BREAKWATER ALTERNATIVES FOR SHAHID BEHESHTI PORT DEVELOPMENT PROJECT

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INTRODUCTION

Shahid Beheshti Port is located along the south eastern coastline of Iran, in the Province of Sistan-Baluchistan at Longitude and Latitude of 60° 31' and 25° 12' respectively. It is situated at the inner side of the south eastern Headland of Chabahar Bay. For the first phase development of Shahid Beheshti Port, existing breakwater should be extended about 1650m. Currently a breakwater exists in the port area and the main purpose for its extension is to provide acceptable calmness at the locations of new berthing structure as well as navigation channel. The overall of the first phase development of the project involves dredging of approach channel and basin, reclamation of new land for the port expansion, extension of the existing breakwater, construction of a new container terminal and multi-purpose terminal, and supply as well as commissioning of cargo handling equipment.

Three different alternatives are designed for extension of breakwater and compared according to technical, commercial and construction aspects. Conventional rubble mound breakwater with Tetrapod and X-bloc armour unit and Berm Breakwater are these three considered alternatives. Among them, rubble mound breakwater wit X-bloc armour unit is determined to be the best choice because of its adequate stability, economical benefits and easy construction.

GENERAL PLAN AND DESIGN CONDITION

Breakwater geometry and its materials depend mainly on hydrodynamic specification in the area and also desirable life time for structure workability. According to design criteria, the design life of the breakwater shall be minimum 50 years. Also Breakwater shall be designed according to event wave with return period of 100 years. Other specifications such as overtopping should also be controlled for 1 year event in addition to 100 year event.

Figure 1 represents the global plan of Chabahar Port for phases 1 of development. Breakwater extension is shown with different color. Both sides of the breakwater will be exposed to hydrodynamic events. Outer part is mostly exposed to wave from south direction while inner part is mostly exposed to in-bay waves. Therefore, breakwater should be designed according to relevant hydrodynamic conditions which are calculated for different return periods [1].

Based on hydrodynamic study [5], maximum 100-year wave height along the seaside of breakwater is 5.38 m with period of 10.69 sec that belong to head of the breakwater. Also, at the beginning of breakwater, 100-year wave has a height and period of 4.83 m and 10.18 sec, respectively. Also seabed level changes between about -11 to -14m (CD) along the breakwater and breakwater head is located at the deepest point. In this paper calculation will be done for design wave height of 5.3 m.

In this project, rock materials will be provided from a mine located 2 Km north of the Ramin port at location of 60° 44' 11" Longitude, 25° 17' 27" Latitude [2]. The source is located near the project area, approximately 12 Km eastward of Chabahar, and there is an existing road to the project location. Based on performed tests on the mine materials, the saturated surface dried density of Ramin mine is 2.1 ton/m^3.

