Shallow foundations of tall buildings, designed on the basis of DMT results

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Keywords: Shallow foundations, tall buildings

ABSTRACT: The objective of this paper is to describe the use of DMT in the design of shallow foundations for tall buildings in Sao Paulo / SP, Brazil. This city in Brazil has a well known geologic formation, with a sedimentary basin in its central area, surrounded by residual soils. Shallow foundations are often economical, both for sedimentary over-consolidated clays and sands, and residual silty soils. The design of those shallow foundations, for typical 20–25 floor buildings, is controlled by settlements. Dilatometer tests DMT, performed with SPT and CPT, were used in those settlements evaluations and provided the necessary support for design decisions.

1 GEOLOGICAL CONDITIONS OF SAO PAULO

Sao Paulo is a 1.516 Km^2 (585 mi^2) city, and when including suburbs its area is about 3.000 Km^2 (1,158 mi^2).

The elevations above sea level generally vary between 730 m (2,395 ft) and 830 m (2,723 ft), with a maximum of 1.126 m (3,694 ft) at Jaragua Peak.

During the tertiary geological age, a sedimentary basin was formed, with many layers of clays and sands, reaching elevations of 830 m (2,723 ft) above sea level.

Gradually, the two principal rivers, Tiete and Pinheiros, partially eroded valleys to about elevation 730 m (2,395 ft).

Many mountains of gneissic or granitic residual soils surround this basin.

In this area a large number of tall buildings have been constructed both in the central area (sedimentary basin) and in the contour area (mountains of residual soils).

2 SITE CHARACTERIZATION PRACTICE

Generally, the practice of foundation engineering in Brazil is based on Standard Penetration Test (SPT) results.

The use of additional site characterization, based on field (CPT, DMT, PMT) or laboratory tests is rare.

Since 1997 we have been encouraging the use of DMT as an additional field test.

This practice has been growing slowly in some construction companies. We have demonstrated that a better site characterization can be obtained with DMT. With the more accurate DMT data a better foundation design can occur resulting, in some cases in lower foundation construction costs.

3 BUILDING FOUNDATIONS IN SAO PAULO

The development of building constructions in Sao Paulo started around 1930 - 1940.

Five to fifteen floors were common at that time.

Shallow foundations on spread footings, drilled piers with enlarged base, obtained by manual under reaming and with or without the aid of compressed air, “Franki” piles, precast concrete piles and steel piles, were all used then.

Since 1970 - 1980 slurry method of drilled pier construction and concrete flight auger piles have been used.

Nowadays, most tall buildings in Sao Paulo are constructed on piled foundations.

The number of floors is growing as well as the total weight of the building.

