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Brazil's Megaproject Shipyard
Winner of the 2010 Outstanding Project of the Year

Aerial view of the Atlântico Sul megaproject

Atlântico Sul Shipyard: Outstanding Project Award Winner

Atlântico Sul Shipyard was established in November 2005 through a partnership between Camargo Corrêa, Queiroz Galvão, Samsung Heavy Industries from South Korea and PJMR, an equity holding and ventures management company in the shipbuilding and offshore sector.

The partnership's goal was to be the biggest and most modern naval and offshore construction and repair shipyard in the southern hemisphere. This undertaking was a landmark in the revitalization of the Brazilian shipbuilding industry, with an approximate investment of $1billion (U.S.).

The shipyard manufactures carrier vessels up to 500,000 DWT, as well as offshore platforms of the semi-submersible type, FPSO (Floating Production, Storage and Off-loading), and tension-leg platforms, among others. It also offers a vast range of repair services for vessels and oil exploration units, taking advantage of the shipyard's strategic location in relation to both the global maritime trade and the large deep-water oil and gas production fields.

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The shipyard can process 160,000 mt (180,000 U.S. short tons) of steel per year, in an area of 1,620,000 sq m (17,400,000 sq ft), from which 130,000 sq m (1,400,000 sq ft) are covered areas used to process, cut and paint the steel. The area also contains a dry dock that is 400 m (1,312 ft) long and 76 m (250 ft) wide and 14 m (46 ft) deep. The dry dock is served by two Goliath Cranes with capacities of 1,500 kN each, with four additional support cranes, two of which have a capacity of 500 kN and two with 350 kN.

The south outfitting quay is 730 m (2,400 ft) long and is served by another two 35 t cranes. The north quay, which extends 680 m (2,230 ft), is used for construction and repair of offshore platforms.

The scale of such a manufacturing facility places the shipyard in the top group of fourth-generation shipyards with Asian plants, now at the forefront of the worldwide shipbuilding industry.

Atlântico Sul Shipyard is in the Industrial Port Complex of Suape in Ipojuca, in the northeastern state of Pernambuco. The Complex of Suape connects to main navigation routes and to 160 ports worldwide. Its location is advantageous in relation to the big oil and natural gas production regions, such as the Brazilian Tupi oil field, Gulf of Mexico and Coast of West Africa.

Brasfond Contract

Brasfond's contract included the foundations and retaining walls for the following structures:

- The retaining wall of a de-waterable dry dock.
- A large expanse of quay wall plus cranage to provide a deep berth for merchant ships.
- All ancillary support facilities and administrative buildings.
- The mega block areas. This term refers to construction methodology in which eight large sections of ships are welded together inside the dock thus reducing overall construction time.

All these works presented geotechnical challenges.

The ground profile across the site was generally made up of loose granular fill material overlying sandy silt/silty sand that in turn, was underlain by claystone and sandstone at approximately 25-35 m (82-115 ft) below ground level. The layer of silty sand directly below the fill was either dense to very dense or, in places, weak sandstone up to 6 m (20 ft) thick. This weak rock layer was clearly not formed by normal sedimentary rock processes and

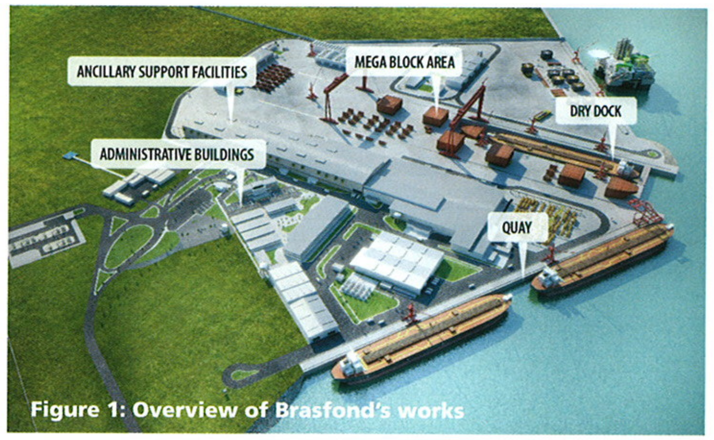


Figure 1: Overview of Brasfond's works

appeared to be a natural cementation of the sand grains as a consequence of the lixiviation (leaching) of the acids from decomposition of organic materials giving the sandy soil the brown color. The material below this sandstone layer was generally a medium dense state, varying from sands to clayey sandy silts. In some localized areas the sandy silt/silty sand directly above the deep sandstone was replaced by soft to firm silty clays up to 13 m (43 ft) thick. These soft clays are believed to be the location of an old river channel. The site has high ground water relating closely to sea level that indicated the generally high permeability of the soils.

