Design of Post-Tensioned Raft and Piled Raft Foundation in the Amazon Region

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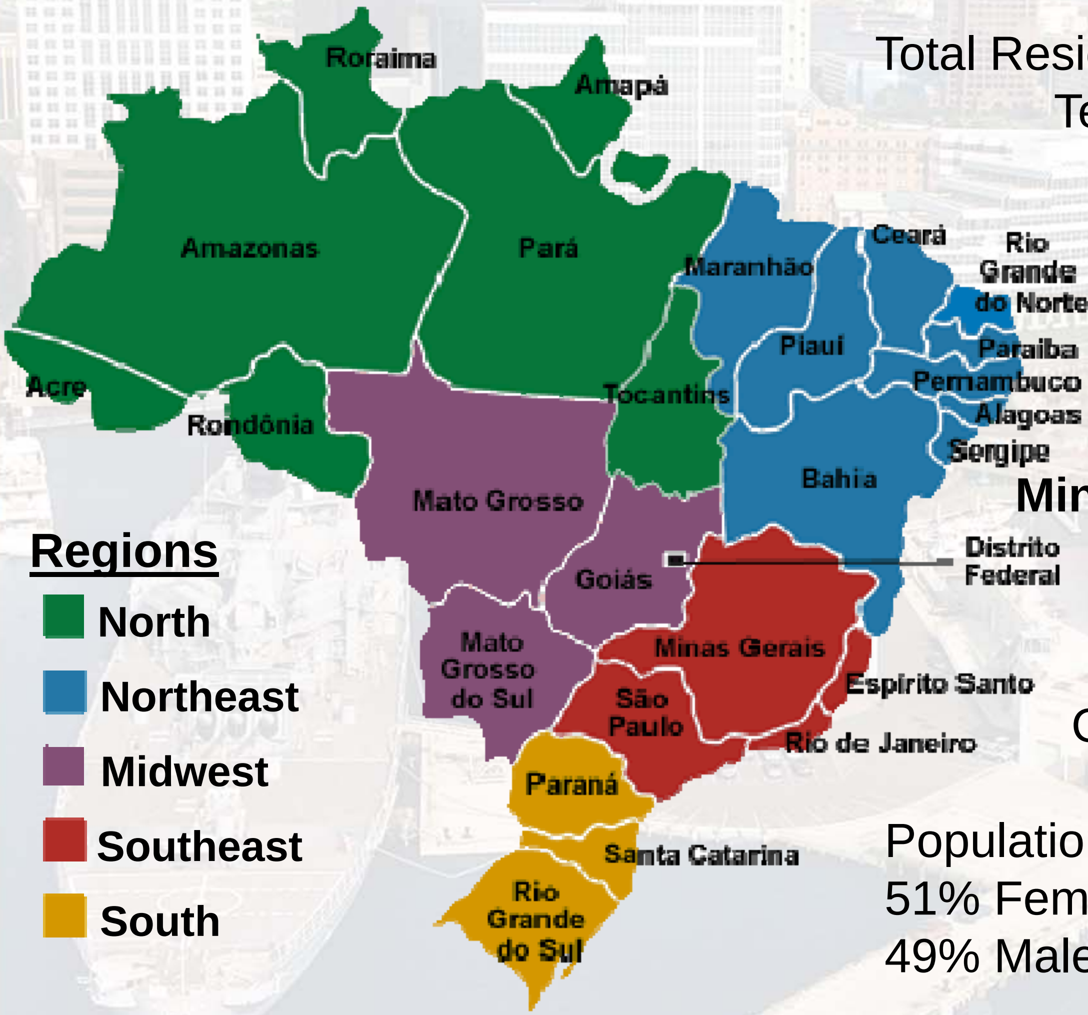
About Brazil

IBGE
Instituto Brasileiro de Geografia e Estatística



Demographic Census 2010

Total Resident Population = 190,732,694
Territorial Area = 8,515,767 Km^2

Capital = Brasília – DF

Official Currency = Real (R$)
1 US$ ~ 2.22 R$

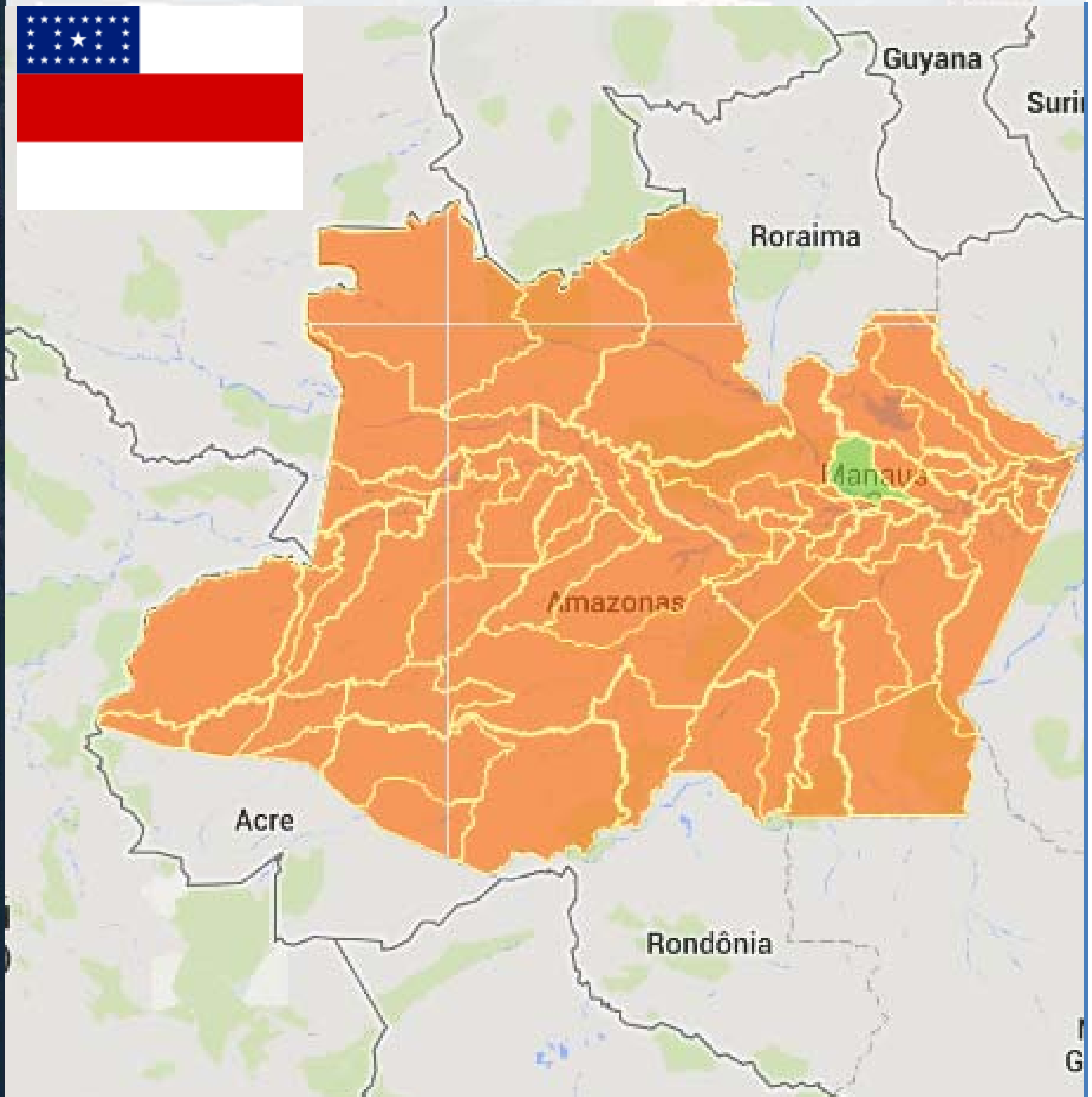
Minimum wage 2010 ~ US$ 292
2013 ~ US$ 335
2014 ~ US$ 323

Official Language = Portuguese

Population
51% Female
49% Male

84.4% - Urban
15.6% - Rural

About the state of Amazonas



Demographic Census 2010

Population = 3,807,923

Total Area = 1,559,159 Km^2

Capital = Manaus

Populational Density = 2.44 inhabitants/Km^2

Native Indigenous Population = 4.8%

Holds 98% of preserved forest cover and one of the planet´s greatest fresh water reservoirs.

Housing Deficit = 10.4 %

About Manaus

Demographic Census 2010

52% of the State of Amazon´s population live in Manaus.

Populational Density = 158.06 inhabitants/Km²

Number of households with monthly per capita income greater than 5 minimum wages range from 8.01 % to 23.44 %

6th richest city in Brazil and its only Free Trade Zone.

One of the greatest industrial areas in the country.

