# APPENDIX F

# BASE GEOLOGICAL CONDITIONS REPORT

# SPONSORED CONCESSION OF PUBLIC SERVICES FOR CONSTRUCTION, OPERATION, MAINTENANCE AND INVESTMENTS NECESSARY FOR THE EXPLORATION OF THE SANTOS-GUARUJÁ IMMERSED TUNNEL

## 1. INTRODUCTION

The Base Geological Conditions Report for the Santos-Guarujá Immersed Tunnel shall be used jointly with the other drawings and tests mentioned in this report and also presented in Appendix F. The purpose of this report is to: (i) describe the geological-geotechnical conditions of the alignment of the reference project, (ii) address construction restrictions associated with these conditions, (iii) establish baselines to be considered in the bidders' proposals, and (iv) be used in accordance with Clause 21.3 and the other clauses of the AGREEMENT associated with Geological Risk.

It should be clarified that the selection of design parameters and their values is the responsibility of the CONCESSIONAIRE, and the requirements of Exhibit 7 shall be followed.

## 2. DESCRIPTION OF THE REFERENCE PROJECT

The reference project, presented in Exhibit 12, considered the construction of an immersed tunnel between the Cities of Santos and Guarujá, the implementation of connection loops with the local road and access buildings for pedestrians and cyclists.

The construction method consists of precast concrete elements, which are designed and built so that they can float and be transported to the tunnel location. The elements are then immersed in a dredged trench at the bottom of the channel, where they are connected by means of immersion joints and the necessary finishing touches are made, such as the implementation of embankments, sidewalk and systems.

In the municipalities, lowered roads will be built using the cut and cover method, with the use of strutted diaphragm walls, with inverted excavation and the construction of ramps, as well as all the necessary structures for access to the local roads.

The reference project dealt with in this Appendix has been divided into two large groups, taking into account the detailing and investigation characteristics of the segments shown in EXHIBIT 12:

- **Group 1:** consists of the TUNNEL and the URBAN ACCESSES, in accordance with the reference layout shown in EXHIBIT 12, with an overview in drawing DE-42.00.000-A08/201, and in Figure 1;
- **Group 2:** deals with the URBAN ACCESSES portion of the connection between the urban road in the city of Guarujá and the vicinity of km 2 of the SPA-248/055.


**Figure 1 - Reference Santos-Guarujá connection project**

**Figure 2 – Reference Project Layout – Connection with SPA-248/055**

## 3. DATA SOURCES

### 3.1. Group 1

Geological-geotechnical subsurface investigations were planned at the site of the immersed tunnel, as provided in report RT-42.00.000-G01/001 and drawing DE 42.00.000-G01/001, issued in July 2013. The initial schedule was subject to changes made during the monitoring of the field work to meet the needs of the project and resulted in drawings DE-42.02.201-G01/001, DE-42.03.301 G01/001 and DE-42.04.401-G01/001 and 002, corresponding to the investigation location plans for Santos, Canal and Guarujá, respectively. Field work began in July 2013 and was completed in December 2014.

The program includes mixed probing and percussion probing, positioned within the limits planned for the project, with spacings of around 50 to 70 m on the Dry Dock stretch and around 100 m on the rest of the stretch from Guarujá to Praça 14 Bis and on the downstream stretch from Santos, in this case due to interference from existing buildings. Percussion probing was planned in the vicinity of the layout.

Infiltration and water loss tests were carried out and piezometers installed in some sections of the probing located on the limits of the work. In addition to the probing, CPTU tests, Vane Tests and the collection of 5” and 3” shelbie samples for laboratory tests were scheduled and carried out in some locations known as clusters, alongside previously carried out percussion and/or mixed probing.

In addition to these probing and tests, other CPTUs were carried out alongside percussion or mixed probing, or even interspersed with these probing. In addition to shelbies, deformed samples for characterization and moisture determination tests were taken every 2m in some selected probing.

The probing in the channel was carried out on a large raft. The mixed probing was carried out with SPT tests every meter up to the impenetrable point, and continued with rotary probing up to around 3 to 5m in rock with recovery of cores in diameter N. The percussion probing was generally carried out until the impenetrable criterion was reached in the SPT test in at least three consecutive tests or when the impenetrable point was reached in the time wash test. These probing carried out infiltration tests on selected stretches of soil and some water loss tests on selected stretches of rock.

Geophysical surveys were planned for the canal in an area measuring approximately 600 x 500 m. A total of 45km of bathymetric surveys, 19km of side scan sonography and 48km of continuous seismic profiling were carried out. The results of the available investigations were analyzed in geological-geotechnical sections along the development limits of the work, indicated on each of the fronts. The results of the in situ and laboratory tests are presented in a specific geotechnical test analysis report.

The geological-geotechnical work carried out is presented considering the fronts of the Guarujá and Dry Dock, Canal, Santos routes and the fronts relating to the OAEs.

- **Guarujá and Dry Dock Sides:**

The investigations carried out on the Guarujá and Dry Dock sides are shown on Drawings DE-42.04.401-G01/001 and the geological-geotechnical sections on Drawings DE-42.04.402-G12/001 to 014. The investigations carried out and the geological-geotechnical sections elaborated for the specific special structures (OAE) can be found in Drawings DE-42.04.401-G07/001 to 002; DE-42.04.402-G07/001 to 002; DE-42.04.403-G07/001 to 002; DE-42.04.405-G07/001 to 004 and DE-42.04.407-G07/001.

The total services for the Guarujá and Dry Dock front, excluding the OAEs, were as follows:

- Percussion probing – 61 probing and 3124.53 m of drilling and sampling;
- Mixed probing – 11 probing and 615.77 m of drilling and sampling;
- CPTUS – 21 probing and 799.88 m of tests;
- Cluster - (site with SP/SM, CPTU, Vane Test, shelby sampling) – 6 sites;

- Shelby samples – 25 samples and a further 34 samples collected at SP-124 (22 shelby samples of the sediments, 8 deformed samples of the sands and 4 deformed samples of the alteration soil);
- Multilevel piezometers – 2 sites and 7 piezometers;
- Infiltration tests – 38 tests;
- Water loss tests – 5 tests.

The total services for the OAEs were as follows:

- Percussion probing – 42 probing and 2417.53 m of drilling and sampling;
- Mixed probing – 4 probing and 247.96 m of drilling and sampling.

- **Canal:**

Indirect investigations were carried out in the canal region through geophysical surveys. In an area measuring approximately 600 x 500 m, 45 linear km of bathymetric surveys were carried out; 19 linear Km of sonography with side scan sonar; and 48 km of continuous seismic profiling with a seismic profiler.

The direct investigations by probing and tests carried out on the Canal front are shown on Drawings DE-42.03.301-G01/001 and the geological-geotechnical sections on Drawings DE-42.03.302-G12/001 to 011.

The total services were as follows:

- Percussion probing – 46 probing and 2115.78 m of drilling and sampling;
- Mixed probing – 4 probing and 237.22 m of drilling and sampling;
- CPTUS – 22 probing and 755.18 m of tests;
- Cluster - (site with SP/SM, CPTU, Vane Test, shelby sampling) – 6 sites;
- Shelby Samples – 17 samples.
- Canal:

- **Santos Side:**

The investigations carried out on the Santos front are shown on Drawing DE-42.02.201-G01/001 and the geological-geotechnical sections on Drawings DE-42.02.202-G12/001 to 019. The probing carried out and the geological-geotechnical sections elaborated for the specific special structures (OAE) can be found in Drawings DE-42.02.201-G07/001; DE-42.02.202-G07/001 to 002; DE-42.02.203-G07/001; DE-42.02.204-G07/001 and DE-42.02.205-G07/001.

The total services for the Santos front, excluding the OAEs, were as follows:

- Percussion probing – 38 probing and 1707.19 m of drilling and sampling;
- Mixed probing – 27 probing and 1632.61 m of drilling and sampling;
- CPTUS – 20 probing and 758.60 m of tests;
- Cluster - (site with SP/SM, CPTU, Vane Test, shelby sampling)
- Shelby Samples – 20 samples
- Multilevel piezometers – 3 sites and 7 piezometers;
- Infiltration tests – 14 tests;
- Water loss tests – 4 tests.

The total services for the OAEs of Santos side were as follows:

- Percussion probing – 3 probing and 124.43 m of drilling and sampling;
- Mixed probing – 29 probing and 1266.64 m of drilling and sampling.

### 3.2. Group 2

The section of Group 2 has no geological-geotechnical tests and the TENDERER shall consider the appropriate solution in its proposal.

## 4. REGIONAL GEOMORPHOLOGICAL, GEOLOGICAL AND SEISMIC ASPECTS

### 4.1. GEOMORPHOLOGICAL ASPECTS

According to the Geomorphological Map of the State of São Paulo (PONÇANO et al., 1981), the region of interest is part of the Coastal Province, which includes portions of the Coastal Mountain Zone – Serra do Mar Subzone and the Coastal Lowlands Zone, with the predominant portions of the Coastal Lowlands Zone being characterized by land reliefs associated with quaternary sedimentation – River plains, Fluvial-lagoon plains, Tidal plains and Lowlands - and by isolated hills and hillocks. A brief description of these land reliefs units is given below:

- River plains: these are flat areas, slightly sloping towards the river and well developed at the foot of the mountains. They are made up of pebbles, blocks of quartzite, granite and schist, interspersed with medium to coarse sands.
- Fluvial-lagoon plains: these are flat, undulating areas where meandering channels move. They are made up of sand, silt, clay and organic matter.
- Tidal plains: these are flat areas where the tides oscillate and where fresh and saltwater meet, sheltered from more energetic circulations. They are made up of soft silt and clay soils and a large amount of plant remains.
- Lowlands: these are submerged depositional features, exposed at low tide. They are made up of silty clay, silt and very fine sand.
- Isolated hills and hillocks: these are isolated, uneven forms with narrow, convex tops and altitudes of between 80 and 150 m. They are made up of stromatolitic, ophthalmitic and nebulitic migmatites. They characterize the Marapé and Embaré hills.

The rivers in the Baixada Santista region acquire a meandering to intertwined morphology, as a result of the low gradients, which induce little competence in the processes of erosion and sediment transport. In this stretch, the region’s drainage systems tend to transport sediments by suspension, with fine, clayey to silty sediments predominating.

The Santos Estuary is in a permanent process of sedimentation due to the influx of material from waterways and marine currents. The loaded material is gradually deposited on the plain, with the coarsest (blocks and gravel) accumulating closer to the foothills, followed by fine gravel, coarse, medium and fine sands, and finally silts and clays, which under the influence of sea water cause the clays to flocculate, resulting in the deposition of dark, muddy material that increases with each period of high tide until it forms the environment conducive to the emergence of mangroves.

With regard to sedimentation, in accordance with FÚLFARO & PONÇANO (1976), the Santos Estuary is considered to be a region in equilibrium and does not show characteristics of rapid siltation. The highest sedimentation rates occur only in Largo do Canéu, at the southern end of the São Vicente and Bertioga canals and at the exit of the Porto canal into the bay. In the Largo do Canéu region, when comparing the topographic sheet of Santos, made with aerial photographs from 1962, and the aerial photographs from 2002, it can be seen that siltation has been of great magnitude, causing significant changes in the land relief of this region.

The occurrence of erosive processes on the escarpments of the mountain may identify the silting up of Largo do Canéu, and indirectly favor the silting up of the Port of Santos Canal. It is also important to note that erosion processes on the slopes of the Plateau and escarpments of the

Serra do Mar have intensified the supply of sediment to the coastal plain, causing significant siltation over the last 40 years in the vicinity of Bagres island, which is practically connected to the plain.

Inside the Santos Estuary canal, in addition to the layers of sediment, there are rocky massif tops corresponding to ancient islands flooded by the processes of sea level oscillation in the Holocene period. They appear at several depths, usually with more than 10 m of sediment covering their highest part.

