UNSUITABLE FILL MATERIAL MANAGEMENT IN PORT TERMINAL CONSTRUCTION: EXAMPLE IN BUENAVENTURA PORT, COLOMBIA

by

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ABSTRACT

The construction of COMPAS' Bulk terminal in Buenaventura Port, on the Pacific coast of Colombia took place in the Aguadulce Peninsula which is a narrow piece of land surrounded by sea. Soletanche Bachy International, in joint venture with Soletanche Bachy Cimas and Constructora Conconcreto were in charge of the design and build contract for the main infrastructures, mainly: the offshore 250m long wharf on piles linked to the land by a 200m long trestle, the conformation of yards and access road by earth movement, pavement and multiple civil structures.

Based on the available ground investigation reports, the design for the yards already considered to use the cut material above the yard final elevation to fill in the lowest parts. The cut material was mostly clay and after lime-stabilization process, it could meet the physical properties required for fill. However, all excavated material was not suitable for backfilling purpose due to its organic content, high water ratio and plasticity index. Therefore, the lack of space to dispose large volumes of unsuitable material inside the terminal boundaries was a critical point during the construction phase as this volume increased significantly. After some unsuccessful attempts to find a suitable dosage of lime, cement or polymer, project team had to find the solution in the disposal areas design. Indeed they built strong vertical retention structure to come as close as possible to the statutory boundaries of the terminal to fit the surplus volume. Some retaining walls were made of sheet pile, others with geotextile megabags filled with the same cut material. Inside the deposit area, due to the high seismicity in the region, it was also required to use ground improvement techniques to guarantee the stability of the bulkhead. Rigid inclusions or consolidation (wick drains with surcharge) were the two techniques employed, and finally extended to the whole stockpiling areas to reach at the final yard level a bearing capacity of 2 ton/m2 and 5t/m2 in order to deliver to the final user an additional yard surface ready for a short-term port development.

That is a good reference for a win-win project where design and site constraints are evolving in line with owner's needs.

INTRODUCTION

The city of Buenaventura on the Pacific coast of Colombia hosts the most important industrial port of for the economy of the country. Due to its favorable location facing Asia, the port is not only a strategical hub for trade with China but also with all countries on the Pacific coast. This explains why in front of the historical port, on the narrow Aguadulce Peninsula, two new terminals have been built under a joint development: COMPAS grain and coal terminal, and SPIA container terminal. Figure 1 shows the initial shape of the peninsular land and the final drone picture.

The COMPAS terminal has been designed to service bulk carriers of 80,000mt, and its onshore infrastructure can store general cargo plus 54,000mt of imported grain and 110,000mt of coal for exportation. It was built in the period 2015 to 2017. The project involved 1) construction of the offshore 250m long wharf on piles linked to the land by a 200m long trestle; 2) the earth movement for the land reclamation; and 3) bulk handling yards and access road, road pavement and multiple civil structures. The project was executed under a design and build contract by the joint venture Soletanche Bachy International (SBI), Soletanche Bachy Cimas (SBC) and Constructora Conconcreto (CCC). BergerABAM Inc. (BA) was the design company chosen by the joint venture.

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Figure 1: Peninsula Aguadulce before and after

PROJECT GENERAL DESCRIPTION

Offshore structures: wharf and trestle

The offshore structure is a concrete open quay, founded on 233 steel piles (diameters 1067mm and 914mm) driven into the seabed. Dimensions of the wharf are 250m long, 32m wide until the extreme end where it's increased to 40m to allow the trucks to make a U-turn. Access to the quay is through a trestle of 190m by 14m wide available to vehicles and walkway, with additional 4m-cantilever beams for the double deck conveyors. Figure 2 shows the wharf and trestle under construction.

In order to shorten the construction time, reduce the safety risks and environmental impact, the design-build team looked for simplification of the tasks done offshore, and particularly to reduce the volume of in situ concreting. Therefore, the use of precast concrete elements has been encouraged and as a result, the quay was delivered to the owner 5 months ahead of the contractual schedule. Allowing him to start earlier the operation of the terminal and generating the financial benefits that come naturally with.

