Site characterization by CPTu, SDMT and PMT tests for "Mémorial ACTe" in Guadaloupe

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ABSTRACT: The urban renewal of Guadaloupe Region (Antilles islands) allowed an extensive site investigation at Pointe à Pitre, in order to build the exhibition building "Mémorial ACTe", also called "Centre Caribéen d'Expression et de Mémoire de la Traite et de l'Esclavage". The construction will replace an old, now demolished, sugar refinery (1870), where in past years different fill materials were placed above the tropical and calcareous coralline soils. A geotechnical campaign was performed during 2012-13 and consisted of two continuous core drillings (10 m deep), ten destructive boreholes with Menard pressumeter (PMT) tests every 1.5 m (18-26 m deep), twelve piezocone (CPTu) tests and three seismic dilatometer (SDMT) tests (8-14 m deep) in virgin soil or a backfilled borehole. By integrating the results obtained from different in situ tests, a geotechnical model of the subsoil was defined, focusing on fill materials, tropical soils and altered calcareous coralline, that needed to be compacted before the construction of the "Mémorial ACTe" to improve the strength and compressibility parameters.

1 INTRODUCTION

The Mémorial ACTe (MACTe) project - Caribbean Centre of Expression and Memory of Slave Trade and Slavery - was initiated by Guadeloupe Region, the public owner of the operation, in 2006 (Fig. 1). It wants to be a highly symbolic place for Guadeloupe, dedicated to the memory, information, knowledge and historical research on the slave trade and slavery, for Guadeloupian population, tourists, students and researchers. In addition, the project wants to be forward-looking and promote a new humanism and understanding between peoples, nations and cultures.

This building is located on the site of the former sugar factory of Darboussier created in 1870. Since 1981, when it became industrial wasteland, the area was subject to a major urban redevelopment project in Pointe à Pitre city, where the Mémorial ACTe project would be the landmark. Other structures (not part of the present project) include roads, buildings, hotels, restaurants, seafront promenades, office buildings, etc. Specifically, the future Mémorial ACTe is a public space including permanent and temporary exhibition halls, multipurpose halls, a convention center with 400 seats, restaurant areas, promenades and plazas and a panoramic garden. A pedestrian bridge will connect the Mémorial ACTe and the Morne Memoire. Located on the seafront, it will also include docks and wharfs for small boats and cruise liner landing craft.

The MACTe is under construction and in the long term will become a major structure for the Guadeloupian territory.

Figure 1.Exhibition building "MémorialACTe", Guadaloupe Region (Antilles islands).

This project is composed by:

- Construction of a conference and exhibition building (Area 1 – 7300m²);
- Construction of an annex building (Area 2 – 1300 m²);
- Construction of a footbridge which will connect Area 1 with Area 3 called " Morne Mémoire".

The main structure is made of reinforced concrete. External structures and the pedestrian bridge are metal structures. Foundations are shallow or based on a stiff column or piled improved soil. Its location presents several constraints considering the high seismicity of the area, (peak ground acceleration: *PGA* = 0.45 m/s²), and the close proximity of the sea, (floods, bad weather).

