The importance of geotechnical knowledge of terrains: Beja municipality, Alentejo, Portugal

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ABSTRACT: The municipality of Beja, in Alentejo (Portugal), is presented as a case in which the insufficient knowledge of the geological and geotechnical characteristics of terrains contributes to serious problems in the establishment of building platforms. In Beja three main geotechnical units can be defined: fills, residual soils from gabbro-diorite weathering and gabbro-diorite bedrock. The knowledge of location, thickness and geotechnical properties of all these formations will contribute to the accurate engineering design and construction work, and also to support urban planning and therefore to minimize geological risk by avoiding zones with thick problematic soils as shown with a case study.

1. INTRODUCTION

Beja is a small Portuguese town (Fig. 1), established before the Roman times. Although it presents a strong agricultural tradition, Beja is currently experiencing an important increase in urbanization. As in many other cities around the world and even though is not a megacity, Beja's historical heritage and the ground geotechnical characteristics are major constrain restrictions to urban development.

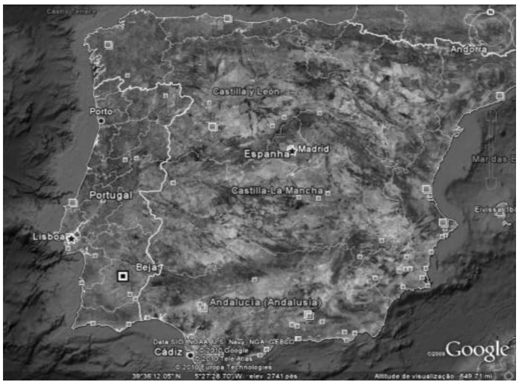

Figure 1. Beja, South of Portugal.

There is no geological detailed map published for Beja. The best geological reference is a 1:200.000 map, displaying the spatial distribution of the main different igneous rocks belonging to the Beja Gabbroic Complex, and the several faults associated with it (Oliveira, 1992).

Although several geotechnical reports have been done over the past years, geotechnical data is scattered along different entities and they'rent easily assessed. Furthermore, in some cases, reports were made, but weren't duly taken into account when some engineering design works were implemented, disregarding the geological risks associated with the construction on problematic soils.

There are various contexts, such as building platforms and infrastructures works that require the knowledge of the strata sequence, thickness of weathered formations, groundwater level position and recognition of fill areas, among others, to predict adverse situations during construction and to prevent non-economic and unsafe conditions.

The soils and rocks main geotechnical parameters necessary for design are usually estimated from comparable situations or correlations which are obtained from references, although it's well known (and hence recommended by EC7 – CEN, 2004) that site investigation and laboratory tests provide more suitable values.

Therefore, it is essential to undertake a large scale geotechnical characterization of the Beja County, defining its main geotechnical units and their properties and make them available to all the entities involved in design and in the county planning and management. Some of the authors have been involved in achieving such knowledge. This paper presents a brief “state of the art” of the geotechnical knowledge for Beja County and also a specific example of what happened during the implementation of a structure at the School of Technology and Management (ESTIG) of the Polytechnic Institute of Beja (IPB) when geotechnical information was underestimated.

2. GEOLOGICAL CHARACTERIZATION

Beja city is located in the central area of the Baixo Alentejo peneplain occupying the top of a smooth elevation, with an average altitude below 260 m (Feio, 1952).

Geologically, the area is situated in the Ossa Morena Zone, a major morphostructural unit of Portugal, were the Beja Gabbroic Complex appears, a variscan basement integrating the Beja Igneous Complex (BIC), a wide curved intrusive belt of approximately 100 km in length. Its northern limit is defined by the Beja strike slip fault (WNW-ESE) and, at the South, the transition is made by the Ferreira-Ficalho overthrust, a major tectonic structure between the Ossa Morena and South Portuguese Zones.

The Beja Gabbroic Complex is a layered suite mainly composed of olivine-bearing gabbroic rocks, bordered by heterogeneous diorites (Jesus *et al.* 2003). It can be considered that the whole complex has a very heterogeneous lithological composition with gabbros, diorites and feldspar porphyries among the most common rocks.