Moreover, with this alternative design the resulting structure had an optimal "seismic" mass and that was a big advantage given the earthquake vulnerability in the area.

Figure 2: Wharf and trestle under construction. Progress 80%

Initial Terminal yard layout and boundaries

On the shore side, the terminal is composed of the following principal structures: four vertical silos of 28,000mt total capacity, two horizontal silos of 26,000mt total capacity, and a coal yard of 110,000mt. The platforms are situated around the elevation +5,30MSL with a total area of approximately 6.5Ha.

A dedicated access road running along the North side of the peninsula connects the terminal yards to the main Aguadulce Port entrance and is independent from the adjacent SPIA Container Terminal.

The layout implied reclamation works with the objective to double the native land surface inside the concession area mainly using the same excavated material (Figure 3). On the North side of the terminal, a disposal area was designated to store the unsuitable fill material, and let it self-consolidate for a few years as no immediate development was envisaged at this early stage.

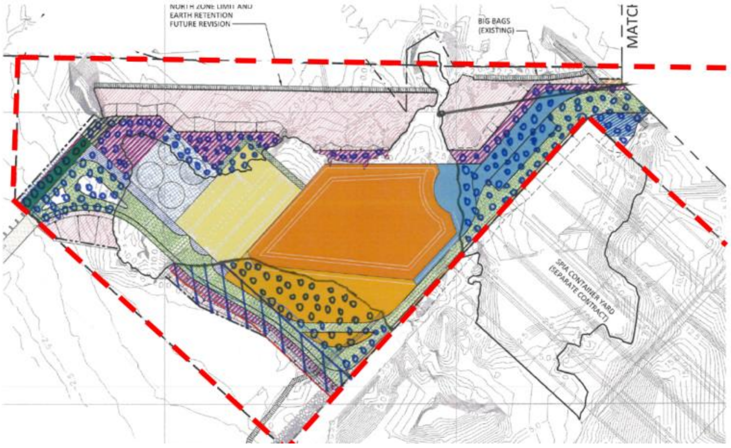

Figure 3: Cut and fill areas at project start date (access road is not shown)
(fill shown with handmade hatch, red discontinued line is concession boundary, pink area is initial unsuitable fill material disposal area)

Design assumptions and initial design for reclamation areas
The design involved reutilizing the in situ excavated material above the elevation +5,30MSL to backfill the lowest spots and to obtain a levelled platform with the required bearing capacities at +5,30MSL. The excavated material was identified mainly as altered claystone and after a stabilization process with lime mixing (around 4% of lime were used), it met the required minimum UCS (Unconfined Compressive Strength) at 7 days of 200KPa and 300KPa for backfilling.
The design-build team had to conceptualize measures to prevent potential of flooding of the reclamation areas by tidal action (mean tide amplitude 4,50m) which occurs almost half day long. The backfilling works in most areas occurred behind a permanent sheetpile wall that could play the role of retaining structure and shore protection at the same time. In some places with shallow retaining height, reclamation occurred behind a temporary dike made of geotextile bags filled with excavated material. Refer to Figure 4 for the cross sections. Parts of the reclaimed areas situated on top of deep saturated silty deposit (upto 10m thick layer) required soil improvement prior to general backfill process. Soil improvement by concrete inclusions was selected due to its fast execution time.

