TECHNICAL NOTE

CEMENT CONCRETE & AGGREGATES AUSTRALIA

Guidelines For The Specification Of Armourstone

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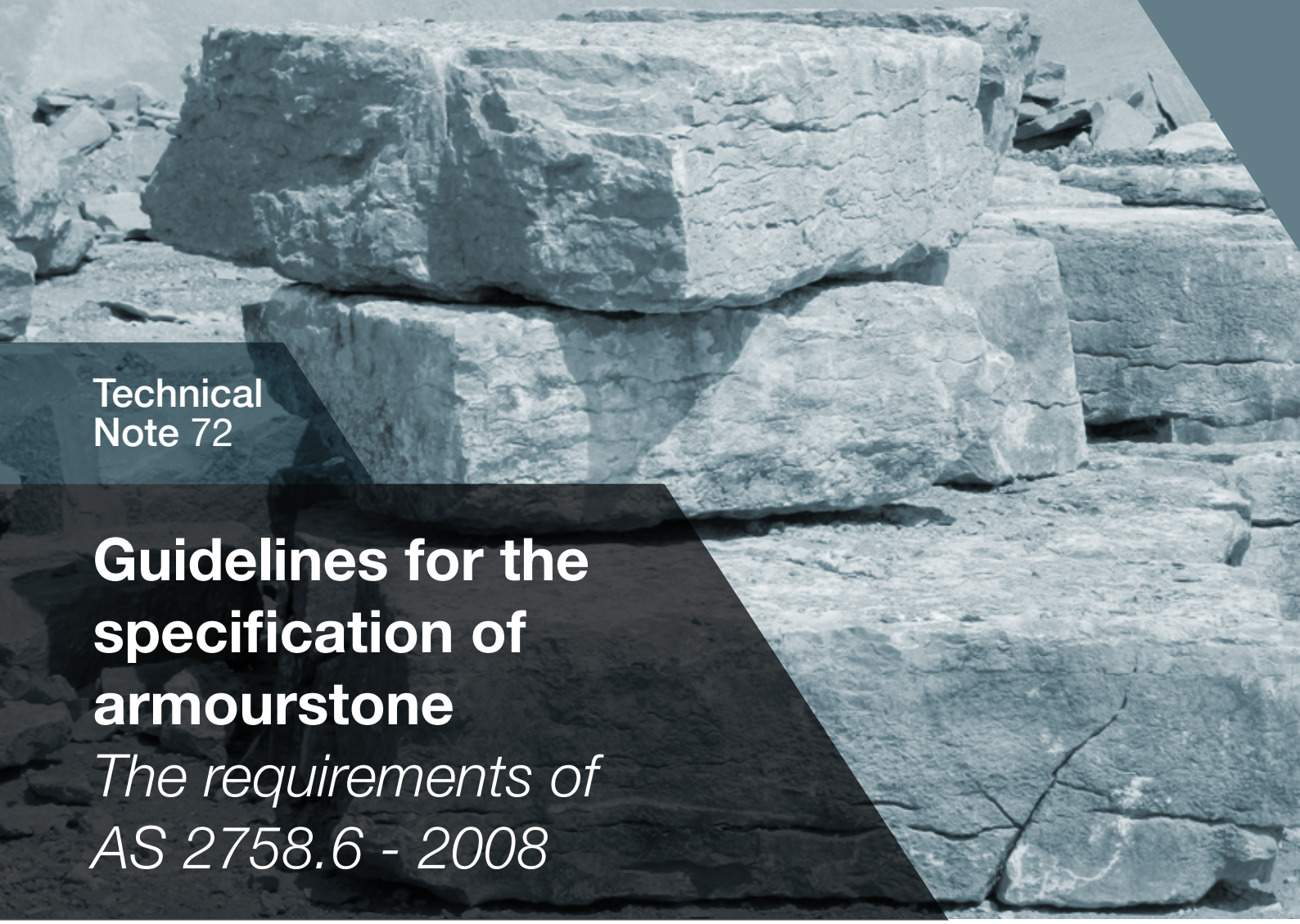

Technical Note 72

Guidelines for the specification of armourstone

The requirements of AS 2758.6 - 2008

1.0 Background to AS 2758

Australian Standards are prepared by committees of industry representatives who contribute their expert knowledge to ensure the information contained in a Standard reflects the best technical, scientific and system knowledge available.