2 GEOLOGICAL SETTING

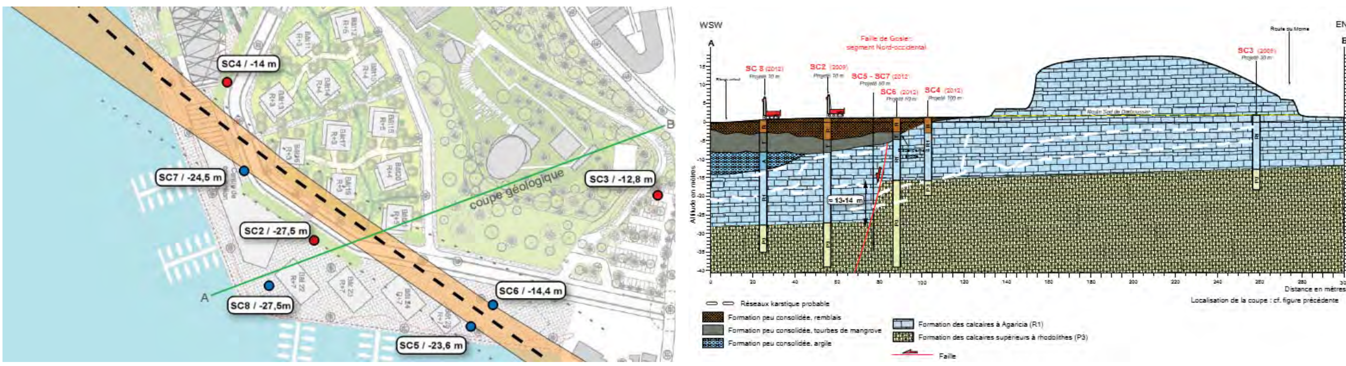
From the general point of view, Guadeloupe is on the border of Atlantic and Caribbean plates. The geology of Guadeloupe has the particularity to be influenced by both internal and external arcs of the Lesser Antilles. Thus, the Basse Terre is part of a volcanic context still active (Soufriere Volcano – 1480 m) and the Grande Terre in a sedimentary carbonated context.

The geological map (BRGM, 1998) indicates that the site falls within the general context of anthropogenic formations with or without fills dating from the quaternary age. It covers sedimentary units very characteristic of the Grande Terre part of Guadeloupe.

GEOTER performed detailed geological studies at the site of Darboussierin (GEOTER 2009, 2012 and 2013), based on visual surveys of the cliffs located South of the site and on deep core boreholes. Their biostratigraphic interpretation identified sedimentary units well known elsewhere on Grande-Terre, thanks to recent academic work (Léticée et al. 2005;Léticée 2008; Cornée et al. 2012).The boreholes drilled at the site indicate that the sedimentary formations begin with recent fills, (dating from the construction of the factory), whose thickness varies from 2 to 6 m. Under the fills, a loose formation mainly composed of peat (tropical coastal swamp soils) was locally observed only in the Southern third of the site. Under these recent formations, carbonate soils start at a variable depth (from 1 to 9 m) as its roof is a paleo-topography having suffered multiple emergences (Cornee et al. 2012).The first carbonate formation encountered corresponds to "limestone with Agaricia" (R1) of Pleistocene age estimated between 780,000 and 670,000 years by Léticée (2008).Recent studies tend to reassess this period between 1.8 and 1.5 Ma (Cornea et al. 2012).These white limestones cover the formation of "higher limestone with rhodolites " (P3) of Pleistocene age. The abundant presence of large rhodolites (several centimeters) and inclusion of volcanic elements is characteristic of these ocher-brown tainted limestone. The stratigraphic boundary between the formations "limestone with Agaricia" / "higher limestone with rhodolites " (limit R1/P3) is an important stratigraphic marker because it determines the presence or absence of a shift in the sedimentary series due to the replay of a fault. A fine biostratigraphic analysis makes identifying the stratigraphic boundary on cores possible. Core boreholes fully confirm this analysis.

In addition to the geological aspect, the site of Darboussier has a complex tectonic setting. It is affected by the South-Western "ponytail form" extremity of the so-called "Gosier fault" (Fig. 2a). GEOTER specifically studied the tectonic aspect of the site during their investigations (GEOTER 2009, 2012 and 2013).With a sub-marine length of about 11 km, the Gosier fault system continues under the sea to reach a total length of about 15 km. Eastward, it belongs to a more general system that continues to the East end of Grande Terre (Pointe des Châteaux), including average East-West faults arranged in relay (faults of St. Anne, May, Bragelogne, St. Francis and Fond St. Bernard). This entire fault system, which is the Northern edge of the graben of Marie-Galante, could reach a length of over 40 km. Some segments of the fault system are expressed in the morphology, especially for the major segments of Gosier between the area of Saline to the East, to the area of Pointe a Pitre to the West. Other faults are hidden below the soils, as present at the site of Darboussier. The escarpment resulting from a normal displacement, can reach a height of 15 to 60m, depending on the sectors and segments of the faults.

