Design of piles – Outline of the Spanish practice

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ABSTRACT

This paper describes the current situation in Spain relative to the design of piles. There are two main factors that govern the situation: the fact that there is not a single authority on geotechnical issues in Spain so there are three normative geotechnical documents (one for buildings, one for roads and one for ports) and there has not been an official delivery of the Spanish National Annex to EC7 so EC7 is scarcely used in geotechnical design in Spain.

1. REGIONAL GEOLOGY

1.1. Iberian Peninsula

The Iberian Peninsula includes Spain, Portugal and Andorra. The peninsula contains rocks from every age from Ediacaran to Holocene, and almost every kind of rock is represented. World class mineral deposits can also be found there.

The core of the Iberian Peninsula consists of a Hercynian cratonic block known as the Iberian Massif. On the northeast this is bounded by The Pyrenean fold belt, and on the southeast it is bounded by the Betic Foldchain. These twofold chains are part of the Alpine belt. To the west, the peninsula is delimited by the continental boundary formed by the opening of the Atlantic Ocean. The Hercynian Foldbelt is mostly buried by Mesozoic and Cenozoic cover rocks to the east, but nevertheless outcrops through the Iberian Chain and the Catalonian Coastal Ranges.

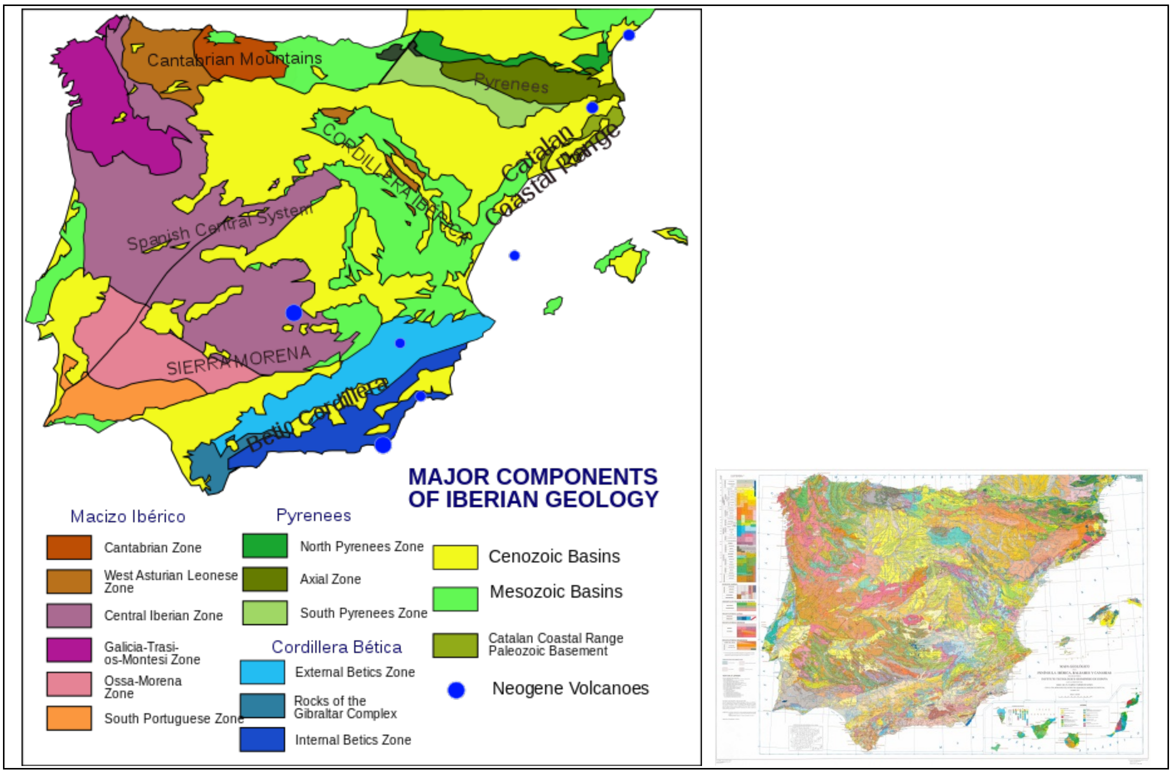

Figure 1: The Geology of Iberian Peninsula (from Wikipedia)

More information on the Spanish Geology can be found in IGME website (www.igme.es), the website of the Geological and Minning Spanish Institute.

1.2. Canary Islands

Seven islands of volcanic origin in the Atlantic Ocean.