Principal Challenges

The main design and construction challenges at Suape were:

- Construction through and/or excavation of an upper sandstone layer that required mobilizing the correct equipment during construction, clearly identified in the design package.
- The presence of soft clay at depth meant there was little passive support for the wall below floor level during temporary stages of construction. Considering that the dry dock (once the dock floor was in place) would support the upper wall, the wall below the floor had to function as a cut-off wall to reduce the volume of water flowing into the drainage system and underside of the dock floor. It was important to consider that the wall was also designed to resist the vertical loads from the big Goliath cranes (up to 15,000 kN) running on it.
- The quay wall depth had to be increased after its construction as a consequence of the changes in the dredge level imposed by Port Authorities of Suape.

The initial basic design concept for the 400 m (1,312 ft) long x 76 m (250 ft) wide x 14 m (46 ft) deep dry dock wall was to use steel sheet piling. Because of the erratic soil profile, the client decided to make a preliminary test on the drivability of the sheet piles to check the

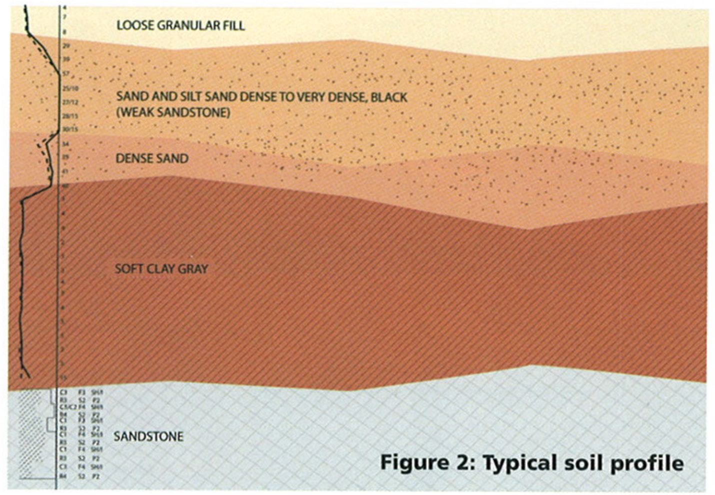


Figure 2: Typical soil profile

efficacy of the solution. These tests proved that the energy needed to drive the sheet piles was so large, due to the presence of a sandstone layer between layers of sand and clay, that it would be necessary to drill a pre-hole with an auger to avoid significant deformations. This drilling would have increased the cost and time schedule with no guarantee of success.

The final design concept was to use a diaphragm wall without tiebacks. Due to the great bending moments involved, a T-shape 60 cm (2 ft) thick wall was designed with support at the top and one at the bottom (counterfort wall).

The depth of the T-shape diaphragm wall ranged between 18 m (59 ft) and 30 m (98 ft), always reaching bedrock. The large difference in depth was due to a layer of soft clay created by what was likely an old river channel.

The diaphragm was installed by a clam-shell 3.20 m (10.5 ft) long x 0.60 m (2 ft) wide mounted in crawler cranes of 70 t. Crawler cranes up to 100 t were used to place the reinforcement cage. The estimated volume of each T-panel was approximately 100 m^3 (3,531 cu ft). The basic concept of the dry dock floor design included:

- A sub-floor drainage system to prevent the buildup of hydrostatic pressure; the water reaching this drainage system had to be pumped away to the sea continuously to keep the dock dry.
- A pressure relief system so that the floor would neither lift nor suffer damage in the event of pressure build up due to the malfunction of the drainage system.
- Consideration of the heavy loads involved when the dock was either flooded or when the mega blocks were being assembled over the floor slab with the dock when dry.

The foundation solution for the floor was bored piles drilled with bentonite slurry, 0.9 m (2.95 ft) diameter for a service load of 5,000 kN.

The design criteria indicated that piles be bored to bedrock. In the dry dock area, the depths ranged between 10 m (33 ft) to 20 m (66 ft) below the floor slab level. The significant difference in the bedrock level was very similar both in terms of depths and characteristics to what was detected in the diaphragm wall perimeter.

Because of the great difference in the depth of the piles, Brasfond proposed to undertake three static pile load tests in areas where the bedrock level was different to confirm the service loads being adopted. The client accepted.

