The use of geosynthetics in a sea port reclaimed area in Southern Brazil

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ABSTRACT: This paper presents a well known solution, however put into practice in a unique situation. A Southern Brazilian sea port, Antonina, Paraná, prepared a relatively huge area, called back port, for disposing of the dredged material from the port entrance canal. Although taking into account the very poor geotechnical quality, due to its liquid state and erratic placement, the reclaimed area from the sea formed by the sedimentation of such heterogeneous mud fill, was devised as part of the increase in available space. A geotechnical design was then carried out to make this idea come true, and this paper describes the situation and procedures for the objective. Soil reinforcement with geosynthetic materials, fill monitoring with time and local experimental site are included in the project, herein reported.

1 INTRODUCTION

The use of reinforcing materials is very old, especially considering soft soils and roads or tracks, going as far back as several centuries. Ancient peoples as the Romans and the Chineses already applied fibers and fabrics to their roads and foundations, in order to improve strength and homogenize settlements of poor natural soils (Vertematti et al, 2004). If another scenary is considered, such as very cold areas with a lot of snow, the Eskimos also put into practice the same reasoning by wearing snow shoes with a mesh at the bottom, that acts very similarly to the other example mentioned.

Much more recently, after the fifties, as the industry began to produce fibers, fabrics and grids from fossil origin, civil engineering professionals started to test and to specify such new material (the use is very old, but the material is rather new). It is basically made out of polymers, a term of Greek root meaning “many parts”, defining Carbon-Hydrogen units repeated several times for each molecule. Chemical composition, elements added, structure and behavior are some characteristics that classify and indicate the more adequate engineering applications for each polymer type (Mano, 1991).

As the ultraviolet rays cause damage to the material, possibly one of the main reasons for its successful and widespread use in geotechnical engineering is because geosynthetics are very commonly buried and so protected by the soil (Bueno, 2004). Among others, physical properties such as tensile strength, elongation at rupture and tensile elastic modulus (Stevens, 1990) are regularly tested and publicized by manufacturers, looking for the selection of the best material for any given application.

This paper presents a rather usual geosynthetic application in civil engineering, namely soil reinforcement. Due however to the particularly difficult in situ state of the dredged heterogeneous deposited material from the sea bed, pumped to a nearby reclaimed area, the situation was considered unique and worthwhile discussing.

Antonina is an important sea port in Southern Brazil, that along with Paranaguá contributes a great deal of for Brazilian goods exported to the whole world. Both ports are located in Paraná, at the Paranaguá Bay. Antonina’s actual ship dock was constructed about ten years ago, by means of heavy precast driven piles anchored in hydraulic fill. The basic port lay-out is about 380 meters long and 70 meters wide with a concrete structure along the sea line, plus the parallel backfill, including an extra rectangular area of 90 x 70 meters (Figure 1).

2 PORT EXPANSION NEEDS AND THE GEOTECHNICAL CHALLENGE

As the country grows and the demand for products increases, obviously the sea port operations require more space and agility. Warehouses, frigorific installations, offices, parking lots and container patios are all more and more needed. The actual Port Authority area includes also a few service buildings, some temporary warehouses (mostly for paper, plywood and frozen meats) and internal roads, besides the administration hall and the federal inspection unit.

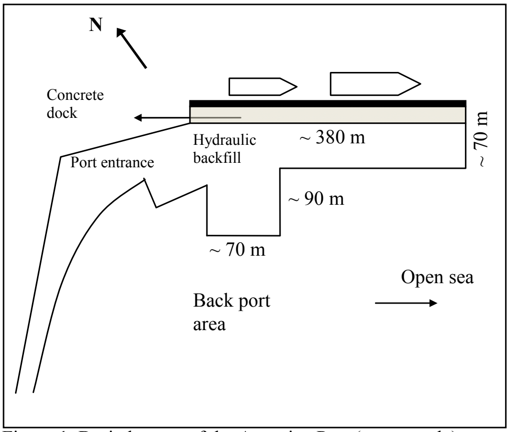

Figure 1. Basic lay-out of the Antonina Port (not to scale).

The navigation canal at the Paranaguá Bay, that determines the way, the size and the weight of ships coming from the ocean to the ports, has always been a problem. All sorts of debris, coming from the surrounding mountains (named "Serra do Mar", following the Southern Brazilian sea coast), are constantly being carried and deposited in the Galheta canal. For this reason, dredging is necessary from time to time in order to keep the ships sailing safely.

Due to the environmental legislation, dredging itself is not a problem, but disposing of the dredged material is. Generally containing soil, decomposed organic matter, gravel, tree branches, leaves and other occasional natural and men made debris, this heterogeneous composite material is highly undesirable.

