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Geotechnical characterization of residual clays in urban subsoil: Gijón city case study (NW Spain)

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Abstract: In this work, the geotechnical characterization and behavior of clays as a product of carbonates decalcification is presented, using the town of Gijón (NW Spain) as a case study. The subsoil of this town is composed of an important clay layer originated by chemical alteration of limestones and dolomites. The studies made on a wide number of compiled samples allow us to establish the current geotechnical properties of the clays. Also, the aptitude of the materials in relationship to shallow foundations has been studied. The results confirm that these cohesive materials, the common laying level for building foundations in the urban area, exhibit mechanical deficiencies such as reduced bearing capacity, and the appearance of remarkable consolidation settlements.

Keywords: geotechnical properties, residual clays, shallow foundations, Spain.

Gijón (population: 273,931), one of the most populated and greater urban areas in northern Spain, is mainly seated on a wide layer of clays originated by calcareous rocks alteration (Fig. 1a). This fact causes special geotechnical problems related to the deficiencies that these materials have caused in civil engineering works and urban construction.

This study tries to define geotechnical properties of these deposits in relation to its origin and geological evolution, and also evaluates their particular geotechnical problems. In addition, its behaviour is analyzed with respect to implantation of shallow foundations, paying special attention to parameters such as its bearing capacity and the primary consolidation settlements consequence of loading application.

Geological setting

Important accumulations of residual clays, owing to processes of meteoric alteration (Fig. 1a), are located in the southern part of Gijón, whereas in the north edge appears an extensive sandy deposit of marine origin (Gutiérrez-Claverol *et al.*, 2002). In both cases, these sediments are placed over bedrock constituted by calcareous Jurassic rocks, known as Gijón Formation (Fig. 1b). The clay layer shows important variations of thickness (from 0 to 14 m), due to sedimentological factors and late tectonic activity. Thus, it is frequent to recognize faults crossing the Jurassic basin that have exerted a control over rocks elimination or preservation, causing its absence in the elevated blocks, which were submitted to erosive processes.

The Gijón Fm, whose age extends from Upper Triassic to Lower Jurassic, is subdivided in three lithostratigraphic members:

Lower member: limy mudstone and dolomites.

Middle member: breccias with limy-marly rocks interbedded.

Upper member: alternation of dark grey limy mudstone, carbonate breccias, oolitic limestones and bioclastic limestones.

