CLASSIFICATION OF SOILS AND ROCKS
FOR THE MARITIME DREDGING PROCESS

The World Association for Waterborne Transport Infrastructure
PIANC REPORT N° 144
MARITIME NAVIGATION COMMISSION

CLASSIFICATION OF SOILS AND ROCKS FOR THE MARITIME DREDGING PROCESS
- ABRIDGED FIELD VERSION -

2017
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This report has been produced by an international Working Group convened by the Maritime Navigation Commission (MarCom). Members of the Working Group represent several countries and are acknowledged experts in their profession.

The objective of this report is to provide information and recommendations on good practice. Conformity is not obligatory and engineering judgement should be used in its application, especially in special circumstances. This report should be seen as an expert guidance and state-of-the-art on this particular subject. PIANC disclaims all responsibility in the event that this report should be presented as an official standard.
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## LIST OF MEMBERS WORKING GROUP 144

<table>
<thead>
<tr>
<th>Name</th>
<th>Company + Address</th>
<th>Email and Web Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucien Halleux</td>
<td>G-tec (Belgium) G1 des Hauts Sarts - Zone 3, 80 Rue des Alouettes, 4041 Milmort,</td>
<td><a href="mailto:l.halleux@g-tec.eu">l.halleux@g-tec.eu</a> <a href="http://www.g-tec.eu">www.g-tec.eu</a></td>
</tr>
<tr>
<td>(Chairman) LHA</td>
<td>Belgium</td>
<td></td>
</tr>
<tr>
<td>Anne Heeling</td>
<td>Federal Waterways Engineering and Research Institute (Germany) Wedeler Landstrasse</td>
<td><a href="mailto:anne.heeling@baw.de">anne.heeling@baw.de</a> <a href="http://www.baw.de">www.baw.de</a></td>
</tr>
<tr>
<td>AHE</td>
<td>157, 22559 Hamburg, Germany</td>
<td></td>
</tr>
<tr>
<td>Miguel La Casta</td>
<td>Port &amp; Dredging Consultant INTECSA INARSA S.A C/Julián Camarillo, 53 28037 Madrid,</td>
<td><a href="mailto:miguel.lacasta@intecsa-inarsa.es">miguel.lacasta@intecsa-inarsa.es</a> <a href="http://www.intecsa-inarsa.com">www.intecsa-inarsa.com</a></td>
</tr>
<tr>
<td>MLC</td>
<td>Spain</td>
<td></td>
</tr>
<tr>
<td>Mark Lee</td>
<td>HR Wallingford Ltd., Howbery Park, Wallingford, Oxfordshire OX10 8BA, United</td>
<td><a href="mailto:m.lee@hrwallingford.co.uk">m.lee@hrwallingford.co.uk</a> <a href="http://www.hrwallingford.com">www.hrwallingford.com</a></td>
</tr>
<tr>
<td>MLE</td>
<td>Kingdom</td>
<td></td>
</tr>
<tr>
<td>Dirk Roukema</td>
<td>Blue Pelican Associates B.V. K.P van der Mandelelaan 90, 3062 MB, Rotterdam, The</td>
<td><a href="mailto:roukema@bluepelican.eu">roukema@bluepelican.eu</a> <a href="http://www.bluepelican.eu">www.bluepelican.eu</a></td>
</tr>
<tr>
<td>DRO</td>
<td>Netherlands</td>
<td></td>
</tr>
<tr>
<td>Gregory A. Sraders</td>
<td>Great Lakes Dredge and Dock Company (USA) 2122 York Road, Oak Brook, IL 60523,</td>
<td><a href="mailto:GASraders@gldd.com">GASraders@gldd.com</a> <a href="http://www.gldd.com">www.gldd.com</a></td>
</tr>
<tr>
<td>GAS</td>
<td>USA</td>
<td></td>
</tr>
<tr>
<td>Luc van Damme (Mentor)</td>
<td>Ministry of the Flemish Community, Coastal Division, Vrijhavenstraat 3, 8400</td>
<td><a href="mailto:luc.vandamme9@telenet.be">luc.vandamme9@telenet.be</a></td>
</tr>
<tr>
<td></td>
<td>Oostende, Belgium</td>
<td><a href="http://departement-mow.vlaanderen.be">http://departement-mow.vlaanderen.be</a></td>
</tr>
<tr>
<td>Marc Van den Broeck</td>
<td>Dredging International NV – DEME Group Haven 1025, Scheldedijk 30, 2070 Zwijndrecht,</td>
<td><a href="mailto:Van.den.broeck.marc@deme.be">Van.den.broeck.marc@deme.be</a> <a href="http://www.deme.be">www.deme.be</a></td>
</tr>
<tr>
<td>MVB</td>
<td>Belgium</td>
<td></td>
</tr>
<tr>
<td>Peter N.W Verhoef</td>
<td>Boskalis Rosmolenweg 20, 3356 LK Papendrecht, The Netherlands</td>
<td><a href="mailto:peter.verhoef@boskalis.com">peter.verhoef@boskalis.com</a> <a href="http://www.boskalis.com">www.boskalis.com</a></td>
</tr>
<tr>
<td>PVE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Majid Yavary</td>
<td>CÅS Group Consulting 22136 Westheimer Parkway, Suite 628 Katy, TX 77450, USA</td>
<td><a href="mailto:yavary@casgroupconsulting.com">yavary@casgroupconsulting.com</a> <a href="mailto:yavary@csg.co">yavary@csg.co</a></td>
</tr>
<tr>
<td>MYA</td>
<td></td>
<td><a href="mailto:majidya@yahoo.com">majidya@yahoo.com</a></td>
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</table>

Sébastien Dupray (SDU, CETMEF, France) and Jann Eliassen (JEL, Norwegian Coastal Administration) actively participated in the first meetings but had to leave the Working Group for professional reasons.

