Project Name: **Port Elizabeth Foreshore Rehabilitation: Short-Term Solution**

Project No.: **XPE.E.0030**

Document Title: **Rock Generic Technical Specification**

Document No: XPE.E.0030-TS-0007

Prepared by: TNPA	Philani Mazibuko Senior Marine Engineer	02/06/2026 Date:
Reviewed by: TNPA	Masupha Letsie Marine Manager	02/06/2026 Date:
Approved by: TNPA	Masupha Letsie Marine Manager	02/06/2026 Date
Accepted by: TNPA	Warrentia Molobela Project Manager	02 June 2026 Date:
Accepted by: TNPA	Tumelo Manaka Port Engineer	03 July 2026 Date:

1. SCOPE 5

2. DEFINITIONS 5

3. MATERIALS 6

3.1. Standard Rock Gradings 6
3.2. Shape: Length-to-thickness ratio 8
3.3. Rock Quality Requirements 8
3.3.1. General 8
3.3.2. Density 8
3.3.3. Water Absorption 8
3.3.4. Resistance to Breakage 8
3.3.5. Resistance to Impact and Mineral Fabric Breakage 8
3.3.6. Block Integrity 8
3.4. Impurities 10

4. EQUIPMENT 10

4.1. General 10
4.2. Safety 10
4.3. Lifting Machinery 10
4.4. Nuisance and Environmental Control 10

5. CONSTRUCTION 11

5.1. Method Statements 11
5.2. Quality Control General Requirements 11
5.3. Source of Rock 11
5.4. Transportation, Handling and Stockpiling 12
5.4.1. Transportation 12
5.4.2. Handling and Stockpiling 12
5.5. Placing of Rock to Specified Profiles 13
5.5.1. General 13
5.5.2. Temporary Haul Roads 14
5.5.3. Underlayer and Core 14
5.5.4. Cover Layer Armourstone 14
5.6. Protection of Placed Materials 15
5.7. Disturbance to Previously Placed Materials 15
5.8. Precautions 16
5.8.1. Safety 16
5.8.2. Storm Water and Groundwater 16
5.8.3. Nuisance and Environmental Control 16

6. TOLERANCES 16

6.1. Tolerances in Rock Grading 16
6.2. Tolerances on Placed Rock Levels 17
6.2.1. Cover Layer Armourstone 17
6.2.2. Underlayer and Core 18

7. TESTING 18

7.1. INSPECTION 18
7.2. SAMPLING 19
7.2.1. General *19*
7.2.2. Homogeneity of the Batch *19*
7.2.3. Size and Composition of Samples *19*
7.2.4. Sampling Methods *21*
7.3. TEST FREQUENCY 25
7.4. DETERMINATION OF THE WEIGHT DISTRIBUTION OF QUARRIED ROCK 26
7.4.1. Equipment and Other Aids *26*
7.4.2. Weighing *26*
7.4.3. Calculation *26*
7.4.4. Report *27*
7.5. DETERMINATION OF LENGTH-TO-THICKNESS RATIO 27
7.5.1. Subject and Area of Applicability *27*
7.5.2. Sample for Analysis *28*
7.5.3. Equipment and Other Aids *28*
7.5.4. Execution *28*
7.5.5. Calculations *28*
7.5.6. Report *28*
7.6. DETERMINATION OF ROCK DENSITY AND WATER ABSORPTION 28
7.6.1. Subject and area of application *28*
7.6.2. Sample for Analysis *28*
7.6.3. Equipment and other aids *28*
7.6.4. Execution *29*
7.6.5. Calculation *29*
7.6.6. Report *29*
7.7. DETERMINATION OF RESISTANCE TO BREAKAGE 30
7.7.1. Sample for Analysis *30*
7.7.2. Method *30*
7.8. DETERMINATION OF RESISTANCE TO IMPACT AND MINERAL FABRIC BREAKAGE 30
7.8.1. Sample for Analysis *30*
7.8.2. Method *30*
7.9. DETERMINATION OF BLOCK INTEGRITY 30
7.9.1. Subject and Area of Application *30*
7.9.2. Sample for Analysis *30*
7.9.3. Equipment and Other Aids *31*
7.9.4. Execution *31*
7.9.5. Calculation *31*
7.9.6. Report *31*

8. SURVEY TECHNIQUES 32

8.1. GENERAL REQUIREMENTS 32
8.2. SURVEY OF ROCK LAYERS 32

9. REFERENCES 33

1. SCOPE

This specification provides definitions and requirements for the production, testing, transport, placement and survey of rock materials for use in the construction of marine rubble mound structures. These structures may include but are not limited to breakwaters, causeways, revetments, scour protection and groynes.

2. DEFINITIONS

For the purposes of this specification the following definitions will apply:

Armourstone/ Armour rock: Coarse aggregate used in hydraulic structures for protection against waves or currents.

Class limits: The size (or weight) defined for each rock grading together with the allowable percentage of a sample that can lie beyond that limit, as follows:

Extreme Lower Limit (ELL)

Nominal Lower Limit (NLL)

Nominal Upper Limit (NUL)

Extreme Upper Limit (EUL)

Coarse grading rock: A grading which is determined with the aid of sieve sizes.

Effective mean weight W_{em}: The arithmetic average weight of all blocks in a sample excluding any rock fragments.

Engineer: To be interpreted as *Supervisor* or *Project Manager* depending on the context if the NEC conditions of contract are used.

Grading: Rock distribution which is graded by sieve sizes or by weight of individual rocks.

GVM: Gross vehicle mass.

Heavy grading rock: A rock grading which is determined by weight for rocks of mean weight of at least 300 kg.

Light grading rock: A rock grading which is determined by weight or size of rock for mean weights less than 300 kg per rock unit.

Load of rock: The quantity of rock per unit of transport.

Mean layer thickness: The ratio of the area under the mean actual profile and the length of the survey profile (

Figure 6-1: (b)).

Nominal layer thickness t: Assumed layer thickness used to prepare design drawings and for the estimation of bulk volume of armourstone.

Nominal rock diameter D_n: The nominal rock diameter, D_n, must be calculated as the cube root of the volume of the rock. The volume must be calculated by dividing the mass of the rock by the saturated surface dry density. Where a numbered subscript is given to D_n, this refers to the percentage by weight of rocks in the grading having a smaller nominal rock diameter.

Rock: Broken natural rock sourced from a quarry.

Rock fragment: A piece of rock in a grading with lesser weight or size than the extreme lower class limit (ELL) for that particular grading class.

Rock Placement: This is categorized as follows (CIRIA, CUR, CETMEF, 2007):

a) **Random placement** is without control of individual rock orientation with void porosities typically up to 2 per cent higher than standard placement.
b) **Standard placement** is where minimum orientation control is applied so that the block attitude is effectively governed by its orientation in the stockpile before lifting. However, a minimum of three points of contact within the layer being placed should be ensured. This will require some re-orientation of individual rocks.
c) **Dense placement** involves the rotation of armour rocks until the orientation achieved is expected to give the maximum number of point contacts and minimum voids. Individual stones are removed and replaced if necessary.
d) **Specific placement** is used when in addition to placement procedures, stone shape constraints are also specified.

