Engineering geological mapping for the urban area of Salamanca (Spain)

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Abstract: The city of Salamanca (200000 inhabitants) is located in the mid-western area of Spain. Its growth in recent years has led to the need for a comprehensive knowledge of the geology and geotechnical properties of the area. The best way to achieve this objective is to develop an engineering geological map, where different factors such as geology, geomorphology, hydrogeology and geotechnical properties are present. Each factor analyzed has its own map, and the overlapping of all the contents creates the engineering geological map.

The particular geological location of the city, within the boundaries of the Tertiary Duero Basin, is reflected in the geological and geomorphologic maps, where it is possible to distinguish between the Palaeozoic domain (slates and quartzites) and the Cenozoic sandstones and clays. On the other hand, on the hydrological map we show the drainage net as well as the position of the freatic level.

Identification and characterization tests were made with more than 250 soil and rock samples: particle size distribution tests, natural moisture content, apparent/dry density, Atterberg limits determination, swelling potential index, odometer consolidation, and shear tests for soils, dry and saturated density, point load test and uniaxial compression tests for rocks.

All the information generated during this stage was introduced into a database, which was improved with the revision of geotechnical reports issued by public institutions (city and regional government), including drilling and laboratory testing.

Using this database, the different areas of Salamanca were grouped in geotechnical units, based on their physical and mechanical homogeneous behaviour.

The final cartography places all the defined units and gives their geomechanic characteristics parameters.

Résumé: La ville de Salamanca (200.000 habitants) est située au centre-ouest de l'Espagne. Pendant les dernières années elle a subit un important élargissement ce qui rend essentiel une connaissance très détaillée de la géologie et des propriétés géotechniques de la zone. La meilleure manière d'atteindre cet objectif est de créer une carte géotechnique, où seraient recueillis des facteurs tels que la géologie, la géomorphologie, l'hydrogéologie et les proprietés géotechniques. Chacune des propriétés analysées génère par elle-même un document cartographique, qui à son tour apporte de l'information à la carte géotechnique.

La localisation particulière de la ville, sur le bord du Bassin Tertiaire du Duero, se voit reflétée sur la carte géologique et aussi sur la carte géomorphique où l'on peut voir la différence entre le domaine Paléozoïque (ardoise et quartzite) et le Cénozoïque (grès et ardoise). Par ailleurs, le réseau de drainage et la position du niveau phréatique sont montrés sur la carte hydrogéologique.

On a collecté plus de 250 échantillons du sol et des roches, qui ont été essayés pour les identifier et caractériser leurs propriétés physiques et mécaniques. Toute l'information obtenue pendant cette étape a été introduite dans une banque de données qui a été améliorée avec la révision géotechnique des differents dossiers des travaux publics menés par les institutions.

Grâce à cette banque de données, on a pu diviser l'environnement urbain en plusieurs zones avec des propriétés physiques et mécaniques communes. La cartographie géotechnique finale situe les unités définies et les associe par rapport à une série de paramètres géotechniques caractéristiques.

Keywords: engineering geology maps, geology of cities, mechanical properties, geodata

INTRODUCTION

Engineering geological maps are very useful tools for storing information on terrains, and are also basic documents where their spatial distribution and mechanical properties are presented. They have been defined as a type of geological map providing a generalized representation of all those components of geological environment significance in lands-use planning and in design, construction and maintenance as applied to civil and mining engineering (IAEG, 1976). It must also provide data to help identify possible problems as well as possible solutions (Abad, Ayala & Perníallera, 1980). In Spain, these documents first appeared in the early seventies, when the Spanish Geological Survey published a series of 93 general engineering geological maps of Spain, on a 1:200.000 scale. A few years later, the same institution produced the engineering geological map of Madrid (IGME, 1976), and in the nineties, a more restricted series of 1:25.000 and 1:5000 engineering geological maps of some cities were published (León, López Santiago *et al.,* 1991a; Ponferrada, López Santiago *et al.,* 1991b, Murcia, Ayala *et al.*, 1991, etc.). In the last few years, regional governments have begun to develop their own maps, the map of Barcelona, 1:25.000 (ICC, 2000) being an example of those.

Salamanca is a city of 200000 inhabitants located in the west of Spain, latitude 40º57 N and 5º40'W. Owing to the rapid urbanisation of recent years, new lands are being used for the expansion of the city, making it necessary to have a document presenting terrain information. The authors of this article have been working on this topic over the last few years, and in this paper we present the methodology followed and some of the results obtained.

METHODOLOGY

Engineering geological mapping started with the compilation of previous information concerning topography and geology (topographic maps scale 1:25000, IGN 1995, IGN 1996, IGN 1999a and IGN 1999b; geological map of Salamanca, scale 1:50000, Martín Serrano *et al.*, 2002).