### ACKNOWLEDGEMENTS

The Working Group members and their colleagues, who produced and reviewed the draft documents, are thanked for their very valuable contributions to this report.

**Status of this document**

1. INTRODUCTION AND OUTLINE OF THE MAIN REPORT

1.1 Context

On 12 November 2015, PIANC MarCom issued a comprehensive report on the ‘Classification of Soils and Rocks for the Maritime Dredging Process’, hereafter termed the ‘main report’. The Terms of Reference prepared by MarCom indicated that in addition to the classification itself, the main report should also deal with the interaction between the soil and rock properties and the complete dredging process, i.e. excavation, transport, disposal and reuse, taking into account the type of equipment used.

The objectives of the main report are:

1. to establish the physical and mechanical properties of soils and rocks that influence the excavation, transport, unloading and use/disposal processes
2. to establish the physical and chemical properties of the materials with respect to disposal or beneficial use at the deposition location
3. to provide guidance as to physical and mechanical properties of soils that influence the suitability of dredged material for reclamation purposes

1.2 Purpose of the Field Document

During the elaboration of the main report and the subsequent reviewing, it appeared useful to issue an abridged version, mainly intended for field use. The field version briefly summarises the content of the main report and includes the tables or templates which are of direct use for the classification. The field version is primarily intended for the geologists and geotechnicians in charge of the description of the samples and the production of site investigation reports. By giving an overview of the main issues related to soil and rock classification, it is also useful for non-specialists involved in the design, procurement, supervision and use of ground investigation campaigns.

The reader is referred to the main report for more detailed information. The main report has precedence over the field version.

1.3 Definitions

Soil is defined as a material consisting of an assemblage of un-cemented mineral grains, rock particles and organic material. Depending upon the grain size, soils may behave in a non-cohesive or cohesive fashion. Non-cohesive soils have no tensile strength. Cohesive soils have shear strength due to electromechanical bonds. The formation of soils results from three main geological processes: weathering of rocks (residual soils); sedimentation of mineral grains or organic material transported by water or wind; biological processes.

Rock is defined as a material consisting of an assemblage of bonded minerals or mineral grains. The bonding confers tensile strength to the assemblage. The bonding is either due to interlocking of the grains or crystals, or to cementation between grains, or to both. Three major rock types are defined, based on their formation: igneous; metamorphic; and sedimentary. A major feature in rocks is the presence of discontinuities (bedding planes, fractures or more generally joints) which have a major influence on the behaviour of a rock mass as opposed to the behaviour of small-scale intact rock samples.

Intermediate material exhibits properties which are transitional between soils and rocks. Such materials result either from the weathering of rocks or from cementation processes in sediments. They may be described either as ‘hard soils’ or as ‘extremely weak rocks’. The resulting ambiguity can be the origin of operational and contractual difficulties. Intermediate material is frequently encountered in maritime dredging, hence the importance of identifying it correctly.
1.4 Description, Testing and Classification of Soils and Rocks

See Chapters 3, 4 and 5 of the main report.

Soils and rocks are extremely complex materials with gradual or sharp transitions from one type of material to another. The description of soils and rocks aims to provide factual and qualitative information about the material. In-situ and laboratory testing is used to determine quantitative characteristics.

Soils and rocks must be classified according to ISO, EN, BSI, ASTM, DIN, NF or other applicable national standard. Site investigation reports must clearly state which system of classification is used. The overriding consideration is to provide adequate qualitative detail in the form of descriptions and quantitative detail in the form of test results such that ground conditions are clearly and unambiguously understood.

Classification procedures with relevant tables are given in Part 2 of the present field version.

1.5 Site and Ground Investigation

See Chapter 2 of the main report.

Site investigation is an essential step in all land and marine construction projects. It consists of collecting all the site specific information which is required to design, plan and realise a construction project. In general, it encompasses meteorological, water column, seabed and ground data.

Offshore ground investigation is a highly specialised and constantly evolving field. It includes geological, geophysical and geotechnical operations. Setting up, realising and interpreting a ground investigation campaign is the task of professionals with adequate multidisciplinary knowledge, training and experience. Quality issues during the ground investigation can lead to major problems during project execution.

Ground investigation provides, amongst others, the samples and input data required for the specific purpose of soil and rock classification. The correct assessment and documentation of the quality of a sample is an important and often difficult task. ISO 22475-1:2006 quantifies the quality in function of the sampling method and custody.

1.6 Soil, Rocks and Dredging Processes

Chapter 6 of the main report deals with the relations between the dredging processes and the soil or rock properties. The complete process is reviewed: excavation, hydraulic transport by pipeline, loading in barges or hoppers, unloading, beneficial use and disposal. Appendix D of the main report discusses special topics regarding execution of dredging works, and their relation with material properties: reclamation, fluid mud, dredge tolerances, and the influence of fines. The following table provides an overview of the relevant material properties for the various dredging sub-processes.
<table>
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<td>unit weight and water content</td>
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<td>mineralogy</td>
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Table 1.1: Material properties of importance for various dredging processes
Chapter 7 of the main report provides guidance on the application of the classification to the various sub-processes in the form of tables and graphs (Figures 7.1 - 7.4).

