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Numerical modeling of seawater flow through the flooding system of dry docks

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ABSTRACT: *Numerical simulations have been carried out on the flooding system of a dry dock in design stage and to be located at the south coasts of Iran. The main goals of the present investigation are to evaluate the flooding time as well as the seawater flow characteristics in the intake channels of the dock. The time dependent upstream and downstream boundary conditions of the flooding system are imposed in the modeling. The upstream boundary condition is imposed in accordance with the tidal fluctuations of sea water level. At the downstream, the gradually rising water surface elevation in the dry dock is described in a transient boundary condition. The numerical results are compared with available laboratory measured data and a good agreement is obtained. The seawater discharge through the flooding system and the required time to filling up the dry dock is determined at the worst case. The water current velocity and pressure on the rigid boundaries are also calculated and discussed.*

KEY WORDS*:* Dry dock; Flooding system; Tidal fluctuations; Seawater hydrodynamic; Numerical modeling.

INTRODUCTION

Most ship yards have at least one dry dock which is used for the construction, maintenance and repair of ships and boats. Dry docks are filled with water to allow a vessel to sail in, and then drained, leaving the entire body of the vessel exposed in the air so that it can be easily worked on. Some dry docks are extremely large to accommodate massive ships in need of repair works. Skilled teams of repairmen work on the vessel while it is dry docked, and then flood the dock upon completion so that the vessel can return to service in the sea.

The marine dry docks are subject to study and research from several points of view such as environmental, hydrodynamics design and construction. The effects of dry docks on the marine hydrodynamics are mainly related to the significant amounts of pollutants which build up over dry dock surfaces because of intensive industrial activity (Akan et al., 2000; Kretzschmar, 2000). The construction of dry docks has complex procedure which needs to scientifically integrate management technology (Kumamoto et al., 1990). Special design concerns shall be considered for a dry dock with marginal wharf structure (Thibeaux et al., 2004; Arroyo et al., 2002) and also in control of dry dock operations (Regan et al., 2007). The special loading pattern exists on dry dock due to uplift pressures (Kinner and Stimpson, 1983) and the interaction of marine hydrodynamics and structures (Fernandes and Correia, 1986; Lai and Lee, 1989; Shugar et al., 1991; Cheng et al., 2004) should be considered.

One of the main concerns in the design of dry docks is the total time required to fill it with the water (JLARC, 2006). The filling time depends mainly on the specifications of a flooding system which is generally operated by gravity. The main components of the flooding system such as an intake channel and guide walls generally have a major complexity. The hydraulic boundary conditions are also time variable because of the tidal variation of sea water level. The interaction of dry docks and the marine hydrodynamics and sedimentation is also a major issue in design (Seelam, 2008). It necessitates investigation of the hydrodynamic behaviors of dry docks, the flow patterns and the efficiencies of flooding system of dry docks. The application of numerical methods is also an option to analyze the flow through the flooding system. The numerical models have a preference because they can be easily adapted to the future changes. But the numerical models should be verified by comparing to experimental results before application. The complexity of the boundaries in the flooding system of dry docks is one of the major issues which should be considered in the numerical modeling.

As per the authors view, numerical study on the flooding system of a dry dock has not been carried out yet. So the main objective of this work is to investigate the seawater flow characteristics inside the flooding system of dry docks with a numerical method. A numerical model is developed using appropriate software to simulate the flow pattern in the flooding system of a graving dock. The complex geometries

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and time-dependent boundary conditions are completely considered in the model. The main goal of numerical tests is to evaluate the flooding time of a graving dock and effects of tidal variation of sea water level on it. It was tested whether the required flooding time can be satisfied only by gravity or an additional pumping system is needed. The flow characteristics in the intake channel of flooding system are also investigated. The bed, walls and ceiling geometries of the intake channel and their influence over the water flow during the flooding of a graving dock are investigated numerically. The flow velocity and pressure distribution is also calculated and discussed. The numerical model can be modified according to any future modifications. The numerical results are compared with the corresponding laboratory measured data (Najafi-Jilani et al., 2009) and a good agreement is obtained.