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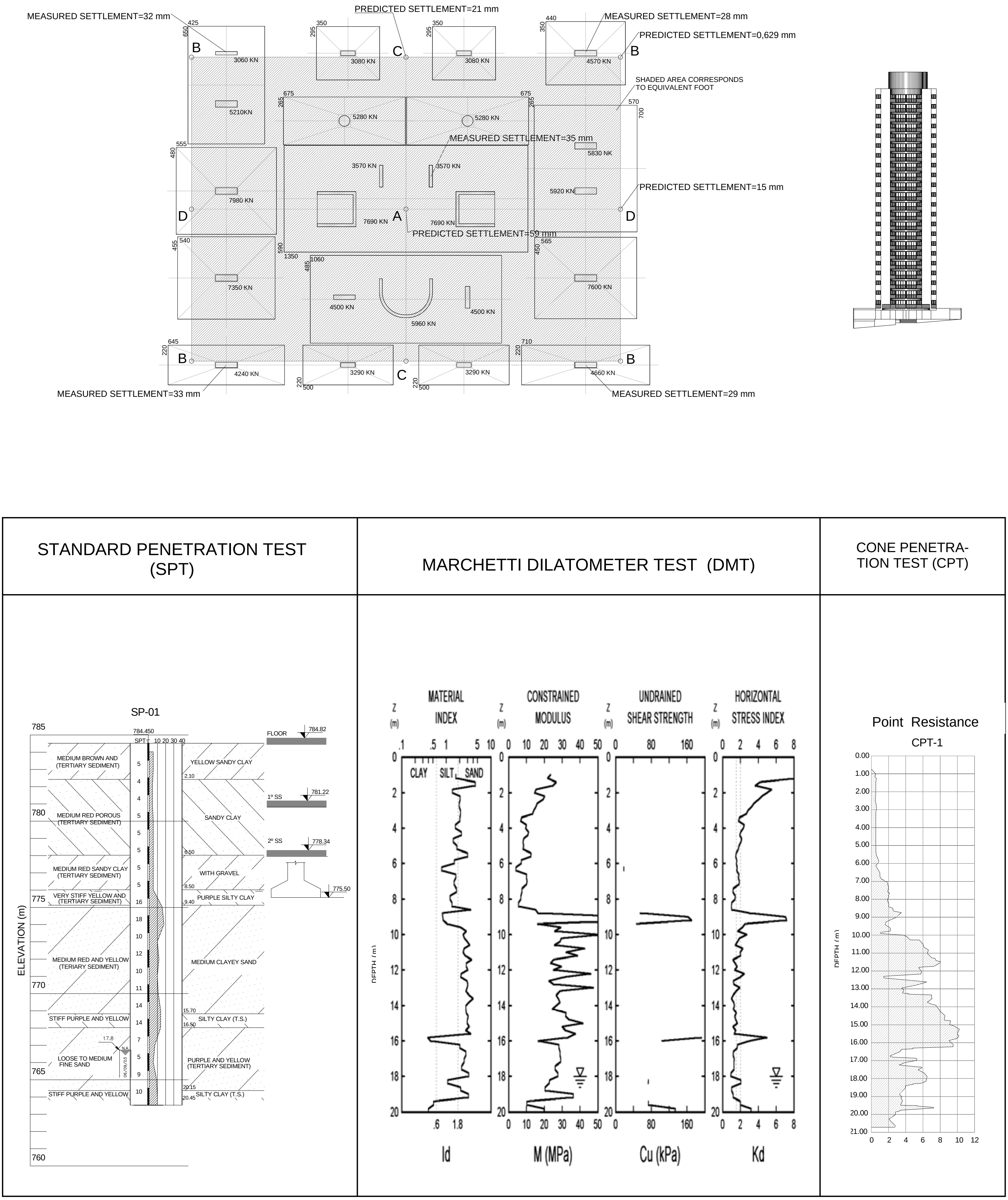