2. SOIL INVESTIGATION

Soil investigation is composed of site exploration and laboratory tests. Site exploration is performed basically by boreholes and penetrometers. Large constructions involve usually also geophysical exploration. Boreholes are performed mainly by rotary drilling with coring bit. Most used drilling diameter is 86 mm. The most used in situ test is Standard Penetration Test (SPT) with automatic hammer inside boreholes. Dynamic continuous penetrometers are used also as routine exploration. DPSH type is the most extended. Static penetrometers are used in soft soils and piezocone CPTU has become usual. Pressiometers and dilatometers are used in large projects.

Push tube samplers are used at the bottom of boreholes, usually driven by percussion. Drilling cores are routinely stored in cardboard or plastic boxes. Laboratory testing include: basic soil identifications tests, unconfined compression, direct shear, triaxial, oedometer and other rock tests.

Geotechnical codes define intensity and type of investigation depending on work category and geotechnical conditions.

3. PILING TECHNOLOGY & CLASSIFICATION

Driven piles and cast-in-situ piles are used in deep foundations. Most of driven piles are precast reinforced concrete piles, square section from 20 cm to 40 cm side, with mechanical splices each 12 m length or less. Driven prestressed concrete piles are less used. There are only three piling contractors driving concrete piles in Spain. They do the whole process: precast, driving using their own hydraulic hammers, trimming and, many times, design and testing. Driven steel tube piles are used by other companies in small docks inside ports.

Augercast piles (or CFA) are the most common cast-in-situ piles for diameters below 1 m. Large piles are bored usually with help of steel casings and slurry fluids. Diameters over 2 m and lengths greater than 50 m are rare.

Some of the larger piling contractors are associated in the technical association AETESS (www.aetess.com). Their website contains interesting documents on the state of the art of piling in Spain.

4. NATIONAL DOCUMENTS

There are three main geotechnical codes or guides:

- Guía de Cimentaciones en Obras de Carreteras. Dirección General de Carreteras del Ministerio de Fomento (2003). [Foundations Guide for Road Works] This guide complies recommendations for foundations in the field of road constructions, delivered by the Ministry of Public Works in 2003.
- Recomendaciones de Obras Marítimas y Portuarias (ROM 0.5-05), Puertos del Estado, Ministerio de Fomento (2005). This document compiles geotechnical recommendations for maritime and port constructions, delivered by the Ministry of Public Works in 2005.
- Código Técnico de la Edificación (CTE- Building Technical Code), Documento Básico SE-C: Seguridad Estructural, Cimientos. Mandatory for building construction. Approved by Ministry of Housing in 2006.

On other hand, the Spanish National Annex to EC7 was approved by the Spanish AENOR corresponding committee (AEN/CTN 140/SC7) in 2014 and it is scheduled to be officially delivered by AENOR (the Spanish Normalization Body) in the first half of 2016.

5. DESIGN METHOD ACCORDING TO THE PRINCIPLES OF EUROCODE 7

5.1. General principles

There is not a single authority on geotechnical issues in Spain so, as a consequence of that, there are three normative geotechnical documents (one for buildings, one for roads and one for ports), as listed in Chapter 4.

The building code (CTE) is the only one which is mandatory, while the other two documents ("Guía de cimentaciones" for roads and ROM 0.5-05 for ports) are only recommendations or guides. However, the last two documents become mandatory, in many occasions, mainly in projects of constructions for the Spanish Estate Government.

CTE is the only of the three codes which includes the partial factor method. The two others were published before EC7 was approved so they use the global safety factor method. In this respect, the National Annex, approved by AENOR in 2014 but still not published, bridges this gap and assigns partial factors for all kinds of geotechnical activities. The calibration of such partial factors was done to achieve the same level of safety than obtained with the use of the different methods currently used in Spain.

5.2. Definitions and symbols

Definitions and symbols used in the text are explained after its reference.

5.3. ULS Design based on soil investigation test results

5.3.1. Introduction

This is the more common method used in Spain which implies, as a previous step, the determination of the representative values of the geotechnical strength parameters (mainly the ones derived from Mohr-Coulomb failure criterion).

5.3.2. Axial compression of a single pile

a.- Design based on Spanish geotechnical documents

The following table contains the expressions set in the three geotechnical documents listed above to calculate the unit base resistance (q_p) and the unit shaft friction (q_f).

