Dibb, T.E., Hughes, D.W., Poole, A.B., 1983, "Controls of size and shape of natural armourstone" Geological Society, London, Engineering Geology Special Publications, 13, 91-106.

Abstract:

The sizes and shapes of armourstone blocks for rubble breakwaters are primarily determined at the quarryface, and later modification then occurs *in situ* in the breakwater environment. The principal controlling parameters in the quarry include: rock type, rock joint frequency and orientation, size and type of blasting charge and the orientation of the blast's fractionating power. The majority of existing data on this subject has been obtained from detailed studies of quarries principally concerned with aggregate production in Britain, but extensive studies have recently been carried out on a variety of rock types in quarries that are currently producing primary armourstone for breakwater structures in the United Arab Emirates and the United Kingdom. These studies combine to permit the relative importance of the various controlling factors which operate during quarrying, transport, placement and subsequently in service to be evaluated and are reported here.

The quarry-orientated study is supplemented by detailed studies of block modification and deterioration in the several different environmental zones of breakwater structures. The principal factors controlling this shape modification are micro-fracture pattern, mineralogy and fabric, grade of weathering of the original rock, grain interlock and intergranular cement type. Changes in shape will modify the stability factors of *in situ* armour blocks and alter void ratios and slope angles, which together are perhaps the most important factors controlling the dissipation of wave energies on rubble mound breakwaters.

The importance of long-term abrasion effects should not be underestimated; to monitor these effects, damage assessments have been used to relate the shape modification to slope.

Latham, J.P., Poole, A.B., 1987, "Pilot study of an aggregate abrasion test for breakwater armourstone" Quarterly Journal of Engineering Geology & Hydrogeology, 20, 311-316.

Abstract:

The long-term performance of the materials out of which breakwaters and coastal protection works are constructed depends not only on physico-chemical degradation processes but also on the mechanical abrasion resistance of the rock or concrete used. The abrasion of breakwater armourstone affects the armour layer stability directly by causing weight loss from the rock blocks. Another important though unquantified source of stability reduction in the armour layer is the progressive rounding of armour by abrasion leading to poor interlocking between individual blocks and their neighbours (see the discussion of this phenomenon by Dibb *et al.* 1983).Gupta (1985) and others have demonstrated that there is a relative decrease in aggregate (macro) porosity for rounded compared with angular fragments. Such a decrease in armour layer porosity due to the rounding of blocks may have a deleterious effect on energy absorbing properties of the layer. The assessment of abrasion resistance is therefore of great interest to the engineer concerned with in-service deterioration of armour layer performance. New quantitative methods

for measuring the effects of abrasion on the entire profile of the breakwater armour layer were reported by Latham & Poole (1986).Several standard engineering tests and analytical procedures have been recommended for the assessment of suitability of a particular rock for breakwater core and armour material (Fookes & Poole 1981; Allsop *et al.* 1985). The test values recommended for acceptance by Allsop *et al.* are drawn from a list of tests which does not include an abrasion resistance test, although several abrasion

Niese, M.S.J., Van Eijk, F.C.A.A., Laan, G.J. and Verhoef, P.N.W., 1990, "Quality assessment of large armourstone using an acoustic velocity analysis method" Bulletin of Engineering Geology and the Environment, 42, 55-65.

Abstract:

Large armourstone blocks are used to protect coastal construction against current and wave forces. Ideally such blocks should be durable and stay intact during engineering lifetime. The quality of these large blocks is, among other factors, influenced by the occurrence of internal disturbances, such as fissures. If the blocks fracture, spall or abrade during engineering lifetime a construction may be significantly weakened and finally failure may take place.

In this investigation attention is focused on the prediction of spalling and fracturing of rock blocks due to pre-existing fissures. The quality of the blocks was assessed by measuring the velocity of acoustic waves propagating through the rock. The acoustic measurements were done with commercially available simple equipment. For an appreciation of the results of the velocity measurements, the blocks were dropped from a specified height in droptests. In the laboratory the effect of normal pressure on open discontinuities to the acoustic velocity was investigated.