### 1.7 Disclaimer

Until a truly unified and globally accepted classification system is created (a task that has eluded all attempts thus far), the classification of soils and rocks will remain a subjective process. In addition, due to the often heterogeneous nature of rocks and soils, their classification (from boulder and cobbles to peats and organics) can be at times quite complex and subject to varying interpretations. Quality issues can further aggravate the situation.

These technical challenges may result in contractual difficulties if caution is not exercised when soils and rocks are characterised for excavation, transport, unloading and re-use. Although the report does not discuss the contractual aspects of dredging works, and how mischaracterisation of soils, rocks and rock masses can result in unexpected and unwanted contractual outcomes, the Working Group believes that readers must take these into account, and try to minimise the inherent uncertainty associated with any classification effort, be it due to sample size, heterogeneous nature of the medium, or the interpretation of test results.
2. CLASSIFICATION AND DESCRIPTION

2.1 Soils

2.1.1 General Basis of Classification

The classification, identification, and description of soils for dredging purposes are summarised in Table 2.1.

There are two different groups of soil that a classification system needs to distinguish: mineral soils being one and peat and other organic soils being the other.

Further comments about the main soil types are given in the main report, Chapter 3.3.

Mineral Soils

The classification of mineral soils is based upon both particle size and plasticity. The main soil type is the range of particle size that dominates the soil behaviour. Plasticity is then used to refine the classification further.

If soil behaviour is cohesion-less, whereby it does not stick together and remould when wet (i.e. sand, gravel, and coarser), the name of the main soil type is the dominant fraction in terms of mass. These soils are non-plastic.

If soil behaviour is cohesive, whereby it does stick together and remould when wet (i.e. silt or clay), the name of the main soil type is identified by plasticity tests and has additionally to be described by its particle size distribution and consistency.

The particle fraction silt can be cohesive or not and, therefore, is often a source of confusion.

Note that in different national classification systems the ranges of the particle fractions vary (see Figure 2.1).

Peat and other Organic Soils

The classification of peat and other organic soils (fibrous, pseudo fibrous, or amorphous peat, gyttja, humus) is based on their genesis and degree of decomposition. The term ‘organic’ is used here in the sense of humic material as opposed to other origins (e.g. carbonate, diatomaceous). In the case of organic soils with mineral particles, the mineral fraction should be described by qualifying terms.

In the case of mineral soils with organic content, the amount of organic matter should be described.

2.1.2 Parameters for Classification

The classification of soils demands in-situ and laboratory testing. Further comments about the individual parameters are given in the main report, Chapter 3.4.

Essential Parameters

Depending on the soil type, the essential parameters for classification are:

- particle size distribution
- plasticity data
- consistency
- organic content
- degree of decomposition

Particle size distribution must include a description of secondary particle fractions which do not determine but will affect the soil behaviour. These are the minimum required data to classify a soil.
Recommended Parameters

To provide important additional information and obtain a full soil description on a borehole log, further factual data is also required. Such data include:

- particle shape for coarse-grained materials
- compactness – resistance to penetration
- carbonate content (qualitative description, if significant)
- mineralogy (if important to distinguish between more than one mineralogy present)
- colour
- odour (if any)
- quantity of shell, its size range and condition (whole shell, shell fragments, shell hash)

Other Helpful Parameters

Further factual data should be presented in the site investigation report. Such data may not contribute to an actual description of materials on a borehole log, but it will be used in detailed analyses of the materials to be dredged. Such data include:

- bulk density, particle specific gravity, and natural moisture content
- laboratory strength results (Undrained Shear and Unconfined Compressive Strengths)
- carbonate content (quantitative results)
- crushability results
- rheological parameters

2.1.3 Soil Description

In addition to the text, a logging pro forma (Figure 2.2) is included at the end. This is based on the information provided in Table 2.1 and offers a basis for the field identification and classification of the main soil types.

Contents and Form

Multiple sentences shall be used as needed to make the description clear and unambiguous. The first sentence must name the principal soil type, quantify the secondary constituents and describe the essential parameters (see above). Additional sentences are to be used, as needed, to qualify the primary and secondary constituents. These sentences can refer to: shape, grading, lithology, strength of particles and mass characteristics, such as soil fabric.

Primary and Secondary Constituents

In practice, no soil will fall precisely within a single, predetermined main type, so combinations of types must be described accurately and intelligibly. Soils will have a size that dominates behaviour, whether by proportion of material in cohesion-less soils or by plasticity in cohesive soils. Most soils will also have secondary fractions that modify the behaviour of the dominant fraction, these also require inclusion in the description.

A noun shall be used to denote the primary constituent of the complex soil (i.e. GRAVEL, SAND, SILT, or CLAY) and adjectives will be used to denote secondary constituents that are present in smaller quantities (i.e. gravelly, sandy, silty, or clayey). For example, if the material is mostly sand, contains significant gravel and has a little bit of silt, it could be described as slightly silty, gravelly SAND.

