SOFT ORGANIC CLAY DEPOSITS – AN EXTREME EXAMPLE AT THE BARIGUI RIVER FLOOD AREA

DEPÓSITOS DE ARGILA ORGÂNICA MOLE – UM EXEMPLO EXTREMO NA BACIA DO RIO BARIGUI

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ABSTRACT

The Barigui River is a tributary of the Iguaçu River, located at Parana State, Brazil. This river is the main water stream of the Metropolitan Area of Curitiba, Southern Brazil. In the flood plain of the Barigui River final stretch, nearby its delta at the Iguaçu River, very soft organic clay deposits are found. The region suffered until some years ago predatory mining activities of both clay and sand, for construction material purposes. Consequently, a degradation process took place resulting in lack of vegetation, excavation open pits and random materials dump areas. Simultaneously several engineering activities have been installed along the river banks such as the Petrobras Oil Refinery (located at the right bank), the Santa Rita Rural Subdivision, the CIC Sewage Treatment Plant of the State owned company Sanepar, the Bolívia-Brazil Gas Pipeline (Gasbol) and the Rio Bonito Housing Development (all located along the left bank). The flood plain area considered herein is located on the river left bank, encompassing approximately an area of 500 m wide by 1000 m long. This paper describes the geological and geotechnical characteristics of the flood plain area, presenting results of several soil tests. A discussion about some practical experiences, including engineering difficulties and solutions implemented during the construction of the facilities above described, are shown. This paper concludes that even though the local organic clay deposits are very soft and compressible, this natural material of the Barigui River flood plain area presents unique engineering behavior, much more complex than well known problematic soils.

Keywords: very soft soil; organic clays; soil compressibility; geotechnical work.

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RESUMO

O Rio Barigui é um afluente do Rio Iguaçu, localizado no Estado do Paraná, Brasil. O Iguaçu é o mais importante curso de água da região metropolitana de Curitiba, situada no sul do Brasil. No trecho final da planície de inundação do Rio Barigui, junto ao seu delta no Rio Iguaçu, são encontrados depósitos de argilas orgânicas muito moles. A região sofreu atividades predatórias de mineração até alguns anos atrás, para exploração de argila e areia visando a construção civil. Consequentemente, um processo de degradação teve início resultando em falhas de vegetação, buracos de escavação abertos e materiais de rejeito acumulados de forma aleatória. Vários empreendimentos de engenharia foram instalados simultaneamente ao longo das margens do rio, tais como a refinaria de petróleo da Petrobras (localizada na margem direita), o loteamento Vila Rural Santa Rita, a estação de tratamento de esgotos ETE-CIC da Sanepar, o gasoduto Bolívia-Brasil (Gasbol) e o núcleo habitacional Rio Bonito (todos estes localizados ao longo da margem esquerda). A planície de inundação aqui considerada está localizada na margem esquerda do rio, cobrindo aproximadamente uma área de 500 m de largura por 1000 m de comprimento. Este artigo descreve as características geológicas e geotécnicas da área de inundação, apresentando resultados de diversos ensaios de solo. Uma discussão a respeito de algumas experiências práticas incluindo dificuldades de engenharia e soluções implementadas durante a construção dos empreendimentos acima citados é feita. Este artigo conclui que estes depósitos de argila orgânica, muito mole e compressível, da área da planície de inundação do Rio Barigui, apresentam comportamento único de engenharia civil, muito mais complexo do que o observado em conhecidos solos problemáticos.

Palavras-chave: solo muito mole; argila orgânica; compressibilidade do solo; geotecnia.

EXTENDED ABSTRACT

The present paper focus on geological and geotechnical aspects of the flood area of the Barigui River, one of the main water streams crossing the Curitiba Metropolitan Area. It is an important river for the city because there is a water treatment plant designed to be fed by this water stream. At the river final stretch, close to the main regional natural canal (Iguaçu River), the subsoil conditions are particularly difficult for engineering activities (Figure 1). With the continuous urban growth in this particular area of the city showing incredible population increase rates of about 100.000 people during the past decade, the river banks were extensively occupied with low income housing developments, warehouses, schools, a sewage treatment plant and one gas pipeline. The most interesting fact is that the local natural organic soil deposit showed exceptionally high compressibility parameters magnitude, indicating that the construction planning and the execution procedure in this area must be defined carefully. A few spots when carefully analysed (both from the geological and geotechnical views) led to conclude that natural void ratio and compression index magnitude are considerably high, even if compared to well known similar deposits found around the world. The literature review carried out confirmed this fact by comparing the data from the Mexico City and Baixada Santista (Southern Brazil) compressible soil deposits. Along with the results of soil tests carried out for some of the construction sites in this area, both in situ and laboratorial, geotechnical solutions designed and implemented are herein reported. In one case, a time-settlement monitoring procedure results implemented is also presented, exemplifying how badly the above cited natural state may influence the performance of constructions supported by this complex very soft organic profile. The differences between the soils geotechnical properties on both sides of the river are also emphasized (Figure 3), calling the attention for the final strip land along the left bank of the Barigui River, where the depth, thickness and poor quality of the soil are observed. The final objective of this manuscript is to call the attention of the technical community for other similar areas in the city, where natural soil deposits, mainly along rivers and creeks, could eventually cause problems for engineering works along time. It is also important to mention the close interaction of geologists, geotechnical and structural engineers, that all together can certainly do a better and safer design for slopes, excavations and foundations in difficult subsoils such as this.

