A REVIEW ON RUBBLEMOUND BREAKWATER DESIGN BY EMPIRICAL FORMULAE AND HYDRAULIC MODEL TESTS

Prof. Supriya Shinde[1], Mr. Aditya Ukalkar[2], Mr. Akshay Tambe[3], Mr. Ashim Prakash[4]

[1]Prof. Supriya Shinde, affiliated to Department of Civil Engineering, Anantrao Pawar College of Engineering & Research,
[2]Mr. Aditya Ukalkar, [3]Mr. Akshay Tambe, [4]Mr. Ashim Prakash,
UG students affiliated to Department of Civil Engineering, Anantrao Pawar College of Engineering & Research, Pune, India.

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Abstract :*Most commonly built marine structure for protection of coastal areas are rubblemound flexible breakwaters. These help in achieving tranquil conditions in the harbours against the destructive forces of waves. Design of flexible rubblemound breakwater involves numerous aspects such as wave-structure interaction, friction between armour, interlocking characteristics of armour, etc. and hence is a complex process. A crucial aspect in the design is the optimum weight of the armour units. The armour units withstand the wave forces due to virtue of their gravitational weight. A number of empirical formulae such as, Hudson's formula (1984) and Van der Meer's formula (1994) have been derived for preliminary or conceptual design of unit weight of armour. They have been modified over the course of time by experimental work. Since a breakwater structure is very important infrastructure project, hence the design should be optimal as well as safe. It is a universal practice to finalise and confirm the section of breakwater based on hydraulic model tests in wave flumes / wave basins. The hydraulic model tests are essential to simulate the complex wave structure interaction as well as correct prototype site conditions of seabed slope, water level etc.*

Keywords: ***Armour unit, Rubblemound, Stability coefficient, Initiation of Damage (Ida), Initiation of Destruction (IDe), Toe-berm etc.***

1. INTRODUCTION

Marine structures are built to shelter the harbour basins and entrances against the action of waves. Coastal structures are subjected to various environmental forces because of winds, waves, tides and currents but the wave forces are predominant and are decisive in the design of coastal structures. Marine structures can be classified into three types: fixed, complimentary and movable.

A harbour is a sheltered part of the water deep enough to provide anchorage for ships and act as a place of shelter. The harbours also provide a location as an interface for inland and waterborne activities and giving safety to ships and boats at moorings.

A protective barrier built to enclose the harbour, to keep the harbour water undisturbed and to protect the harbour facilities by the effect of wind, waves, currents etc. is known as breakwater. These structures make it possible to use the area enclosed as a safe anchorage for vessels.

The main function of breakwater is to break the momentum of water by means of wave breakers to provide tranquillity conditions. The momentum of wave is broken by dividing the mass of the wave into different jets as well as by reducing its velocity. There are various types of breakwaters such as flexible, semi-rigid and rigid. Flexible rubble mound breakwaters are most commonly used, which is a heterogeneous assemblage of natural rubble, undressed stones, sometimes supplemented by artificial blocks heavy in weight. This is achieved without any kind of binding materials. A simple method of construction is by tipping or dumping of rubble stones into the sea till heap comes out of the surface of water. The action of waves consolidates the mound. The quantity of rubble depends upon the depth of seabed, rise of waves and tides and exposure conditions.

The bedding layer of the rubble mound structure is called as core, which increases the size of structure. It is less pervious than armours and filter media. Secondary layer is called as filter media, which is laid around the core having stones larger in size than in core but well graded.

Their function is destroying the energy of waves coming through the armour units. The protective layer on the exterior part is called armour units. They resist a major part of kinetic energy of wind and waves. These armour units can be quarry stones available locally if of required size or else specially designed concrete blocks. Wave forces are most dominant and decisive forces in the design of coastal structures. The other aspects of waves are wave run-up, rundown, overtopping, reflection and transmission. Rubble mound breakwaters stability primarily depends on the stability of armour units on the seaside.

2. OBJECTIVES

1. Understanding about wave, tide phenomena, linear and non-linear wave theories and wave propagation.
2. Literature survey of various Concrete Armour Units (CAU), their design, advantages, disadvantages and failures.
3. Getting to know about the conceptual design procedure of a breakwater.

