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Optimal Design of Rubble Mound Breakwaters with a Reference of Hydraulic Model

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Abstract – Flexible rubble mound breakwaters are most common structures provided for protection of coastal areas and to achieve tranquil conditions in the harbours against the destructive forces of waves. Design of flexible rubble mound structures is complex as it involves various aspects such as wave-structure interaction, interlocking characteristics of armour, friction between armour and secondary layer etc. A major aspect in the design of rubble mound structures is the optimum weight of the armour units required to withstand the design waves. It is a universal practice to finalize the section of breakwater based on hydraulic model tests in wave flumes / wave basins to confirm the conceptual design evolved using empirical formulae. Some of the new concepts have been introduced by CWPRS for optimal design of rubblemound breakwaters.

Keywords: Rubble, Mound, Breakwaters, Hydraulic

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INTRODUCTION

Hydraulic model studies for design of breakwaters are normally carried out in wave flumes with normal wave attack (2-D model). However, it would be more realistic, if longer length of breakwater is tested in a wave basin (3-D model) under the attack of waves from predominant directions. The cross-section of breakwater in 2-D wave flume model may show slightly higher damage than the breakwater, when tested in 3-D wave basin model due to confinement of wave energy. Also, the extent of overtopping observed in 3-D model is less due to lateral spreading of wave energy. In 3-D wave basin, exact terrain in front of breakwater can be easily reproduced, which helps in actual simulation of waves approaching the breakwater structure.

The main components of the rubblemound breakwaters are armour layer, toe-berm, crest, secondary layers, core, and the bedding layer. The toe-berm acts as a seat to the armour layer and also helps in dissipating a part of wave energy incident on the armour layer. The top level of the toe is normally below the low water level. Since the armour layer in the conventional breakwaters bears the brunt of the wave attack, it requires heavy stones / concrete blocks in the armour layer to withstand high waves. The cost of construction of breakwaters is high due to usage of heavy armour units and highcapacity cranes required for placement of armour units.

A concept of providing a wider toe-berm has been introduced to reduce the wave energy attacking the armour layer and thereby to minimise the required weight of the armour units. This reduces the cost of construction of rubblemound breakwaters. In this concept, a wide toe having the berm width of about 15 m to 25 m is provided below the low water level. The main aim of providing such a wide toe berm is to dissipate the part of wave energy striking the armour layer.

As the toe level is kept below the low water level, a wave above a certain height feels the top of the wide toe-berm, which initiates the breaking of the wave and some energy is dissipated before reaching the armour layer.

In the conventional rubblemound breakwater, the structure is normally provided with a small toe-berm having a berm width of about 3 m to 6 m, which acts as a seat to the armour layer. However, if a wide toe having a width of about 10 m to 20 m is provided at the suitable water level of the toe-berm, it will reduce the wave energy attacking the armour layer and thereby reduces the required stable weight of armour units. This concept of a breakwater with a wide toe-berm reduces the cost of construction of breakwater and also useful in rehabilitation of damaged rubblemound breakwaters.

The stability of rubble mound structures depends primarily upon the stability of individual armour units on its seaward slope. A major aspect in the design of rubblemound structures is the optimum weight of the armour units on the seaward slope, required to withstand the design waves. Extensive studies were carried out on the hydraulic stability of individual armour units on the seaward slope and several empirical formulae such as, Hudson's and Van der Meer formula have been derived for the estimation of the required stable weight.

OPTIMAL DESIGN OF RUBBLE MOUND BREAKWATERS

The common practice followed for designing the rubblemound breakwaters is to use the existing design formulae for each individual component of the breakwater and evolve a conceptual design. The overall stability of rubblemound breakwater is however not only a function of the stability of each individual component but also of the interdependence of these parts. Therefore, in the next step, the conceptual design of the breakwater is further tested and optimised through hydraulic model studies in a wave flume or a wave basin.

Toe-berm is a significant part of rubblemound breakwaters. The function of the toe-berm is to support the armour layer and to prevent the armour units from sliding down. The toe also dissipates part of the wave energy, incident on the breakwater. During deep wave run-down / down-rush, the toe is exposed not only to high velocities but also to high hydrostatic pressure from inside the mound. Therefore, the toe itself has to be strong enough to resist the destabilizing forces.

The importance of toe structure has been brought out by the breakwater disasters in recent years. Normally, quarry stones are used for the construction of the toe-berm. The weight of stones in the toe is generally taken as W/3 to W/5 or even as low as W/10, where W is the weight of armour unit. A minimum three-layer thickness with berm width varying between 3 m and 5 m is normally used.

However, thickness and berm width are decided on the basis of physical model studies in a wave flume. The berm width affects the weight of the armour units. The level of the toe-berm is kept below the low water level. By reducing the depth of water over the toe i.e. by increasing the toe-berm level, breaking of the waves can be affected. Wave breaking over the toe-berm is responsible, to some extent, in dissipating part of the wave energy, which ultimately strikes the armour layer.

Further, the performance of the toe-berm enhanced only when the bed immediately in front of the toe is protected from scouring. The soil condition, littoral current, tidal current, wave action, dredging in close proximity of the toe; are the factors, which affect the scour of the bed in front of the toe. Since there is no set procedure for the design of the toe, the model experiments in a wave flume provide vital results on the stability of a toe under the influence of wave action. As mentioned earlier, the interdependence of the various components of the breakwater is important in the design. Recently, a few studies have been reported on the interactions in the stability of toe-berm and main armour of rubblemound breakwaters.

