PORT EXTENSION IN MARTINIQUE, IN THE FRENCH CARIBBEAN: USE OF THE OBSERVATIONAL METHOD IN A HIGHLY SEISMIC AREA

by

Patrick Garcin[1], B. Seidlitz[2] and G. Casse[3]

ABSTRACT

Grand Port Maritime de La Martinique (GPMLM), the public authority in charge of the port of Martinique, is rolling out an ambitious action plan to develop its container terminal "La pointe des Grives".

GPMLM has appointed Artelia to provide design and construction supervision services for its container's yard and quay extension in 2013. The project proceedings were decided in two stages: the South extension, realised in 2016, object of the present paper, and the North one, construction bid for tender under launching.

The southeast extension consists in a 2.4-ha increasing of the harbor reclamation area and a 550-meter enclosing berm, which is located in a seismically highly active area, and built on alluvium with very poor characteristics.

According to the French Ministry requirements, the design incorporates a total absence of dredging (no maritime borrow materials, no substitution), in order to preserve the environment in the bay of Fort de France and significant settlement amplitudes are foreseen. Therefore, the method chosen to monitor works implementation is the observational method, involving appropriate complementary geotechnical surveys, a strategy based on granular blending materials, and instrumentation of the reclamation area.

This challenging extension involves an objective of making targeted investments in order to protect the environment in an area with major ecological issues and responding to growth on the Caribbean market (following the Panama Canal expansion project) and the rapid changes taking place in maritime traffic (consolidation of cargo flows).

This paper presents the project constraints and the construction methodology, and sets out the feedback obtained in regard to settlement upon delivery of the reclamation area after 12 months of work.

---

[1] Project director, Artelia Eau et Environnement, France, Patrick.Garcin@arteliagroup.com

[2] Engineering & Project department director, Grand Port Maritime de la Martinique, France, b.seidlitz@martinique.port.fr

[3] Civil Engineer Project Manager, Artelia Eau et Environnement, France, Geraldine.Casse@arteliagroup.com

1. INTRODUCTION

The French port of Fort de France is currently a major logistical hub serving the Martinique economy: it is the main loading/unloading point for containerized maritime traffic and the only transhipment zone on the island, as shown in figure 1.

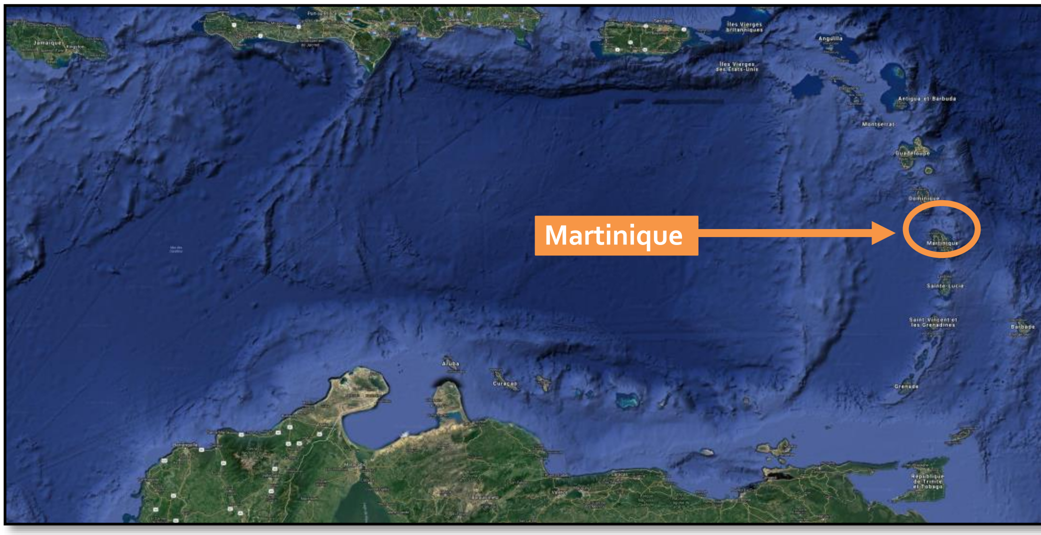

Figure 1: Location of Martinique in the Caribbean (photo: Google Maps®)

The Pointe des Grives container terminal was commissioned in 2003.

It includes a 20-hectare reclamation area for container storage and 2 berths capable of accommodating PCRF vessels (CMA-CGM vessels on the North Europe-West Indies line) up to 200 m in length and with capacities of up to 2400 Twenty-foot Equivalent Units (TEU):

- A 460 m long main wharf with a 12.5 m draft,
- A 180 m long secondary berth with a 8.5 m draft (See Figure 2).

Figure 2: Terminal aerial view in 2016 – 2 vessels berthed (photo: GPMLM)

The commissioning of the third set of locks on the Panama Canal in 2014 portends a significant increase in traffic in the Caribbean area as well as in the size of vessels, container ships in particular.