Figure 1. Pompéia building

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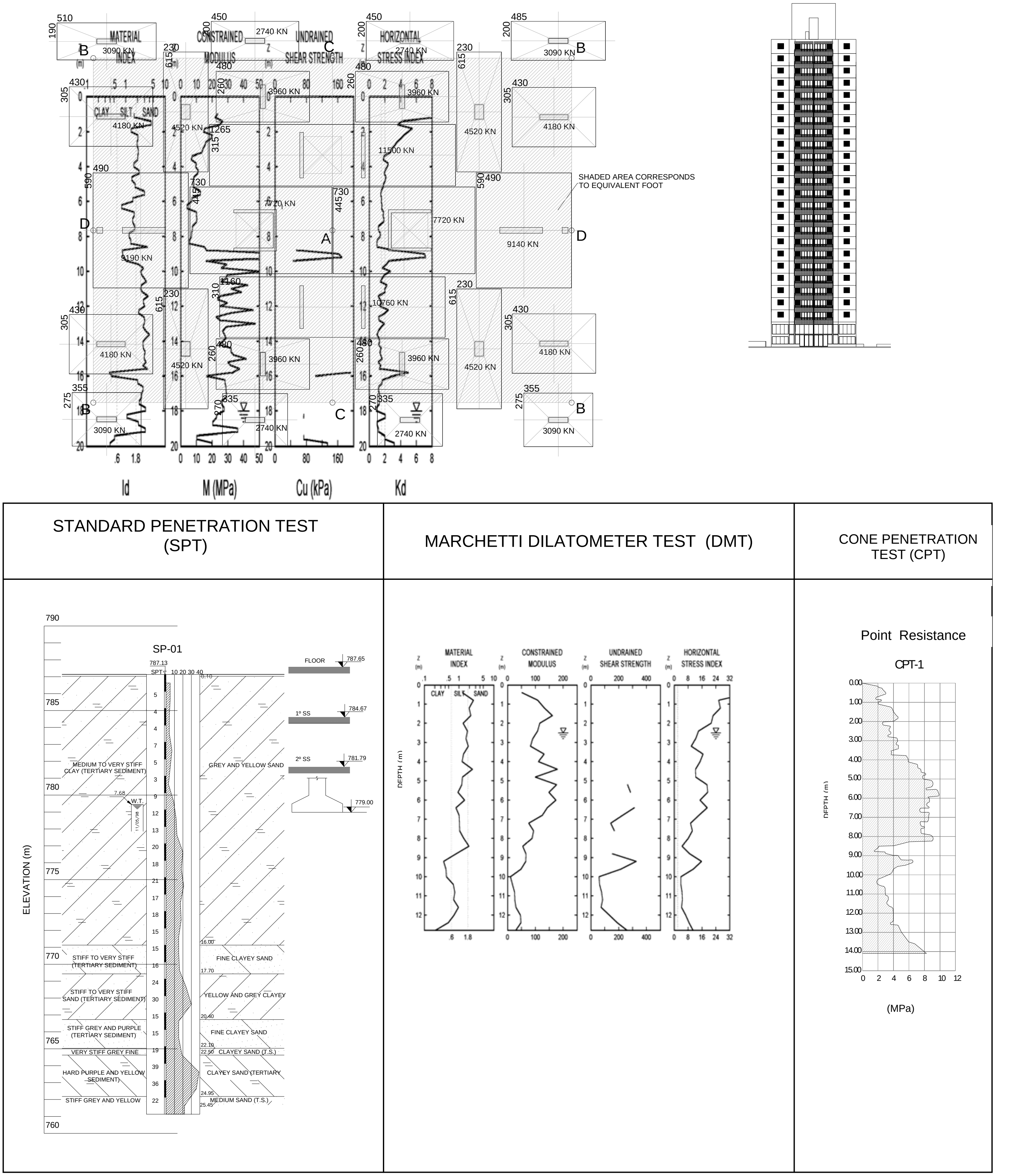

