CHAPTER 82

PLEA FOR THE PLACEMENT OF ARMOUR BLOCKS IN ORDERLY PATTERNS

Fernando Vasco Costa, F. ASCE (1)

Abstract

Just by placing hollow blocks in orderly patterns, all in the same direction and well interlocked among themselves, not only will their resistance against localized wave actions be greatly increased, but their resistance will vary little from one block to another. Furthermore, the risks of their breakage due to "rocking motions" and of the rapid spreading of damage once initiated, will be essentially eliminated.

To render possible the placement of blocks under the water surface in predetermined positions, in the presence of waves and currents, the blocks should be suspended simultaneously from three or four inclined cables.

Introduction

Blocks with a compact form, like quarry stones and cubic concrete blocks, were for a long time the only ones used in breakwater armours. Slender blocks, like tetrapodes and dolosse, came into use only after World War II. They were an improvement because they weighed much less and could be placed in steeper slopes. Hollow blocks, like Seabees and Diodes, were introduced quite recently, but primarily for use along river banks and for shore protection.

Different types of armour blocks should be compared, like alternative designs for any type of engineering structures, by taking into consideration the extreme high

(1) Formerly Professor at Technical University of Lisbon, Consulmar, Rua Joaquim A. Aguiar, 27, 1000 Portugal.

actions their elements may be submitted to, the extreme low resistances some of the elements will not be able to oppose and how will the different modes and degrees of the failure of the elements affect the behaviour of the whole structure.

For compact blocks the more damaging wave actions will consist of pulling forces acting normal to the armour surfaces; for slender blocks the more damaging wave actions will consist of combinations of oblique forces and torques acting in particular orders and directions. The probability of occurrence of such combinations is very low, but it should not be ignored, especially in long breakwaters built in deep water.

The placing of hollow blocks in orderly patterns is advocated as a way to reduce the gravity of the consequences of wave actions, of reducing the dispersion of the resistance of the blocks and of reducing the risk of the rapid spreading of damage.

Oblique forces and torques as determing factors of the stability of armours of slender blocks

Static tests of several types of armour units have been described by Price (1979) and by Wang and Peene (1990). They showed that the mean value and the dispersion of the resistances of slender blocks against being pulled out by forces acting normal to the surface of the armours is not as much affected by the type of block as could be expected.

Had the slender blocks been submitted, during testing, to combinations of oblique forces and torques, not only would the average resistance of the blocks have been smaller but its dispersion would have been much greater.

Just by examining an armour of slender blocks, one can imagine the directions of the forces and torques that need to be aplied in order to disentangle a particular block from its neighbours (Fig. 1). Sea waves can not see, or plan, but they can apply, for hours and days, a great variety of combinations of oblique forces and oblique torques. Once they succeed in removing the first block, neighbouring blocks, lacking the support of the block that left, will also start leaving the armour, one after the other, in a chain reaction (Vasco Costa, 1983).

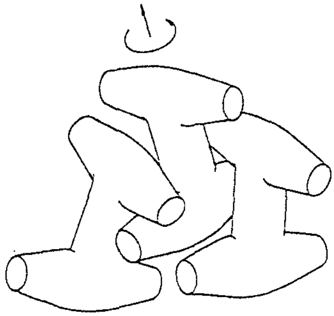


Figure 1 - Forces plus torques are required to disentangle dolosse blocks from an armour

The probability of even well interlocked blocks being submitted to the right (or wrong) combinatinos of forces and torques that can pull them out of an armour increases with the duration of a storm (Lousada and Guimenez - - Curto, 1981), with the number of the blocks in the armour (Burcharth, 1983) and with the range of directions of the waves (Christensen et al. 1984). The deeper the water in front of a breakwater the wider will be the variety of combinations of directions from which the waves will be able to reach the armour.

Tests run in narrow flumes, in which all waves come from the same direction, do not give an adequate picture of the behaviour of armours made of slender blocks. Such tests are conducive to the underdesign of armours of slender blocks. The recommendation to adopt values of the coefficient Kd for dolosse, in the Hudson formula, about 10 times larger than that for rough angular quarrystones, was probabily based on tests run in flumes that did not properly represent the variety of directions of forces and torques to which such blocks are subjected to in prototype (Shore Protection Manual, 1984).

How can a designer benefit from the advantages offered by blocks of slender form (the use of lighter blocks on steeper slopes), without incurring their disadvantages (wide dispersion of resistances, risk of breakage during "rocking motions" and the spreading of damage once initiated)? Just by placing the blocks in orderly patterns, all with the same orientation, well interlocked with their neighbours and without free spaces between them, so as to avoid "rocking motions".