What we have been doing

Minha Casa Minha Vida

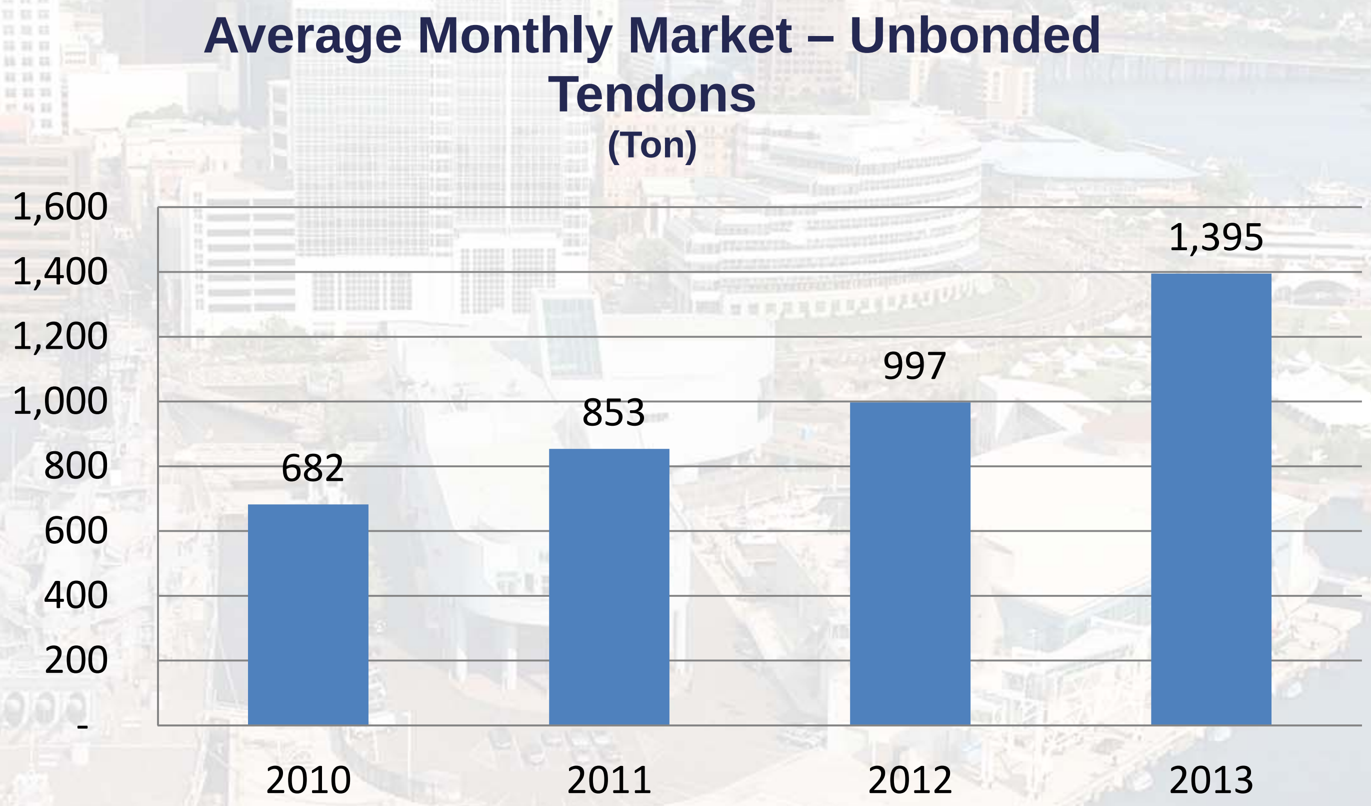
In English:

My Home

My Life

Brazilian Government Dwelling Program: started in March 2009, subsiding low-cost houses and apartments for lower-class families to build one million homes at an estimated total cost of about R$ 34 Bi ~ US$ 17 Bi.

About PT – Market in Brazil



1 year = 16,740 ton

About PT – Market in Brazil

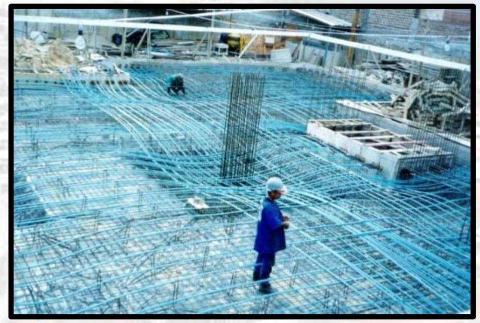
Representative cost of one ton of material USD

	Swiss	USA	Colombia	Brazil	Mexico
Tendon	11,100	2200	1700	2250	1350
Rebar	1,550	1000	900	1500	1000
Ratio	**7.2**	**2.2**	**1.9**	**1.5**	**1.35**

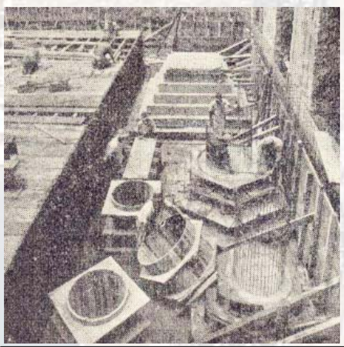
We have a good potential to grow.

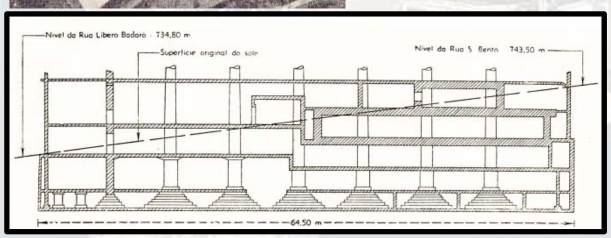
What we have been doing

Some successful experiences in Brazil - slab-on-ground or mat/raft foundations:



Residential Building in Fortaleza in August 1999. The building has fourteen floors





Bank of Brazil Building in São Paulo in the 1950s.

Hotel Le Méridien Copacabana opened in 1975 in the city of Rio de Janeiro. The building has forty floors.

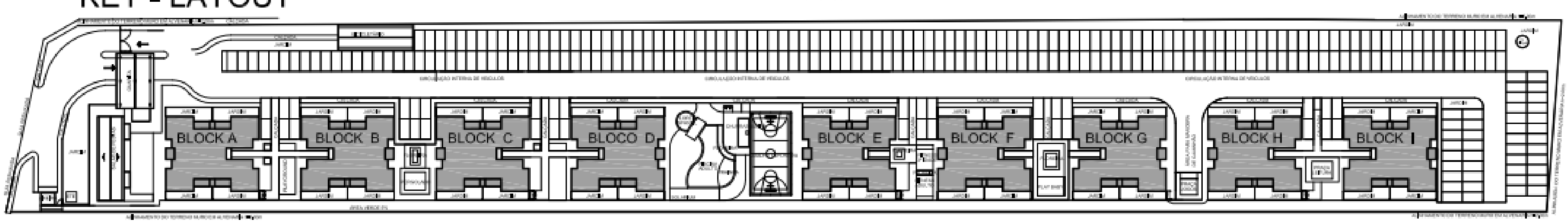
Case Study

Some of the project´s features:

Project = 9 blocks with 4 floors each
Each Apartment Building = 1,440 m^2
Total Height of Each Block = 14 m
Type of Construction = Structural Masonry (Concrete)
Location: Manaus
State: Amazonas
Country: Brazil

10 ELEVATION
SCALE 1/50

KEY - LAYOUT

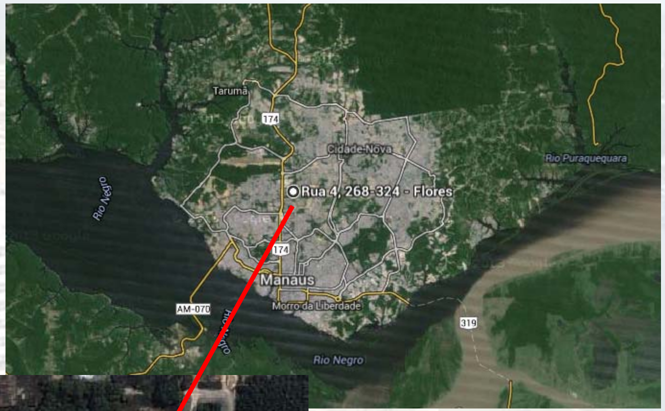


Case Study

Some of the project´s features:

Photo of the construction site

Land Area = 17,000 m^2



Case Study

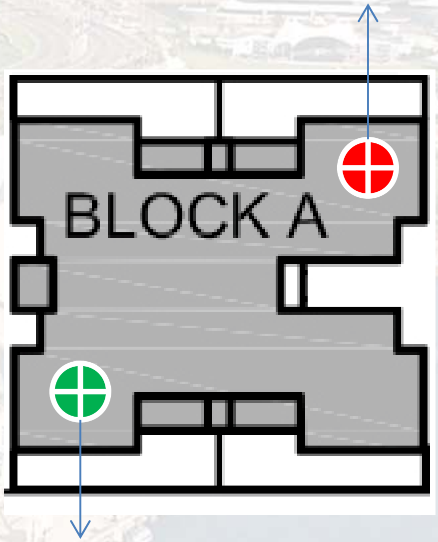
Some of the project´s features:

Soil Investigation

Two points for each block

SPT (Standard Penetration Test)
CBR Test
Liquid Limit
Plastic Limit
Plasticity Index
Soil Classification

After Earthwork



Before Earthwork

Case Study

Some of the project´s features:

Soil Investigation

SPT – Standard Penetration Test

Water level ←

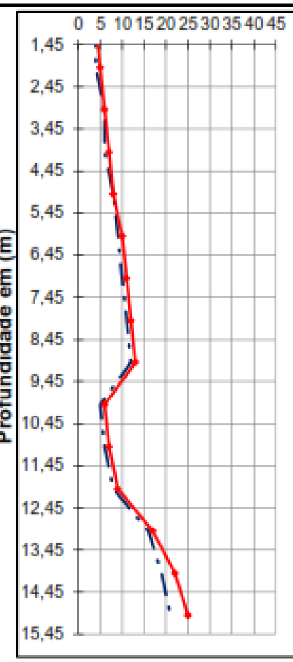
PERFÍL ESTRATIGRÁFICO

N.A inicial:	8,10
N.A após 24h:	8,50
L.S:	15,45

Φ Interno do Amostrador:	1 3/8"
Φ Externo do Amostrador:	2"
Φ Revestimento:	3"

PROFUNDIDADE EM (m)	N.A	AVANÇO	COTA EM RELAÇÃO AO RN	Indices de penetração – Nº de Golpes 1º 15	2º 15	3º 15	N_{SPT} Maior de 1º+2º	2º+3º
		TC	36,0890					
1		TC	35,0890	2	2	2	4	4
2		CA	34,0890	2	2	3	4	5
3		CA	33,0890	3	3	3	6	6
4		CA	32,0890	3	3	4	6	7
5		CA	31,0890	4	4	4	8	8
6		CA	30,0890	4	5	5	9	10
7		CA	29,0890	5	5	6	10	11
8	N.A	CA	28,0890	5	6	6	11	12
9		CA	27,0890	6	6	7	12	13
10		CA	26,0890	2	3	3	5	6
11		CA	25,0890	3	3	4	6	7
12		CA	24,0890	4	4	5	8	9
13		CA	23,0890	8	8	9	16	17
14		CA	22,0890	9	10	12	19	22
15		CA	21,0890	10	11	14	21	25

