Geotechnical Zoning Map for an Industrial Area in the Castelo Branco Region (Portugal)

L. M. Ferreira-Gomes1*), E. Mendes2), L.J. Andrade Pais3), P.E. Maia Carvalho4), P. J. Coelho-Ferreira5), V. Gonçalves6)

1) GeoBioTec, Beira Interior University, 6201-001 Covilhã, Portugal; e-mail: lmfg@ubi.pt; ORCID: https://orcid.org/0000-0002-2367-373X
2) GeoBioTec, Beira Interior University, 6201-001 Covilhã, Portugal; e-mail: e_mendes@hotmail.com; ORCID: https://orcid.org/0000-0001-6965-0595
3*) GeoBioTec, Beira Interior University, 6201-001 Covilhã, Portugal; e-mail: lmfg@ubi.pt; ORCID: https://orcid.org/0000-0002-2367-373X
4) GeoBioTec, Beira Interior University, 6201-001 Covilhã, Portugal; e-mail: pemc@ubi.pt
5) GeoBioTec, Beira Interior University, 6201-001 Covilhã, Portugal; e-mail: pedroferreirajc@gmail.com; ORCID: https://orcid.org/0000-0002-1539-5717
6) GeoBioTec, Beira Interior University, 6201-001 Covilhã, Portugal; e-mail: alvane.goncalves@ubi.pt; ORCID: https://orcid.org/0000-0003-2694-0685

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Abstract

Large-scale geotechnical zoning maps (≥ 1/10 000) applied to Regional and Urban Planning (RUP), and also to the expansion of cities into new areas, such as new industrial areas, generally follow the classic methodology, which corresponds to the presentation of Geotechnical Units Map (GUM) in association with extensive tables with the characteristics of the various Geotechnical Units (GUs). The GUs are defined based on the different lithological and/or lithogenetic types. The tables associated with the GUMs present the characteristics of the various UGs, namely identification properties, in-situ physical parameters, strength parameters, and deformability parameters. In addition to these parameters, it is common to find geological, geomorphological, geodynamic, and hydrogeological elements, with the development of certain specificities depending on each region. In the present case study, in addition to the GUM, in association with some tables with a vast set of parameters, a Geotechnical Zoning Map (GZM) is presented, which is the result of a final document based on a methodology that the authors understand that it should always be used and standardized for this type of situation, i.e. the final map should be the result of overlaying three partial maps, according to the following: 1st Level – Topographic Map, with perfect reading not only of what is common in this type of map but also an adequate reading of the urban fabric, road network, and others.; 2nd Level - Classic GUM; this level must be presented in classic symbology for the different lithologies, so that, when overlapping the previous level, it is possible to read both levels; 3rd Level – GZM, which corresponds to a colour map, with relatively transparent colours, so that when overlaying the previous levels, it is always possible to collect information from the three levels; this last level will have several colours, the main ones being red, green and yellow, which correspond respectively to Very Poor, Excellent and Intermediate Suitability, concerning Suitability for Urban/Industrial Occupation; other intermediate colours may be used, depending on the classification of each area under study. Note that each colour corresponds to a Geotechnical Zone (GZ), representing the suitability for urban-industrial occupation of an area of the territory, as defined in the legend of this map. Therefore, the main objective of this paper is to present a case study with the above situations, but with the advance of applying a methodology that can be implemented with Geographic Information Systems (GIS) to obtain colour zoning, which will be a consequence of overlaying 3 new maps: i) Bearing capacity map for foundations; ii) Settlement susceptibility map, and iii) Slope stability map. Each of these analytical maps is the result of massive calculations using the parameters of each GU for the different places of the territory under study. It should be noted, for example, that different GUs, one made up of clays and the other of sands, which are completely different, can fall under the same GZ. The important point is to define a zoning in which the territory of each zone has the same reaction to any similar action, following what is commonly used for the dimensioning and implementation of urban buildings and/or other similar ones: bearing capacity, settlements, and stability of the natural slope. Finally, the GZM of the area under study is presented, with some conclusions.

Keywords: *Geotechnical zoning map; Bearing capacity; Settlements, Slope stability*

1. Introduction

A wide variety of geotechnical maps have appeared since they first were introduced in 1913 in Germany at the Leipzig Technical Construction Exhibition [1]. This situation led the IAEG Geotechnical Mapping Commission to prepare some work [2-5] to achieve worldwide uniformity of criteria, both about the classification of geotechnical maps, the units on which they are based, and the description of soils and rocks characteristics, and also in recommending symbols for the mapped aspects. Of particular note is the document "Engineering Geological Maps - A Guide to their Preparation" [2], which presents the "guidelines" of geotechnical mapping. Also worth mentioning is the work "Engineering Geological Mapping" [6], which presents didactic aspects of this subject and many examples of application. However, many interesting studies have appeared, more recently with the use of GIS tools [7-9], but in terms of geotechnical zoning maps, they follow very different methodologies about geotechnical suitability for urban-industrial occupation. How important it would be to standardize geotechnical zoning methodologies using GIS. This article, with a simple case study, uses the methodology proposed by Ferreira Gomes et al [10], taking the opportunity to explain it in some detail.