3. MATERIALS

Full quality control of rock as referred to in Section 7 is carried out at the site of the quarry. However, further visual inspections must be carried by the Contractor on a regular basis during delivery of rock

to the workface or to stockpile, as the case may be. These inspections must include at least the following:

a) Verification of origin of the material (agreed section/face of the quarry); indicators are petrography, colour, and grain size.
b) Mass distribution to be carried out by a trained inspector. In case of doubt, the Engineer may require an additional mass distribution test to be carried out. This will involve the weighing and plotting of the weight distribution of an agreed sample as per Section 7.2.3.2.
c) Inspect cracks.
d) Check on cleanliness, absence of soil or quarry dust.

3.1. Standard Rock Gradings

Rock gradings are divided into:

a) Heavy gradings for larger sizes appropriate for amour layers – normally handled individually.
b) Light gradings appropriate for armour layers, under layers and filter layers – produced in bulk, usually by crusher opening and grid bar separations.
c) Coarse gradings often used for filter layers of such a size that all pieces can be processed by production screens with square openings (i.e. typically less than 200 mm).

Standard gradings according to EN 13383 are specified in **Table 3-1**.

Table 3-1: Heavy, Light and Coarse Standard Grading Requirements (BS EN 13383-1, 2002).

	Class designation	ELL	NLL	NUL	EUL	W_{em} [kg]	
Heavy	Passing Requirements [kg]	<5% [kg]	<10% [kg]	>70% [kg]	>97% [kg]	Lower limit	Upper limit
	10 000 – 15 000	6 500	10 000	15 000	22 500	12 000	13 000
	6 000 – 10 000	4 000	6 000	10 000	15 000	7 500	8 500
	3 000 – 6 000	2 000	3 000	6 000	9 000	4 200	4 800
	1 000 – 3 000	700	1 000	3 000	4 500	1 700	2 100
	300 - 1 000	200	300	1 000	1 500	540	690

	Class designation	ELL	NLL	NUL	EUL	W_{em} [kg]	
Light	Passing Requirements [kg]	<2% [kg]	<10% [kg]	>70% [kg]	>97% [kg]	Lower limit	Upper limit
	60 – 300	30	60	300	450	130	190
	10 – 60	2	10	60	120	20	35
	40 – 200	15	40	200	300	80	120
	5 – 40	1.5	5	40	80	10	20
	15 – 300*	3	15	300	450	45	135

	Class designation	ELL	NLL	NUL	EUL	
Coarse						

	Passing Requirements [mm]	<5% [mm]	<15% [mm]	>90% [mm]	>98% [mm]	< 50 % [mm]
	45/125	22.4	45	125	180	63
	63/180	31.5	63	180	250	90
	90/250	45	90	250	360	125
	45/180**	22.4	45	180	250	63
	90/180***	45	90***	180***	250	NA

Notes: * = wide light grading, ** = wide coarse grading, *** = gabion grading, NLL = 20%, and NUL = 80%.

3.2. Shape: Length-to-thickness ratio

Heavy gradings must not contain more than 5 percent of rocks with length to thickness ratio (LT) greater than 3. Light gradings must not contain more than 20 percent of rocks with length to thickness ratio (LT) greater than 3.

3.3. Rock Quality Requirements

3.3.1. General

All samples for rock quality tests must be taken in accordance with Section 7.2.

3.3.2. Density

The average particle density of armourstone (excluding fragments) must be at least 2 600 kg/m^3, with 90 percent of the rocks having a density of at least 2 500 kg/m^3.

3.3.3. Water Absorption

The average water absorption of rock must be less than 2 % and the water absorption of nine of the individual rocks less than 2.5 % (CIRIA, CUR, CETMEF, 2007).

3.3.4. Resistance to Breakage

The mean compressive strength of 9 specimens out of 10 must be higher than 80 MPa. No more than 2 specimens out of 10 may be lower than 60 MPa (CIRIA, CUR, CETMEF, 2007).

3.3.5. Resistance to Impact and Mineral Fabric Breakage

The average Point Load Index in the planar direction of the most pronounced layering if any visible anisotropy exists must be at least 4.0 MPa (CIRIA, CUR, CETMEF, 2007). The average minus one standard deviation must be at least 3.0 MPa.

3.3.6. Block Integrity

Armourstone pieces must be free from visually observable cracks, veins, fissures, shale layers, styolite seams, laminations, foliation planes, cleavage planes, unit contacts or other such flaws which could lead to breakage during loading, unloading or placing (BS EN 13383-1, 2002).

The block integrity must be tested by means of a destructive test, the drop breakage test. The drop test breakage index calculated based on appropriate sampling and testing as described in Section 7.9 must be less than 5 %.

3.4. Impurities

Rock must not contain visually observable or chemically detectable impurities or foreign matters in such quantities that these are damaging for the constructive application of the rock or for the environment in which the rock is applied.

4. EQUIPMENT

4.1. General

Suitable equipment must be provided for the accurate control of placing the rock in the structure and for surveying the seabed and the profiles of the sub-components of the structure to prove compliance with the relevant tolerances.

Spillage of materials, generation of dust, and contamination of public roads with mud or stone fragments from the site must be controlled. The Contractor is responsible for cleaning the haul route of any material spilt from his vehicles.

Audible reversing warning signals must be provided for all transport vehicles exceeding 3 ton GVM.

All equipment must comply with the applicable safety, environmental and legal requirements.

4.2. Safety

The Contractor is responsible for preventing public access to the site of the works at all times.

Construction equipment must be operated by personnel who are suitably trained, licensed and qualified to operate the particular item of equipment.

Stockpiles of rock and stacking areas for concrete armour units must be monitored and controlled by an experienced supervisor to ensure that they present no danger to personnel working in the vicinity.

4.3. Lifting Machinery

All cranes and gantries together with all slings, ropes and hooks, to be used on the site of the works must be tested and certified as required by legislation.

Breakwater construction cranes must be equipped with load measuring devices, and means to monitor the location of the crane hook in three degrees of freedom whether in air or underwater.

4.4. Nuisance and Environmental Control

The contractor must comply with the environmental controls specified in the environmental specifications

5. CONSTRUCTION

5.1. Method Statements

The Contractor must before work commences submit for the Engineer's acceptance method statements describing its proposed method of construction. Each method statement must be revised and resubmitted for acceptance every time the Contractor wishes to change its method of construction. The Contractor must ensure that the works are constructed in accordance with the latest method statement.

The method statements must include details regarding the following:

a) Health, Safety and Environmental risk assessment
b) Index of Quality Control Plans including pro forma inspection and test plans
c) Survey methods and frequency
d) Transportation of rock
e) Handling and stockpiling of rock
f) Setting out
g) Rock placement methods, equipment, production rates, traffic management
h) Access control
i) Storm management

5.2. Quality Control General Requirements

The Contractor must ensure that the production of materials and construction of the structure is included in its project quality plan.

The Contractor must before work commences submit for the Engineer's acceptance an index of Quality Control Plan's (QCP's) which it intends implementing to ensure compliance with this specification as well as an index of supporting documentation (data packs) to prove compliance.

The QCP's must identify all inspections, test and other verification requirements to meet the specifications.

The Engineer will indicate to the Contractor which additional quality control interventions he requires. The QCP's must take account of the required interventions and include these in the QCP.