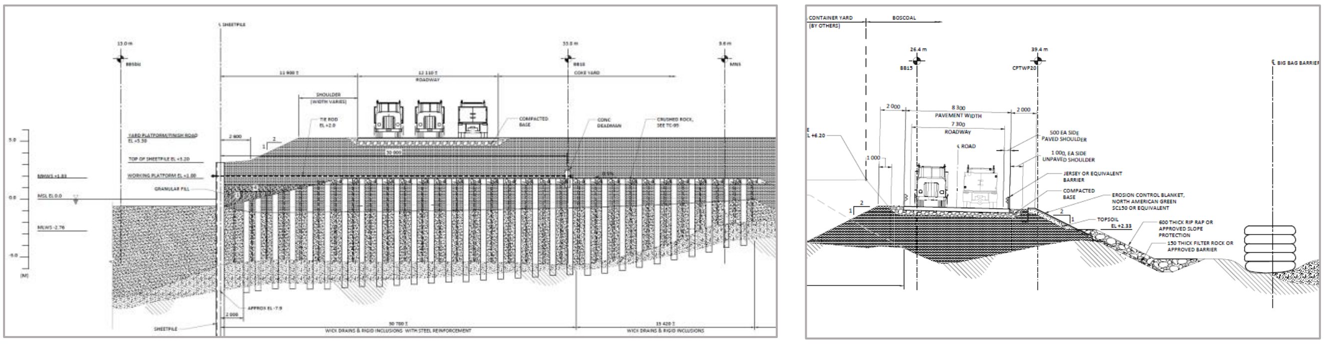

Figure 4: Sheetpile bulkhead for coal yard (left) and temporary megabag barrier for access road (right)

It is interesting to mention also two other environmental conditions that had to be considered.

The first one is the seismic activity. Buenaventura is situated at the toe of the Occidental Cordillera of Colombia, at the convergence of the Nazca plate and the South American continental plate, as shown in Figure 5. The frequency and strength of the earthquakes in the region is very high. As indicated in the Colombian seismic code NSR-10, the design used a seismic coefficient of 0.4g that corresponds to the peak ground acceleration (PGA) of the Contingency Level Event (CLE).

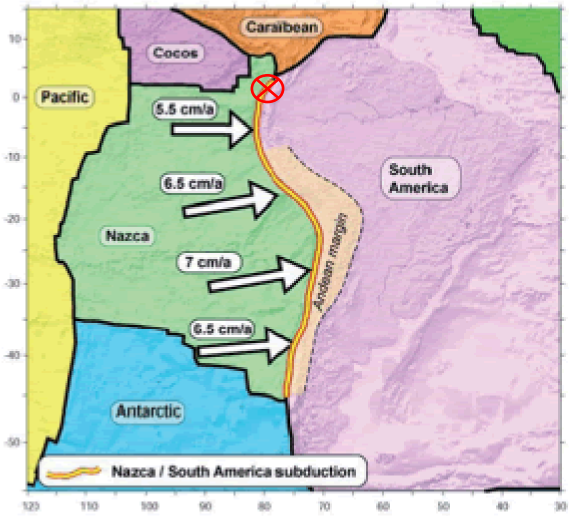

Figure 5: Location of Buenaventura in the south-American subduction system (C.Vigny 2003)

The second local condition is the high quantum of rainfalls and relative humidity. Buenaventura, by its geographical situation mentioned before, is among the cities in our planet with the highest rainfall rates, and does not possess any dry season. The daily average rainfall is 20 liters/m2 (or mm/m2) with peaks reaching 60mm per day, with rainfall mainly occurring at night. Figure 6 shows the monthly rates. The high rainfall was a major consideration in selecting appropriate construction sequence and the methodologies for earth movement. This was true in particular for the lime mixing process and backfilling works that were very sensitive to humidity. For reclamation work, it was not only necessary to block the seawater from entering the area (by megabags barrier or sheetpile wall) but also to drain out the rainwater coming down from the catchment area.

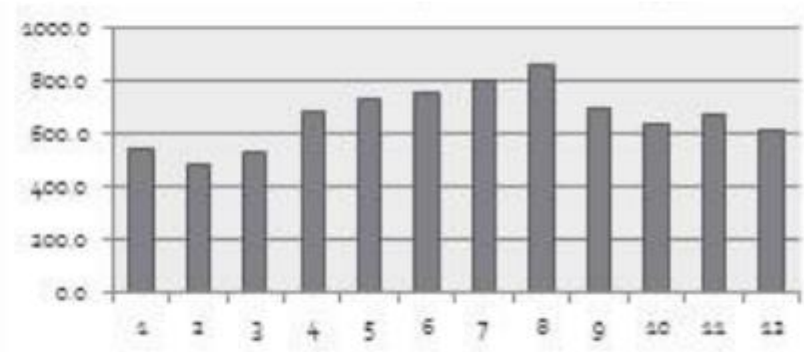

Figure 6: Rainfall histogram in Central Pacific Coast of Colombia (in mm by month)

