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 $t \to \infty$, 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.

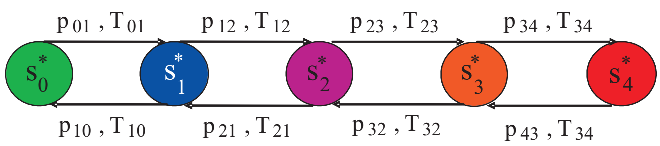

Figure. *State change graph of the process $\{Y(t): t \geq 0\}$*

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]:

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

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] :

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

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] :

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

$$\sum_{i=0}^{4} \pi_i = 1 \qquad (7)$$

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

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

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:

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

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

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

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 :

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

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 :

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

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

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

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] :

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

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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