HR Wallingford
Working with water

17th annual
Armourstone Users Group Meeting

Experiences with the use of the Rock Manual, 2nd edition, and EN13383 in selecting appropriate test methods and frequencies

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Outline

- Projects are different
- Material properties
- Quality control of Armourstone
- Selection of appropriate test methods
- Frequencies of tests
- Definition of theoretical surface
- Survey technique
- System for standard gradings

Purpose of testing of armourstone

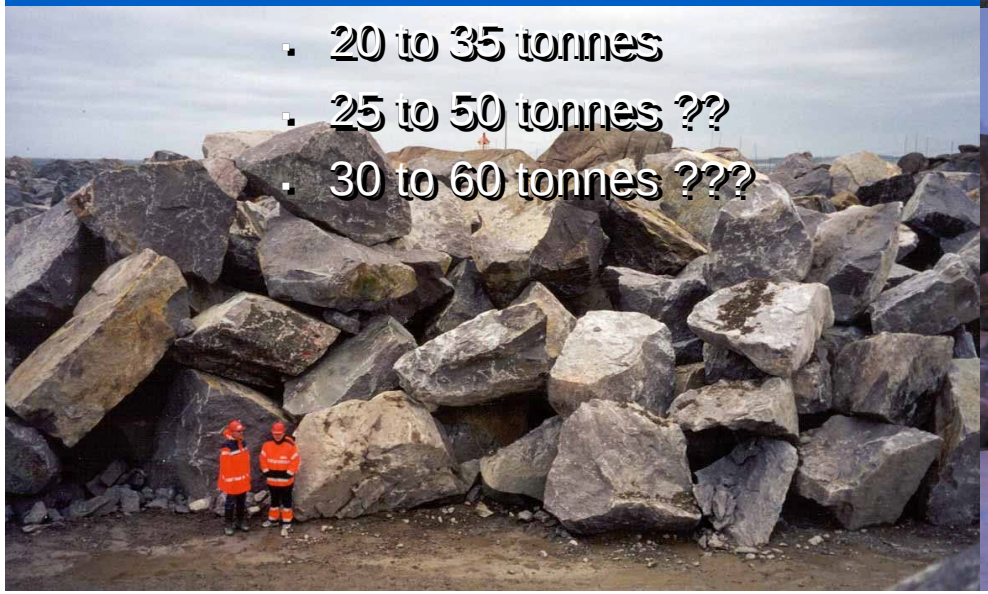
- The purpose of the testing is to verify the properties of the rock source or armourstone and verifying that these are in accordance with specifications
- Selection of appropriate test methods and test frequencies depends on many things:
  - Projects are very different
  - Material properties are different

Projects are different in many aspects:

- Different in scale, volume of material,
  - Small, local, less than 25,000 m^3
  - Medium, regional, 25,000 to 250,000 m^3
  - Large, national/international, larger than 250,000 m^3
- Different production capacity,
  - Less than 1,000 m^3 per day
  - More than 10,000 m^3 per day.

Projects are different in many aspects:

- Different in top sizes or armourstone
  - Heavy Gradings (EN 13383) from
    - 0.3 to 1 tonne
    - 1 to 3 tonnes
    - 3 to 6 tonnes
    - 10 to 15 tonnes
  - Extra large armourstone
    - 10 to 20 tonnes
    - 15 to 30 tonnes
    - 20 to 35 tonnes
    - 25 to 50 tonnes ??
    - 30 to 60 tonnes ???



Projects are different in many aspects:

- Different rock types:
  - Igneous rock,
  - Sedimentary rock
  - Metamorphic rock.
- Rock sources can be
  - homogeneous or
  - inhomogeneous

Projects are different in many aspects:

