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An Overview of Construction and Installation of Vertical Breakwaters

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Abstract: ***Breakwaters have been constructed many years ago and the determination of their design criteria achieved by unsuccessful and successful experiences made them a role model wave breaking structures all over the world. Large and valuable facilities, land, harbors, and ports must be well protected from the effects of wind that generates waves by dissipating and reflecting the force exerted in order to prevent disasters as they play an important role in raising a nation's economy level. Still, many structural elaborated problems in designing breakwaters are yet to be solved. Choosing the right breakwater model considering the environment, water depth conditions, understanding associated with breakwater's failures, wave actions on breakwaters, advantages, disadvantages, important parameters to be taken into account before design and construction are of great significance. This paper gives an overview of some important ways to consider regarding breakwaters concentrating mainly on vertical upright and composite breakwaters. The aim of this paper is to provide the researchers with a clear understanding on how to make a quick decision for the best-fit vertical breakwater selection, where a safety factor and wave distribution formulas are also provided for the ease of design.***

Keywords: Breakwater Structures, Mounds Configuration, Functional failures, Construction parameters, Design safety factor.

I. INTRODUCTION

For the safety of ships and the transfer of cargos, harbors must be in a calm situation where a solution must be implemented. Breakwaters are constructed to provide the required safety in order to have harbors protected and acting as a major key role in the operation of ports that are subjected to wavy sea, in order words it is a worthy solution for protecting navigation channels. (1) Dealing with enormous forces that engender an impact due to sea waves on structures which had been constructed cannot be easily attenuated, therefore breakwater constructions are ideal solutions for resisting high waves. Great efforts had been made by maritime technology since almost 72 years ago and up to date, where the construction of highly stable breakwater structures against waves is now possible. Breakwaters are divided into different types which are mainly vertical and rubble mound breakwaters. Vertical breakwaters consist of upright walls and foundation made up of rubble mound (rubble = rough fragments of broken stone) or can be just upright walls with no rubble mounds.

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This process of formation categorizes it as a vertical breakwater making it of high importance and very well demanded around the world. The second type is rubble mound breakwaters, it contains a protective layer known as armor (concrete blocks designed in a certain shape) and an internal layer that contains rubble mound (2). This paper will only discuss vertical breakwaters.

1.1 Types of Vertical Breakwaters

Construction of breakwaters during the ancient time around the Mediterranean was done by blocky stones, sometimes with cementitious infill. Timber forms, bricks, cement and pozzolana where used by the Roman engineers for underwater constructions, therefore the history of breakwaters had gone through many damages and failure issues. Vertical breakwaters are mainly classified into different types which are mainly caisson, upright, composite, piled with concrete wall, perforated front wall, semi-circular caisson and dual cylindrical caisson breakwaters, only upright and composite breakwaters will be discussed in this paper. Vertical upright breakwaters main purpose is to stand against waves by reflecting them which is totally different from composite breakwaters which break waves depending on its mound height. Vertical breakwaters can be with or without mounds as shown below (3).

- Upright vertical breakwater which does not consist of mound foundation is demonstrated in Figure 1.

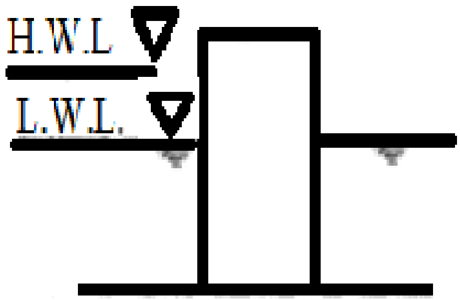

Figure. 1 No Mound Vertical Breakwaters (6)

- Composite breakwater which mainly consists of rubble mound foundation can be classified into three types (low mound, relatively high mound and high mound) as shown below in figure 2.