Recently a new type of armour blocks has been developed; it consists of hollow blocks placed in orderly paterns, so as to avoid "rocking motions". Examples are the COB, the SEABEE, the SHED and the DIODE. As the porosity of armours of hollow blocks is high, about twice that of armours of compact blocks, and well distributed, such armours resist heavy seas effectively. They are so stable that such blocks can be used in a single layer. They have been applied quite successfully in the protection of beaches and shores, where blocks can be placed above the water surface.

By providing the faces of such hollow blocks with ridges and grooves, the resistance of the blocks against occasional localized wave actions can be greatly increased (Fig. 2).

As the blocks need to be placed in quite precise positions below the water surface, even when the water is being submitted to the action of currents and waves, they should be suspended not just from a single cable, as is the current practice, but simultaneously from several inclined cables (Fig. 3).

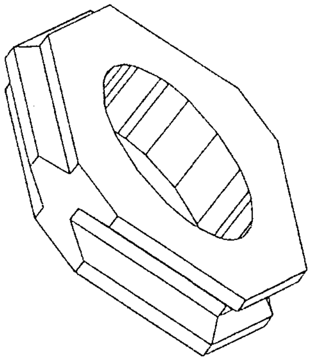


Figure 2 - Block with ridges and grooves on the faces in contact with neighbouring blocks

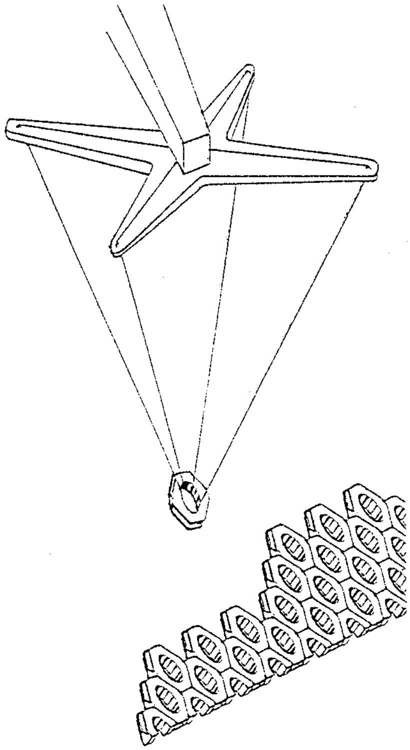


Figure 3 - The placing of blocks suspended from four cables

Importance of the blocks placing operation

Tetrapodes were a great success when they were first introduced because they permitted the use of lighter blocks in steeper slopes. Such success lasted as long as their use required the payment of patent rights to Sotramer. This company used to send technicians to the construction sites to instruct crane operators on how to place the tetrapodes so that the blocks would be well entangled with their neighbours. This procedure was essential not only to increase their average resistances against being pulled but, especially, to reduce the dispersion of such resistances.

In model tests conducted in narrow flumes, as all the blocks are submitted to almost the same flow conditions, the interlocking does not greatly affect their resistance against being pulled out. In prototype structures, however, the blocks are submitted to waves arriving from a great variety of directions and they can, now and then and here or there, exert strong localized actions on some of the blocks. The interlocking is then essential for the stability of the armour.

Dolosse were such a success when they were first used in their country of origin, South Africa, that they were promptly adopted for the armours of several long breakwaters built in the seventies in quite exposed locations. Such blocks did not behave as could be expected from the results of the model tests on which the design of the armours had been based. Because the larger a block the more brittle it becomes, plenty of large dolosse loosely placed broke during "rocking motions", even when submitted to relatively mild storms.

The natural periods of oscillation of suspended blocks have about the same order as those of sea waves. If, when entering the water, a block happens to move in the same direction the water is moving, the amplitude of oscillation is increased, and the risk of breakage during the placing operation is also increased (see Table I). In still water the oscillation would have been damped, but in moving water the oscillation of the suspended blocks can be greatly amplified.