Guidelines for using adjectives as quantifying terms for secondary constituents are given in Table 2.1.
Particle Size and Particle Shape

When describing the size and the shape of grains in granular soils, only the predominant size and shape ranges need be mentioned. It is often the case that in a fine to medium sand some coarse particles will be present or that in sub-rounded to sub-angular gravel a very few particles of the extreme shapes will be present. To include in the description the full range of every particle present is unhelpful as the size and shape descriptors quickly become so broad as to be meaningless (e.g. nearly all sand becomes ‘fine to coarse’ and nearly all gravel becomes ‘angular to rounded’).

Colour

While not an engineering property of the ground, colour plays a major role in identifying geological processes and correlating specific layers at a site. A simple colour terminology is given in Table 2.1. Ambiguous terms must be avoided. Colour charts, such as Munsell or Pantone, are normally unnecessary for ordinary dredging purposes. Consistency ofcolour description, especially between borings and between loggers on the same investigation, is more important than absolute accuracy.

Bedding

The thickness of soil layers and the thickness and spacing of variations within them (beds, laminae, partings and lenses) are described using the terms in Table 2.1.

Beds are soil fabric features of > 20 mm thickness while laminae have < 20 mm thickness. Beds and laminae possess both thickness and spacing (for example ‘widely spaced thin beds’). Partings have only nominal thickness but have spacing. Lenses are horizontally discontinuous.

Classification Systems and Common Terms

For descriptions using different classification systems see Appendix A of the main report.

Commonly used terms (e.g. loam, marl, muck and mud) can be accepted as adjunct terms but primary descriptions should be made as given above.

Example Descriptions

Loose, light grey, gravelly medium to coarse SAND, with occasional shell fragments up to 5 mm. Gravel is fine, sub-angular calcarenite.

Light grey and brown, slightly sandy clayey rounded fine to coarse GRAVEL with low cobble content. Cobbles are sub-rounded strong quartzite.

Very loose, dark grey, sandy SILT, with organic odour and seagrass.

Medium dense brown silty fine to medium SAND with thin soft clay laminae at medium spacing.

Stiff, mottled red and grey, slightly sandy, gravelly CLAY. Gravel is medium (10 to 15 mm) sub-rounded moderately weak limestone.
Classification System, USCS (ASTM D2487), deviates significantly from the ranges given here. The ranges given here are recommended for dredging use. However, it should be noted, that particle size ranges for soil types will vary slightly between classification systems. Most major classification systems vary on the basis of the following:

- **SOILS**
  - ORGANIC
  - OTHER

**COHESION**

- LESS SOILS (COARSE-
  - Fraction of Mass
  - Main
  - Type
  - Rock Mass
  - Blocks
  - Boulder
  - Cobble
  - Gravel
  - Sand
  - Silt
  - Clay
  - Peat
  - Other Organic Soils
  - Humus

**Description of Rocks**

- Organic content:
  - Low: < 1%
  - Medium: 2 - 6%
  - High: > 6%

- Calcium carbonate content:
  - Low: < 5%
  - Medium: 5 - 10%
  - High: > 10%

- Lime:
  - None
  - Very slight
  - Slight

- Texture:
  - Very fine
  - Fine
  - Medium
  - Coarse
  - Very coarse

- Colour:
  - Black
  - Dark
  - Medium
  - Light

**Particle Shape**

- Roundness:
  - Angular
  - Subangular
  - Subrounded
  - Spherical

- Angularity:
  - Very angular
  - Angular
  - Subangular
  - Subrounded

**Density**

- Consistency: Condition
  - Very dry
  - Dry
  - Moist
  - Slightly moist
  - Moist
  - Wet
  - Slightly wet
  - Very wet

- Strength:
  - No cohesion
  - Low cohesion
  - Medium cohesion
  - High cohesion

- Plasticity:
  - No plasticity
  - Low plasticity
  - Medium plasticity
  - High plasticity

- Silt:
  - High
  - Medium
  - Low

- Clay:
  - High
  - Medium
  - Low

**Spacing**

- Bedding:
  - Thinly laminated
  - Medium
  - Thickly laminated

- Hardness:
  - Very hard
  - Hard
  - Medium hard
  - Soft

**Laboratory Testing**

- Laboratory:
  - yes
  - no

**Sedimentary Rocks**

- Size of Bedding:
  - 0 - 10 mm
  - 10 - 20 mm
  - 20 - 30 mm
  - 30 - 60 mm
  - > 60 mm

- Colour:
  - Black
  - Medium
  - Light

**Climate**

- Modification Factor:
  - Low
  - Medium
  - High

**Field Identification**

- Quality of Core
  - Good
  - Fair
  - Poor

**Mining**

- Extraction:
  - Underground
  - Open Pit

**Other**

- To be tested as rock (see Classification and Description of Rocks)
Figure 2.1: Comparison of PIANC and selected national classification systems
**Figure 2.2: Logging pro forma for the field identification of soils for the maritime dredging process**
2.1.4 Laboratory Testing

Laboratory testing must be undertaken on fresh samples of a required quality (see Table 2.2 below and Section 2.5 of the main report) and care must be taken that samples are fully representative. Laboratory tests should be carried out very soon after samples are obtained. As practical and logistical difficulties sometimes cause delays in samples being received at the laboratory, it is essential that the simpler field tests (e.g. hand vane or hand penetrometer) are undertaken at site for later comparison with laboratory tests.