INTRODUCTION

The fact that unconsolidated natural soils can be found easily in Curitiba and its surrounding valleys is not new. Highly organic and compressible deposits of the Barigui River, however, as sampled, tested and reported in this paper, reveals a unique natural state of such material, not yet known by the geotechnical and geological community.

The area is located south of the city of Curitiba, having limits with the Fazenda Rio Grande County, a few kilometers upstream from the Iguaçu River. The main features in the area are (Figure 1):

Right bank:

REPAR Petrobrás Oil Refinery (about 25 years old – higher elevation – good engineering subsoil condition)

Left bank:

Santa Rita Rural Subdivision (about 10 years old – lots of 5.000 m² each to accommodate one house and area for a family own agricultural production – very poor subsoil condition for civil engineering purposes).

a) CIC-Xisto Sewage Treatment Plant (about 5 years old – one treatment pond, several treatment tanks and other structures – same problematic soil)

FIGURE 1 – AERIAL PHOTO OF THE MENTIONED FEATURES

b) Gas and oil pipeline (about 15 years old, for oil, and more recently, for gas piping – Gasbol and Ospar – TBG/ Transpetro – strip land area of about 60 m wide protected by Brazilian specific federal law, limiting access).

c) Rio Bonito Housing Development (private subdivision investment for thousands of lots, on both sides of the gas & oil lines, now under construction).

The approximate area considered on the left bank is an irregular strip of about 500 x 1000 m along the Barigui River. The subsoil is defined by irregular sand and clay natural deposits, both of them highly explored in the past for civil construction purposes (concrete and mortar sand, clay material for bricks and tiles manufacturing).

LOCAL GEOLOGICAL DESCRIPTION

The final portion of the Barigui River flood plain area is almost inaccessible even by foot. When the first subdivision in the area started, vehicles operation was a problem. The organic soft soil had to be reinforced by geossynthetichs and granular fill material in order to provide enough bearing capacity to the loading generated by the heavy traffic. This solution was also later used as houses foundation reinforcement (Nascimento 1995).

Geologically, a much larger area including parts of the Iguaçu, the Barigui and a few other smaller rivers and streams (around several square kilometers in size), shows a similar natural condition. It all belongs to the Curitiba Basin, rich in unconsolidated deposits (MINEROPAR 1998) over the local clayey silt with occasional sand layers and/or gravel, formation deposited along millions of years on top of the weathered rock (Becker 1982). In a few words, the subsoil package can be defined by the three layers, namely unconsolidated organic material, Guabirotuba Formation and rock embedment (Figures 2 and 3, Table I).

