New methodology of simplified rock tests to determine bearing capacity in embankments and excavation bottoms

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Abstract. Engineering works and projects placed in rock terrains require conventional rock testing for its geological and geotechnical characterization. These tests are well-known and used in practice, but they have notable drawbacks such as high execution costs and large amounts of time required. In this research, a new methodology of simplified rock tests is presented to solve the main disadvantages of conventional rock testing and to provide useful outcomes in practical applications. The simplified rock tests proposed were developed by Professor Morilla, being a set of simple, quick, and cheap tests whose results are obtained with relative scoring systems. Furthermore, correlations with the bearing capacity in embankments and excavation bottoms have also been developed, based on the simplified rock test scores exclusively. These correlations do not include units about their magnitude, but they represent quantitative approximations about their field of application. Therefore, this new methodology is not considered as a self-sufficient design procedure for embankments and excavation bottoms. This paper covers the description of each simplified test required to obtain the bearing capacity in embankments and excavation bottoms, including the tools, steps to follow, scoring system, and the parameters and hypothesis established in the proposed correlations.

1. Introduction

Conventional rock tests are those commonly used in engineering works and projects, which allow characterizing the geotechnical and geological properties of rocks, either through laboratory or in-situ tests. These tests can be classified into two main categories: identification and behavior tests [1]. The first category includes a wide range of laboratory tests and rock classifications based on different applications, such as slopes [2] and rock masses characterization [3]. Authors such as Barton et al. [4] and Beniawski [5] have developed geotechnical classifications quite useful in the first steps at facing rock masses engineering problems. On the other hand, the second category includes many laboratory and in-situ procedures, such as resistance, deformability, and permeability tests, in which the intrinsic properties of rocks have some influence on the results obtained with them. Even a simple compression test in a cylindrical rock specimen, aspects such as porosity and dimensions of the rock specimen make the results of the same test different in several laboratories [1]. This dispersion is difficult to interpret and requires further testing than strictly necessary.
In summary, although conventional rock tests are well-known and used in practice, they have the following drawbacks:

- They are very numerous and varied, being almost impossible to cover the entire range of procedures developed.
- There are many tests that are not standardized, making the results hard to homogenize and interpret.
- Many of the equipment needed is quite specific with limited availability, and they require highly qualified personnel when used.
- The dispersion of the results is high and involves a detailed interpretation.
- Both laboratory and in-situ tests are generally expensive, so not always all necessary tests are performed due to lack of budget.
- When large works and projects take place in a rock mass, such as highways or tunnels, the amount of time required in conventional rock testing can even extend for several months.

The previous drawbacks show that quick and simple tests whose results are easy to interpret are also needed to face rock engineering problems. In this research, a new methodology of simplified rock tests is presented to solve the main disadvantages of conventional rock testing and to provide useful outcomes in practice, which is based on relative scores developed for each simplified test. Among the main applications of this methodology is the bearing capacity of embankments and excavation bottoms due to the lack of criteria or formulas that allow using test data directly in their determination. This paper contains all the simplified tests and the correlations necessary to obtain the bearing capacity in both applications according to the procedure developed by Professor Morilla [1].

2. Simplified tests

The simplified tests proposed in this new methodology are a total of 16 divided into three categories: descriptive, resistance, and inalterability tests. Every test has its own scoring system, with values between 0 and 5 and a brief description of each score and the tools required. General characteristics of the simplified tests are as follows:

- All of them can be done in less than 24 hours [6].
- They are simple tests that do not require highly qualified personnel.
- The equipment and tools used are conventional, portable, and easy to acquire and operate.
- Execution costs are small compared to conventional rock testing.
- They are easy to evaluate due to the unique scoring system of each test.
- The outcomes are quantitatively approximate, with lower accuracy than the most sophisticated conventional rock tests.
- Thanks to extensive statistical series from other test results, correlations have been developed to apply the simplified test scores directly in practice [1].