Given the current and future demand for transhipment of containers in the Caribbean zone, Martinique, which occupies an advantageous position on the major maritime routes of the Eastern Caribbean, wishes to develop its containerized traffic and enhance its geographical position as a transhipment port.

The main challenge of the project lies first and foremost in securing domestic container carriers lines by optimizing vessel filling thanks to the development of transhipment traffic.

Secondly, the optimized service and productivity gains generated by the development of complementary transhipment activity must bring about a more competitive service, as illustrated in figure 3.

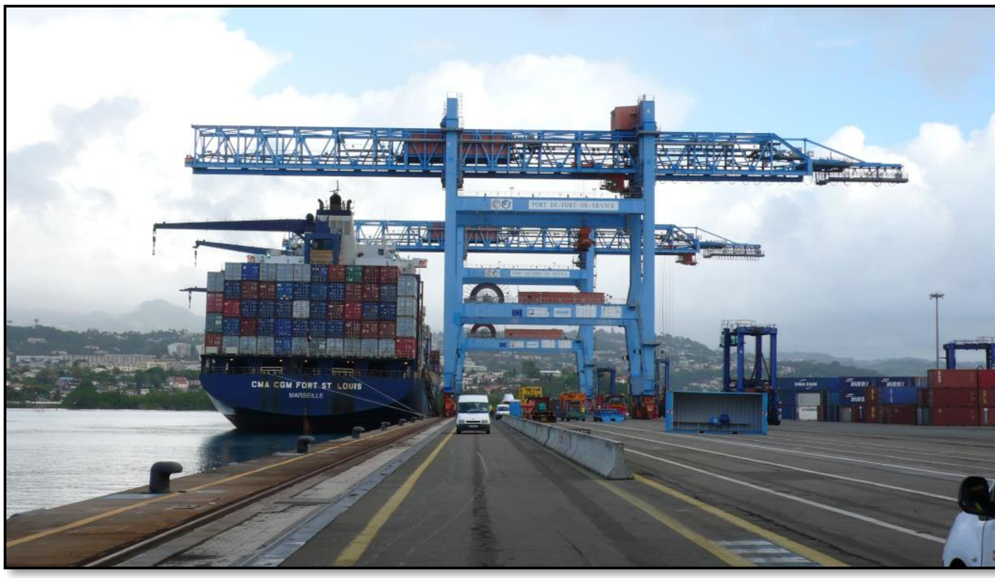

Figure 3: Pointe-des-Grives terminal gantry cranes in service (photo: Artelia)

If it is to achieve these objectives, the port must upgrade its facilities in order to accommodate more traffic, more ships and larger vessels than today (figure 4).

Figure 4: Two CMA-CGM vessels berthed at Pointe-des-Grives (photo: Artelia)

That's why Grand Port Maritime de La Martinique (GPMLM), the public authority in charge of the port of Martinique has appointed Artelia to provide design and construction supervision services for its challenging extension.

The ultimate goal is to accommodate the following vessels:

- Over Panamax:
  - From 260 to 294 meters long
  - 12.5 meters draft (up to 13.5 m on certain vessels)
  - 84,500 tons displacement
- Small ship of the Feeder type (for transhipment in the Caribbean zone)
  - From 120 to 150 meters long
  - Between 12,000 and 18,000 tons displacement

Two stages of works are planned to achieve this goal.

The works presented concern the first stage, i.e. the south-eastward expansion of the terminal including a 2.4-ha extension of the harbor reclamation area and a 550-meter enclosing berm (see figure 5).

Figure 5: Overall aerial view of terminal during the works (photo: GPMLM)

The project challenge consists in design the extension in a seismically highly area, and built the reclaimed area on alluvium with very poor characteristics which implies potential significant settlement amplitudes.

Moreover, the French regulations requires a total absence of dredging (no maritime borrow materials, no substitution), in order to preserve the environment in the bay of Fort de France.

Therefore, the design and works construction are based on the observational method involving: appropriate complementary geotechnical surveys, the use of granular blending materials, and implementation of works instrumentation of the reclamation area.

This paper presents the project constraints and the construction methodology, and sets out the feedback obtained of the reclamation area extension after 12 months of work.

2. MAIN PROTAGONISTS

Project Owner:

Grand Port Maritime de La Martinique (GPMLM): Engineering & Project Department

Project manager:

ARTELIA Eau & Environnement (AEE), Maritime business unit, Grenoble

Contractor:

Colas – Balineau La Martinique Joint Venture

3. MAIN QUANTITIES

The south-eastward extension works involve the following main quantities:

- Hub area: 2.4-ha reclamation area,
  - 550 meter-long rockfill enclosing berm,
  - 8,000 m3 of 30/100 kg rock
  - 13,000 m3 of 100/500 kg rock
  - 6,000 m3 of 0.5/1.5 t rock
  - 10,000 m3 of 2/5 t rock
- 140,000 m3 of quarry and andesite granular fill materials, grading: 0 / 300 mm
- Three instrumentation profiles (Water Pore Pressure Cells (CIP in figure 9), electrical and magnetic settlement monitoring).