### 4.2. GEOLOGICAL ASPECTS

In the vicinity of the Santos canal, the regional geological framework comprises Precambrian crystalline basement rocks, some Cambrian igneous manifestations and Quaternary sedimentary deposits. The formation and current layout of these rocks were controlled by the geological evolution of the São Paulo coast, which provided a great deal of geological structuring, mainly printed on the oldest crystalline terrains and marked by transcurrent shear zones, with an ENE direction, developed between the end of the Precambrian and the beginning of the Paleozoic. The most prominent of these structures is the Cubatão shear zone or fault.

It should be noted that, in general terms, the direction of the coastline is conditioned by geological structures and even the Cambrian igneous and Cenozoic sedimentary units show some conditioning, sometimes through the reactivation of these structures in more modern periods. Regionally, the tectonic framework of the Baixada Santista region comprises the Embu Domain (Embu Complex – Mesoproterozoic) and the Coastal Domain (Coastal Complex – Neoproterozoic), which are separated by the Cubatão Shear Zone (CPRM, 1999).

The metamorphic units of these complexes are intruded by granitoid rocks. Both metamorphic and igneous units can be partially covered by Quaternary sedimentary cover. These coverings make up a large part of the Coastal Plain and correspond to Holocene marine and lagoon deposits and continental deposits, such as alluvium, talus bodies and colluvium. In the Santos Estuary region, units of the Coastal Domain and Quaternary Sedimentary Coverages are found. The distribution of the units can be seen in Figure 3 – Regional Geological Map.

- **Coastal domain:** it occurs in the region in the form of isolated hills inserted into the Coastal Plain or as a large strip in the Serra do Mar, embedded between the Cubatão and Freires-Lourenço Shear Zones. According to CPRM (1999), within the regional context of interest there are three units of this Complex: a migmatite unit with diverse structures, notably nebulitic, schlieren and stromatitic (this unit supports the Botelho, Tejereba and Engenho hills in Guarujá), a (hornblende)-biotite migmatite and/or porphyroclastic granite-gneiss unit and a biotite gneiss unit that grades into stromatitic migmatites.
- **Granitoid rocks:** of Neoproterozoic-Paleozoic age, they are considered to be intrusive in the Coastal Complex and constitute five rock masses in the Baixada Santista region. Within the regional context, the granitoid rock masses of São Bento, Santa Maria, Cachoeira, Marapé and Voturuá Hills stand out, composed of porphyritic, pinkish-gray biotite granite, corresponding to the Santos and Guarujá Granitoid Massifs, and the rocky massif of the Itararé, Santa Terezinha and José Menino hills, made up of (muscovite)-biotite granite, pinkish, massive and equigranular, corresponding to the Santos-Itararé Granitoid Massif.
- **Quaternary Sedimentary Covers:** these partially cover the units of the Coastal Complex and some granitoid massifs and make up the Santos Sedimentary Plain. This plain is made up of Pleistocene marine deposits, Holocene marine and lagoon deposits and continental deposits (SUGUIO & MARTIN, 1978). Pleistocene deposits correspond to

deposits formed in a transitional, continental-marine environment, formed at the base by sandy-clay sediments and at the top by sandy sediments (MARTIN& SUGUIO, 1976). These deposits belong to the Cananeia Formation, as defined by SUGUIO & PETRI (1973). The clays are called “transitional” because their genesis is associated with a marine-continental environment (SUGUIO & MARTIN, 1978) and may contain carbonized plant leaves.

The sandy-clay sediments were formed in a depositional environment that graduated from continental to marine, while the sandy sediments at the top of the Formation resulted from deposition in a coastal environment (MARTIN & SUIGUIO, 1976). Fossil tubes of Callianassa are common, indicating the position of the mean tide level at the time these organisms lived (SUGUIO & MARTIN, 1976b).

Above the Cananeia Formation are coastal marine sands with coastal cord structures, which indicate a regressive phase. These sands are currently found in the Samaritá and São Vicente regions (MARTIN & SUGUIO, 1976). Holocene deposits correspond to marine and lagoon deposits, which can be made up of fluvial-lagoon and bay sediments, mangrove and swamp sediments or bay sediments.

The fluvial-lagoon sediments are made up of predominantly sandy-clay sediments. There are also layers of sand resulting from the reworking of sediments from the older Cananeia Formation. The fluvial-lagoon sediments can be correlated with the Ilha Comprida Formation (SUGUIO & MARTIN, 1994). These are dark gray clays with shell and plant remains.

Mangrove and marsh sediments make up the current mixed deposits and comprise clays and sands. They occur restricted to the shores of lagoons, tidal channels and the lower reaches of rivers on the Coastal Plain.

The sediments of the lowlands consist of fine sands. These deposits result from the movement of currents associated with tidal variation, which places clays in suspension and causes the sands to concentrate. The largest occurrences of lowlands can be found in Largo do Canéu and Largo de Santa Rita.

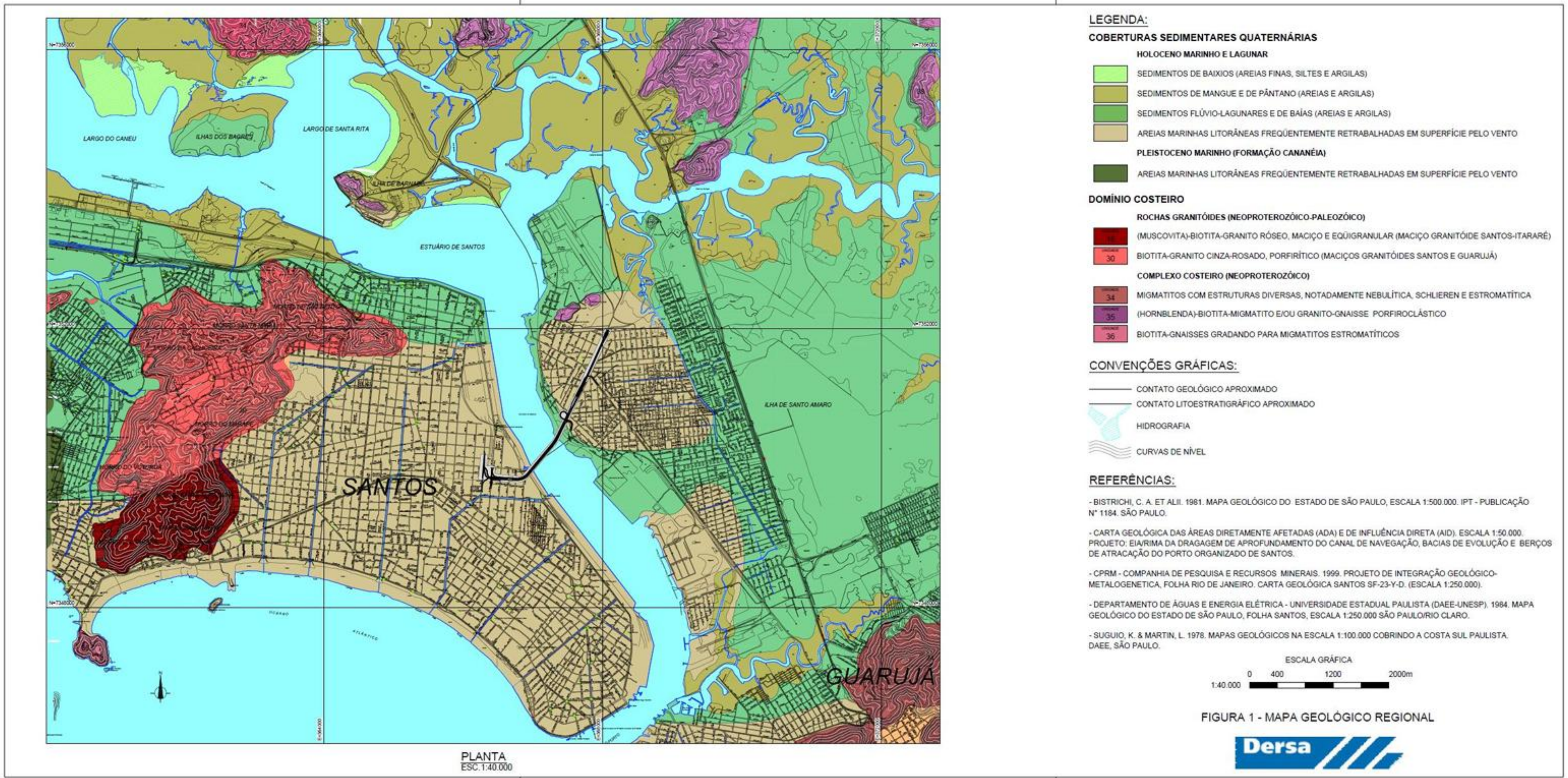


**Figure 3 – Regional Geological Map**

### 4.3. GENETIC ASPECTS OF SEDIMENTARY COVER

The Baixada Santista region has been deeply affected by the sea level changes (MNM) that have occurred over the last 25,000 years, as shown in Figure 4. Around 17,000 years B.P., there was an intense cooling of the Earth, with ice from the poles advancing towards the Equator. The freezing of the water caused the sea level to drop by around 110m, establishing a new base level for the drains that flowed down from the Serra do Mar. With greater erosive power, the rivers were deepened, their valleys widened and coalesced, giving rise to a bay in the Santos region.

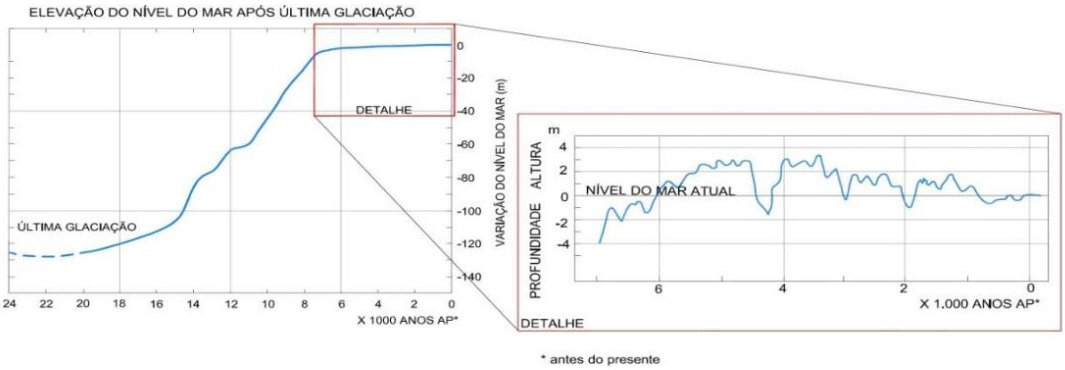


**Figure 4 - Sea Level Change over the Last 25,000 years.**

With the warming of the planet, the sea level has risen again, establishing beach, mangrove and lagoon environments, with the deposition of marine and fluvial-lagoon sediments, replacing the previous predominantly erosive environment. As the rise in sea level fluctuated, there were advances of the beach line towards the mainland (marine transgressions) and retreats (regressions). These processes were repeated over time, resulting in complex interleaving of clay and sand layers. In the initial phase of sea level rise, marine sediments were contributed by materials carried by the rivers that supplied the estuary.

Thus, the genesis of the Holocene and Pleistocene transitional fluvial-lagoon sediments is related to variations in sea level linked to eustatic glacial fluctuations, as elucidated by SUGUIO & MARTIN (1978). Pleistocene and Holocene deposits are associated with transgression and regression events that began between 120,000 and 100,000 years B.P. (SUGUIO & MARTIN, 1978), interspersed with an intense erosion process. The Pleistocene deposits comprise marine-continental sediments made up of sands, partly reworked by the wind, and clays, the latter called “Transitional Clays” (TA) by MASSAD (1986, 1996). According to CPRM (1999), these deposits belong to the Cananeia Formation, formed during a transgressive phase called the Cananeiense Transgression (120,000 - 100,000 years B.P.), during which the sea level was 7 m higher than it is today. A later regressive phase (17,000 years B.P.), due to a glaciation event, would have lowered the sea level by 110 m, implying strong erosion of the sediments of the Cananeia Formation (SUGUIO & MARTIN, 1978).