The geomorphological features of the area were analyzed using aerial photos, on a scale of 1:30000, as well as orthophotos at a scale of 1:10000. Of the first ones, an old flight was chosen because it allowed us to observe some features that in the recent flights are disguised due to the expansion of the city. These old documents are also useful for detecting the effects of human activity, when compared with the more recent aerial photos, especially on the formation of artificial ground.

The geological map was created at a scale of 1:25000. It should be noted that the difficulties in this stage of the work were due to the lack of outcrops across the city. This problem was partially overcome by visiting the foundations of new buildings, as it was the only way to map the geology in the core of the city.

The units mapped were lithological Types (LT) according to the recommendations given by the IAEG, 1981. They were defined on the basis of the previous geological information (Magna, 2002), as well as on recognition of distinctive rock and soil types.

On the hydrologic map, the superficial network of rivers and streams was represented. The depth to groundwater in different places around the study area was also included, as it was considered to be very useful information for the general purposes of this document. One thousand wells were located across the urban area, using the database of the Cuenca Hidrográfica del Duero (CHD, 2000).

Concerning the mechanical characterization, an intensive campaign of sampling was carried out. As no previous information was available, it was decided to sample all the different LTs. Samples with rock features were tested to obtain their density, uniaxial compression strength, point load index and Vp, whereas for those with soil features, moisture content, grading, plasticity, specific gravity, density, consolidation and swelling index tests, as well as direct shear tests, were done.

Old site investigation reports from public institutions were also considered as another source of information, as adopted in Howland, 2001. The Council of Salamanca, The Regional Government of Castile and Leon and the University of Salamanca provided these, but their interpretation was not always easy because in some of them the location, description or other kind of information was not clear.

As a result, huge amounts of data were compiled, and a database method of storage and access to all the information was adopted, as in (Rosenbaum & Warren, 1986, Howland, 2001 and Koukis & Sabatakakis, 2000). We decided to use the Access Microsoft Database, as it is very well known among the potential users of the document.

Analyses of the results lead us to define engineering geological types (ET) and to locate them on the engineering geological map of Salamanca.

GEOMORPHOLOGY

The city of Salamanca is located in the centre of the Meseta, a high altitude area that extends across the centre of Spain. The highest point is in the SW of the mapped zone, Los Montalvos (939m), whereas the lowest terrains (760 m) are associated with the River Tormes, close to Florida de Liébana.

There are two main geomorphologic units: the Palaeozoic zone and the Cenozoic zone. On the former, the slopes are commonly higher, with altitudes around 900 metres, whereas on the Cenozoic zone the slopes are lower and the altitudes are around 800-850 metres. The existence of cliffs associated with the erosion process of the rivers Tormes and Zurguén can be 50 meters high (Cabrerizos area).

The drainage net, is mostly controlled by the alpine fault system NE-SW, making most of the streams aligned in this direction. Also noteworthy is the fitting of the main river, the Tormes, into the Palaeozoic materials, in the W of the area. When leaving this zone, the river is again surrounded by flood plains, as it was before going entering the Palaeozoic domain.

Finally, on comparing aerial pictures from the 1960´s with the 1990 photographs, the effects of human activities are clearly visible on the regular and plain upper surface morphologies, which comprise artificial ground consisting of spoil heaps of municipal and industrial wastes.

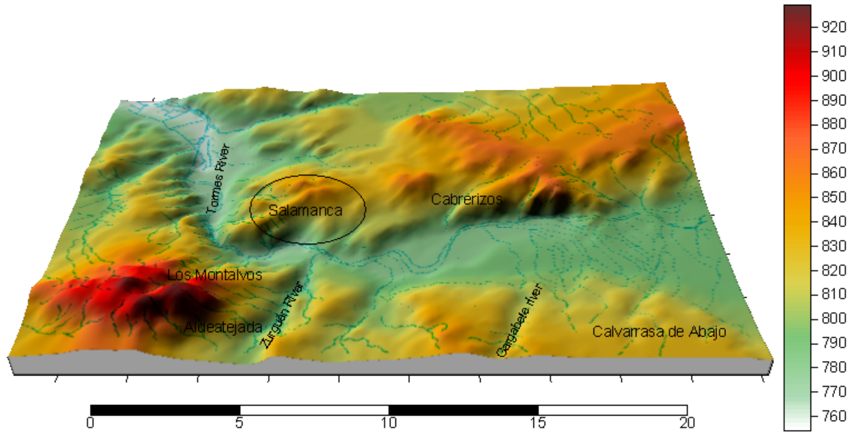


Figure 1. 3D- simulation of the topography and drainage net of Salamanca and its surrounding area. Scale bars: in km (horizontal), and in m (vertical).