2.1. Descriptive tests

2.1.1. Texture test ($D_T$)

This test consists of measuring the size of grains or crystals on the natural surface of rocks, information that provides relating data about their general strength. Texture test is done with the naked eye or with an ordinary caliber using the following table:
Table 1. Simplified texture test. Scoring system.

| Surface texture     | Description                                      | Points (DT) |
|---------------------|--------------------------------------------------|-------------|
| Very rough          | Granular structure. Grains/crystals > 2 mm        | 5           |
| Rough               | Microgranular structure. Grains/crystals from 0.5 to 2 mm | 4           |
| Medium              | Microgranular structure. Grains/crystals from 0.2 to 0.5 mm | 3           |
| Smooth and massive  | Compact or amorphous structure. Grains/crystals < 0.2 mm | 2           |
| Smooth and crystalline | Microcrystalline structure. Grains/crystals < 0.2 mm | 1           |
| Soft                | Soft texture to the touch. Grains/Crystals < 0.2 mm | 0           |

2.1.2. Cracking test (DC)

It characterizes the degree of compactness of the rock as a function of the spacing between fissures. To carry this test out is necessary to delimit an approximately 25 cm² area on the natural surface of the rock tested. The cracks are counted first with the naked eye and then with an ordinary magnifying glass. The score of each counting is as indicated in Table 2, with the cracking test result being the average value of the previous two.

Table 2. Simplified cracking test. Scoring system.

| Crack spacing     | Description                                      | Points (DC) |
|-------------------|--------------------------------------------------|-------------|
| High              | Non-fissures to the naked eye or 1-2 with a magnifying glass | 5           |
| Medium-High       | 1-2 fissures to the naked eye or 3-4 with a magnifying glass | 4           |
| Medium            | 3-4 fissures to the naked eye or 5-10 with a magnifying glass | 3           |
| Low-Medium        | 5-10 fissures to the naked eye or 11-20 with a magnifying glass | 2           |
| Low               | > 10 fissures to the naked eye or > 20 with a magnifying glass | 1           |
| Not applicable    | Loose rock                                       | 0           |

2.1.3. Mohs hardness test (D_M)

It determines the hardness of rocks based on the Mohs scale. Instead of using the minerals from the original method, the simplified Mohs hardness test considers the practical sequence of tools described in Table 3. In order from lowest to highest hardness, the score of this test is according to the first utensil able to scratch the rock.

Table 3. Simplified Mohs hardness test. Scoring system.

| Mohs hardness     | Description                                      | Points (D_M) |
|-------------------|--------------------------------------------------|-------------|
| Very high         | Scratched with a glazier diamond (9-9.5)          | 5           |
| High              | Scratched with a quartz crystal (7)              | 4           |
| Medium            | Scratched with a triangular steel file (5-6)      | 3           |
| Low-Medium        | Scratched with a pocketknife (4-5)               | 2           |
| Low               | Scratched with a copper coin (3-3.5)             | 1           |
| Very low          | Scratched with the fingernail (2-2.5)            | 0           |

1 Values in parentheses indicate the hardness of the tools according to the Mohs scale.

2.1.4. Exfoliation test (D_E)

This test shows the ability of rocks to be separated into sheets, either by mechanical stress or by weathering. Exfoliation test is performed by following the practical sequence of actions and tools defined in Table 4, starting with those with the lowest scores and advancing one by one until exfoliating the rock or consider it as non-exfoliable.
Table 4. Simplified exfoliation test. Scoring system.

| Exfoliation        | Description                                           | Points (DE) |
|--------------------|-------------------------------------------------------|-------------|
| Non-exfoliable     | Massive rock. Cannot be exfoliated with a chisel       | 5           |
| Very difficult     | Exfoliated by hitting with a chisel                    | 4           |
| Difficult          | Exfoliated by leveraging with a pocketknife           | 3           |
| Easy               | Exfoliated by cutting with a pocketknife              | 2           |
| Very easy          | Exfoliated by scratching with the fingernail           | 1           |
| Not applicable     | Loose or soft rock                                    | 0           |

2.1.5. Fracture test (DF)

It consists of observing the roughness of the fracture surfaces to obtain relative information about the general strength of rocks. To carry out the fracture test is required to hit the rock specimen with a flat hammer until one or more fracture faces are formed and analyze their appearance according to the descriptions from Table 5.

