Geotechnical problems during the soil boring in the Seville underground (Spain)

Des problèmes géotechniques pendant la construction du Metro de Séville (Espagne)

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ABSTRACT

In this paper the geomechanical aspects of the Sevilla City (South of Spain) and their general geotechnical problems are summarized. In the Sevilla ground an important thickness of quaternary sediments are detected, with the predominium of gravel and sandy gravel soils. The next substratum is performed by marly clays (Guadalquivir Blue clays), the excavations are conditioned by the presence of a very high phreatic level, due to influence of the Guadalquivir River (one of the most important rivers of the Iberian Peninsula) and the depth of the marly clays. For this motive the tunnel line affect, mainly, to the gravel sediments. Special attention to the zone excavated by a E. P. B. shield (LOVAT kind) are carried out: Two parallel tubes, excavated with a T. B. M. with Ø 6,20 m. The presence of near structures and two parking lots on the tunnels, introduce any special conditions. Several ground treatments have developed for the protection of these structures and the actual channel of the Guadalquivir River. The paper describes the special works carried out and, also, the controls of movements developed. The results of the auscultation principally) and the special events are summarized.

RÉSUMÉ

Cet article aborde la mécanique des sols de la ville de Séville (sud de l'Espagne) et leurs problèmes géotechniques généraux. Dans le sol de Séville, il a été détecté une épaisseur importante de sédiments quaternaires, où prédominent les graviers et sables grossiers. La couche suivante est composée d'argiles marneuses (argiles bleues du Guadalquivir). Le creusement est conditionné par la présence d'une nappe phréatique très élevée due à l'influence du fleuve Guadalquivir (l'un des plus grands de la péninsule Ibérique) et par la profondeur des argiles marneuses. Pour cette raison, le tracé du tunnel traverse principalement les graviers. Une attention toute particulière est portée à la zone creusée avec un E.P.B. du type LOVAT : deux tubes parallèles creusés avec un tunnelier de Ø 6,20 m. La présence de structures proches et de deux parkings au-dessus des tunnels a conditionné les travaux. Plusieurs traitements de sols ont été réalisés pour la protection de ces structures et du canal actuel du Guadalquivir. L'article décrit les travaux spéciaux réalisés ainsi que les contrôles de mouvements mis en oeuvre. Les résultats de l'auscultation (principalement) et les événements particuliers survenus sont reportés.

Keywords: Soil properties, underground construction, tunnel excavation, soil improvement.

1 INTRODUCTION

The Metro of Seville (Southern Spain) will soon inaugurate its Line 1, that crosses the city from the West to the East, from El Aljarafe to the Pablo de Olavide University, crossing the River Guadalquivir, Barrio de los Remedios, Canal de Alfonso XIII, Avenida de San Fernando, etc, with its train sheds by the Su Eminencia road.

These works are an Administrative Concession of the Regional Government of Andalucia (Government of Andalucia, through its Public Entity Ferrocarriles de la Junta de Andalucia) a set of companies (SACYR, DRAGADOS and GEA-21, mainly acting on the installations, and operation by other specialised companies) and this has been performed over the last five years, until building a line approximately 21 Km long. About 35% of this route runs on the surface (at the ends of the line) and about another third has been installed in artificial tunnel (between continuous screen walls of reinforced concrete at the entry and exit of the historic centre of Seville and some important crossing points, under prefabricated vaults and frames (in the Western zone of Seville, El Aljarafe). The rest runs through true tunnels, of which about 250 m (for double track) have been built in El Aljarafe using what is called the "Traditional Madrid Method"; another 60 m (single track tunnels) have been executed in gravel under major "umbrellas" and under the Santa Justa railway; and the rest (about 8 Km) are parallel tunnels for single track, of Ø 6.10 m, executed with E.P.B. type tunnelling machine (by the firm LOVAT, with 40,000 KN of maximum thrust and 600 KN x m of maximum torsion torque). The last two tunnels cross the centre of the city, under the Avenida de República Argentina, Plaza de Cuba, Canal de Alfonso XIII, Puerta de Jerez and Avenida de San Fernando.

All the stations (except for some surface ones on the outskirts of the city) have been executed under the shelter of continuous screen walls, with buttresses at diverse levels and countervault to resist the sub-pressure.