Figure 2.Moóca building

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These conditions combined with a large number of available equipment for different types of piles, and a poor site characterization techniques, lead to the use of pile foundations for most buildings.

Better information about soil properties can change this practice.

The use of DMT, as illustrated in this paper, can give the necessary information for settlement evaluation, allowing in some cases, the use of shallow foundations, with a substantial reduction in costs, when compared with pile foundations.

4 FOUR CASE HISTORIES IN SAO PAULO

This paper presents four case studies of buildings constructed on spread footings.

On Table 1 a summary of those four building cases is presented.

Table 1 – Building characteristics

LOCATION IN SAO PAULO	NUMBER OF FLOORS	DEPTH OF EXCAVATION FOR SUBSOIL FLOORS	LOAD IN EACH COLUMN (KN)	APPLIED STRESS IN SPREAD FOOTING
Pompéia	25	5.5m (18ft)	3,000-8,000	300 KPa
Moóca	25	5.5m (18ft)	3,000-8,000	350 KPa
Água Rasa	20	8.0m (26.2 ft)	1,000-5,000	275 KPa
Morumbi	31	4.0m (13.1 ft)	3,000-10,000	400 KPa

Figures 1 to 4 show the footings of the four buildings and one of the tests results combining SPT, DMT and CPT.

5 FOUR CASE HISTORIES IN SAO PAULO

It is well known that settlement governs foundation design for tall building over spread footings.

That is the reason why when predicted settlements are high pile are preferred, instead of footings, eventhough a pile foundation is usually more expensive than a footing foundation (about 1.3 to 1.6 times).

Using DMT, the design engineer can accurately predict settlement, than with only SPT results.

The DMT method used to compute settlement for those buildings is very simple.

The reduction in stress imposed by the excavation is considered as acting in the whole area and this induces reductions in the layers below the footings. No heaving is considered. The subsoil below the footing is divided in to numerous 20 cm thick layers, each one having a M value determined from the DMT test.

All the footing are considered together, as a large stressed fictitious rectangle, having an area representing the sum of the individual areas of the footings, receiving the total load of the building.

Four points are considered in this fictitious rectangle, the center (A), the corner (B), the middle of the length (C) and the middle of the width (D), as showed in figures 1 to 4.

The stresses induced in the subsoil by the rectangular loaded area are calculated in the centre of each 20 cm thick layer, using Newmark formula.

Thickness reduction in each 20 cm layer is calculated by the expression

$$\Delta\varepsilon_i = \frac{\Delta\sigma v_i'}{M_i} \qquad (1)$$

Settlement evaluated using this method does not consider the effect of the building structure, which will reduce the differences at points on the fictitious rectangle.