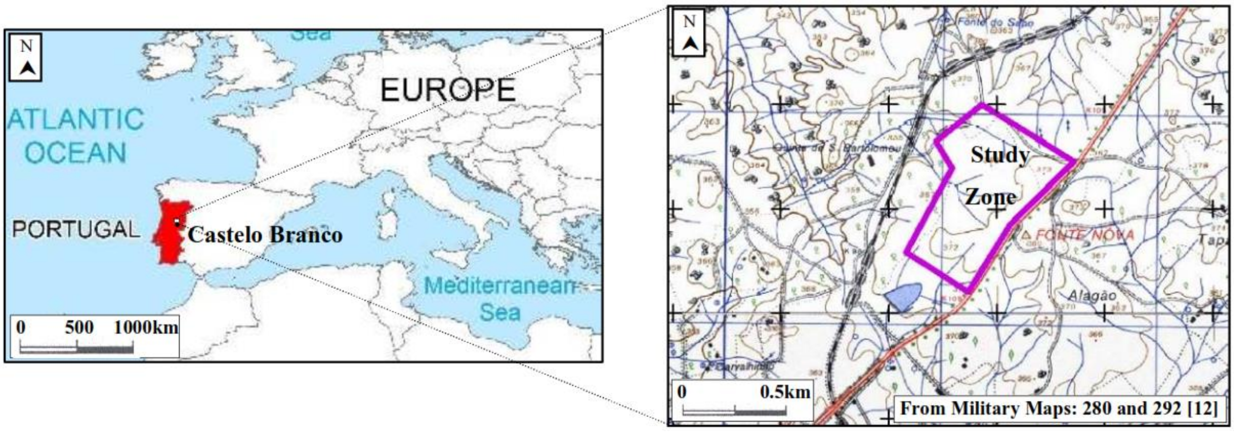
To plan new areas to be occupied or even to recover old areas, it is necessary to establish which spaces are suitable for buildings, special infrastructures, industrial zones, leisure areas, green spaces, sports, and others. To establish general planning, Topographic Maps are generally used at scales between 1/10000 and 1/5000. Those maps, in addition to presenting the morphology of the terrain, present the road network, and the location of the various buildings and other infrastructures, as long as their size allows it in relation to the scale. To plan concrete, urban, industrial or other areas, more detailed scales are used, from 1/5000 to 1/1000, depending on the characteristics of the development.

In relatively sloping terrain, the most frequent concerns of planning designers are whether the terrain will have a foundation bearing capacity and whether it will be adequate settlements for the infrastructures to be built, to plan the heaviest structures in areas with better geotechnical characteristics. In terrains with some inclination, in addition to the previous concerns, the stability of the slope or natural talus is always present.

A geotechnical map in the broadest sense of its meaning, according to Ferreira Gomes [1], can be defined as a synthesis document that presents the delimitation of a set of zones, with each zone having similar technical behavior, i.e. each zone is characterized by presenting homogeneity in a set of characteristics or attributes so that there is a similar response to the same type of mechanical request. The attributes considered in each geotechnical map depend from region to region, however, according to some expert authors, some aspects must be considered in any geotechnical map [11]: i) soil and rock characteristics and their spatial distribution; ii) geohydraulic aspects; iii) geomorphological characteristics; and iv) geodynamic phenomena.

For this proposal, the above aspects are analyzed, with due adaptation to the area under study, especially with significant simplifications due to the modest working area (36.4 ha) compared to what is usual in geotechnical maps of large cities, sometimes associated with various industrial zones and other special infrastructures.

Thus, in this article the objective is to present the GZM for the Alagão area [12], in Castelo Branco, Portugal (Figure 1), and based on this, to present in detail the methodology used to establish the geotechnical zoning to systematize the territory in relation to its suitability or favorability for urban-industrial occupation, based on the overlap of 3 analytical maps: i) Bearing Capacity, ii) Susceptibility to Settlements, and iii) Slope Stability, using GIS tools.



From Military Maps: 280 and 292 [12]

Fig. 1. Geographical setting of the zone under study (Alagão area - Castelo Branco, Portugal)

2. Methodology

The project began with a study of previous work, bibliographical research, followed by the traditional field reconnaissance, drawing up a lithological map. Extensive geotechnical studies, with in-situ tests, soil and rock sampling, and laboratory tests followed this. The following in situ tests were carried out: 26 seismic refraction profiles [13], 174 DPSH dynamic penetration tests [14], 17 SPT tests [15], as well as several mechanical augers and some trenches. In the rocky outcrops, 17 penetration resistance tests were carried out using the Windsor Pistol [16] and 19 tests using the Schmidt Sclerometer type L [17]. Natural unit weight and water content were also determined for 10 sites [18]. The following tests were carried out in the laboratory: Particle size distribution [19], Atterberg Limits [20], Proctor [21], Direct shear [22], and Oedometric Consolidation [23].

