Motorway Rockfill Embankments

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***Abstract* -** The construction of Rockfill Embankments, although it seems to be a trivial procedure, however, it presupposes the observance of study rules and rigorous specifications, followed by a systematic method of construction in order to achieve the optimum performance. In the present paper, some basic requirements concerning the design and construction of rockfill embankments, as well as some engineering tips for a successful construction, are presented and commented. The advantages and drawbacks of the rockfill embankment construction with respect to traditional earthfill materials are also illustrated and the relevant fields of application are defined. Finally, a case study dealing with the construction of a motorway segment using crashed rock materials retrieved from the excavation of adjacent cuts, is briefly presented.

***Keywords*:** material classification, case study, embankment, methodology, rockfill

**1. Introduction – Terminology**

*An Embankment* is an earth structure formed by the placement of fill material in a controlled manner, consisting either of soil particles or rock fragments, named earthfill and rockfill respectively. Embankments are built by specified earthwork construction methods in order to meet a prescribed performance in terms of resistance, deformability, permeability and durability. Geotechnical or Earth structures are civil engineering structures, made of soil, rocks, and excavation products resulting from earthworks. Earthworks is the civil engineering process that modifies the geometry of ground surface, by creating stable and durable earth structures, made usually by compacted, under controlled conditions, natural fill materials. Their design differs along the alignment, with respect to changing geometry and fill material properties. Earthwork design means, in fact, defining the process of construction, such as the geometry of the structure, fill material properties, layering methodology, equipment, specifications, quality control and monitoring.

*Rockfill* embankments are the structures composed of natural, durable rock materials, free-drained, where coarse grained materials, such as gravel, cobbles, boulders, are predominant. Rockfill must also include, in total or partly, small amounts of sandy and fine-grained materials, subject to a specific gradation. On site, rockfill material is spread in horizontal layers, compacted by heavy vibratory rollers. Sound rock is the most appropriate for use but some weathered or weak rocks may also be suitable, including sandstones and cemented shales without important clayey fractions. Rocks that break down to fine sizes during excavation, during placing in layers, or during compaction, should be treated as soil particles and therefore as earthfill. In order to meet construction requirements, excess fine material and unsuitable materials, need to be removed, while oversized stones to be fractured to smaller particles.

**2. Classification of borrow and excavation material**

Most soils are mixtures of particles of different sizes and consist of primary, secondary, tertiary size fractions. The primary fraction in terms of mass (cobble, gravel, sand) and plastic behaviour (fine), determines the engineering properties of the soil. The secondary fraction (sandy Gravel) possibly will affect or modify the engineering properties of the primary soil fraction, but not determine them. Tertiary size fractions are described when they are important.

Rock is the natural occurring assemblage or aggregate of mineral grains, crystals, or mineral based particles compacted, cemented, or otherwise bound together and which cannot be disaggregated by hand in water, while rock material is the intact rock between discontinuities. Rocks are identified, described, and classified according to [2]. There are three major types of rock: sedimentary, igneous and metamorphic. Sedimentary are the most common rock type. Based on their durability, satisfactory rock materials (from harder to weaker) for rockfill usually are: granite, quartzite, basalt, diorite, gneiss, limestone, dolomite, rhyolite, dacite, andesite, schist, sandstone, breccia, conglomerate. Non- satisfactory rock materials for rockfill can be: shale, slate, laminated schist, siltstone, porous and chalky limestone. When rock formations are excavated, with or without the use of explosives, the product of the excavation might have the structure of coarse grained material with varying amounts of fines. Varying may also be the strength of the rock particles, from strong and abrasive to weak and degradable.

