necessary for ensuring the docks appropriate pro-ecological features. It has been also shown that the design procedure should have several stages. The following kinds of design stages have been proposed to be accounted for : offer (canvassing) design, contract (ordered) design, concept (study) design, preliminary design, technical (classification) design and working design as well as the stage of elaboration of technical operational (delivery-acceptance) documentation. Knowledge areas necessary for such design procedure have been indicated. Attention has been also drawn to the necessity of accounting for, in designing the floating docks, diagnostic systems suitable to aid operational decision making .

Keywords : safety, floating dock, reliability, design procedure

INTRODUCTION

Every floating dock should be so designed as to ensure its use with the profitability as great as possible in given conditions and not causing any contamination of port waters during docking operations associated with building new ships or repair works on existing ships [6, 7, 11].

One of the crucial problems in designing the floating dock is to reach its required reliability, especially of its energy systems, because mainly on these systems the dock's profitability, its pro-ecological features and operational safety, depends. A difficulty in realizing the postulate results from that the floating docks built on the basis of the same design form statistical sets of a small number of elements or even are singular and unique. Moreover an additional difficulty associated with forming their reliability is that they are technical systems of a long lifetime. Additionally, design offices do not render their surveillance over the docks in service. For this reason they have not in their disposal any relevant *data bases* necessary in design phase to estimate reliability indices demanded for particular structural units of floating docks. Also, there is a lack of probabilistic design methods to make it possible to build a floating dock for a given reliability [7, 8, 11, 12, 14].

Two approaches to design procedure of floating docks, accounting for reliability are possible [12] :

- design procedure consisting first in determining reliability indices of the devices intended to be installed in a given dock, and next in determining total reliability of the dock in question
- design procedure consisting first in assuming such total reliability of a given dock, which is available for technical and economical reasons, but not less than that demanded by its future user, and then in selecting such particular devices intended to be installed in the dock as to reach the demanded reliability.

Each of the design approaches first of all requires to describe a method for forming the reliability and safety of floating docks, next to determine reliability structures of their subsystems and systems and to perform an analysis and synthesis of reliability of the docks. The reliability problems should be undertaken in all design stages of floating docks in parallel with the problems associated with forming their energy merits [13].

DESIGN STAGES OF FLOATING DOCKS WITH ACCOUNTING FOR THEIR RELIABILITY AND SAFETY

Reliable and safe operation of floating docks makes it possible to use them in a pro-ecological way. To estimate reliability of a dock not always is possible. It results from that design methods used in the contemporary designing of floating docks are deterministic. Though their application makes it possible to elaborate the designs whose realization results in building the floating docks of reliability intuitively estimated to be high, but it does not allow for determining the reliability in the form of reliability indices. In this case the subjective probability serves as an estimate of dock's reliability. Such probability – though possible to be graded – has no numerical measure. However the reliability indices even such as logical or statistical probabilities, are necessary for rational planning and control of operational processes of the docks. Hence there is a need to elaborate the probabilistic methods for forming reliability of floating docks and to apply them in the phase of designing. [3, 9, 11, 12].

To this end the following theoretical tools should be applied : contemporary theory of reliability and safety of complex technical systems, probability calculus and mathematical statistics as well as theory of the devices (mainly heat engines and electrical machines) installed in the docks, and theory of stochastic processes, especially semi-Markovian ones [1, 2, 3, 4, 5, 6, 8, 11, 13]. And, technical diagnostics and results of failure analysis of devices of the docks similar to designed ones should be applied to elaborate sets of reliability states of designed floating docks [13]. Knowing the indices of operational reliability and safety of particular floating docks with accounting for diagnostics, one is able to make more rational operational decisions.

Requirements concerning reliability of floating docks or only their energy systems, as well as operational safety of the systems and whole dock should be submitted in writing by its future user in the form of the design assumptions.

The design offices do not have in their disposal any selective data bases on failures of devices of floating docks and other important events occurred in their service. Hence they do not apply models and techniques aimed at forming reliability and operational safety. For such reasons the design procedure of floating docks should be multi-stage one. Like in ship power plant designing the following design stages could be distinguished in the case in question [11, 13] : offer (canvassing) design, contract (ordered) design, concept (study) design, preliminary design, technical(classification) design , working design, as well as the stage of elaboration of technical operational (delivery-acceptance) documentation. As a result of realization of the above specified design stages the respective design projects should be elaborated. Finally, its technical operational documentation would be delivered together with the dock.

In contemporary designing the first design stage resulting in an offer design, is especially important. **The offer design** is aimed at gaining interest of future buyers of the dock.

In such design, apart from design solutions of the systems intended for installing in the dock , should be contained reliable information on its durability, reliability and operational safety. From the design of the dock it must be clearly seen which its elements are novel as far as its construction , technology and design procedure is concerned. To demonstrate merits of a novel solution of a dock the following items should be included in the project [13] :

❖ general data on the dock such as type of the dock (autonomous or non-autonomous), its use (for building new ships, ship repair, shiprepair and new building), load carrying capacity, main dimensions (total length, internal and external breadths, depth, pontoon height, height of keelblocks, freeboard to the upper deck, freeboard to the pontoon deck), lifting time of a ship of a given mass, capacity of tanks for energy media (diesel and heavy fuel oils, lubricating oil, wash water, boiler water, cooling water) and waste liquids (bilge water, residuals from centrifugal separators and oil separators, sewage) etc.
❖ schematic general arrangement plan of the dock distinctly showing its crucial energy systems and pipe lines as well as reliability structures of its energy systems
❖ data on output of electric generating sets, kind and type of driving engines and generators of the sets
❖ technical specification of energy systems (kind, type, output and rotational speed of combustion engines and electric motors, output and capacity of compressors and main and drying water pumps, steaming rate and pressure of boilers, pulling power of capstans, hoisting capacity of dock cranes etc.)
❖ reliability description of devices, systems and the dock itself (reliability indices of devices, energy systems and dock such as : probability of correct work till the first failure, probability of correct work between successive failures, kind of risk function, expected value of correct work time and standard deviation, availability factors etc.)
❖ schematic diagrams and description of automation of the energy systems
❖ specification of kinds and values of operational parameters of energy media, e.g. maximum values of pressure and temperature of air in compressed air system, water for cooling the combustion engines, fuel and lubricating oils
❖ schematic diagrams and description of main and emergency systems of electric energy supply (output, voltage, current frequency).

In this project is especially important to propose a concept of operation of the dock in accordance with its intended use, that requires to show a model of control over its operational process with accounting for expected operational costs or expected incomes, i.e. profits at a given operational outlays. The concept should be supported by economical calculations demonstrating profitability of building and purchase of such a dock for its future user.

The offer design is useful not only during negotiations and next in elaborating the contract design with accounting for requests from the side of a body ordering the design, but also for preliminary justification of the need for elaborating a study design.

The contract design is the first stage of floating dock design procedure, during which concepts presented in the offer design as well as requirements of future buyers and users of the dock are taken into account.

The contract design is elaborated in compliance with designer’s proposals included in the offer design as well as with the ordering body’s decisions made on the basis of its operational strategy for technical systems.

In the contract design should be also contained suggestions if the successive design stage has to result in elaboration of the preliminary design, or to elaborate the concept (study) design first is more justified.

The concept design should be a continuation of the contract design. This design is an improved and detailed development of the contract design as well as elaboration of novel design solutions.

In the concept design stage should be realized the scientific research projects (planned in advance in the contract design phase) such as modelling, calculations, composition, analysis and synthesis of a few variants of design solutions of the designed floating dock, aimed at selection of an optimum solution satisfying the criteria vital for the dock’s user. Therefore already in the initial part of the design should be presented the problems to be solved and research topics resulting from them in order to make it possible to assess the scope of the mentioned research projects and costs of their realization.

In this design stage special attention should be paid to operational reliability and safety and pro-ecological features of the designed dock by analyzing first of all : correctness of operation of energy systems of the dock, their durability, repairability, functionality, ergonomic features and lifetime. Next one should estimate quantitive reliability measures in order to make reliability analysis and synthesis of the systems, verification of the economically justified solutions and elaboration of data bases. In this stage, methods to improve reliability during designing, manufacturing and operating the floating docks, should be proposed. Also, cost of application of the methods should be estimated.

Choice and effectiveness of application of the methods for improving the reliability of particular systems of the docks depend on :

✶ degree of recognition of physical processes leading to failures
✶ possibility to remove failures occurred in the dock’s life time
✶ possibility to predict occurrence of failures and to counteract them by removing causes of their occurrence.

The study design should be of a breakthough importance for designing any type of docks. From operational practice of various technical objects it results that the initial designing phase has a main impact for ensuring an appropriate level of durability, reliability, serviceability, operational safety etc. As the course of the designing phase is decisive of whether a study design would be ahead of a current technical level, or only keeping up with the level, hence the study design should be at least that ensuring to keep up with the current technical level.

The study (concept) design project, being a result of the considered designing stage, should contain proposals of possibly most up-to-date design solution of floating dock together with description of its technical operational merits (including those economical as well as concerning reliability, durability and safety with accounted for environmental protection demands). In the case if the assumed technical operational parameters are not achieved , a justification of this fact has to be presented together with conclusions about causes of that failure and suggestions on what should be done in further phases of design process, including also future modernization and even recycling of the dock.

In the concept (study) design a concept of operational process of the designed dock should be included. States of operation and maintenance are quantities of such process. The state of modernization can be distinguished out of the latter ones. Contemporary design process of the dock cannot be ended in the moment of elaboration of its technical operational documentation but must also include actions to initiate and support the process of disclosing the manufacturing errors (made during phases of designing and manufacturing the dock) and operational ones , as well as their analysis. From the analysis it should result whether the proposed design solutions do not force by chance the user to make errors leading to failures of the dock devices and systems. The modernization of the dock is necessary as it makes it possible to remove possible defects and design faults, and their causes in particular.

The preliminary design is a result of making the concept (study) design more exact. In the case when in designing the dock no novel solution is required the design stage is only a continuation of the design process with taking into account the contract design and the agreements made with the body ordering the dock.

In the preliminary design process manufacturing conditions and capabilities of a shipyard intending to build the dock should be taken into account after making a prior analysis of manufacturing capabilities of other shipyards also prepared for building such objects.

The preliminary design should contain precise arrangement of the dock systems and devices being elements of the systems. Also, complete technical operational characteristics of the devices intended to be installed in the dock, including those dealing with their reliability, safety and pro-ecological features, should be presented.

The final result of the preliminary design stage should be the design documentation including its most important element – the general arrangement plan of the dock together with its concise description and justification of the presented solutions.

The design should be verified by an independent group of experts and after obtaining their positive opinion – submitted to the ordering body to get its acceptance.

If the verifying procedure is finished the next stage of designing, i.e. the technical (classification) design stage may be commenced.

The technical (classification) design is a more exactly determined version of the preliminary design. It is crucial that results of the earlier planned empirical research realized within the study design stage are already known. In the stage in question design solutions of the dock energy systems and its other structural units should be finally and unambiguously determined. Also, classification schematic diagrams of all systems of the dock should be elaborated in compliance with the requirements of the classification societies. Draining plan of the dock is of special importance for ensuring the required stability of the dock.

The technical (classification) design should be approved by a relevant classification institution, e.g. Polish Register of Shipping. All amendments which could be introduced in the further designing phases must be agreed with surveyors of a classification society supervising the dock's design. After obtaining the classification society's approval for the technical design the last designing stage – the working designing can be commenced.

The working design is a result of the designing stage characteristic of that to elaborate the documentation deep knowledge of manufacturing processes and organization of an enterprise intending to build the dock in accordance with the elaborated technical (classification) design, is required. In the working design all reservations from the side of the classification society should be accounted for. In this phase all detail technical drawings of every element of the dock to be built in the builder workshops should be elaborated and its manufacturing processes described. Also, in the documentation all standard elements not subject to further processing, should be specified.

An important part of the working documentation are the assembly drawings showing the designed structures in the form of appropriate projections and cross-sections. On the drawings more important dimensions should be given , and each element should be specified by providing its gabarites, mass, used materials, symbol of a relevant standard etc.

In the documentation results of all energy tests performed to unambiguously confirm operational usefulness of the devices being elements of the dock's energy systems, should be also accounted for.

The working documentation should make it possible to build the dock with maintaining all its features provided for in the study design, and even better if they are in accordance with those established either in the offer design or contract one.

The technical operational documentation can be elaborated only after completion of the dock. It should contain information making it possible to use the dock rationally. The following items belong to it : principles and procedures of putting the dock's devices into operation, of their loading and stopping, carrying out maintenance , main repairs and those after failure. Information concerning reliability and operational safety is especially important.

The documentation should contain the assembling drawings as well as technical specification of the dock's power plant and other systems characteristic for particular types of docks. Also, reports containing results of delivery-acceptance tests and operational trials of energy systems of the dock should be included.

FINAL REMARKS AND CONCLUSIONS

➲ From the presented considerations it results that verification of reliability and safety indices should be carried out in all the described designing stages of docks.

- The necessity of verifying reliability and operational safety of floating docks as well as their pro-ecological features during elaboration of their technical operational documentation (delivery-acceptance one), cannot be excluded.
- During elaboration of the offer design reliability structures of all energy systems should be considered and the simplest ones applied. At this stage to estimate reliability and safety of docks accurately may be difficult due to the lack of sufficient amount of results of empirical investigations. However it would be possible to assess the reliability *from above and from below* practically for all devices of floating dock, as their risk functions are ascending , e.g. by applying the suitable formulae [13].
- The above mentioned formulae are of practical importance because they make it possible to assess reliability of the dock's systems if only expected values of their correct operation till failure are known. Therefore they enable to make operational decisions by applying the statistical decision theory if only consequences of the decisions are known. Also they make it possible to assess reliability of the whole dock .

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Photo : Cezary Spigarski

Probabilistic concept of defining the situations possible to occur during operation of floating docks

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ABSTRACT

In this paper possibility to assess safety of floating docks as a result of application of the theory of semi-Markov processes both in the phase of their designing and operating, is outlined. Formal description of the situations which may occur during service of floating docks both those intended for building and repairing the ships, was presented. The following situations were distinguished : normal, complicated, hazardous, emergency and disastrous. A model of changing the distinguished situations was proposed in the form of a semi - Markov process with discrete set of states, and continuous with time. The mentioned situations are values of the process. An operational safety measure for dock was formulated in the form of the probability of the event consisting in occurrence of normal or complicated situation. It was proved that assessment of probability of occurrence of particular situations is possible.

Keywords : floating dock, safety, model, reliability, technical object, semi-Markov process, technical state

INTRODUCTION

Operational safety of floating dock greatly depends on its reliability i.e. that of its systems, subsystems and devices taken into account in the investigations. The operational safety of the dock significantly influences safety of the ship docked in it and personal safety of people working on the dock. Such situation results from that in the dock are installed various energy devices such as electric motors, pumps, compressors, capstans, transport cranes, steam boilers etc. A failure of some of them may cause a threat not only to the ship crew members working there but also to the dock itself and the docked ship as well. Hence a great attention should be paid to operational safety of floating docks not only during their service. And, in order to appropriately identify the problem of their operational safety the notion of *floating dock operation* should be defined.

In the descriptive sense the notion of *floating dock operation* should be meant as a complex energy state resulting from its inherent processes of energy production, transformation and distribution due to operation of various devices necessary for building the ship (shipbuilding floating docks) or restoring the technical state of existing ship under repair (ship-repair floating docks).

In the further considerations the term of *floating dock safety* is used instead of *operational safety of floating dock* as it may be generally assumed that the dock in the period of its passive use (in the state of full serviceability or partial one and simultaneous waiting for putting in use) or in the state of its maintenance cannot cause any threat to the ship or persons present in it.

During operation of floating dock various situations different from normal but hazardous to it to a different degree, may be distinguished. They should be identified and known already in the phase of dock designing.

SITUATIONS POSSIBLE TO OCCUR DURING OPERATION OF FLOATING DOCK

During operation of floating dock (like in the case of any other complex technical object) may occur various situations which can be divided – from the point of view of a level of involved hazard – into the following categories [5, 6, 8] : *complicated, dangerous, emergency and disastrous*. Direct users (shipyard workers and /or docked ship crew) and indirect dock's users (shipyard management) aim at ensuring the normal situation, i.e. that in which their safe activity is possible. Such operation of a device, which does not cause any threat to the dock but which may occur due to a major failure of any of the devices and/or due to loss of health (or life) by any of their direct users can be considered as the safe operation of any device of floating dock.

Consideration of :

- features of the devices of floating docks (with accounting for safety aspects)
- psychical and physical predispositions of their users, and
- usage and maintenance conditions of the devices, makes it possible :
  - to determine kind of situation in which work is realized on a given dock (in which dock's devices suitable to current types of work operate)
- to assess an expected value of duration time of particular situations which may happen to a given dock
- to determine frequency of occurrence of the mentioned situations during a longer period of realization of the tasks resulting from the work carried out on the dock and which should be completed in a given time.

Because the situations the floating dock can met are random events, and their duration time – a random variable, the theory of semi-Markov processes may be (after some simplifications) used to determine probabilities of dock staying in particular situations [4, 6, 9].

Therefore for investigation of safety of floating docks and its forming, to elaborate a semi-Markov model of changing the specified situations is necessary. Such model is necessary to determine probabilities of occurrence of particular situations in a longer period (for $t \rightarrow \infty$, theoretically).

To prevent unwanted situations is possible in the case of making suitable decisions first of all by direct users. In order to do it, apart from the knowledge of magnitudes of occurrence probability of the mentioned situations, to know magnitudes of probability of staying the dock (and its particular systems and devices) in the particular states (such as full serviceability, partial, task unserviceability, and full unserviceability) is also necessary. To this end the theory of semi-Markov processes may be also helpful [9].

In the case when serious failures of particular devices of floating docks involve a threat to shipyard workers or crew of a ship under repair, the sea or land rescue units or other persons present in the vicinity of the dock, may be called for help. Effectiveness of such help depends, a. o., on readiness of technical rescue means of the units to undertake and realize rescue tasks. Hence to determine availability coefficients for the rescue units which may take part in such rescue operations is also necessary.

To determine safety of floating docks is not possible without making use of diagnostics, not only technical one, though the most important. The diagnostics is meant as a domain of knowledge dealing with identification and assessment of current, future and past technical and energy states of technical devices.

MODEL OF CHANGE OF SITUATIONS DURING OPERATION OF FLOATING DOCK

Changes of particular situations in which operations of shipyard personnel, rescue units or crew members of a ship under repair are realized, can be considered as the random process $\{Y(t): t \geq 0\}$, discrete within states and continuous with time, having the four-element set of states $S = \{s_i;\ i = 0, 1,..., 4\}$, where t – time of process realization, which practically amounts to time of operation of the dock and persons working there under occurrence of any of the mentioned situations [3, 4, 6].

In this case the general interpretation of the states $s_i \in S$ (i = 0, 1,..., 4) is as follows :

- s_0 – normal situation
- s_1 – complicated one
- s_2 – dangerous one
- s_3 – emergency one
- s_4 – disastrous one.

The distinguished states appear in random instants and last within the time intervals $[\tau_0 , \tau_1)$, $[\tau_1 , \tau_2)$,..., $[\tau_n , \tau_{n+1})$, which are random variables.

In the ***normal situation*** (s_0) shipyard personnel working on an arbitrary dock and crew of any docked ship (regardless of technical solutions of the dock and ship) realize their tasks in the conditions to which they got accustomed. Such conditions do not involve any excessive stress to the employees and crews and do not force them to an excessive physical or intellectual effort.

The ***complicated situation*** (s_1) appears when events which make realization of tasks more difficult have occurred. Among such events the following, for instance, may be numbered : a failure of one of the capstans regardless of on which side wall it is located, a failure of one of the ballast pumps, one of the fuel tanks intended for the intake of fuel from the ship to be repaired, the worsening of ambient conditions due to a sudden drop of temperature, excessive rainfall etc. In such cases shipyard employees and crews of ships under repair would be forced to do temporarily an additional physical and intellectual effort aimed at removal of the occurred failures and their results. In the cases when the shipyard employees and crews of ships under repair are not able to restore technical state of failed devices so as the normal situation would be restored, then to change the dock operation schedule is necessary. Such situation may happen when all devices of floating dock are fully serviceable but the ambient conditions make ensuring a required level of operational safety impossible. As a result, not only the dangerous situation (s_2) and emergency one (s_3) but even disastrous situation (s_4) may happen.

The ***dangerous situation*** (s_2) appears when events which make realization of dock's task impossible, occur. Among such events the following, for instance, may be numbered : a failure of one of the capstans during bringing the ship into/out of the dock in worsening weather conditions (strong wind, heavy rain- -or snowfall), and in the case of other dock equipment – a failure of one of the ballast pumps. Such situations also happen when a fire due to careless welding is started, the docked ship bumps into a side wall of the dock, keelblocks are overloaded during leak-proof tests of ship compartments, side supports of the docked ship are removed too early etc. In such cases to increase efforts of shipyard's personnel or docked ship's crew is necessary in order to restore full operational safety of the dock. When this is not possible the sea or land rescue units should be called or other possible means being at shipyard's disposal and capable to restore the normal situation, should be used.

The ***emergency situation*** (s_3) appears when shipyard personnel and crew of the docked ship cannot prevent from occurrence of exceptionally unwanted events. To such events the following may be numbered :

- bump of the ship against dock's side walls, leading to a failure of ship bow or stern or dock's side wall
- bump of the ship against pontoon deck, resulting in a failure of rudder, screw propellers or bottom of the ship
- capsize of the ship within the dock space due to removal of its side supports
- shift of cargo due to its insufficient lashing, which results in an excessive trim and/or heel of the ship
- water rush into ship's interior through not closed hull openings, resulting in flooding the ship's compartments, etc.

The ***disastrous situation*** (s_4) is that in which collapse of dock's hull structure, sinkage of the dock and / or structural collapse and sinkage of the docked ship, or drowning at least one person out of those currently working on the dock, cannot be avoided.

Operation of every floating dock, its systems and particular devices, at least in its initial phase, is usually realized in the normal situation determined by the following factors [4, 6, 9] :

- state of full serviceability of the dock devices (e.g. capstans, steam boiler, ballast pumps, fire pumps etc)
- high psycho-physical predispositions of shipyard personnel and docked ship crew
- favourable ambient conditions in which ship construction or ship repair work is realized
- correctly performed maintenance of the dock devices in advance of commencing realization of a given task associated with construction of a new ship or repair of an existing one.

In the case when the first of the three specified factors is worsened and / or maintenance (either preventive, or failure – forced) is inappropriately realized the dock in question (together with the mentioned process $\{Y(t): t \geq 0\}$) passes from the state s_0 to s_1. This is equivalent to the change from the normal situation of realization of dock operations to that complicated in which their realization and keeping time limits become more difficult. This occurs with the probability p_{01}, after the time interval which is realization of the random variable T_{01}, i.e. the duration time of the situation (state) s_0 provided that the next is the situation s_1. Obviously an appropriate action of shipyard personnel and, if need be, of docked ship's crew may restore the situation s_0. It occurs with the probability p_{10}, after the time interval which is realization of the random variable T_{10}. When the above mentioned factors are worsened to reach the situation (state) s_0 may appear impossible, that inevitably leads to the dangerous situation (state) s_2, which is equivalent to passing the investigation process $\{Y(t): t \geq 0\}$ from the state s_1 to s_2. Such change of situation occurs with the probability p_{12}, after the time interval which is realization of the random variable T_{12}. Appropriate actions of shipyard personnel and, if need be, of docked ship's crew may cause the situation s_0 to be restored, but only after restoring the situation s_1 earlier. Otherwise, the emergency situation s_3 may happen as a result of worsening the technical state of the dock or only of the docked ship,and simultaneously of the operational conditions (especially ambient ones). Such situation occurs with the probability p_{23} after passing the time interval which is realization of the random variable T_{23}, equivalent to the duration time of the situation (state) s_2 provided that the next is the state s_3. In some cases there is a possibility of coming back from the state s_2 to the above mentioned situations but also the disastrous situation s_4 may happen in which to prevent from occurring casualties of people present in the dock and/or a major damage of the dock or docked ship, is not possible.

The change from s_3 to s_4 occurs with the probability p_{34}, after passing the time interval which is realization of the random variable T_{34}, equivalent to duration time of the state s_3 provided that the next is the situation s_4, from which, in some cases, to come back to the previous states is still possible yet during operation of the dock.

Hence it can be assumed that to consider the process $\{Y(t): t \geq 0\}$ having the graph of its state changes, shown in Figure [9] is reasonable. The states are the situations $s_i \in S(i = 0, 1,..., 4)$. Such form of the change graph of the mentioned situations results from continuously growing hazard [3, 4, 9] and needs and possibilities to distinguish the situations.

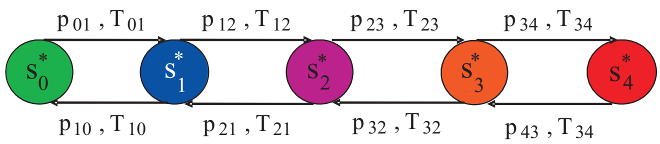

Figure. *State change graph of the process $\{Y(t): t \geq 0\}$*

During operation of any floating dock and docked ship, changes of the states (situations) belonging to the set $S = \{s_i; i = 0, 1,...,4\}$ can be considered as the process $\{Y(t): t \geq 0\}$ of constant (identical) realizations within particular time intervals right-hand continuous [1]. Lengths of the intervals are the random variables T_{ij} equivalent to duration time of the state $s_i \in S$ of the process in question provided that the next is the state $s_j \in S$, where : $i, j = 0, 1,..., 4$, and $i \neq j$. The variables are random, independent, having the finite expected values $E(T_{ij})$ and positively concentrated distributions. Moreover the process is characterized by that the duration time of the state s_i, occurred in the instant τ_n as well as the state appeared in the instant τ_{n+1} do not depend stochastically on the previous states and their duration time intervals. Hence it may be assumed that future states (situations) depend first of all on the current situation. It means that the process $\{Y(t) : t \geq 0\}$ can be considered as a semi-Markov process of the state change graph presented in Figure. In order to define the process its initial distribution P_i as well as its functional matrix $Q(t)$ should be determined in advance.

From service practice it results that the initial distribution of the process $\{Y(t): t \geq 0\}$ is usually as follows :

$$P_i = P\{Y(0) = s_i\} = \begin{cases} 1 \ \text{for} \ i = 0 \\ 0 \ \text{for} \ i = 1, 2, \ldots, 4 \end{cases} \tag{1}$$

Obviously, in some exceptional cases [9,10] the distribution may be different but the functional matrix of the process $\{Y(t): t \geq 0\}$ is the same. The matrix, in accordance with the state change graph presented in Figure has the following form :

$$Q(t) = \begin{bmatrix} 0 & Q_{01}(t) & 0 & 0 & 0 \\ Q_{10}(t) & 0 & Q_{12}(t) & 0 & 0 \\ 0 & Q_{21}(t) & 0 & Q_{23}(t) & 0 \\ 0 & 0 & Q_{32}(t) & 0 & Q_{34}(t) \\ 0 & 0 & 0 & Q_{43}(t) & 0 \end{bmatrix} \tag{2}$$

The elements of the matrix (2) are non-decreasing functions of the variable t, which represent the probabilities of passing the process $\{Y(t): t \geq 0\}$ from the state s_i to the state s_j (s_i, $s_j \in S$; $i, j = 0, 1,..., 4$; $i \neq j$) during the time not greater than t, and which are described as follows [2, 7]:

$$\begin{aligned} Q_{ij}(t) = P\{Y(\tau_{n+1}) = s_j, \tau_{n+1} - \tau_n < \\ < t \,|\, Y(\tau_n) = s_i\} = p_{ij}F_{ij}(t) \end{aligned} \tag{3}$$

where :

$s_i, s_j \in S(i, j = 0, 1,..., 4; i \neq j)$

p_{ij} – probability of one-step passage in uniform Markov chain inserted in the process $\{Y(t): t \geq 0\}$, $F_{ij}(t)$ – cumulative distribution function of the random variable T_{ij} representing duration time of the state s_i of the process $\{Y(t): t \geq 0\}$ provided that the next is the state s_j.

