DESIGN OF POST-TENSIONED SLABS-ON-GROUND IN THE AMAZON REGION

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INTRODUCTION

The city of Manaus, Brazil, is located in the middle of the largest tropical forest in the world, directly on the Amazon River, and is a place with unique characteristics that impose great challenges for construction. The city´s climate is considered humid tropical with an average temperature of 80°F (26.7°C) and with no cold days in winter. It has an average annual rainfall of 86.4 in. (2195 mm) and a high relative humidity throughout the year, with monthly averages between 76 and 89%. The challenges in building new structures begin with production of concrete as the city has a particular geological formation with no rocks of good quality; the main aggregates used in construction are pebbles and sandstone. This paper will present a case study of the construction phase of a project in the city of Manaus. The project consists of nine four-story buildings. The use of post-tensioned foundations was chosen because it is economical, quick, easy, and safe.

CHARACTERISTICS OF THE PROJECT

Land area: 183,000 ft^2 (17,000 m^2)
Project: Nine four-story buildings
Each building area: 3875 ft^2 (360 m^2); all four floors total: 15,500 ft^2 (1440 m^2)
Total project area: Approximately 140,000 ft^2 (13,000 m^2)
Total number of apartments: 144
Total height of buildings: 46 ft (14 m)

Figure 1 shows the construction area.

The buildings are constructed using structural masonry in accordance with the Brazilian Standard ABNT NBR 15961-1 (2011).

Figures 2 and 3 show the layout grade of the floor plan and elevation showing the four-apartment arrangement. It is also interesting to note that the foundation slab extends past the perimeter masonry wall. The slab thickness is 8.7 in. (220 mm) under the apartments and 6.7 in. (170 mm) outside the building perimeter. This type of construction is very common in Brazil, mainly in Brazilian government housing programs for low-income residents.

SOIL INVESTIGATION

The first step is the soil investigation, which is essential in any project and was no different for this project. The main tests included Standard Penetration Test (SPT), California Bearing Ratio (CBR) Test, Liquid Limit, Plastic Limit, Plasticity Index, and Soil Classification.

Because it rains about 180 days a year and the site is close to a large river, a high water table was expected. However, water was found approximately 26.2 ft (8 m) below the surface.

One additional surprise for this project was to find a high plasticity index for the soil layer, indicating the presence of expansive soil. Complete expansive soil maps are not available in Brazil. Some maps made 25 years ago show some areas of expansive soils, but none in the Amazon region. Therefore it was important to confirm the presence of expansive soil on this site.

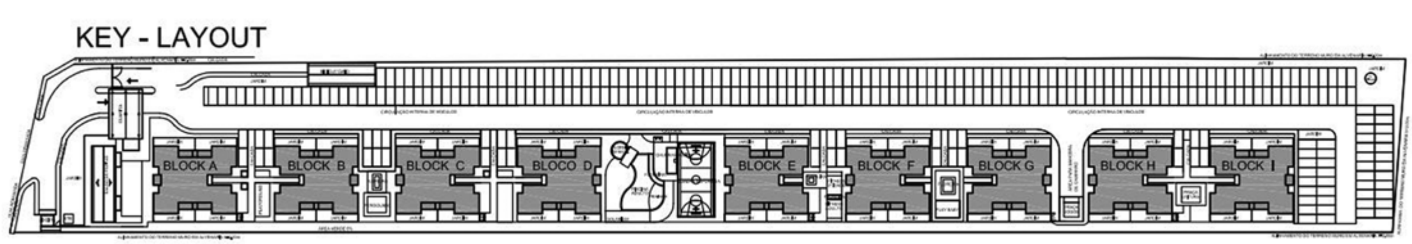

Fig. 1—Construction area.

