ROUGH ESTIMATION OF MATERIALS QUANTITIES FOR CONSTRUCTION OF HARBORS

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ABSTRACT

In this paper an analytical model is proposed to estimate roughly the materials required for construction of breakwaters of harbors. The proposed model is applicable for the harbors having the square-shape plan basin and the cases that the bathymetry map at the location of the harbor is not available (i.e. a few limited simple measurements or information from water depth or sea bottom slope is available) and the maximum water depth is known from the draft and clearance of the Design Ship. The materials (core, filter layer and armor layer) required for construction of breakwaters are roughly estimated by considering the maximum draft of the Design Ship selected to transport the cargos to the harbor and environmental parameters. By calculating the weights and thicknesses of breakwater section, geometry of breakwaters and also the area of a square basin harbor needed to shelter the ships, the amount of materials required to construct the breakwaters considering a proposed Simplified Estimation Model (SEM) for water depth-length relationship are estimated. To validate the formulation proposed for estimation of material quantities of breakwaters, a case study was applied to seven harbors having quasi-square basin plan, located in Iranian waters in the Persian Gulf. The estimated weights using the proposed SEM and Detailed Estimation Model (DEM) were compared using the bathymetry maps and layouts of these harbors. This comparison shows that considering the acceptable tolerances in the conceptual and basic design phases, the proposed SEM is a good tool to be used in the conceptual and basic design phases of a harbor project.

Keywords: Harbor, Rubble Mound, Breakwater, Material Quantity

INTRODUCTION

Since in the phase of planning, conceptual and basic design, some important decisions such as selection of location for construction of the harbor, the allocation of budget for getting the related approvals from top management of the Port and Maritime Organization, Ministry of Transportation, to submit the conceptual and basic design documents to the Planning and Budget Organization, and finally the Parliament for getting approvals and budget, as well as for the bid process and selection of contractor, an analytical model to estimate roughly the quantity of main material required for construction of the breakwaters of a harbor is needed.

The main steps of this research are:

1- To submit a suitable typical configuration for the section of breakwaters of harbors.

2- To propose an analytical model and computer application to estimate roughly the materials needed for the core, the filter layer and armor layer of breakwaters for different sea wave heights and different draft and clearance of the Design Ship.

A numerical simulation procedure is submitted to calculate the wave characteristics and wave loads applied to the breakwaters.

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Materials required for construction of breakwaters are roughly estimated by considering the maximum draft of Design Ship selected to transport the cargos to the harbor, allowable clearances and environmental parameters. By calculating the weights and thicknesses of breakwater sections layers (core, filter layer and armor layer), geometry of breakwaters, transversal and longitudinal sections and also the area of the harbor basin needed to shelter the ships and jetties, the quantity of materials required for construction of the breakwaters are estimated, considering the proposed SEM for waterdepth-length relationship.

To prepare the planning to construct a harbor, the requirements ofthe harbor master planand the application of ICZM rules and regulations also should be considered. (Nouban & Sadeghi, 2013a)

SEA WAVES SIMULATION

Bretschneider, JONSWAP and Pierson-Moskowitz spectrums and formulas are typically employed in the calculation and analysis of the wave parameters in seas and oceans (US Army Corps of Engineers, 2002; US Army Coastal Engineering Research Center, 1980; Sadeghi, 2008). Stream Function, Solitary and Cnoidal wave theories are used mainly for evaluation of waves in shallow waters. Airy, Stockes' (second and fifth orders), and Trochoidal waves are used to determine the wave characteristics in deep waters. See (Sadeghi, 1989,2001, 2007a, 2007 b, 2008, 2013; Sadeghi & Nouban, 2013a).

To estimate the quantity of materials of breakwaters, the formulas proposed by Bretschneider are used to estimate the wave characteristics in deepwater, then by considering the factors related to the effects of the seabed on the waves (shoaling and refraction phenomena), the wave characteristics of transitional and shallow waters are simulated (Sadeghi, 2008, 2007a, 2007b; Sadeghi & Nouban 2013b; U.S. Army Coastal Engineering Research Center 1980).