The contractor must provide to the Engineer all facilities reasonably required for carrying out quality verification activities in a safe and timely manner, including any on-site inspections and audits of the Contractor's records.

5.3. Source of Rock

The rock must be sourced from suitable quarries or from alternative sources if applicable according to the specifications.

The Contractor must before haulage of rock commences submit for the Engineer's acceptance test results demonstrating that the rock intended for use in the works complies with the specifications.

5.4. Transportation, Handling and Stockpiling

5.4.1. Transportation

The Contractor must before work commences submit for the Engineer's acceptance a method statement describing its proposed method for the transportation of rock.

The method statement must be revised and resubmitted for acceptance every time the Contractor wishes to change its method the transportation of rock. The Contractor must ensure that the transportation of rock is performed in accordance with the latest accepted method statement.

The method statement must include details regarding the following:

a) Transportation plan describing the transport from the quarry to the site of the Works, including details of signage, flagmen, dust control, noise control and dealing with spillage and mud contamination on roads.
b) Control of rock leaving the quarry area, ensuring that only rock that has been subjected to quality control inspections and tests can leave the quarry.

It is the responsibility of the Contractor to obtain the necessary permits to perform the quarrying and transport operations as required by legislation, and to perform these operations in compliance with all statutory requirements.

Rock must be transported to the site of the permanent works approved routes only. The Contractor must:

a) Obtain the acceptance of the Engineer and the approval of the appropriate Authorities before using public roads.
b) Avoid damage to public or private roads and repair any damage that does occur due to the transport of rock.
c) Prior to the start of the works make a photographic record of the state of the public and/or private road will be used for transporting rock.
d) Trucks used to transport rock must be of a type specifically constructed for hauling rock and must have tail boards or scow-ends. When transporting heavy armour stone adequate chains and slings must be used and verified before the truck leaves the quarry to ensure optimum security. No other mode of rock transportation may be used unless first accepted by the Engineer and approved by the relevant Authorities.
e) If sea transportation is used, ensure all barges are seaworthy and have the necessary safety certificates and insurance issued by the relevant Authorities. Permission for safe mooring of sea transport vessels must be obtained from the relevant Authorities. The Contractor must have an emergency procedure in place should there be an imminent threat of sea and wind conditions beyond the safe mooring design conditions.

5.4.2. Handling and Stockpiling

A stockpile plan must be drawn up which is commensurate with the overall project planning, giving due regard to the quarry output capacity and production lead-in time.

Stockpiles on site must be sized, taking into considerations the type of grading, access, weight limitations, manoeuvring and handling requirements (tipping or tipping and stacking) and risk of cross contamination

(no overlaps of grades). If possible, a one-way rotation system must be instituted for controlling traffic. The stockpile area should be checked for existing services to avoid risk of damage.

The Contractor must prevent unauthorized pedestrian access, keep stockpile areas well-lit during night operation, maintain equipment in adequate working condition, and keep suitable backup equipment nearby.

The Contractor must before work commences submit for the Engineer's acceptance a method statement describing its proposed method for the stockpiling of rock at or near the site of the Works. The method statement must be revised and resubmitted for acceptance every time the Contractor wishes to change its method for stockpiling of rock. Stockpiling of rock must be performed in accordance with the latest accepted method statement.

The method statement must include details regarding the following:

a) Layout plan for stockpiles
b) Control to avoid cross contamination of rock of different grades
c) Access control
d) Lighting at night
e) Dust and noise control
f) Health, Safety and Environmental risk assessment if not included in a separate Health and Safety Specification.

On-site stockpiles must be managed in a manner that ensures that:

a) Contamination by fines and other non-conforming material is avoided,
b) Safe access is available for handling, inspection and sampling of rock during all weather conditions,
c) Cross contamination by different grades of rock is avoided,
d) Pedestrian access is controlled and safe, and
e) Adequate lighting is provided at night.

5.5. Placing of Rock to Specified Profiles

5.5.1. General

Before commencement of the construction work the Contractor must submit to the Engineer for his acceptance full details of his proposed method of forming the works to the profiles indicated on the drawings (to be prepared after the pre-construction survey).

The sequential placing of layers of different rock grades (i.e. core, armour toe, underlayer and lee armour) must proceed as defined fronts in only one grade of material at each front location. At each location, placing of material for the next front is only permitted after acceptance by the Engineer of the previous front.

Rock that will be placed in the Works in bulk must be transported and handled in such a manner as to minimise segregation of the rock.

For work above low-tide level, fine material on the surface and between already placed stones must be removed before placing the next layer of stone to ensure sound bearing and interlock between stones.

5.5.2. Temporary Haul Roads

Any temporary haul road or track to be created within or on the rubble mound structure, must be constructed of free-draining local material if available and suitable for this purpose, or of other free-draining material accepted by the Engineer. Such material must be removed before placing subsequent layers. The haul road material must be sufficiently removed to expose between one third and one half of the depth of the upper layer of stones of the permanent works upon which the haul road material is placed, when measured from the highest points. Any rocks laid to facilitate haul road construction that do not comply with the specified requirements must be removed and replaced as necessary.

5.5.3. Underlayer and Core

Underlayer and core material must be placed according to random placement as defined under Section 2.

Placing of core and underlayer material must comply with the following requirements:

Core material must be placed to the position, slopes and tolerances indicated on the drawings and this specification. Placement must be in accordance with the method and sequence of construction accepted by the Engineer.

Underlayer and core material must be placed carefully to achieve a dense underlayer or core, avoid damage to the surface below or to the geotextile if used, and to achieve an even distribution of stone sizes without concentration of smaller stones. Underlayer and core material must not be compacted.

Where concrete armour units are used, the licence holder's own specification takes precedence over this specification with regard to the underlayer and toe protection.

Tipping of stones for underlayer from vehicle, or bulldozing or dumping from hoppers or barges into final position, is not permitted without the prior acceptance of the Engineer. Such acceptance will only be considered after carrying out placing trials which demonstrate the proposed method.

Placing light grading stones for underlayer with a side stone dumping vessel-split hopper or a flat top barge- is permitted provided that the position of the vessel and the rate of dumping can be controlled in such a way that the materials are placed according to the required lines and levels.

5.5.4. Cover Layer Armourstone

Armourstone must be placed as specified in the particular specifications and drawings, and to the requirements specified below. In case of conflict the particular specifications and drawings take precedence.

Armourstone must be placed to achieve a dense, fully interlocked armoured slope so that each armour stone is securely held in place by its neighbours. Placing must commence at the toe and proceed upwards towards the crest.

Armourstone must be lowered into place individually and in such a way that they obtain their stability from interlocking and frictional resistance.

The rocks must be deposited carefully to minimise disturbance of any already-placed rock and to avoid damage to geotextiles and any existing structures. The rocks must be placed to achieve an even distribution of stone size without concentrations of smaller stones.

If light grading armourstone is permitted to be placed in bulk, it must be deposited carefully to minimise disturbance to any already-placed rock and to avoid damage to any existing structures.

Unless otherwise stated, the surface of the armoured slope must present an angular uneven face to the water to achieve the desired energy dissipation of waves. Pieces of armourstone smaller than the equivalent of the ELL value of the grading must not be used to fill interstices, or to prop larger stones in order to achieve the required profile.

