OPTIMUM AND SAFE DESIGN OF RUBBLE MOUND BREAKWATER FOR FISHERIES HARBOR

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Abstract - *Breakwaters are typically required for the harbors to provide desired tranquility and protection for the ships approaching and mooring in the harbor. Because of their very nature, breakwaters are exposed to strong wave attack. Flexible rubblemound breakwaters are provided as the most common structures in order to achieve these tranquil conditions inside the harbour against the wave attack. The complex design of these rubblemound breakwater structures involves various aspects such as wave-structure interaction, interlocking characteristics of armour, friction between armour and secondary layer etc. The harbor layout, the length and alignment of protective breakwater are decided through mathematical as well as hydraulic model studies. The hydraulic design of the breakwater structure as a whole is evolved through empirical methods and hydraulic model tests. Several empirical formulae such as, Hudson formula and Van der Meer formula are available for preliminary or conceptual design of unit weight of armour. The hydraulic model tests simulate the complex wave structure interaction as well as correct prototype site conditions of seabed slope, water level etc. (which influence the waves attacking the breakwater) and are simulated in the wave flume or wave basin. These models are constructed to a Geometrically Similar (GS) scale and are based on 'Froudian' criterion of similitude. Optimum and safe design of breakwater cross-sections considering design wave height for various bed levels, design of breakwater on sea/lee side, trunk/roundhead portion etc. are reviewed and illustrated with a case study of design of breakwaters for fisheries harbor.*

Keywords: Breakwater, Wave Flumes, Rubble mound, Hydraulic Design etc.

1. INTRODUCTION

A breakwater is a barrier constructed to break up and disperse heavy seas, to shield the interior waters of a harbor from waves, and to provide shelter and protection for ships, shipping facilities and other harbor infrastructure. The different types of breakwaters used for achieving the above objectives can be classified into:

1. Rubble mound breakwater
2. Breakwater (shore connected)
3. Breakwater(Offshore)
4. Reef breakwaters
5. Floating breakwaters.

The most popular and commonly used coastal structures for harbor protection and combating erosion of coastline are rubble mound breakwaters.

The main components of a rubble mound breakwater are armour layer, toe-berm, crest, secondary layers, core, and the bedding layer. The toe-berm dissipates a part of wave energy incident on the armour layer and functions as a seat to the armour layer. The crest of the toe is usually below the low water level. Heavy stones / concrete blocks are required in the armour layer of conventional breakwaters to withstand high waves as the armour bears the brunt of the wave attack. The weight armour units of the rubble mound breakwater worked out using empirical formula is required to be confirmed with wave flume studies for hydraulic stability and also for further optimization. The safe and optimal design of rubble mound breakwaters at various bed levels on seaside and leeside, confirmed through wave flume is discussed in this paper.

2. OBJECTIVES

1. To be able to make an assessment of hydraulic loads against Rubble mound breakwater
2. To be able to make a preliminary design of a Rubble mound breakwater (length, width, height)
3. To be able to compare Rubble mound breakwater against basis of material usage.
4. Conceptual designing of a breakwater using Empirical Formula (Hudson's Formula).

3. METHODOLOGY

Rubble mound structure consisting of graded layers of stone and a cover layer armor consisting of stones or specially shaped concrete units are employed in the coastal zone. An advantage of rubble mound structure is that the failure of armor layer is not sudden but usually partial in extent and spreads over the duration of storm. If damage does occur, the structure continues to function and the damage can be repaired after the storm abates during a period of lower waves. Rubblemound structures being flexible structures are designed to withstand significant wave height (Hs) and are consequently economical by the use smaller size armor units anticipating a certain degree of damage during a design storm, and providing for subsequent repair of structure. Armor unit must be of sufficient size and weight to resist wave attack. However, if the entire structure consists of units of this size, the structure would allow extremely high wave energy transmission and the finer material in foundation or embankment could be easily removed. Thus the structure unit sizes are graded in layers from the large exterior armor units to small quarry-run sizes and finer at the core and at the interface with the native soil bed.

Other rubble mound structure design consideration include: prevention of scour at the seaward toe caused by turbulence due to wave breaking, spreading of structure load, so there is no foundation failure owing to excessive loads and providing sufficient crest elevation and width so wave run-up and overtopping do not cause failure of the armor units on the leeward side of the structure or regeneration of excessive wave action in the leeward side of the structure. The crest width may be governed by minimum roadway width needed for construction vehicles that have to traverse the structure and subsequent maintenance work.

4. EXPERIMENTAL WORK

There are many different types of breakwaters; natural rock and concrete are the materials which form 95 percent or more of all the breakwaters constructed. Rubble mound structure consisting of graded layers of stone which range from 0.3-1t, 0.5-1t, 1-2t, 2-4t, 10-100kg, 100-300kg and specially shaped concrete units like Tetrapods, Accropods Concrete Cubes of various weights are employed in the coastal zone.

