

Challenges in the Assessment of Harbor Tranquility-Case Studies from Harbors in the Persian Gulf and Oman Sea

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Abstract

Construction of the new ports and harbors is very essential in the development of the coastal zone and also provides opportunities to promote the economics of the further inland neighboring area. One of the key issues in the planning and design of these infrastructures is providing an adequate layout to ensure a safe sheltered area for the navigation and berthing of the vessels accommodated in the harbor. To achieve this goal, analysis of wave agitation inside the harbors should be conducted in the design stage, which can be implemented by employing physical models or numerical models. But both of these tools have their own advantages and disadvantages. Another challenge in the assessment of the harbor tranquility is to define adequate criteria to ensure that the harbor is operational while frequent storms are happening and that the penetrated waves into the harbor during rare events do not cause any damage to the vessels and other facilities in the harbor. In this paper, the tools and criteria applied in the design of the majority of harbors in the Persian Gulf and Oman Sea are discussed and recommendations from the applicable standards are reviewed. The layout of two harbors – one in the Persian Gulf and the other one in the Oman Sea – are revisited by implementing a numerical model. This study reveals that one of the main design defects led to the inadequate layout for these harbors is defining the inadequate criteria for the harbor tranquility.

Keywords: Wave agitation, Calmness, Numerical modeling, Physical modeling, MIKE 21, Boussinesq wave module.

Introduction

A large number of harbors and ports have been constructed along the Iranian coastline of the Persian Gulf and Oman Sea during the last 15 years. These schemes are ranging from small fishing harbors to the mega port projects. As part of the Monitoring and Modeling Studies of Coastal Zone of Hormozgan Province, the layout of some of these harbors were identified that are not adequate [1]. Physical model testing and numerical models are the tools used for the wave agitation study in the harbors. The first tool was used in some of the major ports in Iran before ([2], [3], [4]) but it has rarely been employed in the recent years, which may be due to the high costs associated with conducting these tests although a number of physical modeling laboratories have been developed in the country. The scaled model of harbor breakwaters can be built in a physical model laboratory to investigate the wave disturbances in the harbor. The main aspects of wave-structure interaction can be reproduced in the model to ensure that scale effects will not have a significant effect on the results. It should be noted that the three dimensional scaled model built for the investigation of the wave agitation in the harbor can also be applied to study the overall stability of the armor layer, crest, toe and apron of breakwater, to measure wave overtopping at the breakwater and other structures in the harbor such as quay walls and to verify the stability of the transition between two dissimilar sections. This important advantage may justify the relatively high cost of the physical modeling when the objective of physical model testing is not limited to just investigation of the wave disturbance in the harbors.

One of the drawbacks of the physical model tests are the limitations in scaling the harbors due to the limitation in the size of the basins. The model scale is selected based on the capabilities of the laboratory facilities - including wave

generator and flume dimensions - in respect with the test conditions and breakwater section and the scaling requirements. Therefore, due to economic and technical limitations of the laboratories for the physical modeling of the large harbors, it is inevitable to use a numerical model or a hybrid model, which is a combination of a physical model and a numerical model.

Numerical modeling has been being widely applied to the coastal projects in Iran – varying from small harbors to more important multi-purpose ports. Although numerical models have been developed specially in the last two decades, but there are still some technical issues related to their applications which is mainly due to the introducing of input parameters such as porosity layers and also limited knowledge about the reflections of the oblique waves. Moreover, calibration and validation of wave agitation models requires the measurement of wave characteristics both inside and outside the harbor within a relatively long period to ensure that it includes some storm events, which cannot be implemented for the design of the new harbors. Therefore, the majority of the wave agitation models are not possible to be calibrated and validated against the field measurement data.

Criteria for Harbor Calmness

To investigate the harbor tranquility, proper criteria for the wave inside the basin are required to be established. The criteria can be discussed in the context of the wave heights and related vessel movements. These criteria are mainly divided into two levels, depending on the frequency of the occurrence of the storms. For the more frequent storms, the maximum acceptable wave heights in the basin shall be small enough not to hinder the operation of the vessels in the harbor. This criterion of the wave height exceedance probability in a harbor is mainly concerned with the port operation which is referred as Level I in this paper.

The second Level, i.e. Level II, basically defines the criteria to ensure that the vessels and other facilities in the harbor will not experience damages during the occurrence of rare events. In addition, the facilities in the harbors shall not be damaged due to the wave loads and also the overtopping at the quay walls shall be limited.

OCDI 2002, which has been being widely used in the port design in Iran, recommends that the annual calmness of a specified level shall be achieved for 97.5% or more of the days of the year for basins that are located in front of mooring facilities and used for accommodating or mooring vessels [5]. The Iranian Standards for Design of Ports and Marine Structures have similar recommendations. It limits the annual calmness to 95% to 98% of the days of the year [6]. British Standard specified the maximum significant wave height that can be acceptable in small craft harbours including marinas and fishing harbours [7]. The criteria are based on very little movement of boats to reduce the likelihood of the damage due to collisions of the boats moored close to another. For the fishing harbours the maximum significant wave height is recommended to be less than 0.4m.