Challenges with the excavated material

The peninsula in situ material had been characterized by various campaigns of geotechnical investigations during the tender stage (Figure 7 shows the location of boreholes both onshore and offshore). Onshore, the boreholes were executed at the highest topographic elevations around +11.0MSL. The data showed the fractured siltstone covered by layers of soft plastic clay material with high water content, as illustrated in Figure 8. Material description from the boring logs was “(CH) CLAY, yellow and light gray, high plasticity, moist”. From the lab tests results, the water content W for these

layers situated in the range 40% to 52% was above the plastic limit WL of 27%, meaning that the soil was saturated.
These layers were initially considered as non-suitable for backfill purpose and their destination was in the North disposal area.

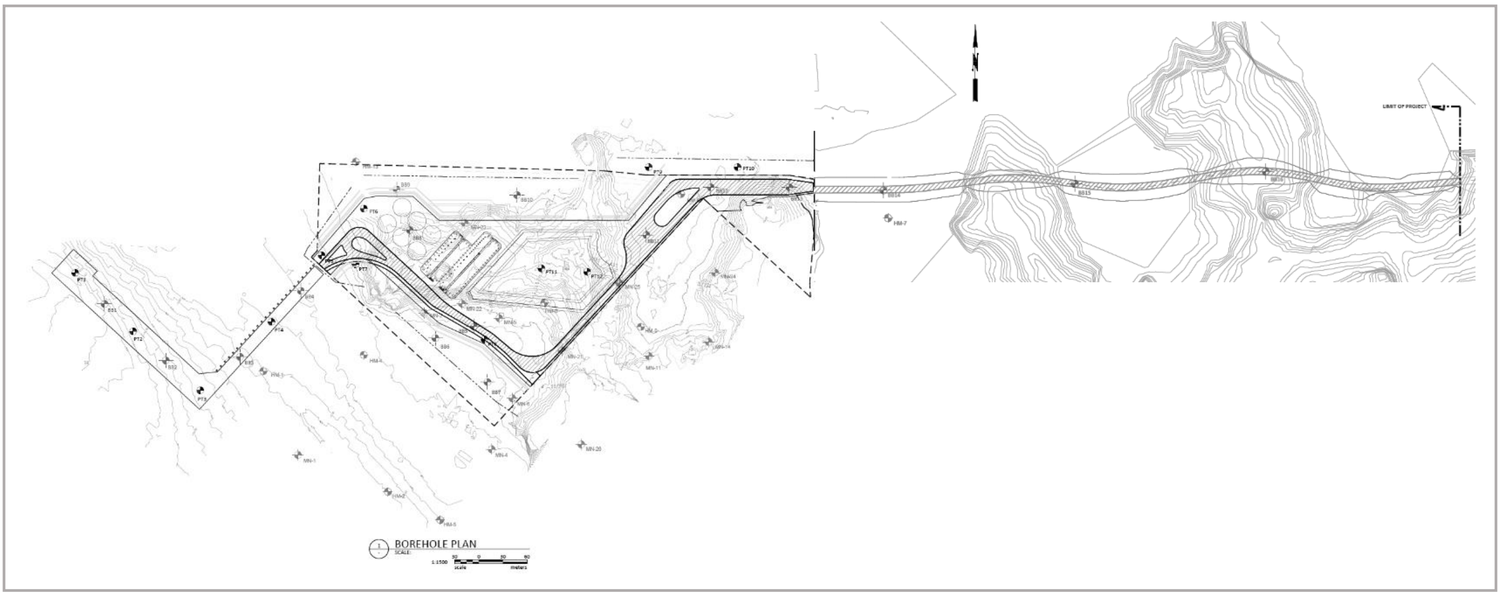

Figure 7: Overall layout of Boscoal terminal and access road, with borehole locations

From the combination of the geotechnical investigation reports and the land survey at tender stage, it was estimated that 290,000m3 had to be excavated to construct the yards and roads of the terminal, including 38,000m3 of unsuitable plastic clay material. However, during the construction phase and the additional work done, the construction team had to deal with a significant increase of that volume. It became a priority topic since the project Environmental license had not considered any disposal area out of the terminal concession boundary. Two options were then investigated.