Table 1: Expressions to calculate the unit base resistance and shaft friction according to the Spanish geotechnical documents

Geotechnical document	Unit base resistance	Unit shaft friction
ROM 0.5-05 (Recommendations for Maritime Works)	*Granular Soils (drained behaviour)* $q_p = 3.\sigma'_{vp}.N_q.f_D$ ≤ 20 MPa being: $N_q = \frac{1+sen\phi}{1-sen\phi}.e^{\pi.tg\phi}$ $f_D = 1 - \frac{D}{3} > 0,7$ $\sigma'_{vp} = \begin{cases} \gamma'.L \rightarrow (H \leq L_{crítica}) \\ \gamma'.(H + L_{crítica}) \rightarrow (H > L_{crítica}) \end{cases}$ $L_{crítica} = D.\sqrt{N_q}$ Fine Soils (undrained behaviour) $q_p = (9 - 3.D).c_u > 6.c_u$	*Granular Soils (drained behaviour)* $q_f = \sigma'_v.K.f.tg\phi$ being: K = 0,75 for driven piles K = 0,5 for cast in-situ piles f = 1 for cast in-situ piles f = 1 for driven piles f = 0,9 for steel piles Fine Soils (undrained behaviour) $q_f = \frac{100.c_u}{100 + c_u}$
Guía de Cimentaciones en Obras de Carretera (Foundations Guide for Road Works)	$q_p = N^*_q.\sigma'_{v0} + N^*_c.c'$ being:	*Granular and fine soils in drained conditions* $q_f = c + K_0.tg\delta.\sigma'_v$ ≤ 90 kPa If no information is available on K_0 and/or δ => $K_0.tg\,\delta\,\sigma_v' = 0,3$

Geotechnical document	Unit base resistance	Unit shaft friction
	$N_q^* = 1{,}5 . \frac{1+sen\phi}{1-sen\phi} . e^{\pi . tg\phi} . f_D$ $N_c^* = \frac{N_q - 1}{tg\phi}$ $f_D = 1 - \frac{D}{3} \geq \frac{2}{3}$ $\sigma'_{v0} \leq \sigma'_{v0,20m}$ at 20 m deep Fine Soils (undrained behaviour) $N_c^* = 9\, f_D$	Fine Soils (undrained behaviour) $q_f = \frac{100 . c_u}{100 + c_u}$ ≤ 70 kPa
Código Técnico de la Edificación (CTE- Building Technical Code)	*Granular and fine soils in drained conditions* $q_p = f_p . \sigma'_{vp} . N_q^*$ ≤ 20 MPa being: f_p = 3 for driven piles f_p = 2,5 for cast in-situ piles $N_q^* = \frac{1+sen\phi}{1-sen\phi} . e^{\pi . tg\phi}$ *Fine Soils (undrained behaviour)* $q_p = N_p . c_u$ $N_p = 9$	*Granular and fine soils in drained conditions* $q_f = \sigma'_v . k_f . f . tg\phi$ ≤ 120 kPa being: k_f = 1 for driven piles k_f = 0,75 for cast in-situ piles f = 1 for cast in-situ piles f = 0,9 for driven piles f = 0,8 for steel piles *Fine Soils (undrained behaviour)* $q_f = \frac{100 . c_u}{100 + c_u}$ ≤ 100 kPa

As it can be seen, there are some differences in the three documents that, in many occasions, lead to significant differences in the pile design.

Besides those expressions collected above, there are other expressions to design pile foundations based on the results of SPT and static and dynamic penetrometers

The global safety factors that design must fulfil are collected in the following tables.

Table 2: Global safety factors used to design pile foundations by analytical expressions according to the Spanish geotechnical documents

Geotechnical document	Load combinations		
	quasi-permanent	characteristic	accidental
ROM 0.5-05 (Recommendations for Maritime Works)	2,5	2,2	2,0
Guía de Cimentaciones en Obras de Carretera (Foundations Guide for Road Works)	3,0	2,6	2,2
Código Técnico de la Edificación (CTE- Building Technical Code)	3,0	3,0	2,0

Table 3: Global safety factors used to design pile foundations by different calculation methods for the characteristic load combination according to the Spanish geotechnical documents

Calculation Method	**ROM 0.5-05** **(Recommendations for Maritime Works)**	**Guía de Cimentaciones en Obras de Carretera** **(Foundations Guide for Road Works)**
Based on SPT	2,2	2,6
Based on static penetrometer	1,8	2,2
Based on dynamic penetrometer	2,3	3,0
Based on analytical expressions	2,2	2,6

As it can be seen the global safety factors to be used with those in-situ test results are lower (for the static penetrometer), equal (for SPT test) and higher (for dynamic penetrometer) compared with those one valid for the analytical expressions.

b.- Spanish National Annex

Spain has chosen Design Approach 2 to design all the geotechnical constructions except for slope stability calculations that shall be done with Design Approach 3.