BREAKWATERS' COMPONENTS

Since among the different types of breakwaters, the rubble-mound breakwaters are the most commonly constructed type of breakwater, the rubble mound structures are presented in this paper.

The conventional rubble-mound breakwaters consist of a core, the filter layer and armor layer are also referred to as multilayer structures. The core is made of finer material, which is covered by bigger size filter layer. Filter layer is covered by big blocks forming the armor layer. The filter layer (also called underlayer) is used to prevent finer material being washed out through the armor layer.

Weight of Armor Units

Hudson formula (Equation 1) (MPO, 2006) has been used for calculation of armor units' weights:

$$W = \frac{w_r \,.H^3}{K_D \,.(S_r - 1)^3 .Cot\theta} \qquad (1)$$

Where:

W represents the design weight of the armor unit(riprap) (Ton)

w_r represents the specific weight of the armor units (Ton/m^3)

H represents the design wave height at the toe of the breakwater (m)

K_D represents the stability coefficient given in (U.S. Army Corps of Engineers, 2011)

$S_r = \rho_r / \rho_w$, where ρ_r and ρ_w represent the densities of armor unit and seawater

θ represents the slope of armor layer with the horizontal

Calculation of Weights of Core and Filter Layer Materials

The weights of the layers of the section of breakwater trunk, recommended by U.S. Army Coastal Engineering Center (2011) are used in the estimation of materials. Estimation of weights of other layers (bedding layer, core and filter layer) for the section of breakwater trunk is performed by applying the values given in the proposed configuration given in Figure 1.

The thicknesses of the armor and filter layers are found by applying the following formulas (U.S. Army Corps of Engineers, 2011):

$$r_a = nk_\Delta (\frac{W_a}{w_a})^{1/3} \quad (2)$$

$$r_f = nk_\Delta (\frac{W_f}{w_f})^{1/3} \quad (3)$$

Where $W_a = W$ and $W_f = W/_{10}$, r_a and r_f represent the average thickness of the armor and filter layers, respectively; n represents the number of concrete or quarry stone armor units in the armor layer thickness (normally n equals to 2); W represents the weight of a single armor unit; W_a and W_f represent the weights of asingle armor unit and single filter layerunit, respectively; w_a and w_f represent the specific weights of the material of armor unit and filter layer, respectively.

PROPOSED SEM

Proposed Section for Breakwaters of Harbors

A typical section for trunk body of breakwaters is proposed as shown in Figure 1. The proposed section, is suitable for construction of breakwaters from land by using dump trucks for handling and purring or placement of materials. The top level of the core layer is considered at the Maximum Design Sea Water Level (SWL) in astronomic high tide. This is due to giving opportunity to the trucks to work in a dry level on the core layer at any moment (Nouban, 2015, 2016).

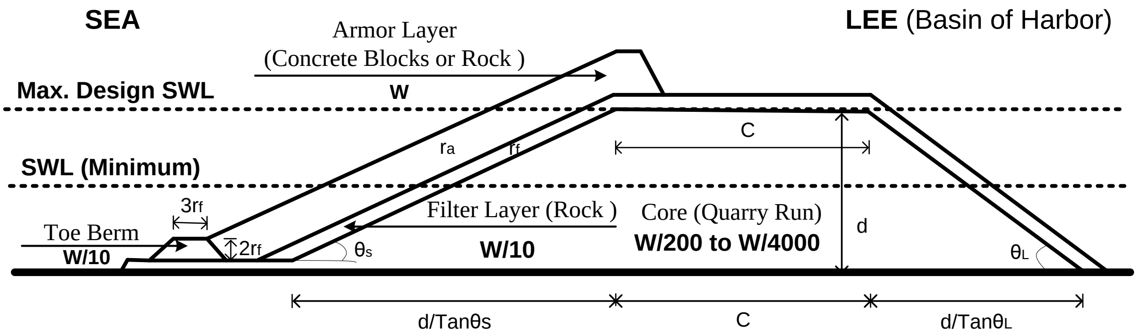

Figure 1. Proposed typical section for breakwaters of a typical harbor

Proposed Formulation

The formulation for estimation of materials of breakwaters for a square basin harbor, considering a linear-constant relationship between the waterdepth and the distance from the shoreline is proposed as follows:

The core cross-section area(A_c) for the typical proposed section shown in Figure 1 is as follows:

$$A_c = (d)\left[C + \left(\frac{d}{2}\right)\left(\frac{1}{Tan\theta_S} + \frac{1}{Tan\theta_L}\right)\right] = (d)\left[C + \left(\frac{d}{2}\right)(Cot\theta_S + Cot\theta_L)\right] \quad (4)$$

The Filter layer cross-section area(A_f) for the typical proposed section is as follows:

$$A_f = r_f[C + (d)\left(\frac{1}{Sin\theta_S} + \frac{1}{Sin\theta_L}\right) + 10r_f] \quad (5)$$

The Armor layer cross-section area(A_a) for the typical proposed section is as follows:

$$A_a = r_a[(d)\left(\frac{1}{Sin\theta_S}\right) + 3r_a] \quad (6)$$

Where:

d: Water depth (from Max Design tide sea level "Max. Design SWL" to seabed)

C: Crest width of core layer

θ_s: Slope angle of armor and filter layers in seaward side

θ_L: Slope angle of the filter layer in leeward side

r_a: Thickness of armor layer

r_f: Thickness of filter layer

In Figure 2, a plan of square basin or similar plan of a harbor, showing lengths and depths of breakwaters, are shown. The assumption used in this figure for lengths, slopes and waterdepths are used in the rough estimation of materials required to construct the breakwaters. In this model two types of waterdepths are considered for the breakwaters: a linearly variable waterdepth(constant slope) and a constant waterdepth(zero slopes) as shown in Figure 3.