Having these aspects of the problem in mind, the port authorities decided to make solution out of a big problem: a levee was built in the back port blocking the sea water in a huge pond, and the dredged material was then pumped from the canal to this pond (Figure 2). As the hydraulic fill advanced, the water was being slowly expelled from the pond and a highly compressive and weak kind of very soft "soil" took place. The dredged heterogeneous material, or DHM, defines the more superficial "soil profile" to be loaded by future roads, parking lots, buildings and other service units for the port expansion.

How to deal with such DHM was the real challenge. A few observations could be drawn from visual inspection of the dredging operation, laboratory testing and rough monitoring of the recently deposited material in the back port space:

- The initial state of the herein named DHM was a dark viscous liquid containing erratic solid matter;
- As deposition occurred from the dredging work nearby, settlements started right after due exclusively to the dead weight of the material;
- The water flow in the pond, oriented from the dock line to the back port area (Figure 1), was forced due to the placement of the dredging pipes by the limits of the existing hydraulic fill;
- It was noticeable that the very soft material gained strength with time rather quickly, making possible to walk on it with plywood boards within a few weeks after deposition – this characteristic was apparently acquired because superficial drainage happened easily, the warm weather and the wind accelerated water evaporation, and the sandy natural subsoil profile also improved consolidation (Figure 3);
- As one more evidence about how the dredged material behaved, after a few months from its deposition from the dredging pumps, a small superficial briquette (5 x 5 x 3 cm) was collected and showed enough strength not to be broken by bare hands.

The reported set of information herein summarized indicated that such a procedure could lead adequately to the necessary use of the back port area filled with DHM. To support this idea, a thorough geotechnical investigation was carried out, and its results oriented the final design for a continuous port expansion, as desired.

3 GEOTECHNICAL DATA AND DESIGN FOR THE BACK PORT AREA

The size of the back port area is about 145.000 square meters, reclaimed from the sea. In some other parts of the world, for example in The Netherlands and Japan, areas taken from the sea are not just usual but needed as well, due to the small size of such countries, comparatively to their needs. This is not exactly the case for Brazil, which territory is as big as 8.5 million square kilometers, but for the Antonina Port Authority the solution was found to be the most convenient.

A wide program of field and laboratory determinations was planned and put into effect, including SPT borings (Solotécnica, 2005), in situ vane shear measurements (Datageo, 2005), undisturbed soil sampling (Solotécnica, 2005) and laboratory consolidation tests (ABNT, 12007; Nascimento, 2005).

It is interesting to mention that the confinement of the pond, defining approximately a triangular shape for the proposed back port, was built around one year before the studies reported in this paper started. For the levee no specific evaluation of soils and foundation was made, and according to informations given by the owner, basically soils and boulders were dumped by earth moving equipment, with occasional points reinforced by geosynthetics. A general inspection of this linear structure done by the authors indicated that, even after considerable settlement had occurred, its main objective had been achieved, that was to block the sea water from the pond and to retain the pumped material inside (Figure 2).

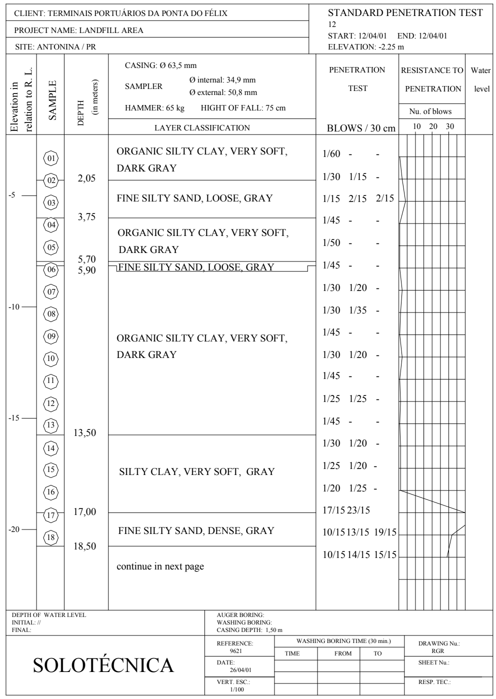

Figure 2. Antonina port area (photo – Google Earth).

Figure 3 – Typical SPT subsoil profile in the back port area

A deeper analysis of this fact gave an indication that, provided careful design, construction and monitoring were done, it was possible to use the whole area loaded with the same applied stress order of magnitude than the levee (~ 50 kPa). Certainly, settlements occurred and will keep occurring, but no evidence of rupture had been observed so far.