As the occurrence of granitic residual soils is frequent, as will be shown in the following item, it is emphasized that the DPSH test was frequently used, as it is a suitable test for this type of situation, being quick and easy to handle, which in addition to allowing knowledge of the depth of the bedrock, enabled the mechanical characterization of the materials crossed. For the results of that test (NDPSH versus depth) to be used to evaluate the detailed mechanical characterization of the soils crossed, a correlation was established between NDPSH and NSPT, resulting in the following equation:

$$N_{SPT} = 2.03\ N_{DPSH} \tag{1}$$

where NSPT is the number of blows/30cm, of the 2nd phase of the test as is classic, using the Terzaghi sampler [15]; NDPSH is the number of blows/20cm of test advancement.

The main characteristics of the dynamic penetrometer for carrying out DPSH tests are the following: hammer mass: 63.5 kg, hammer fall height: 75 cm, unit penetration: 20 cm, maximum cone section: 20 cm2, cone apical angle: 90 degrees.

3. Results and Interpretations

3.1 Geotechnical Units Map - GUM

Topographic and geological aspects were prioritised for the GUMs, starting with the initial works and integrating them into bibliographical research and prior studies. In topographical terms, the area under study is located in the geomorphological unit known as the "Castelo Branco Plateau" [24], which contrasts with the "Central Mountain Range" unit, well known for including the Estrela Mountain and Gardunha Mountain, the north of the work area. Morphologically, the work area is relatively smooth, with altitudes varying between 362 and 376 m, and essentially comprises a plateau area where several water streams begin (Figure 1). The slopes of the entire working area are generally less than 2.5%.

The geological situation is straightforward. The work area is almost entirely located on the geological unit known as Monzonitic Granites of Hercynian age from the Late Series, which are essentially medium to coarse-grained granites [25]. Due to the relatively detailed scale of work (1/2500), it was also possible to map in the lower areas, Fluvial Alluvium, of recent age. The typicality of the study area corresponds to the situation in which the rock mass rarely emerges, due to the cover of vegetation and residual granite soil over the materials considered to be rocky, with only a few granite blocks occasionally occurring, sometimes with bucolic configurations.

Based on the above, the field survey, using the lithological criterion, checking for the possibility of granites with various classes depending on their degree of weathering (W1 ... W5 [26], and also checking for the possibility of granite residual soil (SRG), resulted in the GUM shown in Figure 2. The following GUs were established:

- GU1: Fluvial Alluvium (AF),
- GU2: Granite Residual Soils (SRG), and
- GU3: Weathered Granite (G), including degrees of Weathering W5-W4-W3-W2 [26].

It should be noted that areas of the rock mass with different degrees of weathering were not individualized, since there were no patches of a single type with significance on the mapping scale, and therefore GU3 was considered, in addition to SRG.

In that GUM (Figure 2), the notion of the 3rd dimension (depth) is presented using the "window criterion" [1], i.e. a square is placed on the various patches of GUs that occur on the surface, with the identification and depth of the underlying unit, thus giving an idea of the 3rd dimension.

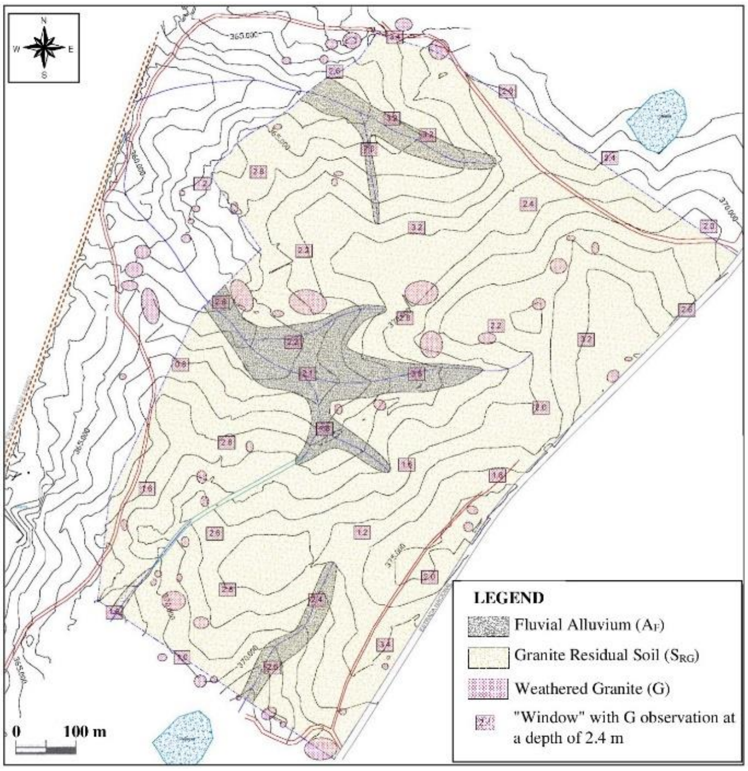


Fig. 2. Geotechnical Units Map (GUM) for the Alagão area (Castelo Branco).

Table 1 shows the basic characteristics of the defined GUs, and also the respective geotechnical classifications [27,28]. It should be emphasized that Units A_F and S_{RG} are earthy and sandy with some generally non-plastic fines, and GU3 is rocky, with varying degrees of weathering, from *Completely Weathered* granite (W_5) to *Slightly Weathered* (W_2); there is no completely *Fresh* granite (W_1).

Tab. 1. Index characteristics of the Geotechnical Units (GU) of the Alagão area, Castelo Branco.

