Geotechnical conditions in the Campana- Zárate industrial complex, Argentina

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Geotechnical conditions in the Campana-Zárate industrial complex, Argentina

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Abstract. The cities of Campana and Zárate, located on the right margin of the Paraná de las Palmas River, in Argentina, host a major logistic and industrial complex formed by a petrochemical pole, ports, power plants and various industrial facilities. This papers presents a brief geotechnical setting of the region and a description of the construction techniques empoyed for foundations, retaining structures, and slopes.

Keywords. Pampeano, Postpampeano, Puelchense, Campana, Zárate.

1. Introduction

The cities of Campana (34° 9'47.84"S - 58°57'33.38"W) and Zárate (34° 5'43.08"S - 59° 1'28.07"W) are located on Buenos Aires province, Republic of Argentina. Campana, founded in 1875, and Zárate, founded on 1854, are strategically located on a neuralgic Mercosur route, close to the Zárate-Brazo Largo Bridge which conveys traffic from Brazil and Uruguay through Argentina and into Chilean ports. Both cities grew as a major logistic and industrial complex formed by a petrochemical pole, ports, power plants and various industrial facilities (chemical, cement, beer, siderurgic, automotive and alimentary). Figure 1 shows an aerial view of the region.

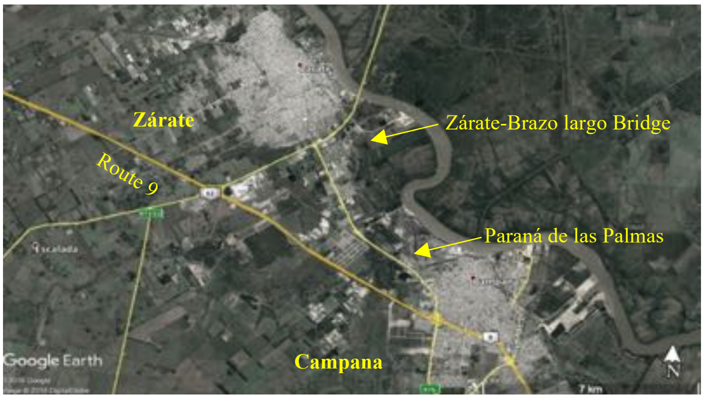

Figure 1. Aerial view of Campana-Zárate region (Google Earth).

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2. Geological setting

2.1. Regional geology & hidrogeology

The *Chaco-Pampeano Plains* is a geological quaternary loess and loess-loam unit covering an extension of 1.000.000km^2 in North-East Argentina, extensively described in a large number of publications (e.g. [1][2][3][7][7][11][12]). On the right margin of the Paraná de Las Palmas river, this formation was partially eroded and covered by a thick deposit of Holocene sandy silts and clays of the Postpampeano formation, also extensively studied (e.g. [2][9][10][11][13][15]). Close to the river, the erosion totally removed the Pampeano soils, Pospampeano soft soils overlaying dense Pliocene Puelchense sands [2][3][11].

The Paraná River Delta region is a huge mosaic of wetlands. It covers over 17,500 km^2 on the final 330 km of the Lower Paraná River basin, between 60°39´W, 32°6S south of Diamante city, and 58°30´W, 34°30´S, next to Buenos Aires city. This delta is formed in a complex littoral developed mainly during the last 6000 years although some former processes took place during the Late Pleistocene and early Holocene periods [7].

3. Geotechnical setting

3.1. Sources of information

This paper summarizes results obtained in a large number of ground investigation programs in both cities over the last 20 years. The sources of information are field tests including SPT, CPT, DPSH, test pits, geophysical probing; and a thorough procedure for lab testing which is common practice in Argentina, where all samples recovered in SPT boreholes are tested for moisture content and classification tests. Triaxial, oedometer tests are also routinely performed on undisturbed Shelby or Denison samples.

3.2. Main geotechnical units

Main geotechnical units are:

a) *Postpampeano formation (PP)*: Fine soft soils including low and high plasticity clays and low plasticity silts, normally consolidated to lightly overconsolidated by ageing, with sandy lenses.

b) *Pampeano formation (PA)*: Fine, stiff to hard low and medium plasticity silts and clays, overconsolidated by dessication and erratically cemented by calcium carbonates and other precipitates.

c) *Puelchense formation (PU)*: Fine to medium dense and very dense clean quarzitic uniform sands.