The ground level was elevated in order to protect the works from floods and cyclones. This general back filling of 1.5 m has been wisely used to form the main part of the load distribution layer between the basement slab and the inclusions.



(a) (b)

Figure 2. Site of Darboussier: (a) Gosier fault; (b) geological section (GEOTER, 2012).

On the site of Darboussier, the different geological (core boring hole) and geophysical (measures H / V) investigations have located the fault South of the project to within roughly 25m accuracy. The vertical displacement of the fault has been measured from 13 to 14m. It shifts the limestone with Agaricia from higher limestone with rhodolites following quite a normal way, the collapsed portion lying South of the site (Fig. 2b).

3 GEOTECHNICAL INVESTIGATIONS

In order to properly design the MACTe, a detailed geotechnical campaign (Fig. 3) was performed during 2012-2013. It consisted of two continuous core drillings (Ca1, Ca2, each 10 m deep), ten destructive boreholes (Pr1 to Pr10) with Menard pressuremeter (PMT) tests (Fig. 4a) every 1.5 m (18-26 m deep), twelve piezocone (CPTu1 to CPTu12) tests (15 m deep, Fig.4b) and four seismic dilatometer (SDMT3, SDMT4, DMT4b, SDMT7) tests (8-14 m deep, Fig. 4c) in virgin soil or in backfilled boreholes (TC16 2001, Marchetti et al. 2008, Totani et al. 2009). Moreover, a resonant column test (Fig. 4) was performed on tropical soils (organic clay) (sample: Ca1 – 5.6-5.8 deep) to analyze the seismic site response. In particular, Figure 4a shows the pressuremeter results, in terms of Menard modulus E_M, while Figure 4b plots CPT data, in terms of the corrected cone resistance q_t, the sleeve friction f_s and the pore pressure u_2. In most cases the PMTs and CPTs commenced between two and five meters below the surface because of the non-penetrable layer of fill material. Figure 4c depicts SDMT profiles: material index I_D, constrained modulus M, horizontal stress index K_D and shear wave velocity V_S. Finally, Figure 5 illustrates the G-γ stiffness decay curve obtained from the dynamic (resonant column) laboratory test.