The probability p_{ij} is interpreted as follows :

$$p_{ij} = P\{Y(\tau_{n+1}) = s_j \,|\, Y(\tau_n) = s_i\} = \lim_{t \to \infty} Q_{ij}(t) \tag{4}$$

In the situation, solving the so formulated problem consists in finding the limiting distribution of the process $\{Y(t): t \geq 0\}$, which has the following interpretation :

$$P_j = \lim_{t \to \infty} P\{Y(t) = s_j\}, \ j = \overline{0.4}$$

The distribution can be determined by using the formula [15,26] :

$$P_j = \frac{\pi_j E(T_j)}{\sum_{k=0}^{4} \pi_k E(T_k)}, \ j = 0, 1, \ldots, 4 \tag{5}$$

where :

$$\pi_j = \lim_{n \to \infty} \frac{1}{n} \sum_{k=1}^{n} P\{Y(\tau_n) = s_j | Y(0) = s_i\}, \text{ and}$$

$[\pi_j; j = 0, 1,..., 4]$ is the stationary distribution of the Markov chain $\{Y(\tau_n): n \in N\}$ inserted in the process $\{Y(t): t \geq 0\}$.

The distribution satisfies the set of equations (6) and (7) [7] :

$$\sum_{i=0}^{4} \pi_i \, p_{ij} = \pi_j \quad ; \quad i, j = 0, 1, \ldots 4 \tag{6}$$

$$\sum_{i=0}^{4} \pi_i = 1 \tag{7}$$

The matrix (2) is stochastic, hence the matrix of the passage probabilities $P = [p_{ij}]$, i , j = 0, 1,..., 4 is as follows :

$$P = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ p_{10} & 0 & p_{12} & 0 & 0 \\ 0 & p_{21} & 0 & p_{23} & 0 \\ 0 & 0 & p_{32} & 0 & p_{34} \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \tag{8}$$

By solving the set of equations (6) and (7) with accounting for the matrix (8) one obtains, in accordance with the formula (5), the following relationships:

$$P_0 = \frac{p_{10}p_{21}p_{32}E(T_0)}{M} \; ; \; P_1 = \frac{p_{21}p_{32}E(T_1)}{M}$$

$$P_2 = \frac{p_{12}p_{32}E(T_2)}{M} \tag{9}$$

$$P_3 = \frac{p_{12}p_{23}E(T_3)}{M} \; ; \; P_4 = \frac{p_{12}p_{23}p_{34}E(T_4)}{M}$$

and :

$$M = p_{10}p_{21}p_{32}E(T_0) + p_{21}p_{32}E(T_1) + p_{12}p_{32}E(T_2) + $$
$$+ p_{12}p_{23}E(T_3) + p_{12}p_{23}p_{34}E(T_4)$$

where :

p_{ij} – passage probability of the process $\{Y(t): t \geq 0\}$ from the state s_i to s_j (s_i , $s_j \in S$; i , j = 0, 1,..., 4; $i \neq j$)

$E(T_j)$ – expected value of the random variable T_j(j = 0, 1,..., 4) representing duration time of the state $s_j \in S$(j = 0, 1,..., 4) of the process $\{Y(t): t \geq 0\}$ regardless of the state to which the process comes.

The expected values $E(T_j)$ depend on the expected values $E(T_{ij})$ as well as the probabilities p_{ij}, in the following way :

$$E(T_j) = E(T_i) = \sum_j p_{ij} E(T_{ij}) \quad ; \quad i, j = \overline{0.4} \quad ; \quad i \neq j \tag{10}$$

and :

$E(T_{ij})$ – expected value of the random variable T_{ij}(i , j = 0, 1,...4; $i \neq j$) representing duration time of the state $s_j \in S$(j = = 0, 1,..., 4) of the process $\{Y(t): t \geq 0\}$ provided that the next will be the state s_i.

The particular probabilities P_j(j = 0, 1,..., 4) have the following interpretation :

$$P_0 = \lim_{t \to \infty} P\{Y(t) = s_0\} \;,\; P_1 = \lim_{t \to \infty} P\{Y(t) = s_1\}$$

$$P_2 = \lim_{t \to \infty} P\{Y(t) = s_2\} \tag{11}$$

$$P_3 = \lim_{t \to \infty} P\{Y(t) = s_3\} \;,\; P_4 = \lim_{t \to \infty} P\{Y(t) = s_4\}$$

The probability P_0 may be considered a measure of operational safety of floating dock, its systems or any of its devices as well as of a ship under construction or repair carried out in the dock. Also, the probability P_1 can be taken as a measure of almost safe operation of each of the above mentioned technical objects. Whereas the remaining probabilities should be considered measures of hazard to safe operation of a given technical object (e.g. dock, ship). The hazard level increases beginning from the state s_2, i.e. from the instant of occurrence of the dangerous situation. Therefore the probability $P_B = P_0 + P_1$ should be considered a safe operation measure for floating dock and every its device on whose functioning the safety of the dock and ship placed in it, depends.

To obtain (obviously in a approximate way) values of the probabilities P_j(j = 0, 1,..., 4) the assessment of p_{ij} and $E(T_j)$ values is necessary.

To assess the probabilities p_{ij} and expected values $E(T_j)$ is possible after obtaining the realizations y(t) of the process $\{Y(t): t \geq 0\}$ within a sufficiently long investigation time interval, i.e. for $t \in [0, t_b]$, and the investigation time of the process, $t_b >> 0$. This way can be determined the numbers n_{ij}(i , j = 0, 1,..,4; $i \neq j$), of passages the process $\{Y(t): t \geq 0\}$ from the state s_i to s_j within a sufficiently long time interval.

The following statistic can serve as an estimator of the most credible passage probability p_{ij} [7] :

$$\hat{P}_{ij} = \frac{N_{ij}}{\sum_j N_{ij}} \quad ; \quad i \neq j \; ; \; i, j = 0, 1, \ldots, 4 \tag{12}$$

whose value :

$$\hat{p}_{ij} = \frac{n_{ij}}{\sum_j n_{ij}}$$

is an estimate of the unknown value of the passage probability p_{ij} .

From the mentioned run y(t) the realizations $t_j^{(m)}$, m = 1, 2,..., n_{ij}, of the random variables T_j can be obtained. Application of the point estimation makes it possible to easily estimate $E(T_j)$ value as the arithmetic mean of the realizations $t_j^{(m)}$.

The presented process $\{Y(t): t \geq 0\}$ dealing with changes of the distinguished situations (normal, complicated, dangerous, emergency and disastrous) is a particular case of such changes of the situations, which may take place in the case of mistakes made by shipyard employees or ship crew members in action [9].

FINAL REMARKS AND CONCLUSIONS

- During service of floating docks may happen various situations which can be divided, from the point of view of a level of hazard to their safety, into the following categories: complicated, dangerous, emergency and disastrous.
- The presented model of changes of the situations during service of any dock makes it possible to assess operational safety of docks.
- The probability $P_B = P_0 + P_1$ may be taken as a safe operation measure of any floating dock and of any its device on functioning of which the dock's safety depends.
- Application of semi-Markov process, instead of Markov process, as a model of changes of the above mentioned situations in which operational process of floating dock and technical state of the dock, depending on its run, can be realized in a given time (instant), results from that the

random variables T_{ij} and T_i should be expected to have arbitrarily concentrated distributions in the set $R_+ = [0, +\infty)$. In this case application of Markov process would be justified, if the random variables T_{ij} and T_i were assumed to have exponential distributions.

- The presented model can have a practical importance due to easy determination of the estimators of the passage probabilities p_{ij}, as well as of easy assessment of the expected values $E(T_j)$. It should be also accounted for that the point estimation of the expected value $E(T_j)$ does not make it possible to determine its estimation accuracy. To determine it, can be used the interval estimation in result of which the confidence interval $[t_{dj}, t_{gj}]$ with random ends, comprising the unknown expected value $E(T_j)$ with a given probability (confidence level) β, is determined.
- The expected values $E(T_0)$ and $E(T_1)$ can also serve as safety measures, and also $E(T_B) = E(T_0) + E(T_1)$ can be considered a safety measure since the magnitudes T_0 and T_1 are random variables.

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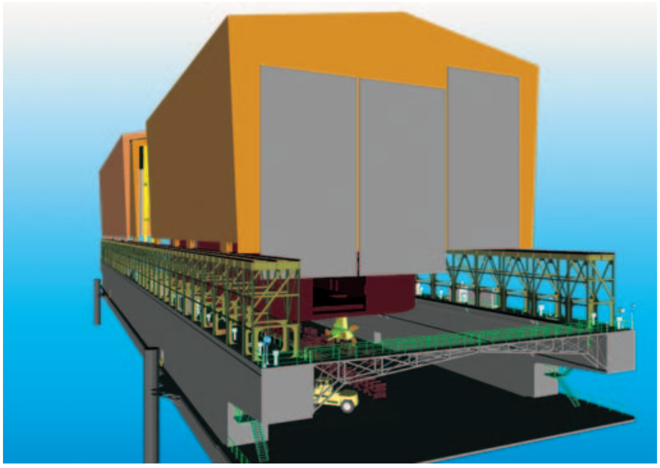

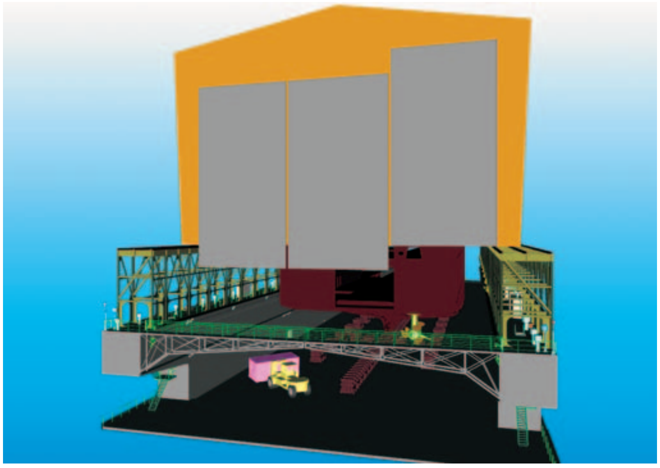

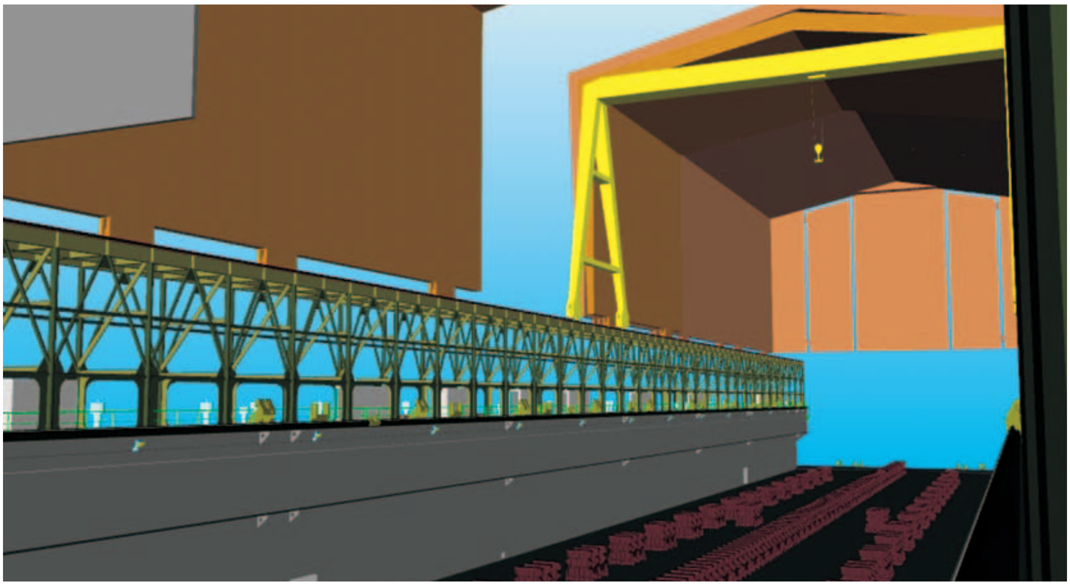

Floatability and stability of floating dock-docked ship system

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ABSTRACT

An analysis of floatability and stability of the floating dock- docked ship system is the subject of this paper. These properties are considered for a cubicoid box dock whose dimensions are close (almost identical) to those of SINE 212 CD dock designed by SINUS design office. The analysis is first of all aimed at determination of the above mentioned hydromechanical properties in the light of the relevant requirements of PRS dealing with minimum freeboard of the dock and its initial metacentric height. It has been concluded that the analyzed dock reveals the designed docking capability which is not constrained by the PRS requirements though the dock in question is fitted with the roofing unfavourable for dock stability. It has been shown that assessing the tranverse stability of the dock as well as of docked ship (floating object) by means of a stability factor instead of metacentric height, is reasonable. The work was performed within the frame of EUREKA – E! 2968 ECOLOGICAL DOCK research project.

Key words : floating dock, docked object, floatability, stability, stability factor.

1. INTRODUCTION

Essential conditions of usefulness (functionality) of floating dock are, among other, possibilities of maintaining the required values of its floatability and stability.

Correctly designed dock should have such floatability (immerseability and load-carrying ability) which can ensure, in the range of its allowable draughts, docking (bringing-in and lifting) the floating objects of demanded values of such parameters as weight and main dimensions. Hence the ensuring of the ability amounts to determining an appropriate design arrangement of the dock, i.e. its main dimensions and correct subdivision determining its ballasting capability.

Correctly designed and used dock must be transversely stable, i.e. both in the case of the whole floating *dock/docked object* system and the docked object itself.

Therefore the dock must have such features due to which, in every phase of its functioning, it can float in the upright position or at most with heel angle of a given allowable value. Also, it should be fitted with such technical devices and service manuals which make it possible to keep docked objects in the upright position effectively and permanently.

This paper presents results of identification and analysis of floatability and stability of a box-shaped cubicoidal dock having its main particulars and performance parameters close to those of SINE 212-CD dock described in [1].

The research task in question was realized as the part of EUREKA – E! 2968 ECOLOGICAL DOCK project, titled: „Ecological floating dock – special hydromechanical problems".

2. GEOMETRICAL AND HYDROSTATICAL CHARACTERISTICS OF FLOATING DOCK

The main hydrostatical characteristics of cubicoidal floating dock, depending on its length L, draught T and geometry of its transverse cross-section as in Fig.1, are expressed as follows:

Volumetric displacement of the dock :

$$V(T) = \begin{cases} LBT & \text{for } T \in (0;h) \\ LBh + 2Lb(T-h) & \text{for } T \geq h \end{cases} \tag{1}$$

Ordinate of the centre of the volume V(T) :

$$z_B(T) = \begin{cases} 0.5T & \text{for } T \in (0;h) \\ \dfrac{h^2(B-2b) + 2bT^2}{2[(B-2b)h + 2bT]} & \text{for } T \geq h \end{cases} \tag{2}$$

Initial transverse metacentric radius :

$$r_0(T) = \begin{cases} \dfrac{B^2}{12T} & \text{for } T \in (0;h) \\ \dfrac{b(3B^2 - 6Bb + 4b^2)}{6[Bh + 2b(T-h)]} & \text{for } T \geq h \end{cases} \tag{3}$$

The hydrostatical characteristics V(T), $z_B(T)$ and $z_M(T) = z_B(T) + r_0(T)$ of the dock whose dimensions L, B, b and h are given in Fig.1 and Tab.1, obtain numerical values given in Tab.2 and shown in Fig.2.

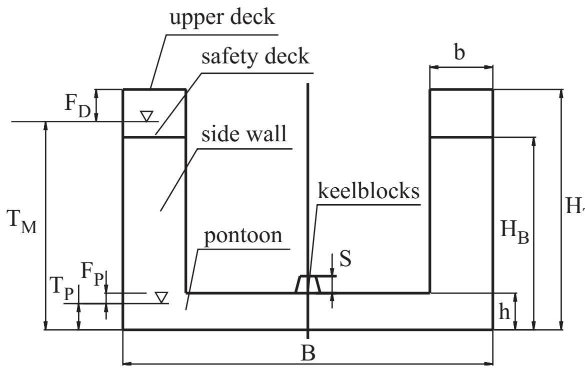

Fig.1. *Transverse cross-section of the dock .*

Tab. 1. *Main particulars of the dock .*

Item	Symbol	Value
Length of pontoon and side walls	**L**	170.00 m
Total breadth	**B**	42.00 m
Side wall breadth	**b**	4.00 m
Pontoon depth	**h**	3.375 m
Dock mass	$\mathbf{P_D}$	8200 t
Height of dock mass centre	$\mathbf{z_{G1}}$	12.90 m
Height of keelblocks	**s**	1.80 m

Tab. 2. *Values of hydrostatic characteristics of the dock of the dimensions as in Tab.1.*

T [m]	V [m³]	z_B [m]	r_0 [m]	z_M [m]
0.500	3570	0.250	294.00	294.25
1.000	7140	0.500	147.00	147.50
1.500	10710	0.750	98.00	98.75
2.000	14280	1.000	73.50	74.50
2.500	17850	1.250	58.80	60.05
3.000	21420	1.500	49.00	50.50
3.375	24098	1.688	43.56	45.24
*) 3.375	24098	1.688	32.01	33.69
3.375	24098	1.688	20.45	22.14
4.000	24948	1.756	19.75	21.51
4.500	25628	1.822	19.23	21.05
5.000	26308	1.898	18.73	20.63
5.175	26546	1.926	18.56	20.49
5.500	26988	1.982	18.26	20.24
6.000	27668	2.075	17.81	19.89
6.500	28348	2.175	17.38	19.56
7.000	29028	2.282	16.98	19.26
7.500	29708	2.396	16.59	18.98
8.000	30388	2.516	16.22	18.73
8.500	31068	2.641	15.86	18.50
9.000	31748	2.772	15.52	18.29
9.500	32428	2.908	15.20	18.10
10.000	33108	3.048	14.88	17.93
10.500	33788	3.193	14.58	17.78
11.000	34468	3.342	14.30	17.64
11.500	35148	3.495	14.02	17.52
12.000	35828	3.652	13.75	17.41
12.500	36508	3.812	13.50	17.31
13.000	37188	3.976	13.25	17.23

*) at the draught T = 3.375 m the functions r_0 (T) and z_M (T) are discontinuous. Their corresponding values are given in the shadowed line.

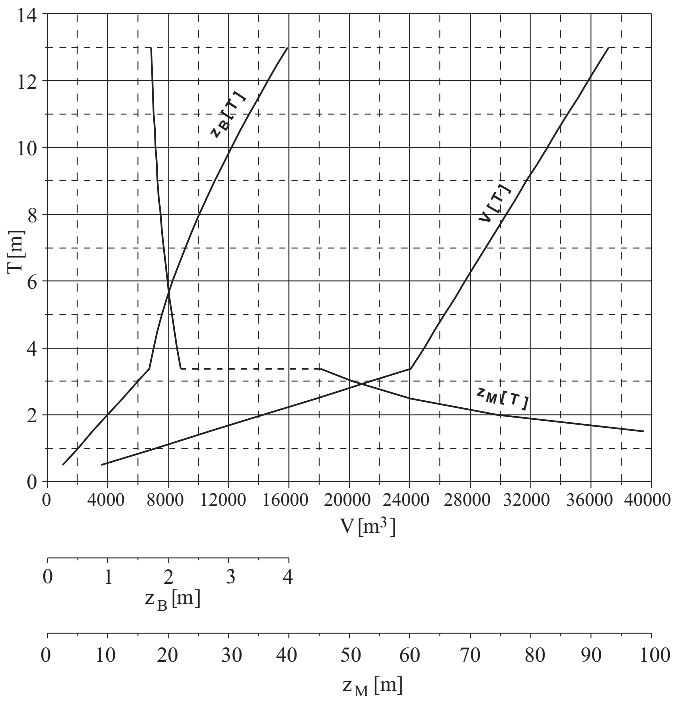

Fig.2. *Hydrostatic characteristics of the dock .*

3. BALLASTING CAPABILITY OF THE DOCK

Ballasting capability of the dock is determined by the data given in Tab.3 and Fig.3. Dimensions of ballast tanks and their schematic arrangement within the dock space are shown in Fig.3. In Tab.3 are given the effective volumes of the tanks, V_i , (determined with accounting for the assumed permeability factor μ = 0.97) and values of the inertia moments of their transverse cross-sections, i_x.

Tab. 3. *Effective volumes of the ballast tanks and values of the inertia moments of their transverse cross-sections*

Tank number acc. Fig.3.	Tank symbol acc. [1]	Effective volume		Moment of inertia i_x [m⁴]
		V [m³]	$\frac{V}{\sum V}$ [%]	
1	TK1CPS	1170.0	3.86	3605
2	TK1CSB	1170.0	3.86	3605
3	TK1SPS	1769.0	5.83	2709/174 *)
4	TK1SSB	1769.0	5.83	2709/174
Σ 1÷4		**5878.0**	19.38	12628/348
5	TK2CPS	900.3	2.97	2773
6	TK2CSB	900.3	2.97	2773
7	TK2SPS	1364.1	4.50	2083/133
8	TK2SSB	1364.1	4.50	2083/133
Σ 5÷8		**4528.8**	14.94	9712/266
9	TK3CPS	900.3	2.97	2773
10	TK3CSB	900.3	2.97	2773
11	TK3SPS	1364.1	4.50	2083/133
12	TK3SSB	1364.1	4.50	2083/133
Σ 9÷12		**4528.8**	14.94	9712/266
13	TK4CPS	900.3	2.97	2773
14	TK4CSB	900.3	2.97	2773
15	TK4SPS	1364.1	4.50	2083/133
16	TK4SSB	1364.1	4.50	2083/133
Σ 13÷16		**4528.8**	14.94	9712/266
17	TK5CPS	900.3	2.97	2773
18	TK5CSB	900.3	2.97	2773
19	TK5SPS	1364.1	4.50	2083/133
20	TK5SSB	1364.1	4.50	2083/133
Σ 17÷20		**4528.8**	14.94	9712/266
21	TK6CPS	1260.4	4.16	3882
22	TK6CSB	1260.4	4.16	3882
23	TK6SPS	1909.7	6.30	2917/187
24	TK6SSB	1909.7	6.30	2917/187
Σ 21÷24		**6340.2**	20.92	13598/374
Total for the dock		**30333.4**	100.00	65074/1786

*) Two values of the inertia moments given in the form „a/b" concern side wall tanks (and their sets) which , depending on their filling degree (water level), have different inertia moments of ballast water surface area.

4. FLOATABILITY OF THE DOCK

For the intended use of the dock first of all two its floatability states determined by its characteristic draughts, are of importance (see Fig. 1), i.e.:

- ✶ by the draught T_M, i.e. the draught at which effective bringing - in – the dock operation of the ship (object) at its draught T_S, is possible.

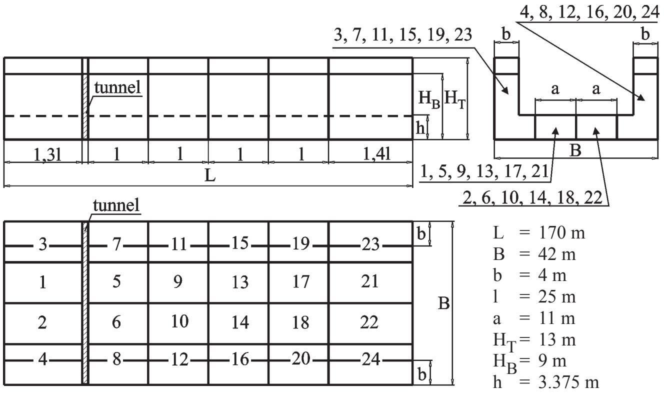

Fig.3. *Ballast water compartments of the dock .*

✶ by the operational draught T_P, i.e. such a draught of the emerged dock at which safe realization of repair work on the docked ship (object), is possible.

4.1. Nominal (design) draught T_M

The design draught of the dock, T_M , is directly determine as a result of simultaneous fulfillment of two requirements :

♦ the requirement, resulting from the classification society rules, that the minimum freeboard value F_P^* defined as $F_D = H_T - T_M$, (see Fig. 1), is to be maintained, which means that :

$$H_T - T_M = F_D \geq F_D^* \qquad (6)$$

♦ the fundamental design requirement which determines the maximum draught T_S of the ships (objects) intended for docking in the designed dock. The draughts T_M and T_S are mutually connected by the obvious relation:

$$T_M \geq T_S + h + s + w \qquad (7)$$

in which the remaining quantities have the following meanings :

- **h** and **s** – pontoon depth and height of keelblocks, respectively (see Fig.1)
- **w** – distance between keel of the ship brought into the dock and the bed of keelblocks, in which some margin for ship trim is also included.

Assuming that the dock of the dimensions given in Tab.1 has to satisfy the freeboard regulations determined in PRS rules [2], i.e. that its design freeboard value F_D cannot be smaller than $F_P^* = 1$ m , one can determine, using the relationships (6) and (7) and under assumption that the distance $w \cong 0.30$ m is sufficient [3], that :

✶ the maximum draught of the dock, T_M , can be $T_{M1} = 12$ m and that

✶ at the draught T_M it is able to receive ships (objects) of the maximum draught $T_S = 6.525$ m.

The above determined immersability features of the dock are merely potential ones as they result only from the linear dimensions of the dock and they at most determine extreme (inexceedable) values of the draughts T_M and T_S . Ballasting capability of the dock, i.e. the maximum mass of water ballast which can be intentionally and effectively put into the dock, decides whether the draught values may be really reached.

Hence the water ballast mass, M_R (or its volume V_R), necessary to immerse the dock to the draught $T = T_M = 12$m should be determined and compared with the dock's ballasting capacity, i.e. the maximum ballast mass M_M (or its volume V_M) which can be taken in and distributed in its designed ballast tanks.

The dock of the draught T will remain in equilibrium of floatation if for that draught the following inequality is satisfied :

$$P_D + P_W + M_R = \rho V(T) \qquad (8)$$

where :

$P_D + P_W$	–	total mass of the dock and its required working stores
$M_R = \rho V_R(T)$	–	the required mass of water ballast of the volume V_R (T)
V(T)	–	volumetric displacement of the dock
ρ	–	density of ballast and overboard water.

Hence the water ballast volume V_R, necessary to reach the draught T, is as follows :

$$V_R(T) = V(T) - \frac{P_D + P_W}{\rho} \qquad (9)$$

Assuming that :

$P_D = 8200$ t (see Tab.1)
$P_W = 150$ t (acc. [1])
$\rho = 1.005$ t/m^3 (with accounting for hull plating thickness)

one can state on the basis of the expression (9) that :

➢ the dock can be effectively immersed to the draught $T = T_M = 12$ m and at the draught

➢ some ballast volume margin amounting to $V_M - V_R = 2814$ m^3 , equivalent to about 9.3% of the dock ballasting capacity $V_M = 30333$ m^3 (see Tab.3), still remains.

4.2. Dock's operational draught T_P

The range of possible values of the dock's operational draught T_P (see Fig.1) is in particular determined by the condition of maintaining the minimum freeboard value $F_P^* = 0.20$ m compliance with the PRS rules [2] :

$$F_P = h - T_P \geq F_P^* \qquad (10)$$

The resulting maximum value of the draught $T_P = T_P^* = 12$ m determines the maximum lifting capacity of the dock, U , or/and its maximum load-carrying ability N equal to the maximum mass of the ship (object) which can be docked in it.

And, in accordance with the obvious equation :

$$U + P_D = N + P_W + M_{RE} + P_D = \rho V(T_P^*) \qquad (11)$$

where :

$M_{RE} = \rho V_{RE}$ - residual ballast mass

the following can be stated :

the maximum buoyancy of the dock is :

$$\rho V(T_P^*) = 22783 \text{ t}$$

its maximum lifting capacity is :

$$U = N + M_R + P_W = 14583 \text{ t.}$$

5. TRANSVERSE STABILITY OF THE FLOATING DOCK - DOCKED SHIP SYSTEM

The problem of transverse stability of floating dock is here considered in two practically distinct aspects. Two cases of the stability are analyzed and assessed, namely :

✦ of the entire dock-ship system when the docked ship rests with its whole length on keelblocks of the floating dock

✦ of the ship itself in every phase of its docking in/out process.

In both the cases only the so called initial stability, i.e that considered only within the range of small heel angles, is investigated, that, in real dock working conditions, fully covers practical problems of its stability.

An initial stability measure is assumed the *stability factor w* defined in Appendix I and identified as w_{SD} factor for the dock-ship system and w_{SS} factor for the ship itself.

Positive values of the factor (w > 0) mean that the considered object is unconditionally stable; whereas negative ones (w < 0) show its initial absolute unstability.