Physical and strength testing of materials available, is a prerequisite for use in embankment construction. This includes the crushed rock, the coarse gravel and the fine soils. All available materials are classified into soil and rock material groups. Identification involves the characterization of the nature of soils and rocks, by laboratory testing after the excavation stage. That usually includes: gradation, water content, carbonates, sulphates, organic content, plasticity and liquidity limits for fine material, stone size, stone density, specific gravity, unit weight, shear strength along discontinuities (cuttings), uniaxial compressive strength (UCS), tensile strength (Brazilian Test), point load index (IPLT), fragmentability, friability, degradability, Los Angeles index, micro Deval index, frost resistance for rocks and specific tests according to the Geotechnical design.

The basic classification of the soil and rock groups are summarised in tables: Table 6 refers to the particle size fractions (according to ISO/FDIS 14689-1 table A1, 14688-1 table 1, 14688-2 table 1, prEN 16907-2 table 3, [7]). Table 7 refers to the Rock material groups related to their strength (prEN 16907-2, table 4a). Once rock has been excavated will behave as a coarse grained material with amounts of fines. Table 8 refers to the classification of Rock material groups for reuse after excavation and fraction (prEN 16907-2, table 4b).

**3. Motorway Design and Rockfill Embankments**

Designers of motorway alignment are obliged to obey rigorous rules for geometric features in order to achieve the optimum comfort and safety levels. Smooth grades and wide transition curves in folded terrain inevitably generate voluminous earthworks, that is, deep cuttings and high embankments. Excessive earthwork operations may be proscribed, for environmental protection purposes, thus leading to more environment-friendly solutions, such as, tunnels and viaducts.

However, high embankments (H>10m) still make the rule in motorway construction, especially at folded terrain. Excavated material, either from cuttings or tunnels, has to be converted, usually after processing, to fill material and, only in rare cases, should be disposed of as unsuitable for road construction. In mountainous areas, excavated material from deep cuttings often contains rock fragments. Even after suitable processing, the material mainly consists of coarse particles and can hardly be classified according to common soil classification methods (USCS, AASHTO, EN, etc.). This material is characterized as rockfill material and is utilized in construction of motorway embankments.

Embankment is the principal geotechnical structure in road engineering. It can be homogenous or divided into different zones in relation with materials available: (A) base-foundation, (B) core, (C) berms-shoulders, (D) transition layers, (L) capping layers, (S) pavement superstructure. A road embankment is sketched by its geometry, that is, its height H, the slope angle i, spacing of berms h=7-12m, width of berms b=4-5m. The slope angle usually varies from 2:3 to 1:1 (height:base) in rockfill and 1:2 to 2:3 in earthfill.

Rockfill material specifications for embankment construction are characterised by its gradation. The percentage of material passing from sieve 1΄΄ or 3/4 ΄΄ (ASTM) must be less than 30%. Alternatively, material greater than 4 inches must exceed 25% (USA). However, these conditions are not sufficient to prescribe a suitable for construction material. Rockfill can contain intermediate and fine particles in order to form a resistant structure, hardly deformable and definitely durable.

This leads to additional requirements for the rockfill material. A satisfactory gradation, must follow a continuous grain curve, and usually has the following % passing from different sieve sizes:

Sieve size D D/4 D/16 D/64

Passing % 90-100 45-60 25-45 15-35

When gradation and soundness requirements are met, rockfill construction proves economical because the excavated material can be directly used without processing. Rockfill material, due to its high shear strength, can be used in motorway embankments when difficult morphological conditions are encountered, especially when the ground water level is high or the ground profile is steep. Moreover, due to its low deformability and susceptibility to self-settlement, rockfill material can be applied to the construction of very high embankments (H>30m), and in adequate foundation conditions even for the replacement of a viaduct structure.

The most important feature of a rockfill material for road embankments is its high shear strength. Generally, earthfill materials have a friction angle of 25-35o, while in rockfill the friction angle varies from 35-50o. A design value of φ’=35o is conservatively proposed for compacted granular material. After conducting shear box tests on well graded granular materials, compacted to the required density, the design friction angle was calculated to: φ’PEAK=40o-45o [6]. An average friction angle of around 50o can be expected for well compacted, good quality, clean, dumped rock material [8].