The following table collects the partial factors included in National Annex to design piles, according to the different structures involved and the different type of piles:

Table 4: Values of partial factors to be used in pile design according the Spanish National Annex

Resistance	**Symbol**	**Value**			
		Building structures	**Other structures**		
			Driven piles	**Bored piles**	**CFA piles**
Base	γ_b	1,55	1,25	1,35	1,45
Shaft (compression)	γ_s	1,55	1,05	1,10	1,15
Total/combined (compression)	γ_t	1,40	1,15	1,25	1,30
Shaft (tension)	$\gamma_{s;t}$	1,80	1,05	1,10	1,15

When analytical models are applied, it is necessary to use an additional model factor with a value of 1,40.

5.3.3. Axial tension of a single pile

The Spanish documents set that the axial tension of a single pile is equal to its shaft friction plus its own weight. On other hand, the experience shows that compression shaft friction is higher than tension shaft friction, so the following expression is given:

$$T = W_p + \alpha \cdot q_s$$

Where T is the axial tension of a single pile, W_p is the pile weight, q_s is the compression shaft resistance and α is a factor between 0,5 and 0,7 to take into account the difference between compression and tension shaft friction.

5.3.4. Lateral loading of a single pile

The well-known abacuses by Broms are proposed as the model to calculate the lateral resistance of piles in cohesive and cohesionless soils.

5.3.5. Specific issues

There are not special calculation models different from the usual ones found in literature to take into the following specific issues: Negative skin friction, group effect, cyclic loading and seismic design.

5.3.6. Problems not covered by National Annexes and future developments

There is not a list of problems expected to be included in the National Annexes or in future developments of EC-7.

5.4. SLS design

This issue rarely governs the pile design is Spain.
Besides, the settlement of a single pile is recommended to be calculated based on an empirical data: the settlement of a single pile subjected to its service load is usually around 1% of its diameter if the serviceability load situation is quite far from the maximum bearing capacity.

5.5. Design based on load tests

This way of designing piles is very scarcely used in Spain.

5.6. Design based on experience

As a normal rule, piles are not designed based on experience in Spain but, of course, experience is used to set the representative values of the different geotechnical parameters that define the mechanical behaviour of the different materials involved in calculations.

5.7. Structural safety

The structural pile design must satisfy the so called "structural limit" ("tope structural", in Spanish) that can be defined as the maximum average compression stress that can be applied to a pile for the quasi-permanent load combination.
The values of such "structural limit" are collected in the following table for different pile types.

Table 5: Values of the "pile structural limit" according to the Spanish geotechnical documents for different pile types

Pile type	Structural limit (MPa)
Withdrawable tube driven and cast in-situ piles	6,0
Bored and cast in-situ piles: Dry technique Bored and cast in-situ piles: Using bentonite slurry	5,0
Rotary auger bored piles, with control of parameters	4,5
Rotary auger bored piles, without control of parameters	4,0

6. QUALITY CONTROL, MONITORING AND TESTING PRACTICE

Pile design quality control depends on the type of owner of the project. In private buildings, design quality control is done by consultants working for assurance companies, always conservative. In public works, projects are bided with less QC and there is nearly always much litigation and changes in the foundation design at the beginning of the construction.
Architect is the only responsible for building construction in Spain, so usually there is not any geotechnical engineer supervising pile construction, only in big building projects. Monitoring of pile rigs with onboard electronic instruments is possible in newer rigs, but usually nobody is interested in it, nor piling contractors nor architects or engineers supervising, by different reasons. Many times, the only QC practice is the moulding of concrete cylinders. In big projects, the piling contractor uses to do QC checklist reports and test the slurry fluid.
Non destructive or integrity testing of piles is common in Spain. Geotechnical codes recommend them in many cases. Big piles are routinely tested with cross-hole sonic logging or sonic transparency inside embedded tubes (CSL). Piles in building foundations are tested sometimes by sonic or echo test method with a handheld hammer. There are few specialized consultants and many general testing laboratories doing integrity testing of piles.
Load test of piles is not common in Spain. Perhaps the reason is that many piles are bearing on rock. Just some static load tests of piles in compression in projects with high loads. Dynamic load test in driven piles are routinely done by drivers, only a few by specialized independent consultants. Dynamic load test is not standard in bored piles.

7. PARTICULAR NATIONAL EXPERIENCES AND DATABASES

There are not public databases that can be consulted.

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