The harbour layout of the shipbuilding yard near Cuddlore, Tamilnadu consists of 2100m long south breakwater and 875m long north breakwater. The crosssections of the breakwater at various water depths were evolved. A 50-year return period significant wave height of 7 m obtained from the extreme value analysis of hindcast storm wave data considered for the design of breakwater. For the design wave height of 7.0 m, a conventional rubblemound breakwater needed 25 t tetrapods in the armour for trunk.

The effect of width and depth of toe-berm plays an important role in the stability of armour layer, since the amount of wave energy dissipated on the toe depends on the size (width and elevation) of the toe-berm. It is essential to develop a relation between the stability of breakwater (in terms of weight of the armour unit) and the dimensions of the toe-berm. Extensive wave flume studies have been planned at the Central Water and Power Research Station (CWPRS) for assessing performance of rubblemound breakwaters with varying width and height of the Toe-Berm.

Water is at the core of many environmental and developmental problems today. Falkenmark (2011) states that water functions are crucial: as a necessity of life on all scales from the cell to the planet; as a solvent continuously moving above and below the ground surface, and the water-wetting of the landscape due to partitioning disturbances. Concern for water as a necessity of life and as a hazard has existed throughout history.

One question is: Is hydrology very old (one of the oldest of sciences) or is it a new one? Biswas (2012) states that hydrology is one of the oldest sciences due to the direct relationship between human beings and the development of civilization. In the modern sense, hydrology is relatively young. The National Research Council (2011) stated that over the past 60 years, the evolution of hydrological science has been in the direction of ever-increasing space and time scales, from small catchments to large basins and to the Earth system, and from storm events to seasonal cycles and to climatic trend. There are many fundamental problems of hydrological science, which have to be addressed in order to provide the ingredients for solving the sharpening conflicts between humans and nature.

Modern computer and numerically oriented hydrology uses most of the new scientific approaches, methods, and technologies such as: the systems approach, artificial neural networks, fuzzy logic, chaos theory, fractals, geostatistical methods etc. Klemes (2015) has concluded that during the past decade, the systems approach to reservoir storage problems has been heralded as something of a jump from the stone age of mass-curve analysis into the modern era of science. In reality, however, no such jump ever occurred. This statement is completely acceptable for other new initiatives, especially for use of numerical models in hydrology.

Harte (2012) finds that the main defect of new complex and sophisticated physical models is their unfalsifiability. He suggests accepting Fermi's approach. This means that models that capture the essence of the problem, but not all the details, might progress science farther. Perfection is when there is no longer anything to take away, not when there is no longer anything to add.

DISCUSSION

Harte (2012) as a physicist suggests a synthesis of the Newtonian and Darwinian worldviews as a promising concept and he believes that this synthesis could expedite progress in Earth system science. It seeks no less than a predictive understanding of the complex system composing organisms, atmosphere, freshwater, oceans and human society. It builds on the basic disciplines of physics, biology and chemistry, which provide the foundations of ecology, climatology, hydrology, oceanography, geology and biogeochemistry. Why are complex and unfalsiftable models so popular in hydrology, especially in the development of Global Circulation Models? The responsibility rests with higher education at universities and with leading scientific international journals, which report, promote and advocate this approach. Young scientists often believe that this is the only real and correct procedure. Experienced and practically oriented hydrologists, well versed in water resources management process, do not always share their enthusiasm.

The trouble with models is that human beings choose what to study and what to ignore, what methods to use in their analyses and what criteria to apply in determining the validity of the data gathered. In making such choices and assumptions, scientists inevitably make value judgments. However, when such value-based assumptions disappear into the background, they may come to be seen as "natural" and are uncritically accepted, often without any conscious thought about either their presence or their implications.

This is especially the case when value-based assumptions are translated into mathematical models (van Asselt et al, 2016). A definite conclusion is that in the context of integrated assessment modelling, it is not always possible to avoid uncertainty and subjectivity (von Asselt et al, 2016). A change in the direction of post-modern modelling is very necessary. Progress in hydrology and water resources management is limited by a lack of data. Hydrological processes are highly variable in space and time, and this variability exists at all scales, from centimeters to continental scales, from minutes to years. Data collection over such a range of scales is difficult and expensive, therefore hydrological models usually conceptualize processes based on simple, often homogeneous, models of nature. This forced oversimplification impedes both scientific understanding and the management of resources (National Research Council, 2011).

There is a growing tendency in hydrology to minimize fieldwork. Investors realize that time is money and there is a no more time-consuming process than fieldwork. As a result, hydrologists are asked to solve problems with computer models, remote sensing, and legal manoeuvres rather than by direct field observation. The quality of their work suffers enormously. Rodda (2016) states that it is something of a paradox that, at this time when the global demand for water is rising faster than ever before, knowledge of the world's water resources is waning.

CONCLUSION

The cross-section of breakwater in 2-D wave model may show slightly higher damage than the breakwater, when tested in 3-D model due to confinement of wave energy. Also, the extent of overtopping observed in 3-D model is less due to lateral spreading of wave energy. In 3-D wave basin, exact terrain in front of breakwater can be easily reproduced, which helps in actual simulation of waves approaching the breakwater structure. The tests carried out at CWPRS in the 2-D wave flume and 3-D wave basin for the rubblemound breakwater indicated that the 3-D tests give a more optimal design of rubblemound breakwaters.

A concept of a breakwater with a wide toe-berm reduces the cost of construction of breakwater and also useful in rehabilitation of damaged rubblemound breakwaters. A few studies carried out indicated that a toe-berm of about 20 m width just at the low water level and having stone weight of 1/5 to 1/10 of the armour units of conventional breakwater, reduces the required weight of stable armour units by about 20-50%. Basic studies are required for establishing relationship between the weight of armour units and the dimensions of the toe-berm in terms of width and depth of submergence.

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