The unconditional stability of docked object (ship) is here assumed the sufficient and unique criterion of its stability. Whereas the stability of the dock-ship system is assessed from the point of view of formal (legal) requirements , i.e. the criteria w^*_{SD} whose values for the considered system are determined on the basis of the relevant PRS rule requirements [2]. It means that in this case, is of importance the relative stability of the object, which takes place and is acceptable only when the following inequality is satisfied : $w_{SD} > w^*_{SD}$.

The so defined stability is here determined and assessed for the dock-ship system in which :

- the dock characterized in Ch.2 and 3 operates within the range of draughts $T_D \in$ < 3.00m ; 12m >
- the ship of the dimensions and hydrostatic features described in Appendix II , is the docked object.

5.1. Stability requirements

Stability of the dock-ship system is here assessed in the light of the relevant rule requirements (criteria) of PRS [2].

They mainly amount to the following regulations :

1) During ship lifting/launching operation the initial metacentric height of the dock, GM_0 , cannot be smaller than 1.4 m. However for the docks of the load-carrying capacity N ≥ 8000 t is recommended the height GM_0 to be not smaller than 3.0 m, that can be expressed as follows :

$$GM_0(T) \geq GM_0^{(1)} \qquad (12)$$

where :

$GM_0^{(1)}$ is the corresponding limiting value $GM_0^{(1)} = \{1.4m ; 3.0m \}$

2) The static heel angle ϕ of the dock-ship system, caused by the heeling moment, M_w , resulting from the wind pressure p = 490 Pa , should not be greater than 1.5°, that can be written as follows :

$$tg\,\phi = \frac{M_W}{9.81 GM_0(T)\rho V(T)} \leq 0.0262 \qquad (13)$$

where :

$\rho V(T_D)$ [t] – dock mass (buoyancy) pertinent to its draught T_D

$M_W(T_D) = 0.001 p A_W(T_D) h_W(T_D)$ [kNm]

$A_W(T_D)$ [m^2] – dock side windage area

$h_W(T_D)$ [m] – height of centre of the area A_W over dock waterline.

For use of the requirements (12) and (13) in this work they have been transformed into the form of an equivalent criterion of stability, i.e. the factors w^*_{SD} (see comments in App.I).

Hence :

the requirement (12) obtains the form :

$$w_{SD}(T_D) = \rho V(T_D) GM_0(T_D) \geq$$
$$\geq w^{(1)}_{SD} = GM_0^{(1)} \rho V(T_D) \qquad (14)$$

the requirement (13) obtains the form :

$$w_{SD}(T_D) \geq w^{(2)}_{SD} = 1.906 A_W(T_D) h_W(T_D) \qquad (15)$$

The limiting values of the dock stability factors $w^{(1)}_{SD}$ and $w^{(2)}_{SD}$ are presented in Tab.4, and the values $w^{(2)}_{SD}$ are given for three variants of the dock design :

- for the dock without any roofing (a hypothetical one only)
- for the dock half covered by a movable roofing whose side windage area, a part of the entire windage area $A_W(T_D)$, is equal to A_{W1} = 3230 m^2 and spread over the length l equal to the dock's half length L = 170 m [1]
- for the dock fully covered by the roofing whose side windage area is A_{W2} = (3230 + 2975) = 6205 m^2 and spread over the full length of the dock.

Tab. 4. *Limiting values of stability factors* $w^{(1)}_{SD}$ *and* $w^{(2)}_{SD}$

Dock draught T_D [m]	Dock volumetric displacement V [m^3]	Limiting values $w^{(1)}_{SD}$ [tm]		Limiting values $w^{(2)}_{SD}$ [tm]		
		Required values ($GM_0^{(1)}$ = = 1 .40 m)	Recommended values ($GM_0^{(1)}$ = = 3.00m)	Dock without roofing	Dock covered over half length	Dock covered over full length
3.0	21420	30138	64581	16205	186680	350754
3.175	22670	31897	68350	15643	185321	348121
3.375	24098	33906	72655	15012	183774	345125
4.0	24948	35102	75218	13126	178982	335845
5.0	26308	37015	79319	10371	171447	321261
5.175	26546	37350	80036	9922	170145	318742
6.0	27668	38929	83419	7940	164074	307001
7.0	29708	41799	89570	5834	156863	293065
8.0	30388	42756	91620	4051	149814	279452
9.0	31748	44669	95720	2593	142927	266164
10.0	33108	46583	99821	1458	136202	253201
11.0	34468	48496	103921	648	129639	240561
12.0	35828	50410	108021	162	123238	228245

It can be observed (see Tab.4) that for maintaining the required relative stability of the dock the following criteria are decisive :

- the criterion (15) of the limiting values $w^{(2)}_{SD}$, in the case of either fully or partly covered dock
- the criterion (14) of the limiting values $w^{(1)}_{SD}$, in the case of not covered dock (hypothetical only).

5.2. Assessment of stability of the floating dock-docked ship system

In Tab.5 are contained values of the stability factors $w_{SD}(T_D)$ and $w_{SS}(T^*_S)$ together with their limiting values $w^{(2)}_{SD}$ and $w^*_{SS} \geq 0$, calculated and presented in App. I (Tab.1.1).

Tab. 5. *Comparison between* $w_{SD}(T_D)$ *and* $w_{SD}^{(2)}$ *values, and the values* $w_{SS}(T_S^*)$ *and* $w_{SS}^* \geq 0$

Dock's draught T_D		3.000	3.175	3.375	4.000	5.175	6.000	7.000	8.000	9.000	10.000	11.000	12.000
Stability factor $10^4\, w_{SD}(T_D)$		79.55	79.82	24.14	24.29	24.69	27.86	31.70	34.87	38.10	4.68	48.15	49.73
Limiting values $10^4 w_{SD}^{(2)}$	Half covered dock	18.67	18.53	18.38	17.90	17.01	16.41	15.69	14.98	14.29	13.62	12.96	12.32
	Fully covered dock	35.08	34.81	34.51	33.58	31.87	30.70	29.31	27.95	26.62	25.32	24.06	22.82
Ship's draught T_S^*		-	-	-	-	-	0.825	1.825	2. 825	3. 825	4. 825	5.800	5.800
Stability factor $10^4\, w_{SS}(T_S^*)$							- 6.80	- 5.05	- 3.78	- 2.66	- 1.48	0.89	0.89
Stability criterion		$w_{SS}(T_S^*) > w_{SS}^* > 0$											

*) the shadowed values show a shortage of the relative stability – in the case of dock, and the unconditional stability – in the case of ship.

From the above presented data the following results:

1) the considered dock, when lifting the example ship of the draught T_S = 5.8 m and total mass F_{GS} = 10032 t, i.e that close to the largest ship (see p.4.1 and 4.2) permitted to be docked in it,

- does not satisfy the PRS stability requirements, if fully covered and the docking phase corresponds to the dock's draught values from the interval : 7.000 m ≥ T_D ≥ ≥ 3.375 m
- always satisfies (for every allowable dock draught T ∈ ≤ T_P;T_M ≥) the requirements if only covered over its half length.

Taking into account that in the course of bringing the ship into the dock and lifting it, the dock is not entirely covered (as there is no need of doing so) one can assume that **the so used dock covered only over its half length can be always (in every phase of ship docking) safe as far as its stability is concerned at least in the light of the PRS rule requirements**.

It can be all the more so assumed that docking operation is also not carried out due to many other reasons, e.g. at strong wind, and surely no longer at the wind force of about 30 m/s.

2) the example docked ship loses its transverse stability (w_{SS} ≤ 0) practically in the instant when its keel rests along its full length on the dock's keelblocks. More precisely, the instant happens at the dock draught $T_D \cong$ 10.8 m and the ship draught $T_S^* \cong$ 5.6 m (see App. I). It means that the ship is to be additionally supported in the dock in every moment of its docking process.

APPENDIX I

Models for calculation of initial stability of the dock-ship system and docked ship itself

The necessary condition of transverse stability (appropriate stable equilibrium) of every free-floating object is its capability to generate „automatically" such moment $M_R(\phi)$ which, in the case of inclining the object by the angle ϕ, will so act as to restore its initial position, back from the heel angle ϕ. It means that the free-floating object will be stable then and only then if all its immanent (internal) forces and moments generate such resultant moment $M_R(\phi)$ whose derivative is :

$$\frac{\partial M_R(\phi)}{\partial \phi} < 0 \qquad (1.1)$$

The moment M_R (ϕ) which satisfies the condition (1.1), is righting moment.

1. Stability of the dock-ship system

Internal forces and moments which act on a free-floating dock loaded with a ship, are the following (comp. Fig.1.1a) :

- the total weight of the dock (together with stores and ballast) : $F_{GD}\,(T_D)g$
- buoyancy of the dock :

$$F_{BD}(T_D)g = \rho g V(T_D)$$

- pressure resultant–load exerted on the dock by the ship :

$$R_D(T_D)\,g = [F_{GS} - F_{BS}(T_S^*)]g \qquad (1.2)$$

- the moment M_{RS} resulting from the forces F_{GS} and F_{BS} acting on the ship :

$$M_{RS}(T_S^*) = [F_{BS}(T_S^*)\, z_{MS}(T_S^*) - F_{GS}\, z_{GS}^*]g$$

- the moment :

$$Q_{RD}(T_D) = \rho\, g \sum i_D\,(T_D)$$

generated by free surfaces of water in ballast tanks.

The quantities appearing in the expressions (1.2) have the following meaning :

- ✶ F_{GS} and F_{BS} – ship mass and buoyancy, respectively
- ✶ z_{GS}^* = KG and z_{MS} = KM – ordinates of ship mass centre and its initial metacentric point, defined in the ship – fixed reference frame (with respect to the point K – see. Fig.1.1)
- ✶ T_D and T_S^* – draughts of the dock and ship, respectively, for which the following relation is valid : $T_D = T_S^* + a$, where a = h + s =5.175 m (see Fig.1 and Tab.1).

If the dock is inclined by a small positive angle ϕ the moment $M_{RD}(\phi,T_D)$ due to the above specified internal forces and moments, acting on it and defined with respect to the point K_D (see Fig.1.1a), is expressed as follows :

$$M_{RD}(\phi,T_D) = -\, w_{SD}(T_D) g\phi \qquad (1.3)$$

where :

g > 0 – gravity acceleration

$w_{SD}(T_D)$ – moment factor of $M_{RD}(\phi,T_D)$ equal to :

$$w_{SD}(T_D) = F_{BD}(T_D)\, z_{MD}(T_D) - F_{GD}(T_D)\, z_{GD}(T) + \\ - F_{GS}(z_{GS} + a) + F_{BS}(T_S^*)[z_{MS}(T_S^*) + a] - \rho \sum i_D(T_D) \qquad (1.4)$$

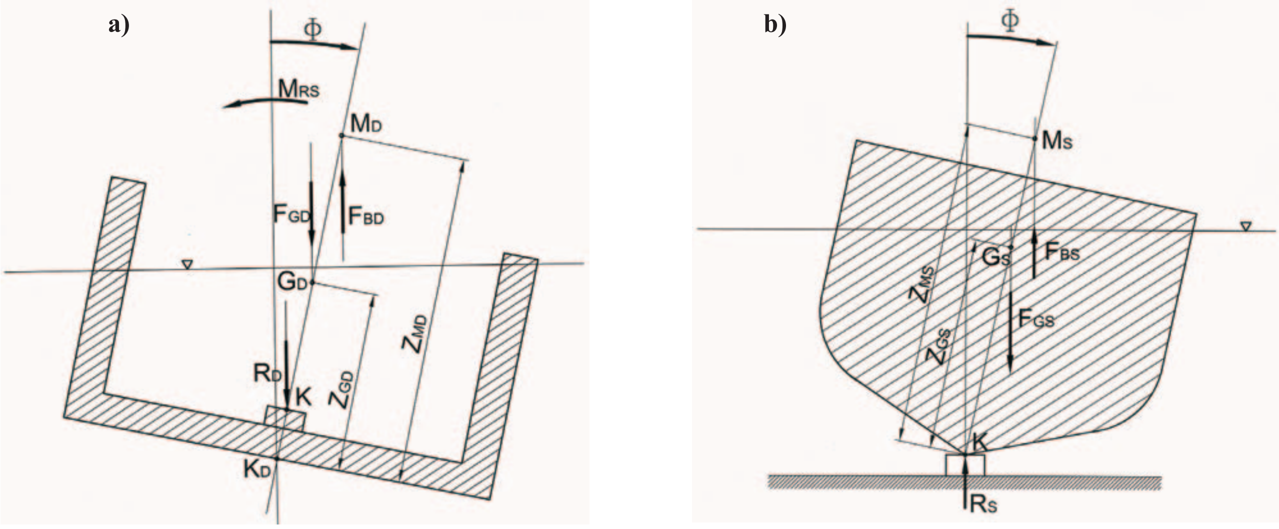

***Fig. 1.1. a)** Loads applied to the dock - ship system .* ***b)** Loads applied to the docked ship .*

The so determined values of the factor $w_{SD}(T_D)$ for the investigated dock loaded by the ship described in App. II, are presented in Tab.1.1.

***Tab. 1.1.** Stability characteristics of the floating dock- docked ship system and the docked ship itself.*

Characteristics	Symbol	Unit	Values at the system draught T_D											
			3.000	**3.175**	**3.375**	**4.000**	**5.175**	**6.000**	**7.000**	**8.000**	**9.000**	**10.000**	**11.00**	**12.000**
for the floating dock- docked ship system														
Buoyancy of the system	F_{BD}	[t]	21527	22783	24218	25073	26678	27806	29173	30540	31907	33274	34640	36007
Ordinate of the system metacentric point	z_{MD}	[m]	50.50	47.89	22.14	21.51	20.49	19.89	19.26	18.73	18.29	17.93	17.64	17.41
Ship weight loading the dock	R_D	[t]	10032	10032	10032	10032	10032	8993	7417	5686	3849	1933	0	0
Ballast mass	M_b	[t]	3145	4401	5836	6691	8296	10463	13406	16504	19708	22991	26290	27657
Ordinate of the ballast mass centre	z_b	[m]	0.44	0.61	0.81	0.93	1.16	1.46	1.53	1.24	1.04	0.89	0.78	0.74
Mass of the dock together with ballast	F_{GD}	[t]	11495	12751	14186	15041	16646	18813	21756	24854	28058	31341	34640	36007
Ordinate of the cen-tre of the mass F_{GD}	z_{GD}	[m]	9.47	8.64	7.91	7.56	7.03	6.52	5.88	5.15	4.56	4.08	3.69	3.55
Stability factor of the system	$\overline{w}_{SD}$	[tm]	832942	835596	558380	280297	284297	315815	345052	376822	409094	444701	483228	499057
Correction to the factor $\overline{w}_{SD}=\sum i_x$	$\Delta\overline{w}_{SD}$	[tm]	37457	37364	37296	37359	37349	37260	28006	28097	28078	27950	1732	1800
Stability factor $\overline{w}_{SD}-\Delta\overline{w}_{SD}$	w_{SD}	[tm]	**795485**	**798232**	**241366**	**242938**	**246948**	**278555**	**317046**	**348725**	**381016**	**416751**	**481496**	**497257**
for the docked ship														
Ship draught	T^*_S	[m]	-	-	-	-	-	0.825	1.825	2,825	3.825	4.825	5.800	5.800
Ship buoyancy	F_{BS}	[t]	-	-	-	-	-	1039	2615	4346	6183	8099	10032	10032
Ordinate of the ship metacentric point	z^*_{MS}	[m]	-	-	-	-	-	24.40	16.40	12.80	10.80	9.80	10.20	10.20
Ship stability factor	w_{SS}	[tm]	-	-	-	-	-	**- 68046**	**- 50512**	**- 37769**	**- 26622**	**- 14838**	**8928**	**8928**

From the condition (1.1) it results that the moment $M_{RD}(\phi,T_D)$ determined by the expressions (1.3) and (1.4) will be really the righting moment of the dock if and only if the following inequality is satisfied :

$$\frac{\partial M_{RD}(\phi,T_D)}{\partial\phi} = -w_{SD}(T_D) < 0 \qquad (1.5)$$

It means that the dock will be really (unconditionally) stable if the factor $w_{SD}(T_D)$, called here **the mass factor of stability**, is positive :

$$w_{SD}(T_D) > 0 \qquad (1.6)$$

In the case of unconditional assessment of stability (with respect to formal legal criteria), its condition determined in the domain of the factor w_{SD} amounts to the inequality :

$$w_{SD}(T_D) > w^*_{SD}(T_D) \qquad (1.7)$$

in which $w^*_{SD}(T_D)$ is the appropriate limiting value (see. Ch.5.1).

Commonly used measure of initial transverse stability of surface floating objects is **the initial metacentric height**

$h_0 = GM_0 = z_{M0} - z_G$, where : M_0 - initial metacentric point, and G - centre of mass of the object. The relevant stability factor is then expressed as follows : $w_{SD} = F_B h_0 = F_G h_0$, where F_B and F_G are values of buoyancy and weight of the floating object, respectively, and, as defined, positive and equal to each other ($F_B \equiv F_G$). The absolute stability condition $w_{SD} > 0$ amounts then to the following : $h_0 > 0$.

However the interchangeable and equivalent application of the conditions : $w_{SD} > 0$ and $h_0 > 0$ is limited to the cases in which values of F_B and F_G can be easily and unambiguously determined, and first of all it concerns the metacentric height h_0. This is always possible when the quantities F_B and F_G are homogeneous and location of the point G of the considered object is unquestionable. Otherwise if at least one of the quantities F_B and F_G is not homogeneous, the metacentric height h_0 usually is a conventional quantity and its value – relative and ambiguous. However the factor w_{SD} remains objective and unambiguous. Therefore this factor should be used to obtain an objective and right assessment of stability.

From the relations described by the expressions (1.2) ÷ (1.4) it results that the righting moment $M_{RD}(\phi,T_D)$ for the dock loaded by a part of weight of the docked ship, is sum of several very different components. First of all for this reason it was decided to measure stability of the dock, but also that of the docked ship (see p.2 , App. I), by using the stability factor instead of metacentric height.

2. Stability of docked ship

On the ship resting with its full length on dock's keelblocks, and inclined by a small positive angle ϕ, acts the righting moment $M_{RS}(\phi,T_S^*)$ taken with respect to the point K (see Fig.1.1b) and equal to :

$$M_{RS}(\phi, T_S^*) = [F_{GS} z_{GS}^* - F_{BS}(T_S^*) z_{MS}(T_S^*)] g\phi \qquad (1.8)$$

where the particular quantities are denoted in the same way as in the expressions (1.2), and the following relationship between the buoyancy of the ship, R_{BS} , and its mass F_{GS} and supporting force $R_S(T_S^*)$ due to reaction of keelblocks, occurs :

$$R_S(T_S^*) = [R_{BS}(T_S^*) - F_{GS}] = -R_D(T_D) \qquad (1.9)$$

Hence the mass factor of ship stability $w_{SS}(T_S^*)$, determined in accordance with the principle (1.3), is expressed as follows :

$$w_{SS}(T_S^*) = F_{BS}(T_S^*)\, z_{MS}(T_S^*) - F_{GS} z_{GS}^* \qquad (1.10)$$

Its values for the ship described in App. II are presented in Tab.1.1.

To illustrate the problem discussed in p.1, concerning the question in which way to measure stability of floating objects, either by means of the stability factor w or the metacentric height h_0, it's worth mentioning that the factor w_{SS} determined by the expression (1.10) may be presented in two ways :

$$w_{SS}(T_S^*) = w_{SS}^{(1)} = F_{BS}\left[z_{MS} - \frac{F_{GS}}{F_{BS}} z_{GS}^*\right] = F_{BS} h_0^{(1)} \qquad (1.11)$$

or :

$$w_{SS}(T_S^*) = w_{SS}^{(2)} = F_{GS}\left[\frac{F_{BS}}{F_{GS}} z_{MS} - z_{GS}^*\right] = F_{GS} h_0^{(2)} \qquad (1.12)$$

The obvious equality of the factors $w_{SS}^{(1)} = w_{SS}^{(2)}$ leads to generally different values of the metacentric height : $h_0^{(1)}$ and $h_0^{(2)}$ which fulfill the relation :

$$\frac{h_0^{(1)}}{h_0^{(2)}} = \frac{F_{GS}}{F_{BS}}$$

and can be equal to each other only in two following cases :

- when $F_{GS} = F_{BS}$, i.e. for free-floating ship, not resting on keelblocks, or
- when $w_{SS} = w_{SS}^{(1)} = w_{SS}^{(2)} = 0$, i.e. in the instant when the ship loses its stability.

Therefore the following statement should be accepted :

In all the cases in which floatation equilibrium of objects is not determined only by the equality of mass and buoyancy of the objects, their stability should be measured by means of the stability factor.

APPENDIX II

Characteristics of docked ship

In this work a general cargo ship of the main dimensions given in the table below, was assumed the docked object.

Dimension	Unit	Value
Length b.p. $\mathbf{L_{PP}}$	[m]	150.00
Total length $\mathbf{L_C}$	[m]	161.00
Breadth **B**	[m]	22.92
Hull depth **H**	[m]	13.30
Design draught $\mathbf{T_K}$	[m]	8.75
Docking draught $\mathbf{T_d}$	[m]	5.80
Docked ship mass $\mathbf{F_{GS}}$	[t]	10032
Ordinate of ship mass centre $\mathbf{z_{GS}}$	[m]	9.31

In Fig.2.1 are presented the following hydrostatic characteristics of the ship : the ship hull volumetric displacement $V_S(T_S^*)$ and the ordinate of initial metacentric point $z_{MS}(T_S^*)$.

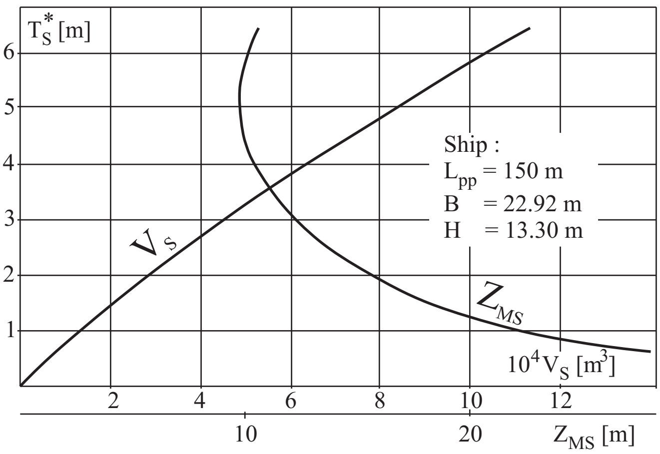

Fig. 2.1. *Hydrostatic characteristics of the docked ship .*

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Hydrodynamical loads on a floating dock towed in sea conditions

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ABSTRACT

Response amplitude operators (RAOs) , short-term and long-term predictions of hydrodynamical response of a floating dock towed in conditions of Baltic and North Sea, are presented and analyzed. The research was focused on : heave and pitch motions, dynamic pressure induced in different parts of the dock's bottom, vertical bending moment and resistance of the dock towed in head seas. The RAOs of the considered responses were determined by means of model tests and/or a computer calculation program based on strip theory. Discrepancies between so obtained values of the characteristics and predicted values of relevant responses, calculated on their basis, were indicated.

Key words : floating dock, sea-keeping qualities, response amplitude operators, short-term and long-term predictions, model testing, numerical calculations – strip theory

INTRODUCTION

Though floating dock is practically a „stationary" shipyard facility a need of its towing in open, more-or-less rough sea waters may appear. For this reason, practical need arises to predict values of its hydrodynamical properties, sea-keeping qualities in particular, apart from the necessity of determination and design control of its hydrostatical properties – floatability and stability . Besides, such predictions have a cognitive merit − they enrich knowledge in the field of shipbuilding.

The subject of the research are numerical characteristics of dock resistance, heave and pitch motions, vertical bending moment and dynamic pressure on its bottom, which are determined :

- ❖ for a box hull dock of the dimensions very close to those of the SINE 212 CD dock described in detail in [1]
- ❖ in the form of short-term and long-term predictions determined for sea states and their statistical distributions characteristic for navigation routes of the Baltic Sea and North Sea
- ❖ on the basis of relevant RAOs obtained :
  - either as a result of appropriate model tests carried out in the laboratory of the Department of Ship Theory and Design, Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology,
  - or by means of numerical calculations performed with the use of STATEK computer program [2] based on the *strip theory*.

This work has been realized within the frame of the *EUREKA*– E! 2968 *ECOLOGICAL DOCK* European research project and its results may find applications as :

- ✸ data for assessment of seaworthiness of the designed SINE 212 CD dock
- ✸ materials to assess adequacy and correctness of various methods for determining sea-keeping qualities of such objects as the considered dock
- ✸ a contribution to more precise determination of strength requirements for floating docks, given in the rules of classification societies, e.g. in [3].

METHODS, PROCEDURES AND MODELS FOR PREDICTION OF HYDRODYNAMICAL PROPERTIES OF FLOATING DOCKS

General statements

Numerical values of short- and long-term predictions of the above mentioned sea-keeping qualities of the floating dock are based on the following assumptions :

- ➢ **1st** – that the *dock-wave* system is a linear, narrow - band dynamic system in which the dock's wave-induced responses (R) are proportional and additive ones in relation to the excitation
- ➢ **2nd** – that the stationary sea wave system (W) is a normal random process fully described by its spectrum density function $S_w(\omega)$
- ➢ **3rd** – that probabilistic distributions of stationary sea states (stationary waving) for the considered navigation waters, are known.

The fundamental characteristics for so predicted sea-keeping qualities are the *Response Amplitude Operators* generally defined as :

- ✦ for the 1st order responses (in this case – heave and pitch motions, pressure and bending moment) :

$$\mathrm{RAO} \equiv \left|H_{R,\varsigma}(\omega)\right| = \frac{a_R(\omega)}{\varsigma_a(\omega)} \tag{1}$$

- ✦ for the 2nd order responses (in this case - resistance) :

$$\mathrm{RAO} \equiv r_{AW}(\omega) = \frac{R_{AW}(\omega)}{\varsigma_a^2(\omega)} \tag{2}$$

The quantities which determine the RAOs are :

⇨ the amplitudes $\varsigma_a(\omega)$ of harmonic (sinusoidal) waves of ω frequencies
⇨ the appropriate characteristics of dock responses : the amplitudes $a_R(\omega)$ of the 1st order responses and the average increase of its resistance $R_{AW}(\omega)$ determined in relation to its resistance in calm water.

The RAOs in question were determined :

☆ by means of the model testing of dock's resistance, heave and pitch motions as well as dynamical pressure on its bottom
☆ by calculations with the use of STATEK computer program [2], performed for heave and pitch motions and vertical bending moment.

Short-term prediction models

A crucial measure of short-term prediction of the 1st order response R, i.e. heave (z), pitch (θ), pressure (p) and vertical bending moment (M), is the variance m_0 (or D_R) of the responses, defined as :

$$m_{0,R} \equiv \hat{D}_R(H_{1/3}, T_1) = = \int_\omega \left|H_{R,W}(\omega)\right|^2 S_W(\omega, H_{1/3}, T_1)\, d\omega \qquad (3)$$

Knowing values of the variance $m_{0,R}$ one can determine any other numerical characteristics of short-term prediction of the 1st order response. Hence for instance the following may be determined :

➲ probability of the event that the amplitude determined by the variance $m_{0,R}$ will exceed a given level of its value, u_R :

$$p_{K,R} = P\{a_R \ge u_R\} = \exp\left(-\frac{u_R^2}{2m_{0,R}}\right) \qquad (4)$$

➲ response amplitude whose exceedance probability in the conditions determined by the variance $m_{0,R}$, is p% :

$$a_{R,p\%} = \sqrt{2 \cdot \ln\frac{1}{p}} * \sqrt{m_{0,R}} \qquad (5)$$

➲ average amplitude value calculated from 1/n part of the largest amplitudes :

$$a_{R,1/n} = C * \sqrt{m_{0,R}} \qquad (6)$$

where the factor C depends only on the value n, and its values amounts to e.g.: 1.25 for n = 1 , 2.00 for n = 3 , 2.55 for n = 10, etc.