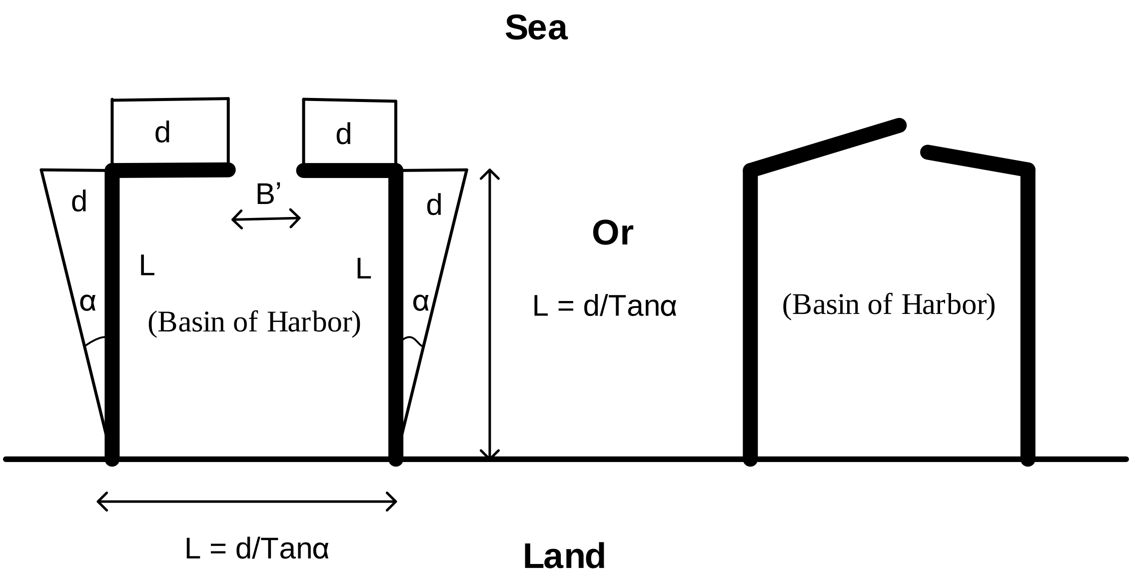

Figure 2. Plan of square basin, showing lengths and waterdepths

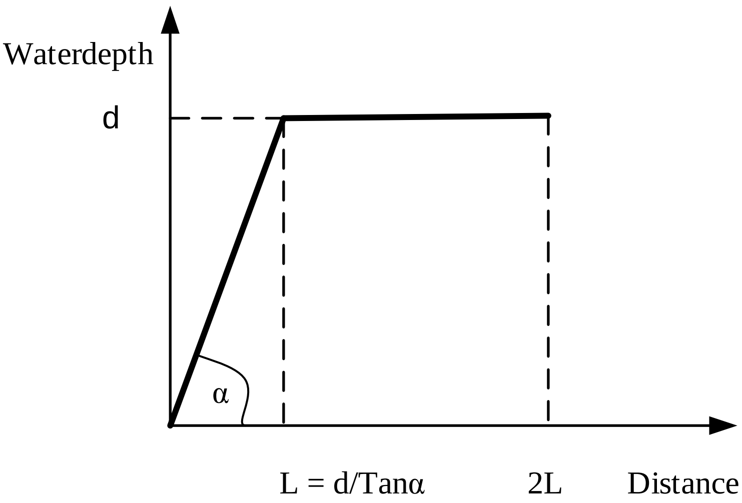

Figure 3. Proposed SEM

The following lengths are considered for a square basin harbor or similar, as shown in Figure 2:

L: Length of the part of the main breakwater constructed on a slope of α on seabed

B': Entrance Channel width, considered as three times of design ship breath (B' = $3B_s$), B_s represents the design ship width.

Since the section area of core (A_c) changes non-linearly versus depth, and at depth d/2 the area is less than half of area at section having waterdepth d.To calculate the volume of core materials between zero depth and depth d, the half of section at depth d, multiply to the length of the breakwater and a reduction factor K_R is considered.

For a breakwater with C = 7m, $Cot\theta_S = Cot\theta_L = 1.5$, using Equation (4), gives:

At d = 0, $A_{c,0} = 0$

At d = d/2, $A_{c,d/2} = (d/2)\left[7 + \left(\frac{3d}{4}\right)\right]$

At d = d, $A_{c,d} = (d)\left[7 + \left(\frac{3d}{2}\right)\right]$

The core area increases nonlinearly with a quadratic form when waterdepth increasing. This is one reason that we have adopted reduction factor $K_R$to the average area for the middle section (at waterdepth d/2) between zero waterdepth and waterdepth d for the core. Thus the proposed Reduction Factor to the average area is defined as follows:

$$K_R = \frac{A_{c,\frac{d}{2}}}{\frac{(A_{c,d}+A_{c,0})}{2}} = \frac{7+\left(\frac{3d}{4}\right)}{7+\left(\frac{3d}{2}\right)} \qquad (7)$$

The Reduction Factor to the average area (K_R) for core, decreases nonlinearly form 1 (at zero waterdepth) and for deeper waters it approaches mathematically to the exact value of 0.5.Therefore,$K_R$has a value between 1 and 0.5 from very shallow water to very deep water, respectively.