The criteria for harbour calmness during extreme storm – which are abnormal waves - have not been well established in these guidelines. The first step is defining the return period of the extreme storm event. OCDI (2009) recommends considering abnormal wave events with the return period of 50 years for facilities with a design working life of 50 years [8]. Another concern is the description of the storm wave condition in a harbor in terms of the absolute value of the significant wave height. Goda (2000) defined the maximum significant wave height in a mooring basin below 1m for the design storm [9].

The Level II criteria - for harbour calmness during extreme storm - have not been being applied in the wave agitation study of the most harbours in Iran and this is likely why majority of them have insufficient overlap of breakwaters relative to the direction of wave propagation, as reported by Ashoor et al. [1].

The design criteria have been applied in this paper to investigate the harbour tranquillity consists of both levels described above. For Level I, the criteria proposed in OCDI for the vessels less than 500 tonnes have been applied. The design criterion for Level II was defined for wave events with the return period of 50 years, which is in line with OCDI 2009 and design guidelines for the small boat harbours ([10] and [11]). The wave height was limited to 0.5m for the Level II.

Modeling of Wave Agitation

The initial studies revealed that the wave disturbance inside of some of these harbors hinders the operation of the harbors specially during the catastrophic storm events which are mainly due to the inadequate harbor breakwaters, as reported by Ashoor et al [1]. Kouh-Mobarak and Lengeh harbors are two examples of these harbors which were adopted for the further studies. A numerical modeling study for the wave agitation was implemented by using MIKE21 BW which was developed by DHI.

The input waves for the wave disturbance model were adopted from the wave propagation studies and field measurements implemented in the Monitoring and Modeling of Hormozgan Province, which was based on offshore wind and wave modeling of Persian Gulf, Hormoz Strait and Oman Sea for the period of 1983 and 2010 ([12] and [13]).

Kouh-Mobarak Harbor

This fishing harbor is located in the south western shoreline of Hormozgan province. As shown in Figure 1, Kouh-Mobarak port consists of two breakwaters, which are approximately 950m, and a shore connected causeway. This harbor provides berthing areas for boats and small fishing vessels. The size of small fishing vessels rarely exceeds 100 Tonne.



Figure 1: Aerial Photo of Kouh-Mobarak Port from World View Satellite (2008).

The maximum disturbance incidence percentage is about 5.2% which occurs in the berth, located in front of harbor entrance. At other berths, disturbance incidence percentage was lower than this part, because a part of these berths lies in the shadow of southern breakwater of Kouh-Mobarak harbor.

The results for the 50 year return period waves shows that the waves from South East can generate significant wave heights up to 0.6m at the north and east of the basin which is relatively higher than the criterion defined for Level II. The results of the numerical model show that the layout of the Kouh-Mobarak breakwaters is not adequate to satisfy the harbor calmness criteria for the both calmness levels. This is more pronounced for the criteria defined for Level I. This defect is mainly due to the location of the harbor entrance. The result of recent met-ocean studies for the Hormozgan Province Coastline shows that the harbor entrance should have been located toward the North.

Lengeh Harbor

The main breakwaters of Lengeh Harbor were constructed in 1967 to provide a shelter for the berths developed to accommodate passenger and container ships. The initial layout consisted of two breakwaters. Later, a detached breakwater was built in front of the harbor entrance to reduce the penetration of the south westerly waves into the basin and consequently, enhance the calmness at the berths.