SPECIFICATIONS OF FLOODING SYSTEM

The flooding system investigated in the present paper is located between two adjacent graving docks and is designed to fill both docks. The general setting plan of two graving docks and their flooding system is shown in Fig. 1. As shown in the figure by the hatched area, only the northern dry dock is included in the numerical model along with the flooding system. So the southern dry dock is not included in the numerical model.

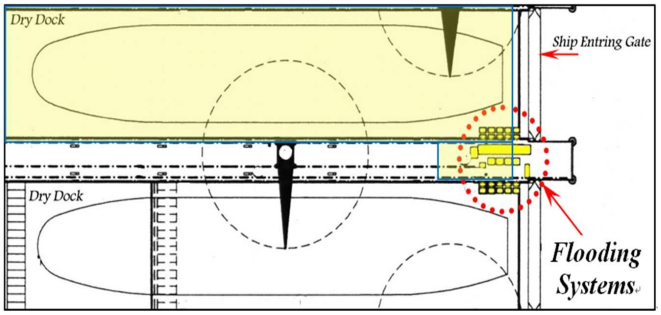


Fig. 1 Central flooding system located between two adjacent graving docks, zone of experimental modeling is hatched.

The detail specification of the flooding system is shown in Fig. 2 and 3. In Fig. 2, a plane view of the system is illustrated in which major parts of the system is numbered. The longitudinal and cross sections of the flooding system are shown in Fig. 3. The hatched area in the figure also indicates the domain selected in the numerical model. The numbers are the same as in Fig. 2. The definition of each numbered parts in the figure is as follows: The entrance trash rocks at the mouth of the flooding system are indicated by numbers 1 and 2. The entrance gates used to control the seawater flow into the flooding system are indicated by number 3. The numerical tests have been carried out for various opening percentages of these gates. The main seawater intake channel is numbered as 4. The barriers located at the bottom of intake channel and the overflow bottom weirs are numbered as 5. These barriers cause the flow to fall down through the four bed openings of intake channel. The lower stage of flooding system with sloped bed is numbered as 6 and its internal vertical guide walls indicated as number 7. The seawater flow after passing the main intake channel and falling down via its bed openings, guides towards the two adjacent dry docks by the sloped bed of lower stage. The seawater passes into four conveyance short pipes and lastly goes up from ten bed openings of dry docks indicated by number 8.

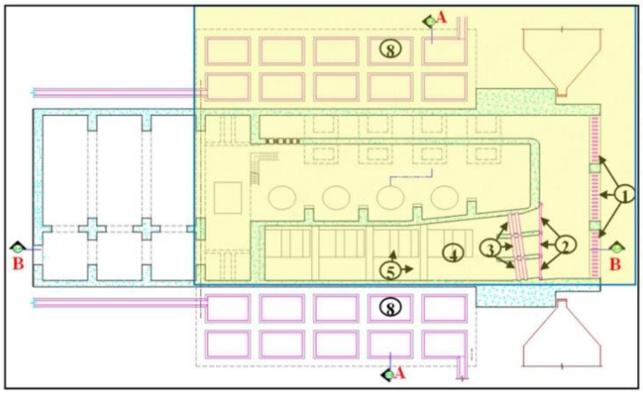


Fig. 2 Plane view of flooding system, numbers are described in the text, zone of experimental modeling is hatched.

The water surface in the graving dock gradually rises due to entering water from its bed opening. When the water surface elevation in the dock reached the sea water level, the flooding stage will be finished.