4. DESIGN

4.1 Geotechnical context

In the context of its assignments, Artelia provided geotechnical design studies at the preliminary (G2-AVP study) and detailed design study stages (G2-PRO study).

The Grives container terminal is located at the mouth of the river Monsieur. The soils consist of alluvium, with organic silty clays and madreporic sands with varying clay contents surmounted by silt. The madreporic sands have a widely varying proportion of coral debris. Large-diameter core samples obtained using suitable drilling techniques are the only means of obtaining a correct representation of the madrepores content. The alluvium thickness varies from 10 m to more than 30 m.

The substratum consists of weathered and then stiff tuffite.

In the southeast extension area, little organic clay is intersected and the madreporic content is higher than in the northwestern area, close to the river Monsieur.

The geotechnical characteristics of the soil layers are given in Table 1.

Layer no.	Soil type	pl* (MPa)	Em (MPa)	E/Pl	α	Qc (MPa)	Rf (%)	Qc/pl*	C' (kPa)	Φ' (°)	Cu (KPa)	<80µm (%)	<2mm (%)

<table>
<tr><td>1</td><td>Silty sands</td><td>0.17</td><td>1.5</td><td>6</td><td>1/3</td><td>0.1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>Madreporic sands</td><td rowspan="2">0.1</td><td rowspan="2">1</td><td rowspan="2">10</td><td rowspan="2">1/3</td><td rowspan="2">0.8</td><td rowspan="2">1.7</td><td rowspan="2">8</td><td rowspan="2">3</td><td rowspan="2">28</td><td rowspan="2">20/50</td><td rowspan="2">32</td><td rowspan="2">67</td></tr>
<tr><td>3</td><td>Madreporic sands clay facies</td></tr>
<tr><td>4</td><td>Substrate alteration clay</td><td>1.2</td><td>12</td><td>10</td><td>2/3</td><td>5</td><td>3.2</td><td>5.5</td><td>14</td><td>26</td><td>100</td><td>67</td><td>88</td></tr>
<tr><td>5</td><td>Weathered tuffite</td><td>2.3</td><td>27</td><td>12</td><td>2/3</td><td></td><td></td><td></td><td>16</td><td>33</td><td>150</td><td></td><td></td></tr>
<tr><td>6</td><td>Stiff tuffite</td><td>4.5</td><td>53</td><td>12</td><td>1/2</td><td></td><td></td><td></td><td>50</td><td>35</td><td>250</td><td></td><td></td></tr>
<tr><td>7</td><td>0/300 mm granular materials</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0</td><td>45</td><td></td><td></td><td></td></tr>
</table>

Table 1: Geotechnical model parameters

4.2 Consideration of seismic risk - geotechnical stability

The maximum reference acceleration in rocky ground is $\mathbf{a_g = 3\ m/s^2}$.

The importance category for the berms given by the owner is **category I** as per French seismic regulations (of minor importance for public safety), which gives an importance coefficient: $\boldsymbol{\gamma I = 0.8}$.

The soil parameter for a class D seismic soil (alluvium in place) is **S = 1.35**.

The stability of the enclosing berms is assessed and validated with a **traditional Eurocode 8 approach**, reducing the shear characteristics of the materials in place and the filler materials.

4.3 Hydrodynamic stresses

The bay of Fort-de-France, to the north of which Pointe des Grives container terminal lies, is open to the west on the Caribbean Sea (2,400 km of fetch to Mexico).

The Pointe des Grives site is thus naturally protected from the northeast trade winds, but is less protected from seas raised by cyclones which, on account of their swirling nature, generate waves towards the site irrespective of their trajectory to the west of the site. Two kinds of wind and wave climates must therefore be considered:

- Local wave motion: chop raised by trade winds within the bay itself (100-year return period), water level = 0.94 m NGH, Hm0 = 1.2 m, period = 4 s.
- Sea wave motion: offshore swell propagated from the southwest (100-year return period), water level = 1.8 m NGH: Hm0 = 2 m, period = 10.5 s.

4.4 Protective berm profiles

The protective berms are composed of:

- Granular material for the core,
- Geotextile between the underlayer and the granular core,
- Rock materials for the underlayer, toe and armor.

The protective berm profiles are illustrated in figures 6 and 7.