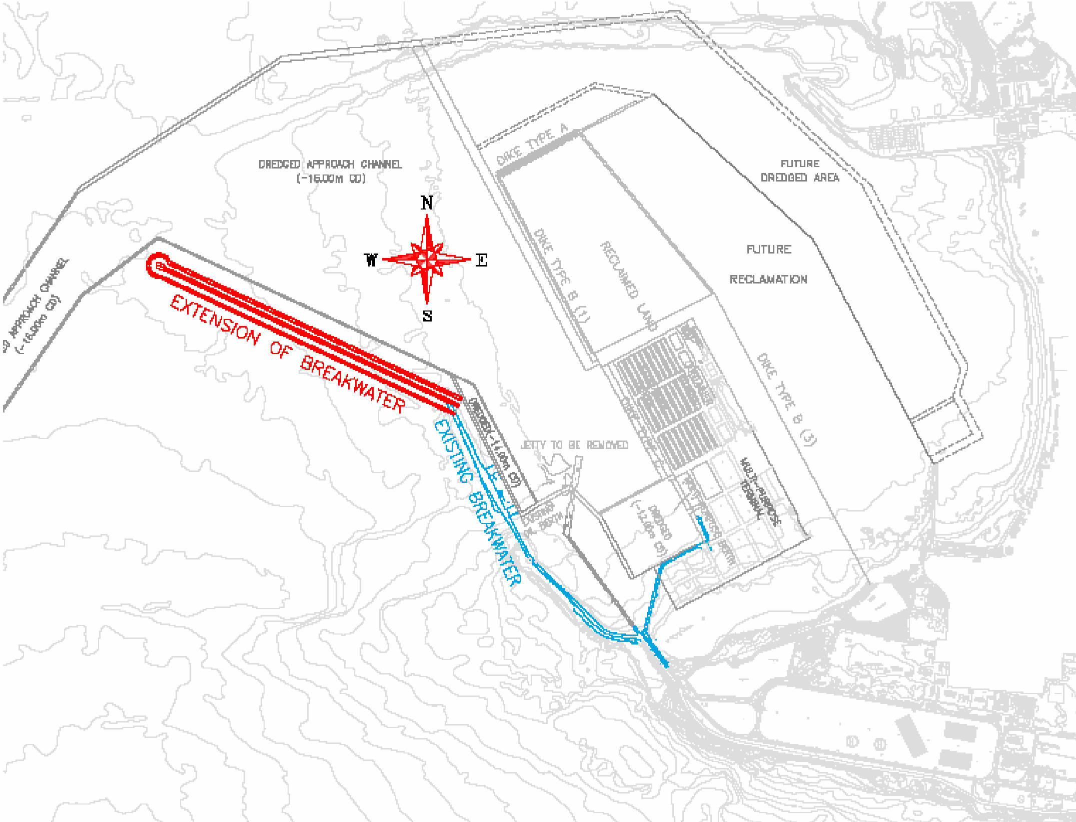


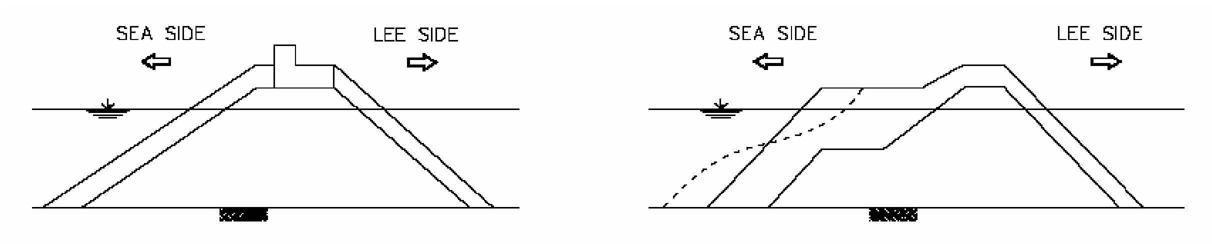
Figure 1: Shahid Beheshti Port Development

BERM BREAKWATER

Considering the design wave height, which is exceeded of 5 meters, the conventional breakwaters needs very large heavy rocks for armour layer. However, the application of rock is limited as the maximum rock size is limited and there is also no large size rock with appropriate quality in the vicinity of project location. Therefore Berm Breakwater is considered.

A conventional rubble mound breakwater is required to be almost statically stable for the design wave conditions, while the berm breakwater has traditionally been allowed to reshape to a statically stable or a dynamically stable profile as indicated in Figure 2, although recently non-reshaping statically stable berm breakwaters have also been considered. Berm breakwater is divided into three categories:

1. Statically stable non-reshaped. In this condition low stones are allowed to move, similar to the condition for a conventional rubble mound breakwater.
2. Statically stable reshaped. In this condition the profile is allowed to reshape into a profile, which is stable and where the individual stones are also stable.
3. Dynamically stable reshaped. In this condition, the profile is reshaped into a stable profile, but the individual stones may move up and down the front slope.



Conventional rubble mound breakwater　　　Berm rubble mound breakwater

Figure 2: Comparison between conventional and berm rubble mound breakwater

The berm breakwater has normally been constructed with a berm that has been allowed to reshape instead of constructing it with the reshaped profile directly. This is so because it has been considered cheaper to construct the breakwater with a reshaping berm. In recent years, there has been a drive to design the berm breakwater in such a way that it will not reshape at all, because the reshaping process may eventually lead to excessive breaking and abrasion of individual stones. However, many of the "old" reshaped berm breakwaters have functioned quite well without excessive breaking and/or abrasion of the stones. Obviously, the question of allowing reshaping or not has to do with stone quality and its ability to withstand impacts leading to breaking and/or abrasion.

According to [4], armor weight for statically and dynamically stable breakwater is calculated by the formula below:

$$N_S = \frac{H_S}{\Delta D_{n50}} \;;\; W_{n50} = \rho_s D_{n50}^{\;3} \quad (1)$$

The amount of N_S depends on the acceptable damage presented in Table 1. The N_S value is proposed between 1.5 and 6.

Table 1: N_S values for different mobility criterion

Regime	N_S
Little movement (non-reshaped, statically stable)	<1.5-2
Little movement (reshaping, statically stable)	1.5-2.7
Relevant movement (dynamically stable)	>2.7

ARMOR SIZE AND STABILITY

As shown in the above table, for calculating the armor size and stability, different values of N_S have been implemented for mobility criterion of armour unit. Here, by accepting threshold of dynamically stable condition, the value of N_S is supposed to be 2.90.