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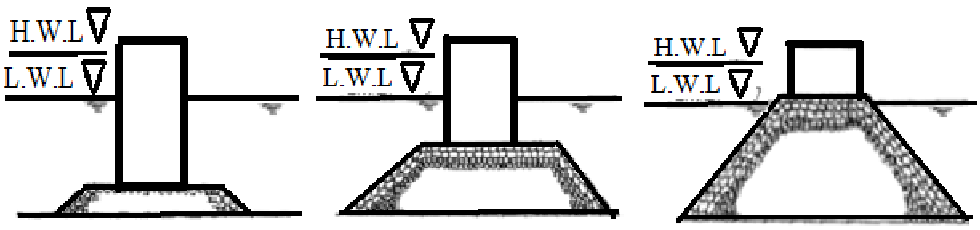
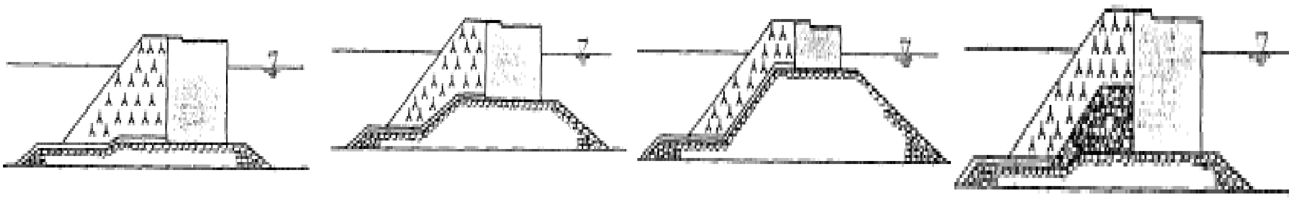


(a) **(b)** **(c)**

Figure. 2 Composite Breakwaters Mound Configuration (6)

As shown above, in Figure 2, high and low water levels can be seen where composite high-mound breakwaters show the mound higher than the low water level. This kind of breakwater (c) causes wave breaking, but also has instability caused by impulsive pressure generated by the wave, and scouring effect caused by the breaking wave while the relatively high mound composite breakwaters (b) triggers impulsive pressures at regular intervals as wave breaking occurs. Commonly used breakwaters are the low-mound (a) type as they do not cause wave breaking on the mound, that is because of its vulnerability to breaking waves and scouring effect in addition to that less budget is needed to build low mound breakwaters (5). Concrete blocks play an important role when constructing vertical walls as they are capable to decrease breaking and reflecting waves. Blocks are placed on the front face; this way is known as the horizontally composite breakwater. This type of breakwater was produced because its mechanism disperses the energy coming along with the waves as well as decreasing the wave force. Rubble mound breakwater consists of concrete blocks that make an armored layer, while horizontally composite breakwaters are likely close to rubble mound breakwaters but not flatly. Horizontal breakwaters will be similar to the rubble mound breakwater by increasing its mound height, and this type of breakwaters is considered as the advanced model of vertical types (3). Different shapes of horizontal composite breakwater's cross sections are shown in Figure 3.



(a) **(b)** **(c)** **(d)**

Figure 3. Various Shapes of Horizontal Breakwaters. (10)

II. METHODOLOGY OF VERTICAL BREAKWATERS SELECTION

Since the development of coastal zones, breakwaters were of a major importance. Breakwaters have many purposes but primarily the protection of navigation water zones (7) protection of working areas around and within harbors, sheltering moorings, stopping floods from getting to land areas and defending lands against erosion. Breakwaters are to serve different purposes, but along a longer period, these may change. The structures composition and how to construct it are aided much to local practice, particularly materials and local conditions should be taken into account. Harbors and coastal structures are of different types, but it is very important to know the most appropriate breakwater structure to raise. Popular and commonly used coastal and harbor breakwater structures are (4)

- Harbor breakwaters.
- Entrance channel breakwaters.
- Water cooling breakwaters.
- Nearshore breakwaters.