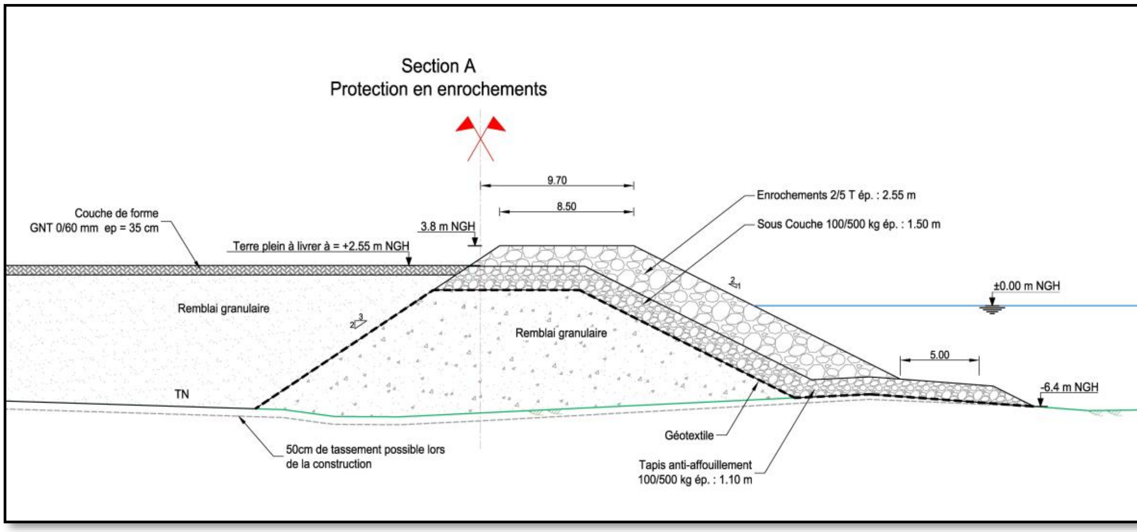

Figure 6: Eastern protective berm – cross section A (Artelia drawing (2015))

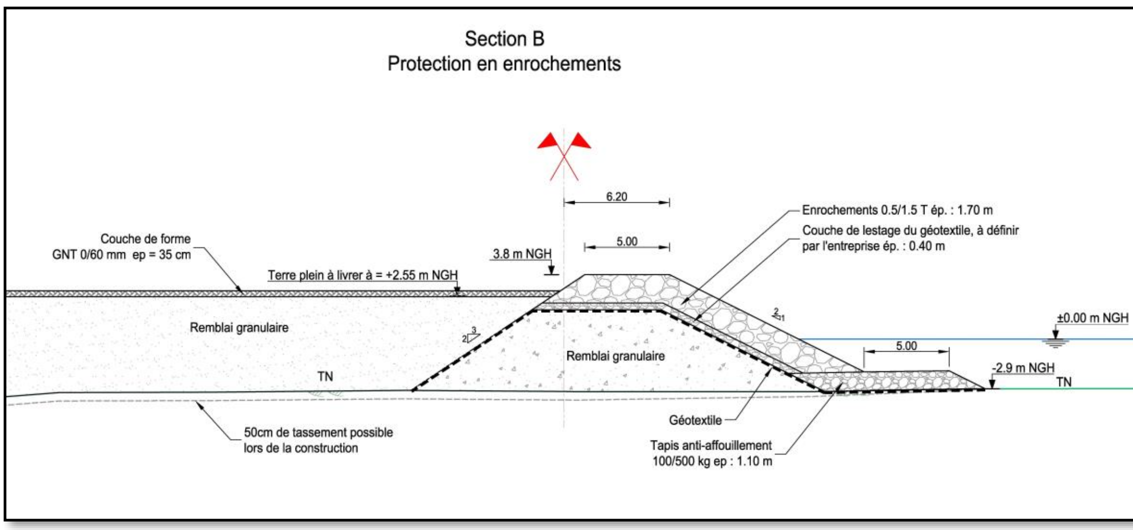

Figure 7: Eastern protective berm – cross section B (Artelia drawing (2015))

4.5 Special features of the design - Observational method

As previously stated, the mechanical characteristics of the soil are poor. However, the representativeness of core samples and pressiometric boreholes is not perfect.

Previous studies found that the soils were compressible, with a metric magnitude settlement.

Since dredging work is prohibited by local regulations, whether for the purpose of obtaining filler materials or purging the most compressible materials, the design solution implemented had to be geotechnical and hydraulic design-based.

In consultation with the client, a strategy of complementary geotechnical surveys suited to the context and the project was implemented. A 20 t heavy static penetrometer was hence transported from mainland France, enabling soil compactness and loose layer thickness to be determined in a continuous manner by crossing the banks of metric madrepores.

The geotechnical and hydraulic design hence take into account the hard, angular and robust quarry materials (quarry materials, Andesite, 0/300 mm, very low fines content).

The calculated settlement amplitude was revised downwards, with values between 30 and 50 cm depending on the fill and madreporic sand heights.

Instrumentation was designed and put in place to monitor settlement, incorporating sensor redundancy to compensate for unavoidable damage during the earthworks:

- Water pore pressure cells (CPI on figure 9) to monitor pore pressure dissipation (verify the consolidation phenomenon),
- Settlement sensors (CT on figure 9; magnetic and electrical) to monitor settlement.