Table I
Period of Oscillation of a Suspended Block

$$T = 2\pi\sqrt{l/g}$$

Lenght of the cable (l)	9m	16m	25m	36m	49m
Period of Oscillation(T)	6s	8s	10s	12s	14s

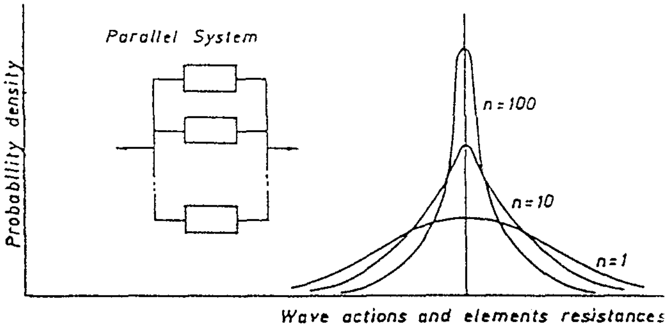
The placing operation is facilitated if the blocks have an octogonal form. The slanted faces will guide the blocks to occupy their proper position among other blocks; the horizontal faces will support the blocks weight; the vertical small faces will allow for minor deviations from the conventional pattern (Fig. 2).

Armours can have a behaviour approaching that of series systems or parallel systems

The way the failure of an armour spreads once a block breaks or leaves the armour needs be analyzed. Some armours fail like a chain, the classical example of a series system. As soon as its weakest link breaks, a chain is no longer useful. The wider the dispersion of the resistance of the links and the larger the number of links, the weaker a chain becomes. Engineers have tended, nevertheless, to base the design of all types of armours on the average resistance of the individual blocks, even when, as is the case with armours of slender blocks placed at random, their behaviour approaches that of a series system (Vasco Costa, 1983).

Armours composed of compact blocks that are placed at random, like natural stones and concrete cubes, can become more stable after being subjected to a few mild storms giving occasion to adjustments in the positions of poorly placed blocks. If a small percentage of the blocks leaves the armour during a storm, up to about 5%, the armour can still be regarded as sufficiently safe (Shore Protection Manual, 1984). As the leaving of a few elements does not imply that neighbouring blocks will also leave, and can even contribute to adjustments that will render such blocks more stable, armours of compact blocks can be regarded as having a behaviour approaching that of a parallel system (Fig. 4a).

The situation is quite different with armours composed of slender blocks, like tetrapodes and dolosse. Their resistances against being removed by strong wave actions exerted on particular blocks depends on how effectively each block is entangled with its neighbouring blocks. As soon as one block leaves its position, its neighbours, lacking the support of the block that left, are likely to leave also, one after the other, in a chain reaction. The larger the number of blocks, the less stable becames an armour of slender blocks (Fig. 4b).



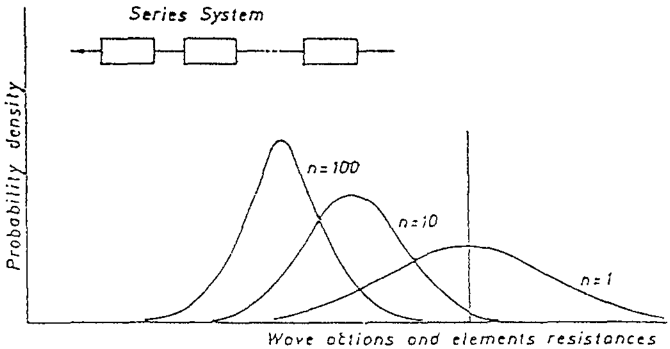


Figure 4 - Probability density of the failure of parallel and of series systems as affected by the number of the elements in a system.

Some of the accidents on very long breakwaters built in deep water during the seventies, with armours of large slender blocks, were attributed to the fragility of the blocks. They were due, however, at least in part, to the fact that the behaviour of their armours approached that of series systems.

The risk of the rapid spreading of the damage when a block occasionally breaks or leaves an armour will be greatly reduced in case of orderly placed and well interlocked blocks. If a block, of the type represented in Figure 5, breaks or leaves an armour, the six neighbouring blocks will lack its support on only one of their faces.

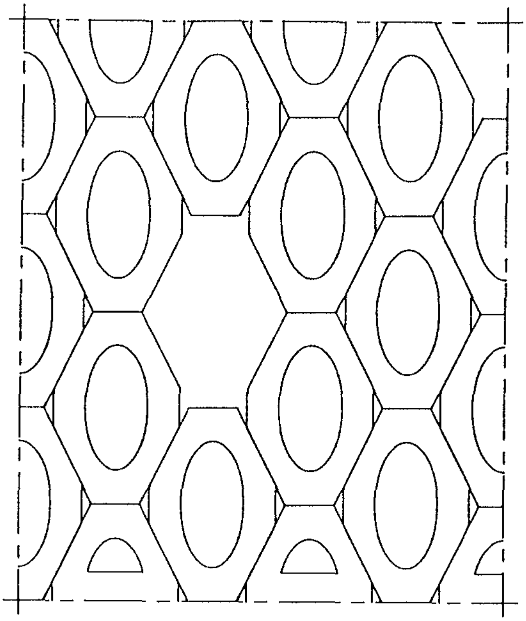


Figure 5 - Armour with a missing block

Side-scan sonar (SSS), already in use to detect damage under the water level of coastal structures, can also be used to guide and check the placement of blocks below the water surface (Kuckarski and Chauster, 1990).