In linear-constant waterdepth case, to calculate the total volume ofthe core, the total equivalent length ($L_{eq,t}$) for a constant section at a waterdepth of "d" is as follows:

$$L_{eq,t} = (1 + K_R)L - 3B_s = \frac{(1+K_R)d}{Tan\alpha} - 3B_s \qquad \text{(for core)} \qquad (8)$$

Core material volume, V_c for the typical proposed section and for square basin harbor is:

$$V_c = (d)[(1 + K_R)L - 3B_s][C + (\frac{d}{2})(Cot\theta_S + Cot\theta_L)] \quad (9)$$

For filter layer, since its volume variation versus waterdepth is linear, K_R =1. Filter layer material volume V_f for the typical proposed section and for square basin harbor is:

$$V_f = (r_f)[2L - 3B_s][C + (d)\left(\frac{1}{Sin\theta_S} + \frac{1}{Sin\theta_L}\right) + 10r_f] \quad (10)$$

For armor layer, since its volume variation versus waterdepth is linear, K_R =1. Armor layer Core material volume V_a for the typical proposed section and for square basin harbor is:

$$V_a = (r_a)(2L - 3B_s)[(d)\left(\frac{1}{Sin\theta_S}\right) + 3r_a] \quad (11)$$

The minimum crest width of the breakwater on the armor layer level is determined by the following formula (U.S. Army Corps of Engineers, 2011):

$$B = nk_\Delta(\frac{W}{w_a})^{\frac{1}{3}} \quad (12)$$

Where B represents the crest width, n represents the number of stone armor units (The recommended minimum value of n is 3), k_Δ represents layer coefficient, given by (U.S. Army Corps of Engineers, 2011), W represents the weight of armor unit andw_a represents the specific weight of armor unit material.

Actually the crest should be wide enough to accommodate the construction and maintenance equipment used during construction and operation periods on the breakwater. A crest width of 7 m is considered for the top level of core layer (C). This value allows passing two trucks side-by-side to each other during the construction period. To reduce the amount of materials used in the core and filter layer, it is normal to use a crest width of 3-4m for the top level of the core layer (C) along with a number of parking places constructed each 50 meters to allow two trucks pass side-by-side of each other at parking places.

The thickness of the armor and filter layers are calculated applying Equations (2) and (3), respectively.

Core material total weight (TW_c) for the typical proposed section and for square basin harbor is:

$$TW_c = w_c(d)[(1 + K_R)L - 3B_s][C + (\frac{d}{2})(Cot\theta_S + Cot\theta_L)] \quad (13)$$

Filter layer material total weight (TW_f) for the typical proposed section and for square basin harbor is:

$$TW_f = w_f\left(1 - \frac{p}{100}\right)(r_f)(2L - 3B_s)[C + (d)\left(\frac{1}{Sin\theta_S} + \frac{1}{Sin\theta_L}\right) + 10r_f] \quad (14)$$

Armor layer material total weight (TW_a)for the typical proposed section and for square basin harbor is:

$$TW_a = w_a\left(1 - \frac{p}{100}\right)(r_a)(2L - 3B_s)[(d)\left(\frac{1}{Sin\theta_S}\right) + 3r_a] \quad (15)$$

COMPUTER PROGRAMMING AND APPLICATIONS

Computer Programming

Computer programming and application have been performed (Nouban& Sadeghi, 2014) to estimate the materials required to construct breakwaters roughly.

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Figure 4 shows the Overall flow chart for the main of rough estimation of materials for construction of breakwaters.