For common practice, the conservatively proposed design values, are summarised at the following Table 1.

Table 1: proposed design values of shear strength for compacted coarse to very coarse grained fill

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | φ’ (o) | c’ (kPa) | γ (KN/m3) | Es (MPa) |
| rockfill | 36-40(≤45) | 0-2 | 21-23 | ≥100 |
| crushed rock to sand-gravel | 34-38 | 3-5 | 20-21 | 70-150 |
| coarse sand | 30-34 | 3-5 | 19-21 | 50-100 |
| fine sand | 27-30 | 3-5 | 19-21 | 40-80 |
| sanitary layer | 30-36 | 0 | 20-21 | 30-50 |
| φ’=effective angle of internal friction; c’=effective cohesion; γ=material wet bulk density; Es=fill mass modulus of compressibility | | | | |

Insignificant is a major advantage of rockfill embankments. Field measurements usually are in the range from 0,5‰ H to 1‰ H for rockfill embankments and from 0,5% H to 1% H for earthfill embankments.

Geosynthetic industrial materials, such as geogrids (mesh opening equal to the diameter of the 50% passing d50 of the fill material), geotextiles, geonets, geocomposites, etc. can be used for basal and/or body reinforcement, in order to increase the fill materials shear strength, for filtration and for soil separation in order to prevent migration of the finer material into the voids of the coarser layers, especially where the ground water is encountered. Geosynthetic industrial materials are usually mandatory in the base of rockfill embankments, where large stones or cobbles are encountered as the constitutive material over fine natural ground material.

**4. Rockfill construction principles and practices**

The basis of the fill construction [2] is about “defining the process” in order to construct a well compacted and durable embankment, after the characterization of the natural ground, the selection of the suitable equipment and setting the rules to design the extraction, the transportation, the compaction and the control of the chosen fill materials.

Dozers and vibrating rollers are the most suitable construction equipment in construction of rockfill embankments. Large pieces of degradable material should be broken down before finishing the spreading of the layer. Alternatively, padfoot or sheepsfoot rollers may be used to crush large boulders. Layers of 50-100cm thickness make the rule in rockfill embankment construction, whereas earthfill layers can hardly exceed a thickness of 50cm (Tables 2 and 3). In any case the maximum size of the rockfill material must not exceed the 2/3 of the lift thickness.

In most cases, no additional water is needed to achieve proper compaction. Vibratory rollers and sheepsfoot rollers are used in the compaction of rockfill material. Rollers must have operating weight from 12 to 25 ton, capable of compacting coarse material in lift layers of up to 1500mm. The required compaction is first checked over a trial section and the best result can usually be obtained after 4-8 passes.

Bulking factor BF is the ratio of borrow material volume prior and after loosening. Compaction factor CF is the ratio of borrow material volume prior to loosening and after compaction. The proposed values are given at Table 2.

Table 2: Bulking factor - Compaction factor - Lift layers thickness after compaction - % Compaction

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Soil / Rock | Clay | Sand | Sandy Gravel | Gravel | Siltstone  Claystone | Limestone  Sandstone | Soft  Rock | Crushed  Rock |
| after loosening | 0,75-0,85 | 0,80-0,90 | 0,80-0,85 | 0,75-0,80 | 0,75-0,80 | 0,65-0,75 | 0,60-0,70 | 0,20-0,70 |
| after compaction | 1,00-1,10 | 1,05-1,20 | 1,05-1,20 | 0,90-1,00 | 0,85-1,00 | 0,75-0,90 | 0,70-0,80 | 0,30-0,80 |
| lift layers (mm) | 200-400 | 300-700 | 400-800 | 500-900 | 300-700 | 500-1000 | 500-800 | 500-1500 |
| % compaction | 96-100 | 92-98 | 92-96 | 94-96 | survey | survey | survey | survey |