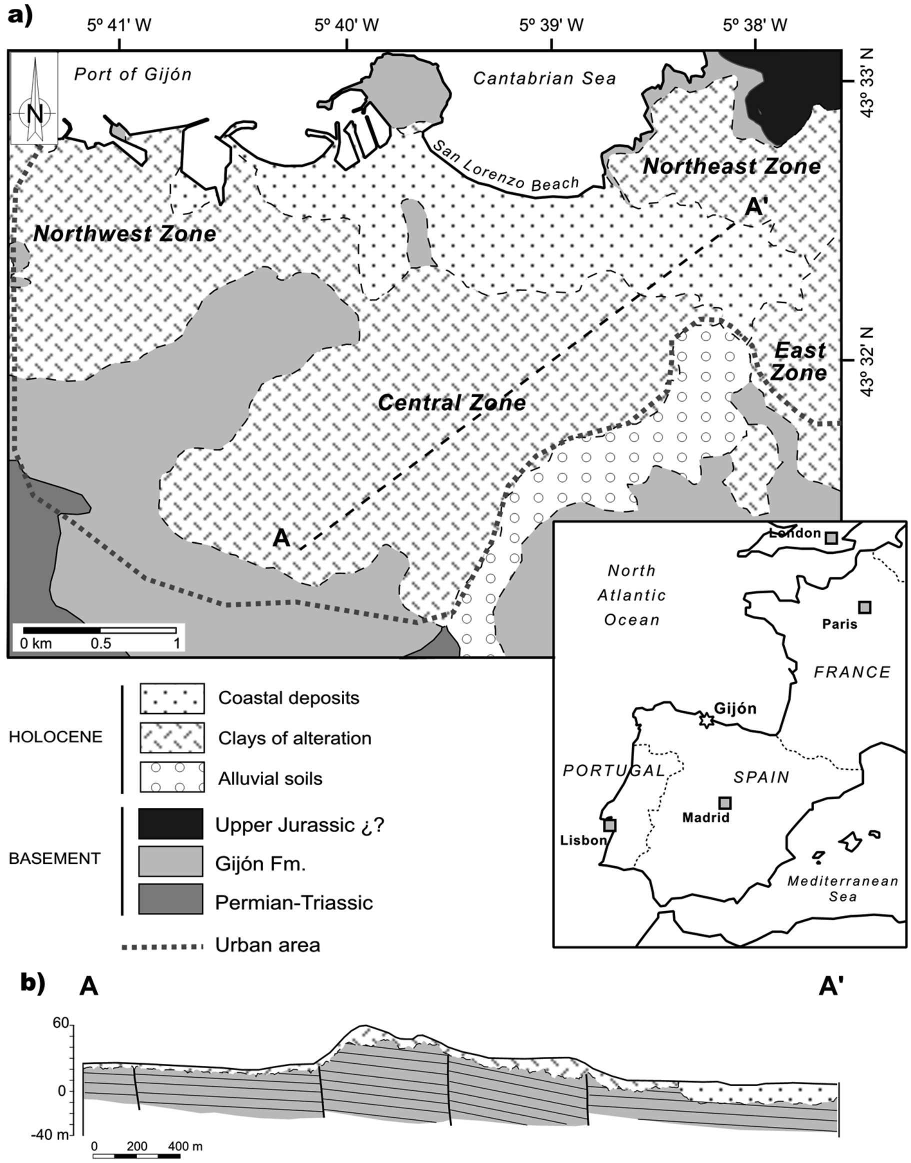

Figure 1. (a) Geological scheme of the town of Gijón, (b) simplified geotechnical profile with increased vertical scale.

Origin of the residual clays

The Gijón Fm has undergone a gradual alteration, essentially a chemical one, giving rise to a superficial and unconsolidated formation of 'alterite' type (Pedraza, 1996). The hydro-geological conditions into the basin (fresh and marine waters) as well as climatic factors have favoured the carbonate dissolution, causing the decalcification of the hard substrate.

This intense process, developed *in situ*, has produced a very thick eluvial soil, conformed to a large extent by brown-yellowish or greyish clays and limy clays. Occasionally fragments of angular dolomite and/or limestone appear at the bottom, indicating an alteration transit profile. Towards the top zone of the eluvial deposit, accompanying to the clay, there is a detritic fraction composed of gravels, sands and sandstone pebbles. Its origin seems to be related to gravitational contributions (erosive dismantling) of nearby conglomerate outcrops.

Mineralogically, illite is the major component in the clayey fraction, with a lower proportion of kaolinite (<15%) and chlorite (<9%). Occasionally, iron colorations and goethite and hematite nodules have also been observed. In some areas, samples containing illite-esmectite and interstratified quartz have been analyzed.

Chemically, the prominence of Al_2O_2, SiO_2 and other cations (Fe, Mg and K) evidences the abundance of

PARAMETER	Gr (%)	Gr (%)	Ag (%)	Af (%)	L+Ar (%)	w (%)	γ (g/cm^3)	MO (%)	$CO_3^=$ (%)	$SO_4^=$ (%)	W_L (%)	W_P (%)	IP
N	12	24	33	38	46	63	45	24	11	8	76	76	76
Maximum value	18	21	32.51	30.76	88.21	52	2.31	8.40	76	-	120	43	77
Minimum value	0.10	0.40	1	1	17	13	1.48	0.20	7.90	-	24	13	3
$\bar{x}$	5.20	6.60	7.60	11.50	74.20	26.70	1.94	3.20	33.4	Neg.	56	27	29

Table 1. Summary of identification tests for the residual clays. Gr: gravel; gr: fine gravel; Ag: thick sand; Af: fine sand; L: silt; Ar: clay; w: natural humidity; : apparent density; MO: organic matter; $CO_3^=$: carbonates; $SO_4^=$: sulphates; W_L, W_P, IP: Atterberg limits; N: number of samples; $\bar{\chi}$: arithmetic average.

illite (hydrated aluminum silicate with K, Mg and Fe) and quartz.

These clays crop out in almost the whole city, although they reach its bigger development at the NW and central zones. These deposits, that cover and refill an irregular paleo-relief, have thicknesses that fluctuate frequently (0-14 m), even at the scale of a building block. At the coastal edge, the clayey sediments are located at depth, beneath an important accumulation of marine sands and limes.

Geotechnical properties of clays

The geotechnical characterization of these clayey materials was carried out from the compilation of 97 sample tests and analyses, included in studies and technical reports previously realized in different points of the city. The obtained results have been synthesized in table 1.