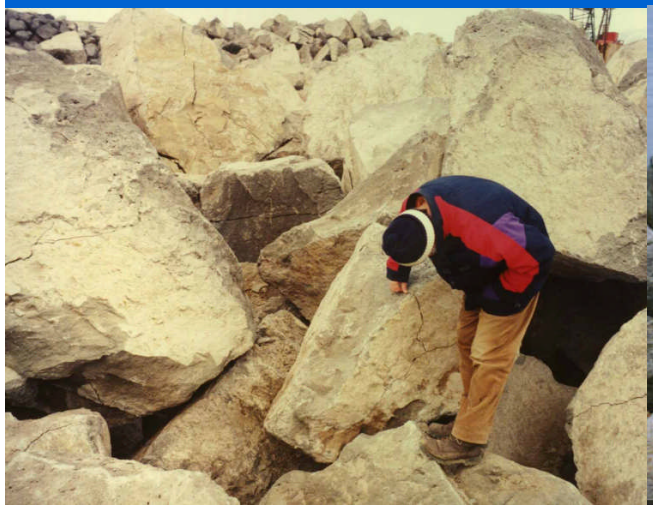
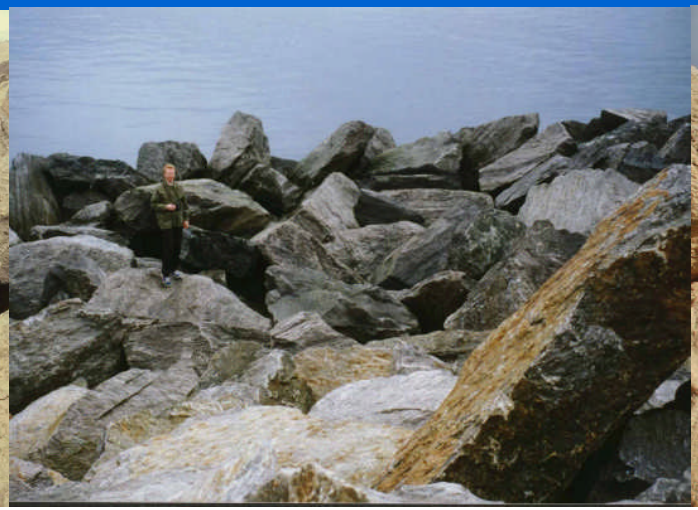
Source of armourstone can be different:

- By-product and available on stock pile, either from:
  - gravel quarry or dimension stone quarry
- Dedicated armourstone quarry,
- Sometimes quarries only supplying armourstone, but sometimes also supplying quarry run as core material
- Tender specified quarry/quarries or open to bidder to supply material that must fulfil technical specifications

Material Properties or Armourstone

We distinguish between different types of properties:

- **Intrinsic properties**, properties of the rock source, eg colour, density, discontinuities, mineral fabric, strength
- **Production-induced properties**, eg block integrity, grading and shape
- **Construction induced properties**, eg layer thickness, porosity, permeability, shear strength


Quality Control of Armourstone

- Quality control consists of the procedures used to monitor and maintain properties of armourstone.
- Necessary at different stages, by different bodies with different aims:
  - During planning and design
  - During armourstone production, producer
  - At tender stage, client, evaluate potential suppliers
  - During supply, client, either in quarry or at delivery
  - During construction, contractor
- Natural variability of the rock source, some rock sources have high variability others less.

Rock Quality Requirements and selection of appropriate test methods

Geometrical requirements:

- Gradation
- Shape (length-to-thickness ratio)
- Proportion of crushed or broken surfaces

Physical requirements:

- Particle density
- Resistance to impact and mineral fabric breakage
  - Compressive strength
  - Point Load Index
- Block integrity
  - Drop test
- Resistance to abrasion or wear
  - Micro-Deval
  - Los Angelis

Rock Quality Requirements and selection of appropriate test methods

Durability requirements

- Water absorption
- Resistance to freezing and thawing
- Resistance to salt crystallization
  - Magnesium Sulphate soundness
- Signs of Sonnenbrand in basalt
  - Sonnenbrand test
- Breakdown of clay minerals, smectite
  - Methylene blue absorption

Prototype experience is the ultimate test

Frequencies of tests, EN 13383

Table D.1 — Minimum test frequencies for general properties

Property		Clause	Notes/references	Test method	Minimum test frequency
1	Particle size distribution	4.2.1	Coarse gradings	EN 13383-2:2002, clause 5	1 per 20 000 tons and immediately after a production break of
2	Mass distributi				
3	Shape				
4	Particle densit				
5	Resistance to breakage [a]				
6	Petrographic description				
7	Dangerous substances [b]				