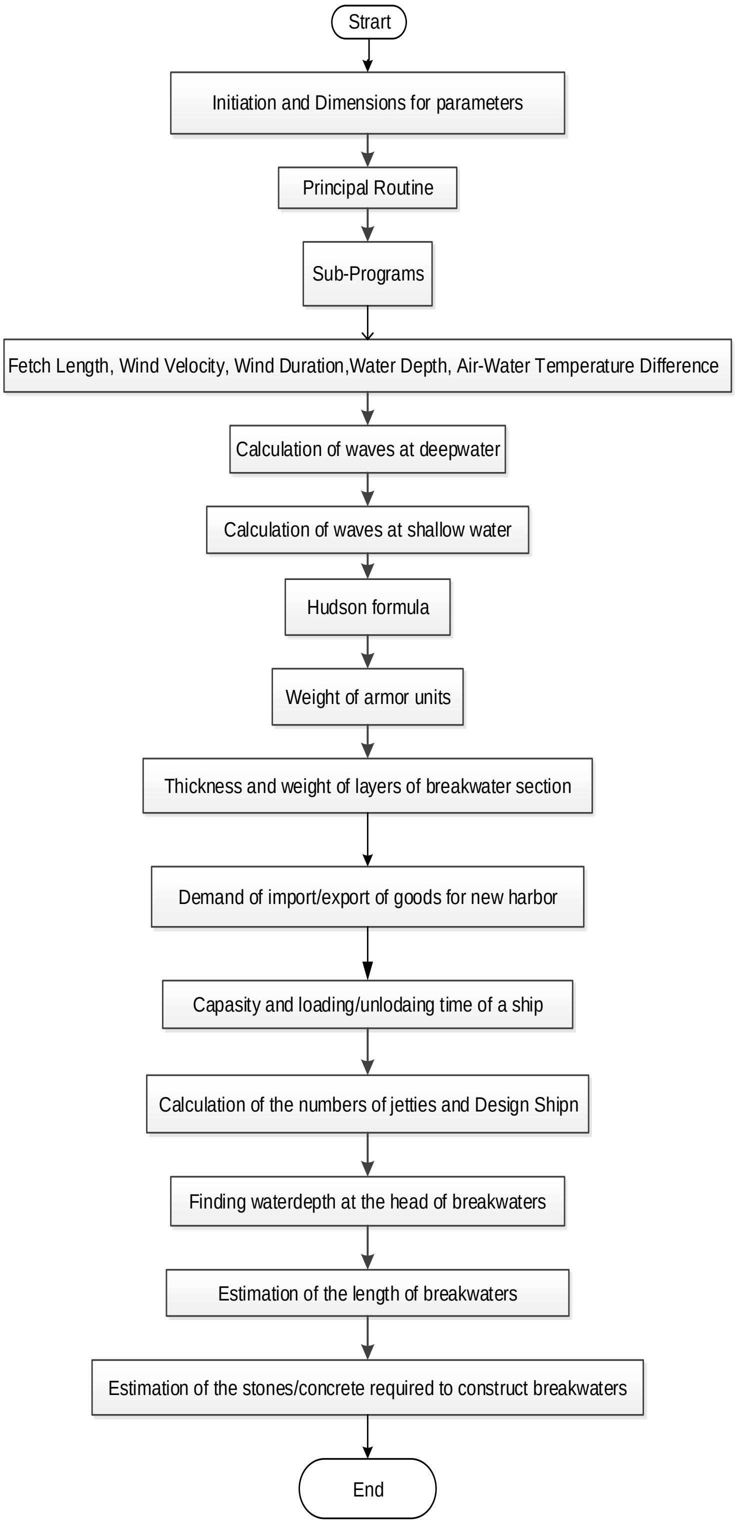

Figure 4. Overall flow chart for the best location of harbor and estimation of materials

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Application of Materials Quantities Estimation Formulation

To examine the validity of the proposed model for estimation of material quantities of breakwaters for the country case study, Iran, seven square basin plan harbors were selected (PMO, 1974a, 1974b, 1995). The results of the comparison of the proposed formulation for estimation of materials of breakwaters for a harbor (SEM) with DEM (general case), applying the proposed section, are submitted in Tables 1 and 2.

Table 1. illustrates the comparison of the estimated weights using the proposed SEM and DEM. In Table 2, the percentages of overestimation or underestimation of the weights for core, filter layer, armor layer and total weights of different harbors are given. These overestimations or underestimations are calculated using the proposed SEM compared to the submitted general case formulas models. In all cases the proposed breakwater section is applied.