GEOLOGY AND GEOTECHNICAL CHARACTERIZATION

Seven LT have been included in the geological cartography. Some of them are the same as those used on the geological map of Salamanca (Martín Serrano *et al*., 2000). Nevertheless, owing to the use of a higher scale, some new units were defined. The geology of the urban area of Salamanca is made up of Palaeozoic, located mostly in the south and west, and Tertiary materials. There are also other areas occupied by Quaternary deposits of fluvial origin.

As regards tectonics, Palaeozoic materials have been affected by the Hercynian orogeny, being folded and faulted. On the other hand, Tertiary materials appear pseudo-horizontally or weakly inclined to the NE. Nevertheless, in some locations and associated with faults, they dip more than 30º. This fact is thought to be related to the reactivation of some late-Hercynian faults.

Each LT was sampled and tested following the standard methods (AENOR, 2002 and ISRM, 1981), and their main geotechnical properties were obtained. Information provided by the revision of construction reports ceded by public institutions was also used to complete the data.

Slates from the Aldeatejada Formation LT (Precambrian-Cambrian)

These slates belonging to the Schist-Greywacke Complex (Díez Balda, 1980) constitute the oldest materials in the study area. They are pelitic and limonitic alternations presented as massive or micro banded. They have been interpreted as flysch deposits in relation to turbidity currents (Teixeira, 1969; Schermerhorn 1956; Rodríguez, 1985).

Los Montalvos Quartzites LT (Lower Ordovician)

They are quartzites originated as littoral sandy barriers, composed of fine and medium sand (Carballeira, Corrales & Pol*.*, 1980). Within this sequence it is possible to observe cross bedding structures as well as current ripples. They are located in the SW of the study area, appearing horizontally. Alternating slaty layers appear towards the roof of this unit, the proportion of slates increasing towards the upper part of the sequence.

As regards their average mechanical properties, they have a dry density of around 2.64 Mg/m^3, porosity of 2.1% and a Vp of 4080m/s. The uniaxial compression test showed that σ_c is 131MPa, with an E_t of 2287 MPa. On the point load test, the average value obtained for Is_{50} was 5.2 MPa. According to the RMR geomechanical classification (Bieniwasky, 1989), these rocks can be included in group II, but it should be noted that in some places, owing to the higher number of discontinuities, they can drop to group III.

Ordovician slates of Salamanca LT (Middle Ordovician)

These outcrop in the South and West of the studied area, overlie the previous unit. It should be noted that they are the only outcrops of Palaeozoic materials in the inner part of the city, occurring in the neighbourhood of Los Pizarrales. During the Mesozoic, these slates were intensively weathered under warm and wet climatic conditions (Molina & Blanco, 1980), creating weathering profiles. Some of them are still preserved, and some were identified across the study area. They are red and/or yellow, with their schistosity often obliterated. Profiles of 10 metres depth have been observed.

Owing to the simililarity of both slaty units, their mechanical properties were evaluated together. They had dry density average values of 2.52 Mg/cm^3, porosity of 12%and a Vp, average value of 1270 m/s was obtained. Uniaxial compression strength was measured normal to foliation, giving an average value of 71 MPa for σ_c and 1468MPa for E_t. The Is50 for point load tests made with samples broken normal to the foliation was 5 MPa. According to the RMR, both units are included in group II. A special sampling campaign was undertaken on the weathered slates. As pointed out, this process is very intensive in some places, to a weathering grade of VI, according to the Anon, 1995. Because of that, soil testing methods were adopted, thus considering them as residual soils. The results obtained classified these materials as CL or ML soils, having a moisture content of 16%, a high dry density and an index void ratio of 0.38 (Nespereira, Yenes & Blanco, 2003). On the oedometric tests they behaved as overconsolidated materials, with a

Cc of 0.16. According to the direct shear tests, c´ is 0.014 MPa and ø´ is 51º. Owing to the presence of discontinuities, anisotropy is an important feature of the Quartzite and slaty units, and this requires careful consideration when projecting construction activities on these materials.

Salamanca sandstones LT (Lower Paleocene)

These are siliciclastic sucessions deposited in braided fluvial systems (Jiménez, 1972 and Alonso, 1981) lying discordantly over the Palaeozoic basement. They underwent an intensive silicification process associated with intrasedimentary palaeosoils, especially intensive in the upper part of the unit (Blanco and Cantano, 1983). They have been dated as lower Lower Palaeocene (Blanco *et al.*, 1983), and in the city centre they are more than 50 metres thick.

They are porous rocks, with a dry density of 2.50 Mg/m3 and porosity of 19.7%. Uniaxial compression strength is lower than for the Palaeozoic materials, with σ_c of 32 MPa, whereas in the point load test, Is_{50} is 1.7 MPa. RMR was measured in several outcrops, classifying this unit within group II.