GU	**Identification characteristics**				**Classification**		**Physical characteristics**					
	P_f (%)	d_{50} (mm)	LL (%)	PI (%)	Unified [27]	AASHTO [28]	γ_{dN} kN/m^3	w_N (%)	n (%)	γ_{dmax} kN/m^3	W_{opt} (%)	V_p (m/s)
Fluvial Alluvium (A_F)	22 - 28	0.3 - 1.1	27 - 37	0 - 3	SC-SM with G SM with G	A-1-b A-2-4 A-2-6	17.2 - 17.8	0 - 17.3	-	17.6 - 19.5	10.4 - 14.5	329 - 524
Granite Residual Soil (S_{RG})	10 - 38	0.15 - 1.1	29 - 38	0 - 4	SW-SM with G, SM with G, SC-SM, SC	A-1-b A-2-4 A-4	14.9 - 19.1	0 - 18.8	-	17.6 - 19.4	10.1 - 14.6	329 - 1600
Weathered Granite (G)	-	-	-	-	-	-	23.6 - 25.3	0 - 5	4 - 11	-	-	1600 - 4641

[a] Notations: P_f - Percentage in fines (% of the material with diameter <0.074mm); d_{50} - "average diameter", LL – Liquidity Limit, PI - Plasticity Index, γ_{dN} - natural dry unit weight, w_N - natural water content, n - natural porosity, γ_{dmax} - maximum dry unit weight, W_{opt} - optimum water content, Vp – P wave velocity, from refraction seismic tests.

In terms of the mechanical characteristics of the various GUs, the DPSH tests were absolutely fundamentals. Carrying out a detailed analysis of all the NDPSH versus Depth results, using the evolving to the minimums, for safety reasons, for all the results for each unit, NDPSH was transformed into NSPT, using Eq.1, and then NSPT was transformed into equivalent values of qc (cone penetration resistance of the CPT - Cone Penetration Test) using Bowles' proposal [29]. With the qc values tabulated for different depths, it was possible to use them to calculate the resistance and compressibility parameters, as there are many solutions available in the geotechnical literature. As the study cases (AF and SRG) are sandy materials, the graphical correlation proposed by Meyerhof [30] was used to obtain the angle of internal friction (ϕ), which is fundamental in this case for assessing the bearing capacity of the soils, as well as Schmertmann's proposal [31], $Es=\beta qc$, with $\beta=2$, to obtain the modulus of deformability of the soils (Es), which makes it possible to assess the settlements of the soils, which in this case, being sands, are assumed to have only instantaneous settlements (no primary or secondary settlements).

Table 2 shows the results obtained for the GUs under study. It should be emphasized that at this stage it is necessary to be very familiar with the use of correlations between geotechnical test parameters and the various mechanical parameters. They should be compared with the results of laboratory tests and when making decisions, regarding which parameters to use in the calculations of the main factors of interest in geotechnical mapping applied to the Regional and Urban Planning, care should generally be taken to use the values that condition stability, such as the lowest values in the case of resistance and the highest values in the case of compressibility. Some detailed information on this type of situation in this case study, with a detailed presentation of the field and laboratory results in the various units, can be found in various works [32-34]. It should be noted that in the case of GU3, being rocky and in an area with low slopes, the situation in terms of mapping the various factors is simplified, since in terms of bearing capacity, due to the results obtained in terms of resistance to uniaxial compression [32-34] leads to completely favorable situations, as well as in cases of settlements that are admitted to be null, and in terms of the slopes that are stable. If rock masses occurred in extensive areas, with different slopes, a lot of detail would have to be given, not only to an analytical map of the degree of weathering, but also to an analytical map of the various fracture systems, not only in spatial terms, but also of resistance, to make an analytical map of the stability of natural slopes.

Tab. 2. Evolution of $q_c^{(*)}$ with depth, based on the minimum envelope of all in situ results, and corresponding mechanical parameters for the various Geotechnical Units (GUs).

Depth (m)	**Fluvial Alluvium - A_F**				**Granite Residual Soil - S_{RG}**			
	q_{c-min} (kN/m^2)	compactness	ϕ (º)	Es (kN/m^2)	q_{c-min} (kN/m^2)	compactness	ϕ (º)	Es (kN/m^2)
0.5	1400	Very loose	31	2800	660	Very loose	30	1320
1.0	2870	Loose	34	5740	1320	Very loose	31	2640
1.5	4270	Medium	35	8540	4026	Medium	35	8052
2.0	5670	Medium	36	11340	9372	Medium	37	18744
2.5	7350	Medium	37	14700	20064	Dense	40	40128
3.0	-	-	-	-	40128	Very dense	44	80256

(*) q_c is the cone penetration resistance of the CPT test (Cone Penetration Test), obtained from correlations between in situ test parameters. ϕ - friction angle, Es - modulus of deformability of the soil.

3.2 Geotechnical Zoning Map - GZM

The final Geotechnical Zoning Map (GZM_F) is based on the execution of documents that result from an overlay of 3 Levels: i) 1st Level - *Topographic Map*; ii) 2nd l Level - *GUM*; 3rd Level – *GZM*.

The 1st Level serves as the basis for all work, enabling adequate sensitivity to the relationship between the other Levels.