Pieces of armourstone broken during handling or placing must be removed immediately at the Contractor's expense. Subject to the Engineer's approval, broken pieces of armourstone may be included in lighter gradings.

Any void below the finished profile level in excess of the $0.75D_{n50}$ size of the armour rock, must be filled with an appropriate rock or rocks. Determination of the acceptability of any void is by means of a test sphere of diameter $0.75D_{n50}$.

5.6. Protection of Placed Materials

Each placed layer must be protected by the subsequent layer (as indicated on the drawings) as soon as possible after placement in order to minimise damage due to currents or due to waves in the event of storms during the construction period. Placing of materials must be one continuous operation, to ensure that none of the underlying layers are left unprotected over a distance greater or for duration greater than that proposed by the Contractor and accepted by the Engineer. If the operation has to be interrupted, temporary protection of the underlying layers must be provided with the same material as to be used for the final construction.

5.7. Disturbance to Previously Placed Materials

Material eroded by wave action or other cause must be made good before placing the appropriate protective layer. However, in respect of core material, if accepted in writing by the Engineer, the core may be built up to the dimensions shown on the drawings with the material specified for the next layer overlying the core and in accordance with the method for this overlying layer at no additional cost to the Employer.

Notwithstanding the above, the Contractor must take all reasonable care to avoid disturbing a previously placed layer due to dropping or other potentially disturbing placing methods.

5.8. Precautions

5.8.1. Safety

Over and above the general safety requirements as specified elsewhere, the Contractor's safety management plan must take cognisance of the following specific risks:

a) The Contractor is at all times responsible for preventing public access to the site of the Works.
b) Construction and equipment must be operated only by personnel who are suitably trained, licensed and qualified for the particular item of equipment.
c) Stockpiles of rock must each be monitored and controlled by an experienced supervisor to ensure that they present no danger to personnel working in the vicinity.
d) Storm management plan (storm warnings, securing of equipment, evacuation of personnel).
e) Emergency sea rescue plan.
f) Working over water.
g) Falling from heights and falling objects.
h) Personnel safety and risk of damage to the Works due to wave overtopping.
i) Communication breakdown between diver and crane operator, could lead to injury to divers.

The Contractor is responsible to implement all required safety measures.

5.8.2. Storm Water and Groundwater

For the duration of the contract, the Contractor must provide and maintain suitable flood control structures to protect the site from storm damage and protection from potential flooding.

5.8.3. Nuisance and Environmental Control

The Contractor must comply with all environmental control requirements specified or required by legislation.

6. TOLERANCES

6.1. Tolerances in Rock Grading

The system for defining heavy, light and coarse gradings requirements is based on setting limit values with an associated percentage passing by mass. A set of nominal limits corresponds to the target size of the armourstone. A set of extreme limits corresponds to tolerances. The standard grading requirements and associated passing values are summarised in **Table 3-1**.

For heavy gradings the associated limits are:

a) ELL (Extreme Lower Limit) – the mass below which no more than 5 per cent passing by mass is permitted.
b) NLL (Nominal Lower Limit) – the mass below which no more than 10 per cent passing by mass is permitted.
c) NUL (Nominal Upper Limit) – the mass below which no less than 70 per cent passing by mass is permitted.

d) EUL (Extreme Upper Limit) – the mass below which no less than 97 per cent passing by mass is permitted.

6.2. Tolerances on Placed Rock Levels

6.2.1. Cover Layer Armourstone

Rock material must be placed to levels, dimensions and slopes shown on the drawings and, when the surface profile is measured using the specified techniques, must comply with the vertical placing tolerances in accordance with as illustrated in

Figure 6-1 (a).

Table 6-1: Vertical Placing Tolerances for Placing Rock in Armour Layers.

(CIRIA, CUR, CETMEF, 2007)

Maximum allowable deviations based on individual measurements [m]		
Dry, i.e. above low water, placed using land-based plant	**Below low water placed using land based plant**	**Below low water, placed by waterborne equipment**
±0.3 D_{n50}	±0.5 D_{n50}	±0.8 D_{n50}

Notwithstanding the tolerances of Table 6-1, the following criteria apply to the armourstone cover layer:

a) The mean layer thickness, t_{mean}, must not be less than the nominal layer thickness (t) on two consecutive surveyed profiles. The mean layer thickness is calculated as the ratio of the area under the surveyed profile and the length of the survey (L) as shown in
b)
c)
d)
e)

f) Figure 6-1: (b).

g) Notwithstanding any accumulation of positive tolerances on underlying layers, the mean layer thickness must not be less than 80 percent of the nominal layer thickness (t), as shown in the drawings. In

h)

i)

j) Figure 6-1 (b), this implies that t_{mean} must be larger or equal to 0.8 t. Where an accumulation of positive tolerances arises and is acceptable to the Engineer, the position of the design profiles will need to be adjusted to suit.

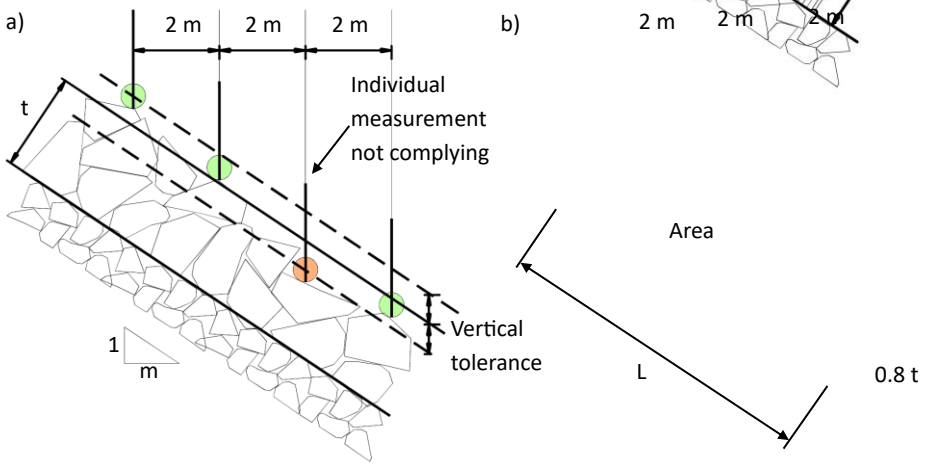


Figure 6-1: a) Individual measurements and vertical tolerances, b) parameters to calculate the mean layer thickness t_{mean} = Area/L.

The Contractor must remove rock outside the specified profiles irrespective of whether the excess is due to faulty placing or due to displacement of the rock by sea action.

6.2.2. Underlayer and Core

Rock material for under layers and core must be placed to levels, dimensions and slopes shown on the drawings and, when the surface profile is measured using the specified techniques, must comply with the following vertical tolerances:

The vertical placing tolerance of individually-placed under layers consisting of heavy grading is the same as the tolerance for placing rock in armour layers given in Section 6.2.1.

The vertical tolerance of under layers and core consisting of bulk placed quarried rock must be in accordance with Table 6-2.

Table 6-2: Vertical Placing Tolerances for Bulk-Placed Material in Underlayers and Core.