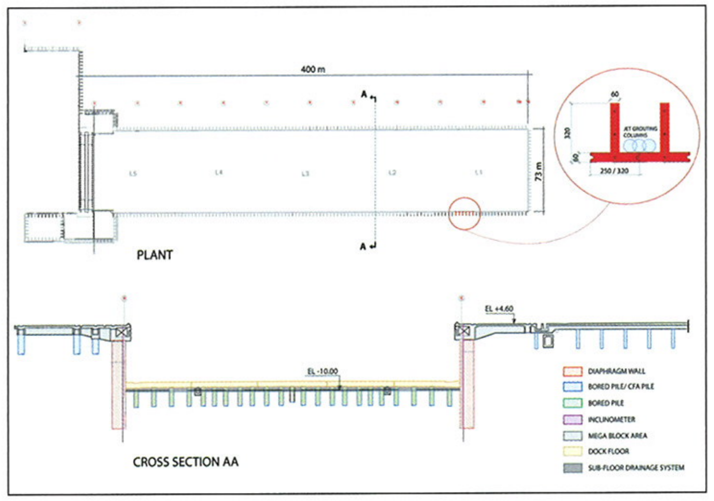


Figure 3: Overview of the dry dock

To save time, all the piles below the slab were installed before the dry dock excavation, so it was very important to be sure that the pile cut-off level was preserved and the reinforcement cage was placed in the right position. The piles were installed by hydraulic rigs up to 260 kNm torque with verticality and depth monitoring systems.

The Overview of the dry dock (Figure 3) shows a general view and a cross section of the dry dock as well as the mega block paved area below. Another important part of the dry dock work was the excavation to concrete the floor slab.

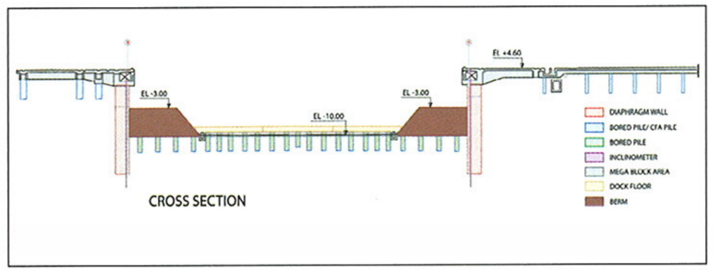


Figure 4: Dock floor execution

This work was done in steps as follows:

a) Concreting the reinforcement beam over the diaphragm wall and the mega block paved area

b) Excavating the dry dock up to 3 m (10 ft) below ground level

c) Installing the dewatering system inside and outside the dock area

d) Excavation of the soil in the central part of the floor up to the final level leaving a berm along the wall

e) Cutting off the pile heads, installing the drainage system, placing the reinforcement steel and concreting the central part of the floor slab, repeated until the floor slab was complete

f) After the concrete was cured, excavating the berm up to the diaphragm wall and final level

The excavation methodology proceeded with the condition that the diaphragm wall would be monitored in real time by inclinometers and strain-gauges.