2 THE SEVILLE SOILS

The geotechnical properties of the ground in Seville have been the subject of diverse studies since the 1970s, when the first studies and experimental works commenced. Later, in the 80s, several kilometres of artificial tunnel were built (now partially taken advantage of) and three underground stations in the centre of Seville, that have now been abandoned (Uriel and Oteo, 1976 and 1979; Oteo and others, 1986; Oteo, Rein and Sola, 1987). Subsequently, on drafting the new Tender Project of the Concession and during construction of Line 1 (21st Century).

In the last three phases, not only were test bores and subsequent laboratory tests carried out (identification, state,

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deformability, resistance to pickaxe cutting and residual, etc.) but the following were also performed:

- "In situ" testing, both of the quaternary as well as the tertiary, by loading plates at different depths and pressiometric trials.
- Diverse auscultations of the works executed, to measure: a) Total pressures on the tunnel linings and continuous screen walls. b) Screen movements. c) Embankment subsidence. d) Surface and deep subsidence caused by drilling the experimental tunnel and the definitive tunnels. e) Movements of multiple buildings, etc.

This has allowed a fairly likely geotechnical image of the ground types around the city of Seville to be obtained. The simple stratigraphic section, for the centre of Seville, is as follows:

- A top clay-sand covering. This material is "hard" in El Aljarafe (west zone) and outside the urban zone (east zone). This material is generally tertiary in these zones, except, except for some thicknesses of anthropic landfill. However, in the centre of Seville (River Guadalquivir valley) that covering is "loose" and consists of anthropic filling (about 4-8 m thick), under which there are quaternary deposits formed by layers of loose sand and soft to medium clay.
- The Pleistocene gravel, which is present throughout the River Guadalquivir Valley, on which the present city centre of Seville stands, and its extension where the River Guadalquivir and its Canal de Alfonso XIII run. The city centre was filled in little by little during the Middle Ages, so the average surface level of Seville is now approximately + 6.0. The gravel also appears toward level -13.0 to -15.0, usually with sizes ranging from 20 to 80 mm, with some interspaced sandy layers. In some areas of the city, there are cemented levels of gravel, that provide the gravel extraordinary cohesion, in thicknesses of 40-100 cm. We have taken some samples of this cemented material and its shear strength may be 25 MPa. Generally, the S.P.T. values in the gravel ranges from 25 g/30 cm to rejection.
- The substrate is formed by what are called the "blue marls of the Guadalquivir", which are neither marl nor blue. These are fissurated Miocene clays, with 12-15% of CaO, medium to high plasticity (liquid limit of 45 to 65), somewhat expansive (above all on the surface), with variable shear strength between 0.3 and 1.4 MPa in the city centre (Uriel and Oteo, 1976; Oteo and Sola, 1993). Hereinafter we shall call them "marly" clays.

Figure 1 shows an average stratigraphic section of the centre of Seville (Puerta de Jerez zone), while Figure 2 contains a more general profile that affects the western and central zones of the city, indicating the construction systems used.

Fig. 3 shows the standard granulometry of that ground (upper clayey mud, gravel and "marl" and Figure 4 shows the distribution of shear strengths of the "marls" (Uriel and Oteo, 1976).

Table no. 1 shows a series of general geotechnical properties of these materials.

The general water table is about 4-6 m deep, under the filled in area.

In the first part of the works, the shoring at the head of the cast in situ walls was provided by prefabricated beams. However, the change was soon made to the "in situ" slab construction method, (or filling of expansion material between screen walls and beams), as that system was not adequate to decrease movements at the head.

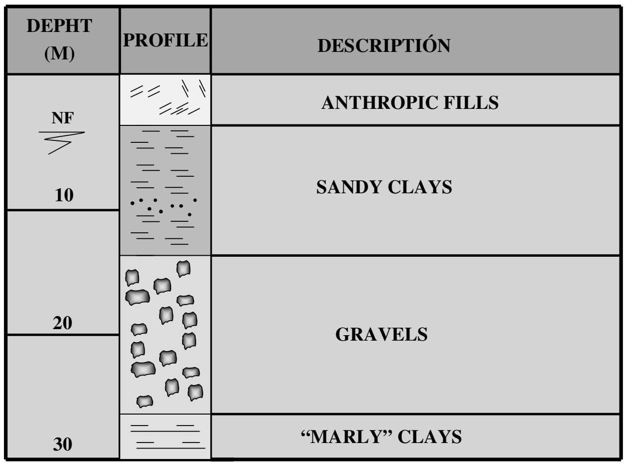

Figure 1. Stratigraphic profile at Seville old town.