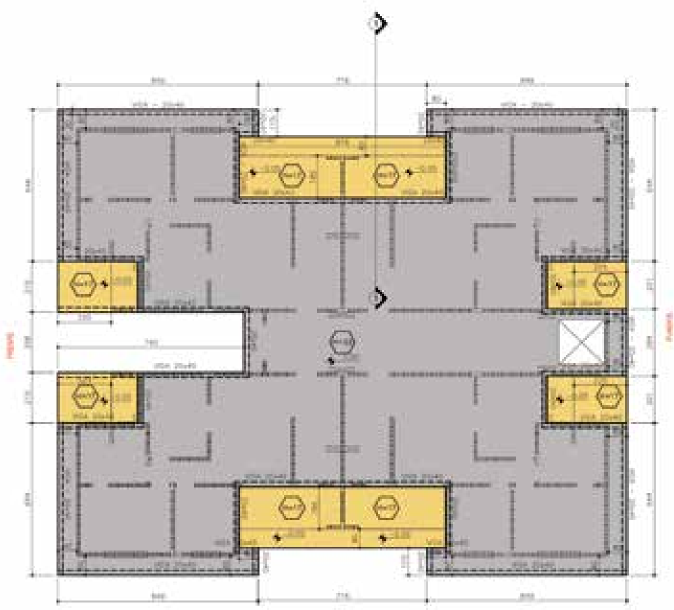

Fig. 2—Layout floor plan.

Fig. 3—Front elevation.

The data found for this layer of expansive soil were:

Soil type: Sand Clay
Soil color: Yellow
ASTM Soil Classification System: SC
AASHTO Soil Classification: A-2-6
Depth of expansive soil: 3.9 ft (1.20 m)
Plasticity Index: 18%
% Gravel: 4.5%
% Sand: 62%
% Mo (Silt): 3.5%
% Clay: 30%
Allowable Soil Bearing: 3.277 psf (1.6 kg-F/cm^2)
CBR: 12.3%

Based on the soil investigation, we considered two foundation options for the project:

1) Design the slab-on-ground on expansive soil; or
2) Remove the expansive soil.

In the end, the expansive soil was removed during the earthwork phase of the project in order to create a level building site. Therefore, the project was designed for non-expansive soil.

DESIGN OF SLAB-ON-GROUND

The slab-on-ground was modeled using the Finite Element Method through the ADAPT MAT and ADAPT EDGE software. All walls, floor slabs, dead load, and live loads were considered. The model is shown in Fig. 4.

After removal of the expansive soil, the allowable soil bearing increased to 3.482 psf (1.7 kg/cm^2). The modulus of soil reaction changed and ranged from 72.3 to 108.4 lb/in.^{3} (2.0 to 3.0 kg/cm^3).

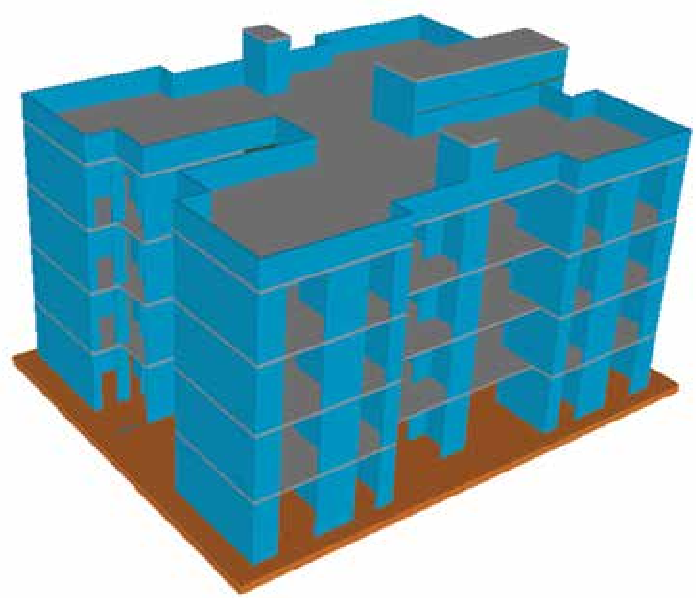

Fig. 4—Modeling slab-on-ground with ADAPT MAT and ADAPT EDGE.

With that, two reinforcement options were analyzed:

Option 1—Design as a reinforced concrete slab-on-ground (Fig. 5 and 6); or

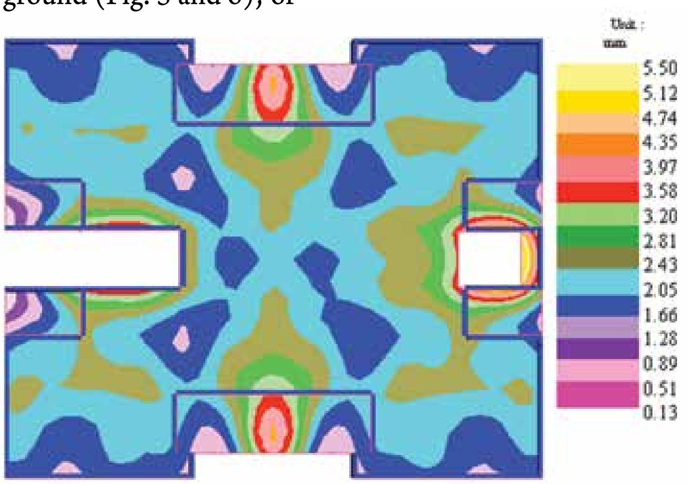

Fig. 5—Maximum displacements—load case: strength.