Results obtained in the predictions based on this method, for those four buildings are shown in Figures 1 to 4.

6 SETTLEMENT MEASUREMENTS

Unfortunately in Brazil, it has been difficult to persuade managers of construction companies to use better quality tests for site characterization to complement the SPT.

With only SPT, settlement predictions have been almost impossible to obtain.

We have been working hard to show the advantages of special field tests, as DMT. For “Moóca” site there were no settlement measurements, and the building is now finished. For the “Pompéia” site the settlement was measured at five columns, with a simple approach, and the building is also finished. For “Água Rasa” and “Morumbi” sites, both are under construction, and a specialized company is measuring settlements monthly.

For “Pompéia Building”, Figure 1 shows the predicted and measured settlements. The mean measured value is 31,4 mm and the mean predicted value is 24,1 mm. This prediction is good enough for design decisions.

For “Morumbi Building”, until now (February, 2006), only 40% of the total loads have been applied. Measured settlements are compared to predicted settlements in Figure 5 (for 40% of the total load).

The mean predicted settlement (13.1 mm) for 40% of the total loads, are compared with the mean measured settlement (8.9 mm) also for 40% of the total loads.

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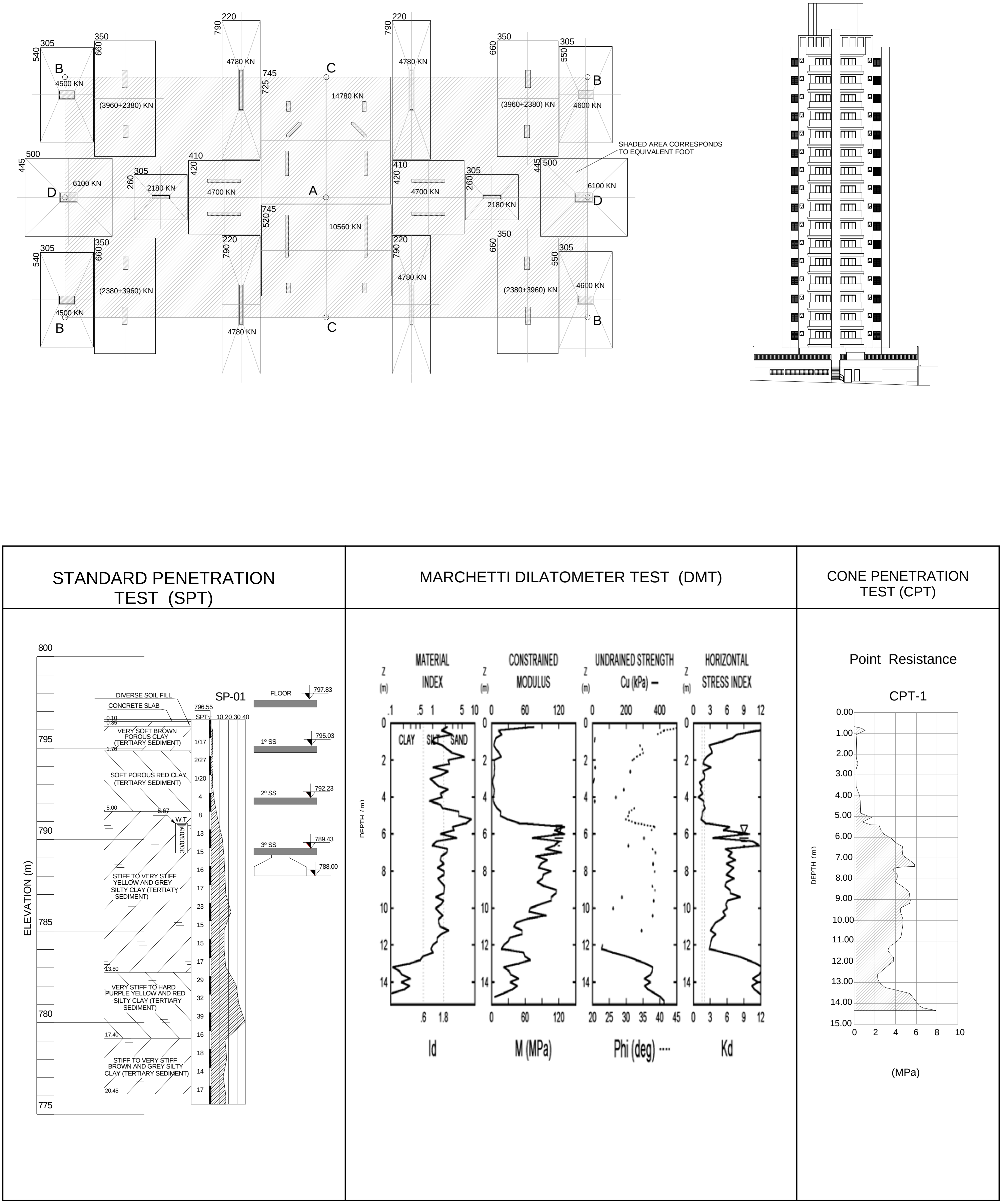