Profundidade X N_{SPT}



AMOSTRA	DISCRIMINAÇÃO DA CAMADA	PROF. CAMADAS (m)
		0,00
	Argila siltosa pouco arenosa, muito mole, cor amarela - Terreno natural	
	Areia média e fina pouco siltosa, muito fofa, cor amarela.	0,85
	Areia grossa pouco siltosa, fofa, cor amarela.	5,85
	Areia média e fina pouco siltosa, fofa, cor amarela.	6,95
	Silte pouco arenoso, consistência média, cor variegada.	9,75
	Areia média e fina pouco siltosa, fofa, cor variegada.	12,95
	Limite da sondagem	15,45

→ **Soil - Standard Penetration Test - SPT**

Case Study

Some of the project´s features:

Soil Investigation

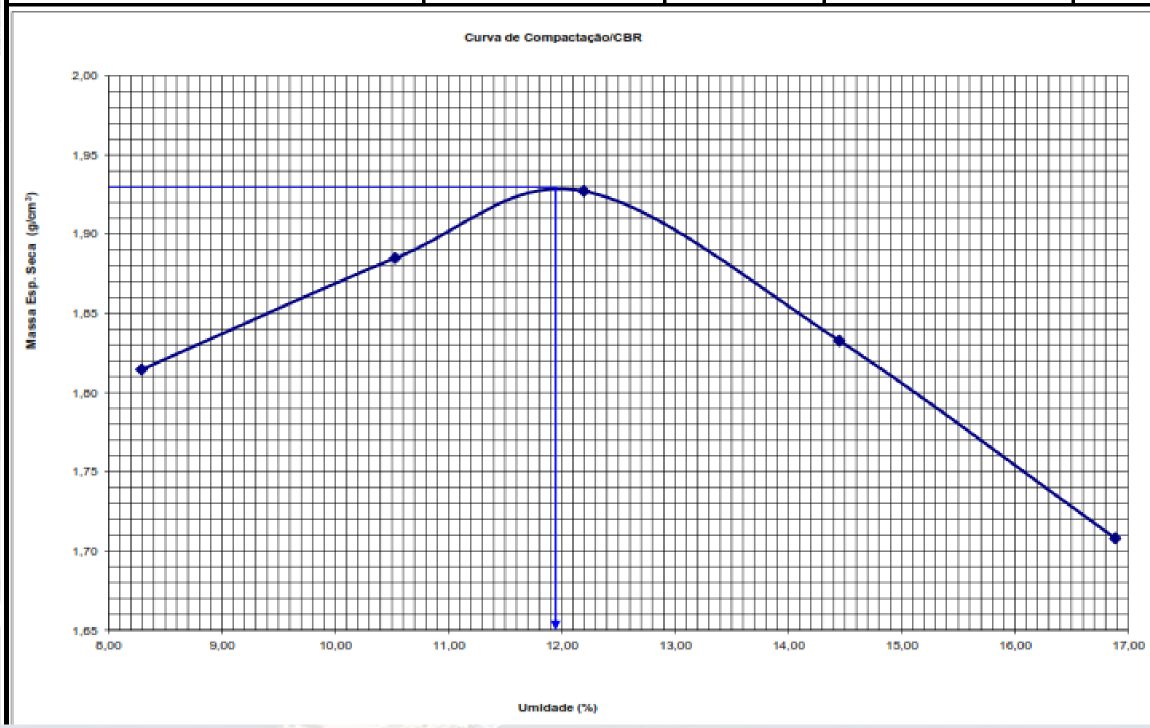
CBR Test

Analysis depth = 0,80 – 2,10 m

CBR $_{(2.54mm)}$ = 11.02%

Expansion = 0.36%

Média das Umidades	%	8,29	10,53	12,20	14,45	16,89
M. Espec. Apar. Seca	(x10³) kg/m³	1,815	1,885	1,927	1,833	1,708
Obs:		Proctor =	Normal	Wot.(%) 11,95	ρdmáx.: 1,929 g/cm³	

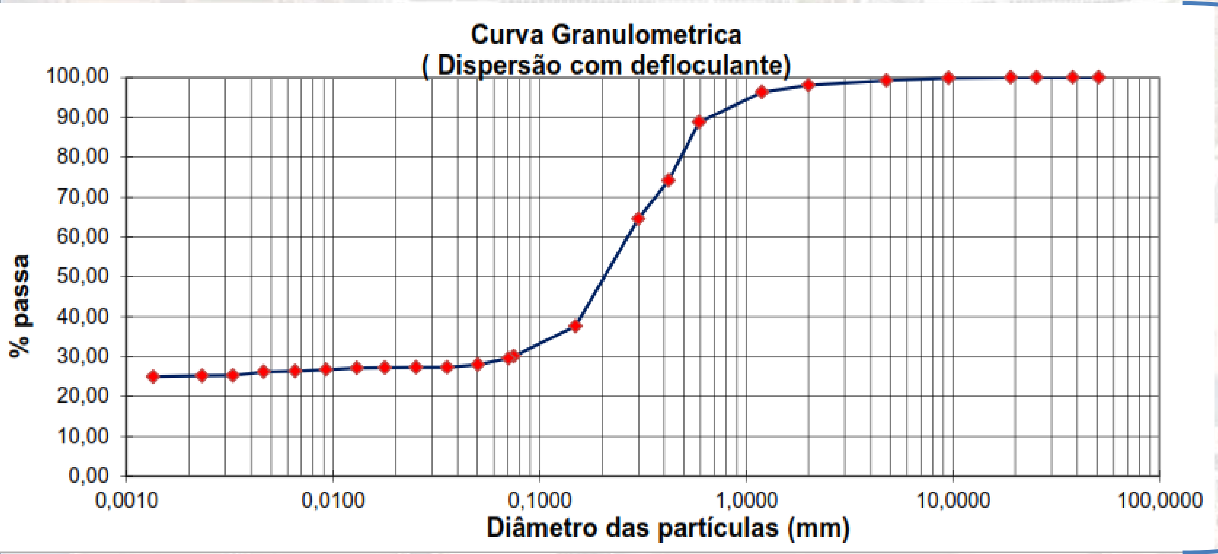


Case Study

Some of the project´s features:

Soil Investigation

Analysis depth = 0,80 – 2,10 m



Soil Classification

% Gravel = 2%
% Sand = 67%
% Mo (Silt) = 5%
% Clay = 26%

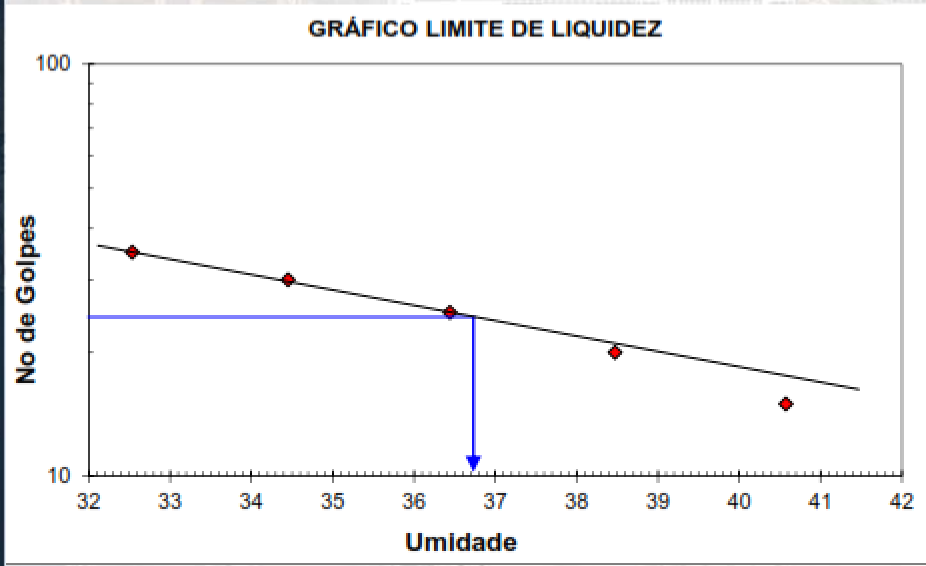
ASTM Soil Classification System = SC
AASHTO Soil Classification = A-2-6

Case Study

Some of the project´s features:

Soil Investigation

Analysis depth = 0,80 – 2,10 m



Liquid Limit = 36.75%
Plastic Limit = 19.72%
Plasticity Index = 17.03%

Case Study

Some of the project´s features:

Soil Investigation

Liquid Limit = 36.75%

Plastic Limit = 19.72%

Plasticity Index = 17.03%

Soil expansivity prediction by liquid limit

Degree of expansion	w_L: %	
	Chen[6]	IS 1498[4]
Low	<30	20–35
Medium	30–40	35–50
High	40–60	50–70
Very high	>60	70–90

Soil expansivity predicted by plasticity index

Degree of expansion	I_p: %		
	Holtz and Gibbs[10]	Chen[6]	IS 1498[4]
Low	<20	0–15	<12
Medium	12–34	10–35	12–23
High	23–45	20–55	23–32
Very high	>32	>35	>32

Source: Nelson J. & Miller D. (1992)