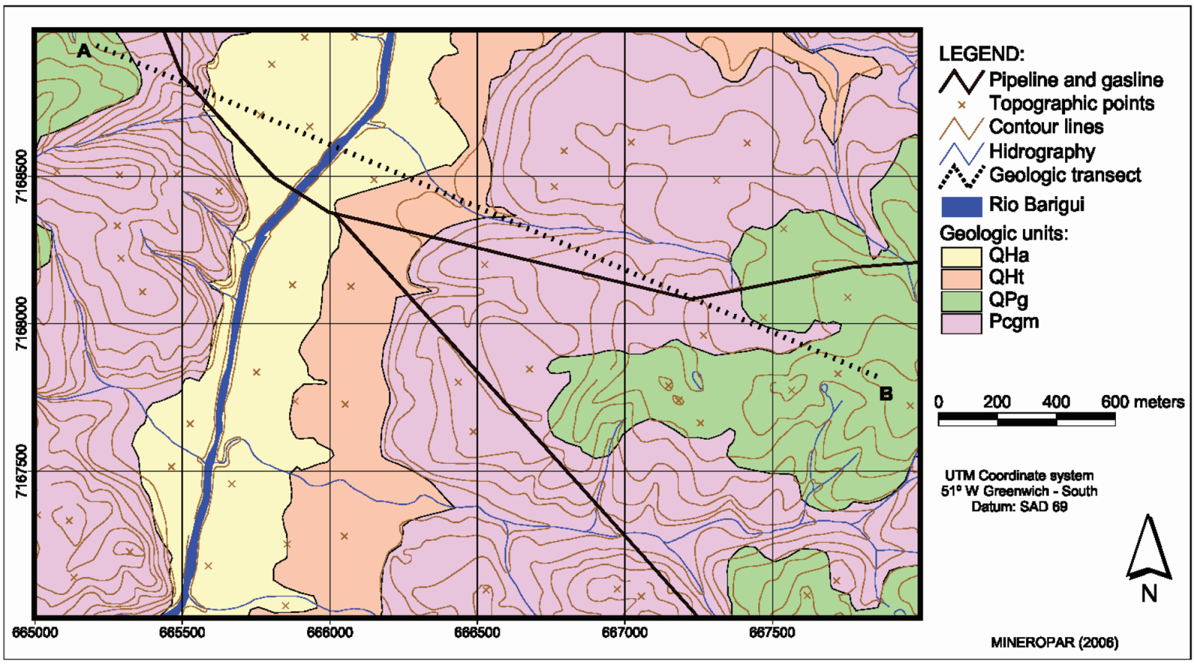
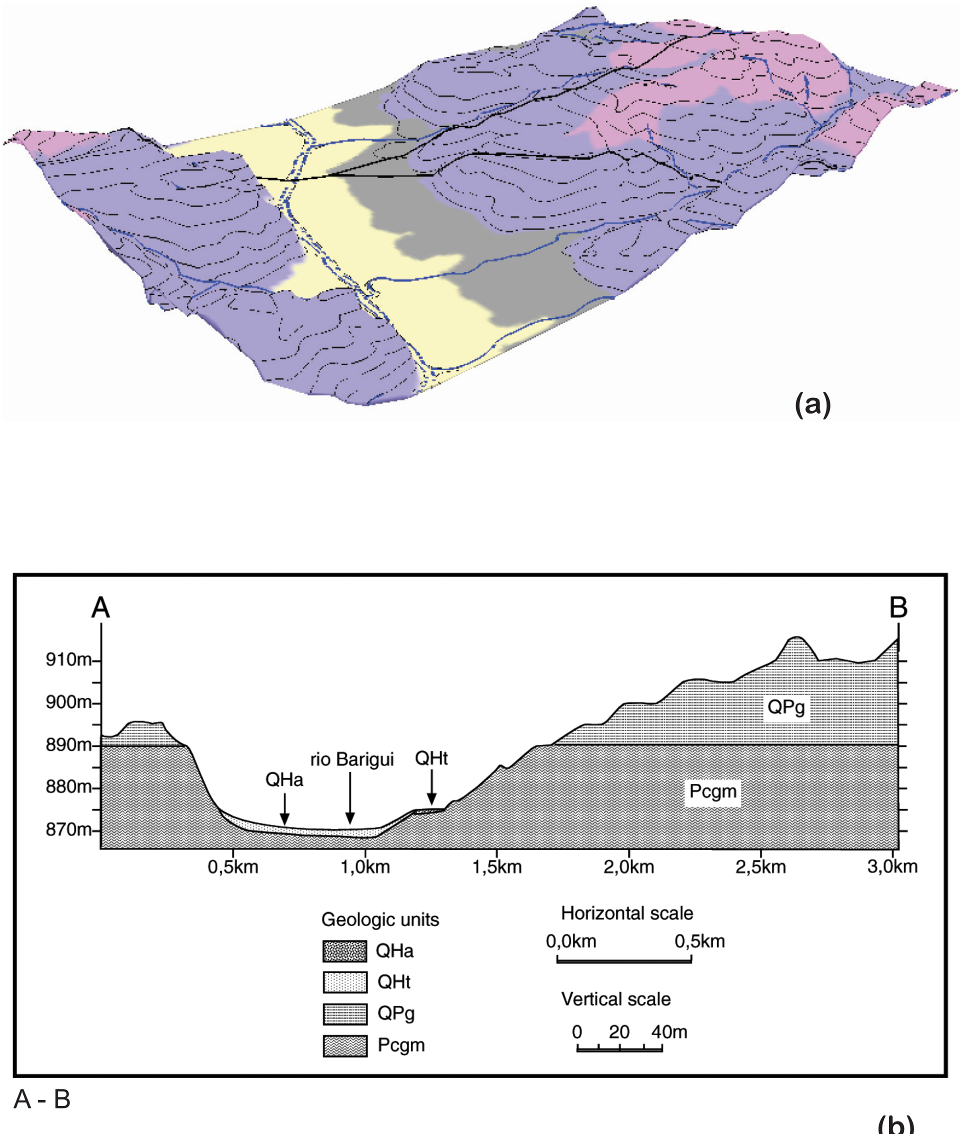