The thickness of each unit is highly variable depending on the distance to the coastline (Figure 2 [11]). Above the hill (elev. +25 masl), Pampeano formation is 20|40 m thick. Towards the coastline, elev. +4|5 masl, Postpampeano formation is found with variable thickness from zero to 35 m, while Pampeano soils disappears gradually. A steep cliff is formed where elevation changes from ~+5 masl at the coastline to ~+15 masl where the cities are located. Figures 3 and 4 show aerial views and the location of the reference boreholes employed (Table 1), while Figure 5 shows typical SPT profiles.

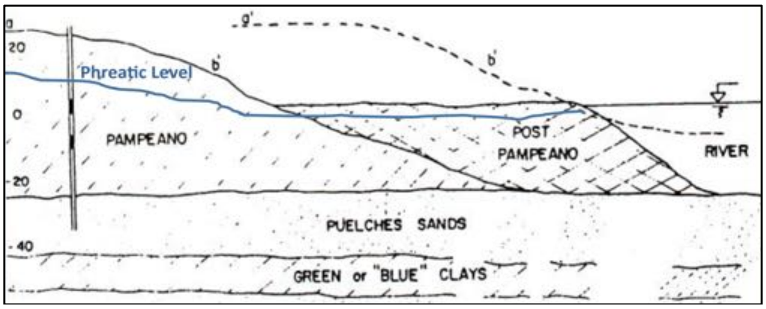


Figure 2. Typical stratigraphic profile [9].

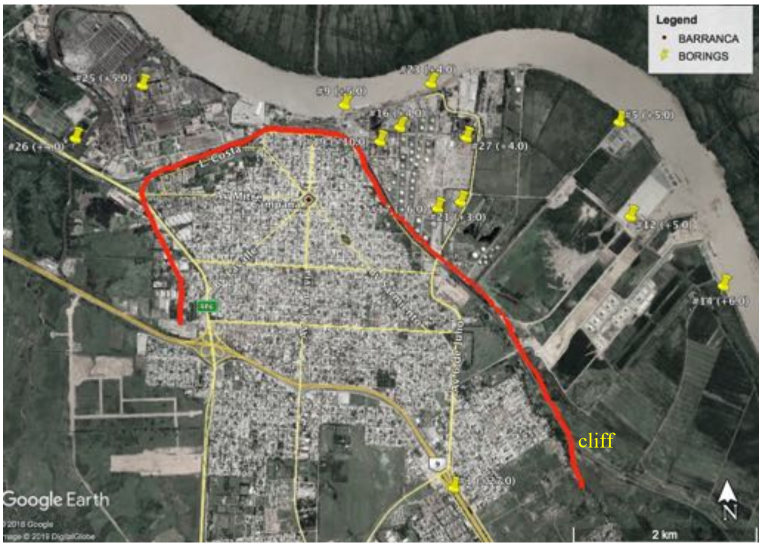


Figure 3. Cliff and SPT borings in Campana city.