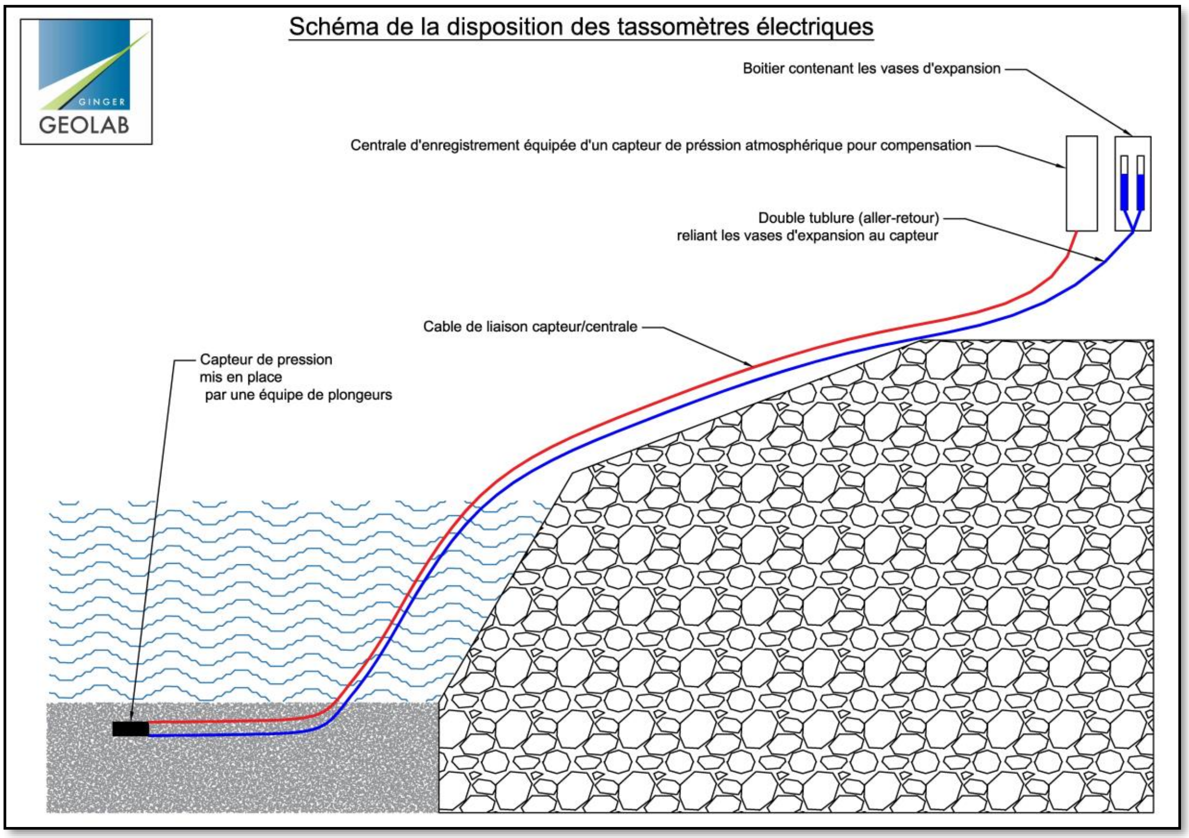

Figure 8: Schematic diagram of automatic data acquisition (Ginger-Geolab sketch, (2015))

Two profiles consisting of 3 IPC + 3 CT were implemented, beneath the water table and the bottom of the rockfill materials (See figure 8), according to the layout presented in figure 9.

The sensors are equipped with automatic acquisition of data and transmission to a control unit placed in an electrical cabinet on the existing reclamation area.

The wiring and ranges of the settlement sensors are geared to an expected elastic settlement amplitude of 20 cm (North) to 50 cm (South).