Figure 8: Yellow color highly plastic clay layer

RESEARCH TO IMPROVE THE SOIL PROPERTIES

The first action of the team was to find a way to use this material in the reclamation process (target 7 days UCS was 300kPa). Further investigation through laboratory tests and site trials were conducted to analyze if other additives would be effective on site and economically interesting. This paper is not focused on that investigation, but the following lines will describe the conclusions. Higher lime dosages

than 4% were tried on site and samples analyzed in laboratory. The UCS results indicated improvement in soil properties for the claystone material but it was not the case for the plastic clay material.
Also, it was studied the effect of mixing with lime 1 or 2% and additional 0,25 to 0,50% of polymers. Lab and small field trials had shown good results, but at a larger scale, this alternative could not reach the same results because of the heavy rainfall that were disturbing the maturation process. It would also require a large infrastructure to mix and store the soil under a shelter on the job site, which was economically not interesting. The same reasons applied to cement mixing.

TERMINAL LAYOUT UPGRADE

The other way to find a solution was to look at the disposal areas themselves.

North yard

It was quickly identified that the planned disposal area on the North side had to be rearranged to accept more material, at least to serve as temporary storage to avoid disrupting the progress of the excavation works. The concept was to expand the area as much as possible and stockpile there all the surplus material. It was made possible due to the owner's foresight since the owner had already set further offshore the concession boundary in view of future development. Therefore, the conditions were created to modify the contour of the project and create a disposal area with the maximum extension that the construction permit could allow. The contour is shown in Figure 9.

However, the owner saw an opportunity to have a new yard of 2Ha in this area; it instructed the design-build team to plan for handling new cargo in the terminal. As a result, the owner then requested to further transform the design-build team to convert the mud disposal area into a yard with a surface load capacity of 5t/m2.