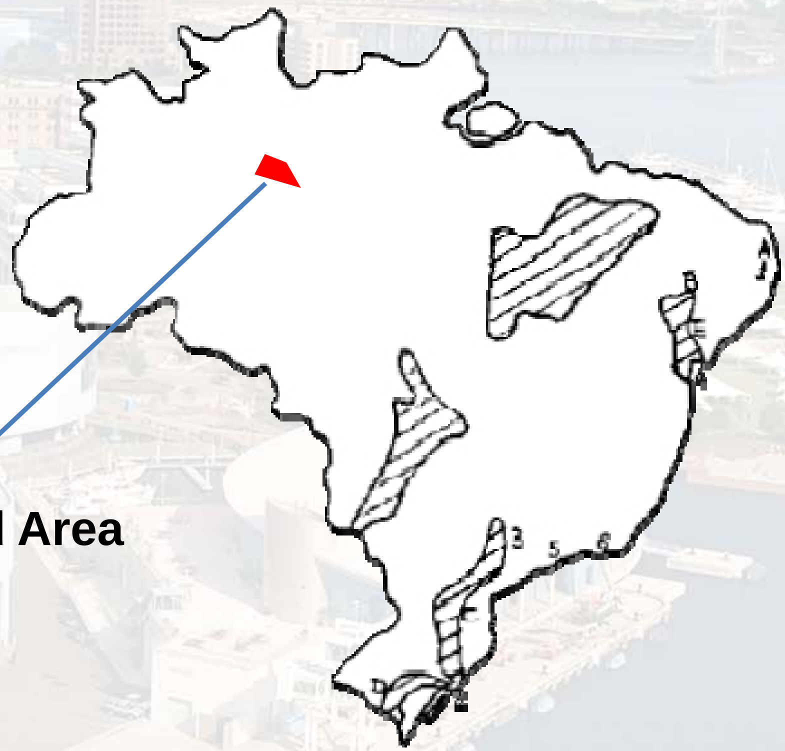
Case Study

Some of the project´s features:

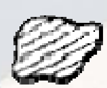
Soil Investigation

<u>Expansive soils: main occurrences in Brazil</u>

New Discovered Area (Manaus)



Source: Vargas et all, 1989.



Areas of sedimentary rocks with montmorillonites potentially subjected to expansion.

Case Study

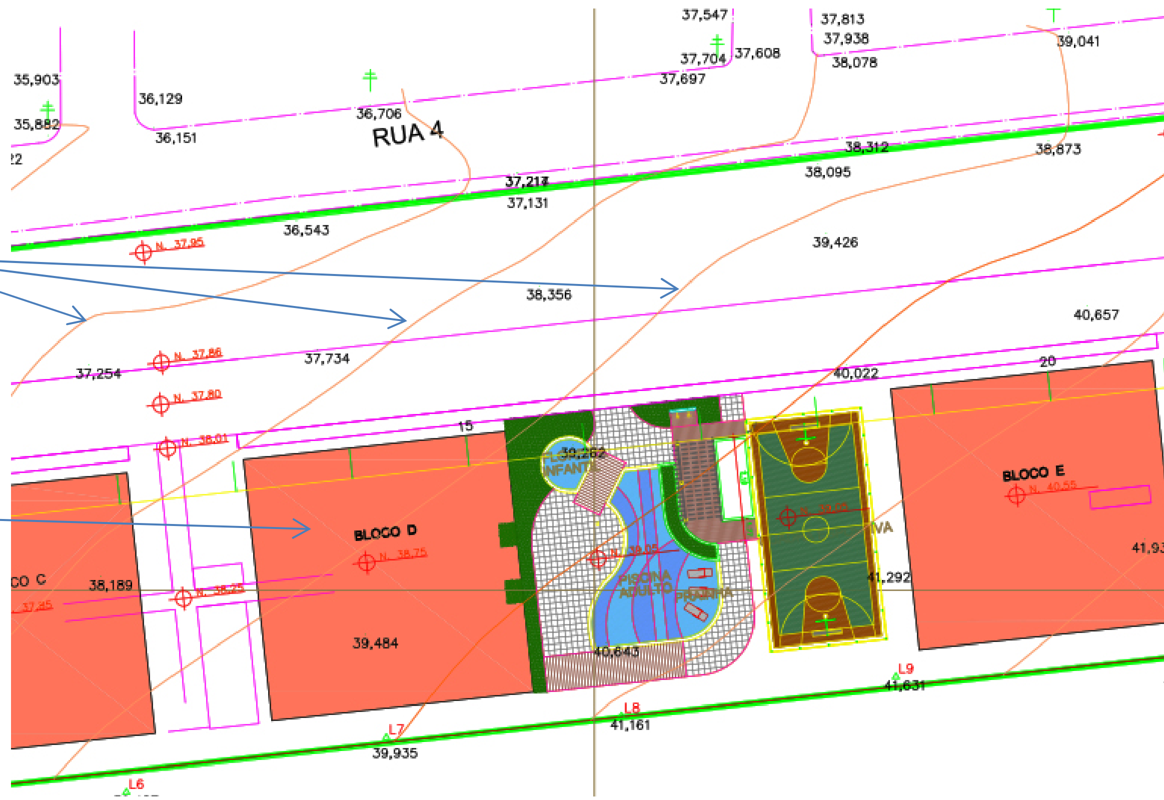
Some of the project´s features:

Soil Investigation

Earthworks project established a level where this layer of expansive soil was removed. So the project was conceived in non-expansive soil after all.

Natural Topography of the Land (Contour Levels)

Level Design



Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation

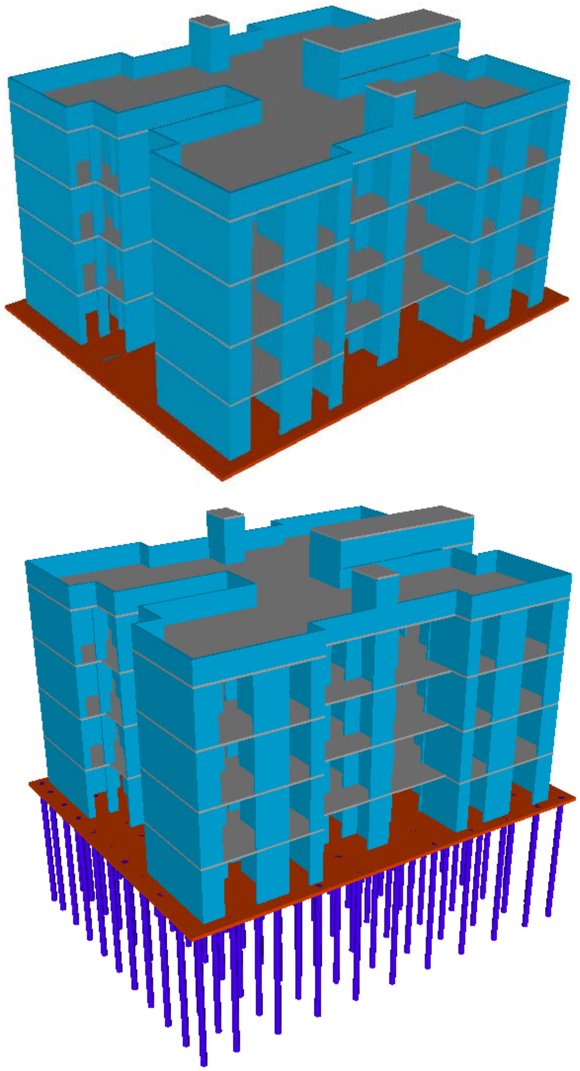
FEM – Finite Element Method

ADAPT
Structural Concrete Software

EDGE

+

MAT

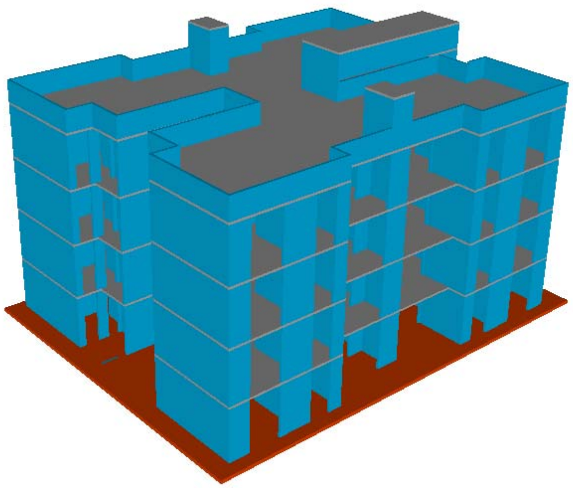


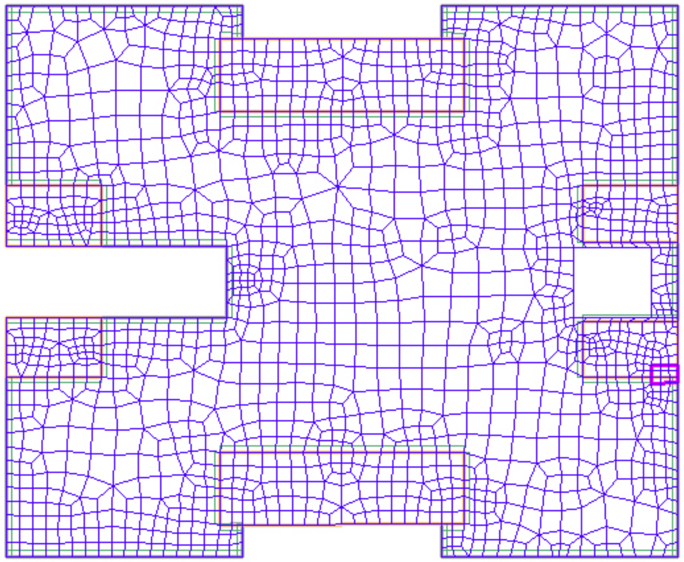
Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation

FEM – Finite Element Method
Shell Element
Cell Size = 0.50 meters
Maximum Distance = 0.50 meters





Case Study

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Design of Post-Tensioned Raft and Piled Raft Foundation