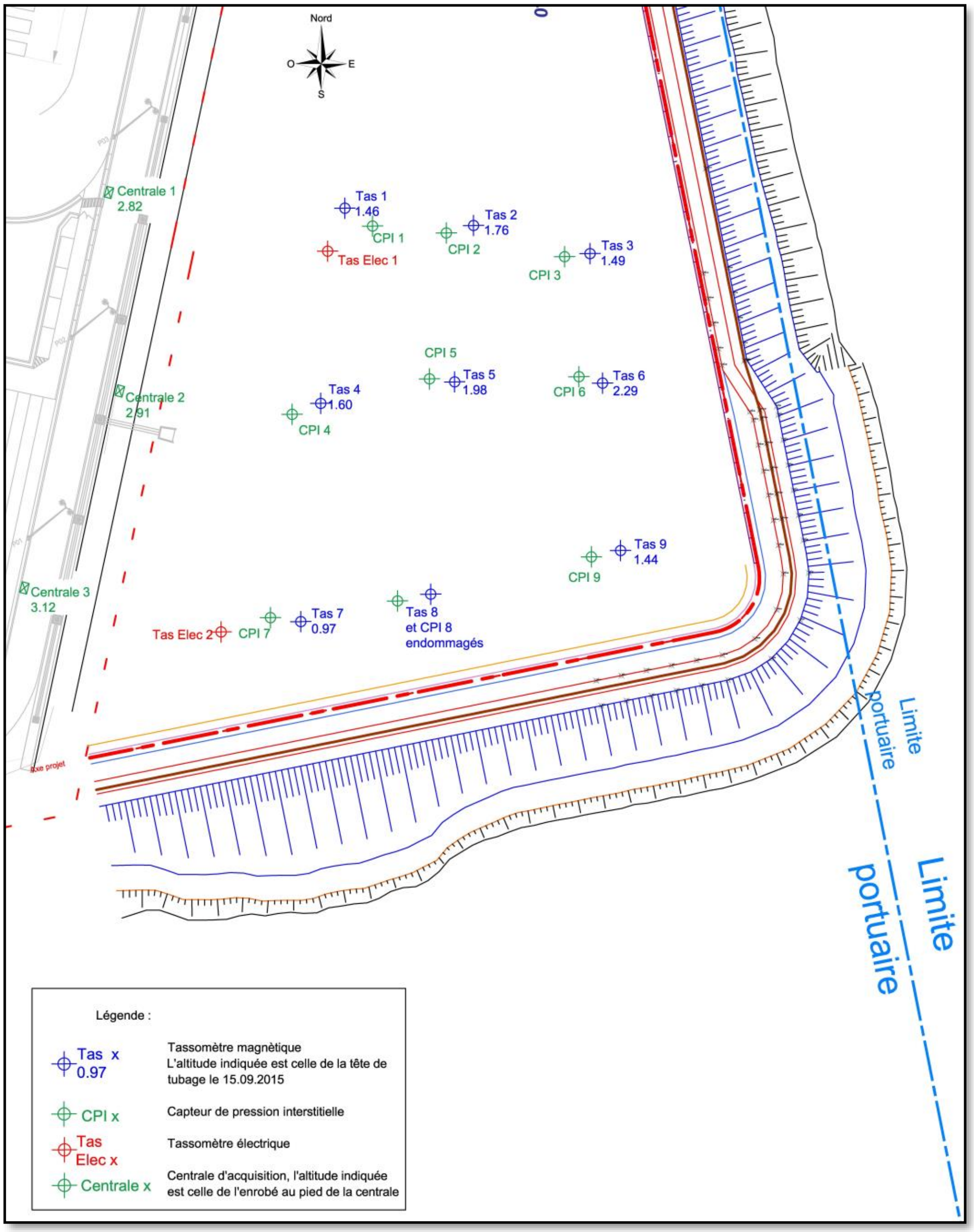

Figure 9: Project instrumentation layout (Ginger-Geolab drawing (2015))

The contractor (a geotechnical and instrumentation subcontractor) carried out measurements with the following frequency:

- Starting point on commissioning the sensors,
- One month after the starting point,
- One month after the reclamation area crest level was reached,
- Then monthly over 6 months.

In the event that settlement exceeds the acceptable design criteria, a soil consolidation solution using ballasted columns can be sized and implemented.

5. CONSTRUCTION WORKS STAGE

The construction works phasing is as follows:

- Dismantling of the berm protecting the existing reclamation area,
- Implementation of new protective berms along about 2/3 of the footprint of the planned reclamation area, in water depths up to 5 m, with a low silt thickness (see figure 10)

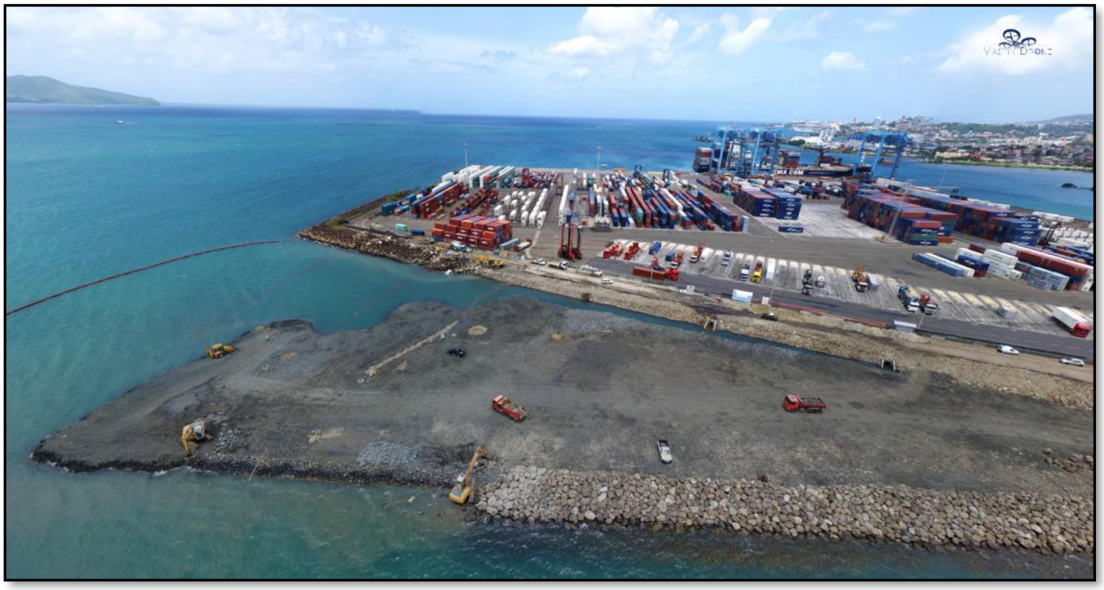

Figure 10: Aerial view of the first work phase (photo: Mad'In Drone (2015))