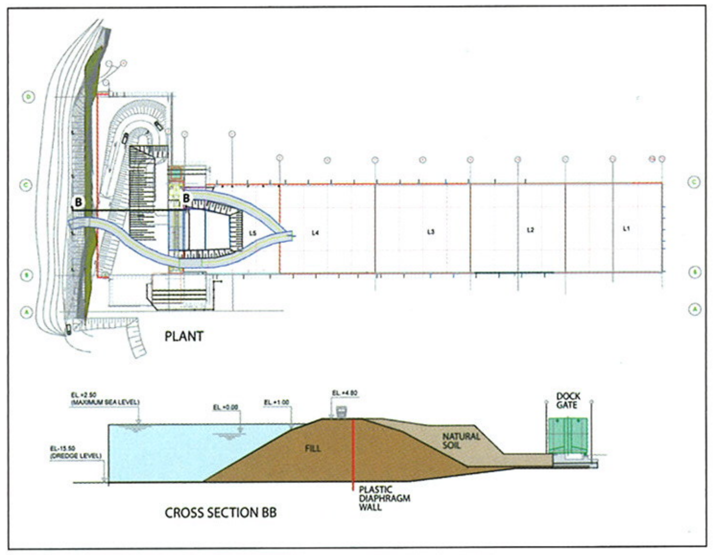


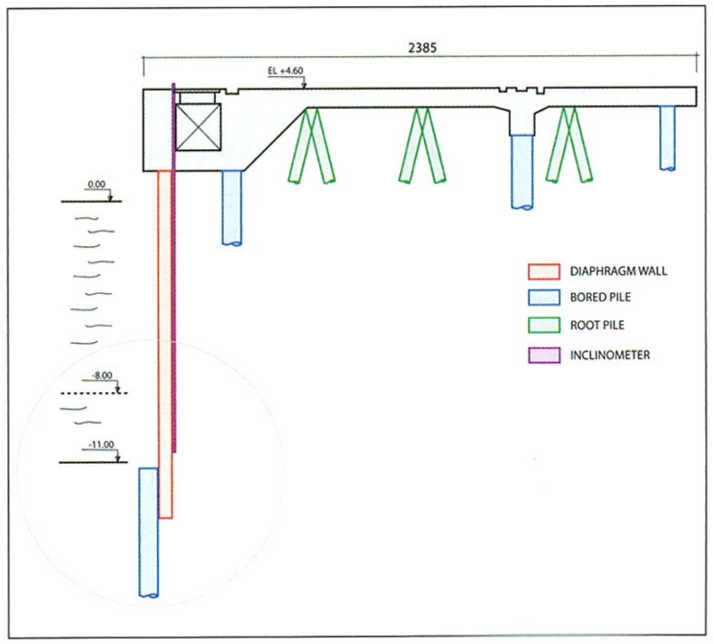
Figure 5: Cofferdam

A cofferdam was necessary to excavate and concrete the last part of the slab, which was closer to sea. A plastic diaphragm wall, 0.6 m (2 ft) wide with an average depth of 25 m (82 ft) was designed and executed up to bedrock, to protect the dock.

After completing the slab and installing the dock gate, the fill and the plastic wall were demolished to allow the final contact of the dry dock with the sea.

Quay Design

The designer's first option was to use steel sheet piles. Because of the soft soil in this region, the problem was the depth that the sheet piles had to reach to take the vertical load. To establish that the piles had sufficient load bearing capacity they would have had to be driven to refusal, and the depth at which this could be achieved was unpredictable.



Figures 6: Quay platform after increasing depth

The final decision was to use a diaphragm wall, with depths ranging between 22 m (72 ft) up to 30 m (98 ft), tied with a group of inclined root piles to resist the bending moment (pile trestle) and bored piles to take vertical loads, as shown below.

The assumption was that the dredging in front of the quay would be carried out after constructing the quay structure, and the proposed dredged depth was -12 m (-39 ft).

When the diaphragm wall was completed, the Port Authorities decided that the dredged depth had to be increased to -15 m (-49 ft). After analyzing the impact carefully, the designers thought it necessary to increase the depth of the diaphragm wall. Because it was already constructed, the solution was to create a spaced curtain (non-tangent/non-overlapping) of bored piles as close as possible to the wall to resist the bending moment induced by the new dredged depth, as shown below.

Inclinometers and strain-gauges were installed in the wall and it was closely monitored during dredging.

Piles rising from the dock floor

Construction underway for the dock floor

Mega Block Area and Ancillary Facilities

This area surrounding the dry dock was designed to resist the weight of the mega blocks constructed to facilitate ship assembly. The large steel blocks are built outside the dry dock in giant pieces and moved into the dry dock by the Goliath cranes. This procedure minimizes the construction time for ships inside the dock and, in turn, maximizes ship production. The basic concept of the design was a slab with piles. Due to the heterogeneous soil condition in the area, the designer sometimes used bored piles and in other cases Continuous Flight Auger (CFA) piles.

Initially, the client thought of installing pre-cast piles for these foundations, and again we conducted a drivability test. The results turned out to be negative, due to a dense upper sand layer that broke the pre-cast elements when they were driven into ground. Once more, it seemed necessary to pre-hole in order to install these. We tested an alternative solution, CFA piles, conducting several static load tests with excellent results. We tested an alternative solution, CFA piles. Consequently, the general solution was CFA piles except in areas where we found the deeper soft clay layer. In these areas, the designer used root piles, 0.4 m (1.3 ft) and 0.5 m (1.6 ft) in diameter, up to 30 m (98 ft) long.

SERVICES	QUANTITIES
Diaphragm Wall	88,327 m² / 950,744 square feet
Plastic Diaphragm Wall	5,468 m² / 58,857 square feet
Bored Piles	5,484 ϕ / 102,824 m / 337,349 linear ft
CFA Piles	4,845 ϕ / 94,342 m / 309,521 linear ft
Root Piles	1,283 ϕ / 32,258 m / 105,833 linear ft
Jet Grouting Columns	2,106 ϕ / 23,800 m / 78,084 linear ft

Conclusion

Some lessons learned from this project were:

- It was extremely important that the client, the designer and the foundation contractor interacted to find the best solution, quickly and inside the clients' budget.
- Due to a good soil investigation and the close monitoring during the execution, we overcame all the underground challenges, minimizing overall construction risks.
- The foundation design was optimized as a consequence of the static load tests that were conducted before the start of the job.
- Due to the short time available to fulfill the contracts for ship assembly, construction of the shipyard was concurrent with the construction of the first ship. This is clearly reflected in the total time taken to complete the foundations of the shipyard, 24 months, in comparison to the completion of the first ship, 32 months.