Table 2.2 indicates the most common laboratory and in-situ tests to be carried out for classification and description purposes. Boxes shaded in blue indicate tests for main soil types that are considered to be of primary importance. Boxes shaded in yellow indicate tests that are considered to be of secondary importance. Soil parameters represented by the primary and secondary tests should be well defined by a sufficient volume of testing (see Section 3.6 of the main report). Tests for boxes not shaded can be restricted to a few representative samples for each soil type. If site investigation results do not include the tests indicated by the primary and secondary shading, the quality of the investigation is judged to be poor. Poor quality site investigations increase risk and cost to both the employer and the contractor (see Chapter 2 of the main report).
### Soil Properties and Characteristics

<table>
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<tr>
<th>MAIN SOIL TYPE</th>
<th>SOIL PROPERTIES / CHARACTERISTICS</th>
<th>ROCK Mass</th>
<th>Blocks (1)</th>
<th>Boulders</th>
<th>Cobbles</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
<th>Peat and Other Organic Soils (2)</th>
<th>IN-SITU TEST</th>
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<td>lab test</td>
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<td>lab test</td>
<td>lab test</td>
<td>lab test on some organic soils; N/A for peat</td>
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<tr>
<td>Particle Shape</td>
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<td>lab test</td>
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<td>N/A</td>
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<td>In-situ or Bulk Density</td>
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<td>lab test</td>
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### Laboratory Test (Site or Central Laboratory)

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<th>Recommended Minimum Tests per Stratum</th>
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<td>Schramm [11]</td>
</tr>
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</table>

### Notes
- N/A: Not applicable
- Blue: Tests are considered to be of primary importance
- Yellow: Tests are considered to be of secondary importance

1. Blocks, boulders, and cobbles to be tested as rock
2. For recommended testing, especially peats and other organic soils see Table 3.12 of the main report
3. For sample quality classes see EN 1997-2 and Section 2.5 of the main report
4. It is emphasised that other national standards exist which may be equally appropriate for use
5. Sand or water replacement and nuclear density can be performed only on dry land at the ground surface or in trial pits. These methods are not suited for use in boreholes or under water
6. Useful in saturated sands if natural moisture content can be assured

### Table 2.2: In-situ and laboratory testing of soils for dredging purposes
2.2  Rocks

2.2.1  General Basis of Classification

A geological material is a rock when the constituent grains or minerals are bonded and form a solid framework that has tensile strength. The transition of soil to rock in sediments occurs through consolidation, compaction and cementation processes. Rock can occur as isolated cemented nodules, boulders or slabs within a sediment, and as a solid bedrock mass.

Sedimentary, igneous and metamorphic rocks are generally distinguished by characteristic features unique for each rock group. Sedimentary rock characteristically is bedded, igneous rock shows a crystalline fabric and metamorphic rocks are commonly deformed and recrystallised.

It is well established that the mechanical properties of a large volume of rock, the rock mass, are determined by the mechanical properties of the intact rock material and by the effect of discontinuities (faults, fractures and joints and void spaces such as dissolution holes) in the rock mass. For this reason both the intact rock material and the discontinuities must be classified and characterised to arrive at a rock mass classification useful for dredging purposes.

For many dredging projects most of the direct information on the rock present in the dredge area will come from cored boreholes. Therefore, the emphasis of the PIANC engineering classification for rock is on those properties that can be determined when describing and testing rock cores. A more detailed explanation of the classification and a description of the index tests and laboratory testing needed to assess rocks for dredging projects is given in the main report, Chapter 4.

The main items needed for an engineering description and classification of rock are given in Table 2.3.

2.2.2  Rock Material Classification

For rock material, the engineering classification for rock as given by international standards (ISO 14689-1:2003, BS 5930, ISRM [4]) is followed. Rocks are described by their strength, structure (the arrangement of the fabric elements on the scale of a core), texture (grain size and shape of the constituent minerals), colour, state of weathering, the rock name (given in capitals), and other characteristics and properties.

The engineering name of the rock shall be derived using Table 2.3 (Tables 4.1A, 4.1B and 4.2 in the main report). The classification is based on the rock group (sedimentary, igneous or metamorphic) and on the grain size of the constituent minerals. The classification can be used separately from a geological classification and should be seen as an engineering classification. For example, the correct geological name of an igneous rock may be 'Trachyte', the engineering name can be either 'RHYOLITE' or 'MICROGRANITE'.

Calcareous Rock

In many coastal areas, carbonate platforms or coastal dune and beach deposits occur that have varying contents of silicate and carbonate gravels, sands and silts and are cemented to various degrees. The Clark and Walker [2] classification was developed for these rocks. Gordon [3] proposed modifications of the Clark and Walker classification, namely leaving out the strength connotation and adding a description for secondary calcareous cementation (CALCRETE, CAPROCK) into the classification for coastal carbonate rock. The classification is given in Table 2.3(b) (Table 4.2 in the main report). Grain-size and the calcium carbonate content of the rock are used to classify calcareous soil and rock. The type of non-carbonate minerals should be verified by petrographic examination. Silicate minerals can be quartz, feldspars, rock fragments and clay minerals. The significance of this classification is that the addition of the term 'siliceous' into the name of the carbonate rock or soil indicates abrasiveness of the rock.
2.2.3 Classification of Rock Mass

The mechanics of a rock mass are dependent on the distribution and characteristics of discontinuities. Singular discontinuities are local features such as faults and shear zones. Systematic discontinuities can be described as one or more sets that form a system or network. Examples of discontinuities that occur in sets are layering or bedding discontinuities and joints. Joints are tensile fractures that are very common in rocks. They usually occur in a system of two or more sets.