The short-term prediction of dock's resistance was determined as follows :

$$R_{TW}(V, H_{1/3}, T_1) = R_T(V) + \hat{R}_{AW}(V, H_{1/3}, T_1) \qquad (7)$$

where :

$R_T(V)$ – dock's calm-water resistance dependent on its forward speed V

$\hat{R}_{AW}(V, H_{1/3}, T_1)$ – average additional resistance of the dock, generated in the conditions of a given stationary sea waving, determined for a given speed of the dock as follows :

$$\hat{R}_{AW}(V, H_{1/3}, T_1) = = 2\int_\omega r_{AW}(V,\omega)\, S_W(\omega, H_{1/3}, T_1)\, d\omega \qquad (8)$$

The spectrum density functions $S_w(\omega)$ of stationary sea waving, appearing in the expressions (3) and (8), were modeled by means of the ISSC standard of the following general form :

$$S_{SC}(\omega, T_1, H_{1/3}) = A\omega^{-5}\exp(-B\omega^{-4}) \ [m^2 s] \qquad (9)$$

where the parameters A and B are expressed as follows :

$$A = \frac{173\, H_{1/3}^2}{T_1^4} \quad ; \quad B = \frac{691}{T_1^4} \qquad (10)$$

and they are the average statistical characteristics of wave states: i.e. the value of their significant wave height $H_{1/3}$ [m] and that of their significant wave period T_1 [s].

Taking into account the made assumptions as well as the form of the wave spectrum density function $S_w(\omega)$ described by (9) and (10), one can observe that the predictions (3) and (8) could be easily determined and presented in their relative form, i.e. that related to square of the wave height $H_{1/3}$. Hence the relative forms of the short-term predictions are as follows :

$$D_R(T_1) = \frac{\hat{D}_R(H_{1/3}, T_1)}{H_{1/3}^2}$$
$$R_{AW}(V, T_1) = \frac{\hat{R}_{AW}(V, H_{1/3}, T_1)}{H_{1/3}^2} \qquad (11)$$

Long-term prediction methods

In this work the following ways of determination of long-term predictions of dock's responses, were applied :

➔ For the 1st order responses was applied the method based on full probability model, which determines the probability p_{LT} of the event that an assumed amplitude value u_{LT} of a given response R will be exceeded once a year during sea service of the dock :

$$p_{LT} = P\{p \ge u_{LT}\} = \sum_i \sum_j \exp\left(\frac{-u_{LT}^2}{2m_{0,R,i,j}}\right) p_j\, p_i \qquad (12)$$

where :

p_j – probabilities determined by a given statistical distribution of sea states (states of stationary irregular waving) in i-th sea region

p_i – probabilities which determine possible appearance of a towed dock in the i-th sea region

$m_{0,R,i,j}$ – short-term prediction of variance of a given response R, determined by the expression (3), and relevant to the situation determined by occurrence of j-th sea state in i-th sea region.

➔ For increase of resistance was applied the method which determines an average statistical (weighted) increase of resistance at accounting for all distinguished sea states which may appear in all distinguished sea regions :

$$\tilde{R}_{AW}(V) = \sum_i \sum_j p_i\, p_j\, \hat{R}_{AWi,j}(V, H_{1/3}, T_1) \qquad (13)$$

where : $\hat{R}_{AW,i,j}(V, H_{1/3}, T_1)$ are short-term predictions of average additional resistance, determined in accordance with the expression (8) for all the distinguished sea states and regions.

Hence, in compliance with the formula (7) the long-term prediction of full resistance of the towed dock can be expressed as follows :

$$\tilde{R}_{TW}(V) = R_T(V) + \tilde{R}_{AW}(V) \qquad (14)$$

TESTS AND THEIR RESULTS

Scope and program of the tests

The tests of sea-keeping qualities of the dock, aimed at reaching the above determined targets, were performed within the following scope :

- the floating dock of the dimensions given in Tab.1, was the object of the tests

Tab. 1. Characteristics of the dock and its model .

Characteristics	Symbol	Dimension	Dock	Model
Length of waterline	L	m	184.16	1.8416
Breadth of waterline	B	m	42.00	0.4200
Draught	T	m	3.00	0.0300
Displacement	∇	m^3	22173.5	0.02217
Wetted area	S	m^2	8840.2	0.8840
Longitudinal radius of inertia	k_{yy}/L	-	0.25	0.25
Water density	ρ	kg/m^3	1.025	998.3
Water kinematic viscosity coefficient	ν	m^2/s	$1.19*10^6$	$1.01*10^6$

- first of all, dynamical pressures induced on the bottom of the dock, its vertical bending moment as well as resistance, and additionally heave and pitch motions, were tested
- all the above mentioned qualities were determined for head waves
- the RAOs :
  - for heave, pitch, pressure and resistance – were determined by means of model tests
  - for all responses except resistance and pressure – also by means of calculations
- short-term predictions were determined in the form given in the expressions (11)
- long -term predictions were determined in accordance with the expressions (12), (13) and (14) :
  - with the use of discrete distributions of p_j for stationary sea waves on the Baltic Sea and North Sea, identified on the basis of [5] and presented in [4] or/and [6]
  - on the assumption that the distribution of p_i is the following: p(Baltic Sea) = 0.7 ; p(North Sea) = 0.3
  - for dock's resistance within the range of its towing speed : V_H = ∈ ≤ 2 kn ; 5 kn ≥
  - for only one value of the speed : V_H = 5w in the case of all the remaining responses of the dock.

Results of the tests

Here, main results of the above described tests (detail information on the tests and their complete results can be found in [6] and [7]) are collected and presented in two parts.

In the first part - the following items :

- the RAOs of heave and pitch motions of the dock (Fig.1), as calculated by using the computer program [2], and as measured during the model tests, and
- values of short-term (Fig.2) and long-term (Fig.3) predictions of the same responses of the dock, as calculated by using the RAOs and determined in the two above mentioned ways.

The presentation has first of all a cognitive merit as it is focused on showing a degree of quantitative coherence (or discrepancy) between the predictions of sea-keeping qualities of floating dock, based on the RAOs determined either experimentally or by calculations.

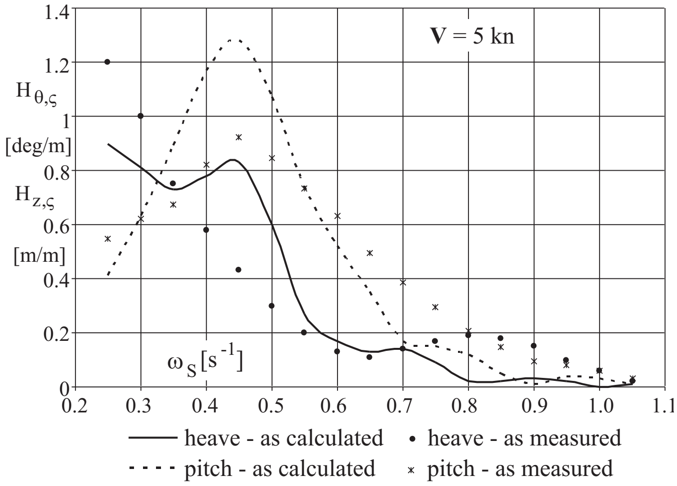

Fig. 1. Amplitude characteristics of heave and pitch motions of the dock .

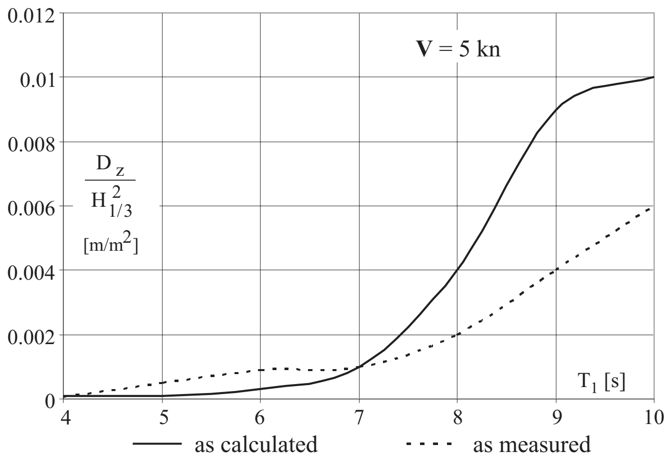

Fig. 2a. Relative variance of heave motions of the dock .

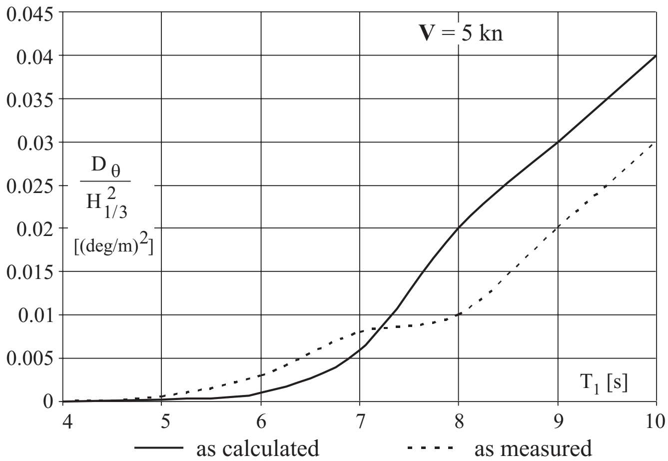

Fig. 2b. Relative variance of pitch motions of the dock .

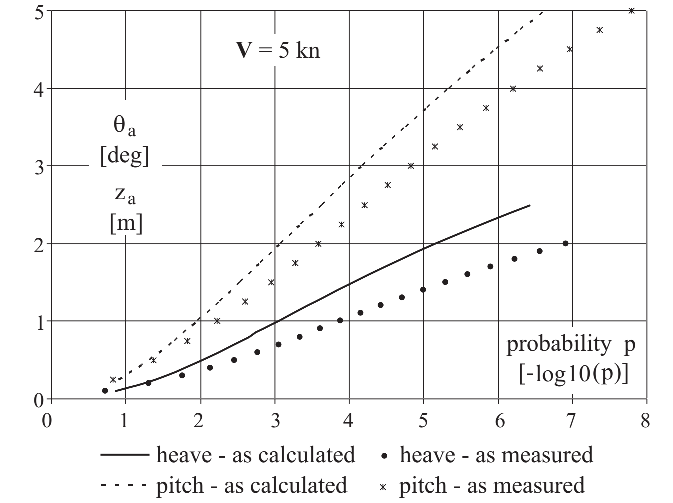

Fig. 3. *Long-term prediction of heave and pitch motions of the dock .*

In the second part are presented values of the predictions of the hydrodynamical loads on the dock towed in sea conditions, whose values may find application in dock designing. Hence, the following items are shown here :

✪ long-term prediction of additional resistance of the towed dock (Fig.4) and short-term and long-term prediction of dynamic pressures acting on its bottom (Fig.5 and 6), determined on the basis of relevant RAOs obtained experimentally

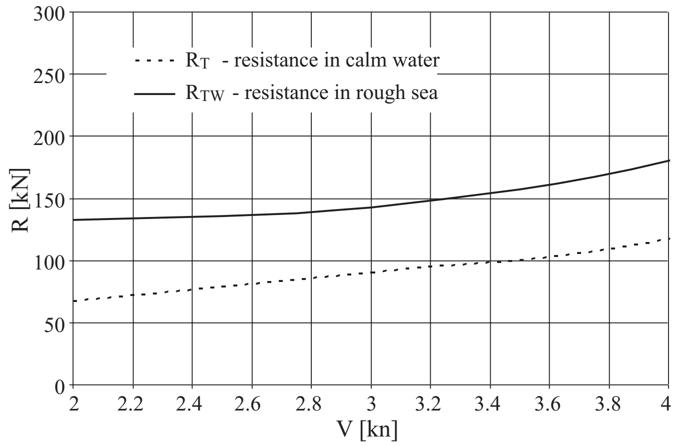

Fig. 4. *Long-term prediction of resistance of the dock .*

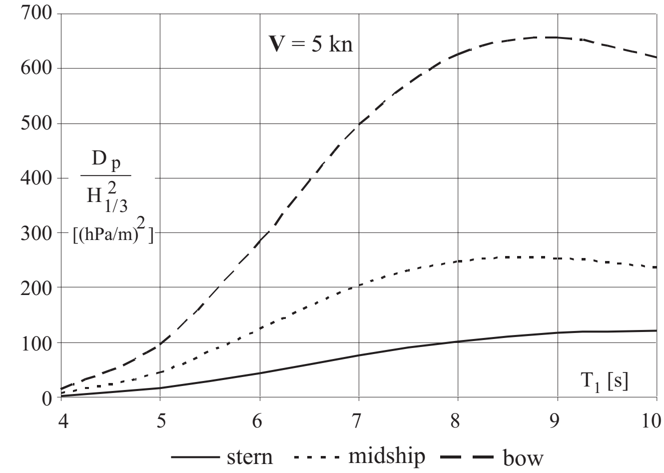

Fig. 5. *Relative pressure variance for the dock .*

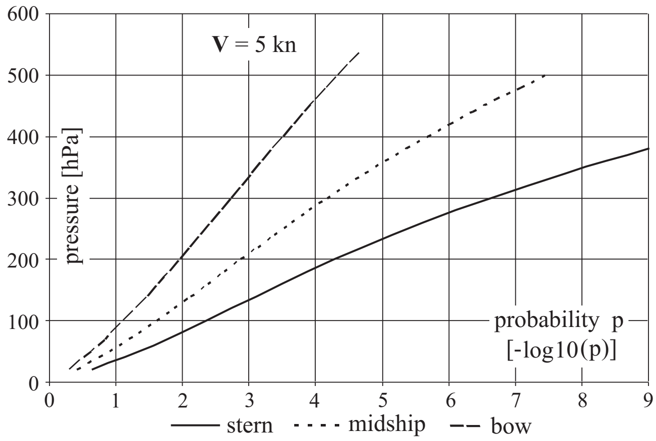

Fig. 6. *Long-term prediction of pressure for the dock .*

✪ short-term and long-term predictions of vertical bending moment (Fig.7 and 8), whose RAO was calculated.

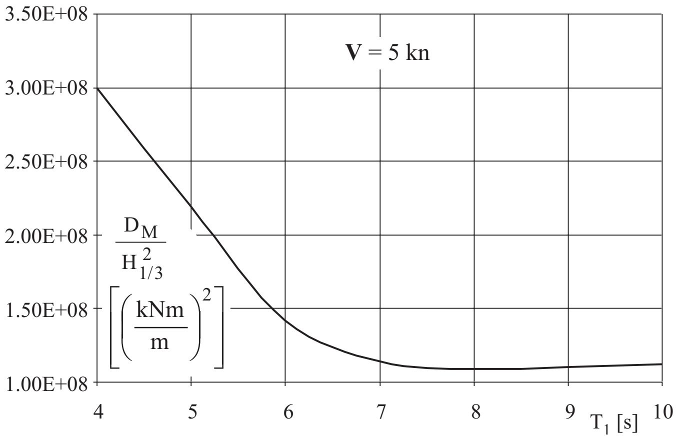

Fig. 7. *Relative variance of vertical bending moment in the dock .*

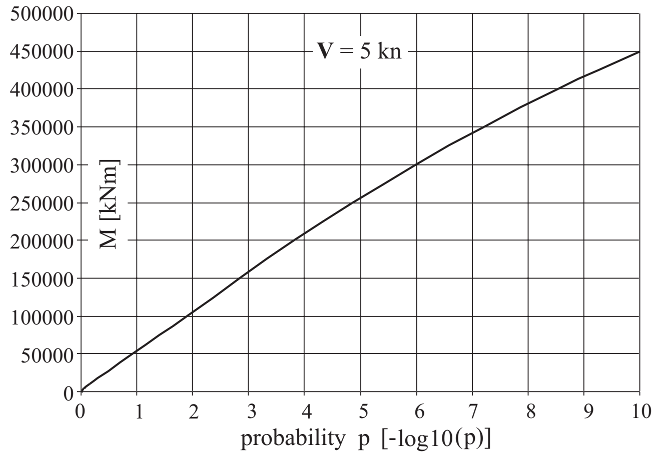

Fig. 8. *Long-term prediction of vertical bending moment in the dock .*

Moreover, in Tab.2 are presented u_R values of predicted pressures induced on the fore part of dock's bottom, and dock's vertical bending moment, determined :

- ♦ on the basis of the relationship (4)
- ♦ for the variances $m_{0,R}$ of those responses relevant to average (expected) and modal sea state of the Baltic Sea and North Sea
- ♦ for the probability value $p_{K,R} = 10^{-4}$.

The so determined values u_R were practically calculated as :

$$u_R = \sqrt{18.42\, m_{0R}(T_1, H_{1/3})} \qquad (15)$$

In Tab.2 the values u_R are given together with the values u_{LT} of long-term predictions of the dock's responses in question determined according to the formula (10) only for Baltic Sea, only for North Sea as well as for both the seas together.

Tab. 2. *Comparison of the predicted values of u_{LT} and u_R determined for $p = 10^{-4}$*

Responses of the dock	u_{LT} values for			u_R values			
				Baltic Sea		North Sea	
	Baltic Sea	North Sea	Both seas together	Average waving $T_1 = 5.36$ s $H_{1/3} = 1.43$ m	Modal waving $T_1 = 5.50$ s $H_{1/3} = 0.95$ m	Average waving $T_1 = 6.35$ s $H_{1/3} = 1.95$ m	Modal waving $T_1 = 6.40$ s $H_{1/3} = 1.20$ m
Bending moment [10^4kNm]	23	17	21	8.2	5.5	9.5	5.8
Pressure (at bow) [hPa]	335	520	460	81.2	59.2	171.5	106.8

SUMMARY

- Very great discrepancies between all quantitative characteristics of heave and pitch motions of the floating dock in question, have been observed, namely :
  - especially large (reaching 100%) are differences of values of the RAOs in the frequency interval : $\omega \in \in < 0.3s^{-1}; 0.5\ s^{-1} >$ and, in consequence, values of variances of the motions corresponding to high sea states (for wave periods $T_1 > 8s$)
  - less different are values of the relevant long-term predictions
  - the differences in values of variances and long-term predictions, especially for pitch motion, are much smaller (by abt. 50%) than those for heave motion.
- It may be assumed that similar differences occur between values of the RAOs and predictions of pressure and bending moment, i.e. the responses having *par excellence* practical, design merit. (For practical reasons it was not possible to investigate the relations within the scope of this work).
- The observed and anticipated discrepancies are difficult to be explained. A much greater quantitative coherence of the calculated and experimentally determined RAOs, has been expected. All the more, the problem seems to be surprising because :
  - the model tests were performed in a sufficiently reliable way, and
  - the calculation model based on strip theory should provide sufficiently correct results for the dock in question first of all because of the uniform form of its frame sections and its very low speed (Fn = 0.06) .

  Perhaps, the very low ratio L/B = 4.38 of the dock could be a cause of the discrepancies as the strip theory is assumed to be applicable only for *slender body* objects. However there are very firm statements, e.g. those given by 18th ITTC, that the calculation models based on strip theory are able to provide sufficiently accurate results in determining motions of the floating objects having L/B ratio as low as 2.5 ([8]).
- One way or another, the observed discrepancies show that practically predicted (in design process) values of wave loads for the dock may be unreliable.
- The uncertainty is additionally heightened by the fact that relevant requirements of classification institutions are given in a very enigmatic, quite ambiguous form.

  For instance, the relevant rules of Polish Register of Shipping (PRS) ([3]) state only that :
  - *calculated (design) pressure applied to dock's plating is to be composed of hydrostatic pressure and hydrodynamic pressure whose values are to be determined at the probability level of 10^{-4}*
  - *total value of design bending moment is to be determined with accounting for values of wave-induced bending moment at the probability level of 10^{-4}.*

The rules do not specify a determination method of the loads or even a way of their prediction. Yet, as shown in Tab.2, very different can be values of various but possible predictions determined at the same probability level (e.g. 10^{-4}) and based on the same method of determination of the variance $m_{0,R}$ for a given load.

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Selected problems concerning strength of a floating dock with roof

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ABSTRACT

The paper presents models and results of the structural strength analysis of a roofed floating dock. Computed thickness of the roof structure walls capable of withstanding the environmental loads is 24 mm. Heavy sliding roof segments generate the dock pontoon floor plate stresses reaching 25% of the permissible stress value. The dock pontoon structure effort under the roof and docked ship weight load was minimized by seeking an optimum balancing ballast distribution. The problem was solved in two ways: analytically, by means of a simplified model of a continuous beam on elastic foundation and numerically, using the linear programming method to construct an accurate discrete FEM model.

Key words: floating dock structure and strength, FEM computations, linear programming

INTRODUCTION

The authors' task was to evaluate structural strength of the ecological floating dock designed by the SINUS company. Additionally, extensive theoretical analyses and considerations were performed in order to investigate the influence of various dock parameters on the keel block loads (from the docked ship weight) and the dock hull stress values. Solutions were sought to minimize those loads and stresses.

Main dock parameters are the following :

- lifting capacity: Q_d = 10 000 tons
- pontoon length: L = 170 m
- width: B = 42 m
- internal width between the side walls: B_w = 34 m
- pontoon depth in the dock plane of symmetry: h_p = 3.5 m
- dock height: H = 13 m
- height of the dock with roof, in the plane of symmetry : H_z = 42 m.

The designed dock is a novel solution as the ecological requirements made it necessary to install a roof, i.e. to mount on the dock side walls a big steel hall constructed of segments slidable along the dock. Large dimensions and weight of such hall (approximately 2000 tons) made a significant impact on the dimensions of the dock itself.

Securing the dock stability, with the side wind pressing on the large windage area and the high up situated heavy roof structure, made it necessary to enlarge the dock width B comparing with classical docks of the same lifting capacity. The relatively large dock width means greater bending moment values in the pontoon bulkheads with the bottom and deck inner plating strakes, induced by the docked ship weight. This in turn makes a relatively great pontoon depth necessary in order to maintain reasonable pontoon bottom and deck plating thicknesses. Because of that, the dock pontoon is very robust in comparison with classical floating docks of similar lifting capacity.

The here described strength analyses indicate that a dock structure with the B/L and h_p/L quotient values greater than in the classical docks is rigid and resistant to the pontoon general bending and middle bulkhead bending by the keel block transmitted forces.

DESIGNING OF FLOATING DOCKS IN ACCORDANCE WITH THE CLASSIFICATION SOCIETY RULES

The dock hull structure strength was evaluated in accordance with the requirements and criteria of the Polish Register of Shipping rules [1]. The rules include requirements of the dock structural element arrangement and strength. For example, longitudinal bulkhead in the pontoon plane of symmetry (PS), side longitudinal bulkheads and transverse bulkheads every 10 to 12 frame spaces must be installed in the pontoon.

The structural strength requirements have a form typical of the floating structures. They include general strength (bending in the vertical plane), transverse strength (bending of the pontoon transverse bulkheads) and local strength (bending of the plating stiffeners and plates). Very simple dock load models are used for the purpose.

The overall bending strength of a dock should at least be sufficient for conventional loading with the weight of a docked ship with symmetrical weight distribution along the dock, as shown in Fig. 1.

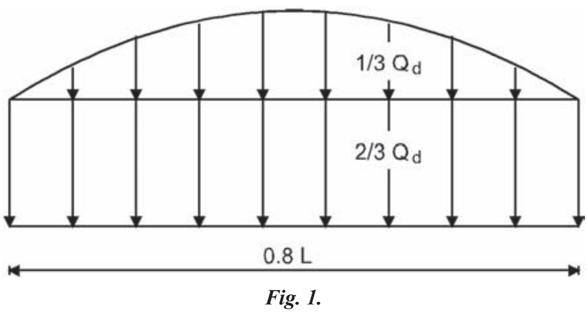

Fig. 1.

The balancing ballast in the dock tanks should be uniformly distributed along the dock length L.

The transverse bulkhead strength should be checked for the condition of loading the dock PS longitudinal bulkhead with a concentrated force :

$$P = 1.5 \frac{Q_d}{L} \cdot d \qquad (1)$$

where :

Q_d – dock lifting capacity
L – dock length
d – transverse bulkhead spacing.

The bulkhead is loaded also with the weight of ballast in the dock tanks and with the dock buoyancy force. These are continuous loads (along the bulkhead) of a value of the respective pressure multiplied be the bulkhead spacing d.

As it can be seen, this computational model assumes a 50% of the mean load overload of the bulkheads from the maximum weight Q_d of a docked ship.

The above described computational loads are supposed to secure a sufficient dock strength to take the real loads dependent on many factors, e.g. docked ship bottom deformability, unintended ship bottom non-rectilinearity, dock pontoon deformability etc. These problems are discussed in the next chapter.

The use of these simple computational models in the rules [1] is probably confirmed by the practice. Classification societies modify their requirements by applying their own experience from the periodical ovehauls of the classed objects.

EFFORT OF THE DOCK AND KEEL BLOCKS

Safe docking of a ship depends on the stress level in the dock structural elements and on the forces in keel blocks. These parameters are determined by: (**a**) size and weight distribution of the dock and docked ship, (**b**) ship and dock structure, (**c**) distribution and relative height of keel blocks, (**d**) dock ballasting method.

The main dock load comes from the docked ship weight. Other loads are dock own weight, ballast weight and movable weights: travelling cranes and slidable roof. The weights are counterbalanced by external water pressure on the bottom. In the dock side walls and PS area, the gravity forces locally overbalance the buoyancy force, in other parts of the pontoon (if there is no ballast there) the buoyancy force predominates. In effect, stresses are generated in the pontoon structural elements and in the dock side walls.

Force differences in keel blocks come from the non-uniform weight distribution of the docked object and from differences in its local rigidity. The non-uniformity of ship weight distribution is caused by equipment locations: heavy parts are the engine room and forepeak with the anchoring equipment as well as the transom stern, sometimes with a ramp. The impact of ship bottom local stiffness on the keel block forces comes from the fact that the ship - keel blocks - dock system is statically indeterminate (over-rigid) and the rigidity differences are mainly caused by the presence of transverse bulkheads. The dock itself does not generate disturbances in the keel block force distribution – the pontoon weight and rigidity are almost constant along its entire length.

The ship and dock are given, non-controllable objects, but effects of their mutual interaction may be corrected by changed configuration of keel blocks and ballasts. The flexibility of use of those two measures is different: the keel block positions may be modified before the docking operation is started, but ballasting is always possible.

Here below the impact of ship and dock weight and structure on the dock and keel block effort is analysed and evaluation is made of the possibility of correcting the effort level by dock ballasting.

Computational models

The computational models of the roof-dock and dock-ship systems and their corresponding internal forces may describe the analysed phenomena in different ways and with different accuracy. There are two groups of models. **The first group** comprises models describing structural details of the dock and ship - discrete models. Solutions are of a numerical character – obtained by the finite element method – and pertain to a concrete data set; generalization is possible only by analysing different variants of the structure and loads, which requires rebuilding of the model.

The second group comprises more or less simplified models, described by continuous functions and leading to analytical solutions. They are useful when the analysed process is subject to many parameters changing in wide ranges. In such a situation even qualitative solutions are valuable as they indicate directions of seeking admissible solutions.

The basic computational model in the first group was a system of two flat grids modelling the arrangement of ship and dock pontoon bottom, sides, side walls and bulkheads, connected by the keel block-modelling bars. The model allowed to represent the ship and dock general bending rigidity as well as the local bottom rigidity to the keel block pressure. The ship weight was distributed along its sides and the dock weight was applied to the side walls and floor plates. The ballast and outboard water pressure was transferred from the bottom shell plating and stiffeners to the pontoon longitudinals and floor plates. In the outboard water impact calculations the dock structure deformability was accounted for.

The general model in the second group was a system of two beams connected by an elastic foundation [5]. It is described in more detail later in this paper.

Dock stresses induced by the slidable roof

The roof is a specific element of the ecological dock. It has a form of segments slid along the rails on the dock side wall deck. The segments may be inserted one into another, their total weight reaches 20% of the dock lifting capacity.

The roof weight is counterbalanced by the water pressure on the whole dock pontoon bottom. The action is transferred from the shell plating to stiffeners, to floor plates and longitudinals and to side walls. With a uniform ballast distribution, the following stresses are generated :

	Centre longitudinal	Side wall	Floors
Roof spread uniformly	–	–	9%
Roof pushed together – middle	8 MPa	13%	10%
Roof pushed together – both ends	9 MPa	15%	13%
Roof pushed together – one end	–	4%	25%

The „–” symbol means negligible stresses and the percentage values are related to the permissible stress values [1].

The dock should be so designed that the loads other than those from the docked object do not generate significant structural stresses. As it can be seen, the centre longitudinal stresses are very low. The side wall stresses arise when the roof segments are pushed together, i.e. when a floating crane must have access to the docked ship. The floor stresses are noticeable (10%) even in normal operation, and during the roof segment handling the additional stresses are quite big (25%).

The keel block forces from non-uniform ship weight distribution

The merchant ship hull weight is non-uniformly distributed: the stern-located engine room is much heavier than the rest of the hull (Fig.2).