Figure3. Água Rasa building

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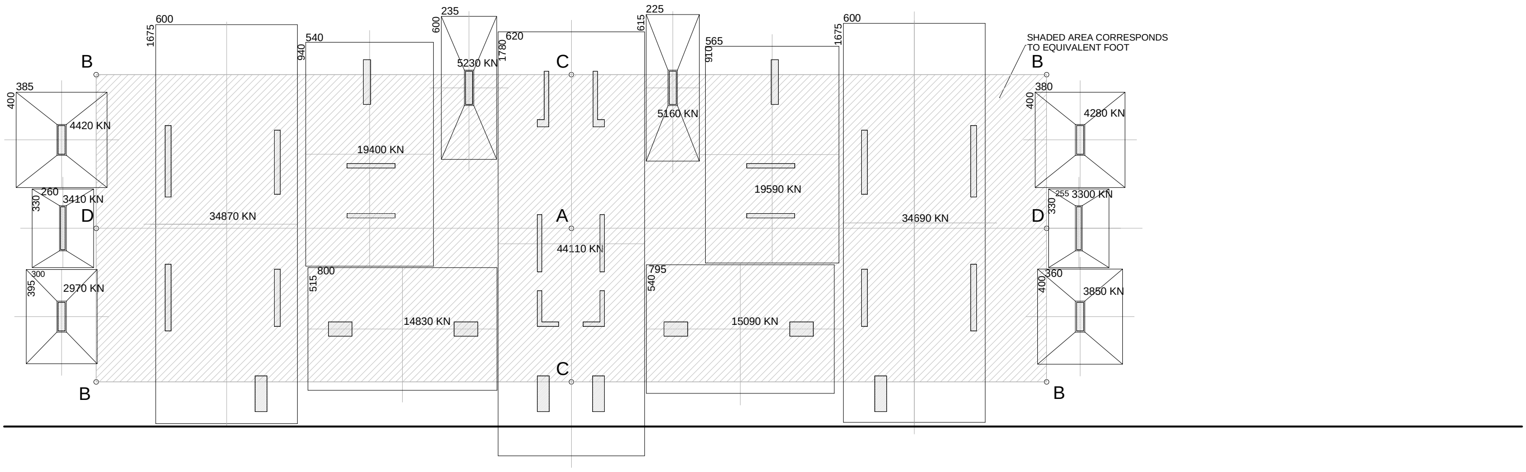
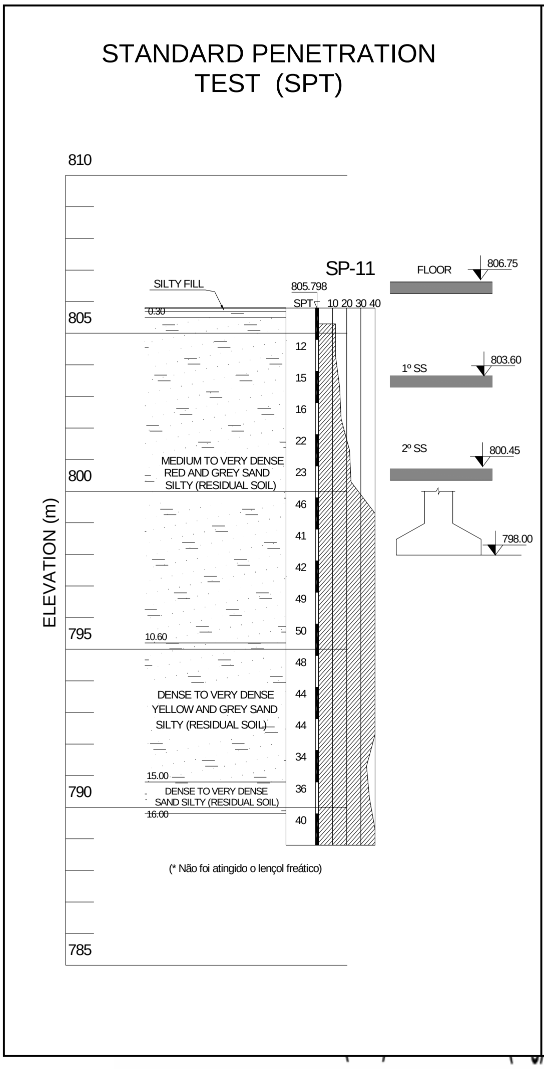
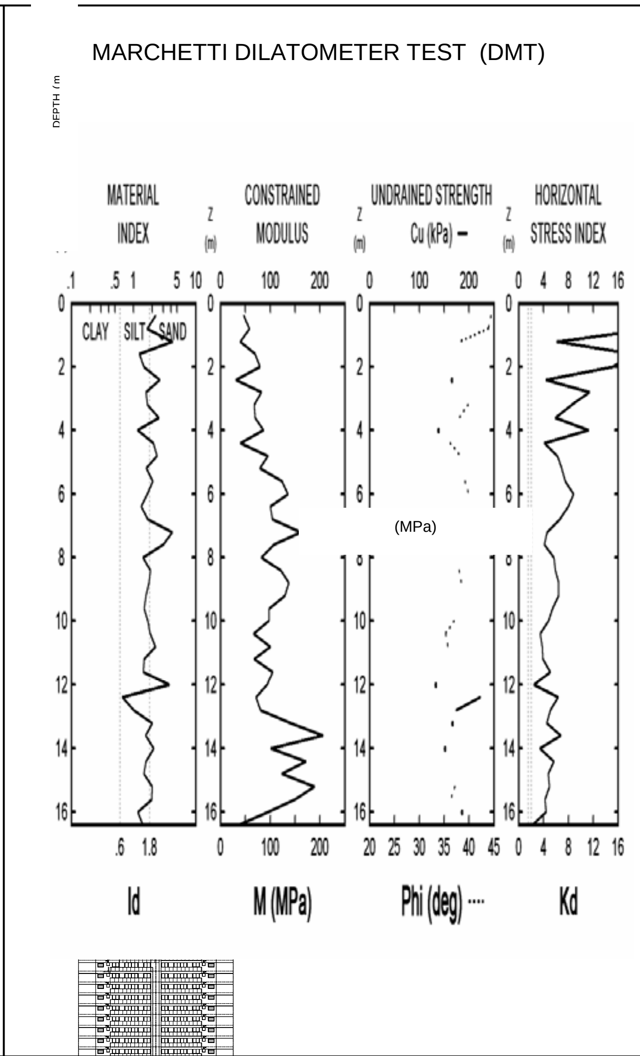
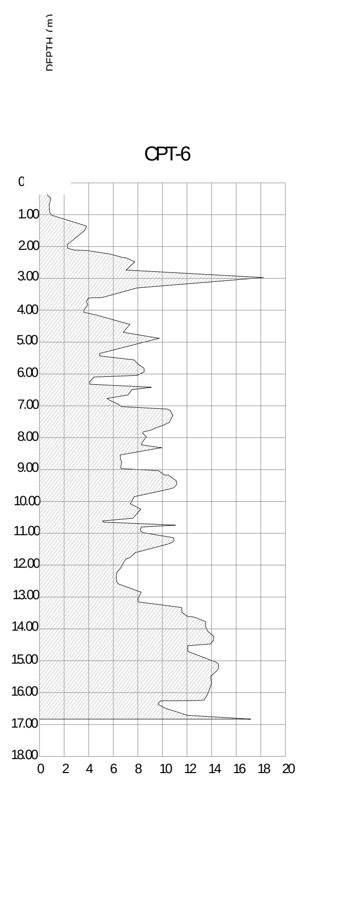