Table 5. Simplified fracture test. Scoring system.

| Roughness of fractures        | Description                                           | Points (DF) |
|-------------------------------|-------------------------------------------------------|-------------|
| Granular and regular          | Rough surface with irregularities and uniform distribution | 5           |
| Granular and irregular        | Rough surface with irregularities and non-uniform distribution | 4           |
| Conchoidal                    | Undulating and curve surface like the shape of a shell | 3           |
| Smooth and regular            | Quasi-flat surface with small irregularities and uniform distribution | 2           |
| Smooth and irregular          | Quasi-flat surface with small irregularities and non-uniform distribution | 1           |
| Flat and laminar              | The surface is like exfoliation or schistosity planes | 0           |

2.2. Resistance tests

2.2.1. Impact test (RI)

This test represents the resistance of rocks to breakage and crumbling by dynamic effects. To perform the impact test is necessary to hit the rock specimen with a ball hammer, and its outcomes are established by following Table 6.

Table 6. Simplified impact test. Scoring system.

| Impact resistance   | Description          | Points (RI) |
|---------------------|----------------------|-------------|
| High                | Resists > 4 hits     | 5           |
| Medium-High         | Breaks with > 4 hits | 4           |
| Medium              | Breaks with < 4 hits | 3           |
| Low-Medium          | Breaks and crumbles with < 4 hits | 2 |
| Low                 | Crumbles with the hand | 1           |
| Not applicable      | Loose or soft rock  | 0           |

2.2.2. Punching test (RP)

It allows studying the tenacity of the rock and its resistance against point loads. This test is carried out with a flat hammer and a metal punch to hit the rock specimen, and its score is obtained by following Table 7.
Table 7. Simplified punching test. Scoring system.

| Punching resistance | Description                                      | Points (RP) |
|---------------------|--------------------------------------------------|-------------|
| High                | Does not break or small splinters are released with > 4 hits | 5           |
| Medium-High         | Does not break and splinters are released with < 4 hits | 4           |
| Medium              | Does not break and fragments are released with < 4 hits | 3           |
| Low-Medium          | Breaks with < 4 hits without crumbling            | 2           |
| Low                 | Crumbles with < 4 hits                            | 1           |
| Not applicable      | Loose or soft rock                                | 0           |

2.2.3. Drilling test (RD)

This test characterizes the strength of rocks to the widia tools from rotation and percussion drilling hammers. The execution procedure involves hitting with a flat hammer an 8-10 mm diameter widia drill placed on the rock surface, spinning the widia drill a 1/4 turn for every two hits, and calculating the score as indicated in Table 8.

Table 8. Simplified drilling test. Scoring system.

| Drilling resistance | Description                                      | Points (RD) |
|---------------------|--------------------------------------------------|-------------|
| High                | No mark or it is clean and < 2 mm with 12 hits    | 5           |
| Medium-High         | 2-4 mm mark and clean edges with 12 hits          | 4           |
| Medium              | > 4 mm mark and not clean edges with 12 hits      | 3           |
| Low-Medium          | Breaks and or > 4 mm mark with < 12 hits          | 2           |
| Low                 | Crumbles with < 12 hits                           | 1           |
| Not applicable      | Loose or soft rock                                | 0           |

2.2.4. Wear test (RW)

This test determines the resistance of the rock against erosion or excavation tools. The wear test is done with a flat steel file, pressing on the rock specimen with its flat surface until a maximum of 10 passes or until the rock breaks or crumbles, as reflected in the scoring system of Table 9.