The fluvial-lagoon and bay sediments, known as SFL (MASSAD, 1985, 1986, 1996), in the region of interest, comprise soft to very soft clays. These deposits have their genesis associated with the Santos Transgression (7,500 – 5,000 years B.P.), during which a system of lagoons would have formed from the ingression of the sea into the mainland. These deposits can be up to 50 m thick (SUGUIO & MARTIN, 1978). Figure 5 shows the geological evolution model of Pleistocene and Holocene deposits, prepared by SUGUIO & MARTIN (1976a). SUGUIO & MARTIN (1976a) proposed five evolutionary stages for the formation of the São Paulo sedimentary plains, as can be seen in Figure 5, which corresponds to:

- 1st stage – maximum of the Cananeia Transgression (120,000 years B.P.): the sea would have reached the foot of the Serra do Mar, deposition of sediments from the Cananeia Formation.
- 2nd stage: deposition of coastal strands on top of the deposits of the Cananeia Formation (coastal marine sands), during the regressive phase after the maximum of the Cananeia Transgression.
- 3rd stage – maximum regression: the sea level was approximately 100 m lower than it is today; partial fluvial erosion of the deposits of the Cananeia Formation.
- 4th stage – start of the Santos Transgression: formation of a lagoon system when the sea entered the mainland, deposition of sandy-clary sediments rich in organic matter; erosion of the Pleistocene sediments of the Cananeia Formation and formation, through reworking, of sandy deposits.
- 5th stage: sea level returns to current level; deposition of coastal strands.

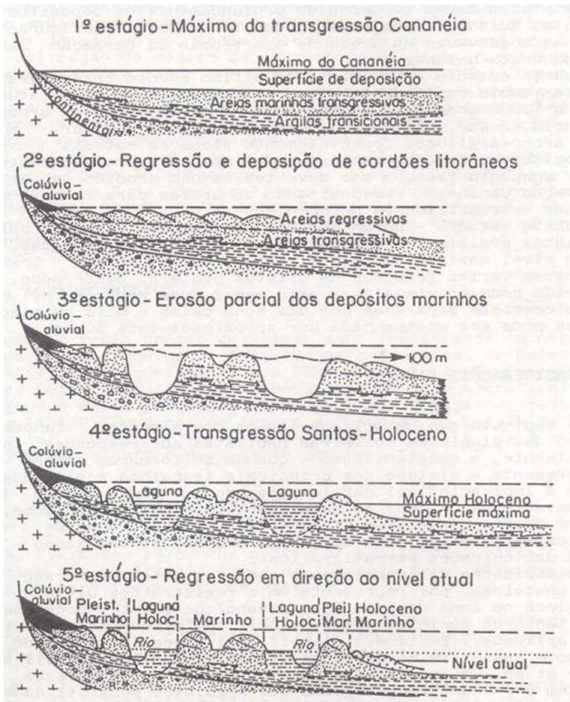


**Figure 5 - Evolutionary Stages in the Genesis of the São Paulo Sedimentary Plains Proposed by SUGUIO & MARTIN (1976a).**

With regard to the formation of the Santista paleobay, Ab'Saber (1965 apud MASSAD, 2009) suggests the existence of two well-defined NE-SW cores in it, as shown in Figure 6.

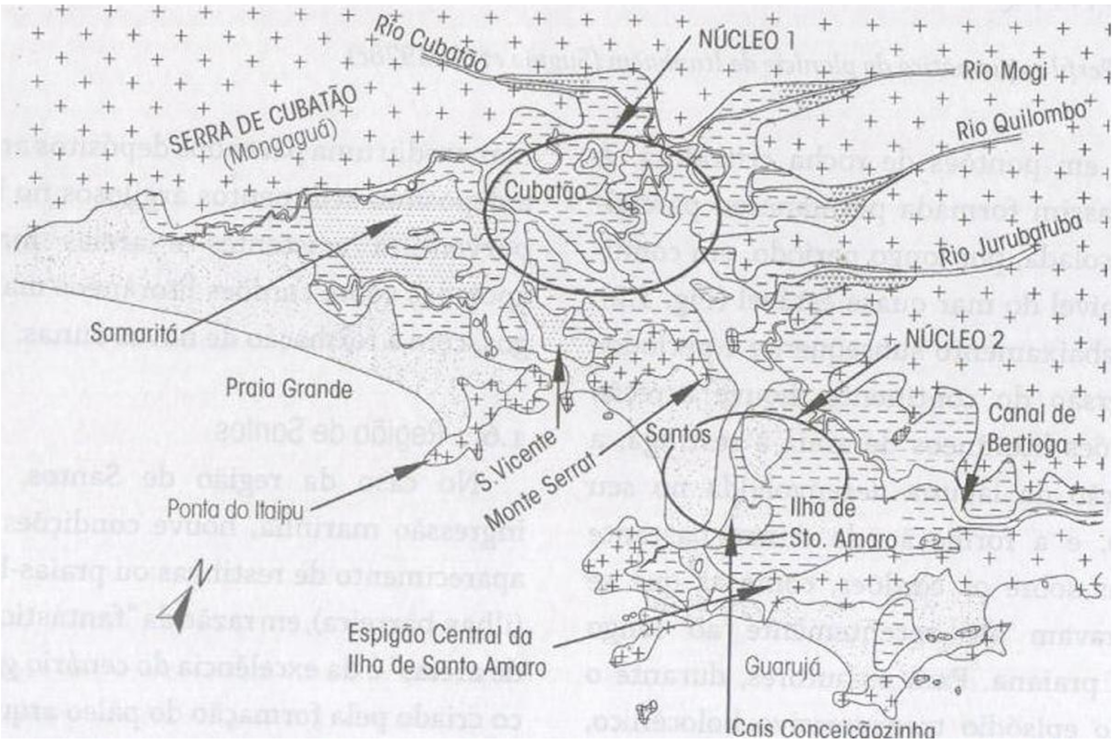


**Figure 6 - Location of the two cores of the Santista Paleobay.**

Core 1 would be located between the Serra de Cubatão and the Monte Serrat Itaipu Massifs, in the current region of Cubatão and Samaritá, where there are still remnants of Pleistocene sands. These sands would have remained protected by the rocky massifs. It is likely that a sandbank or barrier beach was established on the Ponta de Itaipu and Serra de Cubatão. Sedimentation in this Core took place in an environment of turbulent fluvial-marine waters, in front of important rivers in the region, so the deposits are heterogeneous, with more or less chaotic changes of sand and clay layers.

Core 2 is located between the Monte Serrat-Itaipu Massif and the Central Spur of Santo Amaro Island. The Pleistocene sands at this site were eroded during the 2nd and 3rd stages (Figure 5); remnants of transitional clays remain only at depth. The sandbank would have rested on Ponta de Itaipu and at the most seaward end of Spur of Santo Amaro Island. A large bay developed on its side, later transformed into a lagoon. Therefore, in this Core, sedimentation took place in the calm waters of bays. Thus, the deposits show greater homogeneity in the clay layers, with little interleaving of sand layers.

### 4.4. SISMICITY

Southeast Brazil is subject to a low level of seismic activity, typical of intra-plate regions. The state of São Paulo and neighboring areas have seismic records that reach magnitude 5.2 on the Richter Scale and intensity VI MM (Modified Mercalli Intensity Scale), according to MIOTO (1996). Historically, the Cananeia earthquakes (1789 and 1946) have not been surpassed in their magnitude of 4.6 and intensity of V-VI MM, as have the Lorena (1861, with 4.4 and V MM), Pinhal (1922, with 5.1 and VI MM) and Cunha (1967, with 4.1 and VI MM) earthquakes.

These events occurred in areas of geological structures that show evidence of intermittent movements over time, on the scale of millions and thousands of years. The regions of greatest seismic activity were identified by HASUI et al. (1982) as seismogenic zones, areas where earthquakes are generated and where the release of seismic energy is linked to the same set of geological processes. The most recent update on seismogenic zones was presented by MIOTO (1993).

These zones contain the largest seismic events, the outline of the greatest effects caused by the propagation of seismic waves and the tertiary mobility characteristics of their rocky terrain. From interest to the immersed tunnel are the Cananeia and Cunha seismogenic zones. In the Cananeia Seismogenic Zone, located between Barra do Turvo and Peruíbe as far as Bocaiuva do Sul, Morretes and Matinhos, the largest events are those of Cananeia, which occurred in 1789 (V-VI MM) and 1946 (4.6 and V MM). Paranaguá (1887, IV MM) and Rio Vermelho (1978, 3.3 and IV MM) are also important. In 1971, several events occurred associated with the Capivari-Cachoeira reservoir, with a maximum intensity of VI MM.

Between Santos and Bananal, the Cunha Seismogenic Zone is identified. The largest earthquake was the Lorena earthquake (1861), which reached a magnitude of 4.4 and a maximum intensity of V MM. Other important events are Cunha (1967), with parameters of 4.1 and VI MM, and São Pedro and São Paulo (RJ), in 1886, with 4.3 and V MM. Near the Paraibuna-Paraitinga reservoir, seismic events have been recorded since 1977, with 3.3 and IV MM. Near the Jaguari reservoir, earthquakes have been recorded since 1985, with the largest reaching 3.0 and VI MM. In the district of Monsuaba (Angra dos Reis, RJ), in 1988, there were events on the slopes of the Serra do Mar with magnitude of 3.2 and V MM, with very restricted areas of effect. MIOTO (1984, 1996) presented earthquake recurrence studies for southeastern Brazil, showing a probability of 83 to 98 % of the largest earthquake in 5 years being equal to or less than VI MM, with a return period of 6 to 40 years.

Seismic risk assessment considering magnitude was presented by BERROCAL et al. (1996). A magnitude 4 event has a 19% probability of occurring within 1 year and a probability close to 100% within 25 years. A magnitude 5 event has a 2% probability of occurring within 1 year and an 87% probability of occurring within 100 years.

BERROCAL et al. (1996) analyzed earthquakes in southeastern Brazil and presented recurrence intervals for earthquakes of magnitudes 4.1, 4.8, 5.1, 5.5 and 6.3, of 17, 100, 200, 600 and 4,000 years, respectively. He observed that the predicted recurrence intervals are consistent with the values observed in the Seismotectonic Province of the Precambrian Basement up to magnitudes of 5, but for values above the values are inconsistent with those observed, since the observation interval was only 225 years.

Figure 7 shows the events in the State of São Paulo based on the Brazilian Seismic Bulletin and the Interactive Seismicity Map of Brazil (SisGIs), both from the Institute of Astronomy, Geophysics and Atmospheric Sciences of the University of São Paulo (IAG-USP), in a consultation carried out in March 2013. The seismic records range from 1720 to the date of the consultation.

Based on the magnitudes and intensities of the recorded seismic events, the possibility of events with accelerations in the range of 0.030 to 0.080 g in the area of interest can be assessed.