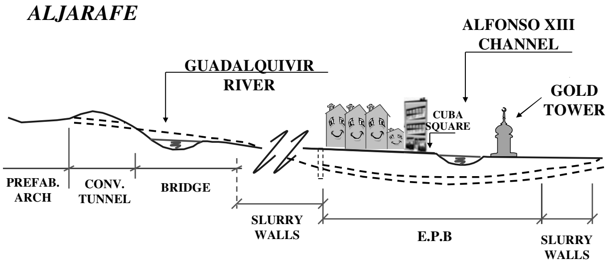

Figure 2. Schematic surfial profile north zone and old town of Seville.

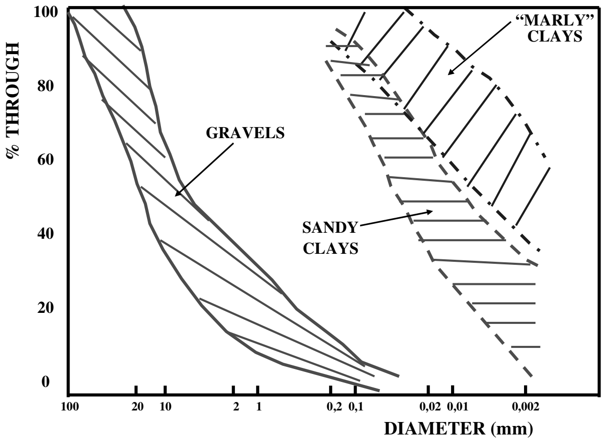

Figure 3. Seville soils granulometry.

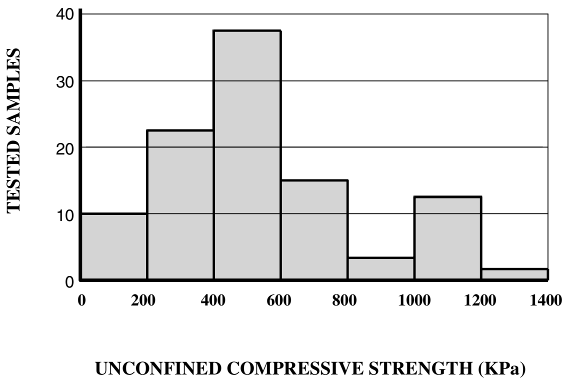

Figure 4. Shear strength of the "marly" clays.

Table 1. Geotechnical properties of The Seville soils (Oteo, 1994)

Property	Material			
	Sandy clays		Gravel	"Marly" clays
	Plastic fraction	Non plastic		
% < # nº 10	100	90-100	15-44	100
% < # nº 200	83-96	12-82	1-8	91-100
% < 0,002 mm	9-36	7	-	37-66
Liquid limit	30-60	N.P.	-	40-70
Plastic limit	15-35	N.P.	-	25-45
% CO_2	-		5-9**	10-15
Natural water content (%)	15-40		5-10	20-30
Dry bulk density (g/cm^3)	1.2-2.0 (1.6-1.8)*		2.1	1.4-1.8 (1.5-1.7)*
Compression index, C_C	0.070-0.300		-	0.055-0.150***
Swelling index, C_S	0.010-0.080		-	0.036-0.120
Unconf. Compres. strength (MPa)	0.050-0.3	0.017-0.090	-	0.46 y 1.0-1.2
Effective cohesion C' (KPa)	11	0	0	12-30
Effective Internal friction, φ' (º)	27.5	35.0	35-45	25-34
Deform. Modulus. Plate tests (MPa)	-		260-540	Horiz. 120-570 Vert. 50-310
Deform. Modulus. Triaxial tests. MPa)	-		-	Drained 56 Non-drained 35
Edometric modulus. Discharge field test (MPa)	-		-	44-190
Deform. Modulus for subsidence analysis. (MPa)				32-45