[a] Properties shall be t
[b] Unless otherwise sp

Table D.2 — Minimum test frequencies for properties specific to end use

Property		Clause	Notes/references	Test method	Minimum test frequency
1	Proportion of crushed or broken surfaces	4.4	Only to armourstone for use in structures, in which rounded pieces of armourstone could lead to instability	EN 13383-1:2002, 4.4	1 per 20 000 tons
2	Resistance to wear[a]	5.4	Only to armourstone	EN 1097-1	1 per 2 years
3	Water absorption[a]				
4	Resistance freezing an thawing[a]				
5	Resistance crystallisati				
6	Impurities				

[a] Properties shall b

Table D.3 — Minimum test frequencies for properties appropriate to armourstone from particular sources

Property		Clause	Notes/references	Test method	Minimum test frequency
1	Dicalcium silicate disintegration	7.2.1	Blast-furnace slag	EN 1744-1:1998, 19.1	2 per year
2	Iron disintegration	7.2.2	Blast-furnace slag	EN 1744-1:1998, 19.2	2 per year
3	Disintegration of steel slag	7.2.3	Steel slag	EN 13383-2:2002, clause 10	2 per year
4	"Sonnenbrand"	7.6	In cases of doubt where signs of "Sonnenbrand" are possible in some basalts	EN 13383-2:2002, clause 10	2 per year

Frequencies of tests, frequently used

- Test frequencies by volume
  - 50,000 tonnes
  - 20,000 tonnes
  - 10,000 tonnes
  - 5,000 tonnes
- Test frequencies by time
  - Every two weeks or every week
  - Every week or every 20,000 tonnes
  - Every day or every 5,000 tonnes
- How to determine acceptable frequency?

Definition of rock armour surface

- Rock Manual, no formal definition, more on layer different layer thicknesses/bulk mass densities for different survey techniques
- When contracts are in volume, not mass, a definition of rock surface is needed
- Common definition of the theoretical surface in North Atlantic: "The theoretical surface is defined as a plane through which stones protrude at least by one third of the area"

Survey techniques

- Survey methods:
  - Highest points
  - Spherical foot staff
  - Conventional Staff

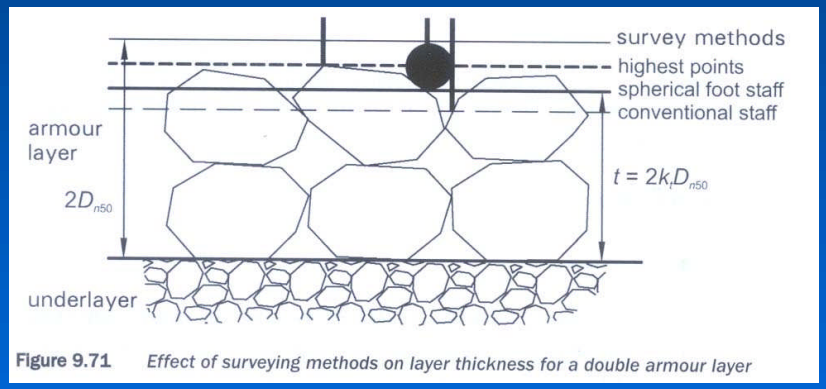


Figure 9.71 *Effect of surveying methods on layer thickness for a double armour layer*

Definition of rock armour surface and survey practice - proposal

- The theoretical surface is defined as a plane through which stones protrude at least by one third of the area
- Measure on top of stones and define theoretical rock surface as 0.20 or 0.25*D_{n50} beneath mean value of measurements
- Lower parameters for more smooth surfaces, 0.1 or 0.15*D_{n50}

EN 13383 system for standard gradings

Table 3.5 *Heavy, light and coarse European EN 13383 standard grading requirements*