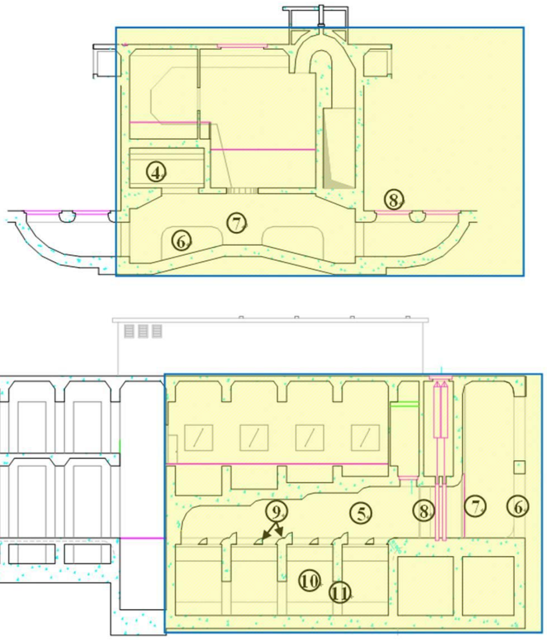


Fig. 3 Cross sections of flooding system, location of sections are indicated in Fig. 2, numbers are described in the text, zone of experimental modeling is hatched.

As it can be seen in Fig. 2 and 3, the system is applied for both flooding and dewatering of graving docks. Both of systems are numerically investigated. But the investigation on flooding system is only presented here. Investigations on dewatering system are under preparation in an independent manuscript.

NUMERICAL MODELING

The flooding system of dry dock is investigated with application of a numerical model. Numerical computation is made using ANSYS 6.0, an appropriate software to describe the complex geometry of the solid boundaries in the intake channel. FLOTRAN module of the software is used to simulate the water current through the intake channel (SAS IP, 2003). The main goals of numerical modeling is to investigate the water pressure and current velocity in the flooding system, including the bed, walls and ceiling of the intake channel, and to find the discharge rate of water into the system. The numerical model can be also used for any probable modifications which are required to optimize the flooding efficiency or to streamline the boundaries in the intake channel. The main components of numerical model of flooding system are shown in Fig. 4.

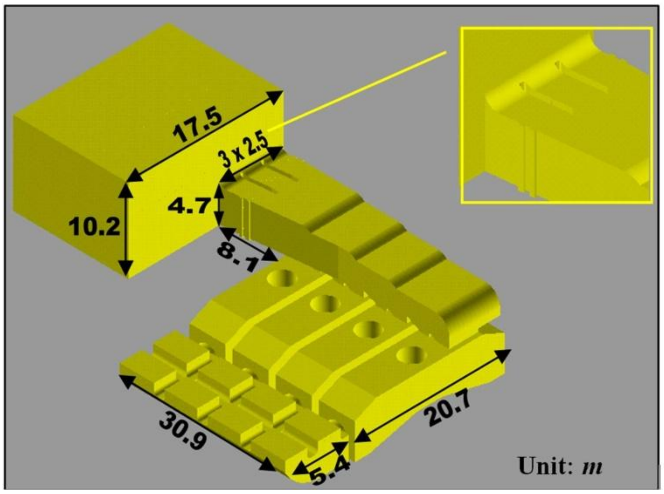


Fig. 4 Numerical model of flooding system, boundary geometries are identical to Fig. 2 and 3.

The mesh of the numerical model is generated using ‘Fluid 142 element’ which is available from an element library of the applied software. The element is nonlinear and three dimensional and is recommended for the simulations of steady and transient water flow. The tetrahedral option of this element is used here to resolve complex geometry of the water intake channels. The degrees of freedom for this element are defined as water current velocity, pressure, and temperature.

The water flow through the flooding system is only simulated in its pressurized form and the initial free surface flow and intermediate phases are neglected in the numerical modeling. The dimensions and arrangement of the elements are optimized through several trials to produce the best and fast convergence of the numerical model. Total of 23,372 nodes and 108,421 elements are used in the final mesh and shown in Fig. 5. The upstream boundary condition describes the tidal fluctuations of sea water level illustrated in Fig. 6.

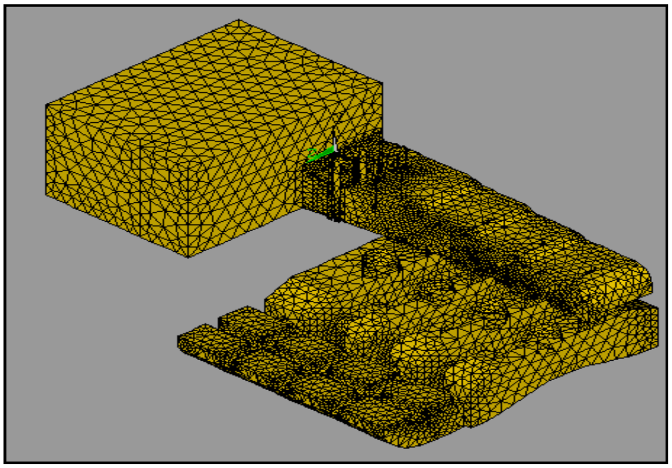


Fig. 5 Mesh generated for the numerical model of dry dock flooding system.