Table 3: Rockfill recommended construction practices

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| PERFORMANCE CRITERIA | Earthfill | | Rockfill | |
| fine soil | coarse soil | degradable | sound |
| gradation, soundness | >35% passing from sieve No200 (0,074mm) | <35% passing from sieve No200 (0,074mm) | soundness (Na2SO4)>10% | soundness (Na2SO4)<10% |
| AASHTO, ASTM D3282 classification | A-4, A-5, A-6 | A-1, A-2-4, A-2-5 | siltstone, schist, (table 7) | granite, gneiss, limestone  (table 7 & 8) |
| EN classification | cSi, mSi, fSi, Cl | cGr, mGr, fGr, cSa, mSa, fSa | (table 8) | (table 8) |
| usual embankment max height | H<15m | H<30m | H<30m | H<50m |
| recommended lift layers (mm) | 200 - 300 | 300 - 500 | 500 - 1000 | 500 - 1000 |
| construction equipment | graders | graders, dozers | dozers | dozers |
| roller type | sheepsfoot, padfoot | vibrating | sheepsfoot- vibrating | vibrating |
| compaction control | sand & cone method,  nuclear by troxler | sand & cone method,  nuclear by troxler | steel slab, CCC, plate load test | CCC, steel slab,  plate load test |
| main use of geosynthetics | core reinforcement | basal, core reinforcement | basal, core reinforcement | basal reinforcement |
| embankment deformation | 0,50 – 1,0 % H | 0,25 – 0,50 % H | 1 ‰ H | 0,5 ‰ H |
| risk of slope failure | significant | intermediate | intermediate | negligible |
| risk of slope erosion | intermediate | significant | significant | intermediate |
| shoulders water-proof | mandatory | useful | mandatory | useful |
| overall assessment | fair | good | good | excellent |

Drainage conditions during construction and lifetime are critical, mainly for stability purposes. Waterproofing and drainage measures are essential to the integrity of the geotechnical structure. Rockfill embankments are self-draining, while for draining purpose, the excavation level should have a transverse grade of 1-4%.

In rockfill embankments, higher than 15m, where applied loads on the rock particles are important, their crushing because of high super-incumbent pressure might cause embankment deformation. Rock particles RMS, RS, RVS, RES (table 6) with compressive strength ≥25MPa should be used in construction.

Concerning the field quality control, in rock fills containing boulders of particle size greater than 200mm, the estimation of the compaction degree using the traditional sand and cone method is difficult or impossible. Field quality control usually consists of levelling measurements and steel slab bearing tests. The levelling tests consist of measuring the settlement of the compacted lift (usually by means of a steel slab placed on the compacted surface) after one pass of the dozer or after as many passes as to obliterate vertical displacement [2 and 9]. In several cases, continuous compaction control (CCC) by specific equipment of vibrating rollers is conducted. For rockfill material, containing at least 6% of fines, the most common field tests are: sampling and suitability laboratory tests, in-situ density (nuclear method by a troxler equipment, sand replacement, etc.), plate load (static, dynamic). Monitoring is performed using settlement plates, settlement cells, slope inclinometers, piezometers.

Trial sections must precede construction to check material suitability and effectiveness of spreading and compaction equipment.

**5. Case study: Reinforced Earth Embankment on Rockfill**

An embankment with alignment of about 500m was constructed next to a lake, having maximum height of 45m. Its lower part consists of a rockfill, 15m high which is tangential to the reservoir, and its upper part consists of a reinforced earthfill, 30m high. The fill was founded on the Alpine formations (Triassic - Jurassic) of Schist-chert (sch) and on the ophiolitic schistose serpentinite (se), rock formations that have high bearing capacity and negligible deformation and settlements. The schist formation has a petrologic sequence of thin-bedded cherts, prevail with intercalations of clay schists, volcanic rock masses, while siltstones, sandstones and limestones were also locally included. The upper weathered part of those formations and the alluvial zone was removed.