Nevertheless, their spatial variation and distribution aren’t thoroughly known at a large scale. Besides that, in some areas, there is a thick coverage of residual soils and, in others, there are heterogeneous fills, and none of them are presently mapped.

3. GEOTECHNICAL DATA

According to the EC7 (CEN, 2004), engineering projects should be based on geotechnical information from site investigation and laboratory tests, complemented by well-established experience.

In the framework of the research, two main types of data were analysed: data from geotechnical reports, belonging to private and public entities (usually Contractors and Owners, respectively); and laboratory tests data, obtained during the research studies in progress.

The main geotechnical reports analysed correspond to site investigation studies in Beja urban area. All of them include borehole logs and SPT, and very few lab tests results.

The geotechnical characterizations included rough estimates of unit weight, angle of shearing resistance, cohesion and modulus of elasticity; such values are quite similar to the ones presented upfront for the case study of the ESTIG-IPB foundations design and thus no further considerations will be made in this section on that subject.

The new data encompasses several disturbed and undisturbed soil samples collected all around Beja urban area, during excavations for building foundations and, therefore, at different depths, and have been submitted to laboratory testing. Those samples of residual soils and decomposed gabbros, correspond to cohesive and granular soils, respectively. Cohesive soils, known as “Barros de Beja”, are dark brown to black color with clayey texture, presenting high plasticity and low permeability, and are very sensitive to water content. Granular soils have a brownish gray color, sandy texture and low plasticity.

Laboratory tests developed up to now have focussed mainly on granular soils. These were submitted to particle size distribution analysis, Atterberg limits (w_P and w_L), specific gravity and Proctor compaction tests.

For all these tests, specific Portuguese standards or recommendations were adopted. Next, some of the results already gathered are discussed.

4. LAB TESTS RESULTS

Soil samples collected were submitted to basic soil characterization tests to obtain their geotechnical classifications. The results of a selected set of samples are illustrated in table 1.

The granular soils of highly weathered gabbros are classified as silty sands with some amounts of fines (usually < 20%). The amount of gravel in these soils can be variable, but usually large enough not to be ignored (> 30%). Those fines show a low plasticity index, usually lower than 10%.

Through the application of geotechnical soil classifications systems, one can conclude that the soils are manly of SM type, silty sands with gravel (17% are GM), according to the Unified Soil Classification System, and A-2-4 (0) (17% are A-2-6 (0)) according to the AASHTO Classification.

These soils exhibit low permeability and compressibility when compacted and a fair use as construction material (Budhu, 2000).

Table 1. Synoptic results of some disturbed samples laboratory tests and their geotechnical classifications (min - minimum; Max – maximum; aver – average; SD – standard deviation; var – variance; CV – coefficient of variation)

	min	Max	Aver	SD	Var	CV
%Fines (< 0,075 mm)	12,6	26,8	16,80	5,49	30,09	32,65
%Gravel (> 4,75 mm)	28	52	39,00	9,78	95,60	25,07
# 10 (<2 mm)	31	60	47,50	10,17	103,5	21,42
# 40 (< 0,425 mm)	12	29	22,83	6,08	36,97	26,63
wP (%)	21	28	24,83	2,64	6,97	10,63
wL (%)	31	38	33,83	2,99	8,97	8,85
PI (%)	3	14	9,00	3,69	13,60	40,98
G_s	2,74	2,81	2,78	0,03	0,00	0,93

As soil compaction is a way to improve soil's behavior as a construction material, Proctor tests were undertaken.

The results of the Modified Proctor test in CBR mold are shown in table 2 and they confirm the fair behavior of these soils as construction materials.

These Proctor results contribute to real compaction situations, on foundation improvement for several constructions around Beja County.

Table 2. Synthesis of results from soil compaction tests.

	min	Max	Aver	SD	Var	CV
γ_d (kN/m^3)	22,20	22,27	20,89	1,2	0,1	37,8
W_{opt} (%)	9,6	11,8	10,68	0,92	0,77	8,19

Cohesive soils from "Barros de Beja" have more than 65% of fines and at least 70% of them are clays. They were submitted to X-Ray analyses confirming the expected existence of clay minerals from the montmorillonite group (Carvalho-Cardoso, 1965). Both field and laboratory observations evidenced swelling (high expansibility and high retraction). In fact, field cracks can sometimes exhibit gaps of more than 10 cm.