Teso Grande Arkosic LT

This unit, not included in previous geologic documents. It has been defined and mapped here for the first time (Nespereira *et al.*, 2005, *in press*). It comprises green arkosic sands with a clayey matrix and sandy clays. Some of the sandy levels present cross bedding, and the presence of a clay level reaching 5 meters depth is noteworthy. They can be considered to be soil materials, as opposed to what happened to the units on their wall and roof, which are cemented and can be considered to be rocks. The maximum depth measured was 28 meters, but in the city centre no more than 10 meters have been observed.

The results of the geotechnical characterization led us to distinguish between cohesive and granular samples. The cohesive samples are CL soils of medium to low plasticity, with clay content usually higher than 71% and a moisture content of 17%. Swelling potential index is low according to the Lambe test, and in the oedometric tests they behave as overconsolidated soils, with a Cc of 0.11. Direct shear tests carried out on saturated samples in consolidated and drained conditions showed an effective cohesion of 0.07 MPa, with an effective friction angle of 43º. On the other hand, granular samples are silty soils classified as SC, with ø ´ of 47º and nil effective cohesion.

Cabrerizos LT

This corresponds to the lithic-arkosic Cabrerizos Sandstones Formation (Jiménez, 1972; Alonso, 1981; Martín Serrano *et al.*, 2000), consisting of coarse to fine sandstones in tabular and lenticular beds, which are intercalated between yellow sandy and clayey silts. Palaeosoils and carbonated scabs are present in this unit. According to (Jiménez, 1982), they are Medium to Upper Eocene materials.

Owing to the less intensive cementation, these sandstones are not as dense as the Salamanca sandstones, and their σ_c is lower (19 MPa). It should be noted that rocks from this unit have been used as ornamental stone, being present in the construction of most of the buildings located in the historic centre of Salamanca, some of them more than five centuries old. The previous Tertiary units are usually disposed horizontally, even though a general trend to dip to the NE is observed.

Serie Roja LT

This is a Lower Miocene red deposit of sands with gravely sands in its lower part, its composition being basically clayey towards its top. In some locations this unit is completely carbonated, making the unit white (Martín Serrano *et al.*, 2000). It is an erosive unit, and because of that it may overlie any of the previous lithological units. Its thickness is very irregular, but more than 10 meters have been observed in the proximity of La Glorieta, in the north of the city.

Owing to the heterogeneity of these deposits, four different groups have been established: two of them corresponding to rocks and two corresponding to soils. Of the soil group, cohesive and granular samples have been characterized separately. The former, located in the W of the city, have been classified as CL soils, with fine contents close to 80%, low plasticity and a bulk density of 1.97 Mg/m^3. According to the Lambe tests, potential swelling is not significant, except for one of the samples located on the border with the El Viso unit, lying above the Serie Roja. They are hard soils, overconsolidated, with an effective cohesion of 0.25 MPa and an effective friction angle of 39º. The granular samples correspond to the SP or SM groups, with low plasticity and high bulk density (2.10 Mg/cm^3), as indicated by their low void ratio and high dry density. The presence of cobbles and gravels did not permit the use of direct shear test equipment, and therefore no parameters were obtained. Within the rocky samples, we distinguished between those with carbonate cementation and the remainder. The former are easily recognizable, and they present an average dry density of 2.50 Mg/cm^3, and a porosity of 29%, however, the variability of this parameter should be noted. The average uniaxial compression strength was 25 MPa, Is_{50} was 1.5 Mpa and Vp was 3246 m/s. On the uncarbonated unit, $_c$ and Is_{50} results were lower, with values of 15 and 1.15MPa.

El Viso LT

The El Viso LT was mapped as the second unit that was not included in the previous geological map of Salamanca, at a scale of 1:50000 (Martín Serrano *et al., 2000).* It consists mostly of sands and clays, but a gravel bed was also detected. Outcrops of this unit are located in the NE, always at altitudes higher than 860 meters. Geotechnical tests grouped samples as cohesive and granular. The former can be considered as MH or CL soils, with a fine content higher than 50%, and a high plasticity. Average natural moisture content was 22%, with a void ratio of 0.71. According to oedometric tests, Cc is 0.17, and the effective parameters obtained from the direct shear tests were c´

0.007 MPa and ø ´ 22º. The granular samples are usually SP or SC, with less than 20% fine particles and plasticity properties similar to the cohesive unit. The average bulk density obtained was 1.90 Mg/cm^3, and the void ratio 0.45.

Quaternary LT

Basically these occur in the areas surrounding the Tormes River, but there are other outcrops related to secondary rivers. They correspond to the actual flood plain and terrace deposits, the former composed basically of sand with scarce silty matrix, and the latter, of gravels and quartz and quartzitic sands within a clayey matrix of variable composition (Martín Serrano *et al.,* 2000). Even though the proportion of fine content varies considerably in both groups, important differences were found in the plasticity index values, being higher for the samples from the terraces. The flood plain samples present medium dry density, with a void ratio of 0.66. In both groups, the swelling potential index was not critical. Direct shear tests carried out with samples from the flood plain deposits yielded no cohesion and an effective friction angle of 34º.