The SPT borings indicated primarily soft and very soft clay layers, alternating with sand lenses or layers. At greater depths, around 16 meters, compact clayey silt prevailed. Blow counts close to 2/45, 1/30 and 1/25, for example, represented either the natural local sea bed soil or the dredged material after a few months. The maximum height of deposition for the DHM was about 3 meters.

As far as the undrained shear strength was concerned, substantial scatter happened, either varying from point to point or with depth. It became clear, however, that an increase with depth does occur; measurements ranged from 10 kPa up to 100 kPa. On the safe side, this minimum value was taken as design parameter, in close agreement with other similar situation (Dias et al, 2002). By the way, for this case other geotechnical values such as natural water content, unit weight and void ratio, besides compression index, also showed comparatively close range of variation (Table 1).

Table 1 – Summary of the site soil parameters

Sample	Natural Density	Natural water Content (%)	Natural void ratio	Specific gravity	Compression index	Coefficient of consolidation (*)
US1	1,302	158,44	3,683	2,36	1,54	0,0005
US2	1,256	193,56	4,912	2,53	1,40	0,0004
US3	1,310	119,70	3,495	2,68	1,15	0,0042
US4	1,246	50,54	1,922	2,42	0,47	0,0030
US5	1,273	168,01	4,328	2,53	1,30	0,0003
Project Value	1,280	160	4,1	2,5	1,35	0,0004

USi: undisturbed samples collected from different points in the pond area (~ 0,5 m deep), a few months after dredging.
(*): Casagrande's approach, cm^2/seg.

Taking into account the poor condition of both the natural soil and the dredged material pumped to the pond, certainly either bearing capacity and settlements were of concern (ABNT, 1996). The first question was about stability of the soil mass (safety against failure) and the second was the amount of vertical compression, time dependant.

Data furnished by the owner indicated that the back port area should withstand uniformly distributed load of 50 kPa plus the container lift equipment with concentrated loads up to 150 kN per tyre.

The analysis involved three main steps:

- Possible deep failure under 50 kPa superficially applied (Low et al, 1990 – apud Palmeira and Ortigão, 2004), with geosynthetics;
- Slope stability of fill over the local weak soil under the same loading and geosynthetics reinforcement (Tenslo, 1994);
- Definition of flexible pavement for the area.

4 SLOPE STABILITY ANALYSIS

Slope stability analysis was performed to evaluate the effect of the surcharge due to additional landfill and containers to be applied over the hydraulic landfill material. Parametric analysis was made with cohesion c = 10 kPa (minimum value for soft soil) and friction angle $\phi = 0°$. Surcharge applied was 25 kPa (half of total surcharge that will be applied by containers). For this situation the safety factor obtained was 1.21, with a circle of rupture tangential to the resistant material below (Figure 4).

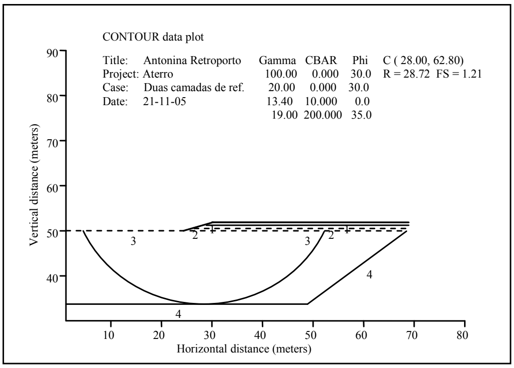

Figure 4. Analysis with c = 10 kPa and $\phi = 0°$, for soft soil.

With a small friction angle (ϕ = 2°) for the soft soil (since this material contains some fraction of sand), the coefficient of safety reaches 1.44, with a circle of rupture above the resistant soil below (Figure 5). It should be noted however that this result was obtained for half of the planned containers surcharge, which implies the need of additional consolidation in order to the shearing resistance of the soft soil to increase, until it is possible to apply the final design surcharge.

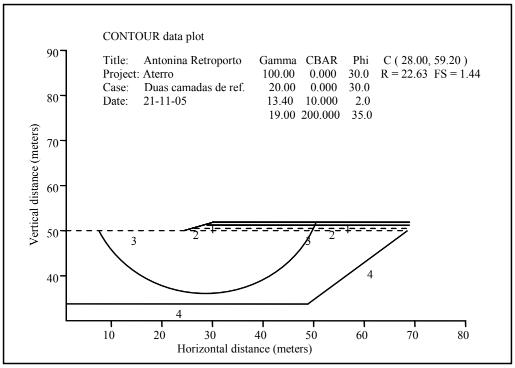

Figure 5. Analysis with c = 10 kPa and $\phi = 2°$, for soft soil.