A challenge in offshore site investigations is that, commonly, only borehole and geophysics information is available. To understand the nature of the rock mass to be dredged, engineering and geological judgement is needed, which can be supported by walk-over surveys along the coast and study of the local geology. Well established rock mass description methods such as outlined by the ISRM [4], BS5930:2015 and Norbury [9] can be used in that case.

Classification for engineering purposes of the rock mass is based on information on the discontinuities in the rock. The discontinuities in rock cores are described by a professional engineering geologist who is able to distinguish fractures induced by the drilling process from natural fractures. Rock Quality Designation (RQD) and Fracture Index (FI) (ISRM [4]; BS 5930) are simplifying indicators of discontinuity density. Definitions for RQD and FI are provided in Section 2.2.4 (item 11). Note that these index values can be misleading in some cases, as illustrated in the sketched examples (Figure 2.3). Using RQD and FI together avoids misjudgement. It is recommended that the natural discontinuities in the core are recorded as accurately as possible and that high quality digital colour images of rock cores are available to be able to judge the information.

![Figure 2.3: Examples of RQD and FI determinations on rock core (Verhoef [13])](image)

More sophisticated rock mass classification systems exist in rock engineering that normally require detailed information on the properties of the discontinuities in the rock mass. If more information on the rock mass is available, it can be helpful to use these systems (see Chapter 4.3.6 of the main report).

The often limited accessibility of the rock mass for observation puts constraints on the interpretation of the ground investigation information based on boreholes only. The entries for rock mass description in Table 2.3(a) mainly deal with discontinuity spacing, block size and shape and weathering state supplemented with a description of the characteristics of the discontinuities that can be determined on a borehole core.
2.2.4 Rock Description

It is recommended that a specific sequence of descriptive terms is followed when describing the rock, such as the sequence given in Table 2.3(a). Note that the engineering descriptions should be supplemented with relevant observations by the geologist so that the geological context of the examined rock becomes clear to the specialist.

Table 2.3(a) summarises the entries used to describe rock and rock cores for dredging projects. The description starts with the characterisation of the rock material. Multiple sentences shall be used as needed to make the description clear and unambiguous.

The engineering description of rock material can follow the sequence of items as listed in Table 2.3(a):

1. **Strength**
2. **Structure**
3. **Colour**
4. **Texture**
5. **Content of important minerals**
6. **Rock name (in CAPITALS)**

For example:

- a) Very weak medium bedded yellow coarse grained quartz SANDSTONE
- b) Moderately strong thin bedded dark grey bioclastic CALCARENITE
- c) Strong pink coarse grained GRANITE

The state of the intact rock material can be further characterised by:

7. **Ductility**
8. **Abrasiveness**
9. **Weathering state**

Ductility and abrasiveness can be estimated on the basis of laboratory tests, which implies that these properties are added to the description of the rock, when the final borehole logs are prepared. If the rock is weathered a description of the weathering state is added, if possible giving an estimate of the weathering grade (item 12). The example descriptions may look like:

- a) Very weak medium bedded yellow coarse grained quartz SANDSTONE. The rock is ductile, abrasive and partly disintegrated.
- b) Moderately strong thin bedded dark grey bioclastic CALCARENITE.
- c) Strong pink coarse grained GRANITE. The rock is brittle, highly abrasive and fresh.

Classification for engineering purposes of the rock mass is based on information on the discontinuities in the rock:

10. **Discontinuity spacing**
11. **Block size and shape**

Discontinuity spacing and block size and shape are input used to arrive at a rock mass model that describes the size distribution of intact rock blocks within a rock mass. If only one borehole is available the information is likely to consist of only discontinuity spacing. When more boreholes are
available or test pits are made more may be said on block size and block shape if one is confident on the 3-D significance of the information. Discontinuity spacing can be derived from the fracture index FI \((\text{mean spacing } l_i = 1/\text{FI} [\text{m}])\).

BS5930:2015 gives definitions and recommended procedures to log discontinuities (see also Norbury [9] for a comprehensive explanation). This includes a description of the fracture state: Total Core recovery (TCR), Solid Core Recovery (SCR), Rock Quality Designation (RQD), Fracture Index (FI). Solid core is taken as core with at least one full diameter (but not necessarily a full circumference) measured along the core axis.

TCR = percentage ratio of core recovered (both solid and non-intact) to the total length of core run.
SCR = percentage ratio of solid core recovered to the total length of the core run.
RQD = total length of solid core pieces each greater than 100 mm between natural fractures.
FI = number of fractures per metre over core lengths with uniform characteristics.
\(l_i = \text{fracture spacing } (= 1/\text{FI})\)

12. Rock mass weathering

The rock mass weathering grades follow the suggested method of ISRM [4]. The grades indicate how much of the rock mass is weathered to a soil, either by decomposition or disintegration. In the case of borehole logging this describes the state of the core.

13. Discontinuity properties

In rock core, the discontinuities are commonly opened and separated, so the in-situ aperture (the width of the discontinuity) is not measurable. In borecore logs, the orientation with respect to the rock core can be measured and information on the surface roughness of the joint or fracture surfaces can be given (ISRM [4], BS5930:2015).