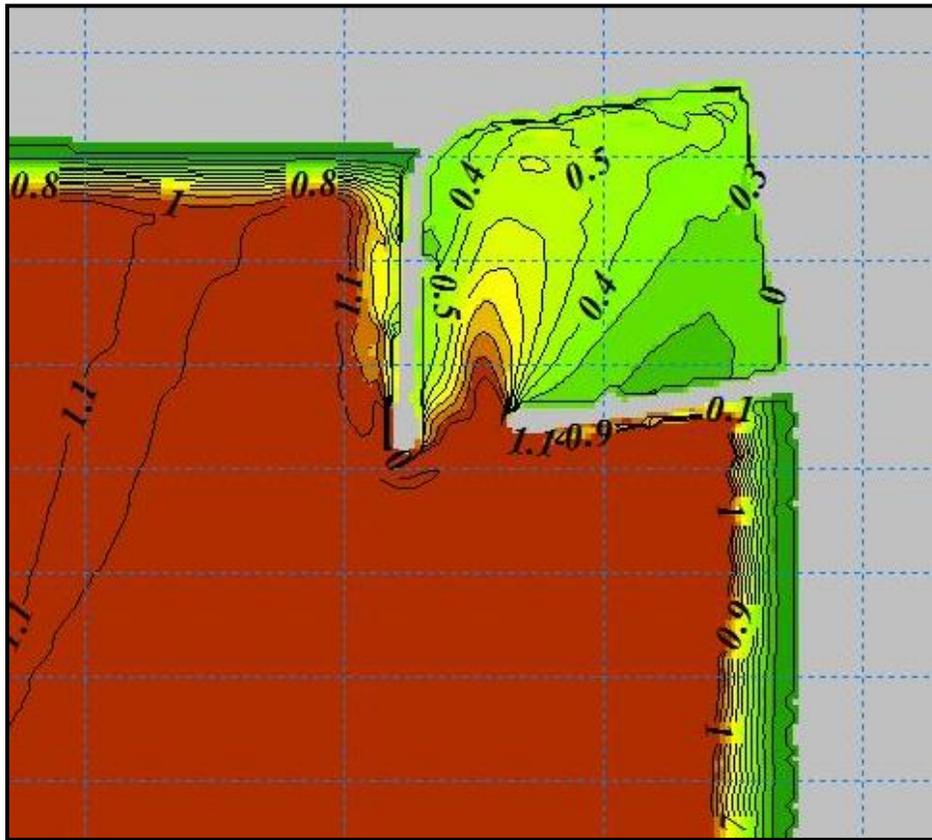


Figure 2: a snapshot of wave disturbance coefficients for waves coming from 180° with the $T_p = 10s$.

Recently, another breakwater was constructed in the east of the existing harbor (Figure 3). This layout was not adequate to provide a safe basin for the navigation and berthing of the vessels, particularly there were some concerns for the functionality of the passenger quay. As a result, PMO decided to substantially modify the harbor layout to improve the harbor tranquility. In this effect, the harbor layout was revisited once more in 2009 and the new layout was implemented (Figure 4), in which the basin level deepened from -5m CD, which was suitable for 2,000 DWT vessels, to -9m CD to enable the accommodation of 10,000 DWT vessels.

Figure 5 shows the plot of the wave disturbance coefficients for the waves coming from 135° for the old layout of Lenghe Harbour. The results of numerical modeling show that the criteria for the annual calmness at berths and north basin are not met. The results also shows that calmness for the Level I is achieved for 97% of times during one year in the north basin which is a bit less than proposed criteria. But the southerly design waves with the 50 year return period penetrates into the north basin and resulted in significant wave heights about 2 m at the quay walls. The south basin of the old layout meets the criteria for the Level I and Level II.

The modified layout significantly improves the harbor calmness and satisfies the Level I criterion but the results of the modeling for 50 year return period wave condition shows that the wave height at the northern quay wall reaches up to more than 0.72 m and therefore, it does not meet the calmness criteria for Level II.

The modified layout of the harbor considerably improves the annual calmness.



Figure 3: Satellite image of old Lengeh Harbor (image from World View Satellite, 2008).

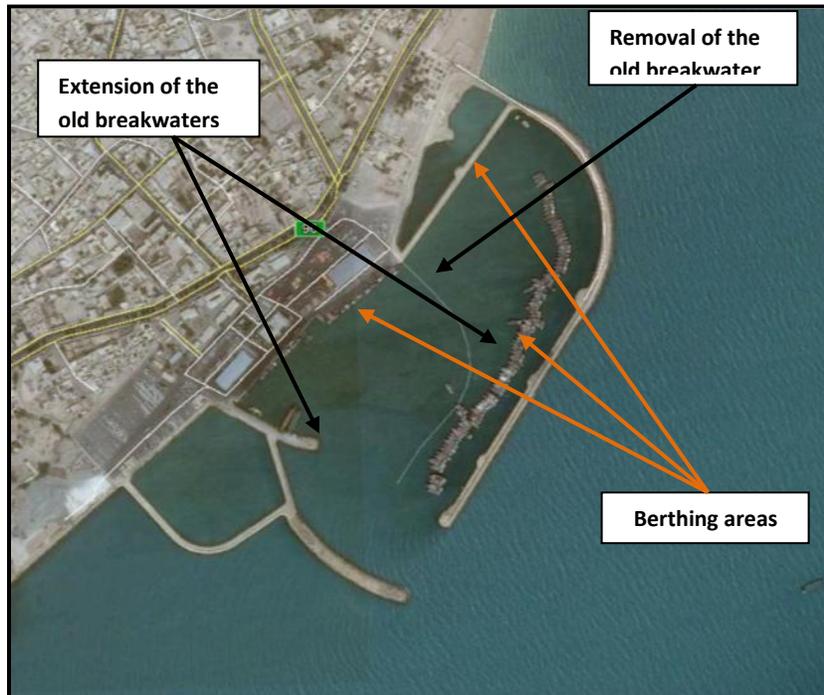


Figure 4: Satellite image of new modified Lengeh Harbor (image from Google 2014).