Table 1. Comparison of the estimated weights using the proposed SEM and DEM

Item no.	*Port name*	*Core (Ton)*		*Filter layer (Ton)*		*Armor layer (Ton)*		*Total weight (Ton)*	
		SEM	DEM	SEM	DEM	SEM	DEM	SEM	DEM
1	Kish	149,544	138,239	43,472	46,741	25,618	25,848	218,634	210,829
2	Tunb	311,640	296,047	56,180	55,789	35,512	33,768	403,332	385,604
3	Farur	201,633	231,056	31,287	37,551	20,229	22,902	253,149	291,509
4	Kangan	156,999	181,272	36,375	47,846	22,010	27,466	215,384	256,584
5	Langeh	183,098	143,413	44,656	52,903	26,506	28,737	238,338	224,952
6	Larak	134,760	146,153	28,118	32,803	17,460	19,159	180,337	198,115
7	Sirri	100,777	89,905	34,744	45,114	19,526	23,584	155,048	158,603

Table 2. Percentages of over/underestimation (+/-) of weights using SEM

Item no.	*Port name*	*Core (%)*	*Filter layer (%)*	*Armor layer (%)*	*Total weight (%)*
1	Kish	+8.2	-7.0	-0.9	+3.7
2	Tunb	+5.3	+0.7	+5.2	+4.6
3	Farur	-12.7	-16.7	-11.7	-13.2
4	Kangan	-13.3	-24.0	-34.4	-19.9
5	Langeh	+16.6	-15.6	-7.4	+5.9
6	Larak	-7.8	-14.3	-8.9	-9.0
7	Sirri	+10.8	-23.0	-17.2	-2.2
	Average error	+1.0	- 18.5	- 10.7	- 4.3

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As it can be seen from Table 2, the proposed SEM underestimates the filter layer weight less than 20%, armor layer weight about 10% and the total weight of breakwater less than 5%. The average error for the weight of stones of the core is about+1%.

In general conclusion, since for the conceptual design the tolerances of ∓30% and for the basic design phase the precision of ∓15% is acceptable, the proposed SEM is a good tool to be used in the conceptual and basic design phases of a harbor project, especially for the core and total weight estimations. Besides, for the filter and armor layers for most cases, there are underestimation only (not overestimation). This fact can be considered in the estimations and can be compensated somehow. This model can be applied in the cases that the bathymetry map at the location of the harbor is not available and only the maximum waterdepth is known from the draft of the Design Ship. This model is applicable for conceptual and basic design phases.

CONCLUSION

An analytical simplified model is proposed for construction of a harbor, having the rubble mound breakwaters. Using the proposed model helps the clients, at the planning phase of a harbor to obtain a quick estimation of material quantity. It gives a good tool to estimate the materials required for construction of breakwaters of a harbor. The proposed model shows close agreement with the detailed estimation used in the harbors constructed, in the case study country, Iran.

Materials required for construction of breakwaters are roughly estimated by considering the maximum draft of the Design Ship selected to transport the cargos to the harbor, keel clearances of the Design Ships and environmental parameters. By calculating the weights and thicknesses of breakwater sections layers (bedding layer, core, filter layer and armor layer), geometry of breakwaters transversal and longitudinal sections and also the area of the harbor basin needed to shelter the ships and jetties, the amount of materials required to construct the breakwaters considering a linear-constant curve for waterdepth-length relationship are estimated.

To validate the formulation proposed for estimation of material quantities of breakwaters, a case study was applied to seven harbors having quasi-square basin plan located in Iranian waters in the Persian Gulf. The estimated weights using the proposed SEM and DEMwere compared using the bathymetry maps and layouts of these harbors. This comparison shows that considering the acceptable tolerances in the conceptual and basic design phases, the proposed SEM is a good tool to be used in the conceptual and basic design phases of a harbor project. This model is applicable for conceptual and basic design phases, and can be applied for the quasi-square basin harbors and for the cases that the bathymetry map at the location of the harbor is not available and only the maximum waterdepth is known from the draft of the Design Ship.

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