The embankment slope angle was 2:3 (vertical:horizontal) for the rockfill, and 2:3 to 1:1 for the reinforced earthfill. Berms 5-10-20m high, with horizontal benches ≥4m width, were shaped at several levels, in order to obtain satisfactory factors of safety in the slope stability design. In order to increase the shear strength and the slope stability conditions, both in static and in seismic loads (α=0,30g), the earthfill was reinforced by Geogrids of nominal tensile strength 55-80-110 kN/m, in lift layers 600mm, wrapped around 3m at earthfill with slope inclination 1:1. In order to separate the rockfill from the earthfill, a 300 gr/m2 non-woven, needled punched geotextile was placed. Rock boulders were used at the fill toe, for slope and for erosion protection. For the earthfill facing protection, against erosion, a FORTRAC 3D 90 geogrid was placed.

The typical embankment cross section is given at Figure 4 and at Table 5 the design parameters are summarized.



Fig. 4: The typical embankment cross section - downhill rockfill - uphill reinforced earthfill

**6. Conclusion**

Since the wheel invention into Neolithic period, rock materials (“λίθος”, “lithos”) were used for road construction. Scientific knowledge, combined with applied technology allow today the use of excavated materials in complex structural geometry, while rockfill allows to construct stronger and safer structures, following detailed design, rigorous specifications and innovative construction methods.

Table 5: case study - Geotechnical design parameters

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | φ’  (o) | c’  (kPa) | γ (KN/m3) | Es  (MPa) | group symbol | Geotechnical parameters  (σci UCS IPLT, units in MPa) |
| earthfill | 35 | 0-5 | 20 | 50 | MSa cSa mGr cGr | lift layers 600mm, sand-gravel, IP<10% |
| rockfill - material from cuts excavations | 45 | 0 | 23 | ≥100 | RMS-RS | lift layers 750mm  L.A.<40% aggregates soundness<8%,  dmax=50cm, maxW200kgr, 25% < 5kgr |
| sanitary layer 30cm thick | 35 | 0 | 20 | 50 | CSa cGr | coarse grained material, fines <7% |
| schist-chert (sch) | 30-37 | 90 | 25,5 | 800 | RMS-RS | GSI=32-48 mi=15 σci=27 UCS=32-69 IPLT=1,7 |
| serpentinite (se) | 27 | 70 | 25 | 150 | RW-RMS | GSI=22-38 mi=13 σci=11 UCS=15 IPLT=1,3 |

Table 6: Classification of Rock material groups, related to their strength (prEN 16907-2, table 4a)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Rock group | | Point Load Index Is50 Assuming Is50=σu/25  (MPa) | Compressive strength σu  (MPa) | Rock examples |
| Rock group symbol | Strength term |
| REW | extremely weak rock |  | 0,6-1 | weathered claystone, siltstone, sandstone |
| RVW | very weak rock | less than <0,2 | 1-5 | weathered claystone, siltstone, sandstone, gypsum-stone, coal |
| RW | weak rock | 0,2-1,0 | 5-25 | claystone, siltstone, sandstone, marlstone, schists, gypsum-stone, coal |
| RMS | medium strong rock | 1,0-2,0 | 25-50 | sandstone, marlstone, limestone, schists, metamorphic rock |
| RS | strong rock | 2,0-4,0 | 50-100 | sandstone, limestone, volcanic rock, plutonic rock, metamorphic rock |
| RVS | very strong rock | 4,0-10,0 | 100-250 | volcanic rock, plutonic rock, metamorphic rock |
| RES | extremely strong rock | >10,0 | >250 |  |
| NOTE 1: RVW and RW materials may be degradable and testing may be necessary to confirm the material stability  NOTE 2: Alternative material specific correlation of Is50 with σu may be used when available  NOTE 3: Other intrinsic properties of rock used in classification may include mineralogy and density | | | | |

**References**

[1] ΕΝ ISO 14688-1 to 2, “Geotechnical investigation and testing - Identification and classification of soil - Part 1: Identification and description - Part 2: Principles for a classification”.