(*) (1.6-1.8) = Greater accumulation intervals. (***) Laboratory test affected by sampling.
(**) Cemented samples: 20-25%

Table 2. Geotechnical parameters assumed for the continuous wall analyses. (Oteo, 2003)

LITHOLOGY	ELASTIC ANALYSIS		BULK DENSITY (T/m^3)	SHEAR STRENGTH	
	DEFORM. MODULUS (T/m^2)	POISSON'S RATIO		COHESSION (T/m^2)	INT. FRICTION (º)
ANTR. FILLS	1.000	0,30	2,00	0,5	25
SANDY SOILS	3.000	0,30	2,10	1,0	32
MUD AND CLAYS	2.500	0,35	2,00	2,0	28
GRAVEL SOILS	6.000	0,30	2,10	0,0	37
"MARLY" CLAYS	8.500	0,35	2,05	4,0	28

3 CONSTRUCTIVE METHODS AT DOWN TOWN

For construction systems have been used (Fig. 2):

- That known as "cut and cover" or "Milan method", with continuous screen walls of reinforced concrete, with a top slab and intermediate piers. The floor slab generally rested on the gravel (in order not to have a deep Metro), resistant to sub-pressure. However, in order to allow excavation without bailing problems, the side screens were taken far enough to "embed" themselves in the "blue marls", by about 1.5-2.0 m, in order to cut off short term filtration.
- Classical structures over the River Guadalquivir.
- A Canadian E.P.B. tunnel boring machine, with a diameter of about 6 m. Two parallel tunnels were made, with a minimum separation - between axes – of two diameters. The drilling was mainly through gravel, touching on or partially penetrating the "marls" at times.
- Tunnel excavated in complete section in gravel under the shelter of double umbrella (vault and side walls), crowns of jet-grouting and reinforced injections (with complementary injection of silicates in some cases). This system was used to pass under the San Bernardo railway tunnel.

In the case of continuous screens, the calculation parameters used are those of Table no. 2, that have provided good results as shown by the instrumentation performed.

4 GEOTECHNICAL PROBLEMS IN THE CITY CENTRE ZONE

These problems were:

- Stability of the excavations, for which adequate bentonite content was studied and excess concrete in the screen walls (gravel) studied; the appropriate mixes of foam at the tunnel boring machine face (MENDAÑA et al, 2008), the convenient systems to drill the gravel umbrellas in the tunnel under San Bernardo (jet injection at low pressure), etc.
- Possible affectation of the general water table (defined by the River Guadalquivir), for which "gateways" were made in the screen wall zones to allow the underground flow through and/or create a "reservoir" effect, thus with a rise on one side and settling on the other side of that barrier.
- Movements caused by the excavations (open cast and underground) and their possible repercussion on buildings or utilities (collectors) nearby. Due to the urban environment, this problem was the one most attention was given to, for which we formed a special monitoring unit (SEVICOT) in charge, among other matters, of the instrumentation throughout the site and its computer monitoring. Figure 5 shows an example of that instrumentation, both with distance markers and rod extensometers installed on the ground, as well as rules installed on the building facades. Jet-grouting protection barriers were used to protect the buildings (such as that in Fig. 6). On commencing the works, the surface settling on

the axis of the first tunnel was large (Figure 7). But, once injection of the gap with mortar was fine tuned, the subsidence was small (2nd tunnel, Fig. 7).

– Passing the Canal de Alfonso XIII (an artificial arm of the River Guadalquivir) was performed with a tunnel boring machine, under a protection on the bed of the River. (Fig. 7).

A series of soil treatments were performed to resolve some of these issues, which are the main objective of this paper and they will be expounded in another future work.