Conditions that helps in the selection of a particular vertical breakwater type are listed below which also has an impact on the topography nearby as a result of wave reflection and water conditions, furthermore it aids to determine the best fit vertical breakwater structure to be used:

- Breakwaters layout.
- The conditions of the environment.
- Available utilization conditions.
- Executive conditions.
- Constructions costs.
- Terms of constructions.
- Breakwaters importance.
- Materials available for construction.
- Maintenance.

2.1. Parameters to be Considered before Vertical Breakwaters Design

Environmental impacts should be very well considered during the construction of vertical breakwaters especially when there is a specific location in the plan. Few important parameters that need to be taking into account before executing a breakwater project will be mentioned (4).

Geotechnical investigation is one of the most critical parameters, it is the key success of a structure, essentially determining the constituents of the coastline, for example, clay, rocks and sand types.

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Special contractors are recommended for proper site investigations especially when construction cost is considerable. Portable equipment is used to obtain necessary sediments for the lab test, thickness measurement and estimating the approximate bearing capacity of a seabed, examples of the used equipment are floating platforms with high stability, Van Veen bottom sampler, diving equipment etc. Wave hindcasting will be the second point and can be defined as incidental exact wave nature actions on a certain shoreline. Wave hindcasting should also be regarded as a major step, wave heights are conjoined to vertical breakwaters theoretically, that gives an idea on how breakwaters behavior is going to be, and the best fit applicable vertical breakwaters size needed. The waves are manifested in a curvy undulant form at the water surface and occur intermittently. Wind actions moving on water surface creates them, strong winds generate high waves. Vertical breakwaters are mostly damaged by stormy winds blowing towards the shore. Last but not least, Hydrographic surveys are surveys that are done before starting a design job, proper maps are essential to be in hands of engineers for making design decisions for vertical breakwaters before executing a project to ensure seabed are free from maintenance issues, safe to use and build on under any condition. (8)

2.2. Advantages and Disadvantages of Vertical Breakwaters

2.2.1 Advantages

- An important thing in engineering is the speed of executing a project, therefore in order to achieve a perfect job and in a small range of time, fewer construction failures in addition to reduced environmental impingement while construction should be taken into consideration.
- One of the most important advantages when regarding vertical breakwaters is that the width is smaller when compared with other breakwaters as it requires fewer construction materials due to that it is considered more economical.
- In some cases, the availability of rubble stones is limited which makes vertical breakwaters more essential and suitable.
- Vertical breakwaters do not require frequent maintenance compared with rubble mound breakwaters which need more maintenance work. (9) (10).

2.2.2 Disadvantages

- Vertical breakwaters are not beneficial in deep sea water level usually two meters or more and under strong wave impulsion.
- The surface foundation of vertical breakwaters must be rigid (rubble mound construction materials) in order to increase its stability otherwise it will not be suitable except for certain conditions like having sand deposits of high thickness.
- If any failure occurs, repairs are more difficult for vertical breakwaters (6)

2.3. Vertical Breakwaters Failures

Storms had been a major issue in causing damages to breakwaters. Well-designed methods in the construction and development of breakwaters had helped in backing up the structures from falling down to complete failure. Breakwater structures have a fatigue and resistance period against the wave impacts with various heights, design can be 50 years or more, but when wave's hits at levels higher than the expected height, a probabilistic method of design will be presented for making evaluations quantitatively of failure probability when designing breakwaters. Waves pressures increases during storms, they exert a push on vertical walls acting as loads, therefore, causing a combination of forces, quasi-hydrostatic, up-lift and geotechnical forces. The main failures of vertical structures are listed below (4)

- Failure of structural elements.
- Forward rotation of wall
- Backwards Overturning of wall
- Overall wall settlement
- Loss of structures solidarity
- Backwards sliding of wall's element relative to its foundation.