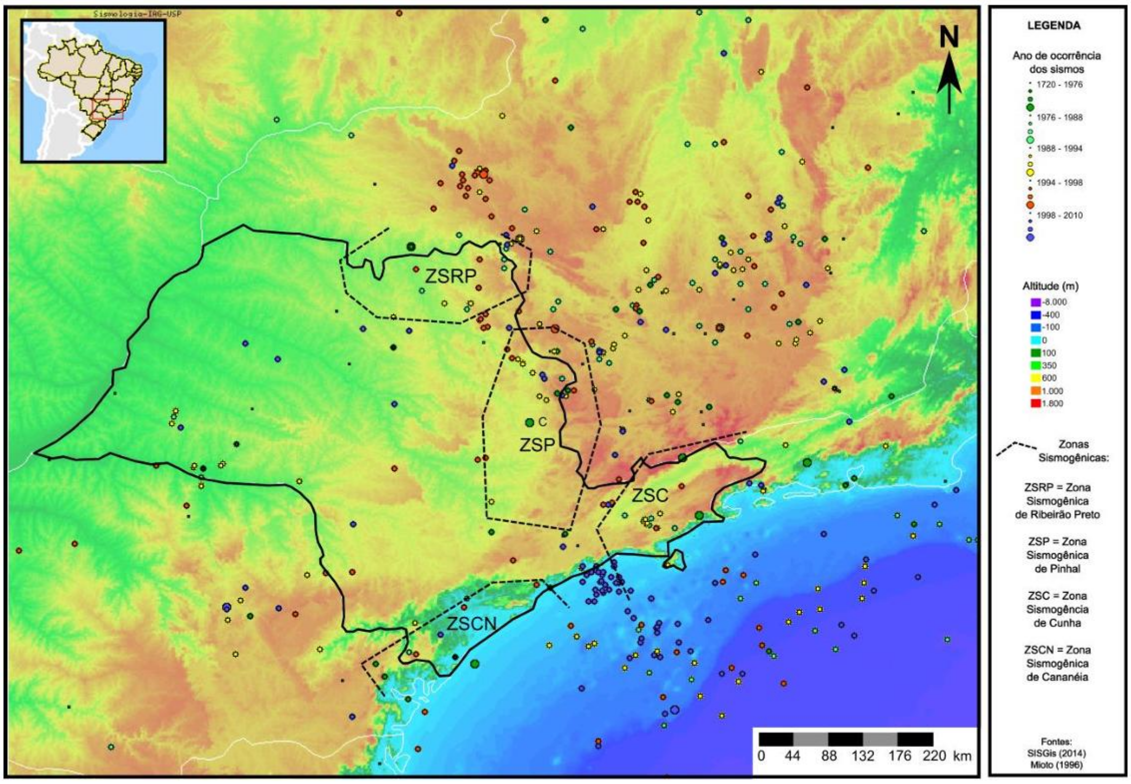


**Figure 7 - A. Earthquakes with Magnitude Greater than or Equal to 2 mb Occurring in the State of São Paulo, in the Period between November 1720 and March 2013 (the size of the circles indicates the magnitude or intensity of the events).**

# 5. CHARACTERIZATION OF LOCAL CONDITIONS

## 5.1. GEOLOGICAL-GEOTECHNICAL UNITS AND WATER LEVEL

### 5.1.1. Characterization of geological-geotechnical units

The following geological-geotechnical units are observed at the site of the Santos-Guarujá Immersed Tunnel: embankment (At), clayey sediments called fluvial-lagoon (SFL) and transitional clays (AT) covered and interspersed by three levels of sandy sediments (called from top to bottom, respectively Ar1, Ar2 and Ar3). The sediment package occurs on crystalline rock alteration soil and in some cases directly on soft altered rock, which normally overlies hard rock. These rocks consist of gneisses, migmatites and granites, and locally pegmatites, mafic portions and possibly quartzite lenses. The top of the soft altered rock was defined when it reached 50 blows for the 30-centimeter penetration of the SPT sampler, or the ratio 2 blows/1 cm in the SPT test.

The main characteristics of these units are presented below.

- **Embankment (At)** – Made up of several materials. Thicknesses are in the order of 1 to 2 m and locally reach 3 to 4 m.
- **Fluvial-Lagoon Sediments (SFL)** – Organic clay, often with micas and shell fragments, occurrence of plant remains in some sections; sometimes sandy and often with discontinuous portions and/or levels of sand, characteristics observed in samples from the sampler nozzle, very frequently and in most of the surroundings, at the base of the layer; rarely shows lenses with a metric thickness of very finer to fine washed sand or with clay portions and/or levels; dark gray and black; SPT<4;

    - **SFLa** - similar to SFL organic clay, not very sandy, with a flocculated appearance, which possibly corresponds to a more recent phase of deposition. This unit is only present on the canal front, Guarujá side.
    - **SFLb** - similar to organic clay SFL, occurring at depth and SPT, generally SPT < 4 and 5. Usually occurs over transitional clays (AT). Sometimes sandy clays and/or clays with sandy levels and/or portions or even clayey sands are found where SFLb occurs.
- **Transitional clays (AT)** – Silty clay, sometimes sandy, with micas, often with peat and rarely with shell fragments; with lenses of metric thickness of fine sand or fine, medium and coarse sand, washed or with clay portions and/or levels; light gray, greenish gray, grayish brown and dark gray; SPT >5.
- **Sandy Sediments (Ar)**
    - **Ar1**- Very fine to fine sand, often washed or slightly silty/clayey (Ar1a); with micas, often clayey or with clayey portions and/or levels, or clayey with washed sand portions and/or levels (Ar1b), mainly near the contact with the SFL; gray, grayish brown and yellowish brown.
    - **Ar2** – Fine washed or slightly/clayey sand (Ar2a), with clayey portions and/or levels (Ar2b), or clayey sand with washed sand portions and/or levels (Ar2c), with micas and often with shell fragments and plant remains; gray and dark gray.
    - **Ar3** – Medium to coarse sand, sometimes fine, with subangular quartz grains, sometimes with pebbles up to 7 cm, almost always washed or slightly silty/clayey, sometimes with clayey sections; with micas and sometimes with plant remains; light gray.
- **Alteration soil of gneiss, migmatite, granite** - Sandy silt with little clay and fine to medium sand with little clay, with micas; gray, greenish gray and white.
- **Pegmatite alteration soil - SA white** -Sandy silt with coarse sand and quartz fragments, kaolinic, micaceous.
- **Quartzite alteration soil** – Fine, slightly clayey, micaceous, whitish sand.
- **Mafic rock alteration soil** – Slightly sandy silty clay, greenish gray.
- **Soft (RAM), hard (RAD) and sound (RS) altered rock** – Gneiss, migmatite, granite, pegmatite and locally quartzite and mafic rock.

#### 5.1.2. Depth and thickness of geological-geotechnical layers and water level

Sections representing the depth and thickness of the geological-geotechnical beds and the representation of the water level have been prepared and are shown in the drawings listed below:

- On the Guarujá side between the left bank of the canal and the end of Rua Dr. Guilherme Guinle and Rua Mato Grosso are shown in Drawings DE-42.04.402-G12/001 to 007 in a longitudinal section near the upstream limit of the work and in Drawings DE-42.04.402-G12/008 to 014 near the downstream limit. The longitudinal geological-geotechnical sections are shown parallel to the shaft upstream (DE-42.04.402-G12/015 to 019) and downstream (DE-42.04.402 G12/020 to 024). The cross-sections of the shaft are shown in Drawings DE-42.04.402-G12/025 to 038. The geological-geotechnical sections prepared for the OAEs are in Drawings DE-42.04.401-G07/001 to 002; DE-42.04.402-G07/001 to 002; DE 42.04.403-G07/001 to 002; DE-42.04.405-G07/001 to 004 and DE-42.04.407-G07/001.
- In the region of the canal – the Guarujá and Santos sides and the central portion of the canal - sections where probing and test investigations are available are shown in Drawing DE-42.03.302 G12/001 to 002 in a longitudinal section near the upstream limit of the work

and in Drawing DE-42.03.302-G12/003 to 004 near the downstream limit. The cross-sections along the site shaft are shown in Drawings DE-42.03.302-G12/005 to 011.

- On the Santos side between Av. Senador Dantas and the right bank of the canal are shown in Drawings DE 42.02.202-G12/001 to 003 in a longitudinal section near the upstream limit of the work and in Drawings DE-42.02.202-G12/004 to 006 near the downstream limit, as well as in the longitudinal geological-geotechnical sections parallel to the site shaft upstream (DE 42.02.202-G12/007 and 008) and downstream (DE-42.02.202-G12/009 to 011). The cross-sections along the site shaft are shown in Drawings DE-42.02.202-G12/012 to 019. The geological-geotechnical sections were also prepared for the OAEs in Drawings DE-42.02.201-G07/001, DE-42.02.202-G07/001 to 002, DE-42.02.203-G07/001, DE-42.02.204-G07/001 and DE-42.02.205-G07/001.

### 5.1.3. Characteristics of the Guarujá, Canal and Santos sides:

- **Guarujá Side:**

In the region of the Guarujá embankment, the contact between the alteration soil and the sediments is located approximately between elevations -32, -36 and -40m. From stake 140 towards Praça 14 Bis, this contact (often a contact between sediments and soft altered rock) is at lower levels around elevations - 43 and - 48 m. From Praça 14 Bis to the end of the layout, the contact is at around elevations -40 and -50 m.

The SFL clay layer present closest to the surface showed values in the order of zero blows for the total penetration of the sampler and even beyond its extension, in general when the probing were drilled with a mechanized auger, and values in the order of 1 to 2 blows in the case of conventional percussion probing. This layer is also characterized by a high frequency of shells.

The AT clay layer which occurs at depth has higher SPT values (usually >5 blows) and sometimes in the order of 10 to 15 blows, especially in the case of higher sand content, the occurrence of charred plant remains or pebbles. In the Ar2 sandy layers, anomalously low SPT values were sometimes observed, often associated with the occurrence of sand flow into the probing. The sandy layers Ar1, Ar2 and Ar3, in general, have relatively high permeability values and certainly with high contrasts with respect to the SFL and AT clays that are in contact with these sands. These characteristics are to be expected, as these layers are made up of fine sands with practically no fines, although they do have portions and/or levels of clay or clayey sand, in the case of layers Ar1 and Ar2, and predominantly medium and coarse sands, generally with no fines, in the case of Ar3.

These generally permeable assets are confined by the clay layers and control the percolation of the sedimentary package. Infiltration tests showed values between 7.15 x 10-5 and 1.06 x 10-3 cm/s, with many values in the order of 10-4 cm/s for the Ar2 layer and between 4.07 x 10-6 and 1.16 x 10-3 cm/s for the Ar3 layer, with many values above 5 x 10-4 cm/s. When tests are carried out where larger volumes are monitored, such as in pumping tests with piezometers, higher permeability values have been observed than in local tests such as infiltration tests. Thus, considering the granulometric composition observed in the samples, the permeability values of these sands can be increased by 5 to 10 times in the case of Ar2 sands and by at least 10 to 50 times in the case of Ar3 sands.

These estimates are based on the experience of other projects where three-dimensional pumping tests have been carried out with instrumentation at several scales, as well as infiltration tests. Therefore, they are permeable sands confined by layers of clay and represent an important condition for watertightness in the area of the panel joints, since they shall be crossed by the diaphragms.

The thickness of the alteration soil is variable, with a predominance of values between 5 and 13 m. As for the characteristics of the alteration soil, it is often compact to very compact, as soon as it comes into contact with the sediments. The occurrence of highly compacted alteration soil can make it difficult to excavate the diaphragm walls planned in the project and to crimp these walls below the contact with the sediments, in alteration soil or soft altered rock, and it may be necessary to use rock excavation equipment and not just clam shell.

Pegmatite alteration soil – known as white SA – can also be important for the diaphragm, especially when it is slightly or moderately compact, silty in nature and possibly very erodible, in cases where it has fractures and/or sandy and quartz veins with a higher hydraulic conductivity that contrasts with that of the alteration soil.

In the same way that the sands crossed by the diaphragm represent an important constraint on watertightness in the region of the panel joints, this alteration soil can represent an important constraint on watertightness at the base of the panel. Infiltration tests on the alteration soil showed values in the order of 6.18 x 10-5 cm/s to 5.83 x 10-4 cm/s, with the highest values expected to be associated with sandy soils with few lines. In the case of white SA, these values range from 7.95 x 10-6 cm/s to 1.49 x 10-3 cm/s. Water loss tests on rock showed zero specific water loss at 2.94 (l/min)/(m.kg/cm2). These relatively low values are associated with very and slightly fractured massifs. The water levels measured in the probing are around zero to +1m and in some cases lower, possibly reflecting a different reading condition than the first NA obtained during the probing.