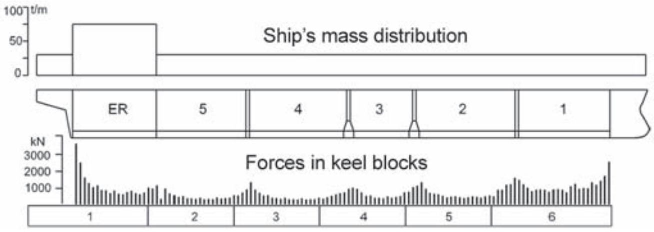

Fig. 2.

In order to investigate how the ship weight distribution and dock ballasting influence the keel block forces, an analytical model [5] was used, including (Fig.3) :

- the „upper" beam representing the ship hull deflection, loaded with the ship weight
- the „lower" beam representing the dock deflection, loaded with the difference between the ballast weight and buoyancy force
- linear elastic foundation, connecting the two beams and representing the ship and the dock pontoon bottom rigidity.

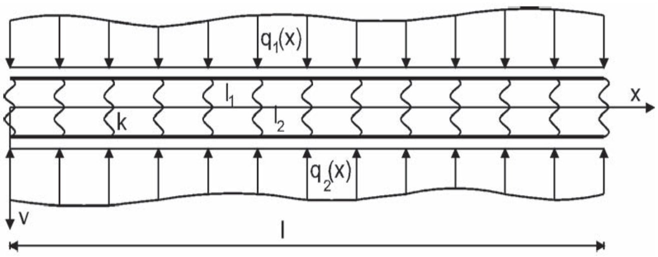

Fig. 3.

The model is described by the set of differential equations :

$$\begin{aligned} EI_1 v_1^{IV} + k(v_1 - v_2) &= q_1(x) \\ EI_2 v_2^{IV} - k(v_1 - v_2) &= -q_2(x) \end{aligned} \qquad (2)$$

which may be reduced to one equation :

$$EIv^{IV} + kv = \frac{EI}{EI_1} q_1(x) + \frac{EI}{EI_2} q_2(x) \qquad (3)$$

where :

$$EI = \frac{EI_1 \cdot EI_2}{EI_1 + EI_2} \quad , \quad v = v_2 - v_1$$

Equation (3) may be used for docking analysis, when :

- ship length is the same as dock length and keel blocks are positioned in the dock PS along the entire length
- the ship and dock structure rigidity is constant along the entire length
- the ship and the dock pontoon bottom structural element system is limited to the floor plates
- the ship weight and the dock ballast are described by continuous functions.

With additional assumptions that the ship-keel blocks-dock system is symmetrical in relation to the dock middle section and that the weight of ship and of the dock ballast is expressed by linear functions (Fig. 4), the model may be limited to 1/2 dock length.

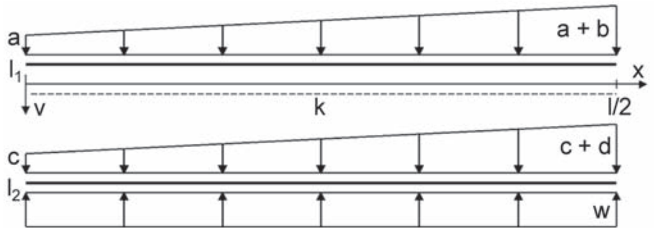

Fig. 4.

By solving equation (3), the keel block pressure forces are obtained :

$$n(x) = k \cdot v(x) = a + \frac{1}{\overline{EI}} \frac{b+d}{2} + \frac{\overline{EI} \cdot b - d}{1 + \overline{EI}} \left\{ 2\frac{x}{l} + \frac{\sqrt{2}}{\beta} \left[\frac{V_0 V_2 + V_3^2}{V_0 V_1 + V_2 V_3} V_0\left(\beta \frac{x}{l}\right) - V_1\left(\beta \frac{x}{l}\right) + \frac{V_2^2 + V_1 V_3}{V_0 V_1 + V_2 V_3} V_2\left(\beta \frac{x}{l}\right) \right] \right\} \qquad (4)$$

where :

$\overline{EI} = EI_2 / EI_1$ – the bending rigidity ratio of dock and ship

$$\beta = \sqrt[4]{\frac{kl^4}{EI_2} \frac{1 + \overline{EI}}{4}}$$

$V_0()\ldots V_3()$ – normal functions [5]

$V_0 \ldots V_3$ without argument mean $V_0(\beta/2)\ldots V_3(\beta/2)$.

As it can be seen, it is possible to obtain n(x) = const, when $d = \overline{EI} \cdot b$. It means that the best dock ballasting method is a „triangular" ballast distribution, depending on the ship weight distribution and on the bending rigidity ratio of dock and ship.

The usefulness of this solution is strongly limited by the lack of transverse bulkheads and longitudinal girders and the full length support assumptions.

Optimum ballasting during docking a ship with transverse bulkheads

An admissible docking condition is determined, among other parameters, by a minimum dock pontoon freeboard and maximum permissible keel block forces. Differences in the keel block forces are caused by the non-uniform ship weight distribution and the presence of transverse bulkheads (Fig.2); the greatest pressure is on the last stern keel block. An attempt may be made to reduce those forces by using the balancing ballast.

The dock has 24 ballast tanks grouped in 6 compartments along the dock. In order to find an admissibility criteria fulfilling solution, a linear programming problem was formulated :

$$0 < N_i^0 + \sum\nolimits_j a_{ij} b_j < \overline{N}$$

$$\sum\nolimits_j b_j = \min \ , \ \sum\nolimits_j b_j \le B$$

$$-M \le \sum\nolimits_j b_j x_j \le M$$

$$\overline{b_j} \ge b_j \ge 0$$

where :

N_i^0 – keel block force for a ballast-free condition
$\overline{N}$ – admissible keel block force
a_{ij} – impact matrix of the weight of ballast in tank on the keel block forces

b_j – ballasts sought
B – admissible total weight of ballast
$\overline{b_j}$ – admissible ballast weight in a tank
x_j – ballast tank centre abscissa
M – admissible trimming moment.

Solution of the problem not always exists as the amount of ballast is limited by the tank capacity and the dock ponto-on freeboard. Such situation occurred in one of the analysed computational conditions. The optimization criterion was then changed from the minimum ballast weight to a minimized value of the maximum keel block force. The keel block forces computed for that condition are presented in Fig.5.

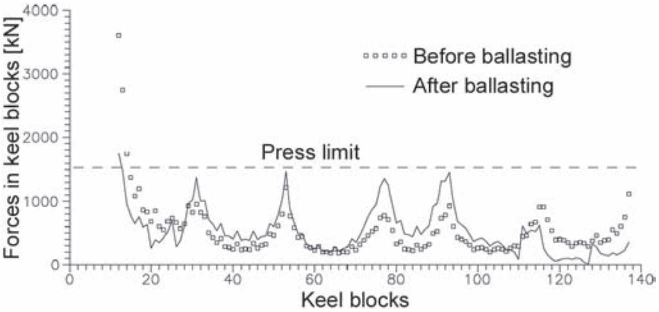

Fig. 5.

THE DOCK ROOF STRENGTH

The dock roof, proposed by the authors of this paper, has a form of the steel hall positioned on the dock upper deck. The hall consists of two segments, which may be slid on/under each other. The hall structure diagram is shown in Fig.6.

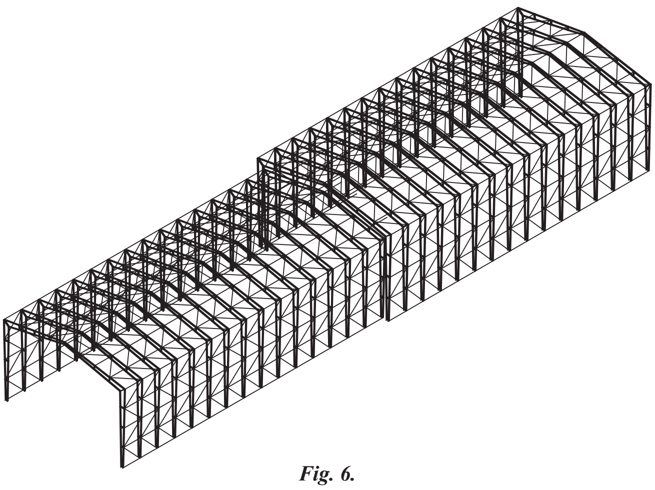

Fig. 6.

The structure consists of transverse frames positioned with a 5.7 m spacing and connected by horizontal and diago-nal braces. The so constructed skeleton will be covered with shaped plating.

The larger segment has the following dimensions :

- external width approx. 42.5 m
- side wall height 24.9 m
- total height 28.75 m
- roof inclination angle 10°.

The height and width of the smaller segment are smaller by approx. 3.8 m and 2.6 m, respectively.

Structures of such a big size are subject to significant environmental loads, e.g. wind pressure and weight of snow accumulated on the roof. The structure own weight is also an important load component.

Classification societies in their rules for floating docks do not give any requirements for the roofed floating docks. Therefore, it was proposed that the roof structure strength be checked in accordance with the civil engineering criteria for steel halls. The computational loads from snow were taken from the standard [2] and those from wind – from the standard [3].

Hence, the computational loads for the Gdańsk area are the following :

- roof load (pressure) from snow : ≈ 0.94 kPa
- wind pressure and suction on the roof : 1.88 kPa and - 2.0 kPa respectively
- wind pressure and suction on the walls : 0.92 kPa and - 0.92 kPa respectively
- load from the shaped plating weight : ≈ 0,13 $\frac{t}{m^2}$

In order to find the cross section dimensions of transverse frames, variants of FEM calculations were carried out with a criterion that the reduced stresses should not exceed the 160 MPa level (for a 235 MPa yield point steel). The FEM model assumed the frame restrain at the dock upper deck. Examples of the FEM calculation results are presented graphically in Fig.7.

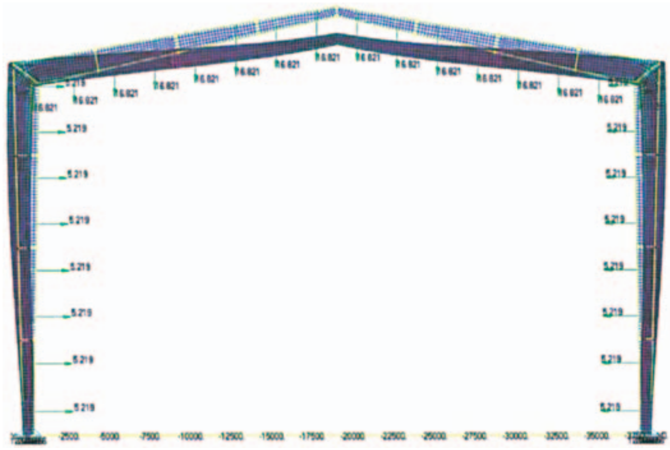

Fig. 7.

The FEM calculations allowed to determine the necessary cross section dimensions of the hall transverse frame beams. In the upper part of the hall, tee bars with 440 mm by 24 mm flanges and 24 mm thick, 660 mm to 1700 mm variable height webs. The frame dimensions are very big indeed.

The impact of dock hull deflections under the docked ship weight upon the roof carrying structure stresses was not analy-sed. The problem of separable connection of the hall skeleton with the dock upper deck must first be solved, in order to be able to move the hall segments along the dock and to fasten the hall to the dock deck. It may be presumed that the dock overall deflections of 100 mm may cause stresses of significant values in the frame horizontal and diagonal braces. The side wall upper part transverse displacements from the dock pontoon deflec-tions under the docked ship weight may also cause significant stresses in the hall skeleton transverse frames.

FINAL REMARKS AND CONCLUSIONS

The floating dock in question has significantly greater di-mensions than its classic version with a similar lifting capacity. The adequate strength of the roof hall structure subjected to the environmental loads from snow weight and wind pressure may be secured by structural elements of solid cross sections. The hall weight appears considerable – it makes 20% of the dock lifting capacity.

The dock pontoon stresses generated by the roof weight reach 25% of the admissible stresses. Heavy ship engine room in the stern part and rigid transverse bulkheads result in much differentiated keel block forces along the dock. The linear programming method allows to find an optimum ballast distribution in the dock tanks, such that the admissible keel block forces are not exceeded.

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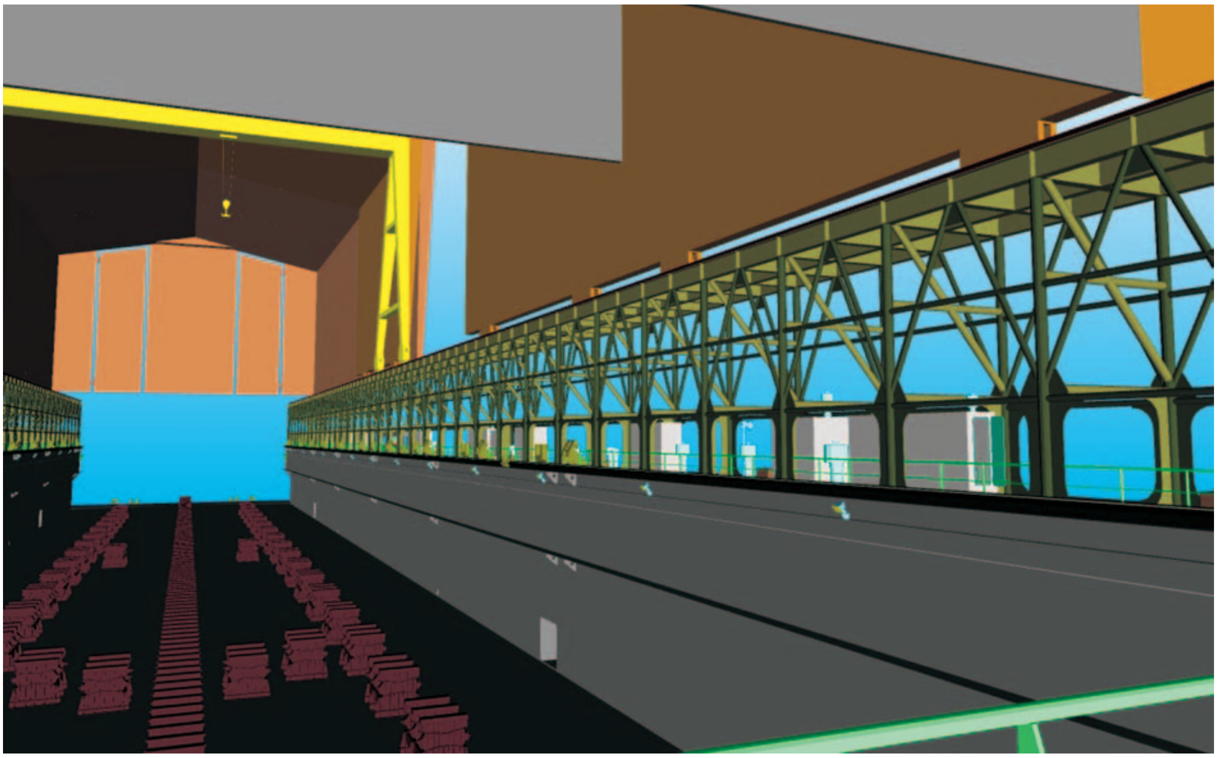

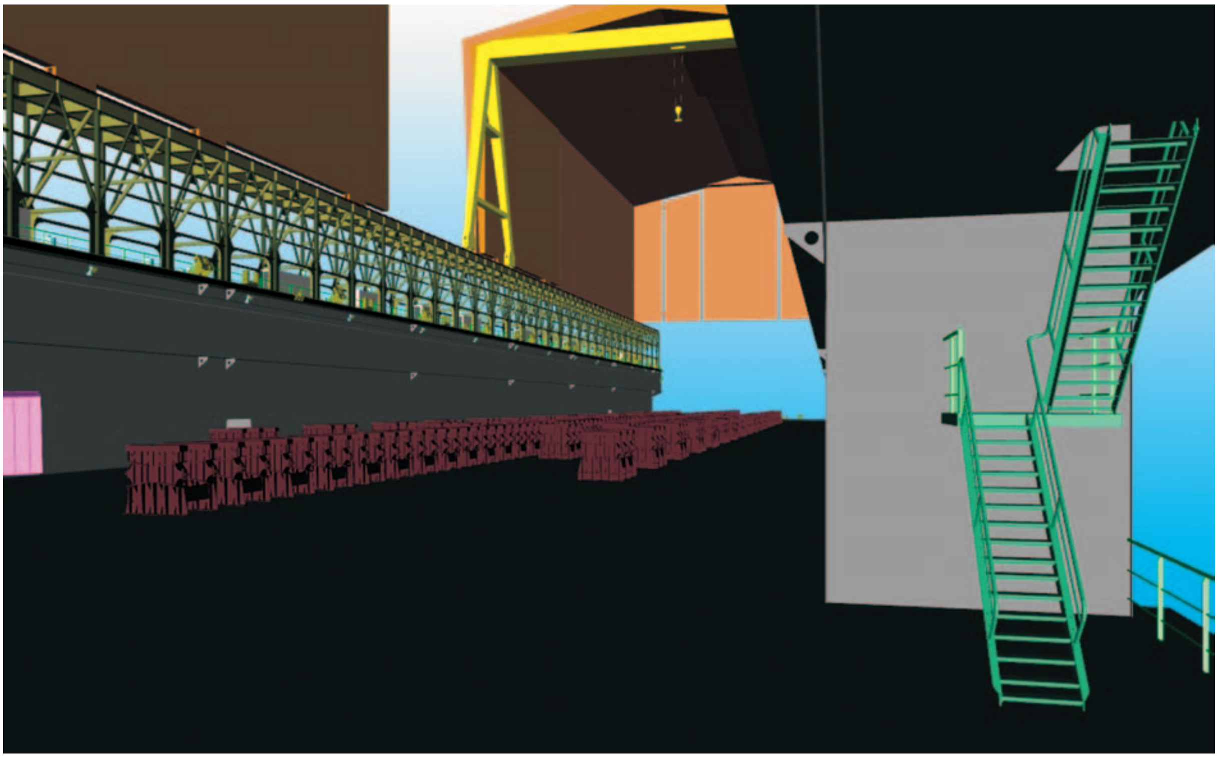

Development tendencies of the new generation classification rules for ecological floating docks in the PRS conceptions

Edmund Bastian, **Marian Bogdaniuk**, **Edward Szmit**
Polish Register of Shipping

ABSTRACT

This paper presents main differences between an ecological floating dock and classical one. The differences will find their appropriate representation in the Rules for the classification and construction of floating docks in the form of requirements to be fulfilled by the dock. They consist in fitting the ecological dock with systems for collecting the contaminations generated during ship repair work on the dock, storing them in tanks, as well as with tight closing the dock's working space by means of roofing.

Keywords : ecological floating dock, dock's hull structural strength, dock's roofing, pollution discharged from docks.

INTRODUCTION

The Polish Register of Shipping participated in a team of enterprises performing the EU EUREKA „Ecological dock" project. The aim of project was to design an environmentally friendly floating dock.

The PRS task was to develop up-to-date and environment protection-oriented rules for classification and construction of floating docks. Meeting the environment protection requirements will be marked by an additional symbol in the dock class notation.

At present there are no rules in the world including requirements of the environment protection against pollution from floating docks.

The ecological quality of a floating dock may be ensured by :

- ➲ Dock hull structure :
  - – dock structure integral tanks for collecting the ship repair waste liquids
  - – tight „closure" of the dock space for the repaired ships.
- ➲ Dock equipment and systems :
  - – collecting the ship repair solid waste.
- ➲ Dock power systems :
  - – additional installations for feeding the environment protection equipment.

The respective solutions are discussed in detail further in this paper.

Part I. Dock hull structure and strength

(Author : **Marian Bogdaniuk**, D.Sc.)

The ecological quality of a floating dock hull means the following differences in relation to the classic floating dock structure :

- ✷ dock structure integral tanks for collecting the ship repair waste liquids
- ✷ tight „closure" of the dock space for the repaired ships by the roof, side walls and front walls, in order to prevent air pollution in the dock vicinity from the repair technological processes (sandblasting, welding etc.).

The above mentioned problems have been taken into account in the Rules for the classification and construction of floating docks [2] developed by PRS.

THE FLOATING DOCK STRUCTURE

A typical floating dock structure is shown in Fig.1. The dock is closed by walls and roof, as it is required for ecological docks.

The necessity of separating the technological waste liquid tanks in the dock hull has little impact on the dock structure and its operational loads. The dock closure has a significant impact on the dock stability and the hull strength.

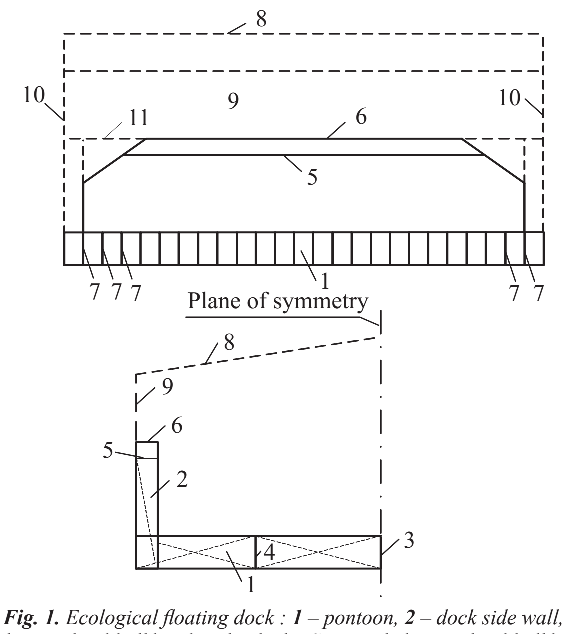

Fig. 1. *Ecological floating dock : **1** – pontoon, **2** – dock side wall, **3** – longitudinal bulkhead in the dock PS, **4** – side longitudinal bulkhead, **5** – safety deck, **6** – upper deck, **7** – transverse bulkheads, **8** – roof, **9** – side walls, **10** – front walls, **11** – running rails .*

The side walls and roof have relatively large windage area and therefore a negative impact on the dock stability. The need to fulfil the stability criteria given in the Rules [2] may cause a greater dock width in relation to a classic solution. Also greater displacement of the ecological dock will be required to achieve the design lifting capacity.

The walls and roof of the dock consist of several separate segments sliding along the dock on special rails. The weight of those segments positioned in the middle or at the ends of dock will have a significant influence on the bending moments in the dock hull transverse sections, induced in the general bending conditions.

The main dock structure elements are presented in Fig.1.

The longitudinal bulkhead in the dock PS is a boundary for the dock pontoon ballast tanks. It is also a strong structural element, directly taking the keel block reaction forces. The side longitudinal bulkheads subdivide the hull space into ballast tanks. They are adjusted to take the side bottom shoring reaction forces. Transverse bulkheads installed every 10 to 12 frame spaces transmit the docked ship weight loads to the dock side walls, which provide the dock general bending strength. The transverse buklheads subdivide the dock hull space into ballast tanks. Most often there are 6 rows of ballast tanks along the dock and 4 tanks across in a row (Fig.1).

Usually between the transverse bulkheads, in the structural frame stations, are the pontoon bottom and deck transverse stiffeners (below the safety deck). Those stiffeners are supported by the pontoon bottom and deck and the side wall tee-bar longitudinals. In the pontoon vertical connecting bars are usually inserted between the bottom and deck tee-bar longitudinals.

Side walls above safety deck and the upper deck are usually longitudinally stiffened, in order to secure an optimum dock adjustment for bending moment compensation in the general bending conditions.

THE DOCK HULL STRENGTH

The rules [1] and the ecological dock draft rules [2] contain traditional structural strength criteria on three levels :

- general strength
- transverse strength
- local strength.

The rules define the calculational loads, admissible structural stress values and the structural element stability criteria.

The dock pontoon structure load from the docked ship weight has a form of forces transmitted by keel blocks and the side bottom shoring. The load depends on many random character factors. The most important factors are the following :

- weight distribution (light ship, stores, ballast etc.) along the ship
- keel unintended non-rectilinearity.

Therefore, some conventional calculational loads are used corresponding to the maximum values of actual loads.

The general bending strength of the dock hull should be assured in two conventional cases of the ship weight load transmitted to the pontoon longitudinal bulkhead by keel blocks, as shown in Fig.2. Those loads determine the traditional dock minimum general strength standard.

In the case of an ecological dock, additionally the weight of walls and roof in their most unfavourable position with a given length of the segments as well as configuration and operation of the sliding system. In the variant „a" in Fig.2 it will be the middle position, in variant „b" the end of dock position. A simple beam calculation model is adopted.

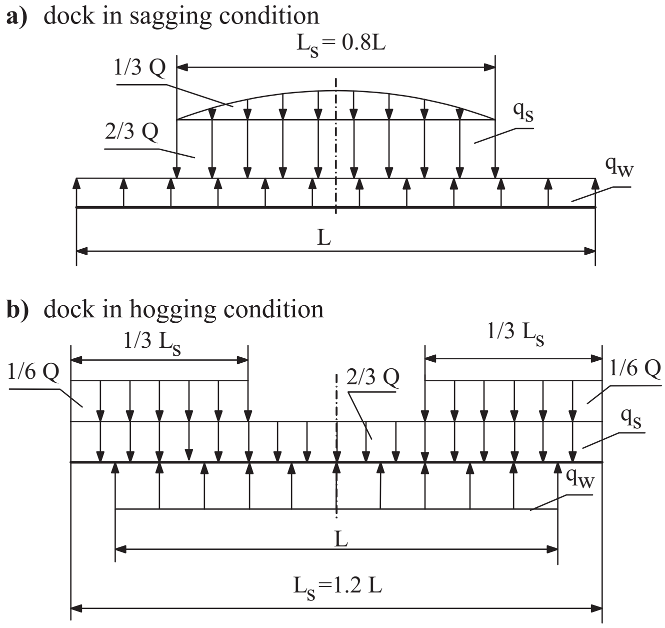

*Fig. 2. Dock general bending loads : **Q** – dock lifting capacity, **L** – dock length, q_s – load from ship weight, q_w – load from buoyancy force.*

In order to fulfil the Rules criteria [2] of the transverse strength, stresses in the dock transverse bulkheads must be calculated. A beam bulkhead model may be used. The beam cross section includes the bulkhead with flanges in the dock pontoon deck and bottom. Beam has pivot bearings at the ends (in the middle of the dock side wall width) and is loaded in the middle of its length (dock PS) with a concentrated force :

$$P = 1.5 \frac{Q}{L} d \tag{1}$$

where :

Q, L – see Fig.2

d – distance between bulkheads.

Additionally the beam is loaded with a continuous load from the buoyancy pressure and the pressure from ballast in the dock tanks.

The 1.5 multiplier in formula (1) allows to take approximate account of the earlier mentioned uncertainties of keel block reaction force values.

At the ends of the dock pontoon, the transverse bulkhead bending will be coupled with the longitudinal bulkhead bending. The reason is that the end keel block under the ship stern is usually at a distance of several to several dozen meters from the dock end. Verification of the dock pontoon structure strength in that area requires the use of FEM calculations.

The dock structure local strength criteria in the Rules [1] have a form typical of the floating structures. The bent plate model is used for the shell plate thickness determination and a single-span beam model for the stiffener required section modulus value determination.

The Rules [2] contain also requirements to be fulfilled to protect the dock against operational overload. A „load control device" is required for a dock. This is usually a dock deflection or hogging measurement instrument. Determination of an admissible value of that deflection or hogging protects the dock against general bending overload. Also required is a „dock operational instruction" document.

It contains admissible values of various dock load parameters (e.g. admissible pressure on the keel and bilge blocks, admissible difference of water level in adjacent dock tanks etc.) as well as an appropriate ship docking procedure.

DOCK ROOF

A feasible dock roof structure has a form of steel hall positioned on the dock upper deck and consisting of at least two slidable (along the dock) segments and opened (e.g. raised) front walls or elastic blinds.

The segments must be movable along the dock in order to allow access to ship by cranes or docking of ships with exceptionally high superstructures or specific upper deck installations. It will be a hall of very large dimensions (see Fig.1).

The hall carrying structure consists of several meters-spaced transverse frames joined together by diagonal braces. The frame elements may be fastened in the roof ridge by rigid or articulated joints. The hall carrying structure is covered with profile plate.

A serious technical problem is gas tightness between the segments or between segments and front walls (or blinds).

In Rules [2] it is assumed that a dock roof should meet the steel hall strength criteria in accordance with the civil engineering standards [3], [4], [5], [6].