Artificial or made ground deposits LT

These have been considered as materials that should be mapped and classified owing to the importance they are acquiring in the development of cities. Some of the areas that were used before as dumping places and were located far from the city are now areas into which the cities are expanding. This is very important in big cities such as Madrid, but in cities such as Salamanca these deposits do not occupy huge areas. Nevertheless, we considered it appropriate to include them in our cartography, as it has been established as a common practice (Ellison, McMillan & Lott, 2002; Forster *et al., 2004)*. The artificial deposits of Salamanca consist of spoil heaps of municipal and industrial wastes, the main outcrops being located in the W of the city. It should be mentioned that in the historic city centre it is not unusual to encounter about 2 meters depth of these materials, but in the mapping we decided to include only those deposits that were easily recognizable due to their size and ease of identification from aerial photographs. Artificial ground is not advisable terrain to work on. Nevertheless, if they were necessarily involved in proposed civil engineering works, each site would need specific research (Rosenbaum *et al.*, 2003). Their properties can vary considerably due to their different origins, compositions and history, so we felt it was useless to include any general characterization, as has been done for the natural units. However, the parameters commonly accepted for them in the reports reviewed were 1.85 Mg/cm^3 for bulk density, porosity of 40% and a friction angle of 28º with no cohesion.

Engineering Geological Types ET

According to the description and results of the testing campaign, sixteen engineering geological units (ET) were defined, considering an ET to be the largest engineering unit that can be expected to have uniform engineering design characteristics. Their characterization was the result of the statistically determined values from individual determinations of physical and mechanical properties, which are displayed in figures 2 and 3.

	ρ_d	Bulk ρ_{sat} (Mg/m^3)	SG	n (%)	UCS (MPa)	E_l (MPa)	Vp (m/s)	Is_{50} (MPa)
Quarzites	2.64 (2.67-2.58)	2,62 (2,63-2,61)	2.68 (2.68-2.69)	1.9 (2.2-1.5)	131	2287 (2425-2149)	4080 (4106-4053)	5.2 (9.9-1.2)
No weathered slates	2.52 (2.65-2.43)	2,7 (2,72-2,67)	2.81	12 (36-7)	71 (105-35)	1468 (1833-1077)	1270 (1735-922)	5.03 (5.67-4.40)
Salamanca Sandstones	2.50 (2.57-2.44)	2,23 (2,29-2,13)	2.54 (2.59-2.53)	19.7 (29.6-7.4)	32 (43-18)	3237 (4101-2251)	2608 (3848-1484)	1.7 (3.5-0.5)
Cabrerizos Sandstones	2.45 (2.62-2.24)	2,09 (2,48-1,97)	2.60 (2.67-2.52)	24.0 (41-1.8)	19 (37-6)	1737 (2932-525)	2133 (3094-1493)	1.91 (3.49-0.64)
Cemented “Serie Roja”	-	-	2.49 (2.66-2.39)	-	15 (17-13)	974 (1117-830)	1693 (1781-1604)	1.15 (2.10-0.46)
Rocky, carbonated “Serie Roja”	2.62 (2.67-2.60)	2,17 (2,3-2,1)	2.54	29 (44-19)	25 (28-17)	3007 (3888-1552)	3246 (3502-2570)	1.53 (2.66-0.27)

Figure 2. Geotechnical properties of the rocky engineering geological types.(ρ_d) real dry denstiy, (Bulk ρ_{sat}) bulk saturated density, (SG) specific gravity, (n) porosity, (UCS) uniaxial compression strength, (E_l) Linear Young modulus, (Is) point load strength index. Average (max-min).