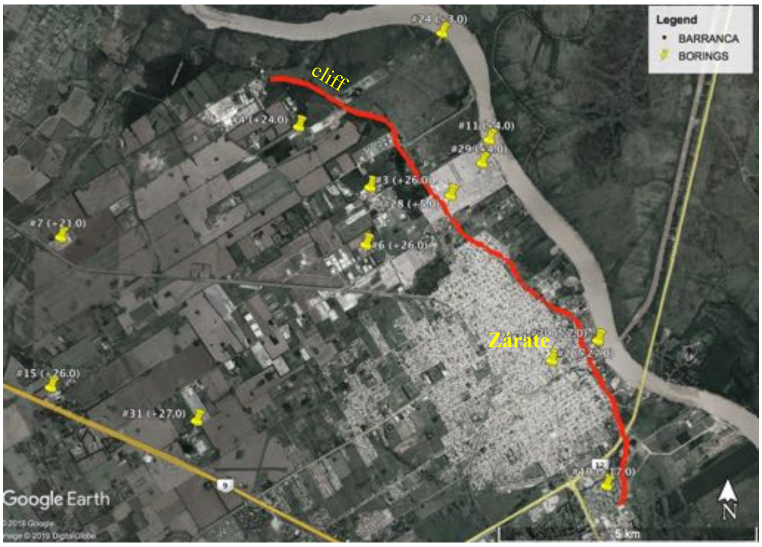
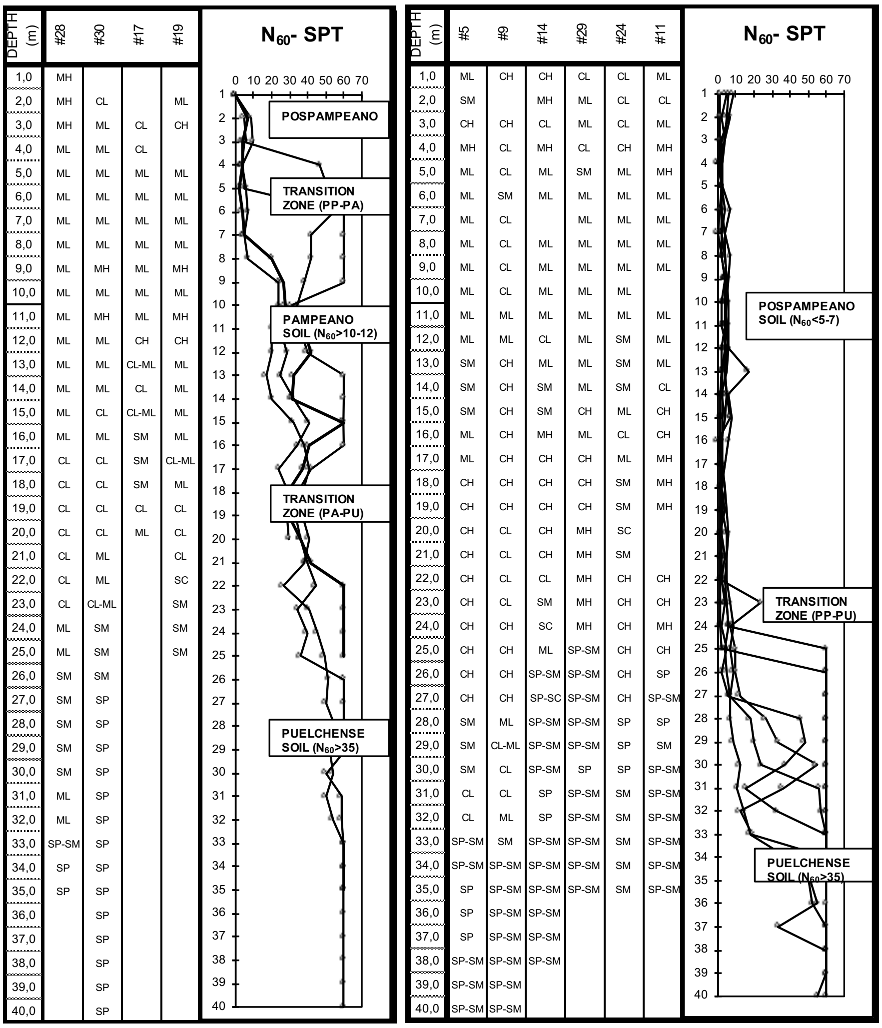


Figure 4. SPT borings on Zárate city.

Table 1. Reference boreholes in Campana & Zárate.