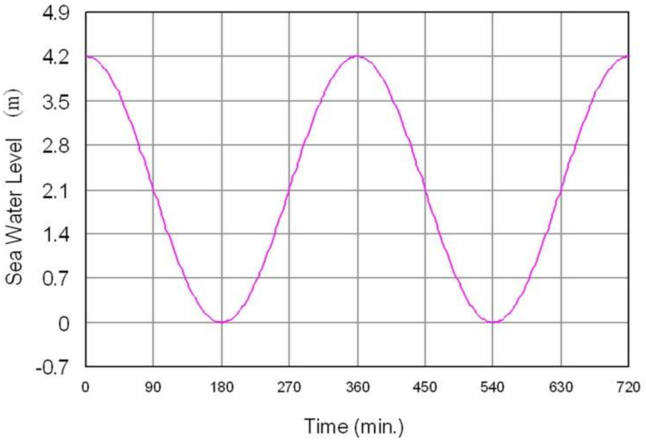


Fig. 6 Tidal variation of sea water level as the upstream boundary condition of flooding system in numerical modeling.

At the downstream, the gradually rising water surface elevation in the dry dock is reflected as a transient boundary condition. This elevation is computed in each time step based on the water discharge volume through the flooding system computed in previous time step. The time steps are selected small enough to eliminate the effects of time lag in calculation of the water level inside the dry dock. In simulation procedure, the accuracy of the solution is cared with Graphical Solution Tracking (GST) option of the applied software. As an iteration procedure is used to determine the main degree of freedom (water velocity and pressure) in each element, the convergence of simulation and the accuracy of the results are optimized using GST at all of the simulation stage. The water pressure and current velocity distribution are the main results of the numerical simulation.

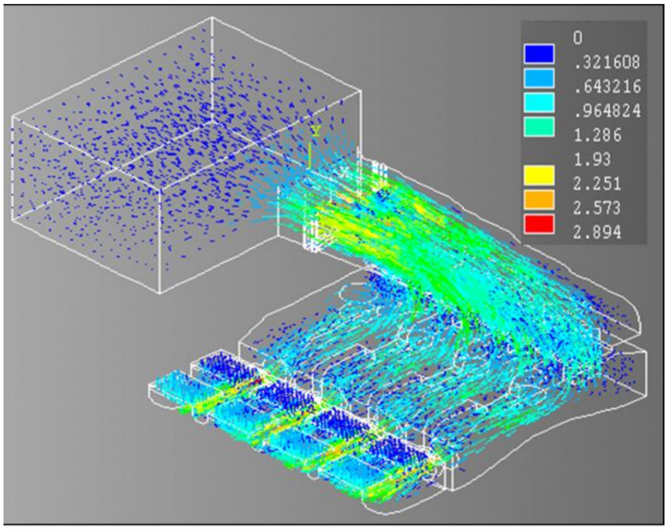


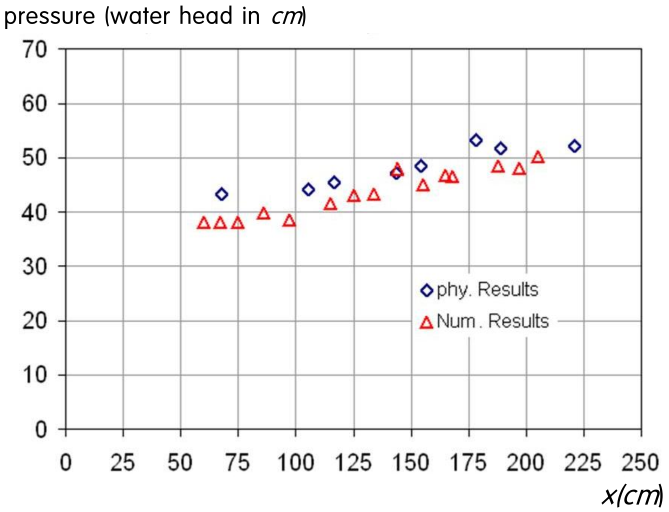
Fig. 7 Numerical results for scaled up water current velocities (*m/s*) in the dry dock flooding system.