Table 9. Simplified wear test. Scoring system.

| Wear resistance   | Description                                      | Points (RW) |
|-------------------|--------------------------------------------------|-------------|
| High              | No mark or it is clean and < 1 mm with 10 passes | 5           |
| Medium-High       | 1-2 mm mark and clean edges with 10 passes       | 4           |
| Medium            | > 2 mm mark and not clean edges with 10 passes   | 3           |
| Low-Medium        | Breaks and or > 2 mm mark with < 10 passes       | 2           |
| Low               | Crumbles with < 10 passes                        | 1           |
| Not applicable    | Loose or soft rock                               | 0           |

2.2.5. Edge notch test (RE)

It encompasses properties such as shear resistance, toughness, and the tensile strength of rocks. In the edge notch test, a triangular steel file is used, pressing on the rock specimen with one of its edges until a maximum of 10 passes or until the rock breaks or crumbles. This test score is determined as represented in Table 10.
Table 10. Simplified edge notch test. Scoring system.

| Edge notch resistance | Description                                                  | Points (R_e) |
|-----------------------|--------------------------------------------------------------|--------------|
| High                  | No mark or it is clean and < 2 mm with 10 passes             | 5            |
| Medium-High           | 2-4 mm mark and clean edges with 10 passes                   | 4            |
| Medium                | > 4 mm mark and not clean edges with 10 passes               | 3            |
| Low-Medium            | Breaks and or > 4 mm mark with < 10 passes                   | 2            |
| Low                   | Crumbles with < 10 passes                                   | 1            |
| Not applicable        | Loose or soft rock                                          | 0            |

2.3. Inalterability tests

2.3.1. Flame action test (I_F)

This test shows the susceptibility of rocks to modify their properties by combustion and climate changes. Flame action test is carried out by holding a rock fragment with tweezers and putting it in contact with the flame produced by an alcohol or Bunsen lighter for a few minutes. The scoring system of this test is as follows:

Table 11. Simplified flame action, heat & cold, and ebullition tests. Scoring system.

| Inalterability to flame | Description                                                                 | Points (I_F) |
|-------------------------|-----------------------------------------------------------------------------|--------------|
| High                    | No apparent alteration                                                      | 5            |
| Medium-High             | Altered in color and or shape, and no fragments are released                 | 4            |
| Medium                  | Altered in color and or shape, and small fragments are released (< 25%)²    | 3            |
| Low-Medium              | Altered in color, in shape, and big fragments are released (& 25%)²          | 2            |
| Low                     | Disintegrates                                                               | 1            |
| Not applicable          | Loose or soft rock                                                         | 0            |

1 It also applies to both heat & cold (I_H) and ebullition (I_E) inalterability.

2 Percentages in parentheses refer to the dry weight of the rock fragments.

2.3.2. Heat & cold test (I_H)

It allows characterizing the tendency of rocks to disaggregation by the action of thermal cycles and wet-dry cycles. The heat & cold test is done by following these steps:

- Place the rock fragment into an iron saucepan, cover the saucepan, and heat it for about 15 minutes.
- Remove the saucepan from the heat and pour cold water inside to sharply lower the rock temperature.
- Withdraw the rock from the saucepan, wash it without losing any material, and dry it.
- Repeat again all the steps above to perform the second cycle of heat & cold.
- After the second cycle, the outcomes are determined using Table 11.

2.3.3. Ebullition test (I_E)

This test determines the opposition of rocks to the combined action of water and heat, representing the effect of water immersion along with thermal cycles. The ebullition test is performed by following the steps below:
• Place the rock fragment into an iron saucepan and fill it with water until the rock is completely covered.
• Heat the saucepan until the water starts boiling and keep the rock inside it for at least 15 minutes once ebullition has begun.
• Remove the saucepan from the heat, withdraw the rock from the saucepan, wash it without losing any material, and dry it.
• Examine the rock and obtain the results with Table 11.