The water levels measured in the piezometers installed have been relatively constant during certain periods over time and have also not shown any major variations in the readings taken in the mornings and afternoons, demonstrating that they are not influenced by the tide in the natural conditions when the surveys were carried out. At SM-204, the piezometer installed in the Ar3 sand layer showed a lower water level than the one installed in the Ar2 sand layer, although the differences are in the order of 0.25 to 0.62 m. At SM-207, the piezometer installed in the alteration soil showed a water level very close to that of the Ar2 sand layer, with a maximum of 0.2 m below it. The piezometer installed in the AT clay and Ar3 sand layer showed the highest water level, with differences between 0.38 and 1.16 m above that installed in the alteration soil.

These differences in hydraulic loads in the sand layers at different levels, although small, may be reflecting the confinement of these layers by the clay sediments. The relatively small differences in the natural conditions when the probing was carried out are possibly attributable to the flatness of the area and the distribution of the sub-horizontal layers in a domain of gentle topography.

The results of the CPTU tests showed behavior compatible with that expected from the classification of the probing samples, as shown below:

- The contacts between the different units obtained through the tactile-visual classification of the percussion and mixed probing samples indicated in the geological-geotechnical sections are located fairly close to the contacts indicated by the CPTUs. When differences are observed, they are often attributed to the transition between one layer and another. An example is the sandy portions and/or levels at the base of the SFL clay layer observed in the classification of the samples, where the CPTUs indicate “peaks” of peak resistance (qt) higher than in the overlying SFL and lower than in the underlying sand. Some differences are due to the different locations of the probing.
- It can be seen that the SFL clays have the lowest peak resistance values (qt), with no major variations, only increasing with depth. Small variations are observed mainly at the base of the layer where there are discontinuous sandy portions and/or levels.

- The sands show higher peak resistance values and also quite variable values, which is possibly due to the clay portions and levels interspersed with the sands. For the Ar1 layer, maximum values in the order of 6000 to 10000 kPa were observed and for the Ar2 layer, values between 2000 and 7000 kPa.
- The AT clays have higher peak resistance (qt) and pore pressure than the SFL clays.

From the CPTUs, below the embankment, sands were identified with peak resistance (qt) between 1000 and 7000 kPa and reaching values of around 10000 kPa, with typically drained behavior. At the base, the peak resistances (qt) are lower and the pore pressure is higher. They correspond to the Ar1a and Ar1b layers identified in the probing. Sometimes the base sub-layer is absent and, when it occurs, it represents changes from the conditions of deposition of SFL clays corresponding to coastal fluvial-lagoon environments to those of deposition of beach sands and/or dunes.

The second layer identified in the CPTUs corresponds to the SFL clays. There is a layer of homogeneous clay with a peak resistance (qt) of around 500 to 1000 kPa and pore pressure between 300 and 600 kPa, increasing with depth. At the base of this layer there is clay with sand levels and/or lenses, probably representing a transitional contact between the Ar2 sandy layer and the SFL clay layer during the Santos Transgressive phase.

The peak resistance is around 1000 kPa, similar to that of homogeneous clay, but there are increases in these values up to 2000 kPa, associated with an abrupt reduction in pore pressure, which indicates the presence of sand. The pore pressure varies between 200 and 700 kPa, with no indication of increases or decreases with depth. The underlying layer corresponds to Ar2 sands, with peak resistance (qt) of around 2000 to 4000 kPa, reaching up to 6000 to 7000 kPa and variable pore pressure behavior. In general, the peak resistances are similar throughout the layer, but in many cases it is clear that they increase with depth and are associated with a decrease in pore pressure.

In CPTUs SP-104, SP-107, SP-159, SM-207 and 105, the sands are permeable with pore pressure values between 200 and 300 kPa. In other CPTUs there are abrupt increases of up to 500 to 700 kPa at the top (CPTUs-101, 102, 104, 107, 108, 119, 124, SP-112, SP-115, SP-120, SP-122 and SP-125); and in others these increases occur throughout the layer (CPTUs-106, 121 and 123). In CPTUs-102, SP-115 and SP-159, sandy clay and clayey sand were detected below the sands, with pore pressure between 700 and 800 kPa and peak resistance around 1500 kPa and 2000 to 3000 kPa, respectively.

Below the sands, the silty clay layer corresponding to the transitional clays (AT) was identified, whose contact occurs abruptly, indicating contact by erosion. The peak resistances (qt) are between 2000 and 3000 kPa and the pore pressures are between 900 and 1500 kPa, characterizing undrained behavior. Interspersed with these clays are sands, as indicated by the abrupt decreases in pore pressures and also abrupt increases in peak resistances, with values of up to 15000 to 20000 kPa.

Some CPTUs reached the Ar3 layer, which has peak resistance values (qt) of over 20,000 kPa and very low pore pressures. CPTU-119 and 108 (probably) tested the alteration soil layer, indicating peak resistance of around 2000 kPa and pore pressure between 500 and 1100 kPa.

- **Canal:**

For the canal, the results of seismic surveys, probing and tests carried out on the Guarujá and Santos sides and in the central portion of the canal are available. A bathymetric contour map of the site was generated from the bathymetric surveys.

The mosaic produced indicated: (i) rocky outcrops on the bottom surface, indicated by a rough texture, in the northwestern portion of the area, corresponding to Pedra do Teffé; (ii) with the exception of the rocky outcrop, the rest of the area has a fairly homogeneous bottom, characteristic of areas with sediments; (iii) the presence of grooves indicating the action of dredging processes, active at the time of the survey; (iv) the absence of large obstacles on the bottom surface of the canal.

The continuous seismic profiling data divides the area investigated into two sectors with different properties, half on the Santos side and half on the Guarujá side. On the Santos side, the outcropping bedrock on the surface upstream of the area, as shown by the side-scan sonar, was followed by seismic profiles that showed the downstream dip of this bedrock and its positioning between elevations – 46 and -52 m in the tunnel region. On the Guarujá side, the data did not allow the acoustic bedrock to be determined. Only in a few restricted stretches was it possible to detect seismic reflectors, which when correlated with data from nearby probing (not on the seismic profiles) seem to represent the acoustic bedrock, or soft altered rock. The small thickness of the water column on the Guarujá side and the probable presence of gas may be factors that prevented the propagation of the acoustic signal in the layers present below the bottom surface of the canal.

Based on the interpretation of the seismic profiles, a contour map of the acoustic bedrock was prepared, which also shows the sections of the seismic profiles where the acoustic bedrock was detected. The tunnel layout and available probing were plotted on this map, as shown in Figure 8. From this figure, there are few seismic profiles that have shown results to be compared with the probing, but it seems that the acoustic bedrock is generally below the surface of the soft altered rock (RAM) obtained from probing. The sedimentary layers overlying the acoustic bedrock were indicated by three reflectors that showed irregular occurrences.

The seismic profiling carried out in part of this region showed resolution in only a few sections and, therefore, the data available are those from direct investigations.

The geological-geotechnical units are the same as those observed in the emerged portion, except for the embankment and the Ar1 sandy layer, which are not present in the canal portion, and the presence of the SFLa subunit on the Guarujá side of the canal. SFLa clay is similar to SFL organic clay, but not very sandy, with a flocculated appearance, which possibly corresponds to a more recent phase of deposition. The SPT test with mechanical equipment also showed a systematic occurrence of zero blows for penetration lengths always greater than the standard 45 cm of the sampler in the SFL clay, while in the submerged portion, tests with similar equipment sometimes showed values of zero to one blow and sometimes values in the order of two blows. The dredging of the canal and the respective reliefs could possibly be related to this difference in behavior. Another possible explanation could be the presence in the canal of more recent and less consistent sediments than those in the submerged portion.

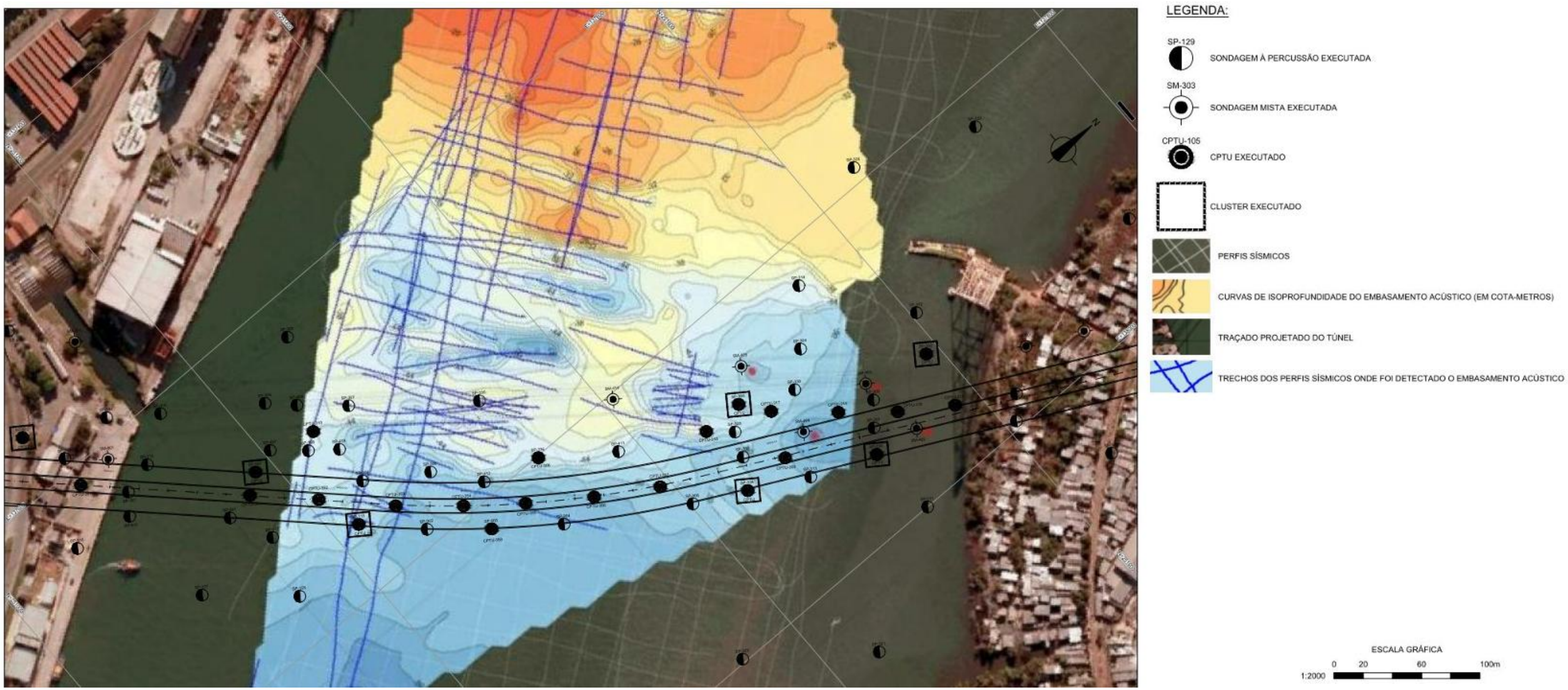


**Figure 8 – Contour map of the acoustic bedrock**

The SFL clay layer is found up to the elevations – 22 m on the Guarujá side, (in modules 4, 5 and 6), its thickness decreases in the central portion of the canal (modules 2 and 3), developing between the elevations – 15 a – 22 m, and its base develops around the elevation -18 m on the Santos side (module 1). There is a subdivision of the SFL clay on the Guarujá side of the canal, SFLa, corresponding to a slightly sandy organic clay. In the region close to the Santos bank (module 1) is the SFLb, on which the tunnel will be built. Below the SFL layer is the sandy sediment layer (Ar2 – Ar2a, 2b e 2c). This layer is generally found between elevations – 20 a – 30 m along the entire canal and in some places, such as module 3, it extends to below the tunnel base.