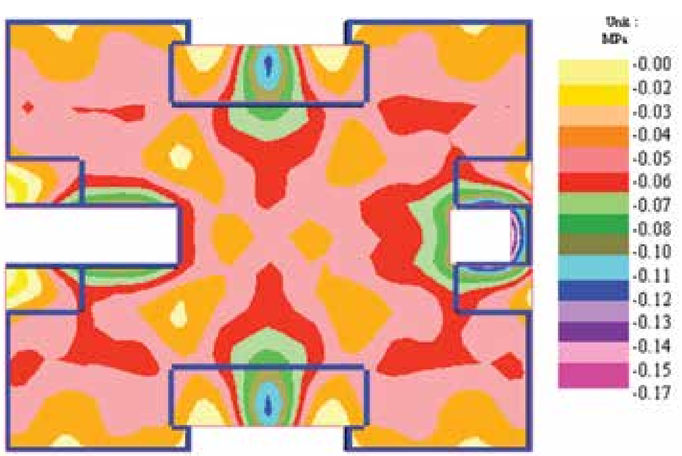

Fig. 6—Maximum soil pressure —load case: strength.

Option 2—Design as a post-tensioned slab-on-ground (Fig. 7 and 8).

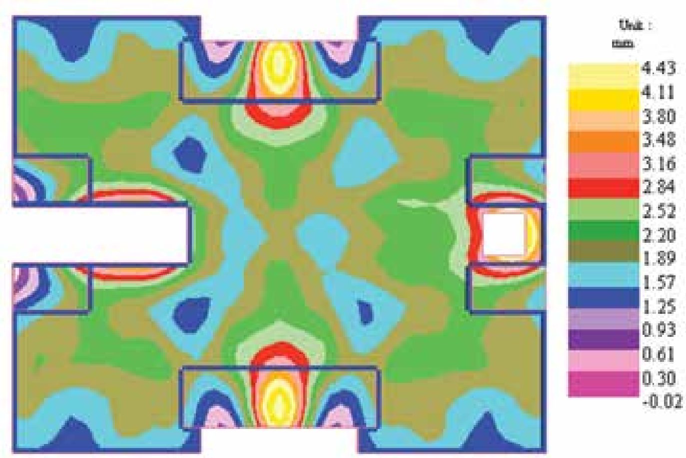

Fig. 7—Maximum displacements—load case: strength.

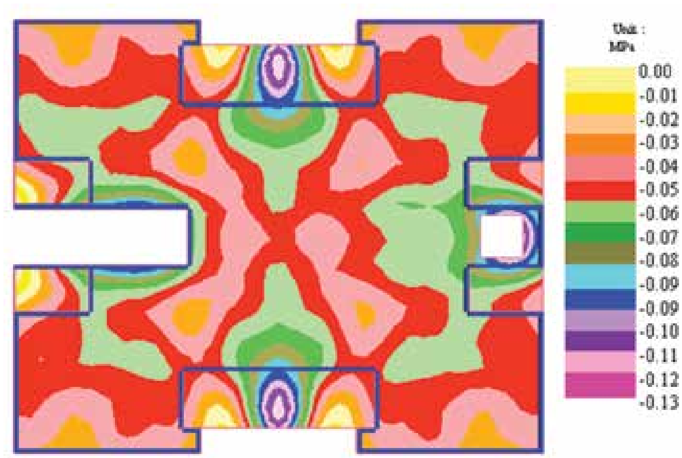

Fig. 8—Maximum soil pressure—load case: strength.

RESULTS

Table 1 shows a summary of the reinforcement comparison.

Table 1—Reinforcement Comparison Summary

Design reference	SOG area	SOG volume	Weight, reinforcing bar	Weight, tendon	Unit, reinforcing bar	Unit, tendon
	ft² (m²)	yd³ (m³)	lb (kg)	lb (kg)	lb/ft³ (kg/m³)	lb/ft³ (kg/m³)
Reinforced concrete	4659 (432.9)	130 (99.7)	9710 (4405)	—	2.76 (44.2)	—
Post-tensioned + Reinforced concrete	4659 (432.9)	130 (99.7)	3091 (1402)	2683 (1217)	0.87 (14.0)	0.76 (12.2)

CONCLUSIONS

The design of the post-tensioned slab-on-ground foundation was selected due to cost savings (Fig. 9).