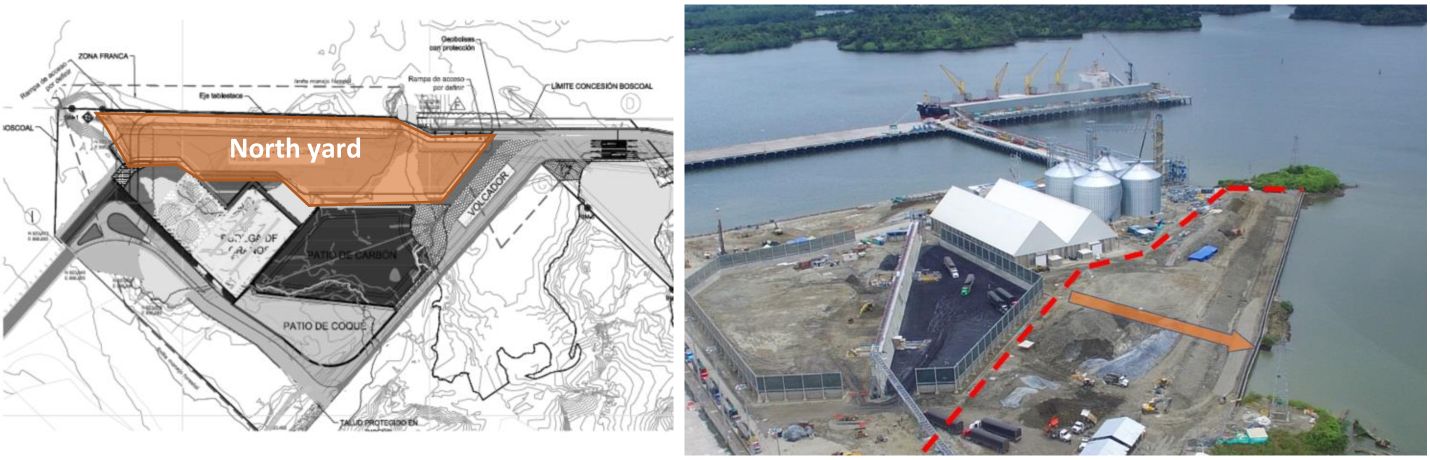

Figure 9: North yard extent

The sequence of work was as follows:
The first task was to build a vertical retaining structure along the concession boundary of 290m long, made of AZ hot-rolled sheetpiles with its wale beam and tie-rods connected to a parallel concrete deadman wall 10m behind. The sheetpiles were installed by both vibratory and impact hydraulic hammers to provide an embedment into the weathered rock located approximately 4m below seabed level. The particularity in that area was the seabed elevation that was above the low tide level (seabed at -1.0MSL, and MLWS at -2.7MSL). A working barge was deployed at the working location during high tide and was purposely grounded on the seabed most of the day; however, it was effective in installing the sheetpiles thanks to its 180t crane with adequate working range.

Once the sheetpile barrier was constructed, the area was filled up and levelled at the elevation +5.30MSL. River granular fill from local quarries was installed to help lower pressure on the sheetpiles and provide proper foundation for the anchor system.

At yard level, an internal road was set up adjacent to the sheetpiles, here again to limit the ground pressure on the wall. In the other parts, to get the final bearing capacity of 2T/m2 at the first stage, and then changed to 5T/m2, the team selected preconsolidation as ground improvement technique above other faster one because of its cheaper cost. Despite the relatively slow process of induced settlement, the selected method satisfied the project schedule.

Figure 10 shows a cross section of the yard where 10,300ml of prefabricated vertical drains (PVD) or 'wick drains' were installed. Then a 2.50m high surcharge was placed to initiate the settlement for a few months. Two types of material were used as surcharge. On the Western portion of the yard, the team used unsuitable fill material. For the Eastern side, as the owner was receiving a vessel with clinker in bulk and was requesting a place to stockpile, the project team naturally proposed to accommodate it in the North yard and utilize it as surcharge. Figure 11 illustrates the settlement vs. time diagram, with a notable difference of the settlement rate using excavated material (density 1.30) and Portland clinker (density 1,51).

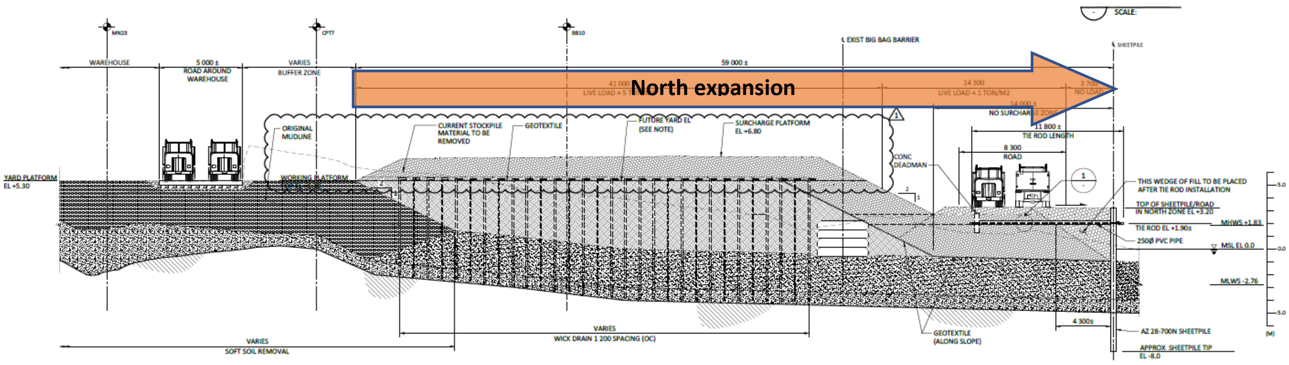

Figure 10: Cross section north yard with typical surcharge (here 1,5m high for 2t/m²)