Sample results of water current velocity vectors are illustrated in Fig. 7 for totally opened entrance gates while the sea water level at the start of flooding is in accordance with the highest high water level as indicated in Fig. 6. The maximum water velocity in the flooding system is occurred in this case. The figure show the velocity vectors ten minutes after the start of flooding. The detail discussion about the numerical results will be given in the following section.

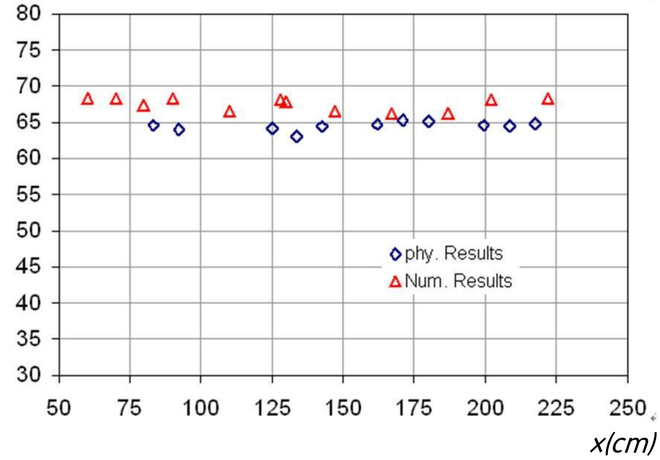
RESULTS AND DISCUSSION

The main concern of this work is to investigate flow characteristics of the flooding system of the dry dock. Firstly, to verify the numerical model, a comparison is made between experimental (Najafi-Jilani et al., 2009) and numerical data at the same conditions. The comparison is made for water pressures on the solid boundaries of the intake channel and also for the water discharge volumes through the flooding system. Fig. 8 shows the comparison of numerical results and measured laboratory data for water pressure on the ceiling, walls and bed of the intake channel.

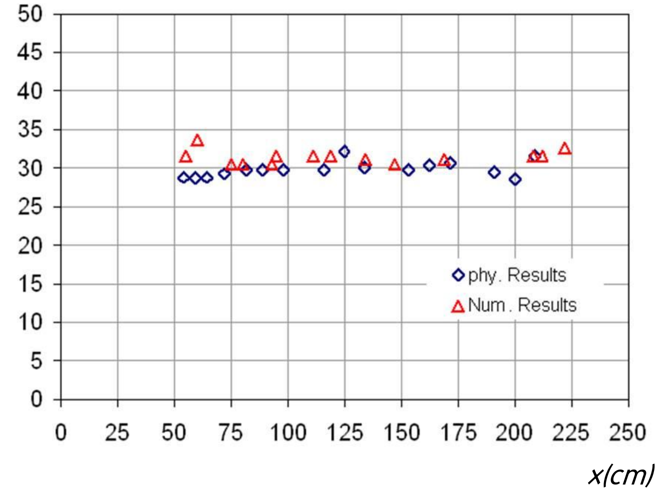
A good agreement is obtained between numerical and experimental results. As it can be seen in Fig. 8.a, the measured water pressures on the ceiling of the intake channel is generally higher than numerical ones. It seems that the effect of the bed barriers such as guide overflow weirs on the flows cannot be completely included in the numerical model.