The 2nd Level, based on geological and geotechnical criteria and organized according to lithological or lithogenetic criteria, is built on top of the previous one, drawing the areas of the GU only with symbology (Figure 2). This 2nd Level allows a notion about the geometry of the massif in lithological terms, both in terms of its horizontal extension and its thickness, using the "window" criterion (a square with a side of about 1 cm is placed on the stain of a certain unit, and the symbol of the unit below it and the respective depth to reach it are placed inside it). Regarding the 2nd Level, it should be noted that each GU is characterized in detail by its geotechnical characteristics (identification characteristics, physical properties, strength, and deformability parameters) and possibly others, such as hydrogeological characteristics (type of aquifer, permeability, position of the water table).

The 3rd Level, to be developed in this item, presents the GZs, which are drawn in transparent colors so that the previous two levels can be read; the basic colors are green, yellow and red, which are associated respectively with areas with no, some and many limitations to urban-industrial occupation.

Thus, to obtain the GZs, i.e. the green, red and intermediate colored areas, the various attributes of the Geotechnical Zoning Factors are superimposed. The proposed zoning factors, following the proposal by Ferreira Gomes et al [10], are as follows:

1. *Bearing Capacity (BC)*
2. *Susceptibility to Settlements (SSe), and*
3. *Slope Stability (SSt)*

To calculate *BC* and *SSe*, not only do you need the geotechnical and hydrogeological characteristics (position of the water table) of the massif, but you also need to define a type of foundation. Of course, the type of foundation, its shape, its size and even its load influence the results to be obtained, which is why some researchers advise against this approach. However, by standardizing a type of foundation and transforming the results into qualitative terms, with a classification of bearing capacity and settlements, it is possible to create zoning maps that show reality and can be understood by even non-specialist users. For example, an area colored red, which corresponds to a very low bearing capacity and a high potential for settlements, is easily understood as an area unfavorable to urban occupation. Surely if only the shear strength and compressibility parameters of that area were presented, as is done in the GUMs, only the experts would understand that it was an unfavorable area.

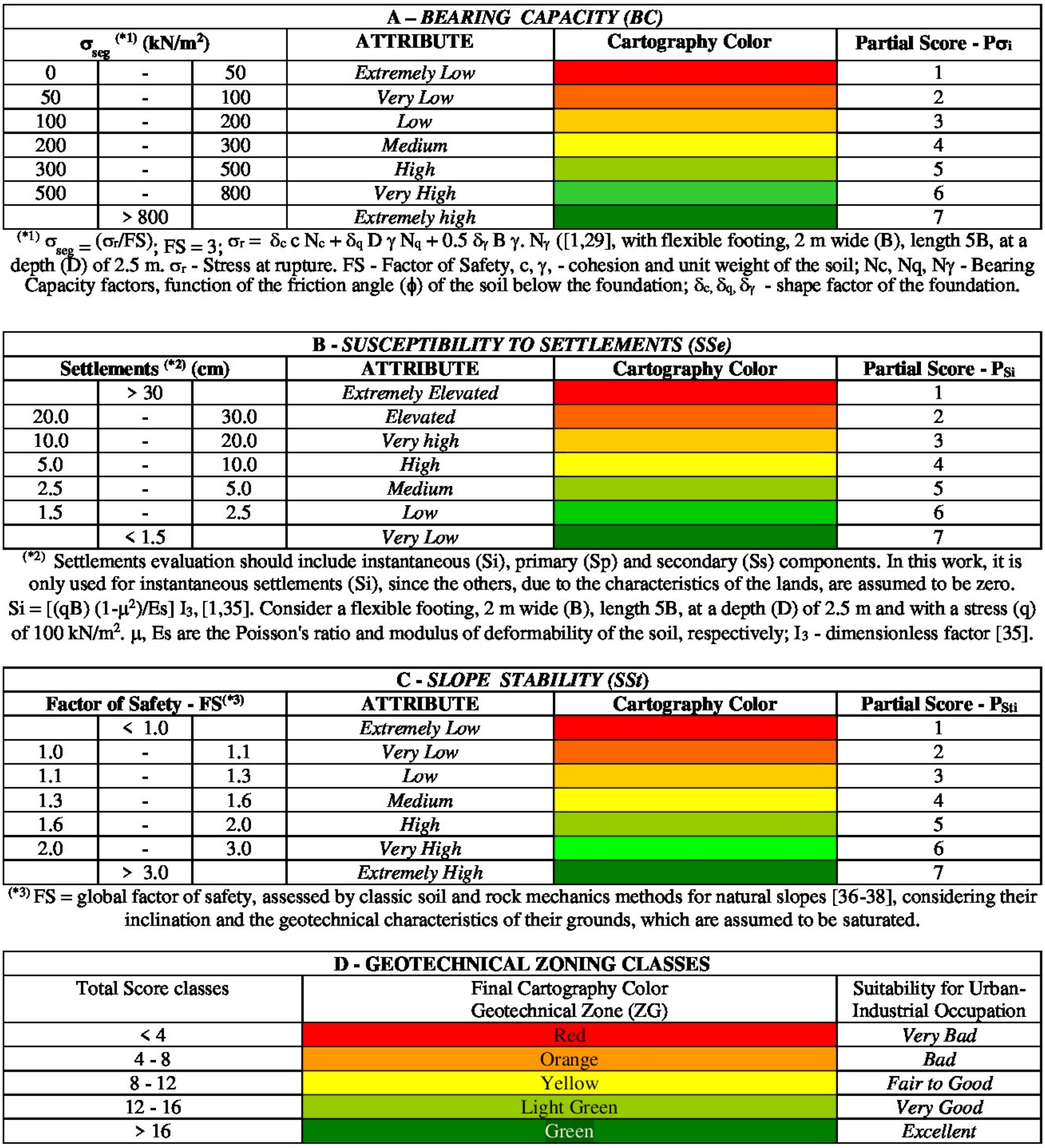
Therefore, a foundation is proposed that is considered a "Standard Foundation" in the assessment of bearing capacity and settlements, in geotechnical mapping, according to:

- 2 m wide flexible footing (B), length 5B, at a depth of 2.5 m, submerged, and with a loading (in the case of settlements) of 100 kN/m^2.

The reason for the proposal, which corresponds to a foundation at a certain depth, is that even at the surface many geological formations are extremely uncompressed, and do not represent what occurs in its entirety.

Bearing capacity, settlements and slope stability are assessed numerically according to the classic and general approach shown in Figure 3. Numerical values are systematized into classes and given a qualitative term (Attribute), so that it is understandable to any user, even a non-expert one. It is given a color to be used more easily in cartography, with the aforementioned notion, in terms of Suitability for Urban-Industrial Occupation, systematized in classes, from the least favorable, the red color, to the most favorable, the green color.

To create a final map, resulting from the overlay of previous maps, with the support of GIS tools, partial scores are assigned, as shown in fields A, B and C of Figure 3. As a result of various combinations, the Total Score classes shown in field D of the same figure are used, using the respective colors and classification shown, to establish the various zones. For example, if the analytical maps of Bearing Capacity, Susceptibility to Settlement, and Slope Stability are superimposed on a zone with a Total Score class of less than 4, it will be colored red, regardless of which GU is underneath.



A – *BEARING CAPACITY (BC)*

σ_{seg} (*1) (kN/m^2)			ATTRIBUTE	Cartography Color	Partial Score - $P_{\sigma i}$
0	-	50	*Extremely Low*	🟥	1
50	-	100	*Very Low*	🟧	2
100	-	200	*Low*	🟧	3
200	-	300	*Medium*	🟨	4
300	-	500	*High*	🟩	5
500	-	800	*Very High*	🟩	6
	> 800		*Extremely high*	🟩	7

(*1) $\sigma_{seg} = (\sigma_r/FS)$; FS = 3; $\sigma_r = \delta_c\, c\, N_c + \delta_q\, D\, \gamma\, N_q + 0.5\, \delta_\gamma\, B\, \gamma.\, N_\gamma$ ([1,29], with flexible footing, 2 m wide (B), length 5B, at a depth (D) of 2.5 m. σ_r - Stress at rupture. FS - Factor of Safety, c, γ, - cohesion and unit weight of the soil; Nc, Nq, Nγ - Bearing Capacity factors, function of the friction angle (ϕ) of the soil below the foundation; δ_c, δ_q, δ_γ - shape factor of the foundation.

B - *SUSCEPTIBILITY TO SETTLEMENTS (SSe)*

Settlements (*2) (cm)			ATTRIBUTE	Cartography Color	Partial Score - P_{Si}
	> 30		*Extremely Elevated*	🟥	1
20.0	-	30.0	*Elevated*	🟧	2
10.0	-	20.0	*Very high*	🟧	3
5.0	-	10.0	*High*	🟨	4
2.5	-	5.0	*Medium*	🟩	5
1.5	-	2.5	*Low*	🟩	6
	< 1.5		*Very Low*	🟩	7

(*2) Settlements evaluation should include instantaneous (Si), primary (Sp) and secondary (Ss) components. In this work, it is only used for instantaneous settlements (Si), since the others, due to the characteristics of the lands, are assumed to be zero. $S_i = [(qB)\,(1-\mu^2)/E_s]\, I_3$, [1,35]. Consider a flexible footing, 2 m wide (B), length 5B, at a depth (D) of 2.5 m and with a stress (q) of 100 kN/m^2. μ, Es are the Poisson's ratio and modulus of deformability of the soil, respectively; I_3 - dimensionless factor [35].

C - *SLOPE STABILITY (SSt)*

Factor of Safety - FS(*3)			ATTRIBUTE	Cartography Color	Partial Score - P_{Sti}
	< 1.0		*Extremely Low*	🟥	1
1.0	-	1.1	*Very Low*	🟧	2
1.1	-	1.3	*Low*	🟧	3
1.3	-	1.6	*Medium*	🟨	4
1.6	-	2.0	*High*	🟩	5
2.0	-	3.0	*Very High*	🟩	6
	> 3.0		*Extremely High*	🟩	7

(*3) FS = global factor of safety, assessed by classic soil and rock mechanics methods for natural slopes [36-38], considering their inclination and the geotechnical characteristics of their grounds, which are assumed to be saturated.