In the case of AS 2758, Aggregates and rock for engineering purposes, a set of Standards has been developed to ensure uniform material compliance is identified and specified, thus minimising the risk of a failure in a project. AS 2758 comprises seven individual standards, viz:

AS 2758.0	Part 0 Definitions and classification
AS 2758.1	Part 1 Concrete aggregates
AS 2758.2	Part 2 Aggregate for sprayed bituminous surfacing
AS 2758.4	Part 4 Aggregate for gabion baskets and wire mattresses
AS 2758.5	Part 5 Coarse asphalt aggregates
AS 2758.6	Part 6 Guidelines for the specification of armourstone
AS 2758.7	Part 7 Railway ballast

This technical note provides background knowledge of the information provided within AS 2758.6 for development of a specification of armourstone in various applications including sea walls, foreshore or dam walls.

This Standard sets out best practice criteria as known at the time of publishing and should not be regarded as a stand-alone material works specification.

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2.0 Armourstone

Armourstone is a natural boulder sized rock material used in applications where its mass can retain material or provide scour protection from fast or slow flowing waters, waves or currents. The boulder size of the armourstone helps determine its applications as larger heavier boulders are needed in ocean or sea walls where they may be shifted by water movement and smaller boulders may be adequate for slow flowing rivers where loading is generally less dynamic etc. For this reason the protection of sea inlets, harbour foreshores, river embankments and dam walls are common applications. Armourstone is also used in retaining walls, for decorative uses, slope stabilisation and bridge abutments. The use of armourstone is not limited to those shown here. Armourstone may range in size from several kilograms to several tonnes mass.

Figure 1: Armourstone use and quarry allocation

The AS 2758.6 Standard differs from others in the AS 2758 suite, in that it is a “guideline” rather than a specification for supply and testing of quarry materials.

For the purposes of armourstone rock selection and testing, a design life of 40 years has been assumed, and in most circumstances, the work specification of a particular project will use these guidelines as a basis of selection, but it is not used as a specification in itself.

The design philosophy and design life of an armourstone structure will determine the choice of test procedures and these in turn will be included in the work specification along with testing frequencies for the specific project.

The use of armourstone in projects is limited and depending on the required sizes for the armourstone it may be difficult and slow for a quarry operator to produce the required volumes as the yield of large boulders in a quarry shot may be low. In addition the same shotrock sold as armourstone would normally be the feed that goes into the quarry crushing plant to produce aggregates, so making armourstone may starve a given quarry of plant feed hence slowing the production of other products.

For this reason it is important that those dealing with supply, understand the need to communicate well in advance the requirements of a project with armourstone. Quarry operators will require some lead time to produce, particularly if the armourstone sizes within a singular project vary. An example of this might be in the construction of a marina where there can be larger and smaller armourstone boulders needed to withstand loading or provide decorative or aesthetic appeal to the development. There will also be a range of design factors to take into account when considering the supply of armourstone to a project, they can be but not limited to the following:

- Stability of the embankment
- Wave action, wave height, the wave extreme and the wave pattern or wave train
- Transition zones
- Armourstone weight
- Permeability

Figure 2: Armourstone on site and in place for decorative use

3.0 Aggregate properties and the test methods

3.1 Overview

AS 2758.6 suggests a range of factors that should be considered when selecting suitable rocks for armourstone construction. Each section within this document provides specific guidance on each area to be considered.

Sections 5, 6, 7 and 8 cover availability, design considerations, exposure risk classification and resource investigation when deciding on a project that will use armourstone.

Armourstone material requirements are described in Section 9 of the Standard.

3.2 General Resource & Design Considerations

3.2.1 Resource availability: Section 5

Armourstone is not always readily available from quarry deposits and as such it is infrequently supplied into many projects that could otherwise benefit from its use. It is important for project users of armourstone to understand the location of available resources close to site to minimise transportation costs and potential handling issues. Even though there may be a quarry supply source of armourstone nearby, that is no indication of the ability of that quarry to supply the correct types, size or properties required by the project.