	USCS	w (%)	% Fines	LL	PI	Gs	Bulk ρ	ρ_d	e	c´	ø ´	Cc
Weathered slates	CL-ML	16 (20-12)		32 (37-25)	11 (35-4)	2.77 (2.87-2.67)		2.00 (2.15-1.89)	0.38 (0.47-0.27)			
Cohesive arkoses	CL	17 (23-12)	71 (92-52)	43 (56-32)	18 (23-15)	2.58 (2.76-2.40)	2.12 (2.26-2.40)	1.84 (1.96-2.08)	0.32 (0.51-0.24)	0.07	43º	0.11
Granular arkoses	SC	12 (19-7)	19 (34-8)	39 (65-24)	18 (44-6)	2.61 (2.73-2.52)	2.07 (2.20-1.96)	1.85 (2.07-1.69)	0.39 (0.54-0.22)	0	47º	-
Cohesive Serie Roja	CL	16 (40-5)	78 (100-57)	45 (95-26)	21 (47-10)	2.56 (2.74-2.36)	1.97 (2.12-1.77)	1.79 (2.01-1.27)	0.46 (0.86-0.31)			0.16
Granular Serie Roja	SP-SC-SM	12 (13-11)	15 (23-1)	44 (50-39)	19 (25-13)	2.53 (2.6-2.39)	2.10	1.93	0.26			-
Cohesive Viso	MH ó CL	22 (25-16)	55 (90-37)	40 (60-28)	16 (26-7)	2.62 (2.70-2.45)	1.92 (2.02-1.71)	1.57 (1.74-1.40)	0.71 (0.92-0.51)	0.07	22º	
Granular Viso	SP ó SC	8 (13-4)	18 (26-9)	39 (41-34)	21	2.56 (2.71-2.46)	1.90	1.76	0.45	-	-	
Plastic Quaternary	GC-SC	10 (18-5)	27 (44-15)	43 (52-39)	23 (27-18)	2.59 (2.67-2.50)	1.42					
Non-Plastic Quaternary	SP-SC-CL	11 (21-3)	35 (84-3)	26 (28-24)	8 (8-7)	2.62 (2.66-2.52)	1.88 (2.00-1.65)	1.70 (1.73-1.68)	0.66 (0.72-0.60)	0	34º	

Figure 3. Geotechnical properties of the soil engineering geological types: (USCS) united soils classification system, (w) moisture content, (% fines) porcentage of particles < 0.008mm, (LL), liquid limit, (PI), plastic index, (Gs) relative density of solid particles, (Bulk ρ) bulk density, (ρ_d) dry density, (e) void ratio, (c´) effective cohesion, (ø ´) effective friction angle, (Cc) compression index. Average (máx-min).

HYDROGEOLOGY

The climatic conditions of Salamanca present an average annual temperature of 12.8ºC, associated with warm temperate conditions. Nevertheless, if thermal oscillations are considered, which are closer to 20ºC, they can be seen to be moderate to extreme. Therefore, the climate is more continental in the pattern of weather, with long and cold winters and a short transition to the summer, which is typically short but very hot. Precipitation is low, being approximately 400 mm/y (Sánchez, Tomás, & Pablo, 1997).

The actual hydrographic network forms part of the Duero Basin, the river Tormes, and the Zurguén and Gargabete streams being the only ones with a constant flow of water. Owing to the weather conditions, most of the streams only carry water in the rainiest months of the year.

We evaluated the position of the phreatic surface across the mapped area. To do this we obtained information from all the wells available across the area, from the Duero Basin Hydrographic Service, a public institution. These data were filtered in order to eliminate the oldest and less accurate data. The database obtained can be used to locate the phreatic level related to either sea level or to the ground surface. We decided to present the data referenced to the ground surface, considering this way of representation more useful for the general purposes required by the potential users of the engineering geological map. This consideration is in agreement with Van Royy and Stiff, 2001, who pointed out that the results of the investigations should be reported as simply as possible for the benefit of those not familiar with the technical terms of the earth and engineering sciences. Nevertheless, the treatment used will also permit the phreatic isolines to be drawn if required.

Finally, the main aquifers in the area were identified as the sands or silty sands of fluvial origin located close to the River Tormes bed. Palaeozoic formations are typically impermeable, but in some places, and associated with faults, spas appear. An example of this can be observed in the Los Montalvos, where a caudal of 3 l/s (IGME, 1982) is obtained. On the other hand, the Tertiary materials, which are commonly very well cemented, can't be considered as aquifers.

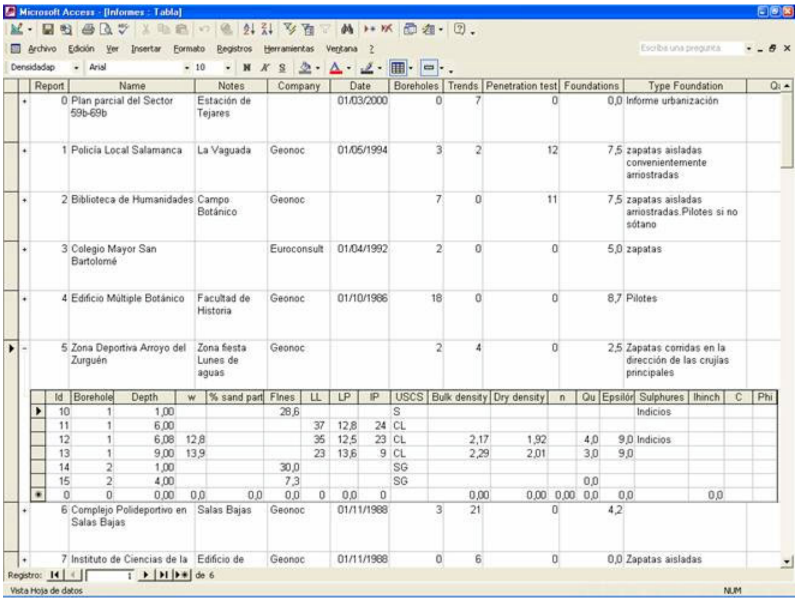
On the artificial ground placed in the urban area, according to the information obtained from reports ceded by several public institutions, perched phreatic surfaces are found.