In general, these clays show typical geotechnical parameters of cohesive soils, being clear their high plasticity. The liquid limit (W_L) shows an average value of 56, having overcome a W_L = 50 the 53% of the samples, while 21% of the whole also a W_L = 75. The plasticity index (IP) fluctuates widely, placing the average value in 29. In any case, 49% of the samples reached a value superior to 25, whereas 12% of the whole overcame an IP = 50. With increasing depth of sampling, the values of both parameters decrease, which is probably caused by compaction processes. The USCS classification allows differentiating several

PARAM.	USCS	N	Maximum value	Minimum value	$\bar{x}$	S	C_V
q_u (kPa)	CH	8	189.14	45.08	91.14	0.49	0.53
	CL	15	312.62	79.38	146.02	0.67	0.45
	ML	4	245	88.2	167.58	0.66	0.39
	SC-SM	2	357.7	178.36	268.52	1.29	0.47
Ø (º)	CH	12	30	4	14	9.68	0.69
	CL	15	32	2	15	8.94	0.6
	ML	5	25	7	18	8.44	0.47
	SC-SM	3	40	10	28	15.7	0.56
c (kPa)	CH	12	124.46	16.66	62.72	0.32	0.5
	CL	15	115.64	4.9	59.78	0.32	0.52
	ML	5	67.62	20.58	46.06	0.22	0.47
	SC-SM	3	69.58	20.58	43.12	0.25	0.57
Cc	CH	5	0.719	0.2	0.356	0.21	0.59
	CL	7	0.361	0.124	0.233	0.08	0.34
	ML	2	0.278	0.209	0.244	0.05	0.2

Table 2. Mechanical tests results for the clays. q_u: uniaxial compression; Ø: friction angle; c: cohesion; Cc: compression index; N: number of samples; $\bar{\chi}$: arithmetic average; S: standard deviation; C_V: coefficient of variation.

types: medium and high plasticity clays and silts: CH (43%), CL (38%), MH (12%) and ML (6%).

The results obtained in the mechanical tests have been summarized in table 2. The uniaxial compression tests, altogether, indicate a low resistance (<300 kPa), that increases with the grain size and is specially reduced in the most plastic clays (CH). The friction angle also grows as the granulometry is thicker, whereas the cohesion, in inverse trend, decreases. The values of the compression index obtained in the edometric tests allow us to classify CL and ML soils as moderately compressible ones ($0.1 < C_c < 0.3$); the CH clays present a very high compressibility ($C_c > 0.3$).

Geotechnical behaviour: shallow foundations

In order to quantitatively evaluate the geotechnical behaviour of these sediments in the urban area, it has been estimated their load capacity for shallow foundations. The methodology begins with the selection of several samples whose geotechnical parameters are considered to be representative of the different USCS clays and limes. With this archetypical data, the applied criteria of calculation are the ones whose validity has been sufficiently proved in analogous load conditions to the common ones in the study environment. In any case, it would be impossible to simulate the casuisty of real possibilities that could be given, so the study pursues to establish the major behaviour guidelines.

As shallow foundation structures, rigid pads of reinforced concrete have been chosen, square in plan (B = L) and subjected to centric vertical loading, which are frequently used as support of inner pillars in building construction, normally beneath the disposition of braced elements. The foundation level has been located at different depths, making possible to simulate conditions of embedding equivalent to the construction of a) 1 basement floor (–4 m), b) 2 underground floors (–7 m), and c) absence of underground floor (–1.5 m).

With regard to the geological environment, it is considered a single continuous and homogenous geological level. Its thickness is sufficiently high to assume that the tension bulb should not concern significantly the carbonates substratum, this assumption being in agreement with the thicknesses recorded before for these clays.

Due to the clayey nature of the deposit, the load conditions judged as appropriate for the calculation correspond to the situation of rapid load without drainage, in saturated soil. It involves the habitually most unfavourable situation with non-existence of pore pressure dissipation according to the usual speed for load application in building foundations, so that the numerical estimation is achieved using total pressures (effectives and hydrostatics). The piezometric level is located in surface.

The geotechnical parameters of the soil selected for the calculations are exposed in table 3. They have been obtained in laboratory test programs adjusted in conditions of total saturation soil ($S_r = 1$). The values of undrained cohesion (c_u) have been obtained from uniaxial compression tests and undrained direct shear tests. In all the cases these cohesive materials present an average consistency ($50 < q_u < 200$ kPa).