D - GEOTECHNICAL ZONING CLASSES

Total Score classes	Final Cartography Color Geotechnical Zone (ZG)	Suitability for Urban-Industrial Occupation
< 4	Red	*Very Bad*
4 - 8	Orange	*Bad*
8 - 12	Yellow	*Fair to Good*
12 - 16	Light Green	*Very Good*
> 16	Green	*Excellent*

Fig. 3. Attributes of Geotechnical Zoning Factors in cartography applied to RUP: A) Bearing Capacity, B) Susceptibility to Settlements, C) Slope Stability; and D) Geotechnical Zoning Classes to suitability for Urban-Industrial Occupation.

Thus, in this case study, using the geotechnical parameters of the various GUs, and in particular those presented in Tables 1 and 2, for a depth of 2.5 m, the results shown in Table 3 and the Final GZM in Figure 4 are obtained. In these calculations and evaluations, the following should be highlighted:

i)The *BC* was evaluated as shown in Figure 3-A, using the geotechnical parameters in Table 2 and considering GU2 at a depth of 2.5 m as purely attritive, with ϕ=40º, and GU3, for safety, as a unit of the S_{RG} family with ϕ=44º, being fundamental the calculation of σ_r [29]. Values of σ_{seg} greater than 800 kN/m^2 were obtained, allowing the units to be classified concerning the *BC* as *Extremely High*. Note that GU1 is not considered, as it is less than 2.5 m thick. Therefore, by imposing the foundation to reach 2.5 m in depth, this calculation would not make sense, since these lands, in this situation, will have to be removed.

ii)The *SSe* assessment was carried out individually for each component (instantaneous, primary and secondary settlements), as shown in Figure 3-B. Again, in this study, when considering the 2.5 m depth, it does not make sense to consider GU1. In relation to the other units, the primary and secondary settlements, due to their characteristics, are assumed to be 0 (zero); in relation to the instantaneous settlements, GU3 was also assumed to be incompressible, i.e. with null instantaneous settlements, as it is a rock mass. For GU2, when evaluating Si [35], using Es= 40128 kN/m^2, μ=0.35 for the aforementioned standard foundation, Si < 1.5 cm is obtained, i.e. the unit is classified as *Very Low* in relation to *SSe*.

iii) In assessing *SSt*, the guidelines in Figure 3-C were followed [36-38], considering the average inclinations, which are often less than 15%, i.e. less than 8.5º, and also considering the geotechnical characteristics of the various UGs, which lead them to be classified as *Elevated* in terms of *SS*t.

Finally, in order to draw up the Final Geotechnical Zoning, once again emphasizing that a depth of 2.5 m is being considered, in terms of Suitability for Urban-Industrial Occupation for the various situations, the Total Zoning Score for any location in the work area is 21 points overall, i.e. the maximum possible value. This situation means that, in terms of geotechnical zoning, there is only one GZ for the entire work area, classified as *Excellent* in terms of Suitability for Urban-Industrial Occupation (Table 3), resulting in only one " stain" of "absolute green" on the map (Figure 4).

In geotechnical mapping applied to the RUP, in addition to all the aspects mentioned above, it is absolutely important that, depending on the region under study, whether it is a mountainous area, or a flat coastal area, or something else, results are presented in terms of the characterization of the various UGs, more frequently depending on the characteristics of each region, such as erosion phenomena, liquefaction, or even geoenvironmental aspects, or underground water resources, or geological heritage that deserves to be musealized, among others.

Tab 3. GU classification in terms of the geotechnical zoning of the Alagão area – Castelo Branco.

GU	***Bearing Capacity - BC***	***Susceptibility to Settlements - SSe:*** Si- instantaneous settlements Sp- primary settlements Ss- secondary settlements	***Slope Stability - SSt***	**Suitability for Urban-Industrial Occupation**	**Observations**
A_F $^{(*)}$ Fluvial Alluvium	-	-	*Elevated*	*Excellent*	Unit to be removed, due to its small thickness and poor geotechnical characteristics
S_{RG} Granite Residual Soils	Extremely High	Very Low, in relation to any type of settlement (Si, Sp Ss)	*Elevated*	*Excellent*	Note that the characteristics shown are for depths ≥ 2.5m.
G Weathered Granite	Extremely High	Very Low, in relation to any type of settlement (Si, Sp Ss)	*Elevated*	*Excellent*	Note that although the characteristics are predicted for depth ≥ 2.5m, in some cases they may be smaller because G occurs at the surface

$^{(*)}$ because this unit has thicknesses < 2.5m, the attributes for *BC*, *SSe*, and *SSp*, in the areas where it occurs, are those of the underlying UG.