2.3.4. Oxygenated water test (I₀)

It represents the oxidation of the rocks' constituent elements and the influence of this process on their properties. The steps required to perform this test are as follows:
• Place the rock fragment into a transparent cup or recipient.
• Fill the recipient with hydrogen peroxide until the rock is completely covered.
• Keep the rock inside the recipient for about 3-4 hours.
• After the time expires, examine the rock without removing it from the recipient and calculate the score using Table 12.

Table 12. Simplified oxygenated water, weak acid, and weak base tests. Scoring system.

| Inalterability in oxygenated water¹ | Description | Points (I₀)¹ |
|------------------------------------|-------------|--------------|
| High                               | No apparent alteration | 5            |
| Medium-High                        | Peeling (<5%)² and bubbles that slowly break off are seen | 4            |
| Medium                             | Fragmentation (5-25%)² and light effervescence are seen | 3            |
| Low-Medium                         | Widespread effervescence with entire decomposition | 2            |
| Low                                | Very strong effervescence with foam and or heat detachment | 1            |
| Not applicable                     | Loose rock   | 0            |

¹ It also applies to both weak acid (Iₐ) and weak base (Iₐ) inalterability.
² Percentages in parentheses refer to the dry weight of the rock fragments.

2.3.5. Weak acid test (Iₐ)

It aims to determine the consequences of subjecting the rock to a mainly acidic environment. To carry out the weak acid test is necessary to prepare an acid dissolution of pH ≈ 3, such as a dilute hydrochloric acid, or using vinegar as an alternative [6]. The required operations are the same as those previously explained in 'section 2.3.4', with the only difference that the recipient contains weak acid instead of hydrogen peroxide.

2.3.6. Weak base test (Iₐ)

Its goal is to simulate the effect of subjecting the rock to a mainly alkaline environment. The weak base test requires a base dissolution of pH ≈ 11, such as a dilute caustic soda, or using bleach as an alternative [6]. This test procedure is similar to the previously defined in 'section 2.3.4', using the corresponding weak base instead of the hydrogen peroxide.

3. Auxiliary parameters

Before calculating the bearing capacity correlation, it is recommended to group the scores from all the simplified tests into those referred to as auxiliary parameters. Their purpose is to facilitate all subsequent operations, classifying the tests according to whether their results are more suitable to characterize the resistance or the inalterability of the rock.
3.1. **Resistance index (R)**

It covers all simplified resistance tests and the simplified descriptive tests of texture, Mohs hardness, and fracture. It has a score between 0 and 10 given by:

\[
R = (D_T + D_M + D_F + R_I + R_P + R_D + R_W + R_E) \times 0.25
\]

3.2. **Inalterability index (I)**

It includes every simplified inalterability test and the simplified descriptive tests of cracking and exfoliation. It has a score from 0 to 10 obtained by:

\[
I = (D_C + D_E + I_P + I_H + I_B + I_O + I_A) \times 0.25
\]

4. **Bearing capacity**

The resistance parameters of rocks are the most decisive when considering if the material is suitable for its application in embankments and excavation bottoms. That is why the resistance index has the highest ponderation in the correlations proposed to obtain the bearing capacity. On the other hand, the importance of the inalterability parameters is not the same in both problems, and the ponderation assigned to the inalterability index is different for each correlation [1].

4.1. **Embankment bearing capacity (B_T)**

Rock material must not be degraded in its particle-size, and even not suffering chemical alterations to guarantee the stability of the embankment. Because of that, the inalterability index is considered in this bearing capacity correlation. However, the very design of these structures attenuates the influence of the inalterability parameters. Examples of this fact are the pavements on roads and the waterproof coatings in dams that protect the core of embankments from weathering. Based on the above considerations, the proposed formulation is given by:

\[
B_T = (R \times a + I) \times (a + 1)^{-1}
\]