FEM – Finite Element Method
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Cell Size = 0.50 meters
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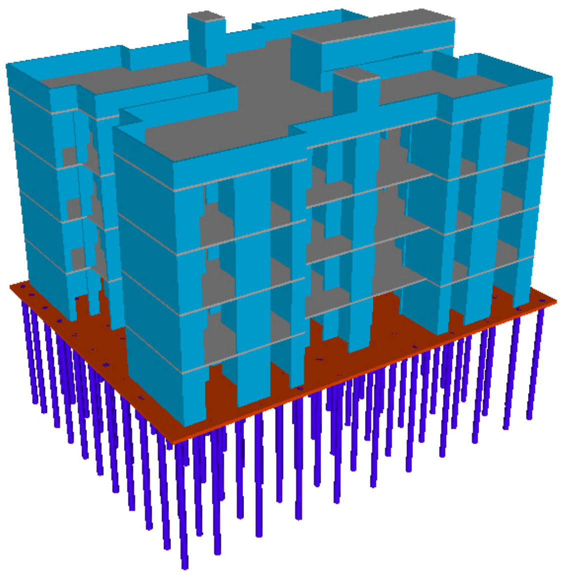
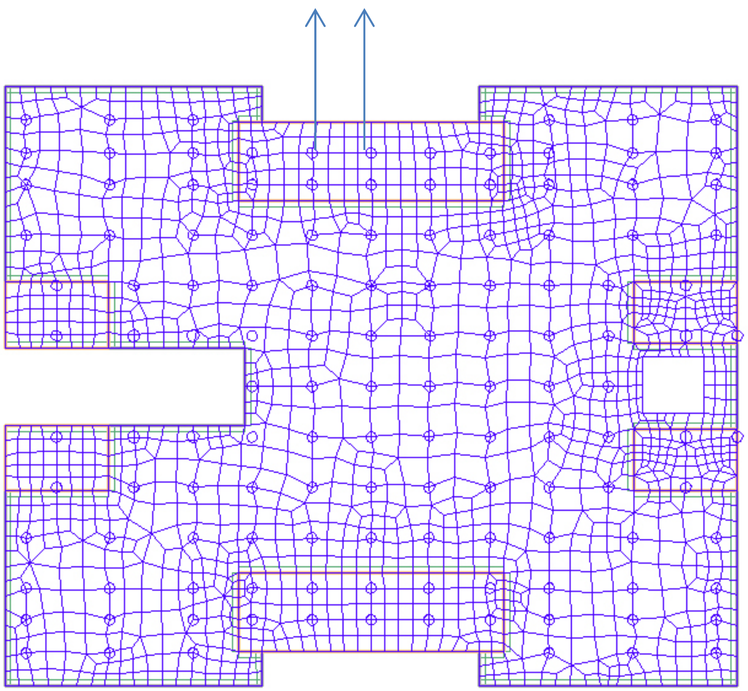


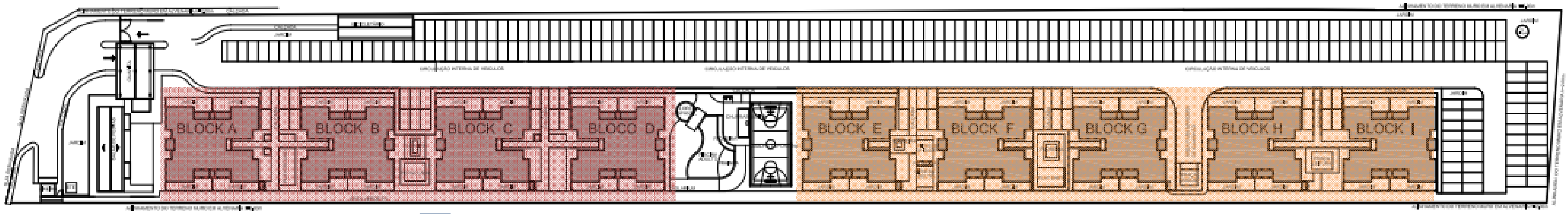


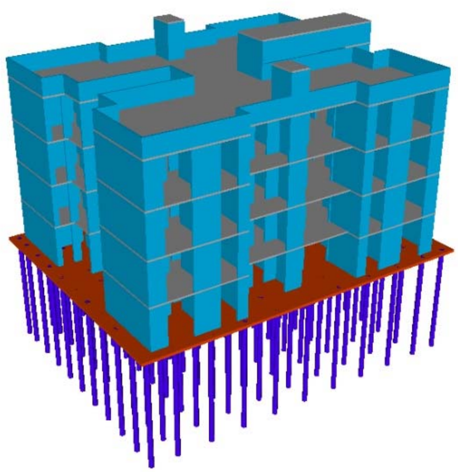
Case Study

Some of the project´s features:

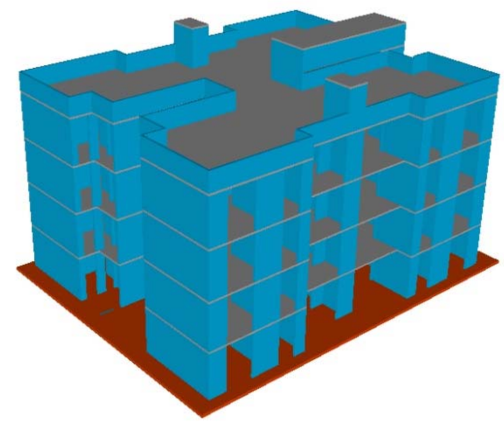
Design of Post-Tensioned Raft and Piled Raft Foundation

KEY - LAYOUT





04 –Blocks with Piled Raft Foundation

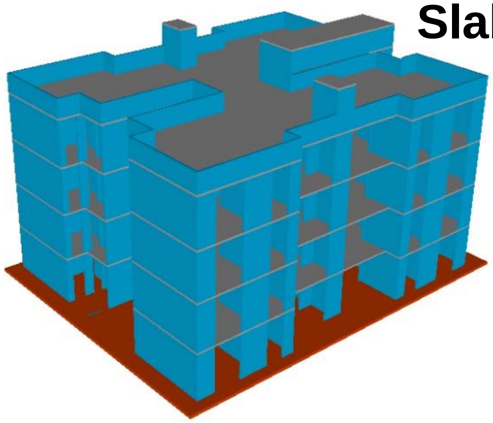


05 – Blocks with Raft Foundation

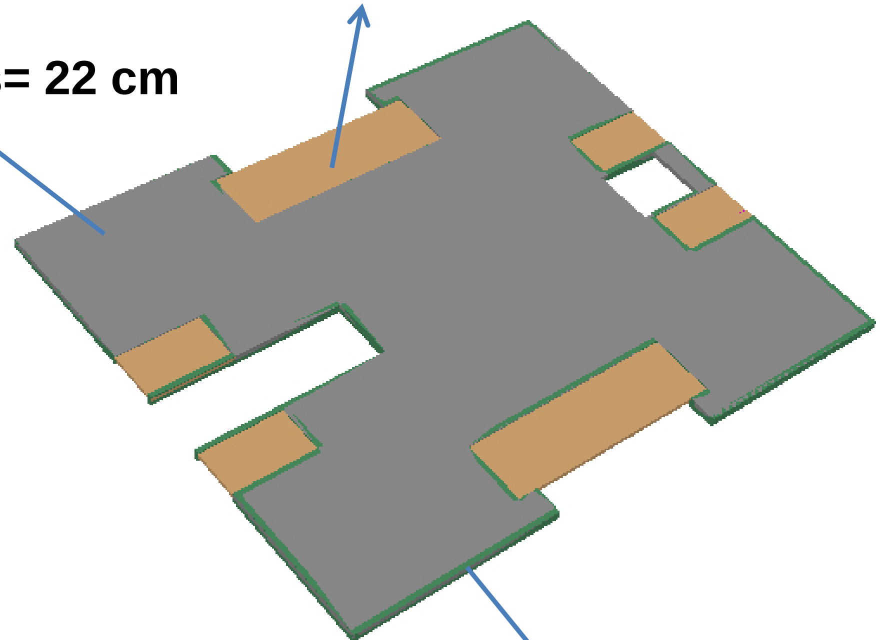
Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation



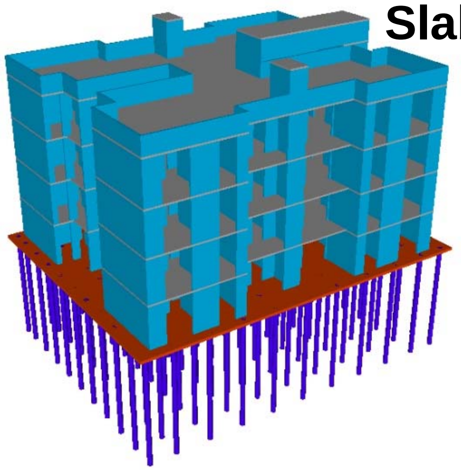
05 Blocks with Raft Foundation



Case Study

Some of the project´s features:

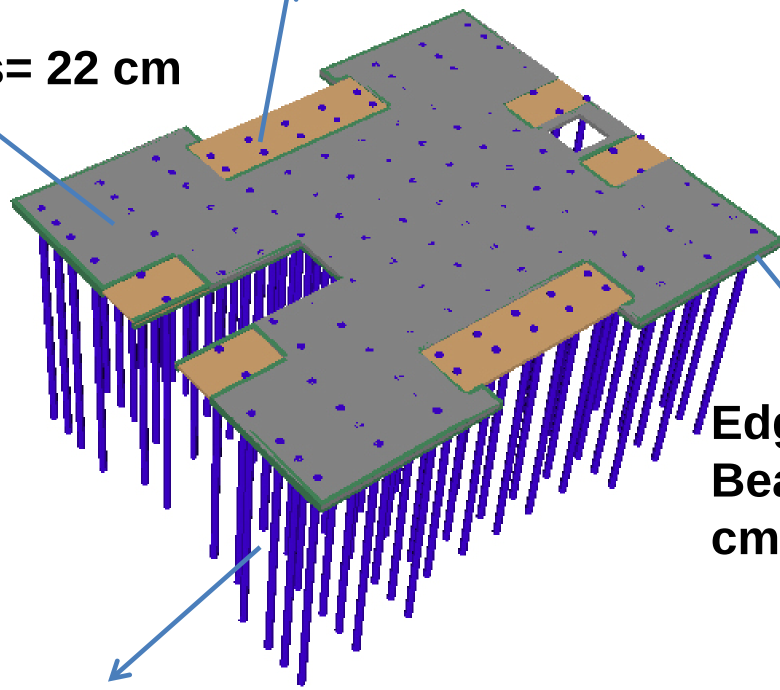
Design of Post-Tensioned Raft and Piled Raft Foundation



04 Blocks with Piled Raft Foundation

Slab Thickness=18 cm

Slab Thickness= 22 cm



Edge Beams = 20 cm x 40 cm

And the length of the piles foundation ???
The piles foundation require much attention!!!

Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation

Diâmetro seção circular	350	mm *
Comp. total da estaca	12.0	m
Carga axial	37.00	ton
Módulo Elasticidade (Ec)	20.00	GPa
Nível d'agua	8.0	m

ρs	1.46	mm
ρe	1.90	mm
ρ	3.36	mm

Capacidade de carga - Método Aoki-Velloso

Capac. carga Lateral (ton)	Capac. carga Ponta (ton)	Capac. Total (ton)	Carga admissível (ton)
36.6	42.3	79.0	39.5

Settlement by the soil

+

Settlement by the elastic shortening

=

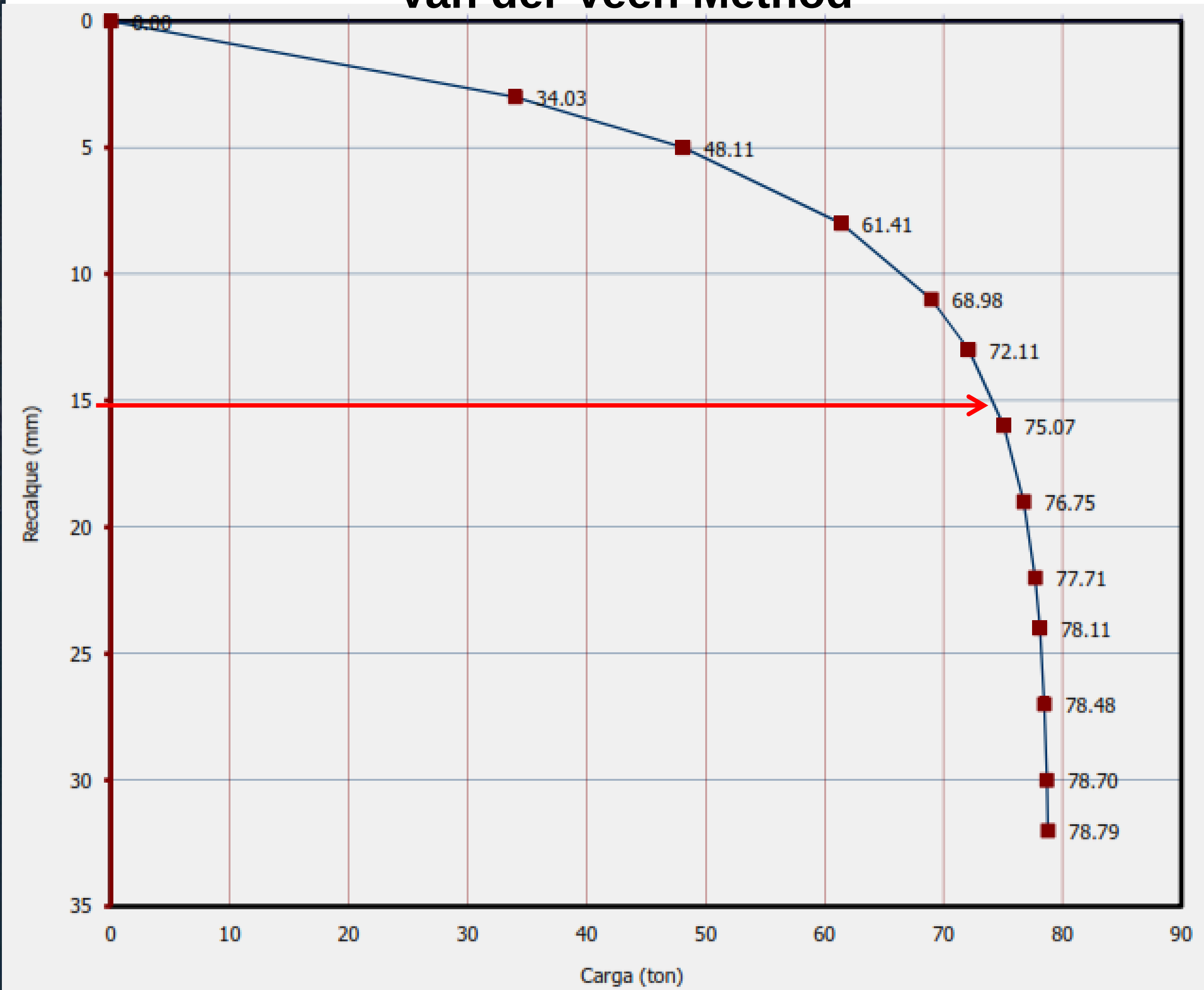
Total Settlement

Type of the Pile Foundation: = Auger Piles

Maximum Allowable Load of the Pile Foundation Aoki-Velloso Method – One of the main methods applied in Brazil.

Case Study

Forecasting Load X Settlement
Van der Veen Method



Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation

Safety Factor = 73/39.5
Safety Factor = 1.85
Recommends the safety factor greater than 1.5 for the group of piles.

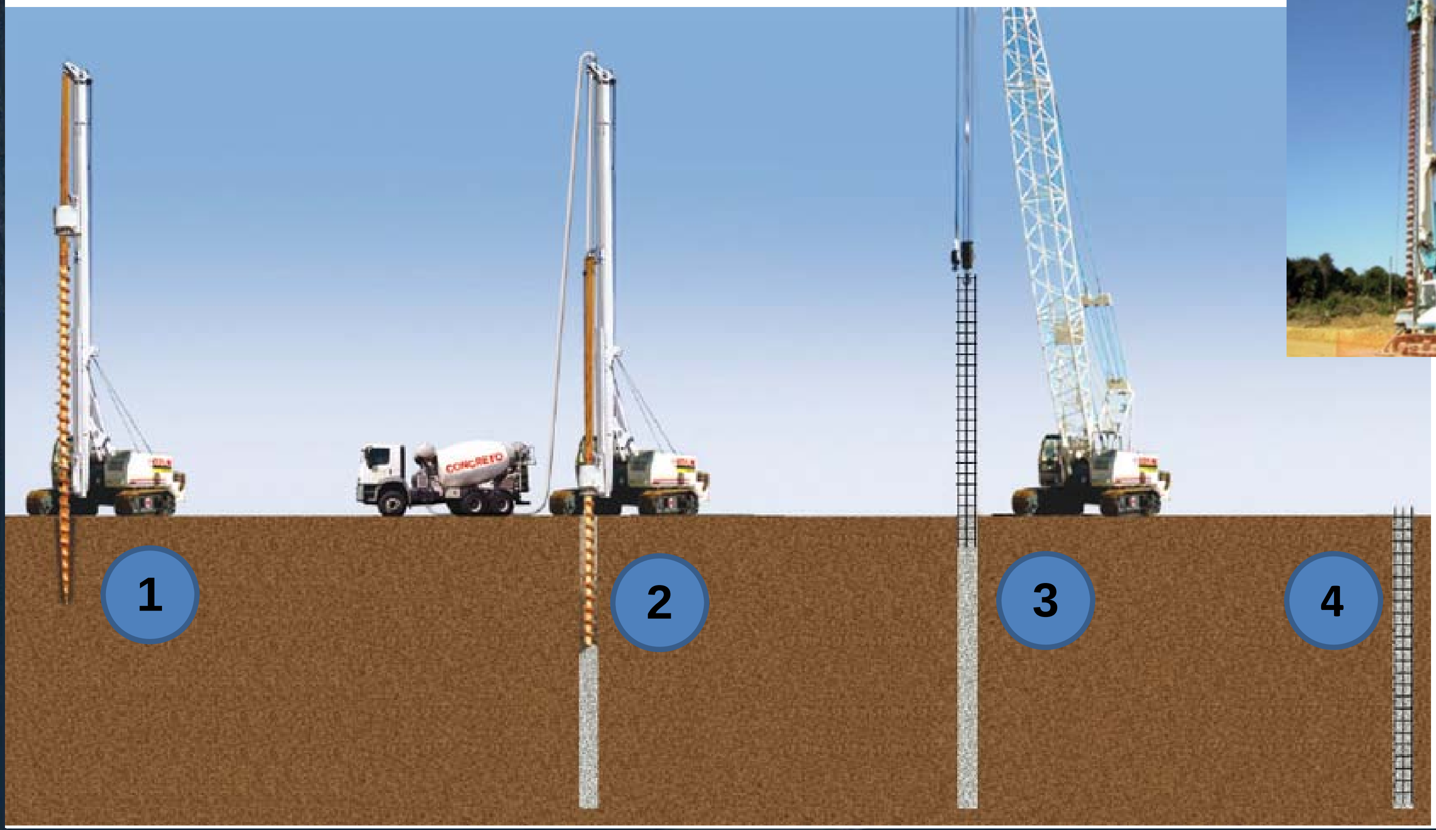
Then OK!!

Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation

Stages of implementation of the pile (Auger Pile)



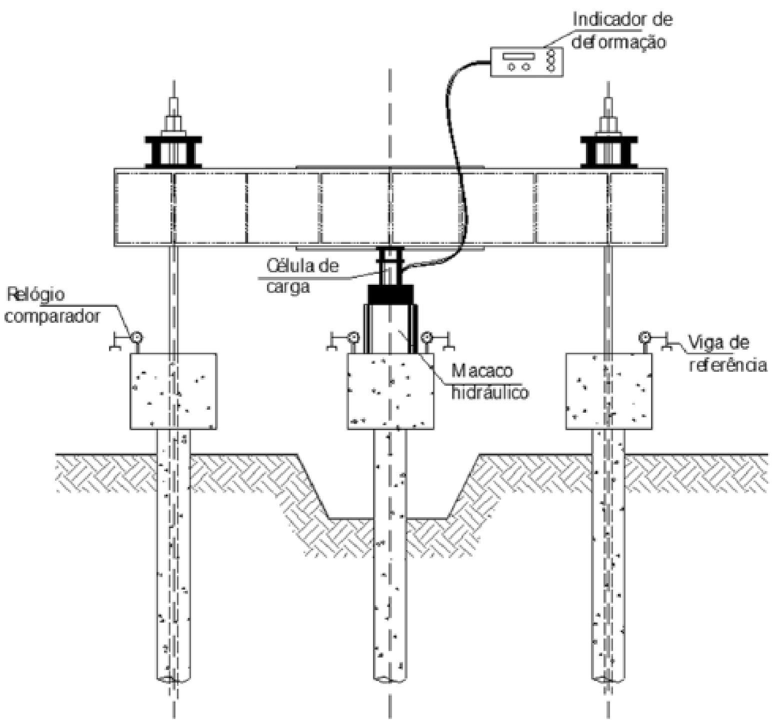
Equipment

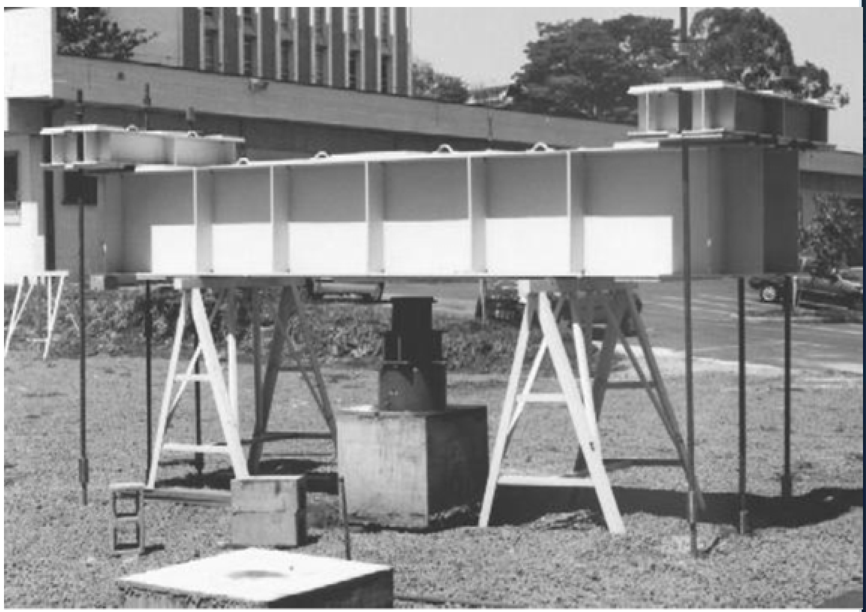
Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation

The Brazilian Standard NBR6122 recommends 1% of the executed piles to be trialed.



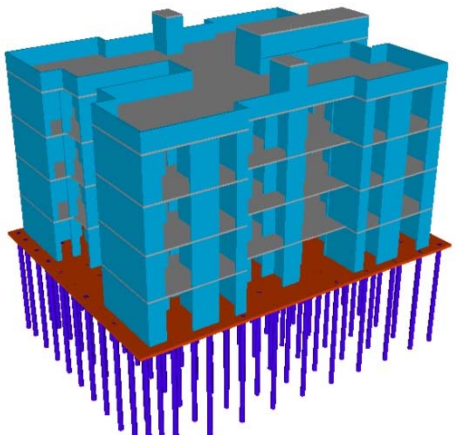


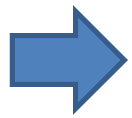
Case Study

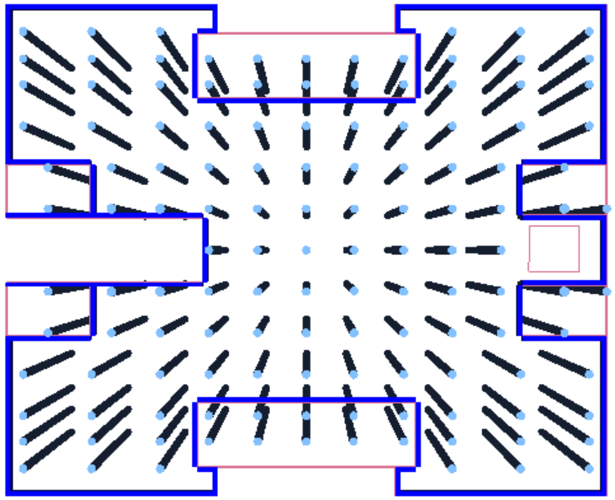
Some of the project´s features:

Results

Post-Tensioned Piled Raft Foundation

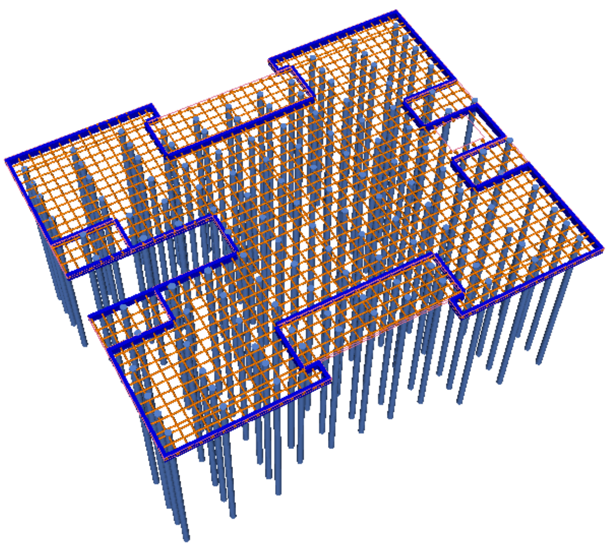






All loads are transmitted only to the piles.

Load Combination	Minimum Displacement (mm)	Maximum Displacement (mm)
Service	0.17	3.24
Strength	0.43	4.55
Initial	0.00	0.89

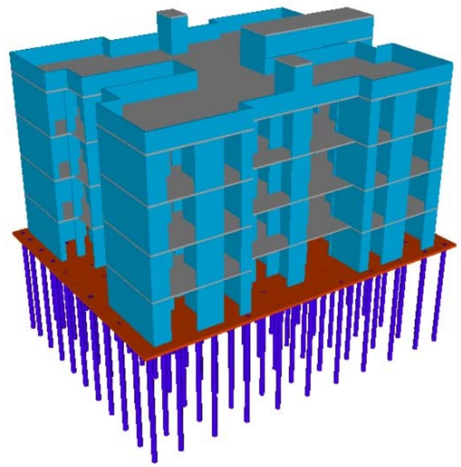


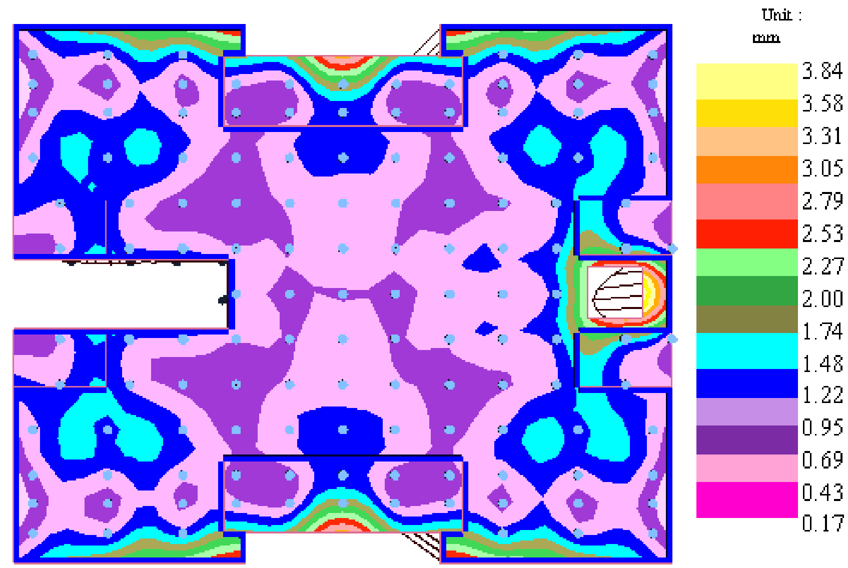
Case Study

Some of the project´s features:

Results

Reinforced Piled Raft Foundation





All loads are transmitted only to the piles.