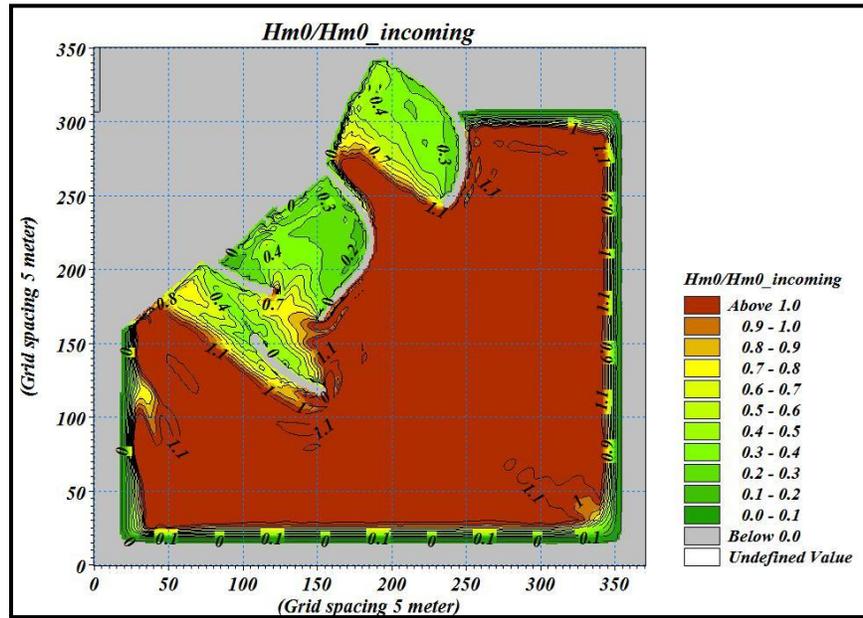


Figure 5: Plot of wave disturbance coefficients for waves coming from 135° with $T_p = 12s$ for the old harbor layout.

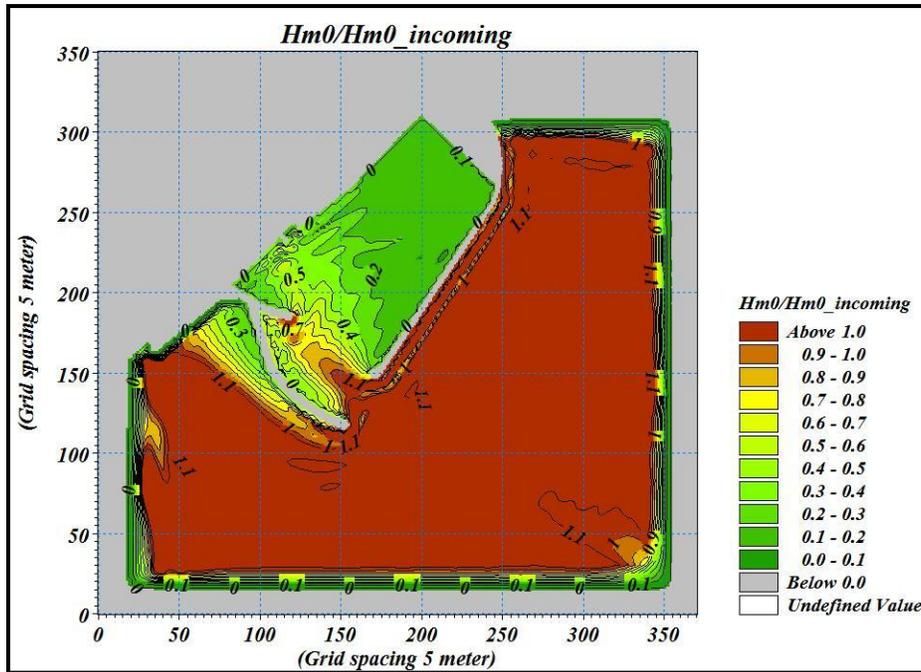


Figure 6: Plot of wave disturbance coefficients for waves coming from 135° with $T_p = 12s$ for modified harbor layout

Conclusion

The criteria for the assessment of the harbor tranquility were reviewed with the emphasis on the criteria applied for the harbors and ports in the Iranian coastline in the Persian Gulf and Oman Sea. The majority of the harbors for small crafts have been designed for the wave agitation generated by operational conditions. The layout of two harbors in Southern coasts of Iran examined by implementing numerical models and the potential causes of the defects in the harbor layouts were presented. The results revealed that the harbor layouts are not adequate especially for the calmness criteria defined for the abnormal wave conditions. Therefore, the direction of harbor entrance and also overlaps of breakwaters should be modified to satisfy both levels of calmness criteria.

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