FIGURE 2 - LOCAL GEOLOGICAL MAP SHOWING SECTION A-B, PIPELINE AND GASLINE



Qha – Quaternary holocene alluvium.

Qht – Quaternary holocene terrace deposits.

Qpg – Quaternary pleistocene - Guabirotuba Formation

Pcgm – Precambrian granite and metamorphic rocks.

FIGURE 3 – (a) LOCAL 3D GEOLOGICAL VIEW AND (b) GEOLOGICAL SECTION A-B

TABLE 1 – SOME LOCAL GEOTECHNICAL PARAMETERS

Construction site	Soil description and geotechnical parameters
Vila Rural Santa Rita (initial phase: 1995)	Very soft, organic clay soil, saturated (~ 3 m); low income houses (Cohapar) with mat superficial foundation and streets over geossynthetic reinforced soil; no geotechnical parametrization; (*)
CIC-Xisto Sewage Treatment Plant (Sanepar – 2000)	Black, soft organic soil, with sand; depth from 0,6 to 2,0 m: natural density: 1,61 to 1,89 dry density: 1,05 to 1,45 natural void ratio: 1,65 to 0,87 specific gravity: 2,62 to 2,66 compression index: 0,39 to 0,25; (**)
REPAR – Petrobrás Oil Refinery (over 20 years of age)	Soil predominantly from the Guabirotuba Formation (silty clay / clayey silt) of high consistency, occasionally with sand and localized organic spots; most of this oil refinery units rest on more competent soils than the unconsolidated deposits found on the left bank; (***)

(*) observation by the authors
(**) Solum Geologia Ltda, 1999
(***) Kormann, Nascimento and Chamecki, 1999

This description is also complemented by a study carried out in about 480 km^2, South of Curitiba, including Fazenda Rio Grande, São José dos Pinhais, Araucária and Mandirituba counties. (MINEROPAR 1996). Hydromorphic soils over alluvional areas are mentioned, with the following general characteristics:

- black organic soil (peat), clayey texture, porous, with low permeability;
- thickness between 0,5 and 2,0 meters, very low penetration resistance (SPT blow count);
- light grey to black, also clayey, porous, plastic, with low permeability (10^{-6} cm/seg) and kaolinite as the main mineral, also showing some illite and montmorillonite;
- the water table is typically very close to the ground level, and lenses or layers of sand, occasionally containing gravel, are also found.

Such a scenario is easily found in the region, specially at the particular portion of the Barigui River lowlands, here under consideration (Figure 4).

The topsoil of the considered area can be taken as derived from organic matter, containing carbon compounds, such as cellulose, lignin, protein, glucose, organic acids, aminoacids and fat (Kavaleridze 1977). A more characteristic term is peat (turf), partially carbonized vegetable tissue formed by decomposition in water, occasionally with the addition of animal matter. In such way, the unconsolidated material is also called the first stage in coal formation and is commonly possible of burning after drying. There are several regions in the world where these deposits can be found, such as in the US, Canada and parts of Asia, just to mention a few, emphasizing the local importance once given to this soil, as far as source of heating (Waldman 1982) and for the industrial process of cheramics (MINEROPAR 2006).

CONSTRUCTION FEATURES RELATED TO THE SUBSOIL CONDITION

a) The case of the CIC-Xisto Plant:

One problem that arouse about 2 years ago was due to excessive settlements (mainly differential) for the sewage treatment tanks at the CIC-Xisto Sewage Treatment Plant (Nascimento & Puppi 1999), owned by the Paraná State Public Water and Sewage Company (Sanepar).

As it can be seen from Figure 5, the structural joint for each of the two huge concrete tanks was made including the mat superficial foundation and when the tanks were submitted to the first loading (hydrostatic test), differential settlements occurred and leveling problems happened, requiring later corrections. Certainly, it became clear that the particularly difficult natural soil condition for constructions (low bearing capacity and high compressibility) was the main cause of this problem, specially for superficial foundation (mat slab).