The thickness of the AT clays in the canal region is most often between 2 and 5 m and between 8 and 11 m. It generally develops between elevations -27 a -43 m, with the Guarujá side (modules 4 and 5) between elevations -27 a -40 m, in the central portion of the canal more often between elevations -27 and -33 m and on the Santos side between -30 a -43. In some places the AT clay is absent, which can be explained by erosion processes prior to the deposition of more recent sediments. The SPT values of the AT clays are variable, with values in the order of 4 to 12 blows, 12 to 28 in some probing and 36 to 46 blows in others, which shall reflect the different compositions: silty clays, silty and sandy clays, clays with lenses and/or layers of sands sometimes with levels of coarse sand and pebbles, clays with charred plant remains and peat.

For most of its length, the tunnel is based on AT clays and in some areas on Ar3 sands associated with these clays or which occur at the base of this layer. The contact between the alteration soil and the sediments is approximately between -32 and -40 m. Thus, in some sections the tunnel foundation is in or near this contact, so there is a possibility that the tunnel is supported on alteration soil in some sections, while in other adjacent sections it may be supported on sediments such as AT clays or SFLb clays, i.e., on materials with different deformability characteristics. As for the characteristics of the alteration soil, it is often compact to very compact from the moment it comes into contact with the sediments.

The high compactness of these alteration soils, when compared to the low consistency of the clays, reinforces the possibility of contrasts between the deformability characteristics of the tunnel foundation. It is also worth noting the difficulties of excavating by conventional dredging in the case of compact to very compact alteration soils.

The results of the CPTU tests carried out in the canal made it possible to identify the sediment layers and the alteration soil in CPTU-306 and CPTU-SP-334. The first layer identified in the CPTUs corresponds to the SFL clays tested only on the Guarujá side of the canal.

The top unit, called SFLa, was only crossed by CPTUs 314 and 317. It has a peak resistance (qt) of between 100 and 300 kPa and a pore pressure of around 100 kPa. In CPTU-314 there is a lens of sand at the base of the layer with a peak resistance (qt) of between 1000 and 4000 kPa. The rest of the layer is a homogeneous clay with a peak resistance (qt) of around 1000 kPa and pore pressure between 300 and 600 kPa, with no major variations with depth. The underlying layer corresponds to the Ar2 sands, with peak resistance (qt) 1500 a 15000 kPa.

In the vicinity of Outeirinhos Pier, the sands with the highest peak resistance (qt) are near the top of the layer, while in the middle of the channel, the sands with the highest peak resistance are at the base of the layer. On the Guarujá side of the canal, these sands are at the top and bottom of the sandy package, often below the clayey sands that occur interspersed with the sandy package or at its base.

The pore pressure is between 200 and 300 kPa, from the Outeirinhos pier to the middle of the channel. From the middle of the canal towards Guarujá, the pore pressures are in the order of

200 to 300 kPa, with localized stretches or longer stretches at depth where the values reach up to 1000 kPa, sometimes following the reduction in the tip resistance of the sands at depth (CPTUs-SP-302, SP-305, 314 and 358).

The behavior observed in the sandy layers characterizes several sedimentation sequences in this sandy package. In some CPTUs, interspersed with the Ar2 layer (CPTUs - 315, 316, 356, 357, 359 and CPTU-SP-333) or over the AT clay layer (CPTU-313), clayey sand, sandy clay and/or clay with lenses and sandy portions were identified, whose peak resistances (qt) are between 1500 and 3500 kPa and pore pressures between 200 and 1000 kPa. Underlying the Ar2 sands, the silty clay layer corresponding to the so-called transitional clays (AT) was identified, whose contact occurs abruptly, indicating erosive contact. The peak resistances (qt) are between 2000 and 3000 kPa, with higher values in the sandy interleaving (3000 - 8000 kPa), and the pore pressure, between 900 and 1500 kPa, being reduced to 300 to 600 kPa in the sandy interleaving. In several CPTUs, the ATs have sandy lenses, as in CPTU-306, 310, CPTU-SP, CPTU-354 and 355. In CPTU-310 and CPTU-SP-315 the clays were in two sequences, one at the top clayey and the other at the base clayey with sandy interleaving. Sandy interleaving throughout the package was observed in CPTUs-306, 354 and 355 and were as thick as in CPTU-306, 310 and CPTU-SP-315.

Some CPTUs reached the base layer of the sedimentary package (Ar3) with peak resistance (qt) varying between 2000 and 15000 kPa and pore pressure of around 100 to 400 kPa and sometimes between 300 and 800 kPa. CPTU-306 and CPTU-SP334 tested the alteration soil layer, indicating peak resistance (qt) of around 3000 to 10000 kPa and pore pressure between 200 and 1200 kPa.

- **Santos Side:**

Below are the main differences between the units present on the Santos and Guarujá sides:

- The Ar1a layer is usually thicker than on the Guarujá side and is clean sand; below it, in some places, there is Ar1b, which occurs more locally and more frequently than on the Guarujá side.
- The SFL clay layer is located below Ar1 and is very thick, developing between -8.0 and -30.0 m; especially at the start of the route.
- The SFL clay layer shows clays with lenses and/or sandy portions, generally very locally at the top, bottom or even inside the layer and not in a generalized way at the base of the package as in Guarujá.
- Layer Ar2 shows interleaving of a SFL clay layer with relatively high continuity and a thickness of a few meters, while layer Ar3 occurs only locally.
- Unit Ar2d was identified locally at the base of layer Ar2, characterized by medium to coarse sand with pebbles, sometimes washed (without fines) and sometimes with clay portions.
- Between stakes 71 and 75 is the SFLb clay, which is found at a greater depth than the SFL, near the -30.0 to -40.0 m elevation.
- Continuing the occurrence of SFLb and up to around stake 65, there is clay with lenses and/or sandy portions laid on top of the AT clay.
- The AT clay layer is discontinuous, especially at the start of the upstream section and between stakes 51 and 61. When present, it develops around 30.0 and -40.0 m.
- The sediment package is found on crystalline rock alteration soil or directly on soft altered rock (RAM) and hard altered rock (RAD)/sound rock (RS).

The contact between the alteration soil and/or rock mass and the sediments is approximately between -30 and -49 m. In the upstream section, up to stake 45, this contact is often a contact between sediment and soft altered rock (RAM) and is located at around -30 and -33 m. In the rest of the section, this contact is between -33 and 49 m. In some cases, such as SM-652, the contact is with sound rock (RS) and in others, more frequently, with soft altered rock (RAM).

The thickness of the alteration soil is variable, with values between zero and 30 m. There are some instances where the alteration soil is absent, such as at the start of the layout and in the stretches near stakes 60 and 65.

As for the characteristics of the alteration soil, it is often compact to very compact from the moment it comes into contact with the sediments. The condition of small thicknesses of alteration soil and the high compactness of these alteration soils are aspects that can make it difficult to excavate the diaphragm walls and crimp these walls below the contact with the sediments, in alteration soil or soft altered rock, and it may be necessary to use rock excavation equipment and not just clam shell.

The irregularities in the tops of the rocks are more noticeable on the Santos side than on the Guarujá side. On the Santos side, the alignment of the works is subperpendicular to the foliation and other structures in the rock mass, while on the Guarujá side the alignment of the works is subparallel to these structures, which may partly explain the irregularities on the Santos side and the differences in behavior between the two sites. Infiltration tests showed values ranging from 1.09 x 10-4 to 4.67 x 10-4 cm/s for the sandy layers, predominantly Ar2. Infiltration tests on the alteration soil showed values between 4.97 x 10-5 and 5.75 x 10-4 cm/s. Water loss tests on rock showed specific water loss between zero and 2.33 l/min/m.kg/cm². The relatively low values are associated with rock massifs that are generally very slightly fractured.

The water levels measured in the probing are around zero to +1.5 m and in some cases lower, in this case, possibly reflecting a different reading condition than the first NA obtained during the probing. The water levels measured in the piezometers installed were constant over time and there were no variations of more than 5 to 6 cm in the readings taken in the afternoon compared to those taken in the morning, with no greater influence from the tide. Higher levels were observed shortly after installation, when cleaning had not yet taken place. It can be seen that the piezometers installed in alteration soil are those that showed higher water levels than those installed at the same site in the Ar3 and Ar2 sand layers, with differences between 0.15 and 0.26 m in the case of SM-653; 0.41 and 0.50 m in the case of SM-604 and 0.76 and 0.83 m in the case of SM-602, indicating the possibility of flow. The results of the CPTU tests carried out on the Santos front made it possible to identify and characterize the layers of sediment and also of alteration soil in some CPTUs. The results of the tests showed behavior compatible with that expected from the classification of the probing samples.

The first layer corresponds to sands (Ar1a) with a peak resistance (qt) generally between 5,000 and 20,000 kPa and typically drained behavior, with no pore pressure generation. At the base of this layer there are sometimes Ar1b sands with decreasing peak resistance (qt) towards the top of the SFL clay layer.

The second layer is made up of SFL clays and in a large part of the region investigated is divided into two sub-layers, with interleaving of Ar2 sands. The first sub-layer is a homogeneous clay with a practically constant peak resistance (qt) of 1000 kPa, in a few CPTUs of around 500 kPa and with a pore pressure of between 400 and 600 Kpa. When the layer is thick and without sand interleaving, at the beginning of the path, the peak resistance reaches 2000 kPa at the base of the layer and the pore pressure is between 500 and 1100 kPa.

The second sub-layer consists of clay, sometimes with sandy levels and/or lenses identified by the increase in peak resistance (qt) and decrease in pore pressure. The peak resistance (qt) of the clay is between 1000 and 2000 kPa and the pore pressure between 600 and 800 kPa. Below and interspersed with the SFL clay layer are the Ar2 sands. They are characterized by peak resistance (qt) between 2000 and even 20000 kPa, often decreasing towards the base of the sequences, as in the CPTUs between the canal and Rua Almirante Tamandaré and in others located towards the beginning of the layout. The pore pressures are around 200 to 250 kPa in the CPTUs between the canal and Rua Almirante Tamandaré and between 100 and 800 kPa in the other CPTUs located in the direction of the start of the layout.

In the CPTUs between the canal and Rua Almirante Tamandaré there are indications of two or three sequences of sand deposition, indicated by the peak resistances and pore pressures, with the highest pore pressure “peak” at around 25 m depth. For Ar2 interspersed with SFL, CPTUs-252, 253, 255 and 256 located towards the beginning of the layout, there are also indications of two sand deposition sequences, due to the presence of sands with higher peak resistance (qt) and lower pore pressure at the top and the opposite conditions at the bottom. In CPTU-259, the conditions indicated above for the top are at the bottom and those at the bottom are at the top.

For Ar2 below the SFL, in CPTUs SM-653, SM-658 and 253 there are also increases in peak resistances (qt) towards the bottom of the layer, characterizing two sandy sequences, without major variations in pore pressure. In CPTU-257, there are increases in the peak resistances (qt) for the top and bottom, characterizing three sandy sequences with small variations in pore pressure. Based on the characteristics of the Ar2 sands, in terms of deposition conditions, beach sands seem to predominate in Santos, while in Guarujá sands and clayey sands from tidal flats seem to predominate. In some CPTUs, in the region between the canal and Rua Almirante Tamandaré (CPTU 202, 206, 207, 251, 586 and CPTU-SP-502), clay was identified with sandy portions (sandy portions with tip resistance of up to 20000 kPa and drained behavior) directly on top of the AT layer or on top of sandy lenses covering the AT. This layer represents the continuity of the SFLb identified in CPTU-201 located along the right bank of the channel. The peak resistances (qt) are in the order of 1500 to 2000 kPa, and the pore pressure, in the order of 1000 to 1100 kPa, with some “peaks” of lower value in the case of SFLb.

In the case of clays identified as clays with lenses and/or sandy portions, the peak resistances (qt) are between 1500 and 2500 kPa, with higher “peaks” and similar pore pressures to SFLb. The AT transitional clays detected in discontinuous stretches, in erosive contact with the overlying layers, showed peak resistance (qt) between 2000 and 3000 kPa and higher values in the sandy interleaving, and pore pressure between 1200 and >1500 kPa, with lower values in the sandy interleaving. CPTU-206 and possibly CPTU-251 reached alteration soil (SA) with peak resistance (qt) between 2500 and 3000 kPa and pore pressure between 500 and 1300 kPa.