Design wave (1 in 100 year wave condition)

$$\begin{cases} H_s = 5.30m \\ T_P = 10.69\,Sec \Rightarrow T_m \approx 8.91\,Sec \end{cases}$$

$\Delta = (\rho_s / \rho_w - 1) = (2.1/1.03 - 1) = 1.04$, $N_s = 2.90$, So:

$$N_s = \frac{H_s}{\Delta D_{n50}} \rightarrow D_{n50} = \frac{H_s}{N_s \Delta} = \frac{5.30}{2.9 \times 1.04} = 1.76m \Rightarrow W_{n50} = 11.39\,ton$$

Based on obtained values, the rock stones are designed to be between 9 and 14 tons.

By considering other hydraulic and geotechnical criteria, designed cross section for body of breakwater is presented in figure 2.

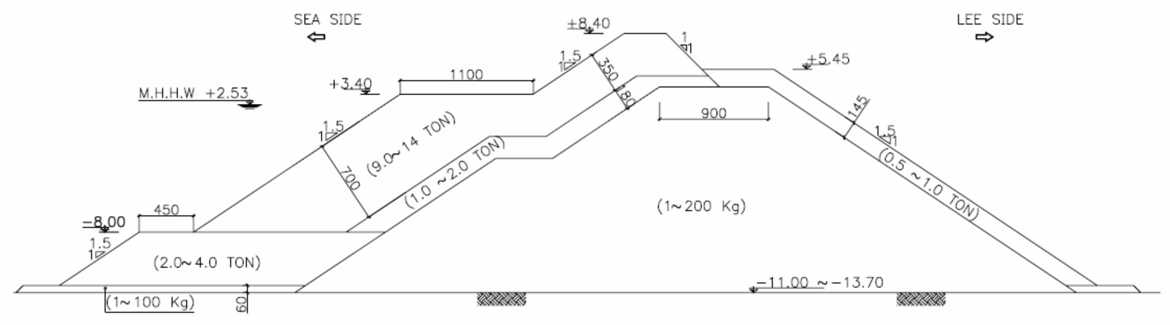


Figure 2: First alternative – typical section of trunk

RUBBLE MOUND BREAKWATER WITH TETRAPOD ARMOUR

Rubble Mound Breakwater with Tetrapod Armour is designed as the second alternative. Tetrapod Armour as illustrated in figure 3 is considered as a representative of two layers concrete armour units. The Laboratoire Dauphinois d'Hydraulique (predecessor of Sogreah) introduced in 1950 the Tetrapod. The main advantages of the Tetrapod were a slightly improved interlocking comparing to a Cube and a large porosity of the armour layer, which causes a little wave energy dissipation and reduces the wave run-up. Tetrapod have been tested for slopes of 1:1.5 and 1:2. It is usually recommended to use a slope of 1:1.5. In this alternative, a slope of 1 (vertical) in 1.5 (horizontal) is considered at sea side and lee side of breakwater. According to SPM(1984), for applying Hudson formula, The K_D values for Tetrapod at non-breaking wave condition that has been used for designing shall be considered equal to 8 and 6 for trunk and head of breakwater respectively [5].

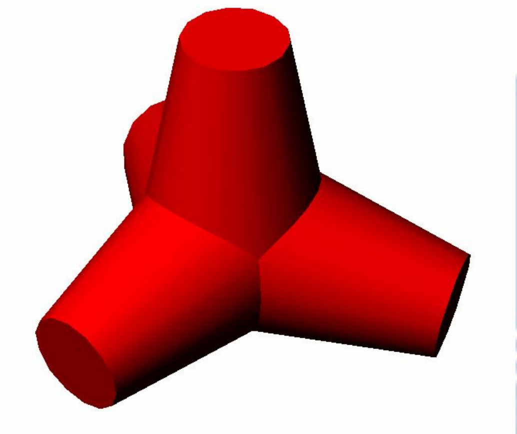


Figure 3: Tetrapod armor unit

Hudson formula:

$$W_{n50} = \frac{\rho_s H^3}{K_D \Delta^3 Cot\alpha} \quad (2)$$

Based on K_D values and Hudson formula the weight of an individual armour unit for trunk and head are 13.85 and 18.47 tones respectively.