(CIRIA, CUR, CETMEF, 2007)

Placement method	Coarse gradings and core	Light gradings (NUL < 300 kg)	Heavy gradings (NUL > 300 kg)
Placed with land-based plant above low water	+0.1 m to -0.1 m	+0.2 m to -0.2 m	+0.4 m to -0.2 m
Placed with land-based plant up to 5 m below water	+0.15 m to -0.15 m	+0.5 m to -0.3 m	+0.8 m to -0.3 m
Placed with land-based plant between 5 m and 15 m below water	+0.2 m to -0.2 m	+0.5 m to -0.3 m	+1.2 m to -0.4 m
Placed with land-based plant below -15 m	+0.2 m to -0.2 m	+0.5 m to -0.3 m	+1.5 m to -0.5 m
Placed with water-borne plant below low water	+0.2 m to -0.2 m	+1.0 D_{n50} to -1.0 D_{n50}	+1.0 D_{n50} to -1.0 D_{n50}

7. TESTING

7.1. Inspection

The requirements of Section 3.3 apply to inspections at or near the site. For inspections carried out at the quarry, the interpretation of inspection results must take into account the possible influence of storage, loading, transporting and unloading on the quality requirements.

7.2. Sampling

7.2.1. General

The samples of the grading of rock to be inspected must be taken at random and must be representative. The sampling, transport and transfer of the samples must be carried out in a careful manner so that breakage is limited to a minimum.

The pieces of one rock which, according to observation, were broken during sampling, will be considered to comprise one rock at the inspection.

7.2.2. Homogeneity of the Batch

When, on the basis of visual judgement of the quarried rock batch to be inspected, non-homogeneity or possible non-homogeneity of the batch is evident with regard to one or more of the relevant qualities, that batch must be divided into parts considered to be homogeneous. Sampling for those qualities must then be carried out separately on the parts.

When one of the parts does not satisfy the requirements, the whole batch of quarried rock is considered non-compliant.

If separation of the divided part(s), which does (do) not satisfy the requirements, is possible without difficulty, it can be agreed to regard the remaining part of the batch as a separate batch.

7.2.3. Size and Composition of Samples

7.2.3.1. Samples for Determining Particle Distribution

For the determination of the particle distribution of a coarse-graded quarry rock, at least six sub-samples must be taken if the sampling takes place from a stockpile or a ship's load. In all other cases the number of sub-samples must be at least three.

The numerical value of the weight X in kilograms of each sub-sample must be at least equal to the numerical value Y of the upper limit (NUL) in millimetres of the designation of the grading concerned if that upper limit is less than or equal to 100 mm. The numerical value of the weight of each sub-sample X in kilograms must be at least twice the numerical value Y of the upper limit in millimetres of the grading designation if the upper limit is greater than 100 mm. A summary of the minimum sample mass required are shown in Table 7-1.

Table 7-1: Sample mass for determining particle distribution.

Numerical value Y of the Nominal Upper limit (NUL)	**Sample mass X [kg]**
Y (NUL) < 100	X = Y
Y (NUL) > 100	X = 2 Y

7.2.3.2. Samples for Determining Weight Distribution

For the determination of the weight distribution, the number of pieces of armourstone required in the sample is as shown in Table 7-2.

Table 7-2: Number of pieces of armourstone in test portion for determination of mass distribution.

Grading	Minimum number of pieces of armourstone heavier than fragments
Heavy grading 10 t – 15 t	25
Heavy grading 6 t – 10 t	30
Heavy grading 3t – 6 t	60
Heavy grading 1t – 3 t	90
Heavy grading 300 kg – 1000 kg	140
Light grading	200

7.2.3.3. Samples for Determining Shape

Same sample and armourstone pieces as used for grading.

7.2.3.4. Samples for Determining Mass Density and Water Absorption

The sample must contain at least 10 specimens of mass from 150 g to 450 g from different armourstones. If mass density is expected to be lower than 2.3 t/m^3, 40 pieces are required.

7.2.3.5. Samples for Determining Compressive Strength

The sample must contain at least 10 drilled cores of 50 mm (or 70 mm if UCS is expected to be less than 40 MPa).

7.2.4. Sampling Methods

7.2.4.1. General

The Contractor must ensure that during sampling the degree of filling of the grab or other extraction equipment does not adversely affect the representativeness of the sample taken.

7.2.4.2. Sampling from a Belt Conveyor

Prior to sampling material on the belt conveyor, let the belt transport for a period sufficient to ensure that deviations from the composition of the material possibly present due to the starting up of the

installation will not be shown in the sample. For sampling from a belt conveyor a sample of a sufficient quantity of material should be taken by catching it from the end of the belt or by stopping the belt and then taking material from the belt. Catch the material from the end of the belt in a manner to ensure that, from the cross-section of the material flow, material is taken from each point for equal periods of time.

Take the required number of sub-samples at approximately equal intervals along the whole batch.

7.2.4.3. Sampling from a Silo

When sampling from a silo, take a sample by catching a sufficient quantity of material discharging from the silo. When sampling from a silo, account must be taken of the fact that particle size reduction and segregation can occur due to the methods of filling and extraction from the silo. Take the required number of sub-samples at approximately equal intervals from the whole batch to be sampled.

If during the sampling, segregation is observed, the number of samples must be adjusted accordingly.

7.2.4.4. Sampling from a Stockpile

When sampling from a segregated stockpile, take a sample of sufficient quantity from the material which is being taken from the stockpile. Take, for this purpose, the contents of one or more loads of a wheel loader, lorry or any other transport or transfer method employed.

Simulate the removal of material from the segregated stockpile if, at the instance of sampling, no material is undergoing routine removal. Before taking the sample, make several extractions of material from the stockpile so as not to distort the sample contents with segregation effects associated with initiation of stockpile extraction.

When sampling from a non-segregated stockpile, take a sample as indicated for a segregated stockpile or take a sufficient quantity of material from a random location which is easily reached with the equipment available.

7.2.4.5. Sampling from Floating Equipment

For sampling prior to the unloading of the segregated load, take adequate quantities of material from the locations shown in Figure 7-1 at the surface of the load, with the aid of the unloading equipment. For the sampling of a non-segregated load the samples must be taken as indicated for a segregated load or by taking an adequate quantity of material at random or evenly distributed locations on the surface of the load, with the aid of the unloading equipment.

When sampling during the unloading, take for each sample an adequate quantity of material with the aid of the unloading equipment. Take the required number of sub-samples at approximately equal intervals from the whole of the load to be sampled.