	Class designation	ELL	NLL	NUL	EUL	M_{em}	
	Passing requirements kg	< 5% kg	< 10% kg	> 70% kg	> 97% kg	lower limit kg	upper limit kg
Heavy	10 000–15 000	6500	10 000	15 000	22 500	12 000	13 000
	6000–10 000	4000	6000	10 000	15 000	7500	8500
	3000–6000	2000	3000	6000	9000	4200	4800
	1000–3000	700	1000	3000	4500	1700	2100
	300–1000	200	300	1000	1500	540	690

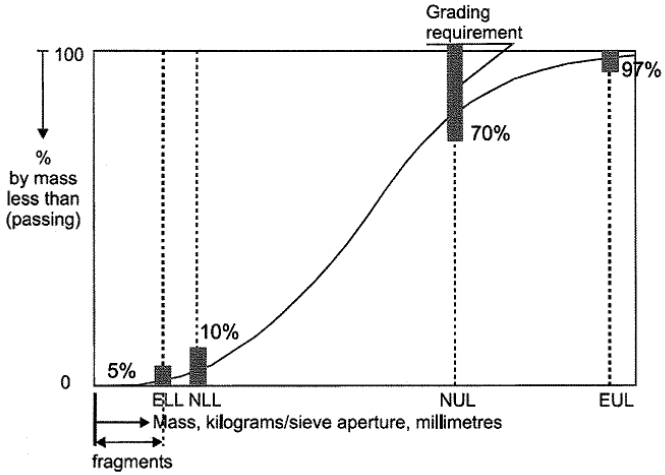
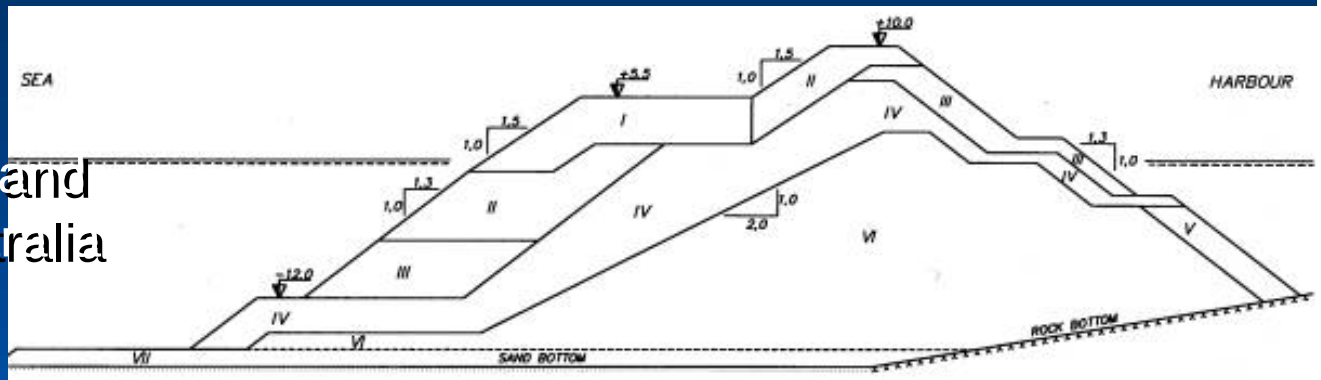


Figure 3.19 *System for limits of EU standard gradings – percentages of passing as given are for heavy grading*

- Why isn't 3-6 t stone class a sample of stone weighing 3-6 t?
- Why do we allow:
  - up to 5% to be less than 2 t and 10% less than 3 t ?
  - up to 30% heavier than 6 t and 3% heavier than 9 t ?
- For projects utilising all size grades it is more practical to work with stricter grading tolerances

Icelandic-type berm breakwater

Sirevåg, Norway
Hammerfest Norway
Over 30 projects in Iceland
Oakajee, Western Australia
LNG project, Russia



Conclusion

- The Rock Manual and the EN 13383 are very good tools for designers, writers of tender documents and technical specifications, supervisors, etc.
- Still we need some guidelines how to determine test frequencies
- For projects in volume definition of rock surface associated with modern survey technique
- Allow for gradings with more strict size control where all size grades are utilised

Thank you for your attention