4. Finding out the applications, limitations of using Empirical Formulae especially Hudson's Formula.
5. Learning the ways and methods to construct a physical model based on Froude's Number similarity.
6. To study ways in which a cross section of breakwater is optimised with the help of wave flume testing.

3. LITERATURE REVIEW

J.D. Mettam et al [8]. (1982) assessed the current design philosophy of breakwaters, their limitations and advised changes to introduce factors of safety. They also recommend that the concept of testing for stability with the once in 50 year or once in 100 year wave should be replaced by a design wave which has a probability of exceeding no more than 5%in the lifetime of the structure. Most designers rely heavily upon hydraulic model tests due to inadequacy of present design formulae, which checks the design for uncertain safety margin against failure. They stated that the chief weakness of the design procedure is that there is no common method to introduce a F.O.S. for failure. The authors said that the easiest way of providing a safety margin against failure of breakwater is by increase the height of the design wave. Another way mentioned in the paper to increase margin of safety, especially for rubblemound breakwaters is by providing heavier armours on prototype than the model. They also stressed on limit state method of designing by applying partial safety factors for loads and materials. They came to a conclusion that the failures should reduce in the future and provided a method to do so, i.e. by deliberately reducing the specific gravity of materials in the model.

Bas Reedijk et al[4]. (2012) illustrated by the means of this paper that permeability of a breakwater core affects the stability of the breakwater armour for which no design guidelines have been established. Core dissipates the energy of the penetrating wave by turbulent flow. Hence if, core is less permeable, then wave reflection increases leading to higher loads on armours. They stated the recent construction method utilizes dredged material as core to gain economic advantage. Another trend is to apply sand filled geotextile containers in a breakwater core may require larger armour due to the reduced core permeability. The paper cites an example of a breakwater at Ijmuiden, The Netherlands, where a 45 tons cube has been displaced due to an impermeable core. They proved with the help of rock stability equations of Van der Meer (1988) and van Gent et al. (2004) that an impermeable core will lead to an increase of mass of armour by a factor of 2.6 and also carried out model tests which showed that armour size in the final design was significantly increased because of the reduced permeability of the core. According to their studies, it can be concluded that, effect of core permeability needs to be addressed while designing, during model testing and also during construction. In addition to it the core material used, must not contain too many fines, unless taken into account during design.

Ilse van den Bosch et al[7]. (2012) investigated the stability of single layered armour units on low crested and submerged breakwaters. Displacements and rocking were considered as parameters of stability, which is largely determined by the interlocking. They referred to the model tests conducted at DMC, Netherlands. Displacement of a single armour unit by more than 0.5 D (with armour unit height D) was considered as start of damage (about 0.3% damage); displacement of 10 armour units (about 3% damage) was considered as severe damage. They concluded that the armour layer stability on the seaward slope is reduced by about 12% (40% larger armour unit weight required) for low crested structures. Therefore, the results of this study should also be applied for other types of single layer armouring unless other guidelines recommend otherwise.

Josep R. Medina et al [10]. (2012) emphasised through their studies that hydraulic stability and performance of the armours layer depend on the specific weight, geometry, the placement arrangement, the number of layers (single or double) and position. Stability coefficient K_d for single- and double-layer armours is being used by practitioners without any clear distinction between technical fundamentals and explicit safety factors to Initiation of Damage (IDa) and Initiation of Destruction (IDe). Therefore, to maintain a reasonable margin of safety to failure, the criterion to define the appropriate design K_d for both single- and double-layer armours must be related to IDe rather than IDa. Authors reported that unstable units from the upper layer of double-layer armours could become missiles, increasing the risk of breakage and concluded that single-layer armours were safer and more cost-efficient than double-layer armours. After a number of series of tests in different conditions using the same CAU and armor slope, Gaussian probability density functions (pdfs) of Ns(IDa) and Ns(IDe) can be estimated. Single-layer armors must be designed far below IDa so as to obtain a reasonable global safety factor to IDe, Nsd<Ns(IDa)<Ns(IDe). When using the generalized Hudson formula. The mass density of concrete and the significant wave height attacking the structure are the two primary sources of uncertainty directly affecting Hudson's formula. For each armor type, small-scale hydraulic stability test results were then used to estimate the corresponding Gaussian pdfs of Ns (IDa) and Ns (IDe). Given a specific armor type (CAU, #layers, etc.), a decrease in the design KD means an increase in the global safety factors. This paper analyzed the implicit and explicit global safety factors associated with the recommended design KDs of the generalized Hudson formula. The authors concluded their studies by stating that safety factors are the lowest for massive CAUs in double-layer trunk armors; they were higher for double-layer roundhead armors and the highest for CAUs in single-layer trunk armors.