More or less, vertical walls may not give the required protection as been designed, even though it has no any structural problems, such cases are regarded as a functional failure. Functional failures are commonly caused by overtopping of excessive waves that causes wave activity to be transmitted into sheltered harbor zones. Breakwater structures might be designed to serve several functions which relate to more functional failures example of that can be for a safe walk on breakwaters by limiting overtopping of waves as they occur, protecting buildings from getting damaged etc. Contributed failures can accelerate failure modes which had been listed above, particularly includes foundation failures which can be either local or global. Geotechnical force and waves are very well resisted by the structures essentially by their own self-weight, friction with underlying materials also helps in resisting. Continuity is maintained and movements are prevented by bonding forces between components under local pressure (2). Backwards slide due to direct wave force is the most issued failure mode for vertical structures, horizontal loads and up-lift force are the main cause of that. Backwards overturning failures can be examined, theoretically assumed as rotation about the wall's rare heel. Practically there is no fixed point for the rotation, it depends on foundation's and rubble mound's geotechnical characteristics and their bearing capacity (2).

III. CONCEPTS OF VERTICAL BREAKWATER DESIGN

Wave's conditions vary from time to time, therefore, the act in a complicated form upon structures exerting pressure on them, this may vary depending on the geometry of the vertical breakwaters. The main and most desired solicitude in vertical breakwater design is to meet the desired protection of harbors during service, especially at extreme wave conditions. According to harbor usage,

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The degree of shelter needed will be estimated. Configuring the plan, vertical breakwater height and length will influence the protection against waves where they should be able to limit penetration of waves at sensitive harbor zones. Wave diffractions are of different levels which have an influence on vertical breakwater's length and position, its freeboard is set in order to avoid excessive wave transmission over the structure. Structures of different geometry must go through laboratory test which helps in assessing the final design stage. The vertical breakwaters main purpose is to stop or break the kinetic force as it touches the front face of the wall (11). Observations had been jotted down together with analytical studies to understand pressures exerted from waves and be able to figure. out best applicable formulas for the exerted pressure. It is very important to know that kinetic energy is reflected vertically along wall face dividing them into two components upward and downward. The upward case which can cause wave peaks to rise up almost twice while downward case causes scrubbing and erosion where the components lead to increase the velocity at the wall base and horizontally away from it for almost half of a wavelength. (10).

3.1. Vertical Break Water Design

Executing a vertical breakwater design undergoes several formulas derived for different purposes, but only wave distribution caused by wave pressure and safety factor formulas are discussed.

3.1.1. Wave Pressure

Wave distribution pressure on an upright section for vertical breakwaters are characterized by the equivalent deep-water wave elevation or height H_0'(corresponding to the significant wave), and significant wave period of deep water waves T which can be calculated using modified (Goda's 2000) formula as shown below in Figure 3 (12)

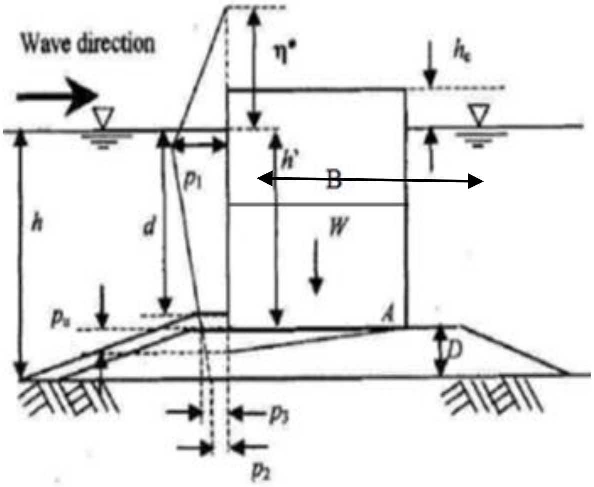

Figure 4. Wave Pressure Distribution On Vertical Breakwater (12)