Coefficient \(a = 2\) provides the best approximation in most scenarios, and it should always be used except for more detailed and local investigations [1]. Assuming this value, the suitability of the rock tested as a building material for embankments is determined using Table 13.

| Embankment bearing capacity | Description | Points (B_T) |
|----------------------------|-------------|--------------|
| High                       | Excellent as a rockfill | 8-10         |
| Medium-High                | Valid for embankment top-graded areas | 6-8          |
| Medium                     | Valid for embankment foundation and core | 4-6          |
| Low                        | Inadequate, but likely to improve with stabilizations | 2-4          |
| Not applicable             | Inadequate and disposable | 0-2          |

4.2. **Excavation bottom bearing capacity (B_E)**

In excavation bottoms, the inalterability parameters barely come into action because they are covered in a short time when executed. Examples of this fact are the road layers, shallow foundations, and retaining walls that protect the excavation bottoms where constructed. In most scenarios, the natural terrain does not have time to be altered, and therefore the inalterability index has not been considered in this bearing capacity correlation. In short, the proposed formulation is as follows:

\[
B_E = R \times b
\]
Coefficient $b = 1$ provides the best approximation in most cases, and it should always be used except for more specific studies [1]. Assuming this value, the suitability of the rock tested as a building material for excavation bottoms is defined in Table 14.

**Table 14. Excavation bottom bearing capacity. Scoring system.**

| Excavation bottom bearing capacity | Description                                                                 | Points (BE) |
|-----------------------------------|-----------------------------------------------------------------------------|-------------|
| High                              | Excellent as surfaces and foundations without drainage in general           | 8-10        |
| Medium-High                       | Valid for surfaces and foundations with normal drainage                     | 6-8         |
| Medium                            | Valid for surfaces and light foundations after intense compaction and good drainage | 4-6         |
| Low                               | Inadequate, but likely to improve with geotextiles and or stabilizations. Needs good drainage | 2-4         |
| Not applicable                    | Inadequate and disposable. A layer of more than 1 m should be replaced, depending on the case. Reinforce with geotextiles and intense drainage in addition to substitution | 0-2         |

4.3. **Corrections**

After obtaining $B_T$ and $B_E$, it is necessary to evaluate the situations in which the actual bearing capacity is lower than the previously calculated. The main factor for decreasing the bearing capacity is the saturation water, as long as the rock is sensitive to being altered by the water. If so, the bearing capacity may be compromised when the groundwater level reaches the embankment coronation or the excavation bottom [1]. Therefore, the following corrections based on the inalterability index and the groundwater level are considered:

**Table 15. Bearing capacity correlations $B_T$ and $B_E$. Corrections.**

| Inalterability index (I) | 0-2 | 2-4 | 4-6 | 6-8 | 8-10 |
|--------------------------|-----|-----|-----|-----|------|
| Groundwater at > 2 m from the embankment coronation or the excavation bottom | -1  | 0   | 0   | 0   | 0    |
| Groundwater at 1-2 m from the embankment coronation or the excavation bottom | -2  | -1  | 0   | 0   | 0    |
| Groundwater at < 1 m from the embankment coronation or the excavation bottom | -2  | -1  | -1  | -1  | 0    |

5. **Conclusions**

The simplified tests proposed in this paper are simple procedures that require little economic effort and short execution time whose results are obtained with relative scoring systems. Because of that, they are suitable for the initial steps of engineering works and projects to reduce the uncertainty of the rock materials, minimizing the conventional rock tests to be carried out and the amount of time and cost required in the geotechnical characterization. However, it must be resalted that the simplified tests proposed do not try to replace the conventional rock tests, but to obtain similar outcomes to complement them and to be used in practical applications.

As for the bearing capacity, the results provided do not include units about their magnitude, but they represent quantitative approximations about their field of application. That is why the new methodology proposed in this paper is not a self-sufficient design procedure for embankments and excavation bottoms. Nonetheless, it is suitable as an indicative calculation and also as a method of checking and contrasting.
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