A. V. Mahalingaiah et al[2]. (2014) wrote about the hydraulic model studies to design breakwaters which is the most commonly used method. They said that although 2-D model are often tested in wave flume, testing a 3-D model would be more realistic as exact terrain in front of breakwater can easily be reproduced. In a 2-D model damage indicated is slightly higher than actual due to confinement of energy. They stressed on providing a toe-berm, which acts as a seat to the armour layers reducing the wave energy attacking the armour layer and thereby to minimizing the required weight of the armour units. This reduces the cost of construction of breakwater and also useful in rehabilitation of damaged rubblemound breakwaters. Thickness and berm width are decided on the basis of physical model studies in a wave flume. The studies should also analyse the scouring in front of toe. Based on the submergence of the toe, CERC (1984) had recommended weight of the stones. The authors after carrying out such extensive studies have reached to a conclusion that a toe berm should be provided in order to optimize the design.

M. D. Kudale[13] (2014) gave an overview of coastal engineering through the means of this paper. He says, subject of Coastal Engineering can be divided in three groups:
1. Understanding coastal processes
2. Coastal structures and their impacts on coastal processes
3. Tools available for solving the problem.

The author discussed coastal environmental processes such as waves, tides, currents and winds and explained the physics behind them. He states that wave is the single most important parameter influencing design considerations. The phenomenon of tides, their harmonic analysis etc. was also discussed in the paper. Wind as a parameter to be considered in the design of coastal structures has also been discussed. The author writes in detail about the different zones based upon wave depths such as deep water, refraction zone, surf zone and swash zone. Further more he discussed about coastal engineering problems like shoreline stabilisation, harbour protection. M. D. Kudale emphasises that, before taking up any construction in coastal area a thorough hydraulic study is required in respect to its functional utility, stability, and its impact on surrounding environment. A way of doing this is by site inspection, field investigation, physical modelling, wave flume studies etc. He also encourages mathematical modelling where, the region of interest is schematised by regular square grids in finite difference method or by irregular triangular grids in finite element method. Finally he concludes that Coastal engineering is a multidisciplinary subject requiring a thorough study.

A. V. Mahalingaiah et al[3]. (2015) explained in detail the deisgn procedure of a rubblemound breakwater by giving an example of breakwaters proposed for the development of fishery harbour at Majali, Karnataka. Empirical formulae such as, Hudson formula and Van der Meer formula are used for preliminary design of unit weight of armour, as the armours provide major stability to the structures. Most of these formulae take into account the wave height, density of the armour units and angle of the breakwater slope. According to the authors the overall stability of breakwater is a function of stability of each individual component and their interdependence. The next step is design optimization through hydraulic model studies in a wave flume. The models are based on Froude's criterion of similitude. They therefore concluded that, to optimize the design of breakwaters, the cross-sections should be evolved for seaside and leeside at various bed levels. This can result in saving around 20% of construction materials.

4. METHODOLOGY

1. Studying literature related to marine and coastal structures.
2. A thorough study of U.S. Army Corps of Engineers, Coastal Engineering, "Shore Protection Manual".
3. Visiting the Coastal Hydraulic Structures (CHS) division at Central Water and Power Research Station, Pune to acquire knowledge of laboratory testing.
4. Construction of a G.S. model based on Froudian similitude for a case study at Central Water and Power Research Station.

5. CONCLUDING REMARK

After reviewing whole literature, it is observed that most of the work is done by experimenting on models in wave flumes. It was seen that extensive research has been carried out for armour units, construction materials, forces, factors of safety etc. Although normally 2-D models are used, 3-D models give accurate results. Hence there is an urgent need to work in this area. Hence it is mandatory to conduct wave flume studies.

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