(a) Water pressures on ceiling



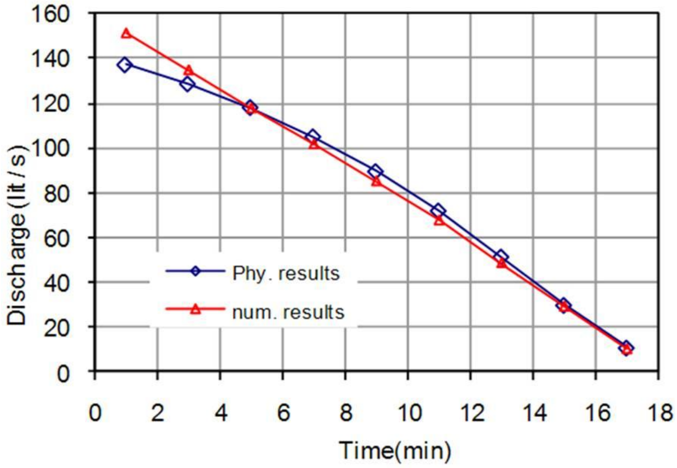
(b) Water pressures on bed



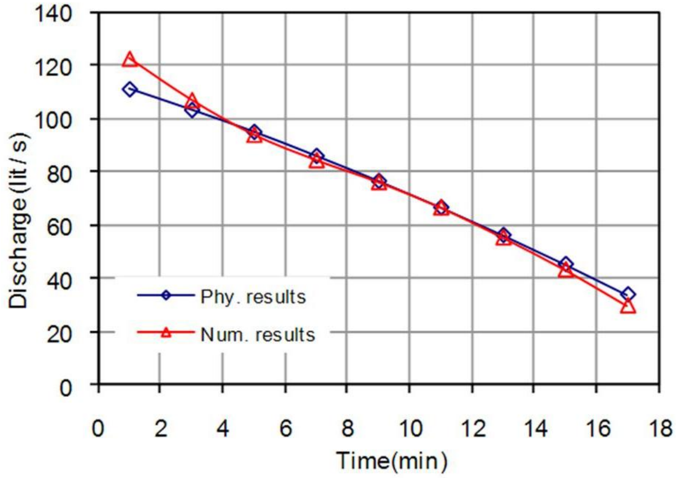
(c) Water pressures on wall

Fig. 8 Comparison of numerical and experimental (phy.) results for water pressures on the ceiling (a), bed (b), and wall (c) of the intake channel.

The deviation from measured values is about 10%. An opposite status can be seen in Fig. 8.b, for water pressure on the bed of the intake channel. The calculated values is about 10% greater than the measured data in the experiment and it seems that the water velocity near to the bed of the channel is faster than the numerical results. Also flow separations occur on the bed which may be caused by the bed barriers cannot be reasonably simulated in the numerical model. The measured water pressure on the walls is generally to the numerical results, as shown in Fig. 8.c. The comparison of numerical and experimental results is also made for the water discharge into the flooding system when the sea water level is the highest high water at the start of flooding. Two opening percentages of the entrance gates is considered as 100 and 50%. As it can be seen in Fig. 9, the water discharge in laboratory model generally coincides with the calculated data.



(a) 100% opening of gates



(b) 50% opening of gates

Fig. 9 Comparison between experimental and numerical results for water discharge variations with time during flooding at (a) 100%, and (b) 50% opening of the gates.

It can be also concluded that if the flooding started when the sea water level is equal to lowest low water level (see Fig. 6), the total required time to fill up the dry dock is about 120 min. in prototype and so a booster pumping is needed to accelerate the rate of filling of dry dock and to reduce the flooding time.

As it is shown in Fig. 9, the maximum deviation from the experimental measurements is observed at the start of flooding in the numerical model. The calculated water discharge from the numerical model is generally larger than the measure data from the physical model. It occurred due to different flow condition in the experimental and numerical models. The seawater flow in intake channel initially has free surface which does not considered in the numerical investigation. It can be concluded that the free surface stage at the start of the flooding leads to reduction of discharge capacity and causes the increase of the flooding time.