[2] ΕΝ ISO 14689 “Geotechnical investigation and testing - Identification and classification of rock - Part 1: Identification and description”.

[3] prΕΝ 16907-1 to 6, “Earthworks”.

[4] US Department of Agriculture, Part 645 Construction Inspection National Engineering Handbook, Chapter 8: Earthfill and Rockfill.

[5] ISSMGE, “Geotechnics in pavement and railway design and construction”, Proceedings of Int. Seminar, Athens 2004.

[6] J. Burland, T Chapman, H. Skinner, M. Brown, “ICE manual of geotechnical engineering”, 2012.

[7] B. Look, “Handbook of Geotechnical investigation and design tables”, Taylor & Francis, Balkema, 2007.

[8] T. Leps, “Review of shearing strength of Rockfill”, Journal of SMFD, Proceedings of ASCE, July 1970.

[9] U. Smoltczyk, “Geotechnical Engineering Handbook”, Volume 2: Procedures, Ernst & Sohn, 2003.

[10] A. Mouratidis “Construction and Performance of Rock Embankments in Highway Engineering”, Proc. 4th Int. Conf. on Bituminous Materials and Mixes, Thessaloniki, 2007.

Table 7: Particle size fractions (according to ISO/FDIS 14689-1 table A1, 14688-1 table 1, 14688-2 table 1, prEN 16907-2 table 3, [7])

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Grain size** | **Particle size fractions (symbol)** | **Range of particle sizes (mm)** | **Primary**  **fraction** | **Rock fragments**  **(fractions are depended to excavation methods)** |
| Very coarse  soil group 1 (fractions less than 63mm: ≤30%)  soil group 2 (fractions less than 63mm: ≤70%) | Large Boulder (lBo) | >630 |  | Sedimentary: conglomerate (rounded fragments), Breccia (angular fragments), Halite gypsum  Pyroclastic: Agglomerate (round grains), volcanic breccia (angular grains)  Igneous (quartz content): granite, aplite, granodiorite, diorite, gabbro, peridotite  Metamorphic: gneiss, migmatite, marble, quartzite, granulite, hornfels |
| Boulder (Bo) | >200 and ≤630 | >50 % of particles by mass ≥200 mm |
| Cobble (Co) | >63 and ≤200 | >50 % of particles by mass <200 mm and ≥63 mm |
| Coarse soil  (fine less than 0,063mm: <5%)  Composite coarse soil  (fine less than 0,063mm: 5% to 15%) | Gravel (Gr) | >2,0 and ≤63 | >50 % of particles by mass <63 mm and ≥2 mm |
| Coarse gravel, cGr | >20 and ≤63 |
| Medium gravel, mGr | >6,3 and ≤20 |
| Fine gravel, fGr | >2,0 and ≤6,3 |
| Sand (Sa) | >0,063 and ≤2,0 | >50 % of  particles by mass <2 mm and ≥0,063 mm | Sedimentary: sandstone, quartzite, arkose, greywacke, chalk, lignite, coal  Pyroclastic: coarse grained tuff  Igneous: microgranite, microdiorite, dolerite  Metamorphic: schist, serpentine |
| Coarse sand (cSa) | >0,63 and ≤2,0 |
| Medium sand (mSa) | >0,20 and ≤0,63 |
| Fine sand (fSa) | >0,063 and ≤0,20 |
| Fine soil  (fine less than 0,063mm: >35%)  Intermediate soil  (fine less than 0,063mm: 15% to ≤35%) | Silt (Si) | >0,002 and ≤0,063 | low plasticity or non-plastic | Sedimentary: mudstone, siltstone  Pyroclastic: fine grained tuff  Igneous: rhyolite, dacite, andesite, quartz, trachyte, basalt  Metamorphic: phyllite, slate |
| Coarse silt (cSi) | >0,02 and ≤0,063 |
| Medium silt (mSi) | >0,0063 and ≤0,02 |
| Fine silt (fSi) | >0,002 and ≤0,0063 |
| Clay (Cl) | ≤0,002 | plastic | Sedimentary: shale, claystone  Pyroclastic: very fine-grained tuff  Igneous: rhyolite, dacite, andesite, quartz, trachyte, basalt  Metamorphic: phyllite, slate |