After several months of operation, the treatment system had to be realigned and releveled, and the structures are operating regularly at present.

CLIENTE: PIEMONTE CONST. E INC. LTDA.	SONDAGEM PERCUSSÃO 11
OBRA: ÁREA MORADIAS RIO BONITO	INÍCIO: 13/01/05 TÉRMINO: 13/01/05
LOCAL: CURITIBA - PR	COTA: 872,76

REVESTIMENTO: 63,5 mm
AMOSTRADOR: D interno: 34,9 mm; D externo: 50,8 mm
PESO: 65 kg ALTURA DE QUEDA: 75 cm

Cota em relação ao R.N.	AMOSTRA	PROFUNDIDADE (em metros)	CLASSIFICAÇÃO DA CAMADA	ENSAIO PENETROMÉTRICO Golpes / 30 cm		
	01		Aterro de argila arenosa, preta, mole, marrom e vermelha	2/15	2/15	2/15
	02	2,00		1/30	1/37	-
870	03	2,63	idem, muito mole, marrom	1/45	-	-
	04	4,00	passagem de aterro para argila orgânica siltosa, muito mole, preta	4/15	5/15	9/15
	05		Areia fina, argilosa, rija, cinza	5/15	7/15	4/15
	06	5,23 6,00	Silte arenoso, com pedregulhos finos, medianamente compacto, cinza	1/30	1/30	-
	07	7,00	Silte argiloso, muito mole, cinza esverdeado	1/15	1/15	1/15
865	08		Silte arenoso, fofo, cinza	1/15	1/15	1/15
	09			1/15	1/15	2/17
	10	10,00		1/15	2/15	3/15
	11	10,45	idem, pouco compacto			
	12		LIMITE DE SONDAGEM (por ordem da fiscalização de V. Sas.)			
	13					
	14					
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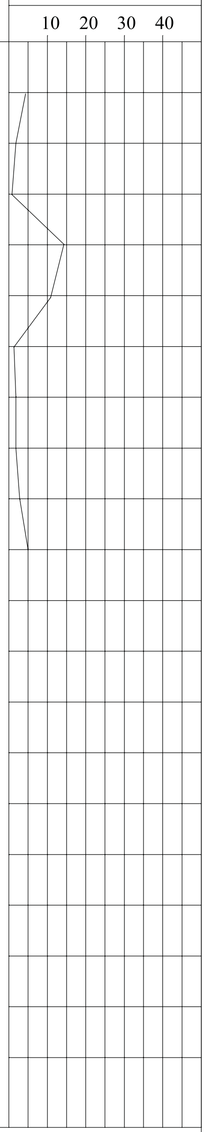
RESISTÊNCIA A PENETRAÇÃO – No. de golpes



PROFUNDIDADE DO NÍVEL D'ÁGUA
INICIAL: 1,20 em 14/01/05
FINAL: 1,20 em 14/01/05

AVANÇO A TRADO: 0,00 m a 2,00 m
AVANÇO POR LAVAGEM:
PROF. DO REVESTIMENTO: 5,00 m

SOLOTÉCNICA

REFERÊNCIA: 10674	LAVAGEM POR TEMPO (30 min.)			DESENHO No.: FRL
DATA: 17/01/05	TEMPO	DE	PARA	FOLHA No.: 04
ESCALA VERT.: 1/100				RESP. TÉC.:

FIGURE 4 - TYPICAL SPT SUBSOIL PROFILE AT THE RIO BONITO HOUSING DEVELOPMENT

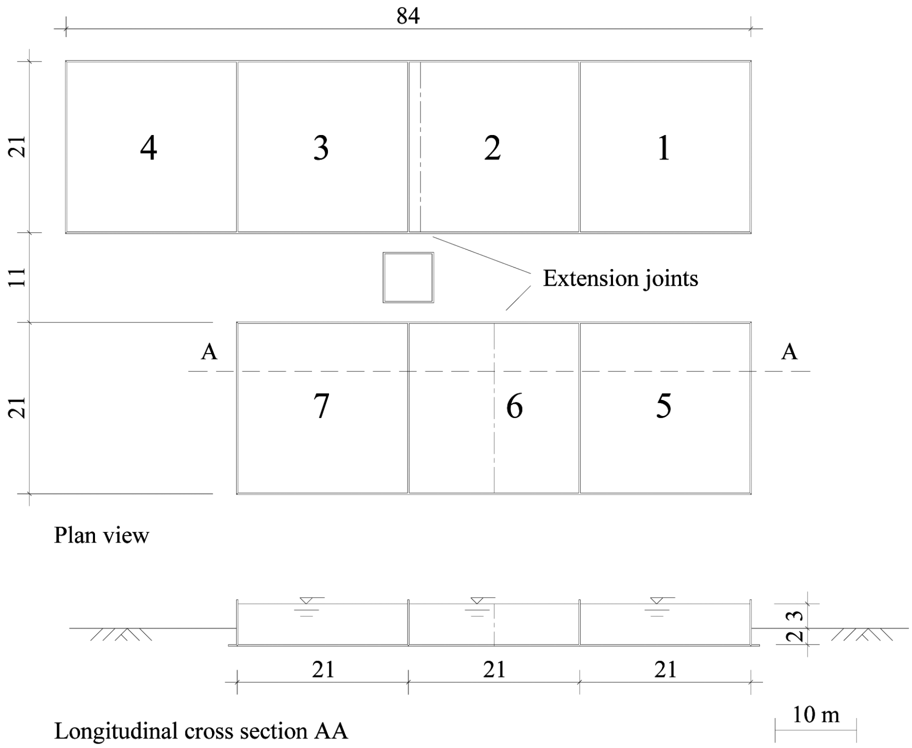


FIGURE 5 – PLAN VIEW AND LONGITUDINAL CROSS-SECTION OF THE TWO SEWAGE TANKS AT CIC-STP (DIMENSIONS IN METERS)

A quick description of subsoil conditions and geotechnical parameters is given on Table 1.

b) The Gasbol case:

Another situation involved the gas and oil lines, that use the same strip of land and go across the housing subdivision, as already mentioned. Additional information is given in a booklet printed and distributed nationwide by the pipelines operator, TBG/Transpetro (TBG 2003) – it is considered INCORRECT to be done on the strip, according to the Federal Law 6766-79:

- to harm the signalization off-sets;
- to plant any tree or vegetation other than grass;
- to use plows, graders or any agricultural machine – before any excavation needed, check by calling a given 0800 phone number;
- to cause any kind of fire on the strip or close by;
- to use explosives;
- to make any kind of construction;
- to cross the strip with any vehicle weighing 10 t or more;
- to use trucks or tractors.

These items give an idea about how restricted the pipeline strip of land is, under the special law cited above. The objective, however, is to point out the very poor geotechnical condition of the local soft soil: void ratio of 9,5 and compression index of 7, as examples. A typical consolidation curve is given on Figure 6. One may expect misbehavior from a simple low cut, fill or any other light load, situations that may trigger severe consequences to high pressure gas lines, for example, built on such weak soil.

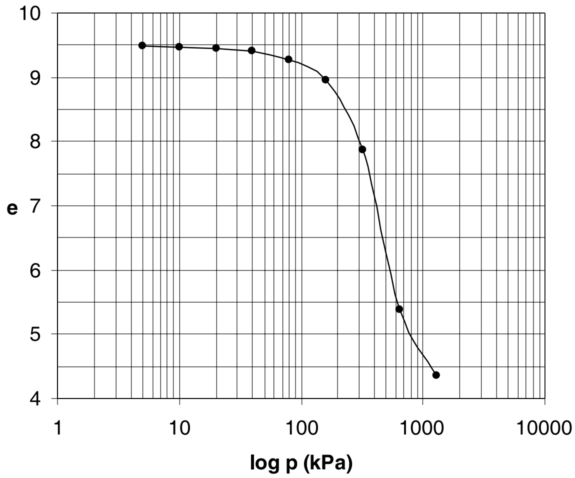


FIGURE 6 – CONSOLIDATION CURVE

c) The Rio Bonito Housing Development case:

The Rio Bonito Housing Development, still today under construction. When the earth moving activity started, about 3 years ago, a cut slope was defined with maximum height of 6 meters, 60° inclination with the horizontal and about 130 meters long, very close to the pressurized gas and oil lines. Geotechnical analysis was then required by the owner to check the slope stability to minimize horizontal movements of the pipelines.

Results of the stability analysis (Nascimento *et al.* 2005) after soil parametrization, modeling (limit equilibrium state), discussions and some geotechnical judgment by the professionals involved (consultants, contractor and owners), lead to a final design with:

- global factor of safety of 1,5 ;
- analysis using Bishop;
- gabion type retaining wall and precast concrete piles at the toe of the slope;
- nails (passive) line at the mid-height of the slope;
- drainage and vegetation.