SITE:	CAMPANA	GEOTECHNICAL UNITS			SITE:	ZÁRATE	GEOTECHNICAL UNITS		
# SPT	**GPS**	**PP (m)**	**PA (m)**	**PU (m)**	**# SPT**	**GPS**	**PP (m)**	**PA (m)**	**PU (m)**
#1 (10m)	34°11'34.24"S- 58°56'36.64"W	-	+27.0	-	#2 (8m)	34° 6'8.56"S- 59° 1'21.42"W	-	+27.0	-
#5 (40m)	34° 9'27.30"S- 58°55'21.18"W	+5.0	-	-28.0	#3 (8m)	34° 4'20.87"S- 59° 3'40.30"W	-	+26.0	-
#9 (40m)	34° 9'18.49"S- 58°57'18.27"W	+5.0	-	-29.0	#4 (10m)	34° 3'43.14"S- 59° 4'35.05"W	-	+24.0	-
#12 (31m)	34°10'0.74"S- 58°55'17.65"W	+5.0	-	-23.0	#6 (20m)	34° 4'57.06"S- 59° 3'42.91"W	-	+26.0	-
#14 (38m)	34°10'26.11"S- 58°54'39.06"W	+6.0	-	-28.0	#7 (6m)	34° 4'54.25"S- 59° 7'34.62"W	-	+21.0	-
#16 (25m)	34° 9'26.88"S- 58°56'54.89"W	+4.0	-7.0	-16.0	#10 (8m)	34° 7'26.24"S- 59° 0'39.46"W	-	+17.0	-
#17 (20m)	34° 9'55.95"S- 58°56'39.84"W	+6.0	0.0	-	#11 (35m)	34° 3'50.10"S- 59° 2'10.04"W	+4.0	-	-22.0
#19 (25m)	34° 9'31.67"S- 58°57'3.61"W	+10.0	+2.0	-13.0	#15 (25m)	34° 6'28.28"S- 59° 7'40.20"W	-	+26.0	-
#21 (15m)	34° 9'53.78"S- 58°56'30.01"W	+3.0	-9.0	-	#24 (35m)	34° 2'42.84"S- 59° 2'46.55"W	+3.0	-	-28.0
#23 (58m)	34° 9'11.79"S- 58°56'41.12"W	+4.0	-	-33.0	#28 (35m)	34° 4'25.66"S- 59° 2'39.17"W	+5.0	+1.0	-21.0
#25 (25m)	34° 9'9.39"S- 58°58'44.18"W	+5.0	-8.0	-14.0	#29 (35m)	34° 4'4.87"S- 59° 2'15.49"W	+4.0	-	-21.0
#26 (35m)	34° 9'27.46"S- 58°59'13.27"W	+4.0	-14.0	-26.0	#30 (40m)	34° 5'55.71"S- 59° 0'46.51"W	+7.0	-2.0	-20.0
#27 (35m)	34° 9'31.23"S- 58°56'26.71"W	+4.0	-	-24.0	#31 (10m)	34° 6'48.24"S- 59° 5'49.53"W	-	+27.0	-



DEPTH (m)	#28	#30	#17	#19
1,0	MH			
2,0	MH	CL		ML
3,0	MH	ML	CL	CH
4,0	ML	ML	CL	
5,0	ML	ML	ML	ML
6,0	ML	ML	ML	ML
7,0	ML	ML	ML	ML
8,0	ML	ML	ML	ML
9,0	ML	MH	ML	MH
10,0	ML	ML	ML	ML
11,0	ML	MH	ML	MH
12,0	ML	ML	CH	CH
13,0	ML	ML	CL-ML	ML
14,0	ML	ML	CL	ML
15,0	ML	CL	CL-ML	ML
16,0	ML	ML	SM	ML
17,0	CL	CL	SM	CL-ML
18,0	CL	CL	SM	ML
19,0	CL	CL	CL	CL
20,0	CL	CL	ML	CL
21,0	CL	ML		CL
22,0	CL	ML		SC
23,0	CL	CL-ML		SM
24,0	ML	SM		SM
25,0	ML	SM		SM
26,0	SM	SM		
27,0	SM	SP		
28,0	SM	SP		
29,0	SM	SP		
30,0	SM	SP		
31,0	ML	SP		
32,0	ML	SP		
33,0	SP-SM	SP		
34,0	SP	SP		
35,0	SP	SP		
36,0		SP		
37,0		SP		
38,0		SP		
39,0		SP		
40,0		SP		

DEPTH (m)	#5	#9	#14	#29	#24	#11
1,0	ML	CH	CH	CL	CL	ML
2,0	SM		MH	ML	CL	CL
3,0	CH	CH	CL	ML	CL	ML
4,0	MH	CL	MH	CL	CH	MH
5,0	ML	CL	ML	SM	ML	MH
6,0	ML	SM	ML	ML	ML	ML
7,0	ML	CL		ML	ML	ML
8,0	ML	CL	ML	ML	ML	ML
9,0	ML	CL	ML	ML	ML	ML
10,0	ML	CL	ML	ML	ML	
11,0	ML	ML	ML	ML	ML	ML
12,0	ML	ML	CL	ML	SM	ML
13,0	SM	CH	ML	ML	SM	ML
14,0	SM	CH	SM	ML	SM	CL
15,0	SM	CH	SM	CH	ML	CH
16,0	ML	CH	MH	ML	CL	CH
17,0	ML	CH	CH	CH	ML	MH
18,0	CH	CH	CH	CH	SM	MH
19,0	CH	CH	CH	CH	SM	MH
20,0	CH	CL	CH	MH	SC	
21,0	CH	CL	CH	MH	SM	
22,0	CH	CL	CL	MH	CH	CH
23,0	CH	CL	SM	MH	CH	CH
24,0	CH	CH	SC	MH	CH	MH
25,0	CH	CH	ML	SP-SM	CH	CH
26,0	CH	CH	SP-SM	SP-SM	CH	SP
27,0	CH	CH	SP-SC	SP-SM	CH	SP-SM
28,0	SM	ML	SP-SM	SP-SM	SP	SP
29,0	SM	CL-ML	SP-SM	SP-SM	SP	SM
30,0	SM	CL	SP-SM	SP	SP	SP-SM
31,0	CL	CL	SP	SP-SM	SM	SP-SM
32,0	CL	ML	SP	SP-SM	SM	SP-SM
33,0	SP-SM	SM	SP-SM	SP-SM	SM	SP-SM
34,0	SP-SM	SP-SM	SP-SM	SP-SM	SM	SP-SM
35,0	SP	SP-SM	SP-SM	SP-SM	SM	SP-SM
36,0	SP	SP-SM	SP-SM			
37,0	SP	SP-SM	SP-SM			
38,0	SP-SM	SP-SM	SP-SM			
39,0	SP-SM	SP-SM				
40,0	SP-SM	SP-SM				