Summary and Recommendations

Slender blocks have the advantage, over compact blocks, of opposing a much greater average resistance against being pulled out. Unfortunatly such resistance, because it depends on how well each block is entangled with its neighbours, varies widely from one block to another. As the behaviour of armours of slender blocks approaches that of series systems, whenever a poorly placed block is submitted to strong localized wave actions, damage is likely to spread rapidly over the whole armour.

The placement of hollow blocks in orderly patterns, without clearances between blocks, helps to avoid "rocking motions". If their surfaces of contact are provided with ridges and grooves to assure a good interlocking, the blocks will present a great resistance against being removed and such resistance will be the same to all the blocks.

The placement of blocks in precise positions below the water surface will require the use of cranes especially built for the purpose, able to suspend the blocks simultaneously from three or four inclined cables, to avoid pendulation.

Acknowlegement

Prof. John S. MC Nown, visiting Professor of the Royal Institute of Technology, in Stockholm, and Carlos F. Abecasis, of Consulmar, read the manuscript and made valuable suggestions for its improvement.

References and Further Readings

Bruun, Per (1982). "Stability and Fragility of Mound Structures". The Dock & Harbour Auth. March.

Burcharth, Hans F., (1983) "The Way Ahead." Conf. on Breakwaters - Design and Construction, Inst. of Civil Eng. London.

Burcharth, Hans F., (1991) "Design Innovations, Including Recent Research Contribuitions", Coastal Structures and Breakwaters, Inst. of Civil Eng., London.

Christensen, F., Thumbo, F. C., Broberg, Stig E., and Tryde, F., (1984). "Behaviour of Rubble-mound Breakwaters in Directional and Uni-Directional Waves". Coastal Engineering, 8, pg 265-278.

"Behaviour of Rubble - Mound Breakwaters in Directional and Uni - Directionel Waves. Coastal Engineering, 8 pg 265-278.

Clifford, J.E. (1991), "Breakwater Research: Single Layer Armour Units", The Dock of Harbour Auth. April. pg 349.

Golit, C.K. and Delok, H. (1976) "Large Scale Model Tests of Placed Stone Breakwaters". 15th Int. Conf. on Coastal Eng. Hawai, pg 257.

Hettiarachchi, Sam and Holmes, P., (1988) "Performance of Single Layer Hollow Block Armours Units". Proc. Conf. of Breakwaters, ICE, Easthbourne, UK.

Kucharski, W.M., and Clausner, J.E., (1990) "Underwater Inspection of Coastal Structures Using Commercially Available Sonars". Technical Report REMR-CO-11, US Army Eng. Waterways Exp. Station, Vicksburg, MS.

Losada, M.A. and Gimenez-Curto, L.A. (1981) "Flow Characteristics on Rough, Impermeable Slopes underWaves Action". Coastal Engineering, 4 pg 187-206.

Oumeraci, H., Bürger, W. W., and Partensky, H. W. (1989) "Induced Pore Pressure in Rubble Mound Breakwaters -- Results of Large Scale Model Tests", 22nd Int. Conf. on Coastal Engineering, Malaga, pg 195.

Price, W.A. (1979) "Static Stability of Rubble-mound Breakwaters". The Dock of Harbour Authority, May.

Shore Protection Manual, Volume II, (1984), Waterways Experiment Station, U.S. Army Corps Engineers, Vicksburg, USA.

Van der Meer, J. W. (1987), "Stability of Breakwater Armour Layers - Design Formulae". Coastal Engineering, Vol. II, pg 219-239.

Vasco Costa, F. (1983) "The Spreading of Damage in Breakwater Armours". The Dock and Harbour Auth. March.

Vasco Costa, F. (1984). "The Large Dispersion in Behaviour of Multilegged Armour Units". The Dock and Harbour Auth. May.

Vasco Costa, F. (1991), "Coastal Structures Design Taking into Consideration the Consequences of Possible Failures" Journal of Coastal Research, Vol. 7, pg 1175-1180.

Wang, Hsiang and Peene, Steven J., (1990). "A Probalistic Model of Rubble Mound Armour Stability, Coastal Engineering, 14, pg 302-331.