- Backfilling with approximately 40,000 m3 of granular material to create a reclamation area measuring approximately 1 ha, by land (See figure 11)

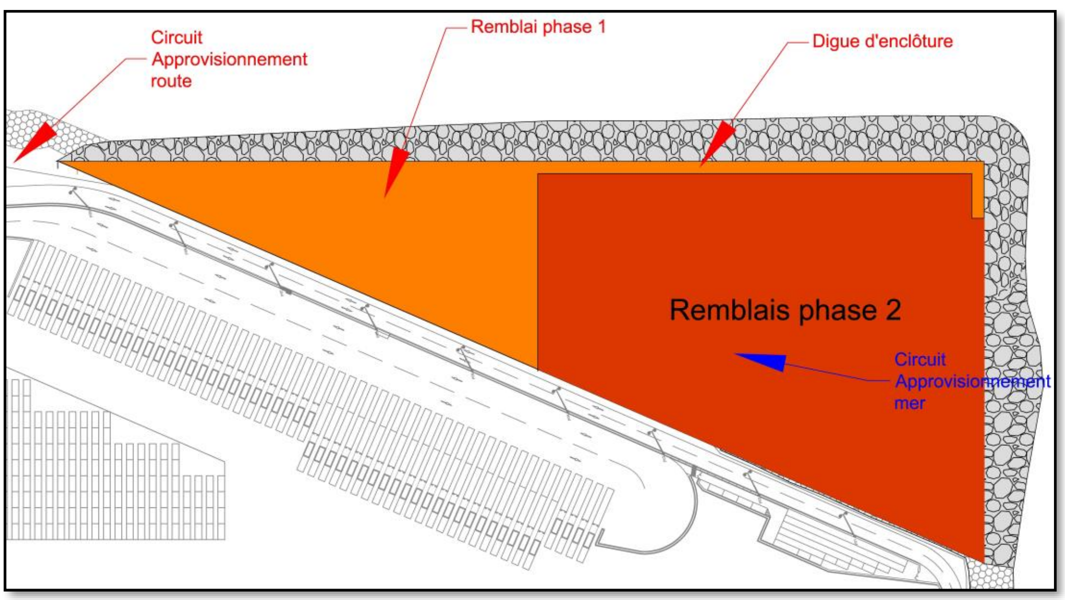

Figure 11: Plan view of stage 1 and stage 2 backfilling (drawing: Artelia (2015))

- Temporary protective rock berm,
- Analysis of the monitoring and of the primary settlement and consolidation kinematics,
- Creation of the reclamation area capping layer using granular materials (see figure 12)

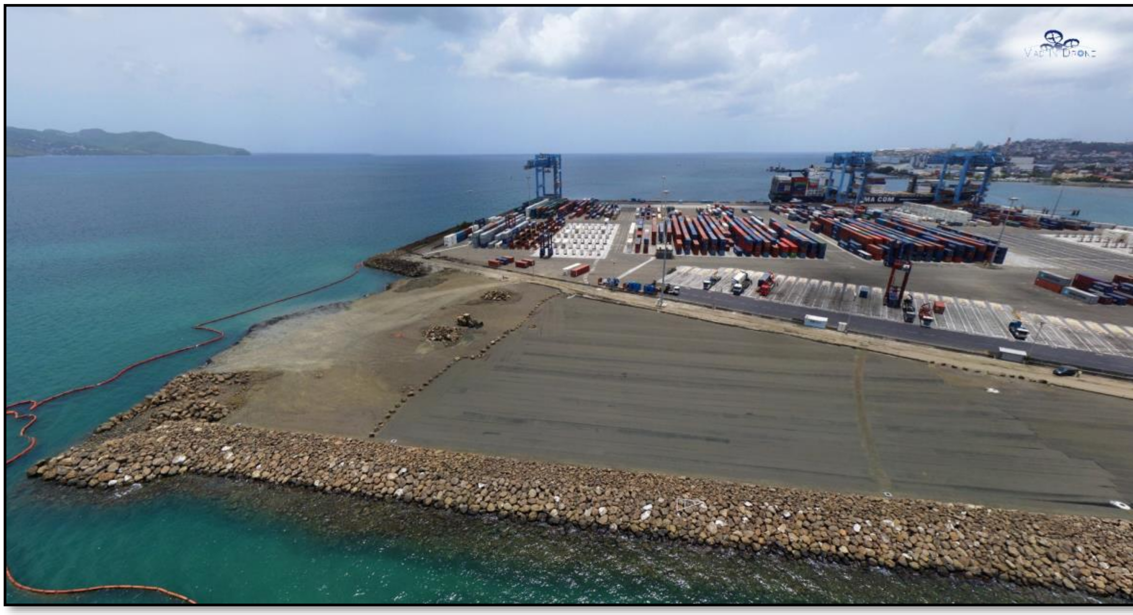

Figure 12: Platform capping and surface dressing layer works (photo: Mad'In Drone (2015))