Van der Meer (1988b) has introduced following formula for Tetrapod armor unit stability [6]:

$$N_s = \frac{H_s}{\Delta D_n} = (3.75 N_{od}^{0.5} / N_z^{0.25} + 0.85) S_{om}^{-0.2} \quad (3)$$

where:

N_{od} : Number of units displaced out of the armour layer within a strip width of one cube length D_n

For Tetrapod armour with 1:1.5 slope: $N_{od} = (S-1)/2 = (2-1)/2 = 0.5$ (Van der Meer, 1988)

N_z : Number of wave

Based Van der Meer formula the weight of an individual armour unit for trunk is 13.53 tones.
So the weight of Tetrapod armour unit for trunk and head shall be 14 and 20 tons respectively.
By considering other hydraulic and geotechnical criteria, designed cross section for body of breakwater is presented in Figure 4.

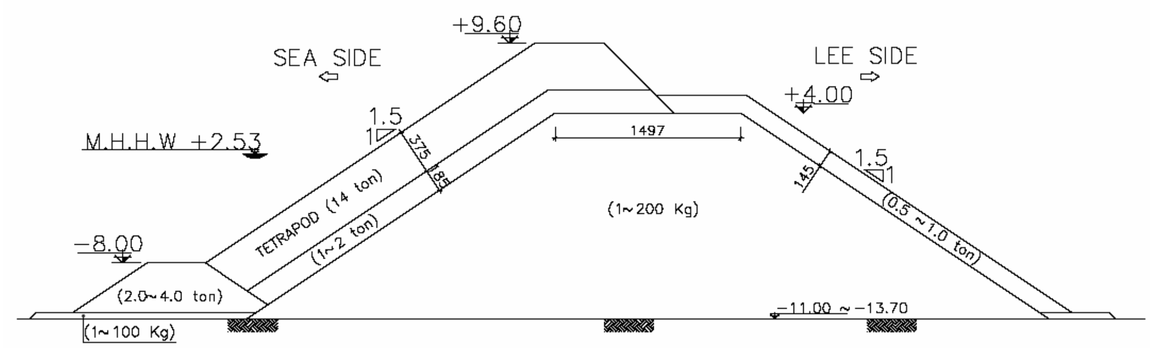


Figure 4: Second alternative – typical section of trunk

RUBBLE MOUND BREAKWATER WITH X-BLOC ARMOUR

Rubble Mound Breakwater with X-bloc Armour is designed as the third alternative. Since 1980, single layer randomly placed armor units have been applied as an alternative to the traditional double layer armor layers. Of these single layer armor units, the Accropode became the leading armor unit worldwide for the next 20 years. Typical features of these single layer armor units are high interlocking, random placement and economical advantages. The economical benefits of a single layer armor unit in comparison to the traditional multilayer armor layers are low concrete consumption and shorter construction time.

In recent years coastal engineers of Delta Marine Consultants [DMC] have developed a new single layer randomly placed armor unit, the X-bloc as illustrated in figure 5. The hydraulic stability of the X-bloc was tested at Delft Hydraulics and other reputed hydraulic laboratories, like the DHI. Results from these tests demonstrate that the X-bloc has similar hydraulic stability as Core-Loc and slightly higher than Accropode. Prototype drop tests and Finite Element calculations indicate that the X-bloc has similar structural strength as Accropode and it is stronger than Core-Loc.

Due to the simple shape of the X-bloc production, its handling is easier than that of Accropode and Core-Loc.