Once defined the necessary information of departure and load conditions under the hypothesis of general shear failure, it follows the selection of the analytical procedure to calculate the ultimate bearing capacity (Das, 1999). For this study case it has been chosen a polynomial expression (Brinch-Hansen, 1970), formulation spread over generalization of Terzaghi's classic approximation. It includes, therefore, the factors of bearing capacity related to cohesion (N_c) and overload (N_q) used by Prandtl, and N recommended by Hansen. Regarding the coefficients of alteration, simplifications have been done not considering an inclination of the terrain neither of the foundation basis, and being scorned, likewise, the positive but variable effect of the embedding depth, attaining greater safety. In order to obtain the admissible pressure related

USCS	PARAMETERS					
	γ_d (kN/m^3)	γ_{sat} (kN/m^3)	n (%)	e	w (%)	c_u (kPa)
CH	18.12	21.38	33	0.49	18	71.05
CL	16.88	20.57	38	0.6	21.86	69.09
MH	16.67	20.38	38	0.62	22.25	52.28
ML	16.36	20.23	40	0.65	23.65	50.96

Table 3. Soils parameters used in the calculation. γ_d: dry specific gravity; γ_{sat}: vacuum saturated specific gravity; n: porosity; e: void ratio; w: humidity; c_u: undrained cohesion.

Depth of laying	q_h (kPa)				q_{adm} (kPa)			
	USCS				USCS			
	CH	CL	MH	ML	CH	CL	MH	ML
Superficial (-1,5 m)	470.4	460.6	352.8	343	176.4	176.4	137.2	137.2
1 floor (-4 m)	519.4	509.6	401.8	392	235.2	225.4	186.2	186.2
2 floors (-7 m)	588	568.4	460.6	460.6	294	284.2	254.8	245

Table 4. Ultimate load (q_h) and allowable pressures (q_{adm}) obtained for the different USCS deposits and depths of foundation.

to collapse, the factor of safety used (F) in Spain for permanent structures, i.e. 3, has been employed.

Interpretation of results

From the defined formulation and the exposed data, table 4 shows the pressure values obtained for different USCS classification clays depending on the depths of support.

The values of allowable bearing capacity have been calculated with respect to failure. It would be essential to verify the safety against excessive settlement magnitude and its compatibility with the structure, to establish the final working pressure. It is appraised that the pressures obtained are low, especially for superficial supports, within a small range of values (130-300 kPa), being slightly minor the bearing capacity in the limy sediments than in the clayey ones in conditions of equality of embedding. On the other hand, inside the same terrain (silt or clay) scarce differences exist depending on the plasticity, so values are very close. In any case, and provided that dependence on the absolute dimensions of foundations does not exist, the level of support takes special interest, with an evident increase of resistance in depth of up to 30% if an underground floor is executed compared to the most superficial foundation.

Taking care of absolute consolidation settlements, the compression indexes (C_c) recorded are elevated, especially in CH clays, so it is expected that the admissible loads in these materials could restrict even more the bearing capacity values reviewed before. Besides, the fluctuations of the clayey package thickness induce a potential risk for differential seats, fact that must be anticipated in the geotechnical design of foundations; this is also one of the reasons why the contact location with bedrock, in depth, turns out to be necessary defined in all the prospective campaigns beneath the support points. The limited general resistance involves in many cases the adoption of rigid slabs and even, in singular buildings, the search of support has been undertaken at depth on the rocky basement, with piles or micropiles. In cases with particularly deficient subsoil, works of improvement by means of terrain substitution with selected material have been made.

Conclusions

The subsoil of Gijón is conformed by an important clayey deposit (thickness: 0-14 m) produced from chemical alteration of Jurassic carbonates. In these clays, variations in their geotechnical properties have been detected depending on their geographical location, which indicates a differentiated petrologic origin. This evidence can be correlated with the geological mapping of different lithologies that conforms the basement (Gijón Fm). The clays originated from limy mudstones and dolomites (lower member) have minor apparent density, natural humidity and organic matter content and, generally, also lower plasticity. The residues of bioclastic limestones, breccias and limy-marly rocks (middle and upper members) show a significantly high plasticity, predominating CH clays (>75 %). In a general way, all of these deposits present a limited resistance to compressive stress (<0.3 MPa) and a high compressibility, deficiencies that are accentuated in those sediments with higher plasticity.

In what concerns to their mechanical behaviour, taking as practical example the structural foundations, it could be demonstrated a low bearing capacity for superficial supports (<300 kPa). Also, edometric tests allow us to define their high susceptibility to generate important consolidation settlements. On the other hand, the stated variations in the clayey level thickness favour the appearance of differential seats. These deficiencies can be minimized increasing the depth of laying or the structural element proportions, meaning to bring the load system near to a compensated foundation. In some cases, the construction of rigid reinforced concrete slabs is needed. And in especially problematic situations it is common the execution of deep solutions with piles or micropiles, as well as the replacement of the subsoil with selected material.

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