Figure 3: Capturing and stockpiling armourstone within a quarry

An inability to supply may be due to a number of different quarrying considerations, including inability to win sufficient rock of a required size (shot pattern), material geological and natural defects, the current plant set up, the inability to handle and deliver large types of rock and the quarry's current customer base.

In a quarry situation, it is generally considered that larger rock represents around 10-20% of the blasted material on ground following the shot. Smaller quarries have smaller blasts and therefore the amount of end product available at any particular time can be limited.

3.2.2 Design considerations: Section 6

When a designer is considering the required protection to be afforded to a given structure from external elements such as water or wave action, the role of each element within the design needs to be clearly understood. The design and selection of armourstone boulder size and mass is an important factor. Turbulent fast flowing water or aggressive wave action may dislodge some boulders and buoyancy forces will assist in transporting the individual rocks away from the structure exposing it to further degradation. Submerged or tidal conditions can also change throughout numerous cycles and the durability of the armourstone rock particles becomes very important to the ongoing integrity of the entire structure.

3.2.3 Exposure risk classification: Section 7

As mentioned in the Standard, the risk to a well-designed structure is loss of dimension and mass of the stone over time due to weathering processes, until a critical mass is reached at which point the integrity of the structure may be lost.

Table 1 of the Standard indicates the range of risk classification there can be. These considerations have a bearing on rock selection.

3.2.4 Resource investigation: Section 8

Section 8.1 - General

As there can be time required to investigate, find and produce these larger rock materials into projects, the Standard highly recommends early proactive interaction between specifier and supplier be commenced as soon as practicable in the design consideration phase.

It should also be noted that where a known resource is already available the need for longer term design action is likely to reduce.

Section 8.2 - Rock type and mineralogy

AS 2758.6 identifies the most suitable rock types to investigate. The Standard indicates that the best source for the production of large armourstone size materials may come from areas known for massive inclusion such as igneous or high-grade thermal metamorphic materials. Generally, regional metamorphic and sedimentary rock will not be suitable for inclusion into armourstone projects while certain types of limestone may be an exception.

When considering rock for armourstone, knowledge of the weathering profiles, rock defect types and joint spacing within the deposit is valuable information to determine if armourstone can be produced in sufficient material quantities for the project.

Section 8.3 - Resource variability
It is important to gain an understanding of the resource supplying armourstone and specifically the amount of large rock that can be made available from that particular site.

By undertaking targeted studies of the available sites for armourstone production the economics of obtaining suitable material may reduce. For a project of significant size, the quantity of material to be quarried can be quite significant if only 10-20% of this same material is finally suitable as armourstone. It must be remembered that even with all the requirements taken into account, the volume of available rock for use as armourstone will still be low in comparison to other quarry products normally produced from the same deposit.

Section 8.4 - Defect spacing
As shown in AS 2758.6, mapping and investigation of defects within a quarry deposit will enable estimations of available and suitable size rock to be made. This also allows for an understanding of potential loss of rock mass that may occur due to fracturing during loading, transport, unloading and placement. In addition an understanding of possible rock fracturing due to in-service conditions, such as expansion of joints due to salt entry and crystallization, for example, may be important to predict the service life of a given structure.

3.3 Material requirements and their purpose in the Standard

As stated earlier, armourstone is not used extensively in Australia and as such, some information used in this standard has been obtained from International experience, European (EN 13383-2) and relevant British Standards.

3.3.1 Material Requirements: Section 9

Section 9.1 - Sampling requirements
Sampling of armourstone can be a difficult process due to the physical size and mass of the individual boulder particles. Samples must represent the rock type and source proposed for a particular project and AS 2758.6 references sampling procedures in AS 1141.3.2 to provide guidance.

Samples that are taken from armourstone are normally forwarded to the testing laboratory and used to confirm the durability of the rock in different environmental exposures. Due to the nature of sampling of armourstone, taking of photographs is recommended to support the procedure used.

Dimensional requirements of armourstone cannot be measured using a laboratory testing procedure and are generally satisfied by random selection of test pieces on site at the quarry. Table 2 of the Standard, taken from EN 13382-2, gives an indication of the number of sample pieces to be used when determining the mass distribution of the supply. There are several sizes shown but only two grades, light and heavy.

Further indication of rock mass can be obtained by using the tables shown in Appendix 1.