Figure 6 shows a construction detail of the pavement structure to be placed on the hydraulic landfill. The top layer simulates the surcharge of the pavement with half of the containers on it. The authors recommended caution for both the construction period and the initial loading, with careful settlements monitoring, to minimize problems and allow for increase in the number of containers along time. In other words, the whole process can be called trial an error.

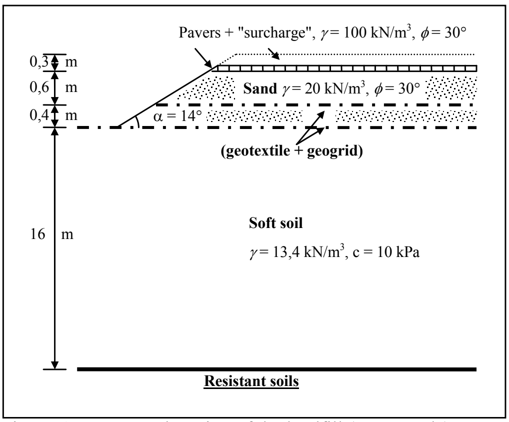

Figure 6. Transversal section of the landfill (not to scale).

The results from the mentioned considerations led to a design (Figure 7) that specified geotextile and geogrid over the dredged material after some consolidation had occurred, with a granular soil on top plus the wearing surface defined by precast concrete blocks – pavers (Peltier, apud de Sença, 1974). Under these circumstances, no failure was to be expected, however a great deal of settlements will occur with time. Evaluation based on Terzaghi's consolidation theory showed numbers between 75 and 200 cm, for a compressible soil layer of 600 to 1600 cm. The time associated to such vertical compression ranged from 14,5 to over 100 years.

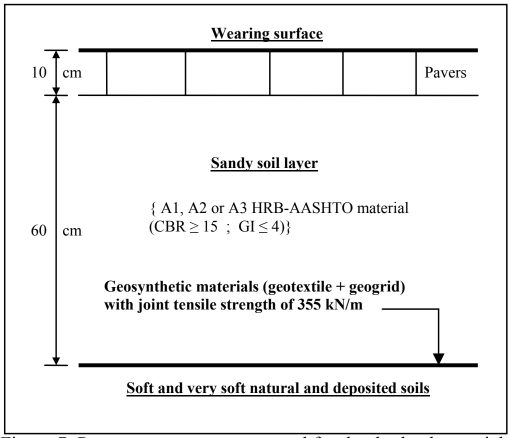

Figure 7. Pavement structure proposed for the dredged material in the back port area (not to scale).

As far as the approach for the construction operation is concerned, the authors suggested that a small area between the port entrance and the first building in the hydraulic fill, was tested first (Figure 1). After a few weeks under loading and with constant monitoring, also depending on the obtained results, other areas should then be added similarly. Unfortunately, such procedure was not materialized so far and the real data from the field behavior is still today not yet available.

5 GENERAL COMMENTS AND CONCLUSION

The authors considered that the most important aspect of the project was the adequate safety factor against eventual rupture of the weak material resulting from dredging, to be subjected to the specified loading. Obviously, settlements of high magnitude will happen along time, probably reaching about 200 cm. The time evaluation made for that, however, is probably too conservative because the soil profile is variable and contains a lot of sand, thus accelerating the consolidation process. This is expected to be a favorable point for the whole back port area because along with that, the dredged fill material will also gain strength. Adequate maintenance for the pavement, however, will be necessary to keep the wearing surface in good condition for its regular use, one of the main reasons for the choice of placing the pavers.

The authors also warned about the use of container piles of two units maximum. A third container in the pile, in accordance to what was obtained from the computations carried out, very likely will cause foundation failure, certainly to be avoided. Emphasis was also given to the first stretch of pavement for the back port area. Labor training, productivity and strict compliance to specifications (sandy fill, geosynthetics, pavers), along with continuous visual and measured field observations, were strongly recommended, preferably with the participation of the designers as well.

Other possible procedures were also mentioned, such as deep drainage and soil profile pre-consolidation, attempting to increase strength of the dredged material more rapidly. Depending on the owner's needs and financial capability when construction begins, they will accelerate settlements and eventually save some pavement maintenance costs along time. It should be emphasized that the experimental construction of the first stretch of the back port area pavement is extremely important; after its initial use under constant monitoring, judgment and consequent decisions can be made and the activity may proceed, or not, according to the results being obtained. Certainly, some maintenance will always be necessary, compensating the settlements and correcting the pavement wearing surface from time to time. These points are a very important part of the whole project, and were clearly pointed out in the final report.

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