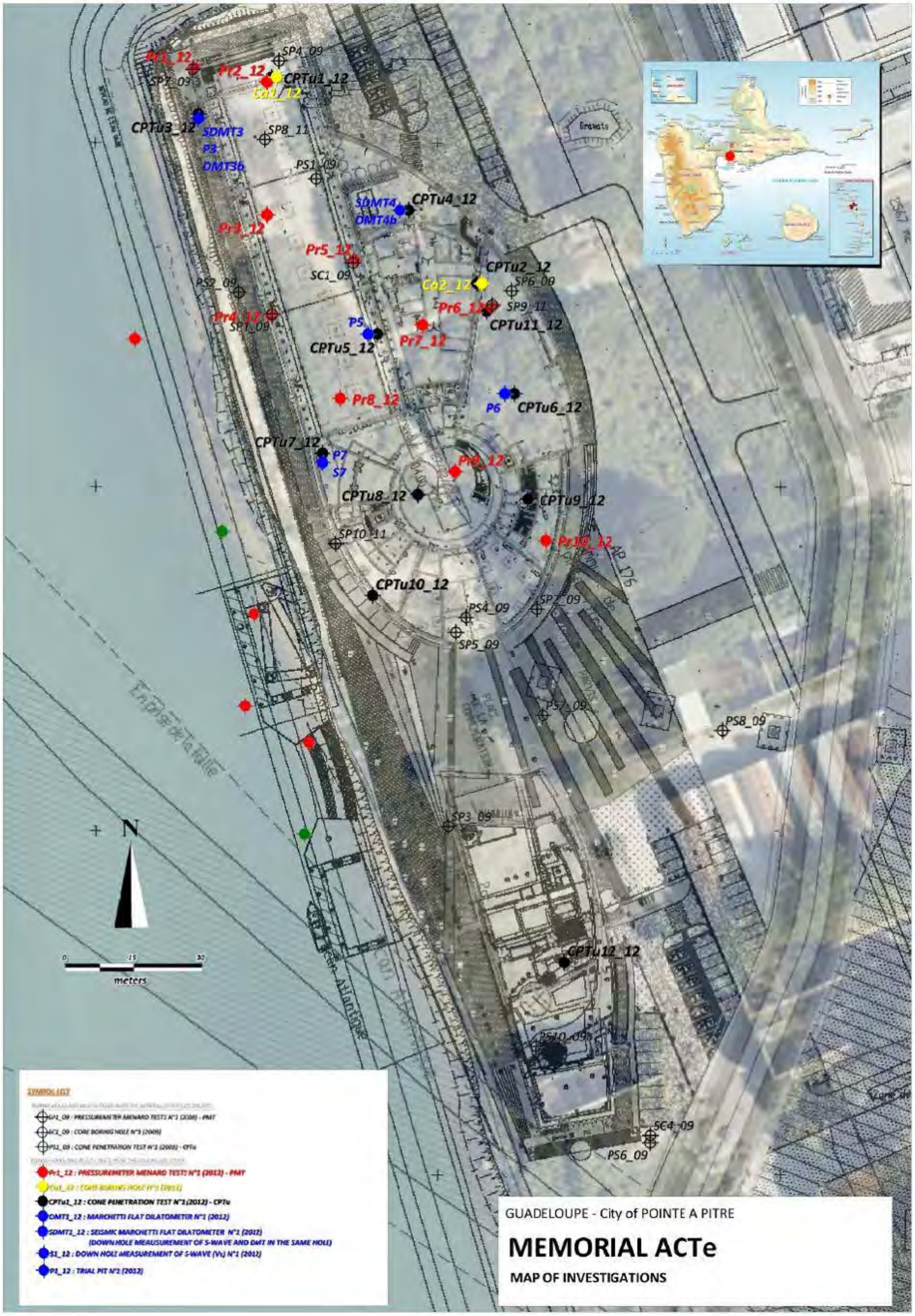


Figure 3.MACTe: plan of the geotechnical investigations.