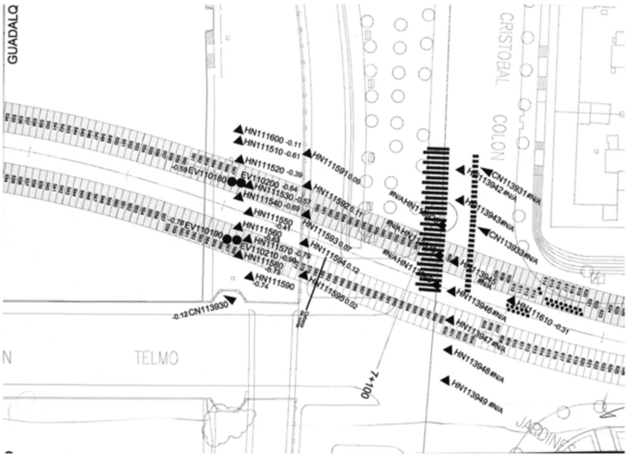

Figure 5. Surface soil and building auscultation. Example, near of the tunnels.

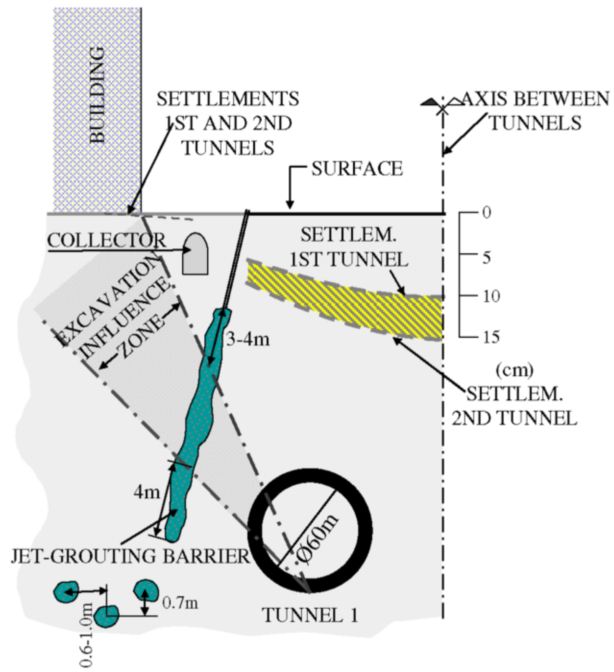

Figure 6. Building settlements at Republica Argentina Ave.

5 CONCLUSIONS

– In simple terms, this paper presents the geotechnical properties of the ground under the city of Seville, Spain, concluded on the basis of the research and auscultations performed for the works of Seville Metro.

– The geotechnical parameters used to calculate the continuous walls have been distinguished in order to use them in calculation programs with springs representing the reaction of the ground.

– The main problems it was necessary to resolve during construction of Line 1 of the Metro are described.

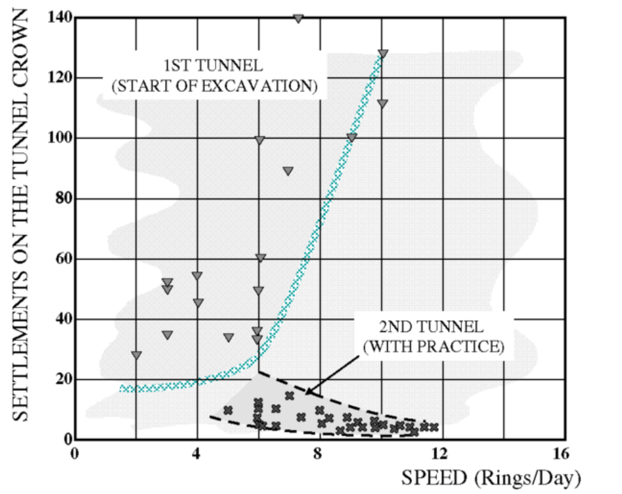

Figure. 7. Settlements originated by tunnel excavation at Republica Argentina Ave.

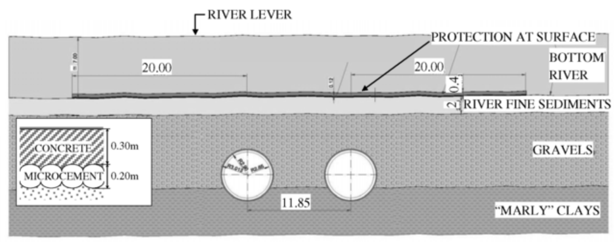

Figure 8. Tunnel excavation under the Alfonso XIII channel (Guadalquivir River).

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