For example:

a) Very weak medium bedded yellow coarse grained quartz SANDSTONE. The rock is ductile, abrasive and partly disintegrated. The rock is moderately weathered, with closely spaced joints occurring locally at a high angle to the bedding. These joints are planar and have smooth surfaces.

b) Moderately strong thin bedded dark grey bioclastic CALCARENITE. Bedding spacing \(l_i\) is medium (average 25 mm), bedding surface is rough and undulating.

c) Strong pink coarse grained GRANITE. The rock is brittle, highly abrasive and fresh. Joints are closely to medium spaced, rough and undulating, a few have a brown surface staining.

The field description and classification of rocks must be part of the borehole logs prepared during a ground investigation. If needed references to template borehole logs can be found in the main report.
Table 2.3(a): Descriptive entries for the engineering geological description of rock material

<table>
<thead>
<tr>
<th>Rock Material Description</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. strength</td>
<td></td>
</tr>
<tr>
<td>very weak</td>
<td>UCS &lt; 1.5 MPa, retained by thumb, gravel sized lumps can be crushed between fingers and thumb.</td>
</tr>
<tr>
<td>weak</td>
<td>UCS 1.5 - 5 MPa, material crumbles under firm blows of geological hammer, can be chip with trowel, gravel sized lumps can be broken in half by heavy hand pressure.</td>
</tr>
<tr>
<td>moderately weak</td>
<td>UCS 5 - 12.5 MPa, only thin slabs, corners or edges can be broken by heavy hand pressure.</td>
</tr>
<tr>
<td>moderate strong</td>
<td>UCS 12.5 - 50 MPa, hard hand specimens can be broken by hammer blows.</td>
</tr>
<tr>
<td>strong</td>
<td>UCS 50 - 100 MPa, when resting on a solid surface specimens can be broken by hammer blows.</td>
</tr>
<tr>
<td>very strong</td>
<td>UCS 100 - 200 MPa, rock only chips by heavy hammer blows (plag ringing sound).</td>
</tr>
<tr>
<td>extremely strong</td>
<td>UCS &gt; 200 MPa, rock only chips by hammer blows, spikes fly, very broken by sledge hammer.</td>
</tr>
</tbody>
</table>

2a. Structure & spacing of planar structures |

- Very thick |
- Thick |
- Medium |
- Thin |
- Thinly laminated (poorly) |
- Thinly laminated (excellent) |
- Very rare (metamorphic and igneous) |
- Very rare (sedimentary) |

2b. structure & terms |

- Bedding, laminated, massive |
- Massive, few-banded |
- Cross-bedding, schistose, gneissose, banded |
- Granite, gneiss, schist, metagraywacke |
- Sedimentary rocks |
- Igneous rocks |
- Metamorphic rocks |
- Rock type |

3. Colour |

- Value: light, dark |
- Chroma: pink, red, yellow, orange, brown, green, blue, purple, white, grey, black |
- Hue: flesh, pink, red, yellow, orange, brown, green, blue, purple, white, grey, black |
- Value: light, dark |
- Chroma: pink, red, yellow, orange, brown, green, blue, purple, white, grey, black |
- Hue: flesh, pink, red, yellow, orange, brown, green, blue, purple, white, grey, black |
- Value: light, dark |
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- Hue: flesh, pink, red, yellow, orange, brown, green, blue, purple, white, grey, black |
Table 2.4(b): Classification of bedded rocks (top left) and aid to identification of igneous and metamorphic rocks (bottom left) for engineering purposes. Right: engineering classification of calcareous rock.
<table>
<thead>
<tr>
<th>ROCK PROPERTIES OR CHARACTERISTICS</th>
<th>NAME OF TEST</th>
<th>LAB (L) OR IN-SITU (S)</th>
<th>PURPOSE OF TEST</th>
<th>REMARKS</th>
<th>REFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rock mass characterisation</strong></td>
<td>Visual inspection</td>
<td>S and/or L</td>
<td>Assessment of rock mass</td>
<td>Indicates in-situ state of rock mass; borecore inspection, walk-over-surveys on land; diver, ROV inspections offshore</td>
<td>ISRM [4]; BS5930:2015; Verhoef (Chapter 21) [13]</td>
</tr>
<tr>
<td></td>
<td>Drillability</td>
<td>S</td>
<td>Assessment of the rock mass</td>
<td>Measurement of drilling parameters including penetration rate, torque, feed force fluid pressure, etc., and statement of drill specification and technique.</td>
<td>Used in Scandinavia [e.g. NGF [8]; SGF [12]]</td>
</tr>
<tr>
<td></td>
<td>Seismic velocity</td>
<td>S</td>
<td>Indication of stratigraphy and fracturing of rock mass</td>
<td>Seismic refraction survey. Indication of compression wave velocity of rock and soil units.</td>
<td>ISSMGE [5]</td>
</tr>
<tr>
<td><strong>Rock physical properties</strong></td>
<td>Ultrasonic L</td>
<td>Longitudinal velocity</td>
<td>Tests on saturated core samples. Indication of V&lt;sub&gt;m&lt;/sub&gt;</td>
<td>ISRM [4]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Density</td>
<td>L</td>
<td>Volume/weight relationships</td>
<td>'As received', saturated and dry density. Can be done on many samples; correlates well with strength (UCS).</td>
<td>Define standard used (ASTM, ISRM [4], EN)</td>
</tr>
<tr>
<td><strong>Rock composition</strong></td>
<td>Petrographic examination</td>
<td>L</td>
<td>Examination mineralogical composition and microstructure</td>
<td>Mineral composition needed to assess hardness; information on grain size and shape, cementation, micro-cracks. To be done by specialist petrographer.</td>
<td>ISRM [4]; Verhoef (Appendix E) [13]</td>
</tr>
<tr>
<td></td>
<td>Carbonate content</td>
<td>L</td>
<td>Determination of CaCO&lt;sub&gt;3&lt;/sub&gt; content</td>
<td>Used for classification (Table 2.3).</td>
<td>Specify method (ASTM D3155)</td>
</tr>
<tr>
<td><strong>Rock material strength</strong></td>
<td>Uniaxial Compression</td>
<td>L</td>
<td>Unconfined compressive strength determination</td>
<td>In general to be done on saturated samples, avoid testing on dry samples. Dimension of test piece and direction of stratification with respect to applied load direction to be stated. Recommend L/D ratio &gt; 2.</td>
<td>ISRM [4]; ASTM D4543 - 08; ASTM D7012 - 07</td>
</tr>
<tr>
<td></td>
<td>Brazilian split</td>
<td>L</td>
<td>Indirect tensile strength</td>
<td>Can be used in Mohr circle construction together with results of UCS and triaxial tests; ratio UCS/BTS gives indication of ductility of the rock; see Table 2.3.</td>
<td>ISRM [4]; ASTM D3967</td>
</tr>
<tr>
<td></td>
<td>Point Load</td>
<td>L</td>
<td>Index test to give indication of strength. Can be used during core logging.</td>
<td>Easy and fast test that is used for classifying rock strength. Can be used on irregular rock fragments. Note that this test cannot be correlated unambiguously to UCS or BTS.</td>
<td>ISRM [4]; ASTM D5731 - 08</td>
</tr>
<tr>
<td><strong>Rock material stiffness</strong></td>
<td>Static modulus of elasticity</td>
<td>L</td>
<td>Deformation modulus rock</td>
<td>Can be determined with uniaxial compression test. Gives an indication of brittleness (or ductility) of the rock</td>
<td>ISRM [4]; ASTM D4543 - 08; ASTM D7012 - 07</td>
</tr>
<tr>
<td><strong>Rock abrasiveness</strong></td>
<td>Surface Hardness</td>
<td>L</td>
<td>Determination of rock hardness</td>
<td>Weighted mineral hardness (Quartz equivalent hardness); see Table 4.6 of the main report. Mineral composition can be obtained by petrographic examination.</td>
<td>Verhoef (Chapter 10) [13]; Vickers Hardness: ASTM E384</td>
</tr>
<tr>
<td></td>
<td>Abrasiveness</td>
<td>L</td>
<td>Cerchar Abrasiveness Index</td>
<td>Scratch Hardness test</td>
<td>ASTM D7625 - 10; NF-P94-430-1</td>
</tr>
</tbody>
</table>