### 5.2. GEOTECHNICAL PARAMETERS

As shown, the definition of the geotechnical design parameters was based on the results obtained from the CPTu tests, using correlations established in the technical literature, with their coefficients calibrated through field and laboratory tests. The raw test results are presented in documents RT-42.02.000-G13/001 to 004, RT-42.03.000 G13/001 and 002 and RT-42.04.000-G13/001 to 004.

With regard to the anisotropy of the clays, Barros et al. (2014) found that Brazilian marine clays show very little resistance anisotropy. In addition, the methodology of using the minimum geotechnical parameters, with a 97.7% confidence interval, leads to conditions in favor of safety.

Based on the interpretation of the results of the geotechnical tests, especially the CPTu tests, similar behavior was observed between the results obtained in the region. Thus, it was possible to group the soils into three groups: Santos Side, Canal Side and Guarujá Side.

It should be noted that on the Guarujá side, there was an alternation between sand and clay layers at depths between 33 and 37 meters. For the Canal, there was an alternation between layers of sand and clay at depths between 30 and 35 meters, for the Guarujá and Santos sides, respectively. On the Santos Side, a thicker layer of clay was observed in profiles 656 and 662/664.

By interpreting the CPTu profiles, together with the geological-geotechnical assessment of the other probing and tests carried out for the different regions of the Development (Dry Dock/Guarujá side, Canal and Santos Side), we sought to group of the soils with similar characteristics and behavior, following the geological-geotechnical units shown below:

- At – embankment;
- SFL – fluvial-lagoon sediments;
- AT – transitional clays;
- Ar – sandy sediments: Ar1 – surface sand; Ar2 – intermediate sand; Ar3 – bottom sand;
- SA – alteration soil;
- RAM – soft altered rock;
- RS - hard and sound altered rock.

Thus, using the CPTu tests as a reference, it was possible to discretize and characterize the geological-geotechnical profiles of each region of the project. For further information on the investigations and geological-geotechnical units, see report number RT-42.00.000-G01-002. Table 1 summarizes the average values of the natural specific weights obtained from the laboratory tests for each geological-geotechnical unit. For more information, see documents numbers RT-42.02.000-G13/001 to 004, RT-42.03.000 G13/001 and 002 and RT-42.04.000-G13/001 to 004.

**Table 1 - Average specific weight of the soils in the geological-geotechnical units.**

| **Soils** | **Ar1** | **SFL** | **Ar2** | **AT** | **Ar3** | **SA** |
|---|---|---|---|---|---|---|
| $\gamma n$ (kN/m³) | 18 | 15 | 16 | 16 | 18 | 18 |

The definition of the geotechnical parameters of the soils was based on the results obtained in the CPTu tests, using the criteria and correlations presented in the following sections. The results of the laboratory tests were used to validate the values obtained through the correlations presented. It should be noted that the distinction between undrained and drained materials was made by interpreting the CPTu profiles, with the SFL and AT clays being classified as undrained and the sands (Ar1, Ar2 and Ar3) and alteration soil (SA) as drained.

**Materials with undrained behavior**

- **Interpretation of CPTu profiles:**

The CPTu test profiles were analyzed and interpreted based on the methodology proposed by Massad (2010), who found that among the Baixada Santista clays there was a practically linear relationship between the corrected peak resistance ($q_t$) of the CPTu and the depth (z), i.e.:

$$q_t = a + b.z$$

where, *a* and *b* are constant of the linear and angular coefficients of the linear relationship between CPTu peak resistance and depth, respectively.

For coefficient *a,* the average value and 97.72% confidence interval were used. Table 2 shows the values of the *a* and *b* coefficients used to define the geotechnical parameters of the SFL and AT clays, for the different universes of geotechnical parameters in the project. In addition, it can be seen that these parameters are consistent with those presented in the technical literature.

**Table 2 - Values of the “a” and “b” coefficients used to define the geotechnical parameters.**

| Linear coefficient (a) | Geotechnical Parameters Universe | | | | | |
|---|---|---|---|---|---|---|
| | Guarujá Side | | Canal | | Santos Side | |
| | SFL | AT | SFL | AT | SFL | AT |
| Average | 403 | 760 | 416 | 1360 | 490 | 1284 |
| Minimum | 272 | 520 | 261 | 1029 | 287 | 768 |

| Angular coefficient (b) | Geotechnical Parameters Universe | | | | | |
|---|---|---|---|---|---|---|
| | Guarujá Side | | Canal | | Santos Side | |
| | SFL | AT | SFL | AT | SFL | AT |
| constant | 32 | 32 | 32 | 32 | 31 | 31 |

- **Coefficient ($N_{\sigma t}$) of the pre-consolidation pressure:**

The empirical correlation proposed by Kulhawy and Mayne (1990) was used to estimate the pre-densification pressure ($\sigma'_p$) with the coefficient ($N_{\sigma t}$) determined according to the methodology proposed by Massad (2010).

$$\sigma'_p = \frac{(q_t - \sigma_{v0})}{N_{\sigma t}}$$

where, $q_t$ is the corrected peak resistance of the cone; $\sigma_{vo}$ is the total vertical pressure and $N_{\sigma t}$ is an empirical correlation factor.

As presented above, Massad (2010) found a practically linear relationship between the corrected peak resistance ($q_t$) of the CPTu and depth (z) among the Clays of the Baixada Santista. Thus, the coefficient ($N_{\sigma t}$) was determined accordingly:

$$q_t = a + b.z$$

Leading to the following relationship:

$$N_{\sigma t} = \frac{(b - \gamma)}{\gamma'}$$

where, *b* is the angular coefficient of the linear relationship between CPTu peak resistance and depth, $\gamma$ and $\gamma'$the natural and effective (or submerged) specific weights, respectively.

Calibration of this coefficient led to the following values for each set of parameters. It is highlighted that these values are consistent with those presented in the technical literature.

**Table 3 – Calibration of the coefficient $N_{\sigma t}$.**

| Coefficient | Geotechnical Parameters Universe | | | | | |
|---|---|---|---|---|---|---|
| | Guarujá Side | | Canal | | Santos Side | |
| | SFL | AT | SFL | AT | SFL | AT |
| $N_{\sigma t}$ | 3.4 | 3.3 | 3.4 | 2.7 | 3.2 | 3.2 |

- **Coefficient ($N_{kt}$) of undrained resistance:**

For the undrained resistance ($S_u$), the following empirical correlation was used:

$$S_u = \frac{(q_t - \sigma_{v0})}{N_{kt}}$$

where, $q_t$ is the corrected peak resistance of the cone; $\sigma_{vo}$ is the total vertical pressure and $N_{kt}$ is an empirical correlation factor.

The correlation coefficient ($N_{kt}$) was determined using the same methodology as $N_{\sigma t}$ (Massad, 2010), which takes into account a linear relationship between the undrained resistance ($S_u$) of the Vane Test and the depth (z), i.e.:

$$S_u = c_0 + c_1.z$$

Resulting in the following relationship:

$$N_{kt} = \frac{(b - \gamma)}{c_1}$$

where, *b* is the angular coefficient of the linear relationship between the tip resistance of the CPTu and the depth, $\gamma$ the natural specific weight and $c_1$ the angular coefficient of the linear relationship between the undrained resistance of the vane test and the depth.

Calibration of this coefficient led to the following values for each set of parameters. It should also be noted that the values presented are similar to those in the technical literature.

**Table 4 – Calibration of the coefficient $N_{kt}$.**

| Coefficient | Geotechnical Parameters Universe | | | | | |
|---|---|---|---|---|---|---|
| | Guarujá Side | | Canal | | Santos Side | |
| | SFL | AT | SFL | AT | SFL | AT |
| $N_{kt}$ | 10.9 | 11.0 | 10.6 | 10 | 10.7 | 10.7 |

- **Coefficients $\alpha$ and $\beta$ the oedometric and unloading/reloading moduli:**

For the edometric ($E_L$) and unloading/reloading ($E_{ur}$) moduli, the empirical correlations proposed by Lunne et al. (1997), respectively.

$$\frac{E_L}{\sigma'_{v0}} = \alpha.\frac{(q_t - \sigma_{v0})}{\sigma'_{v0}}$$

$$\frac{E_{ur}}{\sigma'_{v0}} = \beta.\frac{(q_t - \sigma_{v0})}{\sigma'_{v0}}$$

where, $q_t$ is the corrected peak resistance of the cone; $\sigma_{vo}$ is the total vertical pressure; $\sigma'_{vo}$ is the effective vertical pressure; $e_1$ and $e_3$ are empirical correlation factors.

The coefficients $\alpha$ and $\beta$ of the correlations were calibrated using the results of oedometer tests carried out on undeformed samples (Shelby sampler) of SFL and AT clays.

Initially, the values of $E_L/\sigma'_{v0}$ above and below the effects of pre-consolidation (OCR = 1 and > 1, respectively) were determined using the following equation:

$$\frac{E_L}{\sigma'_{v0}} = \frac{\ln\left(\frac{\sigma'_{v3}}{\sigma'_{v1}}\right).(1 + e_0)}{e_1 - e_3}$$

where, $\sigma'_{v1}$ e $\sigma'_{v3}$ are, respectively, the effective vertical pressures at the end of the stage before and after the stage considered; likewise, $e_1$ and $e_3$ are, respectively, the void ratios at the end of the stages before and after the stage considered.

From the data obtained, the coefficients $\alpha$ and $\beta$ for $E_L/\sigma'_{vo}$, above the effects of pre-consolidation (OCR = 1) and $E_{ur}/\sigma'_p$, below the effects of pre-consolidation (OCR > 1) are determined, based on the following equations, respectively:

$$\alpha = \frac{\left(\frac{E_L}{\sigma'_{v0}}\right)_{LAB}}{N_{\sigma t}}$$

$$\beta = \frac{\left(\frac{E_{ur}}{\sigma'_p}\right)_{LAB}}{N_{\sigma t}}$$

where, $(E_L/\sigma'_{vo})_{LAB}$ is the average of the values obtained by the relationship, above the effects of pre-densification (OCR = 1) and, $(E_{ur}/\ \sigma\ '_{p})_{LAB}$ refers to the angular coefficient of the linear relationship between $E_L/\ \sigma\ '_{vo}$ and OCR below the effects of pre-densification (OCR > 1). Finally, $N_{\sigma t}$ corresponds to the coefficient determined using the methodology proposed by Massad (2010), shown in Table 3.

Thus, the calibrations of these coefficients led to the following values for each universe of geotechnical parameters.

**Table 1 – Calibration of coefficients $\alpha$ and $\beta$.**

| Coefficient | Geotechnical Parameters Universe | | | | | |
|---|---|---|---|---|---|---|
| | Guarujá Side | | Canal | | Santos Side | |
| | SFL | AT | SFL | AT | SFL | AT |
| $\alpha$ | 1.41 | 1.28 | 0.89 | 1.57 | 2.08 | 2.08 |
| $\beta$ | 6.60 | 4.61 | 4.15 | 6.70 | 8.11 | 8.11 |

For the calibration of the coefficients $\alpha$ and $\beta$ only the results of oedoemeter tests were classified as very good to excellent were used, in accordance with the classification in the LD Thesis by Futai (2010) and Coutinho (2007).

Based on the interpretations of the CPTu profiles and the calibrations of the correlation coefficients, the geotechnical parameters of the soils with undrained behavior (SFL and AT clays) were defined following the script presented below.

- **Overconsolidation Ratio (OCR)**

The following equation was used to estimate the overconsolidation ratio:

$$OCR = \frac{(q_t - \sigma_{v0})}{N_{\sigma t}} . \frac{1}{\sigma'_{v0}}$$

where, $q_t$ is the corrected peak resistance of the cone; $\sigma_{vo}$ the total vertical pressure; $\sigma'_{vo}$ the effective vertical pressure and $N_{\sigma t}$ the empirical factor calibrated for each universe of parameters (Table 3).