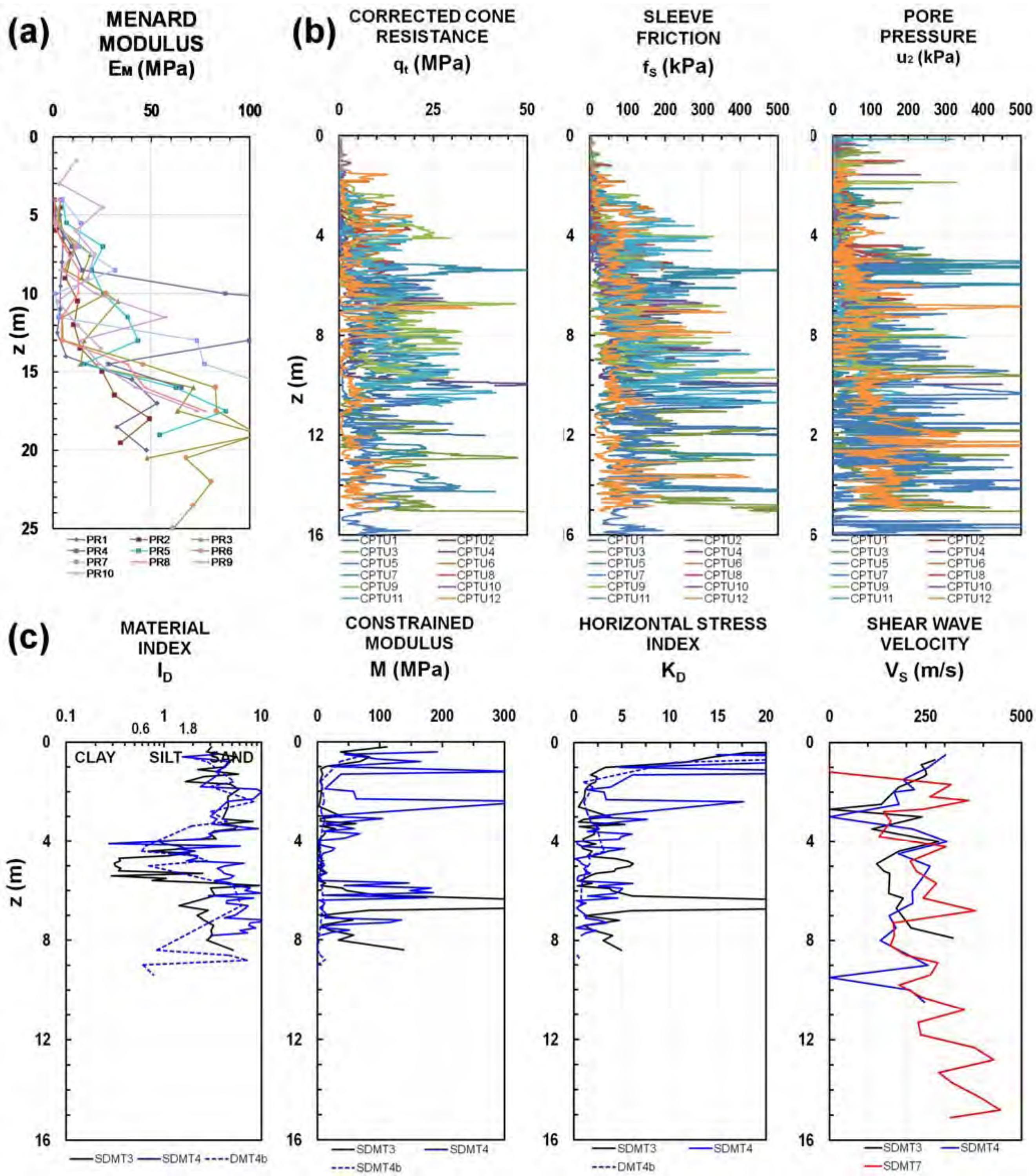


Figure 4.MACTe: (a) PMT results; (b) CPTU results; (c) SDMT results.

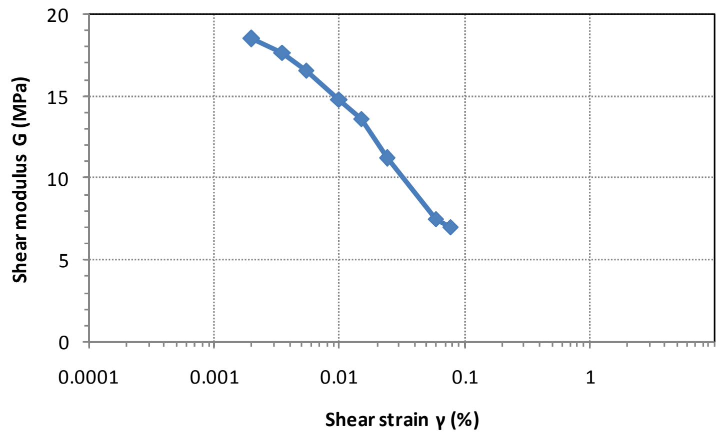


Figure 5.MACTe: *G-γ* stiffness decay curve obtained from a dynamic resonant column laboratory test on tropical soil sample.