The Breakwater cross-sections were evolved using the Empirical methods for conceptual design and Hydraulic Stability and optimization were achieved through Physical modeling. The conceptual design was evolved using Hudson's formula for arriving at the weight of the armor units used in the armour layer. It is the most popular empirical formula and is being used from last 50 years for the design of breakwaters, owing to its simplicity and the fact that extensive KD values are available based on scale model tests.

Hudson's formula:

$$W = \frac{W_r H^3}{K_D (S_r - 1)^3 \cot\theta}$$

Where, W= weight of armor unit (t), Wr = Unit weight of armor block (t/cum), H = wave height at the location of the proposed structure (m), Sr = specific gravity of the armor units, Θ = angle of breakwater slope measured with the horizontal, KD = stability coefficient which varies with the type of armor unit. In Physical modeling preliminary cross sections were then constructed as 2-D models and placed in the wave flume. The models were made according to the geometrical similarity. These models were tested in the wave flume at various tidal levels and wave heights and the required changes were incorporated in the design. The design of cross-sections of breakwaters at various bed levels have been evolved based on desk and wave flume studies.

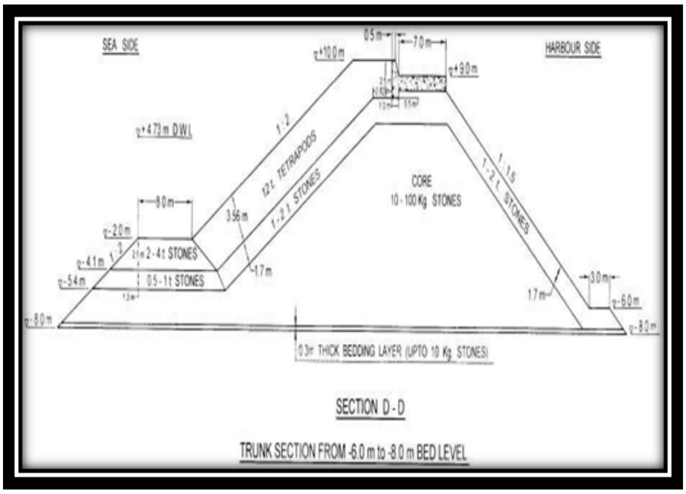

Figure 1: Cross-section D-D trunk section from -3.0m to -6.0m bed level of breakwaters for the proposed development of fishery harbor at, Gujarat.

The section D-D is designed to provide from -6.0 m to -8.0 m bed level of the eastern breakwater. This section consists of 12 t tetrapod's in the armor with 1:2 slope on sea side and 1 to 2 t stones in the armor with 1:1.5 slopes on lee side. An 8.0 m wide toe-berm consists of 2 to 4 t stones provided at the level - 2.0 m on sea side. A 3 m wide toe-berm consists of 1 to 2 t stones provided at the level - 6.0 m on harbor side. A secondary layer of 0.5 to 1 t stones is provided below the toe-berm on sea side. A secondary layer consists of 1 to 2 t stones provided below the armor units on sea side. Core consists of 10-100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is fixed at +9 m level with a parapet top at el. + 10 m. A clear carriage way width of 7 m is provided on the crest slab.

Figure 2: Wave action on armor layer of breakwater consisting of 12 t tetrapods at -8.0 m bed level with + 4.73 m water level and 5.8 m wave height

The section was constructed with a Geometrically Similar model scale of 1:41 in the wave flume. The 12 t tetrapod's are placed in the armor with 1:2 slope on sea side and 1 to 2 t stones in the armor with 1:1.5 slope on lee side. The top level of the toe is fixed at -2.0 m with 8 m wide toe- berm consisting of 2 to 4 t stones on sea side. A secondary layer consists of 1.0t to 2.0 t stones provided below the tetrapod's armor units. Core consists of 10 to 100 kg stones and a bedding layer of stones up to 10 kg weight is proposed. The top of the crest slab is fixed at + 9.0 m level and parapet top is at +10.00 m, with a clear crest width of 7.0 m. The bed slope of 1:100 was reproduced in front of the structure. A Test was carried out with wave height of 5.8 m at DWL of +4.73 m for one-hour duration (corresponding to 6.40 hours in prototype). It was also observed that the highest wave run-up was just above +8.8 m and rundown was up to +1.9 m. The waves were breaking on the armor causing no damage to armor and also to toe-berm consisting of 2 to 4 t stones on 1:2 slopes.

5. DISCUSSION AND TEST RESULTS

The conceptual design was developed using the Hudson's formula. The preliminary cross sections were then constructed as 2-D models and placed in the wave flume. The models were made according to the geometrical similarity. These models were tested in the wave flume and the required changes were incorporated in the design. The design of cross-sections of breakwaters at various bed levels have been evolved based on desk and wave flume studies. It is presumed that, the seabed strata below the construction of breakwaters are adequate to sustain the load of the breakwater structures. The graph i.e. Figure 3 depicts the comparative difference in the weight of armor units calculated from empirical design and those obtained from wave flume studies.