- Application of a platform surface dressing comprising a two-layer tack coat, to allow use of the newly-created surface for a limited period of time (see figure 12) before creation of the final pavement structure (see figure 13)

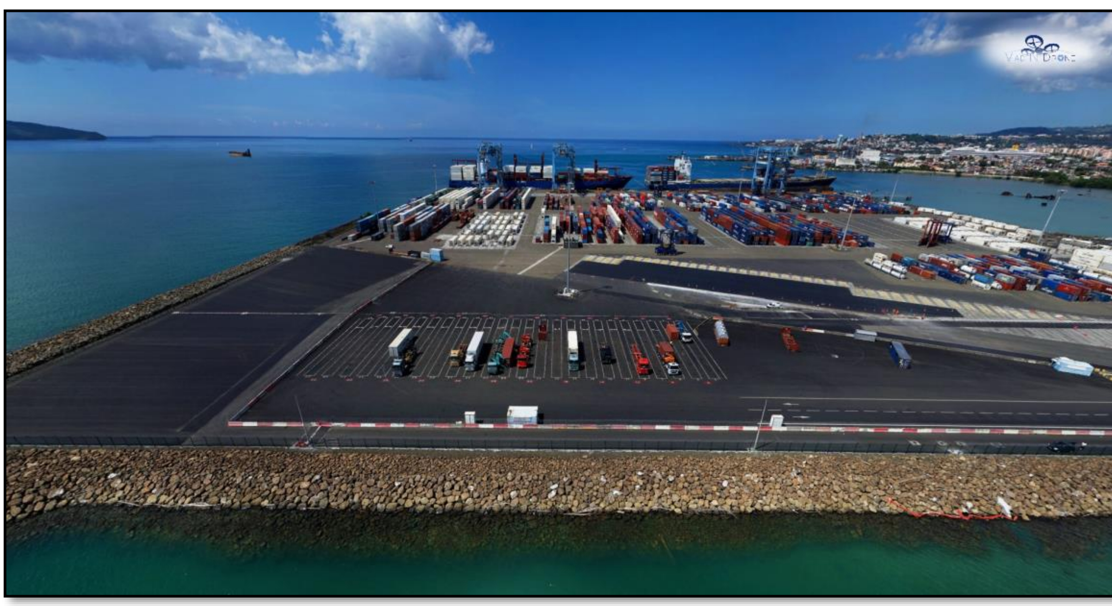

Figure 13: Aerial view of final reclamation area pavement (photo: Mad'In Drone (2017))

- Creation of box-outs for the sewerage network outlets and for the fire network.

6. FEEDBACK

6.1 Monitoring results

The instrumentation cables are protected by concrete culverts laid as the project works progressed: first under water, then on land. Despite this protection, approximately 50% of the sensors were damaged. However, thanks to the measurement redundancy, it was still possible to monitor the settlement profiles correctly throughout the construction period.

The maximum settlement amplitudes measured were in the range of 30 cm, occurring mainly during the construction phase. Deferred settlement after one year of works was limited, including in areas where the silty layer is thick.

Monitoring and analyzing settlement therefore provided a means of validating the design, and soil reinforcement measures were not required.

6.2 Environmental protection during reclamation area cell filling

It should be noted that the filling of the reclamation area cell with materials could generate an overflow and thus result in degradation of berms and other structures and the formation of a turbid plume. The contractor implemented the specific measures required to avoid these phenomena: temporary containment of the reclamation area cell, and use of a geotextile curtain.

6.2 A materials strategy to reduce project construction costs

In conclusion, the observational method combined with the management of quarry materials with very good mechanical characteristics provided a means of implementing the works with optimized costs and within the expected deadline.

Moreover, this work had minimal impact on the environment and complied with the requirements of regulations.

7. REFERENCES

Artelia (2015), Report No.1713189_2 R12_V1, Extension du terminal à conteneur de la Pointe des Grives – Programme 2, Projet, Echirolles.

Ginger-Geolab (2015), Report No.C001.F.047D, Instrumentation – Rapport de mesure n°2- Terre-plein Sud – Extension du terminal de la Pointe des Grives, Fort-de-France.

Mad'In Drône (2015 to 2017), Specialist in aerial view in Caribbean, website company: http://madeindrone.com/Grand-Port-Maritime/Suivi-360.html, Martinique.