The data obtained from the acoustic measurements were handled according to a simple method based on the cumulative distribution of normalized velocities. An important result of the investigation is the development of a general classification system for armourstone based on acoustic measurements: The "I-value" is obtained by the data handling method and gives information about the distribution of the acoustic velocities of a rock block. A value of one means that no significant disturbances are present in the block tested.

I-value	Class	Description
< 1.25	I	good
1.25-2.00	II	moderate
> 2.00	III	bad

Clark, A.R., Palmer, J.S., 1991, "The problem of quality control and selection of armourstone" Geological Society, London, Engineering Geology Special Publications, 24, 119-122.

Abstract:

The successful use of naturally occurring rock as an armourstone depends on the selection of suitable material which will perform the function for which it was designed.

Two recent case histories of coast protection works with a combined total of about 200.000 tonnes of rock armour demonstrates that adequate quality and selection control procedures were not utilized and as a result substantial quantities of rock were rejected, and in one case costly arbitration procedures were involved. In each case the contractor for the works was responsible for the provision of armourstone in compliance with the specification and had simple engineering geological controls been used substantial savings could have been made.

Lienhart, D.A., 1998, "Rock engineering rating system for assessing the suitability of armourstone sources" Geological Society, London, Engineering Geology Special Publications, 16, 31-42.

Abstract:

The process involved in assessing and selecting a potential source of armourstone of suitable quality is one of great complexity. The process involves the inspection and evaluation of the quarry and its production methods, testing of the processed stone, evaluation of the quality of both intact and processed stone, and consideration of both the transportation methods and placement techniques. The entire process, from quarry selection to placement at the project, may be viewed as a rock engineering system. The use of a rock engineering interaction matrix simplifies an understanding of how various factors affecting the quality of quarried armourstone are interrelated. Through this understanding of the various interrelationships a weighted rock engineering rating system may be developed for the assessment of the suitability of various armourstone sources. Such a rating system is designed to pull together all the factors related to both the field and laboratory investigations of a potential source, enabling geologists at all experience levels to arrive at a well-founded conclusion concerning the potential quality of stone produced from a particular armourstone source.

Latham, J.P., Lienhart, D. and Dupray, S., 2006, "Rock quality, durability and service life prediction of armourstone" Engineering Geology, 87, (1-2), 122-140.

Abstract:

Rock armourstone is unusual amongst geomaterials because of the extremely wide range of intrinsic rock strengths that often have to be used and the range of end use conditions in which it must serve. The authors' experience has been distilled to formulate suitable guidance as demanded by practicing coastal and hydraulic engineers for the forthcoming update to the 1991 Rock Manual (CIRIA, CUR, CETMEF. in press. The Rock Manual. The use of rock in hydraulic engineering (second edition). C683, CIRIA, London.). The armourstone evaluation theme of earlier work by Lienhart, and abrasion testing and degradation modelling of armourstone by Latham are revisited. A general in-service degradation model for wear of armourstone, based on a progressive fractional mass loss with time, is redeveloped. The innovation is to introduce two new methods that are both practical and simple to implement. One method uses abrasion resistance, water absorption and block integrity in a system that couples the rock susceptibilities to various common site conditions. The other treats intrinsic rock properties from the quarry all together to achieve a global armourstone quality designation, AQD, of the rock, that is independent of the actual conditions of the proposed site of application. Depending on the assessment of site aggressiveness, the degradation with time on site is generated by retarding or accelerating the standard mass loss plot invoked from the AQD value, but adjusted by semi-qualitative engineering and/or scientific judgement of the rating geologist. Examples are used to illustrate and compare the two methods. Discussion is included on the need for more rigorous future research approaches based on breakage prediction and on the need for further case histories.