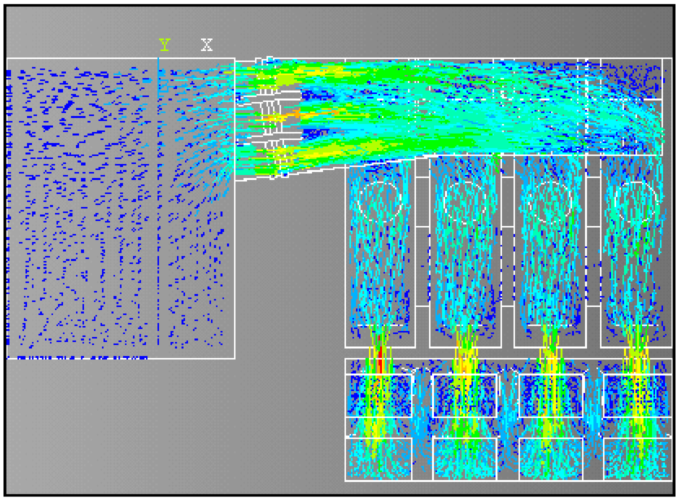


Fig. 10 Plan view of flooding system, water velocity domain calculated by numerical model.

It can be generally concluded that the procedure explained in the present study is successful in numerically simulating the sea water flow in the intake channel of the flooding system of a dry dock. Moreover, the maximum water velocity is computed to check with the related limitations in the flow velocity. As shown in Fig. 10, the maximum flow velocity calculated in the numerical model is 2.85*m/s*, equivalent to 11.6*m/s* in prototype. This maximum water velocity is much less than 16*m/s*, the maximum allowable velocity in the pressurized channels (The British Standards Institution, 1988).

The investigation on the numerical results is also made on the water pressure domain in the intake channel. As it is shown in Fig. 11, the general pattern of water pressure in the channel is hydrostatic but some fluctuations are observed around the internal guide overflow weirs. The comparison between numerical and experimental results shows that the local effects of these internal barriers are not exactly simulated in the numerical model. But the deviation is generally less than 10% in the maximum value and a good agreement is obtained in the entire pressure domain.

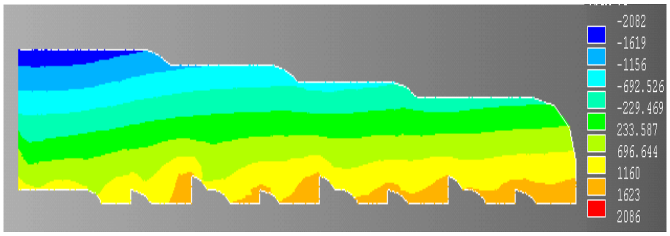


Fig. 11 Cross sectional view of water pressure distribution in the intake channel, calculated by the numerical model.

In general, it can be concluded that the present numerical approach to model the flow in the flooding system of the dry docks can yield reliable results.

The flow characteristics of the flooding system are not investigated thoroughly in the present study. However, the verified numerical model can be applied to any future changes which may occur in the geometries of the flooding system or in boundary conditions.

CONCLUSIONS

Numerical simulations have been carried out on the flooding system of a dry dock to be located at the south coasts of Iran. The main goals of the investigations are to evaluate the flooding time as well as the flow characteristics and pattern in the intake channels. The time dependent upstream and downstream boundary conditions of the flooding system are considered in the modeling. The results include the required filling time of the dry dock and also the water pressure distribution on the bed, walls and ceiling of the intake channel.

It is concluded that if the flooding started when the sea water level is equal to the lowest low water level, a booster pumping is needed to accelerate the rate of filling of the dry dock so as to reduce the flooding time. The numerical investigations show that regular stratified pressure regions occur on the walls of the intake channel but it is not a major variation in the pressure along all the length of the channel. Local uprising in water pressure is occurred around the guide overflow weirs located at the bed of channel. The water pressure on the bed has a different pattern with the walls in general. A major variation of bed water pressure can be seen along all length of the intake channel. The water pressures gradually increase with the distance from the entrance gates.

The maximum discrepancy between numerical and experimental data is occurred in the water discharge rates into the dry dock, especially when the flooding starts because of the different flow patterns at this stage in numerical and experimental model. It seems that the reduction of discharge capacity is caused by the initial free surface flow. It is generally concluded that the possibility of damage and cavitations in the flooding system is considerable during the initial free surface and intermediate flow conditions.

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