Figure 7 shows, schematically, the geotechnical solution devised, detailed and later constructed in the area, around three years ago. The final decision about its materialization was taken together by the subdivision owners, the TBG-Transpetro technical group and the geotechnical consultants.

More recently, the geometric design of the Rio Bonito Housing Development required fill of about 2 meters high over the natural organic very soft soil. This material was also characterized by SPT (Standard Penetration Test. ABNT 2001) borings and undisturbed sampling, for laboratory tests, mainly consolidation (Pinto 1989). The test results showed exceptionally poor civil engineering behavior for this soil: very low strength, very high compressibility, high water content and the impressive magnitudes of void ratio and compression index as summarized on Table 2 (data gathered from the bibliography and also from the authors' data records).

The comparison of values such as natural void ratio and compression index shows, the great compressibility of the Barigui River organic clay deposits. Under this circumstance even without any surcharge, settlements could be under way and affect the pipelines – a transition process from sedimentation to consolidation might be occurring with the soft clay deposit. This observation

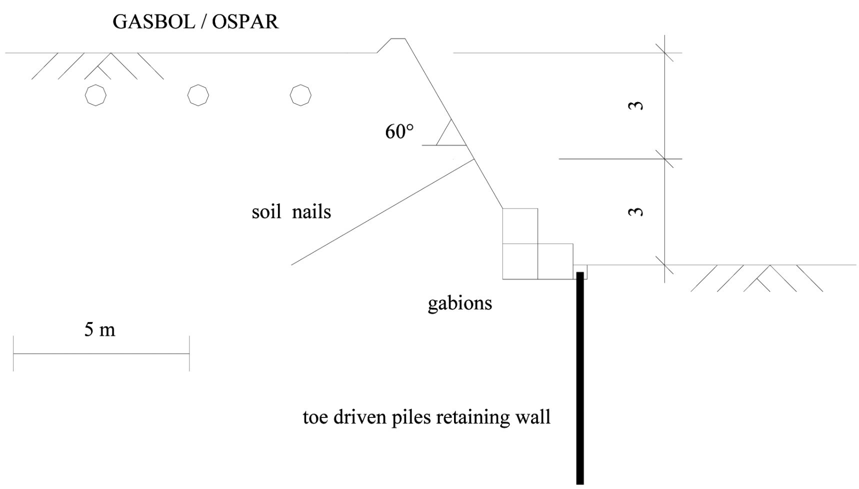


FIGURE 7 – STABILIZING SCHEMATIC SOLUTION FOR THE CUT SLOPE (DIMENSIONS IN METERS)

was not totally confirmed, but some pipe settlement measurements provided by TBG close to fill areas, indicated around 20 cm of vertical displacement (Transpetro-Concremat 2005), leading to the conclusion that at least part of the vertical movements was due only to the natural clay compressibility. For such a high natural void ratio, surprisingly if compared to some numbers summarized on Table 2, one might expect serious compression problems.

After having finished the geotechnical analysis and defined the problem, the results indicate that even a small height of fill material placed on this soil could easily affect the gas pipelines, including eventually soil rupture. Excessive settlements caused concern as well, reminding the two aspects very clearly mentioned in the Brazilian foundations standard (ABNT. NBR 6122/96).

Earth moving was found not be the best solution because it would compromise the subdivision area. Actually it would be more risky (even mild slopes could be subjected to eventual rupture) and it would certainly be more difficult to materialize in the field because of compaction problems. Some other solutions were also taken into account, such as soil reinforcement, injections and soil nailing, but finally the cost evaluation converged to “fix” the fill to the natural foundation soil by constructing a driven piles wall anchored in the lower soil layer, more competent foundation material. The pile wall was stiffened superficially by a longitudinal reinforced concrete beam (Figure 8) in order to provide a 3D effect.

This figure shows the general situation of the local subsoil profile, obtained both from the Standard Penetration Tests in the field and also from similar river bank areas in the vicinity, reported elsewhere (MINEROPAR 1996) and known by the authors (personal communications). A few of these places were used as construction sites and testify similarities with the soils here under consideration.