Table 2.5: In-situ and laboratory testing procedures of rocks for dredging purposes
2.3 Intermediate Material

Some materials excavated during dredging in the marine environment exhibit properties which are in a transition range between soils and rocks. These are frequently referred to as 'hard soils' or 'extremely weak rocks'. In the present document, this type of material is called 'intermediate material'. Intermediate material is characterised as follows, based on laboratory tests:

- $c_u$ range from 300 kPa to 640 kPa
- UCS range from 0.6 MPa to 1.25 MPa.

This corresponds approximately to the following values based on field tests:

- SPT N value above 50 blows per foot
- CPT values above 50 MPa
- Seismic velocities in the range 1,700 to 2,200 m/s

These values are shown graphically in Table 2.6. It must be stressed that the transition from soil to rock is gradual and open ended. The correlations between laboratory tests and field tests are empirical and indicative.

![Diagram of indicative range of field test values](image)

**Table 2.6:** Range of laboratory and field test values for soils, intermediate material and rocks and Coffey Geotechnics appraisal of cementation grade (based on UCS)

Whichever classification (ISO, EN, BSI, ASTM, DIN etc.) is used, it is essential to provide adequate qualitative detail in the form of descriptions and quantitative detail in the form of test results. Pictures of the samples must also be provided.
Standards

A list of some important standards is given below. It must be stressed that this list is necessarily incomplete. In particular, it is important to verify the availability of national standards or regulation of projects in a given country.

General Standards

- BS 1377-2:1990: Methods of test for soil for civil engineering purposes. Classification tests.

Specific Standards


Abbreviations

BDP – borehole dynamic probing
BTS – indirect tensile strength
CPT – cone penetration test
CPTU – cone penetration test with pore pressure measurement; sometimes called a piezocone test
$c_u$ – undrained shear strength
DPH – dynamic probing heavy
DPL – dynamic probing light
F – modified Schimazek value
FI – fracture index
$h_t$ – half-turn
$HVQ_{eq}$ – Vickers Hardness relative to quartz
$l_f$ – fracture spacing ($= 1 / FI$)
N – blowcount used to report SPT results
$q_c$ – measured cone resistance from a CPT
ROV – remotely operated vehicle
RQD – rock quality designation
SCR – solid core recovery
SPT – standard penetration test
TCR – total core recovery
UCS – Unconfined (or Uniaxial) compressive strength
$w_L$ – liquid limit
WST – weight sounding test
$\bar{\phi}$ – average grain size abrasive minerals
References

It should be noted that this section lists the references used in the abridged version of the report only. A wider list of references is available in each chapter of the main report should the reader wish to explore a particular subject in more detail.