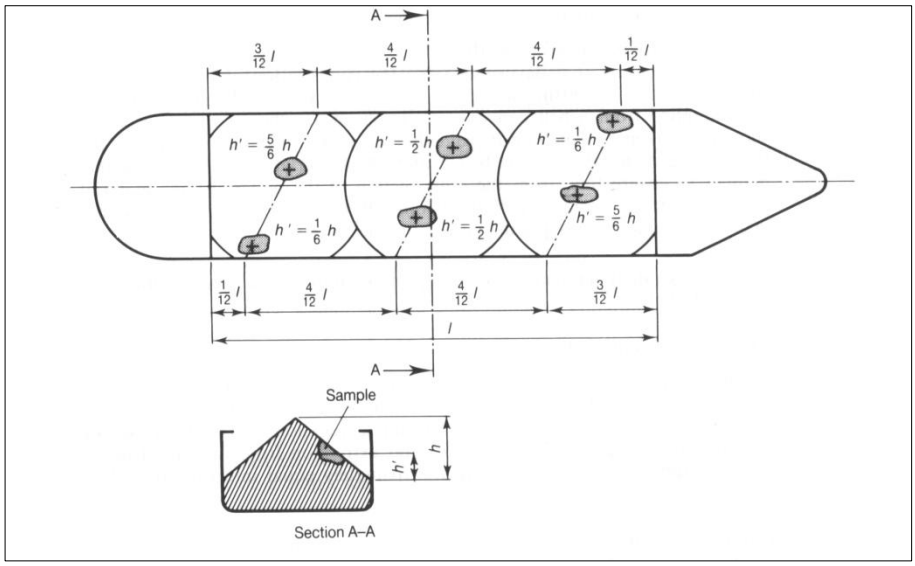


Figure 7-1: Sampling Locations in the Load on Floating Equipment.

7.2.4.6. Sampling from Wheeled Transport

For the sampling of a load of rock, let the load be tipped out partially or completely in a manner which produces an evenly distributed long pile. Take the required number of sub-samples from across that pile by removing at random or at equally distributed locations an adequate quantity of material, while avoiding the possible segregated material at the start and finish of the pile. Take the material in long strips over the full width of the pile or in equal numbers of half strips from the left – and right-hand side of the centre line of the pile.

7.2.4.7. Splitting of Samples of Light and Fine Gradings

If the collected sample to be inspected for compliance with the rock quality requirements of Section 3.3 is too large, reduce the size of the sample according to one of the methods described below.

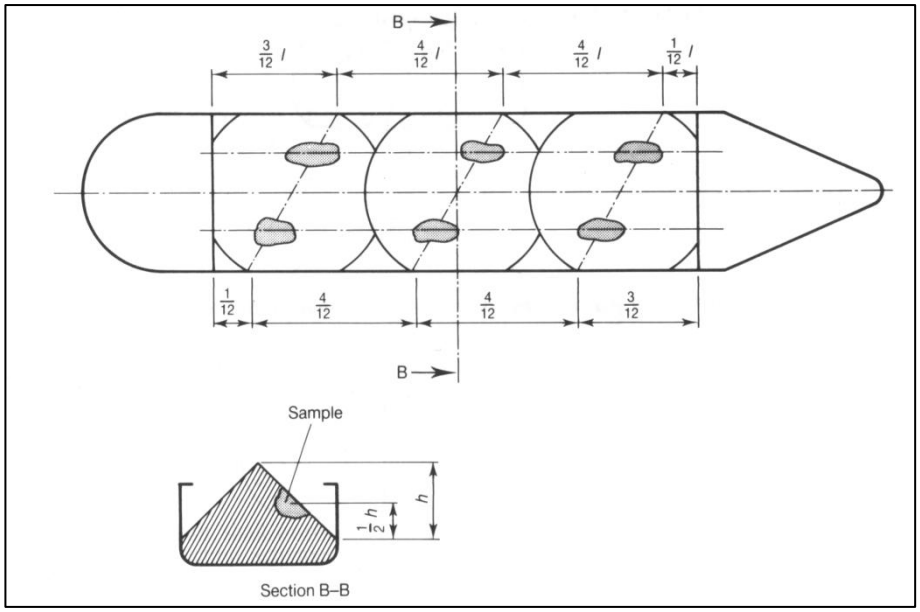


Figure 7-2: Sampling Locations in a Non-Segregated Load on Floating Equipment.

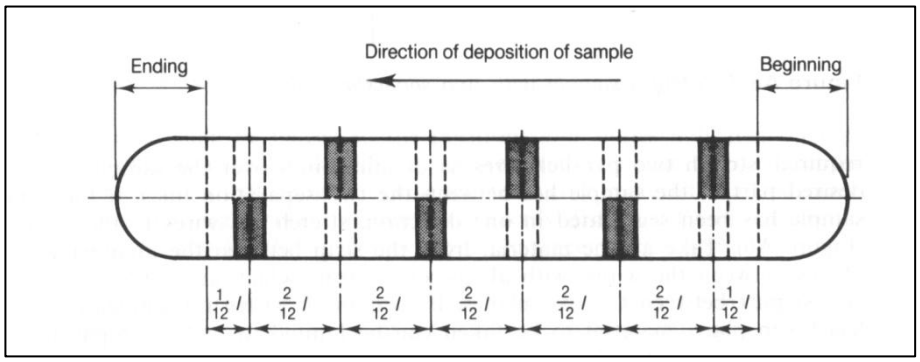


Figure 7-3: Sampling Locations in a Spread Dumped Load.

When depositing a sample, take into account the splitting to be carried out by spreading the sample appropriately. Dump the sample to be deposited and to be split into one or more buckets in a manner which limits segregation as far as possible. When dumping material from a wheel loader bucket, catch all the material from an imagined cross-sectional width of the bucket content in the sample bucket(s). The diameter of the (sample) buckets must be twice the sieve dimensions of the largest piece of rock.

If so desired dump the sample, which is to be deposited and to be split, over one or two vertically set plates, which will create separation planes as shown in Figure 7-4 and Figure 7-5. Proceed further in accordance with the work methods presented in the following description, utilising wires representing the imaginary vertical separation surfaces. Stretch a wire as a separation line over the sample already deposited to indicate the desired demarcation into two approximately equal parts. Where segregation has taken place in one direction of the deposited sample, place the wire in the same direction. Remove

all material where all pieces of rock or the majority are placed to one side of the imagined vertical plane projected by the wire (Figure 7-4).

When, for division of the deposited sample, less than half of the total sample is required, stretch two parallel wires as dividing lines over the sample, so that the desired part of the sample lies between the two separation lines (Figure 7-5). If the complete sample has been segregated in one direction, stretch the wires in the same direction. Take all the material from the strip between the imaginary two vertical planes between the wires, with all pieces of rock which are completely or for the largest part between the two planes. If so desired, where no segregation of material has taken place, material to be taken can be limited to half the separated strip.

Take a sample, which consists of a not too large number of rocks, by a random collection of the necessary number of rocks. Take the rock pieces at random by choosing them blindfolded by lottery numbers or by selecting rocks at pre-determined but irregular intervals.

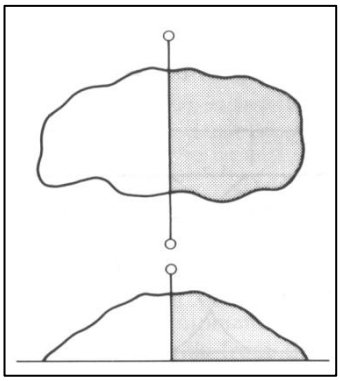


Figure 7-4: Halving a Sample by means of a Separation Plane.

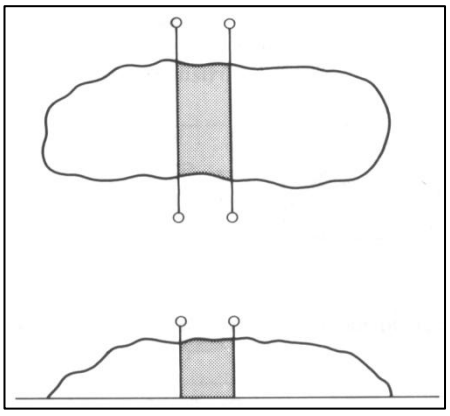


Figure 7-5: Dividing a Sample with Two Separation Planes.