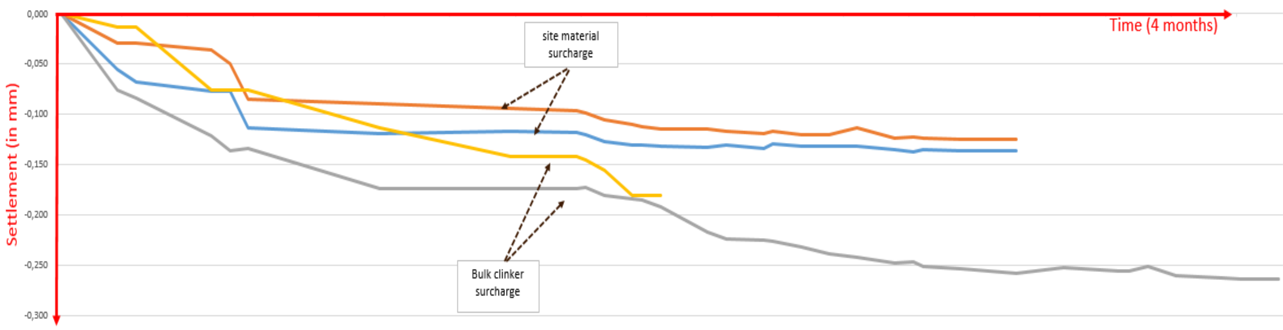

Figure 11: Settlement graphs

South Yard

As the North disposal area had been transformed since an early stage into an operational yard, the area could not bear the same large volume of material that was initially calculated. The owner was open to a proposal for another yard expansion within the allowed boundaries. Therefore, the design-build team developed a solution in the south part of the terminal with a fast track solution to build a 1Ha yard with 5T/m2 bearing capacity. The new reclaimed area is built on the sea side of the sheetpile retaining wall. Figure 12 is showing the aerial view of the area.

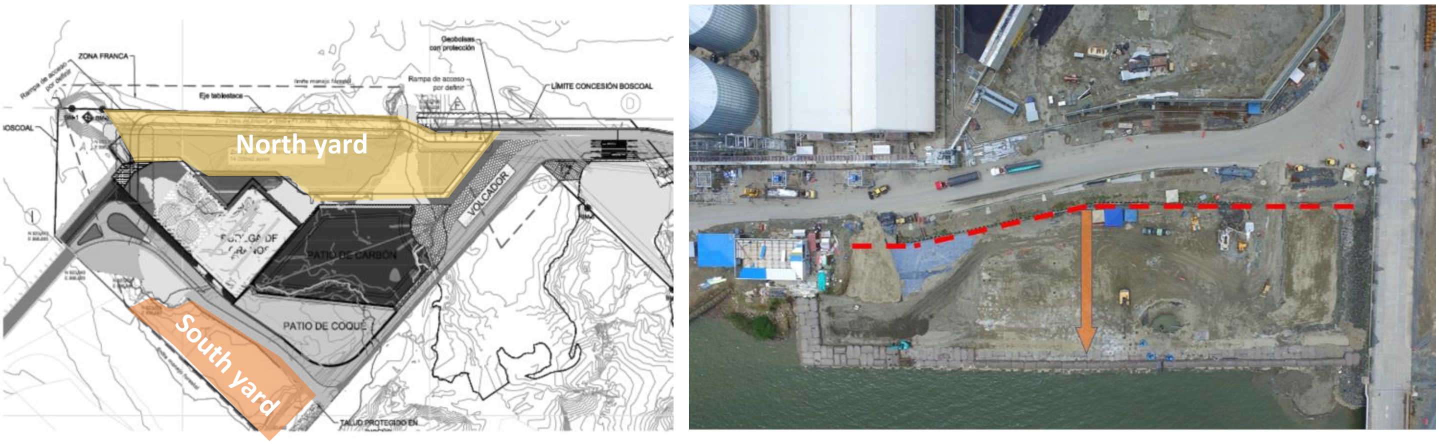

Figure 12: South yard extent

To create this new yard space, fill material was retained by a system of heavy duty geotextile bags filled with the same unsuitable materials directly supported on the seabed and interlocked with each other. A pyramidal dike geometry was formed along the concession boundary with the soil filled bags, as shown in Figure 13. Part of the surplus volume of unsuitable soil was incorporated and confined into the retaining structure, that made this solution adequate to the situation.