Table 8: Classification of Rock material groups for reuse after excavation (prEN 16907-2, table 4b)

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Rock groups for reuse** | | |  |  | |  | |  | |  | |  |  |  |
| **Indicative  strength** | **Geological  nature** | **Parameters (Intrinsic properties)** | | | | | | | | | | | **Symbol** | **Behaviour** | **Comments** |
| **Compressive  strength (MPa)** | **Fragmentability FR** | | | **Degradability DG** | | **Los Angeles  Index LA** | | **Micro deval  Index MDE** | | **Density Yd** |
| Weaker | Clay rocks | < 5 | > 7 | | |  | |  | |  | |  | CRw | as a soil after extraction | usable in earth  structure |
| Limestone |  | | |  | |  | | > 45 | | < 1,8 | LIw |
| Sandstone | > 7 | | |  | |  | |  | |  | SAw |
| Conglomerate | > 7 | | |  | |  | |  | |  | COw |
| Igneous rocks | > 7 | | |  | |  | |  | |  | IRw |
| Metamorphic rocks | > 7 | | |  | |  | |  | |  | MRw |
| Intermediate | Clay rocks | 5-50 | > 7 | | | > 5 > 2 | |  | |  | |  | CRid | evolutive or  degradable rock | depending on the design |
| Clay rocks | < 7 | | | < 5  < 2 | |  | |  | |  | CRind | non evolutive or  non-degradable rock | usable in earth  structure |
| Limestone |  | | |  | |  | | > 45 | | > 1,8 | LIi | depending on the earth work procedure |
| Sandstone | < 7 | | |  | | > 45 | | > 45 | |  | SAi |
| Conglomerate | < 7 | | |  | | > 45 | | > 45 | |  | COi |
| Igneous rocks | < 7 | | |  | | > 45 | | > 45 | |  | IRi |
| Metamorphic rocks | < 7 | | |  | | > 45 | | > 45 | |  | MRi |
| Strong | Clay rocks | 50-100 | < 7 | | | > 5 > 2 | |  | | < 45 | |  | CRSd | evolutive or degradable rock | depending on the design |
| Clay rocks | < 7 | | | < 5 < 2 | |  | | < 45 | |  | CRSnd | non evolutive or  non-degradable rock | usable in earth  structure |
| Limestone | < 7 | | | > 5 > 2 | |  | | < 45 | | no limit | LIS | as a granular soil |
| Sandstone | < 7 | | | < 5 < 2 | | < 45 | | < 45 | |  | SAS |
| Conglomerate |  | | |  | | < 45 | | < 45 | |  | COS |
| Igneous rocks |  | | |  | | < 45 | | < 45 | |  | IRS |
| Metamorphic rocks |  | | |  | | < 45 | | < 45 | |  | MRS |
| Very strong | Igneous and  metamorphic rocks | 100-250 |  | | |  | | < 35 | | < 25 | |  | IRVS MRVS |  |  |
| Extremely  strong | Igneous and  metamorphic rocks | > 250 |  | | |  | | < 25 | | < 10 | |  | IRES MRES |  |  |
| NOTE: The values for FR and DG will vary depending on the test procedure adopted. In this Table: parameters for FR according to French standard NF P 94-06; parameters for DG according to French standard NF P 94-067 (first value) and Spanish standard UNE 146510 (second value) | | | | | | | | | | | | | | | |