Figure 5. Typical N_{SPT} profiles (left: toe of cliff and transition soils; right: coastline).

Table 2 shows typical ranges of physical properties of each soil unit. Postpampeano formation was divided in fluvial and marine sub-units, having distinct physical and mechanical properties. Permeability tests on Postpampeano and Pampeano soils were obtained in triaxial cells. In situ secondary permeability of Pampeano formation induced by fissuring is close to 10^{-6} m/s [12]. In addition to this description, the surface of the upper plains (above the cliff) is often covered by a shallow deposit of dark brown potential expansive clays, 0.50 m to 0.80 m thick [4].

Table 2. Physical properties of main soil units. Typical ranges.

<table>
<tr><th>Soil unit</th><th>USCS</th><th>ω_l (%)</th><th>IP (%)</th><th>#200 (%)</th><th>γ (kN/m^3)</th><th>ω_0 (%)</th><th>k (m/seg)</th></tr>
<tr><td>PP (fluvial)</td><td>SM|ML</td><td>25|35</td><td>5|10</td><td>45|100</td><td>18.0|20.0</td><td>20|35</td><td>1 10^{-5}|1 10^{-7}</td></tr>
<tr><td>PP (marine)</td><td>CH|CL</td><td>50|80</td><td>25|45</td><td>90|100</td><td>15.0|17.0</td><td>40|90</td><td>1 10^{-7}|1 10^{-10}</td></tr>
<tr><td>PA</td><td>CL|ML|MH</td><td>30|50</td><td>8|15</td><td>80|100</td><td>18.5|20.5</td><td>25|35</td><td>1 10^{-7}|1 10^{-8}</td></tr>
<tr><td>PU</td><td>SP|SP-SM</td><td>-</td><td>-</td><td>0|15</td><td>21.0|22.0</td><td>10|20</td><td>1 10^{-4}</td></tr>
</table>

3.3. Strength, stiffness and compressibility

Table 3 shows typical ranges of strength and stiffness parameters of the various soil units. Samples for laboratory tests are routinely obtained by employing fixed piston sampler for soft soils (Figure 6) or Denison sampler for stiff soils. Figure 7 shows a typical result of oedometer tests in the marine sub-unit of the Postpampeano formation. For a complete set of material parameters required for the numerical simulation of the behavior of these soils, see [17].

Table 3. Mechanical properties of main soil units. Typical ranges.

<table>
<tr><th>Soil unit</th><th>C_c</th><th>C_r</th><th>OCR</th><th>E (MPa)</th><th>s_u (kPa)</th><th>c' (kPa)</th><th>ϕ' (º)</th></tr>
<tr><td>PP (fluvial)</td><td>0.2|0.3</td><td>0.02|0.05</td><td>1.0|1.3</td><td>25|50</td><td>10|50</td><td>0</td><td>27|32</td></tr>
<tr><td>PP (marine)</td><td>0.4|1.0</td><td>0.10|0.15</td><td>1.0|1.3</td><td>20|40</td><td>10|30</td><td>0</td><td>25|28</td></tr>
<tr><td>PA</td><td>-</td><td>-</td><td>>>2.0</td><td>150|350</td><td>80|300</td><td>10|45</td><td>29|36</td></tr>
<tr><td>PU</td><td>-</td><td>-</td><td>-</td><td>100|250</td><td>-</td><td>0</td><td>34|38</td></tr>
</table>

Figure 6. Sample of Postpampeano soil by fixed piston sampler.