$$p_1 = \frac{1}{2}\,(1 + cos\beta_w)(\alpha_1 + \alpha_2 cos^2\beta_w)\rho g H_{Max}, \quad (1)$$

$$p_2 = \frac{p_1}{\cosh\left(\frac{2\pi h}{L}\right)} \quad (2)$$

And: $p_3 = \alpha_3 p_1$

$$\alpha_1 = 0.6 + \frac{1}{2}\left(\frac{\frac{4\pi h}{L}}{\sin h\left(\frac{4\pi h}{L}\right)}\right)^2 \quad (3)$$

$$\alpha_2 = min\left(\frac{h_b - d}{3h_b}\left(\frac{H_{max}}{d}\right)^2, \frac{2d}{H_{max}}\right) \quad (4)$$

$$\alpha_3 = 1 - \frac{h'}{h}\left(1 - \frac{1}{\cos h\left(\frac{2\pi h}{L}\right)}\right) \quad (5)$$

Where:
$\alpha_1, \alpha_2, \alpha_3$ = Goda's equation coefficient
h = depth of water in front of the breakwater
h_b = depth of water at $5H_{1/3}$
L = length of wave
ρ = seawater density.
g = acceleration of gravity.
H_{max} = Maximum wave elevation needed for design
η = elevation to which wave pressure is exerted
β_w = angle between a line normal to the breakwater and the direction in which wave approaches.

$$\eta = 0.75\,(1 + \cos\beta_w)\,H_{max}, \quad (6)$$

Note that h_b is the depth of water at a range of 5 $H_{1/3}$ from breakwater where $H_{1/3}$ is the wave elevation which is significantly related to the analog wave elevation or height (H'_0) of the deep water. Characteristics of deep water waves (h_0 and T) have an equivalency functions which are $H_{1/3}$, Height H_{max} and wavelength used in the equations above. The coefficient of nonlinear shoaling should be considered for evaluating variable values by two nonlinear equations method.

The upright section has an uplift pressure acting on its bottom section and considered to have the shape of a triangle with a pressure at the toe (Pu) as illustrated in figure (5a) and the formula below can be used to calculate it.

$$p_u = \frac{1}{2}(1 + cos\beta_w)\alpha_1\alpha_3\rho g H_{Max} \quad (7)$$

3.1.2. Overall Safety Factor Design

Horizontal moments M_H, vertical moments M_V, Uplifting wave force F_v and Horizontal wave force F_H can be evaluated by the wave pressure obtained from Goda's formula, where M_V and F_V exerted by the uplifting pressure depends on body width B, also the upright section effective weight W is dependent to B.
Finally, the safety factor for overturning S_{fo} and sliding S_{fs} can be written as (12)

$$S_{FS} = \frac{\mu(W - fv)}{F_H} \quad (8)$$

And

$$S_{Fo} = \frac{\frac{WB}{2} - M_V}{M_H} \quad (9)$$

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Where,
μ = coefficient of friction between rubble mound and upright body
W = upright section effective weight
$F_{v = Uplift}$ wave force
F_H = Horizontal wave force
B = Body width
M_v = Moments due to uplift pressure
M_H = Overturning moments due to horizontal wave force

For additional information on the environmental data together with necessary formulas of wave and wave hydrodynamic loading, the following references: (1) (11) (13) (14) (15) (16) (17) (18) (19) (20) (21) (22) can be used.

IV. CONCLUSION

Vertical breakwaters' main purpose is to stand against waves; they had been deployed/constructed for sheltering moorings avoiding ships from getting damaged, depending on the type used, with or without a mound, reflection, breaking and stability against wave changes. Geotechnical investigation, hydrographic surveys and wave hindcasting are the keys to a perfect vertical breakwater selection. Through analytical studies and observations, formulas had been derived dealing with wave-exerted pressures. Modified Goda's formulas may be used for calculating the distribution of waves on an upright vertical section of a vertical breakwater.

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