By integrating the results obtained from different in situ and laboratory tests, a geotechnical model of the subsoil was defined focusing on the fill materials, tropical soils and altered calcareous coralline that needed to be compacted before the construction of the "Mémorial ACTe" to improve the strength and compressibility parameters. In particular, the subsoil model detected four geotechnical, listed from the surface down:

- Coarse-grained fill materials until 5 m deep: the thickness of the deposits increased in the NW area, as shown in boreholes;
- Tropical soils: they consist of clay and organic clay (organic content of 19%) that reach a maximum depth of 6 m in the North;
- Altered calcareous coralline soils (alterated marly limestone) until 9-16 m deep;
- Unaltered calcareous coralline soils (marly limestone).

4 SOIL IMPROVEMENTS WORKS

By considering the low geotechnical properties of the fill materials, tropical soils and altered calcareous coralline, the high seismicity of the area and the close proximity of the sea a genuine innovative solution was proposed by Keller. Designed in accordance with the latest recommendations of ASIRI and AFPS (French Association for Earthquake Engineering), and Eurocode 8, MACTe is the first major building designed according to these regulations in the Guadaloupe Region.

In situ and laboratory tests helped to validate the seismic hypothesis and to achieve an optimum solution by using a maximum settlement of 3 cm, as the design criteria (Fig. 6, Table 1).

The adopted solution consisted of the inclusions. They are installed practically without any excavation using a hollow tool that enables concreting the inclusions by their tip. The hydraulic composite (concrete), introduced via the web of the screw, is set within the soil cavity throughout the rise tool; it must be easily pumped and is often added under slight pressure.

Two cases should be differentiated: either inclusions are necessary to justify bearing pressure under seismic actions (Domain 1), or rigid inclusions have, as a principal function, the reduction of settlement and the soil can assure the bearing capacity under seismic actions without the rigid inclusions (Domain 2). The first step is to define the domain. For Domain 1, the internal stresses (shearing action, moment) in inclusions appear because of the deformation of the ground at the time of the passage of the seismic wave train (kinematic effect) and because of the inertial efforts of the structure transmitted to the ground reinforced at the base of the structure. The objective is to check that the stress induced in rigid inclusions under the kinematic effects and inertial remain acceptable (no traction), taking into consideration property of the used mortar: compressive strength, tensile stress, shear strength. The soil improvement shear equivalent modulus G^* can be comparable with the shear modulus of the ground alone G_0, (the contribution of inclusions to the shear strength remains indeed negligible in comparison to the ground). This parameter is used to define the cinematic and inertial deformation (Fig. 7).

