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Experimental investigation of parameters affecting the stability of articulated concrete block mattress under wave attack

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ABSTRACT

Revetment is a protective structure for a shoreline with stony material, usually natural stone or concrete, with a thickness of only one layer of elements and of which the elements are placed in a pattern. Various conditions of designing and implementing coastal protection structures such as implementation speed and construction cost; cause the use of Articulated Concrete Block Mattress (ACB Mat). ACB mattresses have an appropriate flexibility that can be installed on different conditions of slope revetments. ACB mat system includes a filter layer that allows infiltration and exfiltration to occur while providing particle retention of the soil subgrade. To determine the extent of the effect of hydrodynamic, structural and non-structural factors as well as presenting dimensionless relations and design charts of ACB Mats, experimental data are needed which can be achieved by an appropriate laboratory scale model ($\lambda = 1 : 10$). In the present study, the effect of various parameters was investigated to improve existing formula by adding effects of mattress length, construction slope, filter layer, ACB mat thickness and friction coefficient. Accordingly, new modified equation was obtained by adding parameters; stability shifting factor, stability course factor and stability shape factor which can be presented as "$1.8 < a < 5.4$", "$7 < b < 12$" and "$c \approx 1$" respectively. At the end, six design charts will be presented which can be helpful to determine minimum length of mattress for different wave's characteristics and construction's slope on two type of filter layer.

1. Introduction

Various conditions of designing and implementing coastal protection structures such as implementation speed and construction cost, and the distance of appropriate stone materials transportation should be considered in such projects. In some regions, the distance of stone materials' mine is too long and the cost of stone structures implementation are extremely increased. Due to such problems, the possibility of replacing other materials (instead of stone) should be investigated. In such conditions, one of the common ways is to use concrete block armours (such as Tetrapod, Accropode, XBlock, etc) which are designed and made in various shapes and sizes. On the other hand, using such armours has its own problems. For instance, using common concrete armours imposes cost; therefore, they may not be so different from stone armours which can be better alternatives that have been suggested and studied for these regions. To increase the speed of implementation and decrease the weight of concrete blocks unit, concrete blocks can be designed and implemented as ACB Mats. This structure acts integrally and can be used as a revetment in coastal zones. ACB mattresses have an appropriate flexibility that can be installed on different conditions slope coastlines and breakwater. ACB mat revetment system includes a filter layer underlay that allows infiltration and exfiltration to occur while providing particle retention of the soil subgrade. The filter layer may be comprised of a geotextile or properly graded aggregate or both. Considering current information and formula design available, there is no possibility of taking advantage of this revetment

Environmentally, block revetment can be provided a suitable condition for growing marine plants. Articulated concrete block mattresses have porous and very rough surface. On the other hand, they have open area that allows growing plants on the lower bed. ACB Mats also allow marine organisms, particularly seaweeds to stick and grow. Therefore, an environment-compatible coastal cover is obtained. The negative effect of blocks is very limited and they have almost no considerable effect on hydro-system in beaches and rivers [1].

By reviewing the coastal revetments failure mechanisms, it is revealed that hydrodynamic forces due to wave attacks and current