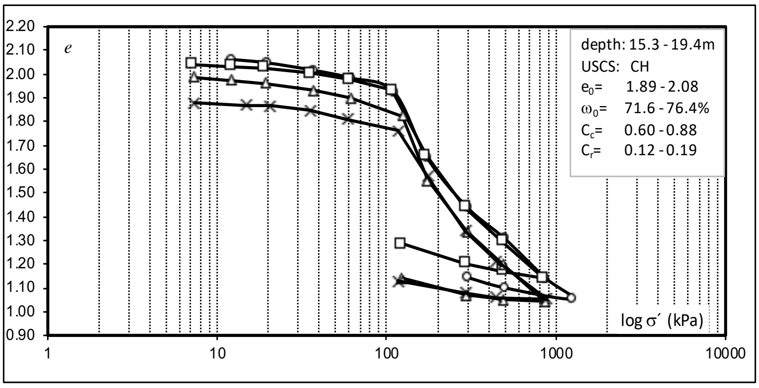


Figure 7. Typical oedometer test in Campana (PP soil) on samples extracted by fixed piston sampler.

3.4. Small-strain properties

Table 4 shows typical values of compressional and shear wave velocities measured on SASW/MASW tomography and cross-hole/down-hole tests on Postpampeano and Pampeano soils. In the Pampeano formation, shear wave velocities up to 250m/s are common, and values up to 400|600 m/s were reported for strong cemented layers [13].

Table 4. Small-strain properties of Postpampeano and Pampeano soil units. Typical ranges.

Soil unit	V_P (m/s)	V_S (m/s)	ν	E_0 (MPa)	G_0 (MPa)	M_0 (MPa)
PP (fluvial)	1500|1600	100|130	0.45|0.50	50|90	20|35	4000|4300
PP (marine)	1200|1400	80|120	0.50	40|80	15|30	3000|3500
PA	1700|2200	250|450	0.47|0.50	400|800	130|350	5500|8500

4. Local experience

4.1. Shallow foundations

Shallow foundations are typically employed in the highlands, even for massive structures. For instance, the Atucha Nuclear Power Plant, located further north but in similar ground conditions, is founded on a massive mat, 50.000m^3, placed in an excavation 21.4 m deep and exerting a mean pressure of 417 kPa [3]. Settlements induced during the construction of the foundaton are shown in Figure 8 and are largely due to the presence of old, aged clays below the Puelche Formation ("blue clays", see Figure 2).

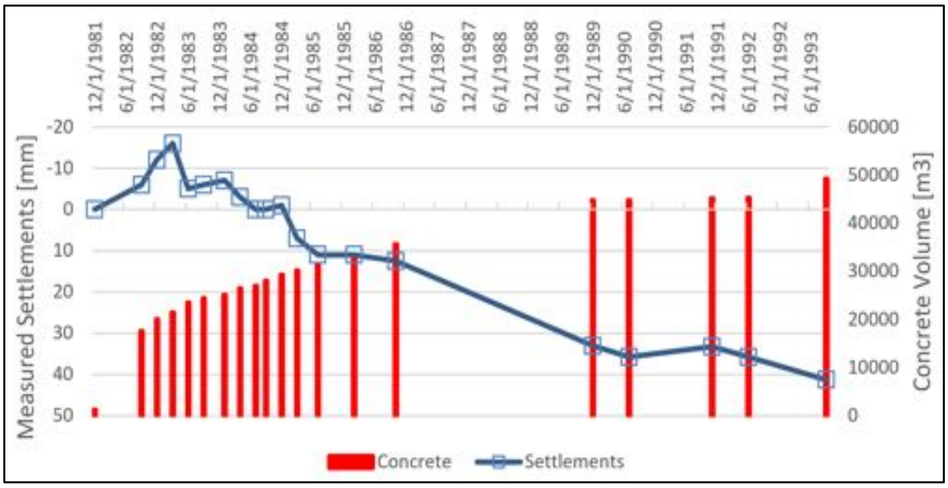


Figure 8. Evolution of settlements during construction, Atucha II. Example of a massive mat foundation in Pampeano soils.