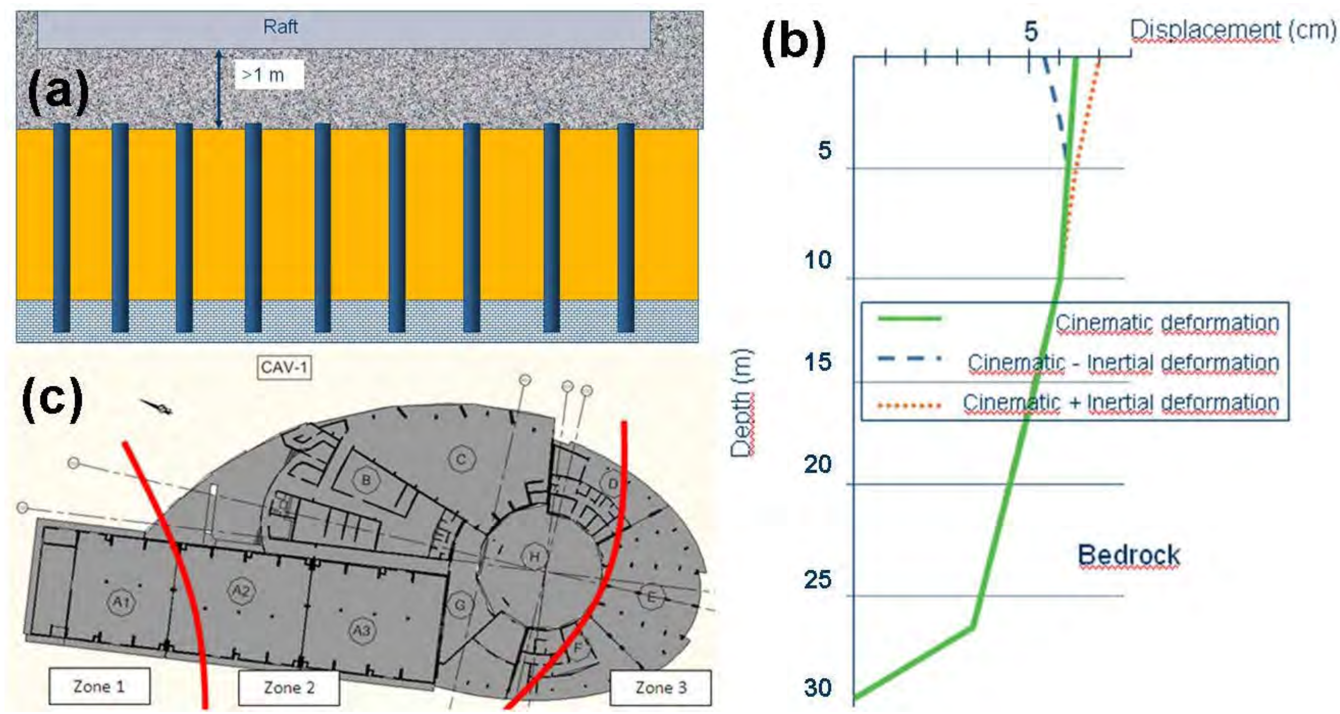


Figure 6.MACTe: (a) section of the reinforced soil; (b) cinematic and inertial deformations; (c) schematic rigid inclusion plan.

Table 1.Static and dynamic design soil hypothesis.

DEPTH (m)			Soil	γ (kN/m^3)	q_t(MPa)	E_M(MPa)	p_l(MPa)	q_s(kPa)	K_p(MPa)	α (-)	E_{oed} (MPa)	G_0 (MPa)
Zone 1	Zone 2	Zone 3										
+ 4	+ 4	+ 4	Gravel	20	20.0	20.0	1.5	150	-	0.25	80	160
+ 2.5	+ 2.5	+ 2.5	Fill material	18	4.0	8.2	0.8	70	-	0.66	12.3	60
- 1.5	-	-	Tropical soil	17	0.7	2.2	0.25	27	-	1.00	2.2	30
- 7.5	-0.5	-1.8	Alterated	19	2.5	4.2	0.8	75	2.3	0.66	6.3	60
- 10	-5.5	-	marly limestone	10	5.0	10.0	0.8	75	2.3	0.66	15	120
- 11.5	-22.5	-3.3	Marly Limestone	20	>15.0	33.0	2.9	154	2.3	0.50	66	264

Remarks: γ = unit weight; q_t = corrected cone resistance; E_M = Menard modulus; p_l = limit pressure; q_s= skin friction; K_p = load bearing factor; α = rheological factor; E_{oed} = oedometric modulus; G_0 = small strain stiffness modulus.

According to the calculations, this layer should have minimum thickness of 1m. Then, the works proceeded by reinforcing the lower layer with rigid inclusions of about 15 meters length (Fig. 5):

- 270 Rigid Inclusions: Ø 420 mm, 120 reinforced (Domain 1);
- 1274 Rigid Inclusions: Ø 340 mm (Domain 2).

In terms of time schedule, this solution offered some advantages. The inclusion works need 2.5 months, whereas piling works would have taken 6 months minimum.

In addition, there were no spoils or cuttings to evacuate and the treated areas could be released as construction moved on, thanks to the displacement tool.

In terms of money, the superficial foundation system enabled the client to return to the primary budget.

5 CONCLUSIONS

The integration of different geotechnical in situ (CPTu, SDMT and PMT) and laboratory tests allowed a detailed subsoil model to be developed that was useful for the design of the foundation system of MAC-Te.

The rigid inclusions reinforced the geotechnical properties of the surficial soils, (fill materials, tropical soils and altered calcareous coralline), by earning time and money for the construction of the exhibition building.

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