- **Pre-Consolidation Pressure (σ’p)**

The following relationship was used to calculate the pre-consolidation pressure:

$$\sigma'_p = OCR.\sigma'_v$$

where, OCR is the overconsolidation ratio and $\sigma'_v$ the effective vertical pressure. It should be noted that the OCR value was adopted for the middle of the study layer.

- **Undrained Resistance (Su)**

The following relationship was used to calculate the undrained resistance:

$$S_u = \frac{N_{\sigma t}}{N_{kt}} . OCR.\sigma'_v$$

where, OCR is the overconsolidation ratio; $\sigma'_v$ the effective vertical pressure; $N_{\sigma t}$ and $N_{kt}$ are the empirical factors calibrated for each universe of parameters. The OCR value was adopted for the middle of the study layer. It should be noted that the $S_u$ values were corrected according to the design assumptions, which take into account the values of the minimum geotechnical parameters obtained through statistical analysis of the CPTu tests (slope of the $q_t$ curves) and which have a confidence margin of approximately 97.7%.

- **Edometric Modulus (EL)**

The following relationship was used to calculate the edometric modulus:

$$\frac{E_L}{\sigma'_{v0}} = \alpha. OCR. N_{\sigma t}$$

where, OCR is the overconsolidation ratio; $N_{\sigma t}$ and $\alpha$ are the empirical factors calibrated for each universe of parameters. It should be noted that the OCR value was adopted for the middle of the study layer. To define the secant modulus at 50% of the deviatoric tensile strength ($E_{50}$), a ratio equal to 1.25 of $E_L$ was used.

- **Unloading/Reloading Modulus (Eur)**

The following relationship was used to calculate the unloading/reloading modulus:

$$\frac{E_{ur}}{\sigma'_{v0}} = \beta. OCR. N_{\sigma t}$$

where, OCR is the overconsolidation ratio; $N_{\sigma t}$ and $\beta$ are the empirical factors calibrated for each universe of parameters. It should be noted that the OCR value was adopted for the middle of the study layer.

- **Thrust Coefficient at Rest (K0)**

The following relationships suggested by Massad (2009) were used to calculate the coefficient of thrust at rest for the SFL and AT clays, respectively:

$$K_0 = 0{,}57 * OCR^{0{,}45}$$

$$K_0 = 0{,}58 * OCR^{0{,}45}$$

where, OCR is the overdensification ratio. It should be noted that the OCR value was adopted for the middle of the study layer.

- **Recompression index ratio (Cr / 1+e0)**

To estimate the recompression index ratio ($C_r$/1+$e_0$), the following equation was used, adjusted from the ratio proposed by Lunne et al. (1997).

$$\frac{C_r}{(1 + e_0)} = \frac{2{,}3}{\left(\frac{E_{ur}}{\sigma'_p}\right)_{LAB} * OCR_{campo}}$$

where, $(E_{ur}/\sigma'_p)_{LAB}$ refers to the angular coefficient of the linear relationship between $E_L/\sigma'_{vo}$ and OCR, below the effects of pre-consolidation (OCR > 1); $OCR_{field}$ is the overconsolidation ratio for the field condition, i.e., for the acting effective vertical stress ($\sigma'_v$).

**Table 2 – Values of $(E_{ur}/\sigma'_p)_{LAB}$.**

| Coefficient | Geotechnical Parameters Universe | | | | | |
|---|---|---|---|---|---|---|
| | Guarujá Side | | Canal | | Santos Side | |
| | SFL | AT | SFL | AT | SFL | AT |
| average | 21.1 | 13.3 | 14.1 | 17.9 | 25.9 | 25.9 |
| minimum | 10.5 | 10.6 | 10.8 | 15.6 | 16.8 | 16.8 |

**Materials with drained behavior**

To estimate the geotechnical parameters of soils with drained behavior, several correlations established in the technical literature have been used. Below are the guidelines for defining the main geotechnical parameters of this type of material.

- **Effective friction angle ($\phi$')**

The effective friction angle was estimated according to the correlations proposed by Kulwahy and Mayne (1990) and Robertson and Campanella (1983), presented below, respectively. Estimating this parameter using the correlations led to differences of less than 10%. Therefore, the lowest values obtained between the correlations were adopted.

$$\phi' = 17{,}6 + 11.log(Q_n)$$

$$\tan\phi' = \frac{1}{2{,}68}.\left[log\left(\frac{q_t}{\sigma'_v}\right) + 0{,}29\right]$$

where $Q_n$ is the normalized tip resistance of the CPTu; $q_t$ is the corrected tip resistance of the CPTu and $\sigma'_v$ is the effective vertical stress. Table 9 summarizes the average and minimum values of the friction angle of the sands for the different parameter universes.

**Table 3 – Friction angle of the sands.**

| Friction Angle | Geotechnical Parameters Universe | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Guarujá Side | | | Canal | | Santos Side | | |
| | Ar1 | Ar2 | Ar3 | Ar2 | Ar3 | Ar1 | Ar2 | Ar3 |
| average | 32.0 | 25.0 | 36.0 | 33.0 | 36.0 | 41.0 | 32.0 | 33.0 |
| minimum | 29.0 | 22.0 | 33.0 | 30.0 | 34.0 | 39.0 | 28.0 | 30.0 |

As there are no CPTu tests available for Alteration Soil (SA), the correlation proposed by Teixeira (1993) was used for $N_{SPT}$ results, as follows:

$$\phi' = 15 + \sqrt{20.N_{SPT}}$$

where, $N_{SPT}$ is the number of blows of the percussion test (SPT). It should be noted that, in this case, the $N_{SPT}$ values from the percussion probing (SPT) carried out near the section in question were used.

- **Deformability modulus ($E_{50}$)**

The deformability modulus corresponding to 50% of the deviatoric shear stress ($E_{50}$) was determined using the correlation presented in Schnaid (2012) for calculating the maximum shear modulus ($G_{máx}$) and the correlation presented in Robertson and Cabal (2012) for determining the deformability modulus corresponding to 0.1% deformation ($E_{0,1\%}$)). The $E_{50}$ modulus was estimated from $G_{máx}$, following the recommendations of Howie and Campanella (2008); for the $E_{0.1\%}$ modulus, the correlation of the constitutive model of the Hardening Soil Model (Schanz et al., 1999) was used.

$$G_{máx} = 110.\sqrt[3]{q_t.\sigma'_v.P_a}$$

$$E_{0,1\%} = 0{,}015.(10^{0{,}55.I_c}).(q_t - \sigma'_v)$$

where, $q_t$ is the corrected peak resistance of the CPTu; $\sigma'_v$ is the effective vertical stress; $P_a$ is the reference pressure and $I_c$ is the soil behavior index.
Table 10 shows the average and minimum values of the deformability modulus (E50) of the sands for the different parameter universes.

**Table 4 – $E_{50}$ Deformability modulus of sands.**

| Friction Angle | Geotechnical Parameters Universe | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Guarujá Side | | | Canal | | Santos Side | | |
| | Ar1 | Ar2 | Ar3 | Ar2 | Ar3 | Ar1 | Ar2 | Ar3 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| average | 12.0 | 18.0 | 40.0 | 18.0 | 27.0 | 26.0 | 24.0 | 32.0 |
| minimum | 6.0 | 10.0 | 32.0 | 15.0 | 25.0 | 20.0 | 18.0 | 26.0 |

As mentioned in the previous item, since there are no CPTu tests for Alteration Soil (SA), the correlation proposed by Trofimenkov (1974) was used, adjusted by Teixeira (1993) for $N_{SPT}$ results, as follows, respectively:

$$E = \alpha . q_c$$

$$K = \frac{q_c}{N_{SPT}}$$

where, $q_c$ is the peak resistance of the CPTu; $\alpha$ an empirical factor of the correlation; K the conversion factor from $q_c$ to the equivalent number of blows $N_{SPT}$ of the percussion test (SPT). The $N_{SPT}$ values from the percussion probing (SPT) carried out near the section in question were used.

For materials with drained behavior, the edometric modulus ($E_{oed}$) was equal to the secant modulus ($E_{50}$) and the unloading/reloading modulus (Eur) was equal to 3 times the secant modulus ($E_{50}$).

- **Relative compactness ($D_r$)**

The relative compactness or density was estimated using the correlation presented by Lancellota (1985), according to the following equation:

$$D_r = -99 + 66. log\left(\frac{q_c}{(\sigma'_{v0})^{0,5}}\right)$$

where, $q_c$ is the peak resistance of the CPTu and $\sigma'_{v0}$ is the effective vertical stress.

Table 11 shows the average and minimum values of the relative compactness (density) of the sands obtained for the different parameter universes.

**Table 11 – Relative compactness of the sands.**

| Friction Angle | Geotechnical Parameters Universe | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Guarujá Side | | | Canal | | Santos Side | | |
| | Ar1 | Ar2 | Ar3 | Ar2 | Ar3 | Ar1 | Ar2 | Ar3 |
| average | 70.0 | 55.0 | 90.0 | 65.0 | 85.0 | 95.0 | 75.0 | 85.0 |
| minimum | 55.0 | 45.0 | 80.0 | 55.0 | 70.0 | 80.0 | 50.0 | 70.0 |

## 6. INSTRUMENTATION AND MONITORING

Instrumentation is particularly important in excavation and foundation work, both to check the assumptions, calculations and models used in the project, and to verify variations in the characteristics of the subsoil and the properties of the land. The main hypotheses evaluated for the distribution of instrumentation are:

- Monitoring to verify design assumptions;
- Monitoring to assess the interaction between the massif and the construction method;
- Checking response effects on structural supports;
- Checking the effects of the interaction between the structural system and the construction method on buildings and other areas of influence.

It should be noted that the instrumentation is also located in order to prevent and guide possible impacts on public utility networks in their area of influence on the surface of the excavated massif. Generally, the following instruments were used to measure the deformations (of the retaining walls and the pumping basis in the areas surrounding the development), the possible assessment of the stresses in the thrusts, the integrity of the diaphragm walls and piezometry.

- **Settlement pins in the retaining structure and buildings:** used to measure horizontal and vertical displacements (leveling), installed on top of the retaining structures or in the buildings near the works.
- **Surface settlement markers:** their purpose is to monitor the surface settlement of the massif affected by the construction work or any activity that interferes with it.
- **Inclinometers**: these are instruments that make it possible to monitor horizontal movements at depth. They are installed in order to control the displacement of the soil massif affected by the activity related to the implementation of the underground work.
- **Tassometer or Deep Settlement Marker**: they measure the vertical displacement (settlements) in depth of the soil or rock massifs with respect to a Level Reference (RN).
- **Piezometers and Water Level Gauges (MNA) or Water Level Indicators (INA):** To control the system for lowering the water level in the massif, the following shall be adopted: Piezometers (PZ), which record the piezometric load, i.e., the value of the pore pressure in a given geological horizon (soil layers). Water Level Gauges (MNA) or Water Level Indicators (INA), which record the water level in a tube drilled into the massif. The purpose of the process is to monitor the behavior of the water table during construction work, especially during the lowering and recharging of the water level.
- **Cross-Hole Test**: to check the integrity of the diaphragm wall's concrete continuously, using a seismic wave picked up by geophones (transmitter and receiver), based on the speed of the wave. The test is carried out using longitudinal tubes installed in the lamella reinforcement.

## 7. CHANGES TO THE REFERENCE PROJECT

The CONCESSIONAIRE may make changes to the reference project, provided it complies with the requirements of EXHIBITS 2 and 7.

In the event of a change in the layout of the Group 1 reference project, the CONCESSIONAIRE shall carry out probing at the site of the new layout in order to review the geological-geotechnical sections used as a base. It may also request that new tests be carried out in order to review the geotechnical parameters of the affected regions (Guarujá, Canal and Santos Sides).

In the case of Group 2, as the geological-geotechnical conditions of the region are not known there is no risk sharing as provided for in Clause 21.3 of the AGREEMENT.

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