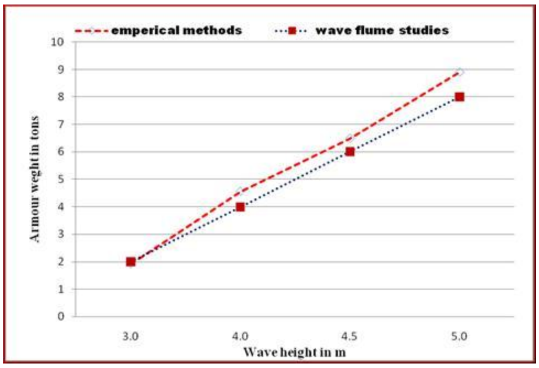

Figure 3: Armor Weight V/S Wave Height

6. CONCLUSIONS

The density of concrete and stones to be used for the construction of the breakwaters should be about 2.4 t/m^3 and 2.6 t/ m^3 respectively. The tetrapod's of 12 t weight in double layer in the armor of breakwaters should be placed with correct slopes as specified, as per the packing density of 64 blocks/ 100 m^2 respectively.

There should not be any deviation from the design during the construction of the breakwaters in respect of the levels, slopes and the weights of stones. The rubble mound structures are flexible structures and it is essential to monitor and maintain them regularly. Therefore, periodic survey and maintenance of the breakwaters may be undertaken as and when damage occurs. The construction phasing may be adhered, in order to have a safety and economy of project. The construction of the breakwaters may not be possible during one season. As such, a temporary roundhead may be provided wherever the work is curtailed. The grading of the stones to be used in the breakwaters construction should be as follows:

- 2-3 t stones - 50% stones should be higher than 2.5 t
- 1-2 t stones - 50% stones should be higher than 1.5 t
- 0.5-1 t stones - 50% stones should be higher than 0.75 t
- 300-500kg stones - 50% stones should be higher than 400 kg
- 100-200 kg stones - 50% stones should be higher than 150 kg

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REFERENCES

1. Alexander Schendel, Nils Goseberg and Torsten Schlurmann, "Experimental Study on the Performance of Coarse Grain Materials as Scour Protection", International Conference on Coastal Engineering, 2014.

2. A. V. Mahalingaiah, M. D. Kudale, "Hydraulic Model Studies For Safe And Optimal Design Of Rubble mound Breakwaters" International Journal Of Earth Sciences And Engineering, ISSN 0974-5904, Vol. 07, No. 02, Pp. 400-404, April 2014.

3. A. V. Mahalingaiah, B. R. Tayade, N. V. Gokhale, M. D. Kudale; "Design Of Submerged Offshore Reefs For The Coastal Protection Measures" Science Direct, Aquatic Procedia, Elsevier Journal Publication, ISSN: 2214-241X, Volume 4, Pp. 198-205, March 2015.

4. Arthur De Graauw "The Long-Term Failure of Rubble Mound Breakwaters" 2014.

5. Bas Reedijk, Markus Muttray, Arnoud Van Den Berge and Richard De Rover, "Effect of Core Permeability On Armor Layer Stability", International Conference On Coastal Engineering, Spain, 2012.

6. Christos V. Makris, Constantine.D. Memos, Department Of Civil Engineering, National Technical University Of Athens, Wave Transmission Over Submerged Breakwaters: Performance Of Formulae And Models, Proceedings Of The Sixteenth (2007) International Offshore And Polar Engineering Conference Lisbon, Portugal, July 1-6, 2007.

7. Constantine Memos, "Hydraulic Behaviour of Submerged Breakwaters" 2007.

8. D.M.D.T.B. Dassanayake, S. Kumuthini, R. Galappatti, D. Wootton & M. Mendis, University Of Plymouth Faculty Of Science And Engineering, "Hydraulic Model Study To The Breakwater Design For Colombo South Harbor", Conference Paper - February 2008.

9. H.F.Burcharth, "The Importance of Pressure Sampling Frequency In Models For Determination Of Critical Wave Loadings On Monolithic Structures" 2007.

10. J. D. Mettam, J. G. Berry, "Factors of Safety for the Design of Breakwaters", International Conference on Coastal Engineering, Spain, 1982.

11. J. S. Reedijk, M. Muttray, A.Van Den Berge, R. Derover, "Effect of Core Permeability on Armor Layer Stability", International Conference on Coastal Engineering, Hamburg, 2008.

12. Joseph R. Medina and M. Esther Gomez-Martin, "Kd and Safety Factors of Concrete Armor Units" International Conference on Coastal Engineering, Spain, 2012.

13. Kenneth Kaplan and Henry E. Pape Jr, Department of the Army San Francisco, "Design of Breakwaters", 1948.

14. K.G.Shirlal & Subbarao M, 2014, Department Of Applied Mechanics And Hydraulics, Karnataka Regional Engineering College, "Laboratory Studies on the Stability of Tandem Breakwater", 2014.

15. Marcel R. A. Van Gent and Ivo M. Van Der Werf, "Toe Stability of Rubble Mound Breakwaters", International Conference on Coastal Engineering, Spain, 2014.