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Nomenclature

Notation

A	Cross section (m^2)
D	Thickness of a top layer (m)
D_{50}	Median diameter of the aggregate size distribution (m)
E	Module of elasticity (N/m^2)
F	Total stability factor
F_p	Downward force (N)
F_r	Resistance force (N)
F_t	Tension force (N)
G	Gradient of the original experimental determined relation
H_s	Significant wave height (m)
H_{scr}	Critical significant wave height (m)
L_{mat}	Mattress length (m)
L_{wave}	Wave length (m)
M	Mass of an element (kg)
M_A	Mass per unit area (g/m^2)
O_{90}	Geotextile characteristic opening size (m)
R	Tension force absorption ratio (capacity ratio)
$R_{d2\%}$	Run down (m)
T_{allow}	Allowable tensile strength (N/m^2)
T_P	Wave period at the peak of the spectrum (s)
T_{ult}	Ultimate tensile strength (N/m^2)
V_F	Velocity flow through the filter layer (m/s)
V_T	Velocity flow through the top layer (m/s)
a	Stability relation shift factor
b	Stability course factor
c	Stability shape factor
dA	Compartment width (m)
d_f	Diameter of fibers (m)
f	Stability coefficient, mainly dependent on structure type and with minor influence of Δ, tanα and friction
f_{CBD}	Reduction factor chemical and biological degradation
f_{CR}	Reduction factor creep
f_{ID}	Reduction factor installation damage
f_{UV}	Reduction factor installation damage
f_s	Friction coefficient
j	Permittivity (s^{-1})
k_F	Permeability of a filter layer (m/s)
k_n	Geotextile coefficient of permeability normal to its plane (m/s)
k_T	Permeability of a top layer
r	Tension force ratio
t	Thickness of a sub layer (m)
t_{GT}	Thickness of the geotextile (m)
Δ	Relative volumetric mass of concrete block
Λ	Leakage length (m)
$\mathfrak{R}$	Coefficient of determination
α	Slope angle (degree)
β	Exponent related to the interaction process between waves and revetment type –
ε	Strain (N/m^2)
ϕ_F	Piezometric head filter layer (m)
ϕ_T	Piezometric head on the top layer (m)
λ	Scale parameter
ρ_s	Density of the concrete block (kg/m^3)
ρ_w	Density of water (kg/m^3)
σ	Tensile stress (N/m^2)
ξ_{0p}	Breaker parameter
$-_{old}$	Subscript "old" stand for original situation
$-_{new}$	Subscript "new" stand for dependent situation
$-_p$	Subscript "p" stand for prototype situation
$-_m$	Subscript "m" stand for model situation

load cause various failures in revetments. These failures mechanisms can be categorized in three groups:

1. Mattress instability: Blocks compression in the direction of slope, particularly to the toe, local buckling of a part of revetment due to tensile forces towards the slope downstream, total mattress sliding, and the displacement of a part of mattress due to under pressure forces.
2. Instability of the bed and subsoil: Locally slip wedge known as S-profile, and erosion of the materials under the revetment.
3. Failure during the structure life (durability problem): rupture connections; block body erosion, transferring materials under the revetment to the surface, erosion and failure due to physical impact.

Some of failure mechanisms in blocks mattress, gabion mattress, geobags and geo-mattresses may be introduced similar to each other [2]. In general, coastal protective revetment design were presented based on some of certain revetments design manuals including the reports of EAK [3], EAU [4] and GBB [5], using design relations such as Hudson [6] and Van Der Meer [7]. Wouters [8] performed experimental researches on interlock blocks using a small scale (1:25) model. Wouters [8] investigated the stability of such revetments against waves. The results obtained by Wouters [8] cannot be generalized with respect to the effects of bed soil. Therefore, Gier et al. [9] completed Wouters' [8] results by a systematic study to analyze hydraulic stability of concrete block revetments. In 2011, PIANC [1] presented some advices for interlock concrete block revetments. PIANC [1] also presented the techniques of installing concrete block revetments.

Before 2003, few laboratory studies were performed on ACB Mats as coastal protective revetments and breakwaters. However, the studies performed by Pilarczyk [10] are considered as one of the most important resources of ACB Mats. According to Pilarczyk [10], when blocks are arranged very closely to each other without open area, the condition of higher permeability of top layer relative to the filter layer is not satisfied. Therefore, in revetment with low permeability, many uplift forces are created due to waves attacks. Under such conditions, the permeability ratio of filter and revetment shown in the form of leakage length is the most important structural parameter and determines uplift force. This issue forms the base of an analytical model which is based on the theory of rubble mound layer which is stable on a granular filter [11].

Also in recent years, other factors were considered in the determinants of the stable thickness of the hinged concrete slab mattress. Wu et al. [16] have discussed the stable thickness of the hinged concrete slab mattress under the different wave heights, water depths and wave periods. Zhou et al. [17] tested the stable thickness under the action of the stream. Tian et al. [18] investigated the stable thickness under the interaction of the regular wave and stream. But Wu et al. [16], Zhou et al. [17] implemented their researches based on the regular wave, the performances of the hinged concrete slab mattress under the irregular wave still unknown.

Cox et al. [19] with approaches for prediction of ACB mat stability use a moment stability analysis with a ratio of the boundary shear stress to critical shear stress to account for all hydrodynamic forces, which results in the exclusion of the flow velocity.