7.2.4.8. Transport and Identification of the Samples

For the transport of a sample, precautions must be taken to ensure that no material is broken or lost and that the sample is not contaminated. A sample must be accompanied by a certificate drawn up by the person responsible for taking the sample. The certificate must include the following information:

a) A reference to this specification
b) The name of the producer and location of the quarry or other source where the broken rock is produced
c) The description and class designation of the grading
d) The number of rock pieces (or weight for coarse grading) in the sample
e) Details about location and method of sampling, including the date when the sampling took place
f) The name of the sample taker

7.3. Test Frequency

Quality control must take place during production of the rock and should routinely be performed by the producer. Part of the quality control consists of ensuring that the rock is coming from the areas designated in the extraction plan as suitable for rock. Significant variation within the rock source should be detected by quality control that focuses on petrography, density, porosity and discontinuity content. The production method should also be considered to determine the optimum quality control, e.g. quality control of gradings should be more frequent for eye-selected than for mechanically produced rock. The frequency of testing should be selected to be representative of homogeneous batches of production. It should be selected by considering the potential range of variability of the properties.

Guidance on the frequency of testing armour stone properties during deliveries is given in Table 7-3.

Unless specified differently in the particular specifications or drawings the frequencies stated in Table 7.3 must be used.

Table 7-3: Guidance on Frequency of Testing Rock Properties during Deliveries.

Property considered	**Frequency for mechanically sorted armourstone**	**Frequency for individually selected armourstone**
Size – coarse gradings	Every 3000 – 5000 t	N/A
Mass – light gradings	Every 3000 – 5000 t	N/A
Mass- heavy gradings	Every 3000 – 5000 t	Every 1500 – 2500 tonnes
Core material – mass	Every 10 000 – 25 000 t	N/A
Shape – coarse and light gradings	As for size/mass grading testing (see above), but take into account the type of use, i.e. armour or under layer	
Shape – heavy gradings	Visual inspection of 50 per cent of the stones	

Property considered	Frequency for mechanically sorted armourstone	Frequency for individually selected armourstone
Block integrity	Drop test at least every 20 000 t. Visual inspection of all stones for heavy grading; further quality control may be required for borderline blocks or poor integrity.	
Rock density, water absorption, durability, strength (using point load at the quarry)	Adapt based on known variability of the source and the risk of further weathering: at least every 20 000 t	

Note: N/A = not applicable

7.4. Determination of the Weight Distribution of Quarried Rock

7.4.1. Equipment and Other Aids

Weighing equipment, accurate to 2 % of the NLL

Lifting equipment and lifting aids for pieces that cannot be moved manually

7.4.2. Weighing

Weigh each piece of armourstone heavier than the ELL separately (W_i), and all pieces lighter than the ELL (the rock fragments) together (W_s). Record the total weights falling in each weight fraction together with the total number of rocks (n), heavier than the ELL.

7.4.3. Calculation

Calculate the total weight $\sum W_i$, of pieces equal to or heavier than the ELL.

To obtain the cumulative curve where W_y is the weight for which the fraction y is lighter, calculate the successive points on the curve at weight intervals given in Table 7-4: .

Table 7-4: Weight Intervals for the Cumulative Weight Plot.

NLL of grading class [kg]	Weight interval [kg]
10-60	5
60-300	25
300-1000	50
1000-3000	200

3000 or greater	500

To obtain only those values of y for which a requirement has been set, i.e. the fractions corresponding to W_y at the ELL, NLL, NUL and EUL, calculate the total weight W_n, for W_y corresponding to each of the four class limits, with the formula:

$$y = \frac{W_n}{W_s + \sum W_i} \times 100 \ [\ \%]$$

where

W_n = the total weight of rocks lighter than W_y [kg]

$\sum W_i$ = the total weight of all pieces heavier than the ELL [kg]

W_s = the total weight of pieces lighter than the ELL [kg]

Calculate the effective mean weight, W_{em}, to the nearest kilogram, using the formula:

$$W_{em} = \frac{\sum W_i}{n} \ [kg]$$

where:

W_{em} = the effective mean weight of the rock sample which equals the average weight of rocks heavier than the ELL,

n = the number of rocks heavier than the ELL.

7.4.4. Report

The following data must be included in the report:

a) The measured cumulative percentage by weight passing the ELL, NLL, NUL and EUL holes
b) The average weight of pieces not passing the L hole
c) The rock density tested according to Section 7.6
d) A reference to this specification
e) A description of the sample; including its weight
f) The source of the sample
g) The date of the inspection

7.5. Determination of Length-to-Thickness Ratio

7.5.1. Subject and Area of Applicability

The test method applies to light and heavy gradings that are placed in less than three layers, and it requires LT to be estimated visually and measured only on borderline blocks.

7.5.2. Sample for Analysis

Same sample and pieces as used to determine the grading.

7.5.3. Equipment and Other Aids

a) Witness stones for visual comparison
b) A calliper and a trained controller

7.5.4. Execution

The length to thickness ratio (LT) is defined as the maximum length, l [m], divided by the minimum distance, d [m], between parallel lines through which the particle can just pass.

Measure the length of each rock as the maximum distance between two points on the rock, l [m]. Measure the thickness of each rock, d [m], defined as the minimum distance between two parallel straight lines through which the rock can just pass. Calculate LT and determine the number of rocks (n_{LT}) with LT greater than 3. Count the total number of rocks in the sample, n.

7.5.5. Calculations

Calculate the number percent of rocks with length-to-thickness ratio (LT) greater than 3 using the formula:

$$C_{LT} = \frac{n_{LT}}{n} * 100[\ \%]$$

7.5.6. Report

The report must provide the following data:

a) The measured number per cent of rocks with length-to-thickness ratio greater than 3 (C_{LT})
b) A reference to this specification
c) A description of the sample, including the weight and the number of rocks
d) The source of the sample
e) The date of the test

7.6. Determination of Rock Density and Water Absorption

7.6.1. Subject and area of application

This method applies to all rock samples. Density and water absorption are determined simultaneously.

7.6.2. Sample for Analysis

Sample 10 representative pieces of mass from 150 g to 450 g. If mass density is expected to be lower than 2.3 t/m^3 then 40 pieces must be analysed.

7.6.3. Equipment and other aids

a) Drying oven or other appropriate, adjustable to (110±5) °C
b) Weighing scales, accurate to 0.05 % of the rock weight, suitable for weighing in air and under water
c) Water-bath, filled with tap water at room temperature and suitable for weighing rocks under water
d) Thermometers, suitable for recording temperature in the water bath, accurate to 1 °C
e) Moist chamois leather

7.6.4. Execution

Remove all loose parts and brush the rock clean with water. Measure the water temperature in the water-bath to 1 °C accuracy. Keep the rock submerged in the tap water at room temperature for at least 5 min and then weigh it submerged (m_1) with an accuracy of 0.05 percent of the rock's weight.

Take the rock out of the bath, dry it with the moist chamois leather to the point that no shiny-wet surface remains and then weigh the rock (m_2) again with 0.05 percent accuracy.