The structure load is composed of the own weight, wind pressure or snow weight. In comparison with the land-based halls, additional internal force components may appear caused by the dock structure deflections. In accordance with the requirements [2], those additional forces should be added to the above mentioned load components and the structural safety evaluation criteria should be used as for a land-based structure.

Part II. Dock equipment and systems

(Author : **Edmund Bastian**, M.Sc.)

The classification society rules for docks most often include only the ballasting system requirements whereas requirements for other equipment and systems are taken, as appropriate, from the rules for classification and construction of seagoing ships.

The PRS dock rules will contain the present requirements and additionally requirements on the environment protection against pollution from the ship repair work in a floating dock.

In view of the progressing natural environment degradation, its protection against pollution becomes a more and more important problem, both for individual countries and for the world as a whole. The marine community has long been aware of the problem, hence many existing environment protection legal acts. Therefore, requirements of the natural environment protection against pollution from bilge waters, sanitary sewage and rubbish need not be widely discussed in this paper. Besides, in the Polish yards using floating docks the mentioned pollution problems are being satisfactorily solved.

A still unsolved problem is pollution generated in the ship repair process. For instance, in the area administetred by the Maritime Office in Gdynia the Order No. 6 of Director of the Maritime Office in Gdynia is in force, which in § 5 clause 1 item 10 requires that a dock should meet requirements of the water protection against various contaminants produced during the ship repair in dock. The order does not indicate how this requirement could be fulfilled and does not give any admissible pollution limits.

The problems of marine environment protection against the ship repair in dock-generated pollution are dealt with in the currently being developed PRS Rules for classification and construction of floating docks [2].

POLLUTION SOURCES IN A DOCK

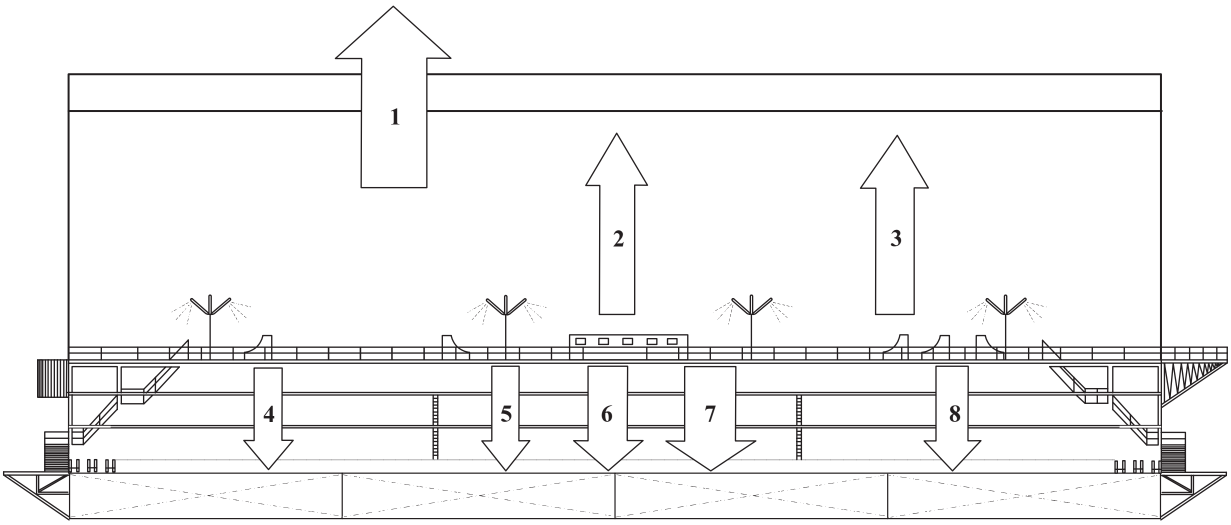

Fig. 3. 1*. Exhaust gases : electric generating sets, boilers, incinerators,* ***2****. Ship hull painting,* ***3****. Ship hull cleaning,* ***4****. Ship hull painting,* ***5****. Ship hull cleaning,* ***6****. Sewage from dock's living accommodations,* ***7****. Sewage from dock's living accommodations and machinery compartments,* ***8****. Oil spills on the pontoon deck .*

In the Rules [2] the pollution sources are subdivided in the following way :

1. contaminations from the dock machinery operation
2. sanitary sewage from the dock crew accommodations (if any) and the repaired ship crew living compartments
3. rubbish produced in the dock
4. contaminations from the ship repair process.

Ad 1. The contaminations are :

a) oiled bilge water from the dock machinery compartments
   The dock should be equipped with :
   – permanent or temporary retention tanks of a sufficient capacity to collect all the oiled water
   – oiled bilge water disposal installation in order to empty the tanks into the shipyard waste water receiving system
b) oil residues (sludge) - remnants of the oil centrifugal separation process, oil leaks, drains of settled oil, dewatering of oil tanks and also all kinds of used oil. Procedure as in a)
c) nitric oxides (NO_x) emitted from the dock combustion engines. The combustion engines should meet the requirements of Appendix VI to the MARPOL 73/78 Convention, rule 13
d) sulphur oxides (SO_x)
   Fuel used on the dock should meet the requirements of Appendix VI to the MARPOL 73/78 Convention, rule 14
e) contaminations generated by the dock incineration processes. The dock incineration processes should meet the requirements of Appendix VI to the MARPOL 73/78 Convention, rule 16.

Ad 2. Sanitary sewage should be collected in the dock permanent or temporary retention tanks of a sufficient capacity to collect all sewage. Besides, the dock should have a disposal installation in order to empty the tanks to the shipyard waste water receiving system.

Ad 3. Rubbish from the dock crew accommodations and machinery compartments should be collected and kept in metal containers until it is delivered to the shipyard receiving system. The rubbish disposal procedure should meet the requirements of the MARPOL 73/78 Convention, Appendix V.

Ad 4. The most serious environment protection problem are contaminations from the ship repair process. The contaminations may be generated by the following work :

- ship hull cleaning
- ship hull painting
- shaftline repairs
- bilge tank repairs
- fuel tank and lubricating oil tank repairs.

Ship hull cleaning and painting

It is recommended to close tightly the dock repaired ship space by means of roof, side and front walls (the dock space closure – see the **Dock hull structure and strength** chapter), also an efficient ventilation with appropriate filters should be installed as the most effective protection against volatile pollutants from cleaning or painting of the ship hull.

Also portable roof structures may be used for shielding only the currently cleaned or painted ship sections. This solution also requires the use of efficient ventilation with appropriate filters.

The following waste material is produced during the ship hull cleaning process :

- ✶ preliminary cleaning waste – removing the hull fouling and paint remnants with hydraulic monitor; it is recommended to collect the waste from the dock or the repaired ship deck and to put it into properly marked tight containers and then deliver it to the shipyard waste store
- ✶ the shotblasting process waste; it is also recommended to collect the waste from the dock or the repaired ship deck and to put it into properly marked tight containers and then to deliver it to the shipyard waste store for utilization and recycling.

The ship repair process-produced contaminated waste accumulates on the repaired ship decks and on the dock pontoon deck. The dock pontoon deck should be adequately framed in order to prevent pollution of the shipyard basin waters. Before submerging the dock, the pontoon deck must be thoroughly cleaned. Liquid contaminants may be removed through piping and wells installed under the pontoon deck. Solid waste may be removed by means of special vacuum cleaners, suction devices or manually from some ship areas.

Shaftline repair

Special attention should be paid during the shaftline repair to a possibility of pollution by leaking lubricating oil. The lubricating oil leaks should be gathered in properly marked tight containers. Oil spills on the pontoon deck must be absolutely avoided. If an oil spill happens then the oil must be thoroughly cleaned from deck before the dock is submerged. Containers should be delivered to the shipyard waste receiving system.

Repairs of bilge water tanks, fuel tanks and lubricating oil tanks

Before starting the bilge water tank repairs, the tanks must be checked for possible bilge water residues. Any remaining bilge waters must be delivered to the shipyard waste receiving system. Discharging bilge waters to the shipyard basin is strictly prohibited.

A similar procedure should be followed with the repairs of fuel tanks and lubricating oil tanks.

CONCLUSIONS

- ❍ The PRS Rules [2] contain the requirements, in the above described scope, for environment protection against the ship repair pollution.
- ❍ However, the following question arises: are the domestic, European or world repair yards, using floating docks, (or will they be) interested in investing large sums in the natural environment protection systems when there are no legal regulations to enforce such behaviour.
- ❍ Every action should be taken to improve the natural environment protection. Appreciating the importance of the matter, PRS has developed the corresponding Rules [2].

Part III. The power generation, remote control, automation and monitoring systems

(Author : **Edward Szmit**, Eng.)

The ecological floating dock electrical installations, apart from the power generation system, are not much different from the installations of any other large floating unit. So, the classification society electrical installation requirements contained in the *Rules for Classification and Construction of Floating Docks* should be similar to those contained in the *Rules for Classification and Construction of Seagoing Ships* or in rules or codes for the offshore units. The principles are similar, details may be different.

THE FLOATING DOCK POWER GENERATING SYSTEM

As it was mentioned, the floating dock power generating system differs considerably from a ship power installation. Moored all the time at a shipyard quay, floating dock for its normal operation needs large amounts of electric energy, most often delivered from the shore power network. The floating dock power system should be fed by at least two circuits - main and reserve circuit, in order that the dock energy receivers can operate reliably, in particular the mechanisms and equipment connected with safety of people and the unit as well as with the clean environment inside and outside the dock. The new edition of Rules reads: **The main circuit should be designed for the full electric energy demand. The reserve circuit for emergency feeding of the power network should be designed to feed at least 33% of the total number of ballast (water extraction) pumps, gate valve mechanisms, lighting and the necessary auxiliary equipment and also at least one fire pump**.

Another rule requirement allows feeding from the shore power network by one circuit, on the condition that an own generating set is installed in the dock, capable of ensuring normal operation of one ballast (water extraction) pump, gate valve mechanisms, lighting and the necessary auxiliary equipment and one fire pump.

Other requirements contained in the *Dock feeding* chapter determine the dock power system organization, e.g. the necessity of installing reserve feeder cables, laid between the dock side wall main switchboards and ensuring 100% power circuit reserve and 20% control cable reserve. Besides, the chapter contains also requirements of the shore feeding terminal and the admissible short-circuit power level.

THE CONTROL, AUTOMATION AND SIGNALLING AND MONITORING SYSTEMS

Another very important requirement of the ecological floating dock submerging and lifting mechanism and the tank filling level measurement control and signalling systems is compliance with the PRS Publication No. 9/P – *Requirements of the computer systems*. The aim is to ensure reliability of operation of the dock safety and environment protection equipment.

THE ELECTRIC ENERGY EMERGENCY SOURCE

As in every other floating unit, the emergency source of electric energy is designed to provide, for 2 hours i.e. until an external rescue action is undertaken, emergency lighting of the escape routes, steering stations and fire equipment locations as well as operation of the warning lights, internal communication means, general alarm and fire detection systems as well as the ballast tank water level measurement system.

Generally speaking, the emergency source is provided in order to ensure safety of the floating dock, the docked ship and people on the dock in the case of main feeding system failure.

ADDITIONAL CONDITIONS AND CONCLUSION

- Other requirements connected with the dock safety and environment protection include installation of an internal communication, general alarm and fire detection systems as well as a link with the shipyard or public telephone exchange.
- Question may arise: why a stationary telephone, when almost everybody have a mobile phone? Because stationary telephone is always in the same place which everyone knows.
- In conclusion one may say that the electrical installations have no specific ecological functions, but they feed and support the environment protection installations.

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Preliminary analysis of proposed ship docking systems for a designed floating dock

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ABSTRACT

In this paper are presented alternative design concepts and their comparative analysis of ship docking systems for a floating dock. The floating dock was designed by a team of Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology, within the frame of the ECOLOGICAL DOCK E!2968 project. The presented design solutions differ to each other mainly by the kinds of applied devices: in the first case these are mooring winches and docking cars, whereas in the other – rope warping winches. For both the specified systems a comparative analysis was carried out in which their features, complexity of construction and associated costs were among other accounted for. In the opinion of the authors the presented analysis may help the principal designer of the dock in making choice of a more suitable system.

Keywords : floating dock, shipboard equipment, mooring devices

INTRODUCTION

The basic mooring system of floating dock consists of the following elements :

- ✶ mooring winches or docking cars driven by warping winches
- ✶ warping capstans
- ✶ mooring bollards
- ✶ mooring fairleads.

The mooring winches are located at the upper deck ends of both side walls of floating dock. They make it possible to bring a ship in and out the dock. The warping capstans serve for positioning the ship inside the dock. Their number and pulling power depend on size of ships to be docked. For instance in the Gdańsk Shiprepair Yard two floating docks each of 10 000 t carrying capacity (total mass of a docked ship) are in service, on whose each side wall are located, in the case of the first dock, 2 mooring winches and 3 capstans of 60 kN pulling power, and in the second case, 2 mooring winches and 2 capstans of 80 kN pulling power. On the upper deck of both side walls are also located bollards and fairleads which make it possible to handle the mooring ropes. Near the capstans single roller fairleads are installed.

PROPOSED SYSTEMS

I. Design solution based on docking cars

The solution which has been proposed by *Sinus* Co., is shown in Fig.1. The system is composed of such docking devices as :

- ✦ warping winches of guiding ropes (Fig.3)
- ✦ docking cars (Fig.2)
- ✦ warping capstans (Fig.5)
- ✦ roller fairleads (Fig.4)
- ✦ mooring bollards.

For ship docking operation have been used the docking cars (see item 2 in Fig.1), driven by means of the warping winches (item 3) placed on the safety deck.

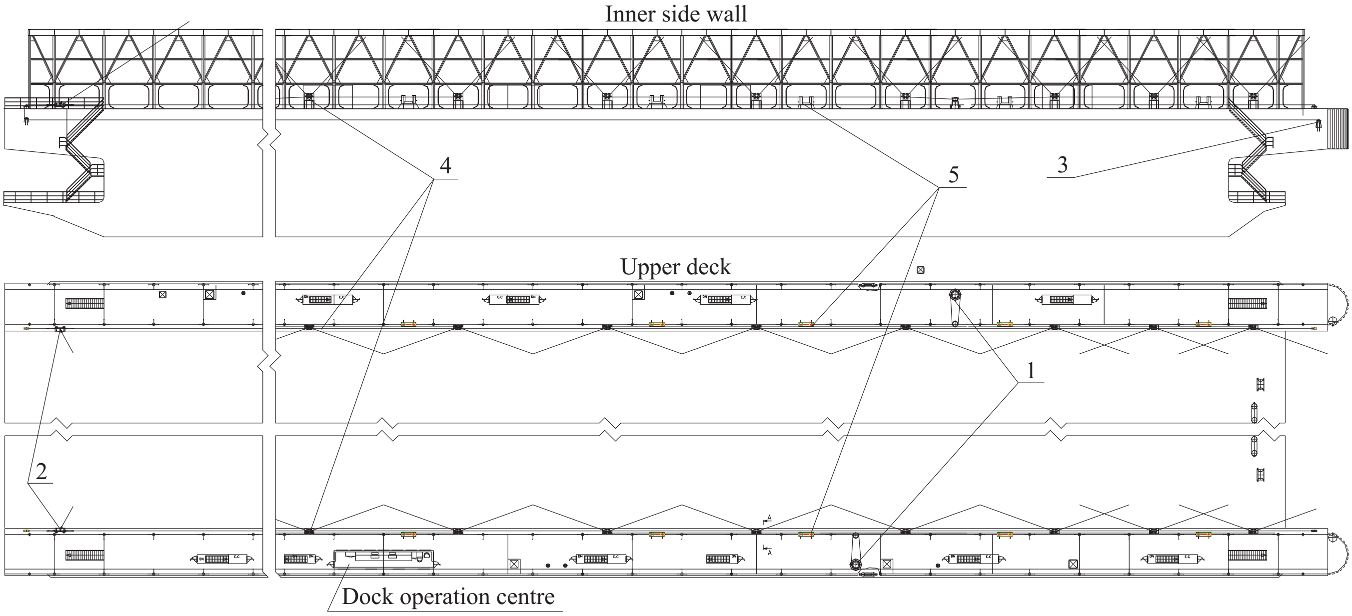

Fig. 1. *Variant I.* ***Notation*** *:* ***1*** *– capstan,* ***2*** *– docking car,* ***3*** *– warping winch,* ***4*** *– fairlead,* ***5*** *– bollard .*

Docking the ship is realized with the use of two cars shown in Fig.2 in the position beginning the entire operation. To the cars mooring ropes of the docked ship are fixed. The cars are placed on the leaders attached to both side walls. Driving the cars in question is executed by means of the rope-pulley system and warping winches, shown in detail in Fig.3. The winches of 100 kN pulling power each are located on the safety deck placed beneath the upper deck.

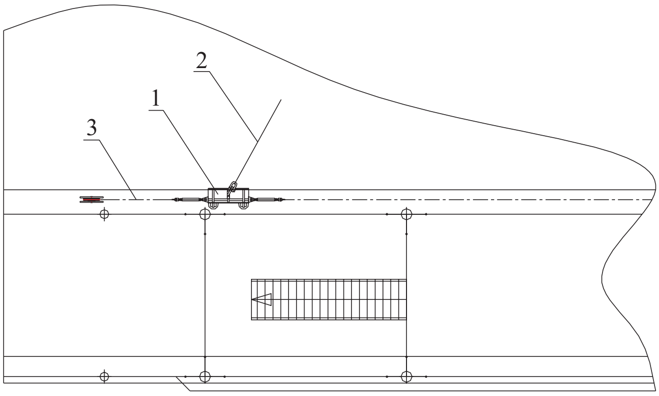

Fig. 2. *Initial position of the car on the side wall .*
Notation *: **1** – docking car, **2** – rope gone out the ship, **3** – guiding rope .*

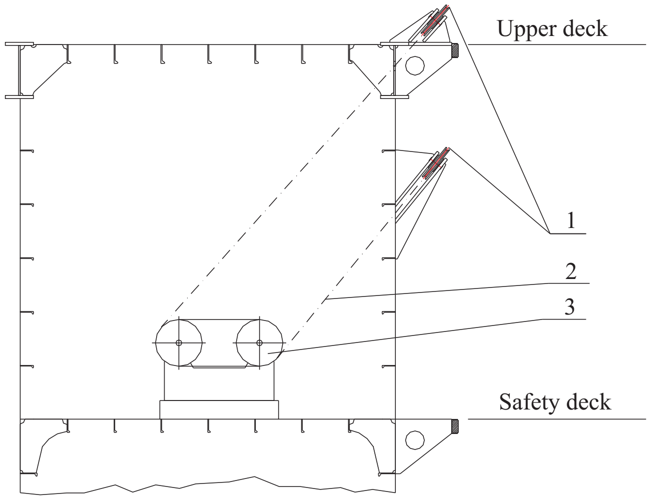

Fig. 3. *Location of the warping winch of docking car .*
Notation *: **1** – guiding rollers, **2** – car guiding rope (shifting the car along the side wall), **3** – warping winch .*

A ship to be docked is positioned in the dock's plane of symmetry by using ropes, capstans, special roller fairleads and bollards.

To both sides of docking cars the ends of the guiding ropes are attached by means of Roman bolts. Application of such bolts makes straining the ropes easier. In the considered solution to use the system in question for moving the dock's roof segments is also possible. For such operation the guiding rope is released from the car and then fixed to a special catch pawl of the movable roof segment.

Two capstans are installed on each of the upper decks of both side walls of the dock. The capstans (item 1, Fig.1) are placed near the dock's ends. Their rated pulling power amounts to 80 kN. They are auxiliary devices used for positioning the docked ship (i.e. guiding the ship onto the keel blocks).

The roller fairlead (4) makes it possible to appropriately guide the rope from the capstan either onto the deck of docked ship or the bollards (5) and chocks, and next from them onto the ship.

The applied roller fairleads make it possible to guide the rope in various directions. In Fig.4 an example of guiding the rope is shown. Application of the dismountable upper rollers makes it possible to easily translate the rope to other roller fairleads during mooring the docked ship or moving the dock's roof segments.

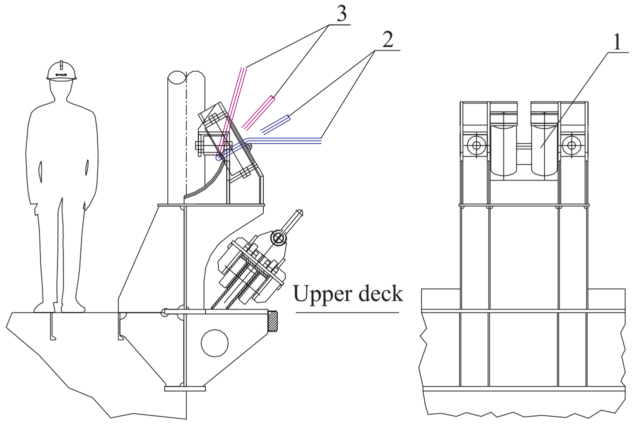

Fig. 4. *Roller fairlead which makes it possible to dock the ship as well as to move the dock's roof segments.* ***Notation*** *: **1** – dismountable roller, **2** – direction of running the ship docking ropes, **3** – direction of running the roof moving ropes .*

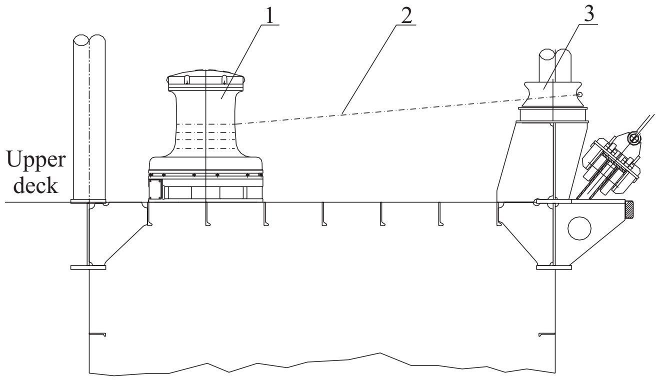

Fig. 5. *Auxiliary devices for docking the ship and moving the dock's roof elements.* ***Notation*** *: **1** – capstan, **2** – rope to moor the dock or to move its roof elements, **3** – directing roller .*

It can be observed that the solution in question may fulfill two important function : the docking of the ships and the moving of the dock's roof segments. The operations require to synchronize work of warping winches and appropriate straining the rope. One can consider if to strain the rope by means of the Roman bolts is sufficient. Such function can be better realized by hydraulic stretchers or spring elements.

The described solution is relatively simple and inexpensive. However it requires two cars and two mutually synchronized warping winches to be installed on each of the dock side walls. In the opinion of the authors a weakness of the solution is that in the case of non-uniform strain of the rope by both warping winches some rope slip can occur which may lead to the lack of control over the length of working string. It is associated with the danger of non-uniform distribution of loads in both ropes and – in consequence – skewing the roof segment during its motion.

II. Design solution based on docking winches and four capstans

The solution proposed by the team of Gdańsk University of Technology, is composed of the following docking devices (Fig. 6):

- 4 ship docking winches
- 4 capstans
- roller fairleads (Fig.4)
- bollards.

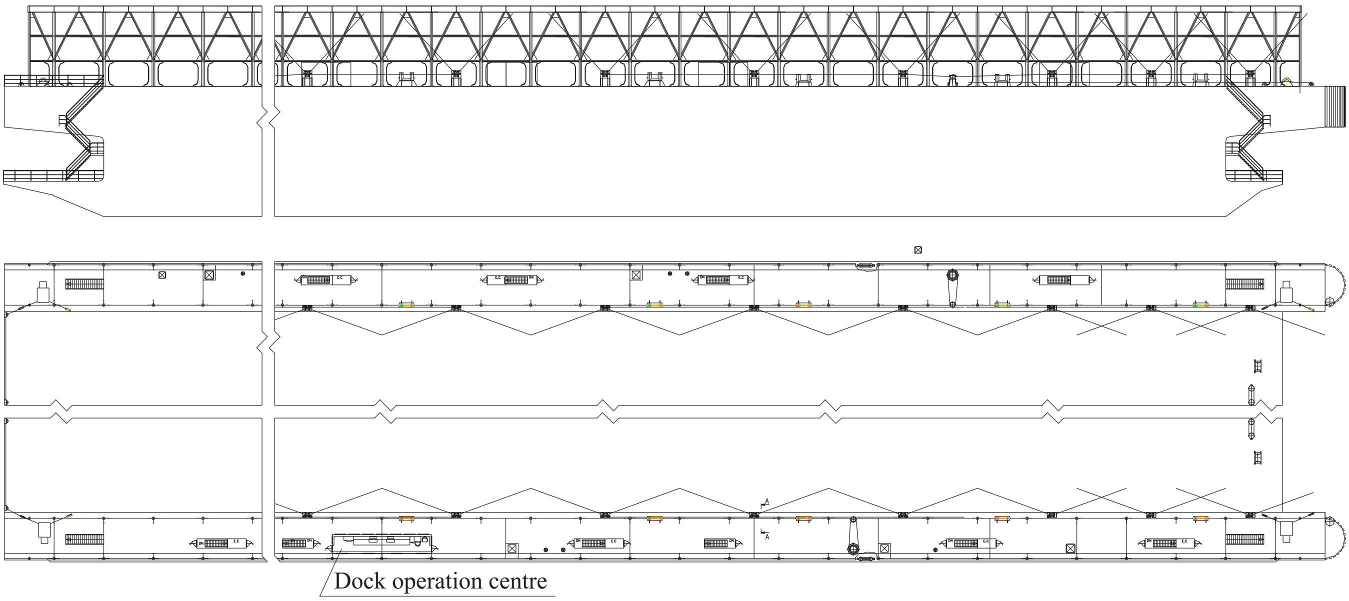

Fig. 6. *Variant II*

Docking the ship is realized by using two main winches installed in the front part of the dock, namely one on each side wall, and two auxiliary winches located in the rear part of the dock. From the main winches ropes are passed to the ship bow where they are fixed to towing bollards. During 1st docking phase only the main winches are used, and a tug operating behind or alongside the ship secures the operation. 2nd docking phase begins when about 1/3 part of the ship is already towed into the dock. In this phase take part the capstans placed near the dock's end, which help positioning the ship in the dock's plane of symmetry. In the successive phase, ropes are passed from the ship's stern to the auxiliary winches, and the ropes from the capstans situated at the dock's end are transferred to the capstans situated nearer the main winches. Next, the whole ship is towed into the dock.

The solution, like the preceding one, makes it possible to use it also for shifting the roof segments. All four winches installed on the dock must then operate. On each of the side walls two winches are installed, one in the front part, and the other in the rear part. Ropes from the both winches are fixed to the catch point of the roof segment, placed in the mid-length of the segment (see Fig.7). The winch hauling away the rope is set up to work at higher values of parameters, and the winch laying out the rope – to work at lower values of pulling power, so as the difference of the pulling powers were sufficient to overcome resistance to motion of the displaced object. In such case there is a danger of uneven winding the ropes onto the drums of the winches located at both side walls of the dock. For this reason the motion of the displaced object should be continuously controlled.

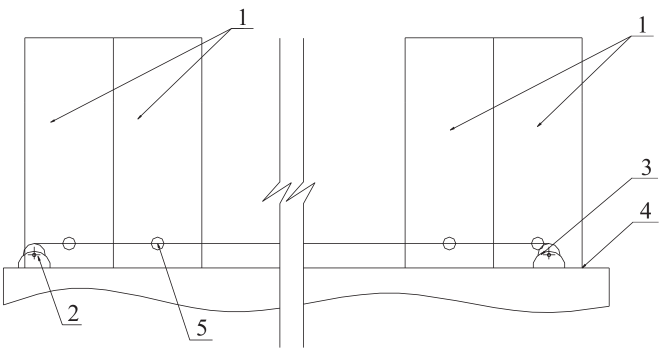

Fig.7. *Operation of the winches in the case of moving the dock's roof segments.*
Notation *: **1** – roof segment, **2** – the winch hauling away the rope, **3** – the winch laying out the rope, **4** – main deck, **5** – rope fixing element .*

ASSESSMENT OF WARPING WINCH PARAMETERS

In the *Rules for the classification and construction of floating docks*, Part IV, p. 1.1. [4] concerning general regulations a reference to the *Rules for the classification and construction of sea-going ships* [3] is given, therefore the pulling power of dock mooring winches was estimated by applying the Equipment Number for the largest ship which can be placed in the dock in question.