Section 9.2 - Grading requirements
As stated in AS 2758.6, larger rocks, greater than 10 tonnes have been used before but the rock mass defects within these large boulders tends to be the limiting size factor in most cases. Mostly, rocks of 10 tonne mass and less are normal for armourstone.

This section discusses the range of grading requirements and is based on weight ratios. An example of a weight ratio grading is shown in the table in this section. The weight limits used are 85 and 15 and the ratio limits shown W_{85} / W_{15} where:

- W_{85} is the weight that is just greater than 85% of the blocks
- W_{15} is the weight that is just greater than 15% of the blocks

Sampling procedures and frequencies should be detailed in any works specification.

As there is no suitable Australian Standard test method for grading materials of this size, the procedure nominated as suitable is European Standard EN13383-2. The assumption for the grading requirements is that there will be up to 3% of material larger than required and also in taking samples, some fragments will be included.

Table 3 shows the requirements for average mass and the mass distribution for “light grading”.

Table 4 shows the requirements for average mass and the mass distribution for “heavy grading”.

Section 9.3 - Shape requirements
To reduce the amount of non-conforming shaped stone, it is advised to place sample specimens in the stockpile area that allow operators to visually compare with armourstone being loaded to assist in the appropriate selection of suitably shaped rocks.

Should there be a more detailed need to ensure the final shape characteristic of a block, it is usually done by a Length (L) and Thickness (E) ratio test as per the requirements of EN13383.1.

The blocks are measured for their average length and average thickness and the ratio determined.

For heavy grade, the proportion is the number of misshapen blocks against the total in the test. For light grade, the proportion is the mass percentage of misshapen particles as this test is performed by weighing. In EN13383.1 the L/E Ratio designated is less than 5% for heavy grade and less than 20% for light grade stone when the requirement is specified.

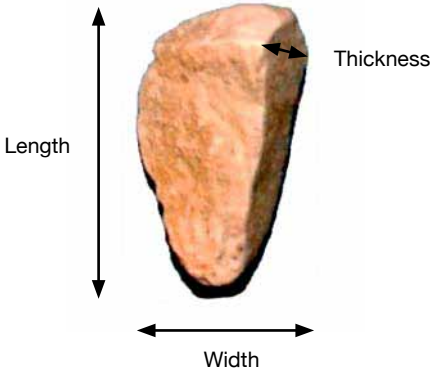

Figure 4: Typical measurements used to calculated rock mass (length, width & thickness)

Section 9.4 - Rock defects

For projects where larger stone is required, it is important the stone maintains its mass. This will ensure the long term integrity of the structure being constructed.

The one area that causes great concern and consternation during a supply into an armourstone project is the rejection of the armourstone by inspectors due to cleavage and jointing weaknesses. Not all visual defects lead to rejection as there are times where the stone defect is self-healing, is a filled joint or is a strong bedding plane. The works specification should clearly state the requirement for rejection and acceptance of the armourstone product.

Although AS 2758.6 discusses several tests that can be used to determine defects, the most common test stipulated in Australia is the simple “drop” test. It is an easy way to establish whether the stone will easily break during the transportation and installation process. If a stone survives the drop test it is likely to be suitably strong and will normally withstand a range of impact situations in situ.

The drop test is performed by dropping the test piece from a height of three metres onto a platform made up of the same rock in similar shaped blocks. The test is repeated a number of times and is used to calculate the “breakage index” for that particular armourstone. This is obtained by calculating the median stone mass before the test (original) and calculating the median stone mass after the test. The after test value is divided by the original to give the percentage of change. This requirement should be stipulated in the works specification if deemed appropriate due to expected handling or specific project concerns.

Figure 5: Cracking and defects that can affect the integrity of a structure and test results

It is important that anyone inspecting armourstone for defects and using visual determinations as a means of rejection, are qualified to understand the different breakage indicators. Also that a stone that loses 10% of its mass in a drop test may still be suitable and a stone losing 30% may also be suitable depending on where the stone fits in the overall structure.

Section 9.5 - Abrasion resistance

As the most visual constructions of armourstone are near the ocean and waterways, it is most important to use a stone that shows high resistivity to abrasion. It is well known that waterways carry a range of sediments that in turn are abrasive to their surrounds. Waves also tend to bring sediments and sand with them and so they also tend to be considered highly abrasive.