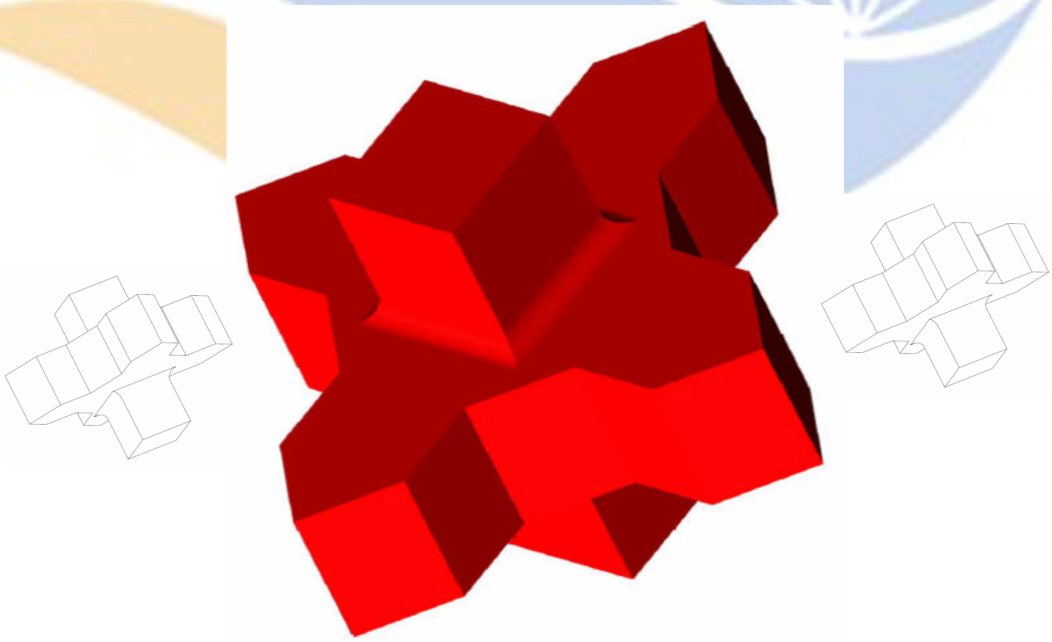


Figure 5: X-bloc armor unit

The important advantage in comparison to other units is the ease of placement. Therefore X-bloc is chosen as main unit for the study of placement of single layer armor units.
The K_D values for X-bloc that used for designing are 16 and 13 for trunk and head of breakwater respectively [7].
Based on these values and Hudson formula the weight of an individual armour unit for trunk and head are 6.92 and 8.52 tons respectively. So the applied weight of X-bloc armour unit for trunk and head of breakwater shall be 7 and 9 tons respectively. By considering other hydraulic and geotechnical criteria, designed cross section for trunk of breakwater is shown in Figure 6.

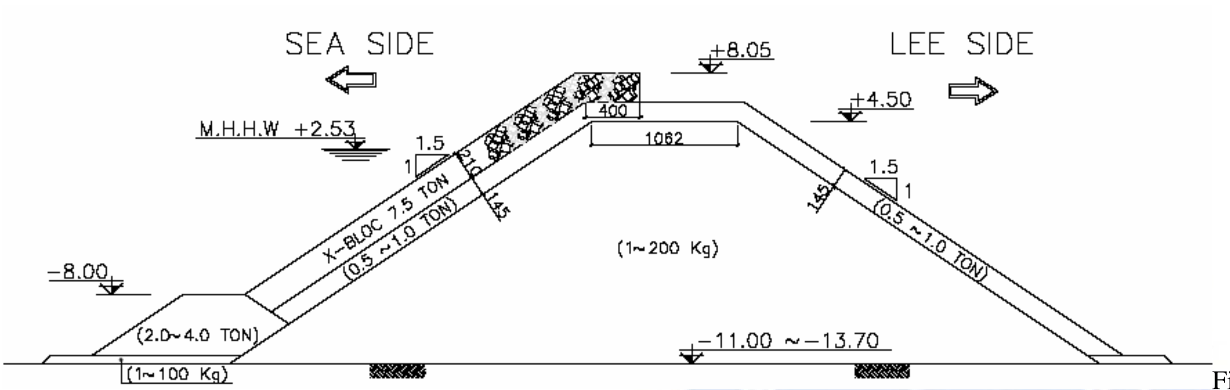


Figure 6: Third alternative – typical section of trunk

EVALUATION AND CONCLUSION

One of the most important parameter for Berm breakwater is availability of high quality rock sources in the vicinity of the projects. Around the chabahar, there are several mines like Ramin, Tiss, Beris and Pirsohrab, but their materials which are dominantly Lomashells will undergo high amount of erosion especially in dynamic conditions. So, the applying of local source materials as armour layer is not acceptable. Also providing and transporting of large amount of materials from sources located far from the project area is not commercially and practically feasible. So Berm breakwater is not recommended.
Among two other considered alternatives, X-bloc is proposed as the best alternative respecting the below technical and commercial advantages.

1. High hydraulic stability and reserved stability if the incidental wave height exceeds the considered design wave
2. High porosity and roughness of the armor layer (maximum dissipation of wave energy)
3. High structural strength
4. Ease of the X-bloc placement
5. Light equipment requirements for execution
6. Low maintenance requirements
7. Single layer placement and minimum required rock and concrete materials
8. Less overall expense

Cost estimation for considered alternatives is presented in table 2 as well as their required material. It should be noted that required concrete for X-bloc breakwater is about 38% of required concrete for Tetrapod breakwater and this will decrease the total cost significantly.

Table 2: Comparison between required material and cost for proposed alternatives

	Required concrete (m^3)	Required Rock material (m^3)	Ratio of estimated cost to X-bloc alternative
Barm breakwater	0	1,803,084	1.39
Tetrapod	118,843	1,375,696	1.82
X-bloc	45,904	1,298,933	1

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