In routine engineering, allowable contact pressures in the range 150|350 kPa are usually adopted for footings, beams-on-ground and slabs-on-ground supporting large structures and heavy equipments and founded at about 1.5|3.0 m deep. Settlements generally do not exceed a few milimeters and occur during construction. Larger settlements, however, must be expected in rare cases like Atucha (Figure 8), where the massive weight of the structure (+1500 MN) and the very deep position of the foundation level (+20 m below surface) activates primary compression of the deep, miocene clays.

4.2. *Deep foundations*

Deep foundations are routinely used at the toe of the cliff and on the coastline facilities. Driven and bored concrete piles are employed on-shore and rest on Transition or Puelchense soils (Figure 5). Bored piles are often used in projects with heavy loads. A summary of typical geotechnical pile design is shown in Table 5.

Table 5. Typical bored and driven piles installed along the coastline of Campana and Zárate ($B\mid\phi$: side or diameter, L: pile length, f_u: ultimate skin friction, q_u: ultimate toe capacity, K_v: vertical stiffness).

Pile type	$B\mid\phi$ (m)	L (m)	f_u (kPa)	q_u (MPa)	K_v (MN/m)
Bored	0.80|1.50	28|40	~0 (PP) 60|80 (PP-PU) 100|120 (PU)	10|12	200|350
Driven	0.35|0.50	28|35	~0-5 (PP) 90|120 (PP-PU) 120|150 (PU)	12|14	300|450

4.3. *Coastal structures*

On coastal structures, geotechnical problems are often associated with large consolidation settlements and slope stability / erosion. Figure 8 shows the behavior of a preload embankment (q_{max}=123kPa) 400m along the coastline on Terminal Zárate [9]. While the thickness of the compressible Postpampeano soils below the embankment was 22-23m, the excess pore-pressure largely dissipated within five to six months with no wick drains, a frequent experience with these soft alluvial soils showing that the average permeability of the deposit is at least one order of magnitude higher than the values determined at the laboratory on undisturbed samples.

The stability of the natural slope forming the coastline is known to be marginal. Figure 9 shows a slope failure of an area 6.000m^2 at the shoreline, just because it happened to be loaded too fast to allow for proper dissipation of excess-pore pressures [16].

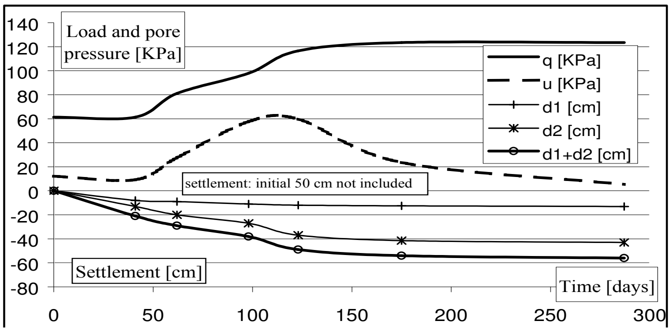


Figure 8. Evolution of settlements (d_1:settlement of upper layer; d_2: settlement of deep clay), pore pressure (u) and preload (q) on a preload embankment at Terminal Zárate.

5. Concluding remarks

A general scene setting of the geotechnical conditions and recent experiences with the desing of foundations in the Campana and Zárate region was presented. The body of data shown summarizes a large number of ground investigation programs performed in the region in the past 20 years, along with information available from other sources. Typical design parameters for foundations and earthworks were given, which might prove useful in preliminary design of constructions in the area.

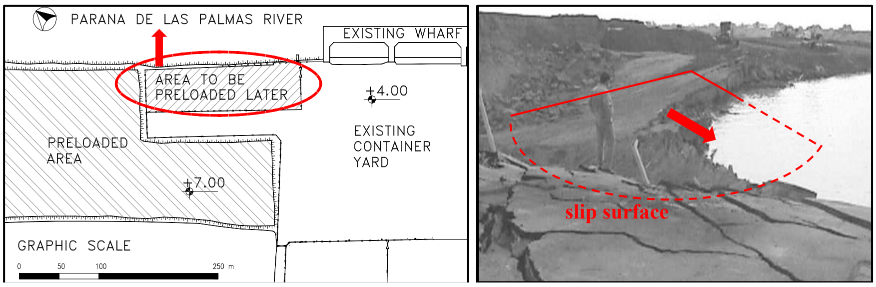


Figure 9. Embankment collapse at shoreline (left:sketch with fast loaded area in red line - right: sliding mass as seen from the wharf).

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