In Australia, the most common abrasion test is the Los Angeles abrasion test (LA).

To obtain suitable samples for testing the armourstone it is recommended to break samples from the actual armourstone to provide a composite sample that is then crushed and graded to “B grading” as per test method AS 1141.23.

The Los Angeles (LA) test is performed in accordance with AS 1141.23 and is a dry abrasion test. The test is performed in a rotating steel drum loaded with steel balls and aggregate sample. A bar across the inside of the drum interrupts the flow structure of the steel balls and ensures they perform a crushing/impact process on the aggregate sample and do not just roll around the drum during rotation. The drum is rotated for 500 revolutions and through this action fine aggregate particles are generated from the sample due to the interaction of the steel balls and the aggregate. After completion of the test, the sample is sieved over a 1.7mm test sieve and the percentage (%) loss is expressed as the % LA abrasion loss. A high % LA abrasion loss may indicate a weak material, which could degrade in service.

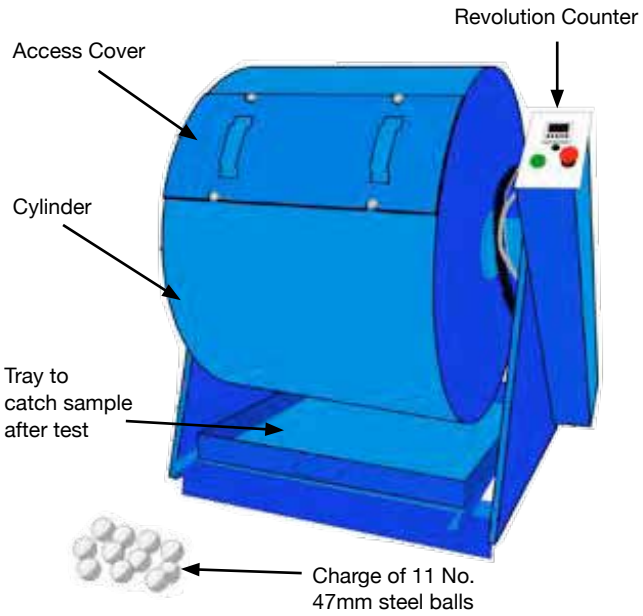

Figure 6: Typical Los Angeles test machine layout

An LA value of no more than 25% for high risk projects and 30% for low risk projects is recommended. Where sedimentary materials are used in low risk constructions, the use of the LA test is of little value and the use of local knowledge and local test requirements are best implemented.

Section 9.6 - Particle density and water absorption

To obtain suitable samples for testing the armourstone it is recommended to break samples from the actual armourstone to provide a composite sample that is then crushed and graded to "passing 26.5mm and retained 9.5mm" and then tested as an aggregate sample as per test method AS 1141.6.1.

The following information describes both the procedure for particle density and water absorption. The particle density test is performed by taking a sample of aggregate and determining its mass in air and then determining its mass in water with the air voids removed. The sample is soaked to ensure all available voids are filled with water and water able to get into the stone can. The result is the ratio of the density of the aggregate (with the air voids removed) to the density of water.

Water absorption testing is performed in conjunction with determining the particle density, both in the dry state and in the saturated surface dry condition (SSD).

The water absorption, which is the amount of water a particle can absorb, can be calculated from the test procedure and is the difference between the dry material and the saturated surface dry state. There are aggregate particle voids, and there are voids between aggregate particles. As solid as aggregate may be to the naked eye, most aggregate particles have voids, which are natural pores that are filled with air or water. These voids or pores influence the particle density and water absorption of the aggregate materials.

The voids within an aggregate particle should not be confused with the void system which makes up the space between particles in an aggregate mass. Refer to Figure 7 below.