Table. *Main particulars of the largest ship to be docked*

Maximum overall length	~170 m
Maximum supported length	156.00 m
Maximum breadth	34 m
Maximum draught	5.8 m
Maximum mass	10 000 t

To estimate the Equipment Number for the largest ship to be docked is possible on the basis of the above given data (according to *Sinus* Co.), hence the breaking strength of towing rope can be determined from the relevant PRS rules (Part III „Hull Equipment", Tab. 4.1.2) and in consequence to estimate the pulling power of the warping winch intended for docking operations.

The so estimated Equipment Number amounts to 878 [-]. The breaking strength of the towing rope amounting to 518 kN was determined from the above mentioned Tab. 4.1.2.

By making use of the formula for the pulling power of the winch :

$$U = \frac{P_{zr}}{x}$$

where :

U – winch pulling power [kN]
P_{zr} – rope breaking strength [kN]
x – safety factor [-] ,

the following is achieved :

$$U = \frac{518}{3} = 172.67 \text{ [kN]}$$

Therefore the pulling power of the winch should be equal to 173 kN.

CONCLUSIONS

- **Variant I** is relatively inexpensive because of the number and kind of the devices applied to ship docking : these are 4 capstans, 2 warping winches and 2 cars. In the design solution in question a problem associated with ensuring a correct run of winded rope appears, especially if its length of 375 m is taken into account. An advantage of the system is the possibility of ensuring relatively constant speed of rope winding due to constant diameter of winch drum. In the applied drums circumferential grooves are made to improve conditions for frictional coupling of the grooves and rope. However it should be stressed that as a result of the application of the grooves accuracy of keeping constant speed is somewhat decreased as the effective diameter of the rope winding in the drum's groove, decreases along with increasing the load.
- **Variant II** is even simpler and less expensive design solution than the preceding one. However it has a fundamental drawback, namely the necessity of winding the rope around the drum in two layers at least. This results from limited gabarites of the winch. As a result, to ensure uniform guiding the ship into the dock or shifting the dock's roof segment, the control over motion of a displaced object must be made stronger. To ensure relatively uniform conditions for winding the rope on both winches they should be fitted with a rope layer. Possible differences of instantaneous length of ropes on both winches must be currently corrected by manual control of each of the winches.
- The application of the roller fairleads to both the presented variants makes it possible to lead the rope in various directions : towards the docked ship or dock's roof segment (Fig.4), and the application of the easily dismountable upper rollers greatly facilitates necessary transferring the rope from one fairlead to another.
- In the above presented design solutions the capstans fulfill an auxiliary role – they help maintaining rectilinearity of guiding the ship during docking operation.
- Both the discussed variants do not guarantee maintaining the same speed of hauling away or winding the ropes on both dock's side walls, therefore appropriate measuring instruments for controlling motions of a displaced object should be provided to ensure correct execution of the operations in question.

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Photo : Cezary Spigarski

A design proposal of driving system for roof segments and gantry crane of ecological floating dock

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ABSTRACT

In the conceptual design of an ecological floating dock, has been assumed to be applied a roof system consisted of six movable segments whose aim is to shelter dock's working space from environmental influence. The dock has to be also equipped with a gantry crane. Each of the devices is fitted with a traction system whose drive is the subject of this paper. The driving system consisted of synchronous electric motors with external frequency control of their rotational speed, is proposed. Such system may ensure the same rotational speed at both supports, unambiguously determined by voltage frequency and independent of load. The solution could make it possible to avoid dangerous skewing displacements of the structures on rail tracks during service. Additionally, a simplified procedure of determining the main loads necessary for calculation and selection of the devices and traction systems is also presented.

Keywords : floating dock, shipboard equipment, gantry crane driving mechanisms, systems of movable roof segments

INTRODUCTION

The traction system provided for the roof segments and gantry crane of the floating dock has to displace them almost horizontally by driving a number of rail wheels. If the moving route is horizontal frictional tractive adhesion of the wheels is sufficient to initiate their moving.

An important problem which may occur in operation of the dock's roof and gantry crane is their skewing on the railway, that, in consequence, produces additional resistance against motion or also inadmissible deformation of structures.

The phenomenon can occur due to non-uniform driving the traction wheels on both rails (small differences of mechanical characteristics of driving motors can lead to different lengths of way done by the wheels), wear of the wheels, non-parallel position of rails making wheel flanges to act, as well as a non-uniform wind pressure distribution. It is hence necessary to apply devices protecting against excessive skewing. The permissible value of skewing depends on design arrangement of mounting the roof structure onto traction wheel units, as well as roof's rigidity (in the case of gantry cranes the estimated permissible advance of one support by the other amounts to about 4 % of span of the crane bridge [1]).

As the dock's roof elements and gantry crane are similar to each other regarding their construction it is reasonable to propose the same design solution for their driving systems, which will lead to a decrease of unit cost because of application of a greater number of the same units. The dock's roof as well as the gantry crane is of a large span therefore it requires providing for separate traction drives on both side. Such drive should be so designed as to ensure synchronous run or also to control and eliminate possible skewings (i.e. keeping them within permissible limits). Moreover both the roof segment and crane should have an additional protection against strong wind effects, e.g. devices for jamming their structure onto traction rails.

One of the considered design proposals of the traction mechanism's driving system for the roof segments and gantry crane of the ecological floating dock in question is presented below.

TRACTION MECHANISM'S DRIVING SYSTEM FOR ROOF AND CRANE, FITTED WITH SYNCHRONOUS MOTORS AND FREQUENCY CONTROL OF THEIR ROTATIONAL SPEED

Electrical drive is assumed to be applied for the traction systems of roof elements and gantry crane. This solution is dominating in applications of the kind and its common use results from the following merits :

- easiness of energy supply
- large starting and braking moments
- easiness of remote control
- easiness of reversing and possible speed control
- lack of energy consumption during breaks in operation
- easiness of maintenance, replacement of parts, and service
- great flexibility of permissible load-carrying ability.

The proposed traction mechanism's driving system is of individual type because of a large span of roof segments and crane, it means that separate driving units are provided for both supports. In comparison with common driving systems an important advantage of the individual one is the lack of any long transmission shaft.

Load equalizers should be applied in order to obtain uniform distribution of pressure loads on traction wheels, and only a half of number of traction wheels would be driven.

The driving system's operation could be based on application of an electric asynchronous motor. In this case classical solutions aimed at synchronization of running the traction mechanisms of both supports could be :

- electric shaft (simplified one or fitted with auxiliary motors)
- measuring synchro-tie.

However it should be stressed that a modern solution which makes it possible to precisely control advance speed of both supports, is the driving system fitted with synchronous motors and frequency control of their rotational speed.

Synchronous motor

Synchronous motors are first of all applied to machines requiring a constant rotational speed. They are alternating current (AC) motors in which the following relationship occurs between the current frequency *f* in their armature and the rotational speed *n* of their rotors :

$$f = p \cdot n \quad [Hz]$$

where :

f – current frequency [Hz]
n – rotational speed [rps]
p – number of pole pairs of motor,

hence, respectively :

$$n = \frac{f}{p} \quad [rps]$$

$$\omega = 2 \cdot \pi \cdot n \quad [rad/s]$$

The motor's torque is :

$$M_s = \frac{P}{\omega} = \frac{P}{2 \cdot \pi \cdot n} \quad [Nm]$$

where :

M_s – shaft driving moment [Nm]
P – power output [W]
ω – angular speed [rad/s]
n – rotational speed [rps].

The property of concurrence of rotational speeds of motor shaft and magnetic field determines synchronous character of operation of the motor, which it should be brought in. Due to a large inertia moment of the motor's rotor its start-up appears difficult, that makes application of special starting methods necessary. The used solutions are as follows :

- asynchronous start-up
- start-up by using an auxiliary motor
- frequency-controlled start-up.

By applying the frequency control the problem of starting is solved in a natural way by gradual increasing supply current frequency and simultaneous maintaining synchronism of shaft rotation. For the frequency-controlled start-up a synchronous starting generator of the controlled voltage U and frequency *f*, or a controllable frequency converter is necessary. In the case of starting by means of the generator the motor's armature is connected with the starting generator, and exciter's winding with a constant voltage source. By increasing the generator's frequency from zero to its rated value the motor is driven into a synchronous speed. Next, the motor is synchronized with the electric supply network and after that it is switched off the starting generator and switched in the electric supply network.

Driving system based on synchronous motor with cycloconverter control (external control)

The cycloconverter-based systems are the systems used for speed control of synchronous motors (also asynchronous cage motors) by changing supply voltage frequency. This is the system in which rotational speed of synchronous motor is controlled externally. Such control is realized when the speed of rotating field, forced by the inverter, does not depend on a motor state but it is forced by an external control system. The so controlled motors maintain their initial features , i.e. the synchronous ones fall out of step under overload (but induction ones have a distinct point of falling out of step). A wide range of rotational speed control is available and reversible operation is possible both for motors and generators. Therefore it is possible to form mechanical characteristics of the drives in all four quadrants of the speed-moment reference system.

The cycloconverter is a direct frequency converter, being a set of thyristor rectifiers in which ignition angles vary in function of time with the period corresponding to a required initial frequency. Such operation is based on modulation of the voltage wave of 50 Hz by means of a control signal of a controllable frequency. The rotational speed control by changing supply voltage frequency is the most effective way to control AC motors.

The cycloconverter driving system based on a synchronous motor has very important merits in comparison with the systems based on direct current (DC) motors or asynchronous ones, namely :

- ❋ maintaining rotational speed constant and precise representing rotational speed by keeping it proportional to frequency of motor's supply voltage (setting-up the cycloconverter output frequency simultaneously means direct setting-up the rotational speed, that results from the synchronism principle: n = f/p). The advantage is especially valuable for the multi-motor driving system of traction mechanism for the roof segments and gantry crane in question, which has to satisfy the condition of equal running
- ❋ possible operation in both rotation directions
- ❋ a wide range of possible monitoring and control of important operational parameters of the drive
- ❋ large overload capacity
- ❋ high value of efficiency coefficient
- ❋ unlimited driving power
- ❋ low requirements for maintenance, hence a greater serviceability
- ❋ rotational speed not restricted by motor's design, on the contrary to the case of DC motors
- ❋ compliance with the redundancy principle by applying divided winding to the synchronous motor
- ❋ lower consumption of passive power (or even zero consumption of passive power).

The following features may be taken as disadvantages :

- ☆ high initial cost, (however in service, cycloconverters give measurable profits in comparison with the drives of other kinds in which static converters are applied)
- ☆ starting-up difficulties
- ☆ work at a lower electric supply frequency.

Work of such electric motors at a lower electric supply frequency is their basic design problem. Both synchronous and induction motors are designed for 50 Hz frequency, but 15 Hz frequency at the most is used for cycloconverter - based drives. So significantly lowered frequency means that simultaneously significant lowering the power output of the motor must happen due to the supply voltage dropping approximately proportional to the change of frequency. Hence a motor designed to develop a given power is capable of developing only 1/3 of its rated output when operating in conditions of cycloconverter-based driving system. It leads to greatly over-dimensioned gabarites of the motor.

Driving system based on synchronous motor with internal control

Another solution of synchronous motor control is internal control system. The synchronous motor supplied from the inverter tripped in function of rotor's position is called *the con-*

verter motor. The internal frequency control of rotational speed is characterized by that the rotating field velocity ω_S depends on motor's state e.g. its mechanical speed Ω, or on mutual position of resultants of the vectors Ψ_S and u_S. The internal control system makes unlocking a successive inverter's valve dependent on rotor's position. As a result, under greater loads the slowed--down rotor needs more time to cover the rotation angle within which the position indicator is able to send an impulse to initiate commutation. Therefore the period of alternating current delivered to stator's winding also increases which is equivalent to lowering the rotational speed. The converter motor cannot operate at extremely small speeds as then the induced rotation voltage is not sufficient to commutate inverter's valves.

Process of making the rotor rotating with 10% of the rated speed at which a sufficiently large rotation voltage is induced, is realized by breaking the current in the intermediate circuit. The current is then directed to the successive pair of inverter's valves, which connects the stator's winding strips whose resultant area in the gap moves by 60% towards the motor revolution direction. The internal control system is favourable when applied to a single synchronous motor, as it ensures its stable operation and eliminates the danger of falling-out of step because the motor's voltage frequency adjusts itself to the applied load.

DETERMINATION OF MAIN LOADS

The simplified scheme of determination of the main loads necessary to calculate and select devices and traction mechanisms of a roof segment are presented below. A similar scheme may be used to determine main loads applied to the gantry crane.

Calculation of pressure loads on traction wheels

The pressure loads on traction wheels are calculated by taking into account distribution of deadweight of the structure, mechanisms, equipment and snow. Lateral wind pressure forces may also appear out of the plane of axes of the traction wheels, hence some changes of the pressure loads on traction wheels in function of changes of sense of the loads may occur. Since head shields are assumed to be applied on the dock's heads the wind pressure forces acting both on the lateral area of the roof and its front areas should be accounted for.

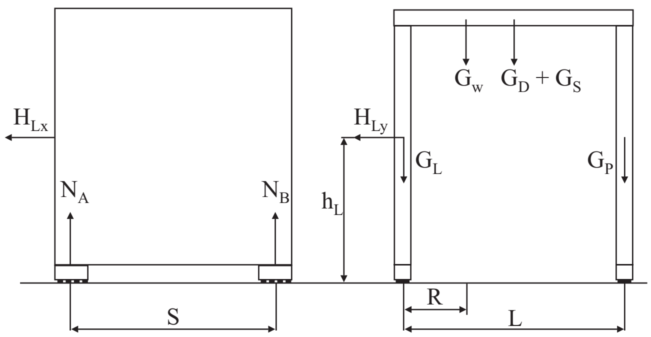

Fig. *Distribution of forces acting on roof segment*

Vertical forces acting on one side of the roof segment (support) are as follows :

$$\sum G_L = G_w \cdot \left(\frac{L-R}{L}\right) + \frac{G_D}{2} + \frac{G_S}{2} + G_L$$

$$\sum G_P = G_w \cdot \left(\frac{R}{L}\right) + \frac{G_D}{2} + \frac{G_S}{2} + G_P$$

where :

G_D – load resulting from mass of the roof

G_L – load on the left-side support

G_P – load on the right-side support

G_w – load resulting from equipment elements of the roof

G_S – load resulting from mass of snow or ice.

Horizontal forces acting on one side of the roof segment (support) are as follows :

$$\sum H_L = H_L$$

$$H_L = \overrightarrow{H_{Lx}} + \overrightarrow{H_{Ly}}$$

$$\sum H_P = H_P$$

$$H_P = \overrightarrow{H_{Px}} + \overrightarrow{H_{Py}}$$

Pressure loads acting on the equalizers of the left-side support :

$$N_{AL} = \frac{\sum G_L}{2} + \overrightarrow{H_{Ly}} \cdot \frac{h_L}{l} + \overrightarrow{H_{Lx}} \cdot \frac{h_L}{s}$$

$$N_{BL} = \frac{\sum G_L}{2} + \overrightarrow{H_{Ly}} \cdot \frac{h_L}{l} + \overrightarrow{H_{Lx}} \cdot \frac{h_L}{s}$$

Pressure loads acting on the equalizers of the right-side support :

$$N_{AP} = \frac{\sum G_P}{2} + \overrightarrow{H_{Py}} \cdot \frac{h_P}{l} + \overrightarrow{H_{Px}} \cdot \frac{h_P}{s}$$

$$N_{BP} = \frac{\sum G_P}{2} + \overrightarrow{H_{Py}} \cdot \frac{h_P}{l} + \overrightarrow{H_{Px}} \cdot \frac{h_P}{s}$$

Pressure loads falling to one traction wheel (for 4-wheel equalizing system) :

$$N_1 = 0.25 \cdot N_{AL}$$

$$N_2 = 0.25 \cdot N_{BL}$$

$$N_3 = 0.25 \cdot N_{AP}$$

$$N_4 = 0.25 \cdot N_{BP}$$

Calculation of tractive resistance

Tractive resistance of flanged wheels :

$$W_t = (1+\beta)\sum G \frac{2f + \mu d}{D}$$

where :

β – coefficient accounting for tractive resistance resulting from action of flange

G – pressure load on traction wheels

f – shift of reaction

μ – friction factor in bearings

d – axle diameter

D – traction wheel diameter.

Resistance of rising :

$$W_{wz} = \pm \sum G \sin\alpha$$

where :

α – railway inclination angle

G – total load

Resistance resulting from wind pressure applied to a movable object :

$$W_w = \pm\, cAq$$

where :

c – flow resistance coefficient

A – windage area
q – specific wind pressure load.

Total tractive resistance :

$$W_c = (1+\beta)\sum G \frac{2f + \mu d}{D} \pm \sum G \sin\alpha \pm cAq$$

Calculation of power output of driving motor

Power output of the driving motor :

$$N_u = \frac{W_c \cdot V_j}{\eta \cdot z}$$

where :

W_c – total tractive resistance of the roof segment
V_j – traction speed of the roof segment
η – efficiency of mechanism
z – number of driving motors.

Checking the protection against slip of wheels

The traction mechanism cannot cause the traction wheel's slip on the rail during start-ups and brakings. During wheel slip in the start-up phase circumferential wear of the wheel and local one of the rail occurs as well as an initial skewing the structure may happen. During braking, wheel slip causes local wear of the wheel as well as it can cause the roof segment falling-out of the rails which results from high kinetic energy of the roof's tractive motion and skewing due to slip of a wheel. Therefore the wheel slip during braking is very dangerous. Checking the protection against wheel's slipping is thereby the checking if the motor's power output is correctly determined as just its surplus can cause the danger of wheel slip. The traction mechanism of a small height is assumed hence horizontal forces do not influence pressure loads on the wheels during start-ups.

The condition of starting-up without slip of wheels

$$T \geq B + W'$$

where :

T – wheel-rail friction without wheel slip
B – inertia force
W' – total tractive resistance reduced by rolling resistance of bearings of driven wheels. The condition results from the fact that friction moment in bearings is internal one balanced by motor's torque but not by wheel-rail adhesive force.

$$W' = W_c - \sum F_n \mu \frac{d}{D}$$

where :

W_c – total tractive resistance
F_n – pressure load on driven wheels
μ – friction factor in bearings
d – axle diameter
D – traction wheel diameter.

Inertia force at the maximum acceleration not causing wheel slip :

$$B = \frac{\sum G}{g} a_{max}$$

where :

$\sum G$ – total load
a_{max} – the maximum acceleration not causing wheel slip
g – gravity acceleration.

Friction force :

$$T = \mu_1 \sum F_n$$

where :

μ_1 – friction factor.

Under the assumption that :

$$\sum F_n = \sum F_o = \frac{\sum G}{2}$$

where :

$\sum F_n$ – pressure load on driven wheels
$\sum F_o$ – pressure load on not driven wheels
$\sum G$ – total load.

by substituting the expressions to the formula :

$$T \geq B + W'$$

$$\mu_1 \frac{\sum G}{2} \geq \frac{\sum G}{g} a_{max} +$$

$$+ \left[(1+\beta)\sum G \frac{2f+\mu d}{D} - \sum G \sin\alpha - cAq - \frac{\sum G}{2} \mu \frac{d}{D} \right]$$

and after transformations the following is obtained :

$$a_{max} \leq g \left[\frac{\mu_1}{2} - \frac{2f(1+\beta)}{D} - \frac{\mu d(0.5+\beta)}{D} + \sin\alpha + \frac{cAq}{\sum G} \right]$$

Traction mechanism cannot generate any greater acceleration than that above given, therefore :

$$a = \frac{\varepsilon}{i} \frac{D}{2} \leq a_{max}$$

$$\varepsilon = \frac{M_d}{J_{zr}} = \frac{4g(M_{max} \pm M_o)}{GD^2_{zr}} = \frac{4g(mM_{zn} \pm M_o)}{GD^2_{zr}}$$

$$a_{max} \geq \frac{2g(mM_{zn} \pm M_o)D}{GD^2_{zr} i}$$

$$\frac{2g(mM_{zn} \pm M_o)D}{GD^2_{zr} i} \leq$$

$$\leq g \left[\frac{\mu_1}{2} - \frac{2f(1+\beta)}{D} - \frac{\mu d(0.5+\beta)}{D} + \sin\alpha + \frac{cAq}{\sum G} \right]$$

hence after transformations the following is determined :

$$M_{zn} \leq \left[\frac{\mu_1}{2} - \frac{2f(1+\beta)}{D} - \frac{\mu d(0.5+\beta)}{D} + \sin\alpha + \frac{cAq}{\sum G} \right] \cdot$$

$$\cdot \frac{GD^2_{zr} i}{2Dm} \pm \frac{M_o}{m}$$

where :

M_{zn} – rated torque of driving motor
GD_{zr}^2 – equivalent flywheel effect reduced to high-speed shaft
D/2 = r – radius of inertia
M_d – dynamic moment
M_{max} – maximum moment
m – mass of moving elements
M_o – active driving moment

The condition of braking without slip of wheels :

$$T \geq B - W''$$

where :

T – wheel-rail friction without wheel slip
B – inertia force
W” – tractive resistance – total resistance calculated without accounting for the friction in bearings of driven wheels as well as friction of wheel flanges because the latter reduces the danger of wheel slip during braking.

$$W'' = \frac{W_c}{1+\beta} - \sum F_n \cdot \frac{\mu d}{D}$$

The inertia force at the maximum deceleration (braking) not causing wheel slip :

$$B = \frac{\sum G}{g} a_{maxh}$$

Friction force :

$$T = \mu_1 \sum F_n$$

Under the assumption that :

$$\sum F_n = \sum F_o = \frac{\sum G}{2}$$

by substituting the expressions to the formula :

$$T \geq B - W''$$

first the following :

$$\mu_1 \frac{\sum G}{2} \geq \frac{\sum G}{g} a_{maxh} + $$

$$-\left[\frac{(1+\beta)\sum G \frac{2f+\mu d}{D} - \sum G \sin\alpha - cAq}{1+\beta} - \frac{\sum G}{2} \cdot \frac{\mu d}{D}\right]$$

hence after transformations the condition is achieved as follows :

$$a_{maxh} \leq g\left[\frac{\mu_1}{2} + \frac{2f+0.5\mu d}{D} - \frac{\sin\alpha}{1+\beta} - \frac{cAq}{\sum G(1+\beta)}\right]$$

The braking moment is to be greater than the permissible one determined by means of the above given maximum value of limiting deceleration. With the braking moment coacts the tractive resistance moment which should be determined without accounting for friction of wheel flanges :

$$M'_{oh} = \frac{W_o D}{2i} \eta_h$$

$$W_o = \sum G \frac{2f + \mu d}{D}$$

$$M_H + M'_{oh} \leq J_{zr} \varepsilon_{maxh}$$

$$M_H \leq \frac{GD^2_{zrh}}{4g} \frac{2a_{maxh} i}{D} - M'_{oh}$$

hence after substitution the following is obtained :

$$M_H \leq \frac{GD^2_{zrh} i}{2D}\left[\frac{\mu_1}{2} + \frac{2f+0.5\mu d}{D} - \frac{\sin\alpha}{1+\beta} - \frac{cAq}{\sum G(1+\beta)}\right] + $$

$$-\frac{\sum G(2f+\mu d)\eta_h}{2i}$$

where :

M_H – braking moment
M'_{oh} – tractive resistance moment
W_o – tractive resistance without accounting for friction of flanges.

CONCLUSIONS

- The driving system based on synchronous electric motors and external frequency control of their rotational speed seems to be, as far as its operational merits are concerned, the most favourable solution of the traction mechanism for the roof segments and gantry crane in question. The internal control is favourable in the case of application of one motor, but in the considered case its cooperation with a greater number of motors is needed.

- The external control ensures that the driving motors maintain an important feature of synchronous motors : their rotational speed is unambiguously determined by supply voltage frequency and not dependent on their load. As the shaft load increases the load angle δ_i also increases, and if the load becomes excessive the motor will – at the angle close to $\delta = \pi/2$ – fall out of step. Therefore any overload resulting from skewing the roof segment or crane structure on the railway will make their drive switching off and their stopping due to triggering off the brakes fitted with electromagnetic releases. Such system will ensure parallel run of the shafts of multi-motor driving system as well as protection against consequences of skewing the structure.

- In order to monitor and supervise motion of the roof segments and gantry crane the system should be additionally equipped with measuring, signaling and control devices.

- The selected traction mechanism driven by synchronous motors will ensure the mobility of roof segments and fulfilment of the above mentioned requirements; however it should be stressed that its initial cost will be higher than that of another solution based on a ship docking system (described in a separate report), considered by the authors.

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A design concept of fire protection system for an ecological floating dock

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ABSTRACT

This paper presents possible fire risks to an ecological floating dock and a design concept of its fire prevention system. The design concept covers: the water main fire system, froth- smothering system for fire prevention of the main deck area and CO_2 – fire extinguishing system for fire prevention of engine room, workshop and cable duct of the dock.

Keywords : floating dock, electric installations, fire protection systems

INTRODUCTION

Designing the floating docks, offshore drilling units or other ocean engineering objects requires to apply an individual approach to a much larger extent than that in the case of sea-going ships.

This can be specially observed in the design process of fire protection systems. Such publications as design guidance or hand books do not pay much attention to the fire protection problems concerning individual protection of docks and other ocean engineering objects.

In the set of regulations which determine principles of designing the docks in the area of fire protection, because of their general form, the main burden of creating a concept of dock fire protection is put on the designer's experience.

A number of built docks as compared with that of ships is very small therefore a level of designer experience gained in designing fire protection systems for docks is rather low. Due to a small number of orders for such elaborations possible emergence of experts solely in the area of fire protection of docks, out of all experts in fire protection of sea-going ships, is practically excluded.

Special character of the objects in question makes it necessary to include not only designers but also representatives of fire units to discussions on the problems since docks are elements of equipment of shipyards and some harbours in which regular fire fighting units are responsible for their fire protection. As a result, when designing the fire protection systems for such objects one should be aware of the relevant regulations being in force in shipyards. This is why many designs of fire protection systems for docks may be effectively improved in practice. Moreover, because many engineering branches are involved in solving fire protection problems, the designer responsible for fire protection of an ocean engineering object should have broad knowledge in the area of : fire fighting systems, electronic engineering associated with work of fire detection systems, fire fighting procedures, general knowledge on maritime engineering objects, and sometimes – even elements of law.

Similar problems have been met during design process of the fire protection system for the ecological dock designed in the frame of "EUREKA"project. The design was first of all based on the Rules for the Classification and Construction of Docks of Polish Register of Shipping. As information on location of future operation of designed dock was lacking the most versatile use of it was assumed.

This is connected with the necessity of analyzing fire hazards to a dock operating in ship building mode and also ship repair one. From the point of view of the designer of fire protection systems it may be limited to a large extent to the problems associated with conditions of evacuation of persons, i.e. those in the range not connected with operation of fire extinguishing systems, and covered by separate elaborations. Due to the lack of suitable data the problem of adjusting the design to regulations of national administration was left to be solved in further design stages of the dock. Docks are designed rather rarely and they are intended for long lasting use that results in limited possibility of basing on proved solutions in designing the docks. This is why appear great differences in effectiveness of new fire protection systems as compared with the existing ones. The observation may be related to e.g. fire detection and signaling systems which very fast evolve along with development of electronics.

CHARACTER OF FIRE RISK TO THE ECOLOGICAL DOCK

The ecological dock designed in the frame of the EUREKA ECOLOGICAL DOCK project has many features differing it from the existing classical docks. This also relates to the problems which affect the form of the fire protection design concept. From the point of view of fire protection the following problems are very rarely met: the glass roof over the dock, which, in some circumstances, may be conductive to spreading a possible fire (however real influence of the roof remains not tested). An additional risk factor is its own power source – the combustion engine driving electric generator. From obvious reasons the dock's power plant fitted with the combustion engine and the associated lubricating oil, fuel oil and exhaust gas systems as well as electrical systems associated with electric power production, should be accounted for as the sources of additional risk, in the design in question. Moreover according to the design project the dock is equipped with a cable duct connecting dock's side walls, workshop and electric switching station.

Places of the ecological dock, especially hazardous to fire

No.	Name of place	Description of risk
1	Main deck	During the dock's operation a ship or other offshore floating object is docked in it. It is assumed that on the docked object all fire extinguishing systems and other fire protection ones are out of order. As the dock is assumed versatile its operation is possible both in the ship-repairing and ship-building modes. Description of other risks resulting from the particular modes of dock's operation is given below.*
2	Engine room	In this compartment a high fire risk is due to work of fuel supply, oil lubricating and exhaust gas systems associated with combustion engine operation.
3	Cable duct together with vertical casings	In the cable ducts, due to possible occurrence of shortings in electric cables and restricted access to them, providing for a fire fighting system is necessary for these spaces.
4	Workshop compartment	The compartment is characterized by a higher fire risk as fire-risky operations are conducted in it, such as : welding, work with electrical tools, storage of combustible materials.
5	Electric switching station	In this compartment a fire risk results from the accumulation of many electric installations in one place.