Figure 13: Geotextile megabags retaining wall

After the dike was completed (and the lake formed by the rainwater drained out of the confined area), the area was backfilled with the remaining stockpiled material and the surcharge material from the North yard. Above that layer, a working platform was prepared to allow the heavy equipment to access the area and install rigid inclusions through the soft ground (the backfilled material and the marine clay below). 190,000ml of inclusion were installed, mainly with a 2mx2m grid, except along the dike where the grid was changed to 1mx1m with a center rebar in each column to suppress the slip failure risk. See Figure 14 the cross section though the South yard.

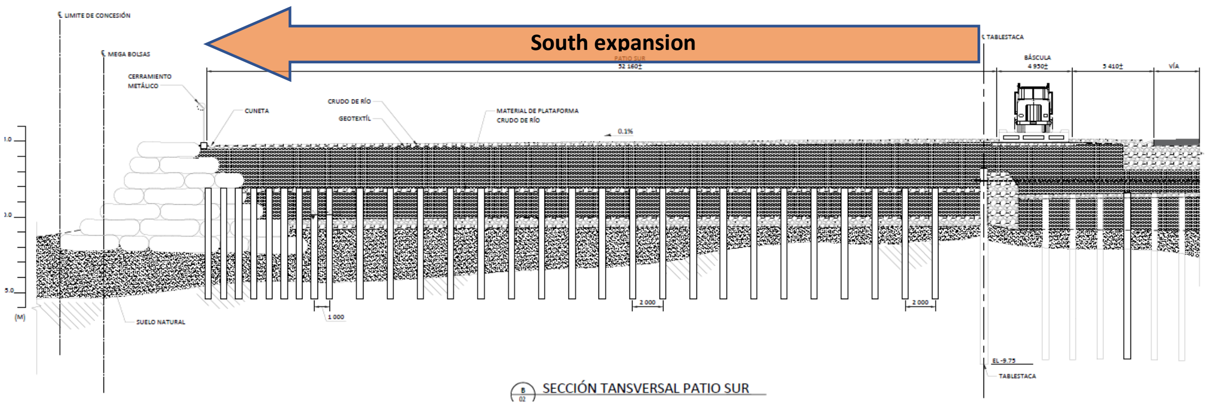

Figure 14: Cross section South yard

Finally, the backfilling continued until the final level 3m above the top of the inclusion to reach +5.30MSL with the remaining lime stabilized claystone available on site and the top layer with of granular fill.

CONCLUSIONS

The construction of the Boscoal Terminal in Aguadulce, Colombia within the tight schedule given the site and environmental constraints reflects a major success due to the interaction between the Owner and design-build team who worked hand in hand to find on time practical and cost-effective solutions to the challenges that appeared during the construction phase. All areas were delivered on time with some ahead of schedule so that the owner could start operation before the full completion of all the works under the scope of the contract. The partnership was moreover witnessed in the use of the unloaded cargo for the purpose of the ground improvement phase, saving natural resources.
Also at the planning stage, it is relevant to highlight that the owner had already planned for the terminal future expansions Northbound and Southbound, and got the statutory permits accordingly. The empty space originally planned to be not developed but available since the first stage of terminal construction was the foundation for the adequate management of the surplus material. The project is a prime example on the importance of conducting detailed and accurate ground investigation campaigns that are necessary to have a detailed characterization of the soil conditions to select an appropriate construction sequence. We think that similar projects in challenging sites should consider this ‘win-win’ example of partnership between the design-build team members as reference to resolve unforeseen conditions during terminal yard construction.

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