Dry the rock in the oven to a constant (steady) weight, which is reached when two consecutive weightings with a 24-hour interval show less than 0.05 percent loss of total weight.

Weigh the rock again after cooling to room temperature (m_3) with 0.05 percent accuracy.

7.6.5. Calculation

Calculate the density of the rock rounded to the nearest unit with the formula:

$$\rho_r = \frac{m_3}{m_2 - m_1}\rho\ [kg/m^3]$$

Calculate the Water Absorption (WA) with the formula:

$$WA = \frac{m_2 - m_3}{m_3} * 100[\ \%]$$

Where

ρ_r = the density of the particle, [g/ml] or [kg/m^3]

ρ = water density [g/ml] at the test temperature of the water-bath

m_1 = apparent weight of the rock submerged [g]

m_2 = weight of saturated-surface dry sample [g]

m_3 = weight of oven-dry sample [g]

7.6.6. Report

The report must supply the following data:

a) The density of the sample
b) The Water Absorption (WA) of the sample
c) Reference to this specification
d) A description, including the weight of the rock and of the part of the rock that is used
e) Source of the rock
f) Date of testing

7.7. Determination of Resistance to Breakage

7.7.1. Sample for Analysis

Ten specimens must be prepared from different pieces of armourstone.

7.7.2. Method

The determination of the resistance to breakage (compressive strength) of armourstone (excluding fragments) must be done in accordance to BS EN 1926.

7.8. Determination of Resistance to Impact and Mineral Fabric Breakage

7.8.1. Sample for Analysis

Twelve specimens must be prepared from different pieces of armourstone randomly selected.

7.8.2. Method

The average Point Load Index is determined in accordance with ISRM 1985 "Suggested Methods for Determining Point Load Strength".

The average and standard deviation are calculated from at least 10 valid results after the largest and smallest valid test results have been excluded from the calculation.

7.9. Determination of Block Integrity

7.9.1. Subject and Area of Application

This destructive method is used to determine the percentage of rock loss in a standard drop test (DT). This method applies to heavy gradings.

7.9.2. Sample for Analysis

The sample must contain at least 50 blocks taken at random from ELL-EUL weight of the grading class being tested.

7.9.3. Equipment and Other Aids

a) Suitable hydraulic grab (e.g. orange-peel type).
b) Weighing equipment, accurate to within 2 percent of the lightest piece to be weighed.
c) Bed of rocks of same grading as the sample to be tested.
d) Sufficient volume of crushed rock aggregate to give a 0.5 m thick layer covering an area to support the bed of rocks.

7.9.4. Execution

Determine the individual weights of the rock sample prior to the test in accordance with Section 7.4. Prepare a bed of rocks of armourstone of similar size by laying them out in a single compact layer on a 0.5 ± 0.05 m thick layer of crushed rock aggregates. Subject each block in the test sample, in turn, to a drop onto the bed of rocks from a fall height of 3 m ± 0.1 m. Record the result of each drop, such record to include the number and type of visible flaws in blocks and the number and type of blocks resulting.

Remove the block, or broken parts thereof, from the bed of rocks. Set aside all resulting pieces whose weight is greater than the ELL weight, or whose weight is assessed to be close to the ELL weight, for further weightings. Clear all rock fragments from the bed of rocks, leaving clean surfaces prior to dropping the next block in the test sample.

Individually weigh each rock piece in the test sample heavier than the ELL on completion of drop testing accurate to within 2 % of the NLL weight. Record the total weights in each weight fraction.

7.9.5. Calculation

Calculate the cumulative weight distribution curves for the sample prior to drop testing and after drop testing for all pieces heavier than the ELL and calculate the median sample weight before testing (W_{50i}) and the median sample mass of pieces above ELL after testing (W_{50f}), all in accordance with Section 7.4.3.

Calculate the Drop Test breakage index, I_d, as

$$I_d = \frac{W_{50i} - W_{50f}}{W_{50i}} * 100[\,\%]$$

7.9.6. Report

The following data must be included in the report:

a) The Drop Test breakage index;
b) A reference to this specification;
c) A description of the sample, including its weight;
d) The source of the sample;
e) The date of the testing

If agreed beforehand, the cumulative weight distributions before and after testing must be provided and it is recommended that this be on a single graph.

8. SURVEY TECHNIQUES

8.1. General Requirements

Profiles of rubble mound structures must be plotted at a scale of 1:100, unless agreed otherwise, and provided to the Engineer in digital CAD format.

Survey points must be recorded with a horizontal accuracy of 500 mm and a vertical accuracy of 100 mm. This tolerance applies to the bottom of the survey staff or probe and any inclination of the staff or probe must be accurately accounted for in the survey method.

8.2. Survey of Rock Layers

Measurements must be carried out using a probe connected to a rigid stem with a rigid connection between stem and special spherical end of diameter 0.5 D_{n50}, unless for reasons such as health and safety an alternative method is deemed necessary e.g. for certain gradings of heavy armourstone. If the Contractor intends to use an alternative method to the spherical foot probe, the alternative method for obtaining individual armourstone surface heights across the profile must be submitted to the Engineer for acceptance.

For land-based survey, measurements must be carried out at intervals not exceeding 2 metres (measured horizontally) along the measurement profile, and not exceeding 1 metre at the toe and at benches.

Measurement profiles must be at intervals not exceeding 10 m, but must be more frequent as directed by the Engineer where the profile is changing rapidly or on tight-radius curves. Roundheads must be surveyed by radial profiles at not more than 15 degree intervals.

The Contractor must provide and maintain chainage markers at each measurement interval. Chainage markers must be visible from both the land and seaward side of the structure. Surveyed sections must extend to a distance of 5 m beyond the as-constructed toe and 2 m for the other edges. No layer may be covered by a subsequent layer until the profile of the former layer has been accepted by the Engineer.

The Contractor must perform a post storm re-survey of the rock layers in areas where in the opinion of the Engineer storm damage may have occurred, before covering with a subsequent layer.

9. REFERENCES

BS EN 13383-1, 2002. *Armourstone - Part 1: Specifications,* s.l.: BSI.

BS EN 1926, 2007. *Natural stone test methods. Determination of uniaxial compressive strength,* s.l.: BSI.

CIRIA, CUR, CETMEF, 2007. *The Rock Manual. The use of rock in hydraulic engineering (2nd edition). C683,* London: CIRIA.

CIRIA, CUR, CETMEF, 2007. *The Rock Manual. The use of rock in hydraulic engineering (2nd edition, reprint 2012). C683.,* London: CIRIA.

Medina, J. G.-M. M., 2016. *Cubipod Manual 2016,* s.l.: s.n.

O. T Magoon, J. W. W. B. B. E., 1994. *Rehabilitation of the West Breakwater - Port of Sines, Portugal,* s.l.: s.n.

PRDW, 2018. *Richards Bay Breakwaters Upgrade and Repairs Design Basis,* s.l.: s.n.

Silvestre, C. P. O. P. A. e. a., 2004. *Inspection and Diagnosis of Sines' West Breakwater,* s.l.: ICCE.

TNPA, 2015. *Upgrade Breakwaters-New Dolosse. Owners Requirements Specification,* Richards Bay: TNPA.