* Fire risks to the docked objects can be classified by using many criteria, among which the following are considered the most important :

❖ **Mode of operations carried out on the dock**
The mode of operations carried out on the dock is of a great importance in creating fire risk. A docked offshore object can be in state of construction or repair works. Distinction of the two modes of operation affects fire risk to the dock crucially. Building the ship is much less dangerous in contrast to ship repair work carried out on the dock. It results first of all from that on the ship under repair inflammable materials and their vapours may be often found, as well as accumulation of wood in the form of furniture and other outfit elements may occur. The ship under repair is often used up, its electrical installations may be in a bad technical state, some of its systems usually are almost unserviceable, sometimes the ship's crew is still onboard. All the factors increase potential fire risk. In the fire protection design for the ecological dock in question the ship repair mode was assumed as being more hazardous.

❖ **Kind of docked object**
Fire risk to a docked object obviously depends on its specificity. A to-be-repaired fuel oil tanker is the most dangerous because of its tanks which may be, e.g., not sufficiently emptied from oil residuals and gases. Size of fire risky compartments on board the docked object and easiness of access to them also greatly affects the fire protection design process, for instance ro-ro ships have closed spaces between the decks, which involve additional fire risk resulting from difficult access for use of dock's fire fighting systems, another example is a docked offshore drilling unit whose some elements may reach over the upper deck of dock's side walls, that makes fire fighting more difficult.

In the course of the performed analysis in advance of commencing the design work the most unfavourable conditions associated with fire risk were assumed. In the working design stage of the fire protection system the fire hazard analysis should be agreed with fire protection experts.

DESIGN CONCEPT OF FIRE PROTECTION SYSTEM FOR ECOLOGICAL DOCK

After performing the fire risk analysis for the dock as well as after consulting it with experts dealing with fire protection in shipyards and ports , the design concept of fire protection of the ecological dock in question was elaborated.

Specification of fire protection elements for the ecological dock

No.	Name of item	Application
1	Water fire main system	Required by PRS Rules, the overall dock fire fighting system covering all the working area of the dock and its side wall decks, and having an unlimited amount of fire extinguishing medium.
2	Froth fire-extinguishing system	The low - expansion froth fire-extinguishing system cooperating with the water system, and covering all the working area of the dock and its side wall decks.
3	Carbon dioxide smothering system	The fire fighting system for dock's engine room, electric switching station, cable duct and workshop, started manually or in result of operation of the fire detection and signaling system.
4	Fire detection and signaling system	Not covered by this design
5	Fire fighting outfit	Fire extinguishers, fire electric generating sets, fire hoses, fire-hose nozzles, froth nozzles, fire blankets etc.

This specification shows only one design variant of fire extinguishing systems for the dock in question.

Description of the designed water fire main system

In the concept design stage designing of the water fire main system consists in :

- determination of parameters of water fire and emergency pumps
- preliminary selection of size and route of water pipe lines and the most favourable arrangement of fire hydrants
- determination of optimum parameters of all elements of hydrant equipment.

The rule requirements in this range could be greatly limited in the case of permanent water supply to the dock's fire main system from a land-based water source.

Calculations of the water fire main system were carried out with assuming the largest ship possible to be docked, due to lack of any publication concerning an individual procedure of designing the fire extinguishing systems for docks.

Principles of selection and calculation of water fire pumps

Two fire main pumps simultaneously operating and one fire emergency pump of the same capacity as the main pump were assumed to be applied. Their calculations were carried out on the basis of the assumption that during operation of the system two hydrants most distant from the pumps are under work. Hydrant hoses of 50 mm diameter and 20 m in length, cooperating with the nozzles of 19 mm outlet, were assumed. The maximum capacity of the system was calculated on the basis of the following formula :

$$Q_c = k \cdot m^2$$

where :

$$m = 1.68\,[L\,(B+H)]^{0.5} + 25$$

$k = 0.008$ for the objects over 1000 RT

L, B, H – main dimensions of the largest ship to be docked.

$$Q_c = 180\ m^3/h$$

Moreover, in compliance with the PRS Rules, it is possible to apply water ballast pumps as fire pumps, however the condition of simultaneous starting the water fire main system and ballast system must be satisfied in order to make it possible to dock out the ship in emergency of a fire in dock compartments. The water fire main pumps should be located on both sides of the dock that makes it possible to obtain uniform parameters of water flow for both sides of the dock. To determine the pressure head of the fire pumps the following formula has to be applied :

$$P_p = H \cdot \rho \cdot g \cdot 10^{-6} + p_h + \Delta p_{str}$$

where :

- H – height from water level to the highest located fire hydrant valve [m]
- ρ – water density [kg/m^3]
- g – gravity acceleration [m/s^2]
- p_h – water pressure before hydrant valve [MPa]
- Δp_{str} – sum of pressure losses for the least favourably located valve.

The pressure before hydrant valve $p_h = 0.28$ MPa was assumed in accordance with the requirements of the PRS Rules. Now only the sum of pressure losses for the least favourably located valve remains for calculation. It consists of the losses resulting from friction drag of water flow through piping as well as the losses resulting from local drag in piping elements. Therefore it is necessary to carry out hydraulic calculations on the basis of the schematic diagram of the system divided into sections; for each of them the calculations are performed separately and then their results are added together.

$$\Delta p_{str} = \rho\,[\Sigma\,(\Sigma\,\xi_{ij} + \lambda_i \cdot l_i/D_i)\,w_i^2/2 + w_h^2/2] \cdot 10^{-6}$$

where :

- ρ – water density [kg/m^3]
- $\Sigma\,\xi_{ij}$ – sum of local drag coefficients in ith section
- λ_i – linear drag coefficient in ith section
- l_i – length of ith section [m]
- D_i – diameter of ith section pipe [m]
- w_i – velocity of water flow in ith section [m/s]
- w_h – water flow velocity before hydrant valve [m/s].

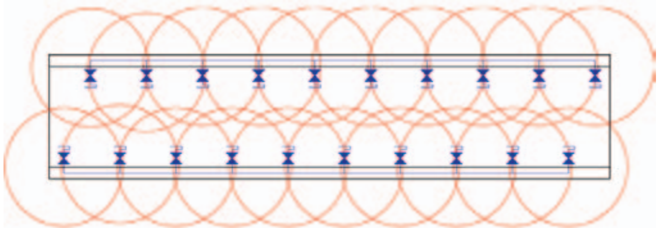
The pressure head of the pumps should be as follows :

$$P_p \geq 0.6\ MPa$$

In order to select a fire pump its maximum power demand should be determined in advance on the basis of energy balance of the dock, as well as its allowable gabarites.

Principles of pipe line design procedure

Designing the pipe lines of water fire main system for the dock should start from optimization of arrangement of fire hydrant valves. The basic criterion of the arrangement is the possibility of leading 20 m hydrant hoses to every point on the dock. The most effective method for arranging the hydrant valves is to map particular fire-fighting posts (at each hydrant valve) as the circles of 20 m radius, which have to tightly cover the entire protected space. In the case of the ecological dock the use of the method made it possible to reduce the number of fire fighting posts by 4 units due to shifting the valve lines on both sides of the dock by 4 m, to each other.



Dimensions - as on the schematic diagram of the water main system. The radius of every circle, R = 20 m.

Fig. 1. *Method of arranging the hydrant valves on the dock (the authors' original drawing).*

The next phase is selection of pipe line diameters. Diameters of particular kinds of pipe lines are chosen on the basis of the system's schematic diagram by using the following formula :

$$D \geq 9.4032 \cdot Q^{0.5}$$

where :

Q – maximum volumetric rate of water flow through a given section of pipe line at the assumed water flow velocity w = 4 m/s .

Specification of kinds of the pipe lines used in the water fire main system for the ecological dock

No.	Name of pipe line	Nominal diameter D [mm]
1	The pipeline between the pump and water main	90
2	The vertical main pipe line for branch pipes leading to hydrant valves	50
3	The pipe line connecting the fire systems in both dock's side walls	125

The pipes should be installed inside the side walls so as prevent them against direct atmospheric exposure, a temperature below 0°C in particular. Non-heat resistant materials cannot be applied to the pipe lines unless they are suitably insulated. The pipe lines should be fitted with draining equipment.

Specification of elements of the designed water fire main system

No.	Name	Number of pieces
1	Main fire pump (or ballast one)	2
2	Emergency fire pump	1
3	Vertical pipe lines for branch pipes leading to hydrant valves, D = 50 mm	-
4	Pipe line from fire pump to water main, D = 90 mm	-
5	The pipe line connecting the fire systems in both dock's side walls, D = 125 mm	-
6	Φ52 hydrant valve	74
7	H52/20 hydrant hose	38
8	Hose nozzle of 19 mm outlet diameter	38
9	Hydrant hose box	38

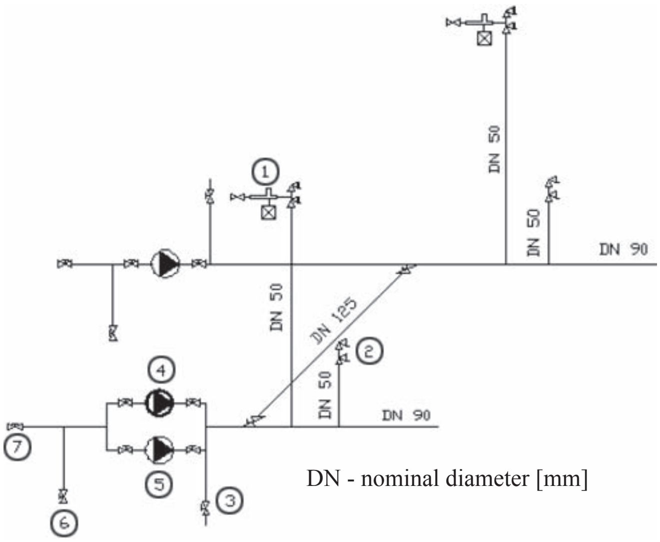


Fig. 2. *Schematic diagram of the main elements of the designed water fire main system for the ecological dock. (the author's original drawing)*
***Legend** : **1** – fire fighting post for water and froth fire-extinguishing – froth stub pipe, pipe line choke, frothing liquid tank, two hydrant valves; **2** – fire fighting post for water extinguishing - two hydrant valves; **3** – cut-off valve in pipe line to the right side wall ballast system (the same on the left side wall); **4** – fire emergency pump; **5** – water fire main pump for the right side wall (the same on the left side wall); **6** – kingston valve for water input to the right side wall (the same on the left side wall); **7** – cut-off valve for water input from a land-based water system, installed in the right side wall (the same on the left side wall).*

The described method determines an algorithm of preliminary designing the water fire main system for the dock, applying a strict approach to fire protection problems. In reality during design process many simplifications are possible to be applied under the consent of classification society's surveyor provided the designer has in his disposal a more exact information on real working conditions of the designed object.

Description of the froth fire-extinguishing system designed for fire protection of the main deck area of the ecological dock

Decision on application of an additional fire fighting system is left to the designer, however in the PRS rules any arguments justifying it cannot be found. Nonetheless, the preliminary design calculations of such installation were performed as the versatile character of the dock was assumed. The dock in question should be fitted with a permanent froth fire-extinguishing system for fire protection of the dock's main deck and a docked object because the possibility of docking the tankers whose systems are out of operation, has been assumed.

The application of the froth fire-extinguishing system for docked objects is necessary in the case when various inflammable liquid substances are stored in them. This is rather inexpensive in the case of the designed fire fighting system because in the proposed type of froth fire-extinguishing system the use has been made from some elements and the principle of work of the water fire main system required by the rules. This way no large investments associated with its application are necessary.

In contrast to elsewhere proposed design solutions of fire protection system for ecological dock the proved production method of a low-expansion froth by using pipeline choke, was selected. The designed froth fire – extinguishing posts are arranged on the upper decks of both dock's side walls, inside hydrant valve boxes. Every post is composed of the pipeline choke terminated in stub pipe with Φ52 universal root, and the frothing agent tank connected to it. The pipeline choke is connected to the water fire main system and makes it possible – due to its construction – to produce a low-expansion froth smoothly.

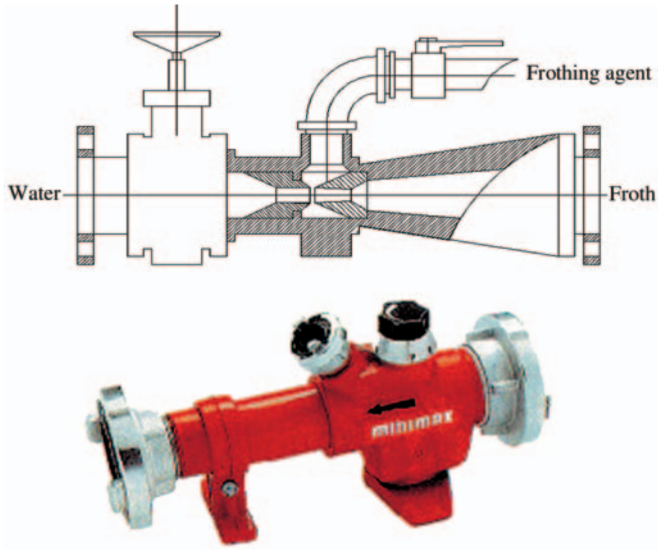


Fig. 3. *Schematic diagram and photograph of pipeline choke (acc. Catalogue of products of MINIMAX Co.).*

In this case the shown solution is the least expensive. Moreover, under assumption that the froth fire-extinguishing system is not equipped with fire-fighting monitors this solution would not require additional frothing agent pumps, that – in consequence – makes its reliability greater. Due to its simplicity the design system is versatile and makes it possible to adjust kind of froth to a particular fire hazard. It seems to confirm that : *the simplest the best*. Owing to application of the concept, to design any frothing agent tank is not necessary. Producers of frothing agents of the kind deliver them in ready-made tanks which are suitable for temporary installation on board the dock to be connected to pipe line chokes. This greatly simplifies the process of supplementing amount of the frothing agent within the system, and generates next savings.

Calculations of main parameters of the designed froth fire-extinguishing system

A low-expansion froth of the expansion ratio $L_s = 8 \div 12$ was assumed as the fire-extinguishing medium applied in the froth fire-extinguishing system for the dock. Froths of the kind are used to extinct fires of inflammable liquids. In this design also possible work of the installation by using various frothing agents is assumed. By adjusting the choke individual selection of concentration of frothing agent in the mixture is possible.

The specific consumption of 6% frothing agent is:

$$Q = 0.06\ (F \cdot c)$$

where :

F = 3000 m^2 - deck area of the largest ship possible to be docked (with some margin)
c = 0.6 $dm^3/min \cdot m^2$ – average froth delivering rate for the entire deck of docked object :

$$Q = 108\ dm^3/min$$

The required standard amount of stored frothing agent (together with a surplus) for fire extinction within the standard time t :

$$Q_c = t \cdot Q$$

where :

t = 30 min – standard time of fire-extinguishing

$$Q_c = 3240\ dm^3$$

The required standard amount of stored frothing agent for particular fire froth-extinguishing posts and selection of capacity of the tanks installed at the fire fighting posts :

as required : V = 180 dm^3 – as assumed : V_{zb} = 200 dm^3

Water delivery rate from the fire main system, required for operation of the fire froth-extinguishing system :

$$Q_w = F \cdot c \cdot [(100\% - 6\%) / 100\%] =$$
$$= 1.80\ m^3/min\ (108\ m^3/h)$$

An alternative concept of the froth fire-extinguishing system is the solution consisting in application of froth monitors to deliver froth to a protected area. The solution provides some advantages resulting from the possibility of more favourable froth streams manoeuvring, as compared with the above considered one. However the solution is much more expensive and complicated. The differences results first of all from the necessity of application of frothing agent pumps , additional pumps delivering water to the system, or designing a pipe line to connect the system with a land water source.

Calculations of main parameters of fire froth-extinguishing system equipped with froth monitors

The specific consumption of 6% frothing agent – under assumption that the deck area of docked object is fire-protected with the use of froth monitors :

$$Q = 0.06 \cdot (F \cdot c)$$

where :

F = 3000 m^2
c = 3 $dm^3/min \cdot m^2$ – average rate of froth delivering onto the entire deck area of docked object in the case of application of froth monitors :

$$Q = 540\ dm^3/min$$

The required standard amount of stored frothing agent (together with a surplus) for fire extinction within the standard time t :

$$Q_c = t \cdot Q$$

where :

t = 30 min – standard time of fire extinguishing.

$$Q_c = 16200\ dm^3$$

Capacity of frothing agent tank with the assumed 5% surplus :

$$V = 17\ m^3$$

Capacity of froth agent pumps :

$$Q_p = 1.25 \cdot Q = 675\ dm^3/min\ (40.50\ m^3/h)$$

Total capacity of water supply pumps for the fire froth-extinguishing system fitted with froth monitors :

$$Q_w = 507.60\ m^3/h$$

In the case if two froth monitors are assumed the calculated capacity values of frothing agent and water pumps have to be divided by two.

Description of the designed CO_2 - smothering system intended for the protection of engine room, workshop, electric switching station and cable duct

In the PRS Rules for the Classification and Construction of Floating Docks the necessity of application of a CO_2 - smothering system for the protection of such compartments as engine rooms, cable ducts etc located on the dock, is not clearly stated. The mentioned compartments are not required to be attended though they contain many fire hazardous objects in engine room, electric switching station, workshop and cable duct between dock's side walls such as e.g. electric generating sets , electric switchboards and cables hence their risk to fire is much greater as compared with other compartments. Possible fire in any of the above mentioned compartments could be detected too late. It seems that this is sufficient reason to consider application of an automatic volumetric fire extinction system for those compartments. The volumetric fire extinction method consists in filling a protected space with a gas medium not supporting the combustion process. Therefore during designing the systems of the kind special attention should be paid to correct assessment of volume of a given protected space.

„*The rated volume of protected space V* – gross volume of the protected space limited by water-tight or gas-tight bulkheads, walls and decks, without any deduction for volume of structural elements and equipment contained therein" (according to the PRS Rules for the Classification and Construction Sea-going Ships, Part V p. 1.2).

Calculation principles for parameters of main elements of CO_2 - smothering systems

The most classical solution of volumetric fire extinction system is the application of CO_2 - smothering one. For the ecological dock in question a CO_2 high pressure system (using gas cylinders) designed with the use of standardized elements offered by ANSUL INC, was proposed.

The designing procedure for such system consists in :

- finding the correct location of CO_2 extinction station
- calculation of a required amount of fire-extinguishing medium
- choice of solution for triggering the system working, and
- choice of parameters of CO_2 distributing pipe lines, as well as other components of the system.

The designed system is intended for fire protection of the following spaces of the dock

No.	Name of space	Capacity (volume) [m^3]	Percentage volumetric ratio relative to the largest one
1	Compartment of electric generating sets	160	50 %
2	Electric switching station	320	100 %
3	Workshop	80	25 %
4	Cable duct together with vertical casings	312	98 %

According to the PRS Rules the required amount of carbon dioxide for fire-extinguishing systems should be calculated with the use of the following formula :

$$G = 1.79 \cdot V \cdot \varphi$$

where :

V – rated volume of the largest space to be protected [m^3]
φ – compartment filling ratio, $\varphi = 0.35$ – for engine rooms whose total volume is determined with accounting for volume of casings.

$$G = 200.48 \text{ kg}$$

Carbon dioxide for such systems is stored in cylinders. To calculate a number of CO_2 cylinders located in the CO_2 fire extinction station the following formula should be applied :

$$n = G/V_{zb} \cdot \beta$$

where :

G – amount of carbon dioxide for protection of a given space (compoartment) [kg]
V_{zb} – capacity of CO_2 cylinders [dm^3]
β – filling ratio of CO_2 cylinders [kg/dm^3].

The capacity of CO_2 cylinders, $V_{zb} = 67.5$ kg was obtained on the basis of a design handbook for high-pressure CO_2 smothering systems, published by ANSUL Inc.

The filling ratio of CO_2 cylinders, $\beta \leq 0.675$ kg/dm^3 at the rated cylinder pressure $p \geq 12.5$ MPa, was assumed in accordance with the PRS Rules.

Number of cylinders, n = 4.4 was obtained from the calculations hence by rounding up 5 CO_2 cylinders of ANSUL Inc. production, were finally assumed.

The next phase of designing is to decide where CO_2 fire extinction station has to be located. In accordance with the rules of classification societies such stations should be located on open decks. Moreover they should be separated from adjacent compartments with gas-tight decks and walls. Thermal insulation should be provided so as to ensure a positive temperature inside the station.

In the course of designing of such small CO_2 - smothering systems the designer should decide whether the designed system has to serve for local or total fire protection purposes. In the case in question the second variant should be accepted as the dock's machinery compartments and cable duct are unattended.

Photographs and schematic diagrams of the local CO_2 - smothering system are presented in Fig. 4 and 5.

Currently, producer of fire protection systems makes a complete catalogue of system components available to the designer. However majority of producers stipulates that only original components made by a given producer have to be applied. Therefore the role of the designer in selecting particular elements for a fire protection system has become very limited.

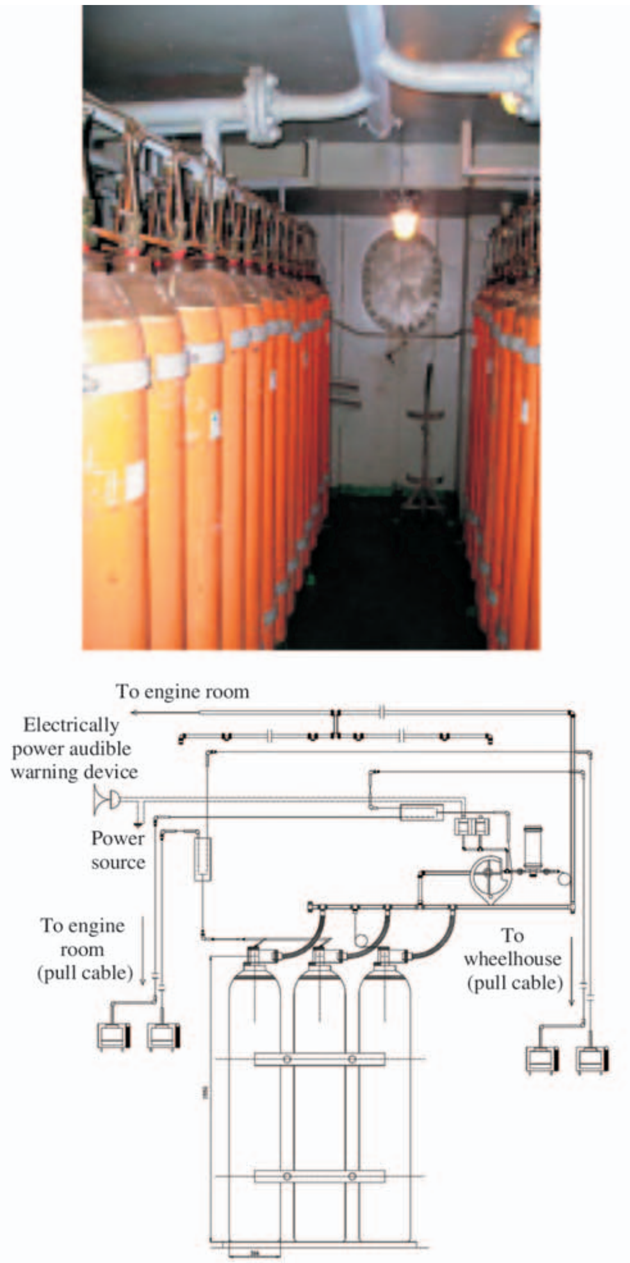


Fig. 4 and 5. *Photographs and schematic diagrams of the local CO_2 - smothering system for fire protection of the emergency electric generating set.*

Choice of pipe line diameters for CO_2 - smothering systems consists in making use of the following principle given in the PRS Rules :

$$d^2 \geq \sum d_i^2$$

and

$$d^2/m = d_i^2/m_i$$

where :

d – inlet pipe line diameter equal to sum of all cross-sectional areas of cylinder valves [mm]
d_i – i-th branch pipe line diameter [mm]
m – mass of CO_2 amount which has to be delivered through the inlet pipe line [kg]
m_i – mass of CO_2 amount which has to be distributed through the i-th branch pipe line [kg].

The cross-sectional area of ANSUL GV97 cylinder valve is :

$$D_z = 20 \text{ mm}$$

Diameters of the pipe lines leading to particular compartments were calculated by using the following formula and schematic diagram :

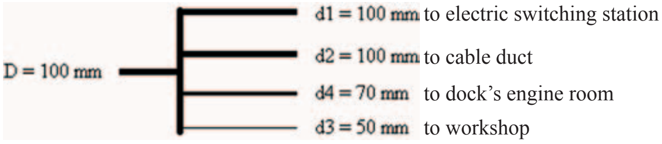


Fig. 6. *Auxiliary schematic diagram for calculation of pipe line diameters of CO_2 - smothering system intended for the ecological dock in question.*

Calculations of the parameters of another components have been omitted as they are of a minor importance in the course of conceptual designing the CO_2 - smothering system.

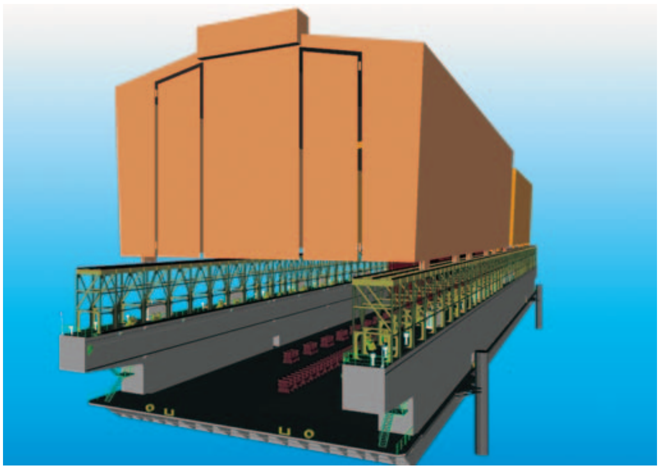
The CO_2 - smothering system can cooperate with fire detection and warning systems. In such case the fire extinction procedure is controlled by an approved central fire extinction station. The relevant procedure may approximately proceed in the following steps :

- ❖ detection of a fire automatically by a fire detector, or by pushing a button of manual fire alarm
- ❖ activation of time-delay counting to make a check, and possible immediate extinction of a fire in one of the protected compartments, and in the same time automatic switching--off the ventilating systems in these compartments, and switching-in the audible fire warning alarm
- ❖ after ending the time-delay counting or intentional cutting--off the time delay by an operator, starting the system of sealing all openings in the endangered compartment
- ❖ starting the fire extinction system.

For safety reasons such procedure should be always determined and strictly obeyed.

The presented design and associated calculations represent only one of the possible variants of fire protection system for the ecological dock designed in the frame of "EUREKA" project. Only an analysis of several elaborations of the kind makes it possible to choose an optimum solution. It seems to be many possible variants of fire protection system for the dock since its designer has a wide room for decision making in this respect.

An intention of the designer of the described concept was to present the most practically realizable set of technical solutions applicable to the fire protection system for floating docks.



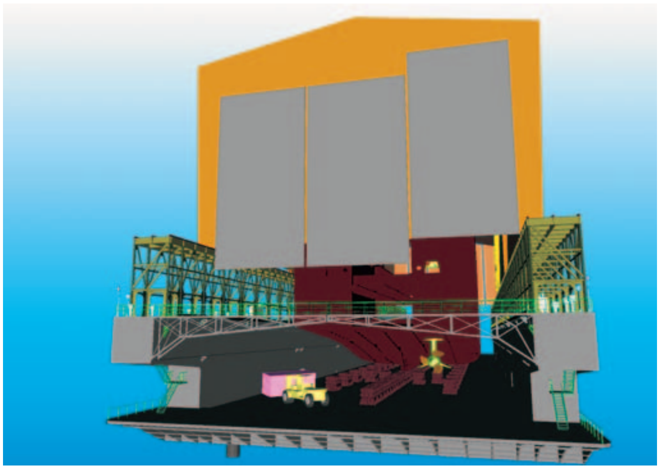


Photo : Cezary Spigarski