The following observations can be made:

1) Although not demonstrated in this case study, it would be possible to reduce the thickness of a post-tensioned slab-on-ground. Therefore, the volume of concrete would be lower, adding further economy.
2) Considering the relationship between the cost of tendons and reinforcing bar (In Brazil, the ratio of cost of tendon to reinforcing bar is 1.5):

   2683×1.5 + 3091 = 7115 lb (1217×1.5 +1402 = 3227 kg) of equivalent reinforcing steel.

The economy of using post-tensioned slab-on-ground was 2595 lb. (1177 kg). Considering only the cost of steel, the economy would be 26.7%. This translates to almost three same-sized foundations worth of savings.

3) It is expected that as more post-tensioning is used in Brazil, local technical standards will change, leading to the construction of more post-tensioned foundations and allowing Brazil to contribute more to the sustainability of the planet.

Fábio Albino de Souza *is a Civil Engineer from Pontifical Catholic University of Campinas (Brazil), with Masters of Science in Structural Engineering - FEC - UNICAMP and CEO EBPX (Office Brazilian Prestressing). At the Imperial College London, he participated in professional development courses in post-tensioned structures. He is a member of PTI and in 2010 he completed the PTI Level 1 Unbonded PT - Field Installation certification. He is a member of the American Concrete Institute (ACI) and the Brazilian Concrete Institute (IBRACON) and has published dozens of articles in international conference proceedings (France, Italy, Portugal, Chile, and Argentina), national conferences, and journals. In 2012, he was the founder and President of the Latin American Seminar of Prestressing (SELAP). For 5 years, he was a professor at the University Adventist Center of Sao Paulo (UNASP) and Metropolitan College of Campinas (VERIS), Metrocamp. Overall he has been in structural engineering design for 10 years, with extensive experience with slabs-on-ground on expansive and non-expansive soils.*

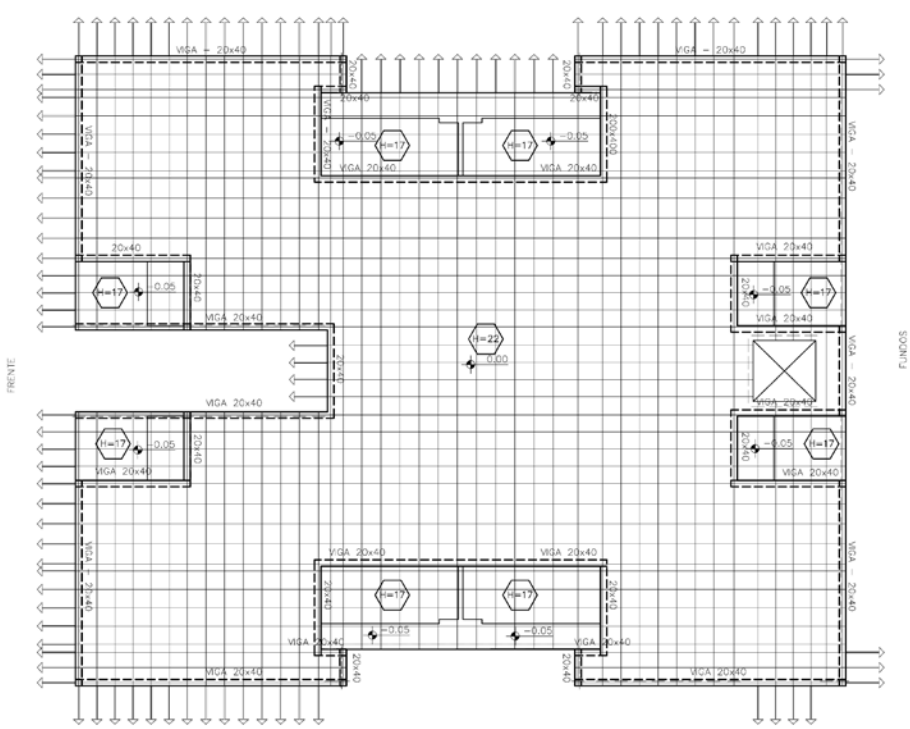

Fig. 9—Foundation tendon layout.