GEOTECHNICAL DATABASE

While field and testing works were carried out, all the information was digitized and stored in a geotechnical database. We used Microsoft ®Access© software, as it is one of the speediest databases and we considered that most potential users would be familiar with it (figure 4).

The first information included was the location of the sample and each of the boreholes, including the ones that were obtained from the reports of the public institutions. For the laboratory tests, an identity number was assigned to each sample, as was their lithological type and the rest of the information obtained. The creation of a series of correlations between the different tables provided a means of rapid and selective data retrieval. We also included pictures of the samples collected, which will be very helpful for the unification of the nomenclature used for the Salamanca terrains.

This database is an open document, meaning that more information can be added for the users. Currently it is made up of the following tables: samples, laboratory results, wells, location of the reports, samples and boreholes from the reports.



Report	Name	Notes	Company	Date	Boreholes	Trends	Penetration test	Foundations	Type Foundation
0	Plan parcial del Sector 59b-69b	Estación de Tejares		01/03/2000	0	7	0	0,0	Informe urbanización
1	Policía Local Salamanca	La Vaguada	Geonoc	01/05/1994	3	2	12	7,5	zapatas aisladas convenientemente arriostradas
2	Biblioteca de Humanidades	Campo Botánico	Geonoc		7	0	11	7,5	zapatas aisladas arriostradas.Pilotes si no sótano
3	Colegio Mayor San Bartolomé		Euroconsult	01/04/1992	2	0	0	5,0	zapatas
4	Edificio Múltiple Botánico	Facultad de Historia	Geonoc	01/10/1986	18	0	0	8,7	Pilotes
5	Zona Deportiva Arroyo del Zurguén	Zona fiesta Lunes de aguas	Geonoc		2	4	0	2,5	Zapatas corridas en la dirección de las crujías principales
6	Complejo Polideportivo en Salas Bajas	Salas Bajas	Geonoc	01/11/1988	3	21	0	4,2	
7	Instituto de Ciencias de la	Edificio de	Geonoc	01/11/1988	0	6	0	0,0	Zapatas aisladas

Id	Borehole	Depth	w	% sand part	Fines	LL	LP	IP	USCS	Bulk density	Dry density	n	Qu	Epsilón	Sulphures	Ihinch	C	Phi
10	1	1,00			28,6				S						Indicios			
11	1	6,00				37	12,8	24	CL									
12	1	6,08	12,8			35	12,5	23	CL	2,17	1,92		4,0	9,0	Indicios			
13	1	9,00	13,9			23	13,6	9	CL	2,29	2,01		3,0	9,0				
14	2	1,00			30,0				SG									
15	2	4,00			7,3				SG				0,0					
0	0	0,00	0,0	0,0	0,0	0	0,0	0		0,00	0,00	0,00	0,0	0,0		0,0		

Figure 4. View of two of the related tables created with the reports information.

CARTOGRAPHY

Engineering geological mapping is used to zone the area according to the geographical distribution of the engineering geological types (ET) defined. However, we decided not to represent all sixteen ET described, because it would result in an incomprehensible cartographic document, which would be very confusing to read. Another reason behind the adoption of this limited method of representation resulted from the fact that the geological origin of such deposits as Teso Grande Arkosic Unit or Serie Roja, which exhibit several lateral lithological changes, makes it extremely difficult to detect exactly the boundary of each ET in the area.

Units represented on the engineering geological map (figure 5) are:

U-1 Aldeatejada and unweathered Ordovician slates
U-2: Quartzites
U-3: Weathered Ordovician slates
U-4: Salamanca and Cabrerizos sandstones
U-5: Teso Grande Arkosic Unit
U-6: Rock materials from the Serie Roja (carbonated and not carbonated)
U-7: Serie Roja, soils.
U-8: Viso
U-9: Plastic Quaternary deposits
U-10: No plastic Quaternary deposits
U-11: Artificial and man made ground.

With the adoption of the previous units, simplification of the geotechnical properties was undertaken. However, this simplification can be overcome by consulting in the database for the location of the samples and boreholes.

CONCLUSIONS

Expansion of the urban area of Salamanca requires the generation of geological and geotechnical information at a large scale. The engineering geological map is the document where all this information should be represented in order to enable better development of the expansion of the city. In Salamanca, sixteen have been identified within ten lithological Types. However, their complete representation was not possible due to varying geologic characteristics, so some of them were displayed together as single cartographic units.