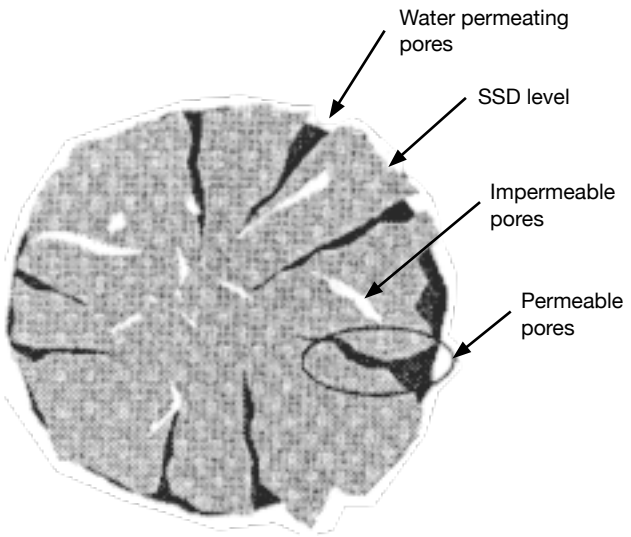

Figure 7: The effects of water and its absorption into the aggregate

AS 2758.6 sets the requirement for particle density on a dry basis at not less than 2600kg/m^3 and the maximum water absorption as 1.5%. Other values can be specified but care must be exercised if doing this as for instance a change in water absorption can indicate a higher porosity and thus a potential to greater penetration of salts in a particular environment.

Section 9.7 - Salt attack and freeze thaw

Australia has few areas affected by freeze thaw and they are generally limited to some parts of Tasmania and the Alpine regions. Should material be supplied to these locations, care should be taken to assure the rock has low water absorption. Less than 0.5% water absorption would be considered to be resistant to a freeze/thaw situation.

Salt attack on armourstone is generally limited to where it is used in or near a marine environment. In these cases, the use of the Sodium Sulfate Soundness test is the best guide (AS 1141.24). Samples are best taken from the blocks being supplied and maximum limits of 6% for high risk and 9% for moderate risk are the requirements.

Figure 8: Sodium sulfate soundness bath and test portions after soaking

The Sodium Sulfate Soundness test is carried out by taking particular sized test portions and submitting them to cycles of wetting and drying in salt saturated solution. This cycling of the samples allow salts to enter into the cracks within the material and as the wetting and drying cycles continue, the salt crystallises and builds such that the expansion of the crystals will in some cases cause the test particle to break.

The test portion is re-sieved and the loss calculated to assess the sodium sulfate loss.

Section 9.8 - Durability tests
As noted in the Standard, various states of Australia use different methods for assessing armourstone durability and the required methodology should be documented in the works specification.

As with other methods, the samples used for testing are best obtained by breaking pieces from the material being supplied. In cases where the wet/dry strength variation (AS 1141.22) is used as a specifying criterion, the limit of variation should be less than 25% for high risk areas and less than 30% for moderate risk areas. The minimum wet strength requirement for both these risk areas is a minimum of 100kN. For low risk areas, the wet/dry variation limit is less than 35% and a minimum wet strength of 80kN.

The wet/dry strength variation test is performed in accordance with AS 1141.22 and is an aggregate crushing test. It is performed by taking a measured quantity of sized aggregate and subjecting the sample to a force within a confined space. The test is performed on aggregate in both the wet and dry conditions. The aim is to obtain, by crushing, 10% of produced fines in order to ascertain the strength of the aggregate in both wet and dry conditions and to determine the percentage variation between the aggregate's strength in those two conditions.

Figure 9: A Wet/Dry sample under test in a compression machine

The strength of the aggregate is defined as the crushing force which, when applied to a known mass of the aggregate, will produce fines amounting to 10% of the mass of the dry test portion. The wet test is performed on a sample of the same size as that for the dry test but it is soaked for 24 hours then towel dried to Saturated Surface Dried condition (SSD), and crushed. This allows an understanding of the change in strength between the dry and wet states, thus identifying any sensitivity to water.

Appendix A - Mass to dimension conversion for boulders
The appendix in this standard is used to convert blocks of known dimensions when measured over three perpendicular axis, to a mass. In this standard the mass conversion are based on an assumed rock density of 2.65t/m^3. In general, rock mass may vary from these calculations as the density of a particular rock type may be known to be different from that quoted.

The appendix should only be used as an indicator of the rock mass only as shot rock shape will vary greatly also and will have an effect on density estimates.

4.0 Conclusion

Rocks that satisfy the guideline requirements of AS 2758.6 are likely to be suitable for use in armourstone construction provided they are consistently supplied and regular sampling and testing is undertaken to ensure those properties remain compliant with the relevant Australian Standard documents and relevant works specifications or industry requirements.