Point Resistance







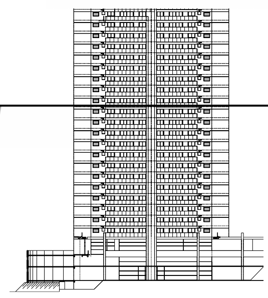


Figure4. Morumbi building

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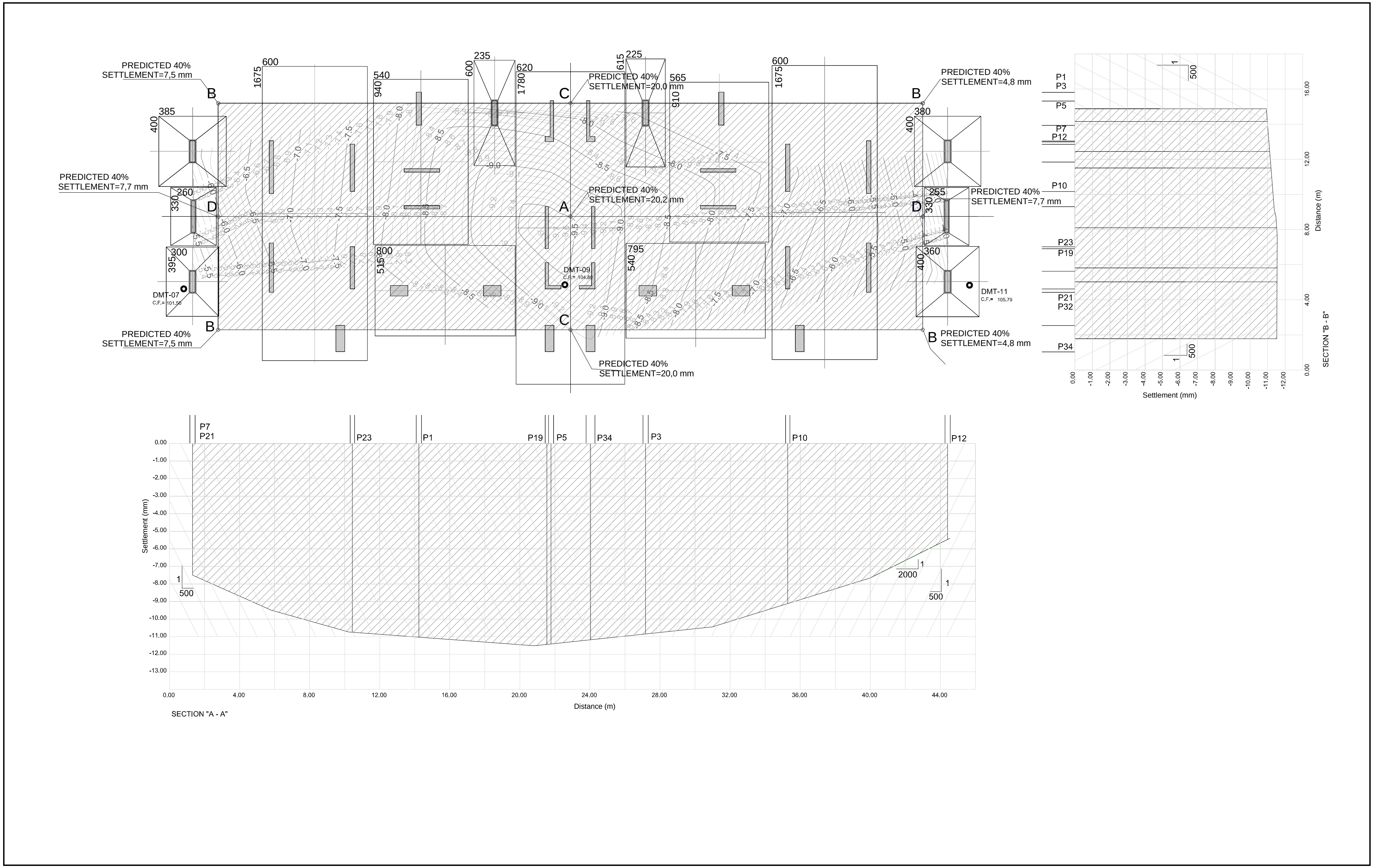

Figure 5." Morumbi building" in constrution, with 40% of the total load

7 CONCLUSIONS

The Marchetti Dilatometer "DMT" is a powerful tool to predict settlements for buildings on spread footings, where no primary or secondary consolidation is involved.

The mean values predicted with dilatometer results, area accurate for design decisions.

The influence of building structure in settlement distribution is somewhat complex. In profile view the predicted settlements give a more curved "dish" shape than what is measured, because of the rigidity of the building frames.

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