5. GEOTECHNICAL ZONING

According to the data brought together, one can define 3 main geotechnical units. Usually, the deepest one, G1, comprises gabbroic rocks with no or small weathering. An intermediate zone, G2, corresponds to soils formed *in situ* mostly by chemical weathering of the gabbroic rocks and lying directly in the parental rock; thus its depth is highly irregular. G2 includes two subzones: G2a, correspond to granular soils resulting from the weathering of gabbros rock mass, and G2b, the cohesive residual soils designated by "Barros de Beja". In flat areas, the late ones, highly expansive dark soils, have drainage problems due to their low permeability. These subzones usually present less than 2,0 m of thickness, but they may appear solo, directly on top of the rock mass, and in this case they attain a higher thickness; a maximum of 3,0 m, has been registered so far.

Another important unit, related to anthropogenic activities, may covered the above mentioned geotechnical units in some areas. It is identified as G3 and corresponds to very heterogeneous fills deposits with large thickness variations and composition. They contain all sorts of debris and usually have large amounts of "Barros de Beja" soils, since they aren't used as construction materials.

The units G3 and G2b (“Barros de Beja”), should be avoided in any civil engineering works.

6. A CASE STUDY

The field results presented next corresponds to an example of a particular geotechnical study developed to support the construction of the ESTIG-IPB building, located on the west area of the Beja town. The report and *in situ* tests were performed by the firm ‘Geocontrole, Geotecnia e Estruturas de Fundação, S.A.’.

At a first stage and during summer time, six hollow steam auger boreholes with SPT every 1,5 m, or whenever lithological changes occurred, were executed. Their depth ranged from 7,5 m to 9,0 m. The main units identified by them along the foundation site were fills and highly weathered gabbro soils. Two borehole logs registered a water level table near 4,0 m depth; the remaining ones detected it between 5,0 m and 7,0 m.

Values for geotechnical parameters estimated for the highly weathered gabbros soils are summarized in Table 3.

Table 3. Estimated parameters for highly weathered gabbros soils based on site investigation (Geocontrole, 2004).

Weathered gabbro	Degree of weathering	N_{SPT} blows	γ (kN/m^3)	c kPa	φ deg	E MPa
1	W5	40	20	10	34	25
2	W4-5	60	21	15	36	30

Fills were defined as an heterogeneous units with thickness ranging from 0,5 m to 4,0 m and N_{SPT} values ranged from 1 to 5 blows. The geotechnical report mentioned the variability of the fill thickness and the maximum depth registered at a borehole were 4,0 m.

The first phase of the ESTIG-IPB foundations design defined pad footings (5,90x2,50x0,80 m approximately) at a depth of 4,5-5,0 m.

During the excavation works for the footings, *in situ* observations pointed out a 7,0 m thick fill and a water table at 4,0 m depth (Fig. 2). This situation led to changes in the foundation design.

Figure 2. Fill and water table detected during excavations.

Engineers decided to replace the “weak soil” below 4,0 m in the footing area by cyclopean concrete (Fig. 3) and then made pad footings of 2,0 m thickness.

Figure 3. Cyclopean concrete at the pad footing basement.

The situation described above emphasizes the relevance of the need for an engineering geological map of the county which will alert for the ground inhomogeneity, swellingness and imperviousness, and also that point data, such as boreholes, cannot provide all the indispensable information for design, namely of foundations sites.

7. CONCLUDING REMARKS

Geological and geotechnical knowledge is never enough when preventing the (negative) impacts of soil swelling and squeezing, such as cracking of building walls or pipings.

Laboratory tests are still progressing, namely the already presented above and also several others for mechanical characterization of undisturbed soils as well as gabbroic rock samples. Moreover, “Barros de Beja” (G2b unit) will require further extensive characterization.

In the future, it is intended to provide more geotechnical parameters directly assessed to improve foundation design.

Field work and geological knowledge will also progress contributing to update the geological mapping of the area and to refine local geotechnical units.

8. REFERENCES

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