The data used in the identification and definition of the engineering geological Types came from geotechnical reports provided by public institutions and also from our own fieldwork and experimentation. First, two main problems can were found: differing terms were used for the descriptions of similar types, and second, the lack of accuracy in the location of some boreholes was of concern. Nevertheless, the large-scale geological map created proved very useful in overcoming these problems in most of the cases. As a result, we consider that revision of geotechnical reports constitutes a useful tool for engineering geological mapping.

An open-database, with information concerning boreholes, water table location, laboratory test data, sample locations and photographs of the samples, should be added to the engineering geological maps. Such a database will permit a rapid evaluation of the geological and geotechnical conditions of the ground, allowing the design of a more efficient geotechnical investigations for each construction project.

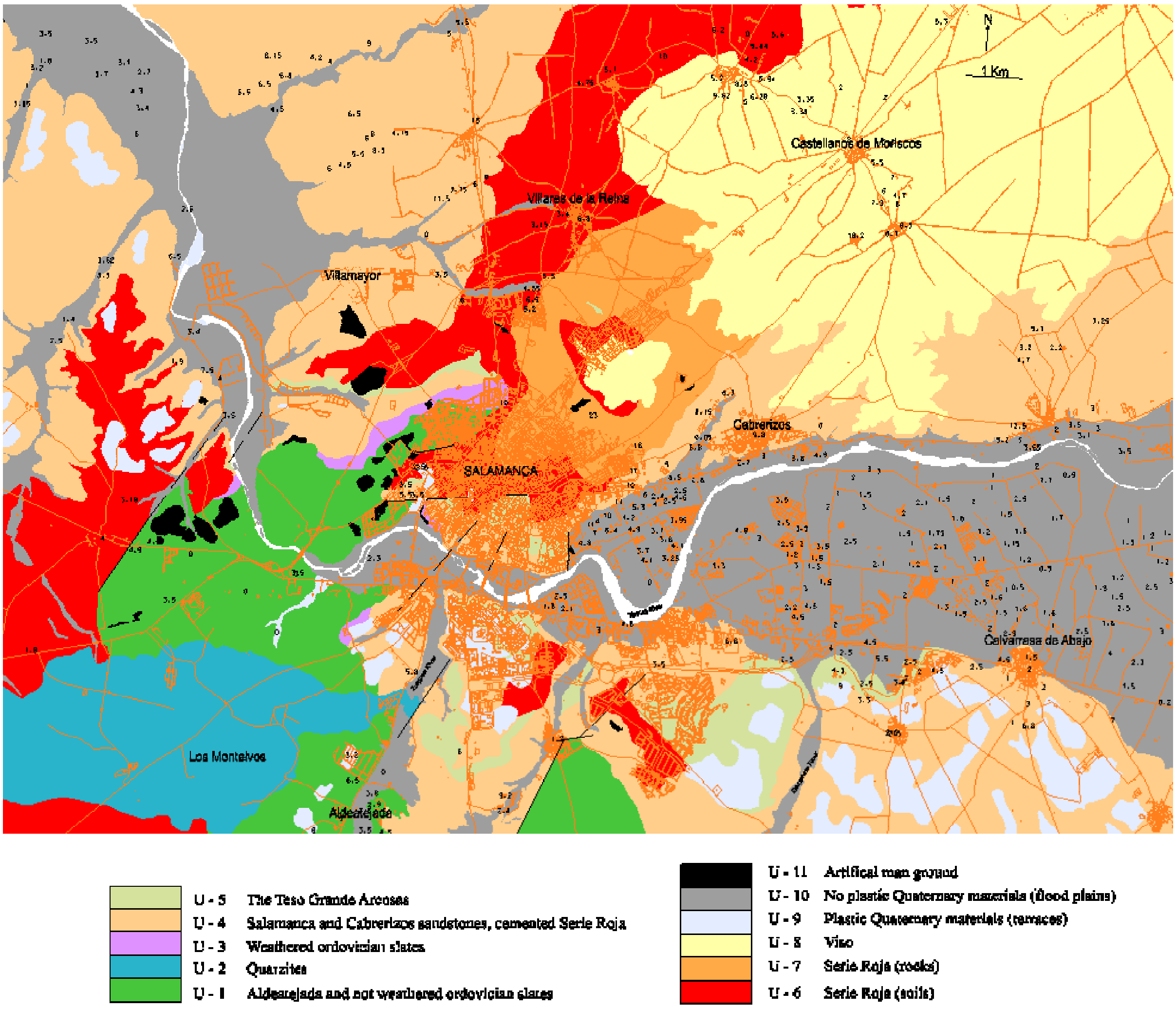


Figure 5. Engineering geological map for the urban area of Salamanca. Numbers represent the position of the water table from the surface.

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