TABLE 2 – GEOTECHNICAL PARAMETERS- PUBLISHED AND UNPUBLISHED DATA

Parameter	Natural density	Dry density	Natural void ratio	Specific gravity	Compression index
Organic very soft (Rio Barigui). (i)	0,988	0,153	9,525	1,611	7,0
Organic clay from Baixada Santista, São Paulo. (ii)	1,5	0,625	3 a 4		2,0
Silty clay from Mexico City. (iii)	1,5	-	~ 8	-	~ 6,2
Grey sandy clay, hard, from Guabirotuba Formation, Curitiba. (iv)	1,99	1,66	0,612	2,698	0,16
Redish silty clay of medium consistency, Maringá, Paraná. (v)	1,59	1,01	1,876	3,060	0,88

(i) Lactec-UFPR – tests report RE LAME 029.2005-RO 16/Feb/05.
(ii) Milton Vargas – 1977.
(iii) Leonardo Zeevaert – 1983.
(iv) Ney Nascimento – 1992.
(v) Ney Nascimento – 1992.

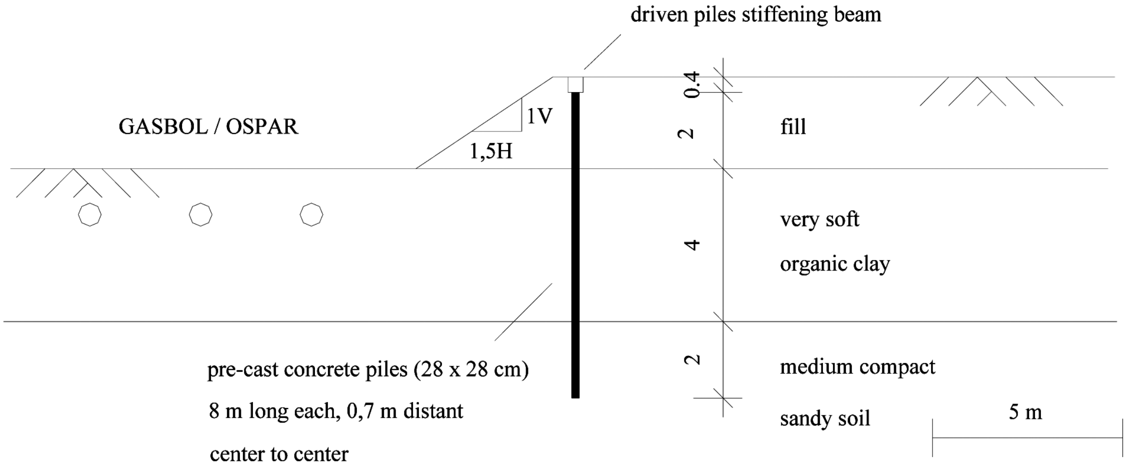


FIGURE 8 – SCHEMATIC CROSS-SECTION OF THE PROPOSED SOLUTION (DIMENSIONS IN METERS)

Geotechnically, the experience accumulated as far as earth moving and foundations may be valuable for other similar sites, as well.

This line of pre cast driven piles, stiffened by the longitudinal beam, was designed to work as a “pseudo vertical wall”, subjected to the active thrust from the fill and taking advantage of the passive resistance of the compact sandy layer existing below the soft soil. After the stability analysis of the system, it was concluded that its behavior will probably satisfy the needs for minimum movements that could affect the pipes, giving an overall acceptable factor of safety of 1,5.

Maximum bending moment of about 50 kNm was computed for the piles (Alonso 1989) and indicated their concrete type, cross-section and reinforcement, as well as the structural design for the superficial cast in place reinforced concrete beam.

The approach was found to be acceptable and kept the original layout of the subdivision, fact that was considered very important when discussing the alternative solutions for this problem.

CONCLUSIONS

Among a few examples of constructions undertaken in the Barigui Valley during the last decades, one case was particularly considered in this report. The Rio Bonito Housing Subdivision represents a geotechnical challenge because its area includes a strip land were both oil and pressurized gas lines are present, with several restrictions imposed by the specific federal law related to this situation.

It is very easy to understand such severe conditions of land use around and on the protected strip land, here also complicated because the geotechnics is complex as well. The soft organic clay deposited by the river was considered extremely compressible, having shown surprisingly high natural void ratio (~ 9,5) and compression index (~ 7,0), even if compared to well known problematic soft soils (Mexico City, for example).

The need for better soil parameters and more complete geotechnical evaluation is also very clear – apparently not too much attention was given to the site when the pipelines were placed, and the event of a new subdivision nearby brought about the real complexity of the local material.

The warning is given and, as the pipelines owner information booklet mentions, a lot of care must be taken when dealing with pressurized gas, specially, subject that is also directly related to the natural soil conditions and the geotechnical solutions devised and put into effect. Both bearing capacity and settlements are very important and occasionally heavy and expensive structures must be designed to withstand the forces and pressures caused by cuts, fills or other constructions nearby.

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