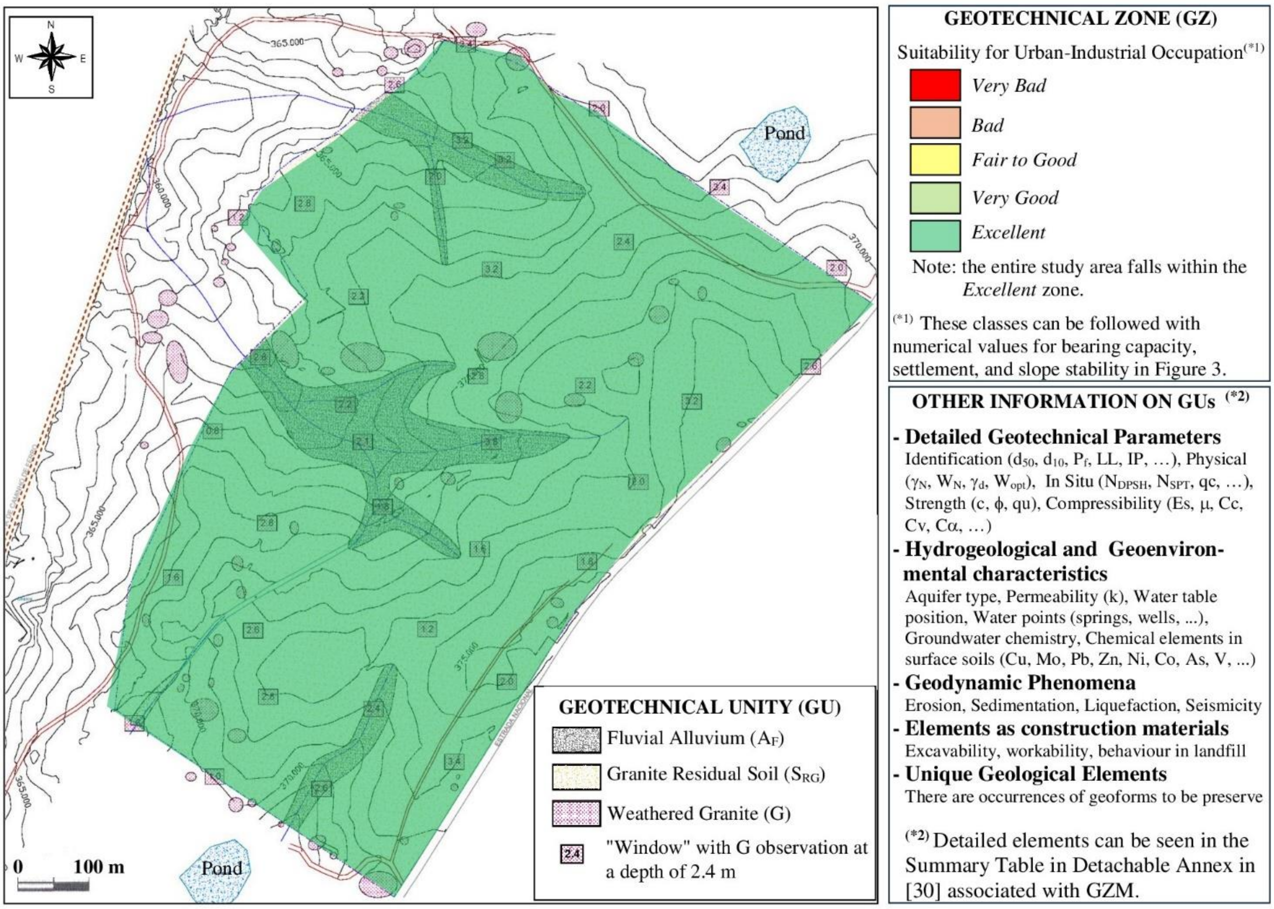


Fig. 4. Final Geotechnical Zoning Map (GZM) for the Alagão area (Castelo Branco).

4. Conclusions

The Alagão area, i.e. the area where the future Castelo Branco business zone is to be located, was subjected to a series of studies with the ultimate aim of drawing up a GZM to enable adequate planning of the new structures, infrastructures, roads, among others, to be built.

To establish a mapping with zones classified according to the favorability or suitability for the implementation of buildings to be constructed, and taking into account what is classic and basic for designers (bearing capacity and potential settlement of the foundations, and also the stability of the natural slope of the areas to be built), a methodology was implemented, so that this final map, the GZM, resulted from the superimposition of 3 levels: 1st Level, topographic map, with visibility of contour lines, elevations, water courses and the network of roads and accesses; 2nd Level: GUM, whose units are defined according to the lithological criteria, represented in symbology, so that there is an adequate reading of the distribution of the various GUs, and at the same time there is an adequate reading of the previous level; 3rd Level, the GZs, represented in transparent colors, so that in each place there is a reading of the 3 levels. This final level is intended to be immediately readable, even for non-specialists, considering that the red areas are poorly favorable, and the green areas are the most suitable, therefore with excellent favorability for urban and industrial occupation, and other colors with intermediate situations. The color zoning is the result of overlaying 3 analytical maps (bearing capacity map, settlement susceptibility map and slope stability map), also in color, where the use of GIS tools is fundamental, following the methodology shown in Figure 3.

After the various works carried out, the main conclusion was that, considering the depth of around 2.5 m, the entire work area was classified as being suitable for urban-industrial occupation with an *Excellent* classification, i.e. the overall area was colored green (Figure 4).

This situation, among other very favorable features, will allow direct foundations to be laid at that depth or even shallower, depending on the location, and it is a matter of observing the geotechnical zoning map, with permissible stresses of around 800 kN/m^2, and without settlements of any significance, and with total stability of the natural slopes.

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