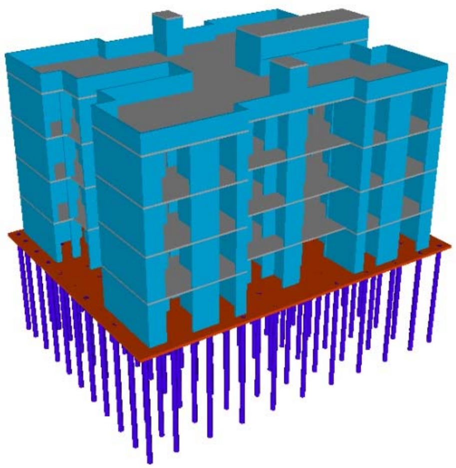
Load Combination	Minimum Displacement (mm)	Maximum Displacement (mm)
Service (TL)	0.17	3.84
Strength (DLO)	0.24	5.37
Cracked Sustained Load	0.17	4.05

Case Study

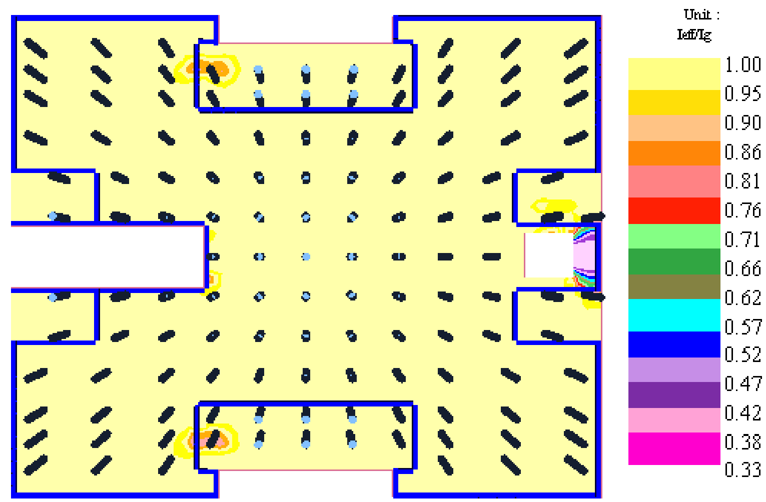
Some of the project´s features:

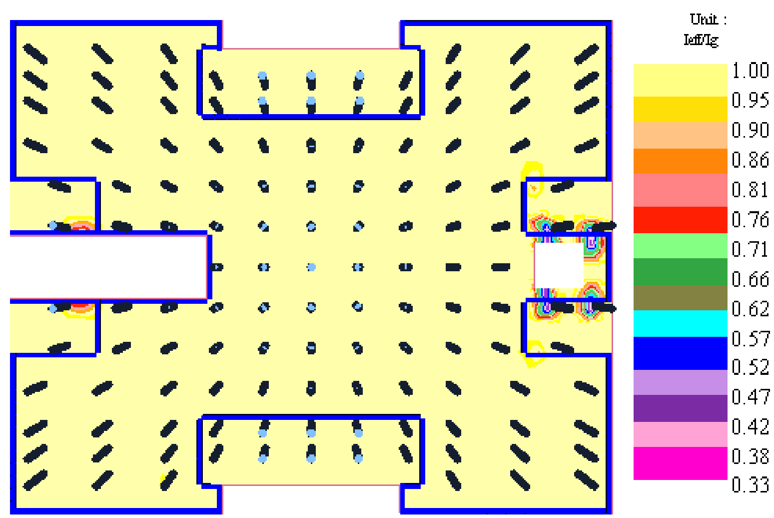
Results

Reinforced Piled Raft Foundation



Reduced Rotational Stiffness About XX and YY

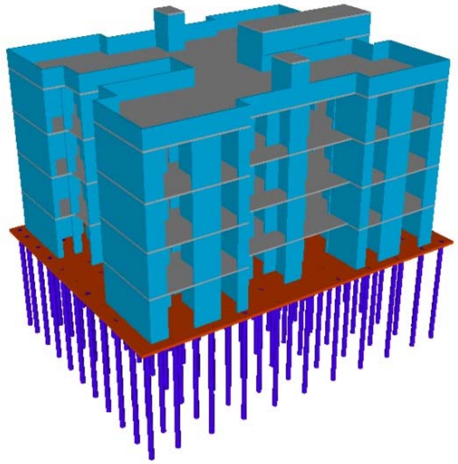




Case Study

Some of the project´s features:

Summary

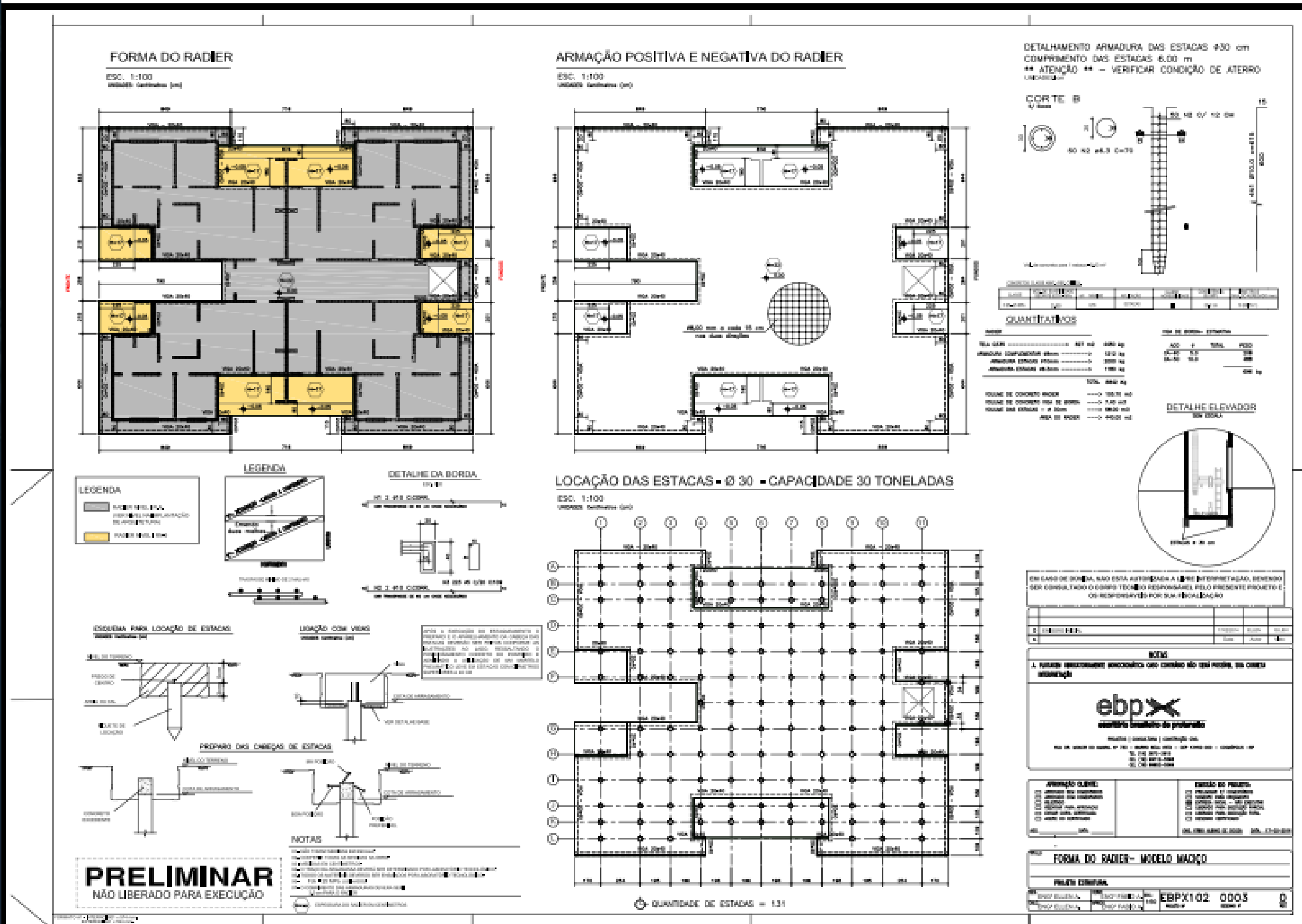


Design Reference	SOG Area (m^3)	SOG Volume (m^3)	Weight Rebar (kg)	Weight Tendon (kg)	Rate Rebar (kg/m^3)	Rate Tendon (kg/m^3)
Reinforced Concrete	432.86	99.68	4,250	-----------	42.64	-----------
Post-Tensioned + Reinforced Concrete	432.86	99.68	1,790	1,207	17.95	12.11

Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation



Piled Raft Foundation

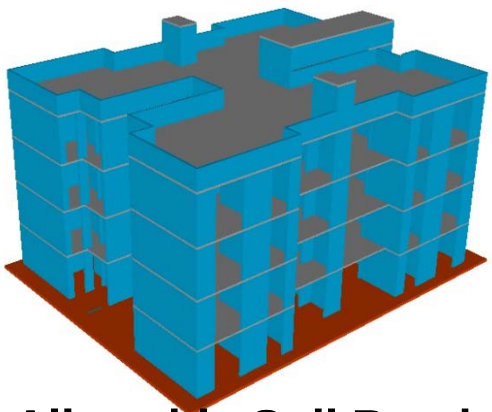
Preliminary Design – Reinforced Concrete

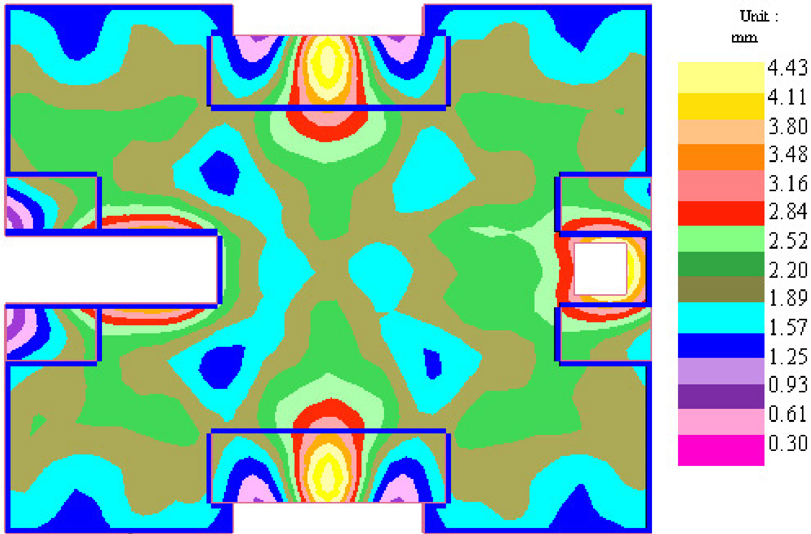
Case Study

Some of the project´s features:

Results

Post-Tensioned Raft Foundation





Allowable Soil Bearing = 0.17 Mpa (1.7 kgf/cm^2)
Modulus of soil reaction = 2.00 – 3.00 kgf/cm^3

Load Combination	Minimum Displacement (mm)	Maximum Displacement (mm)	Minimum Soil Pressure - MPa	Maximum Soil Pressure - MPa
Service	0.04	3.18	0.007	0.09
Strength	0.30	4.43	0.01	0.13
Initial	0.02	0.60	0.001	0.02

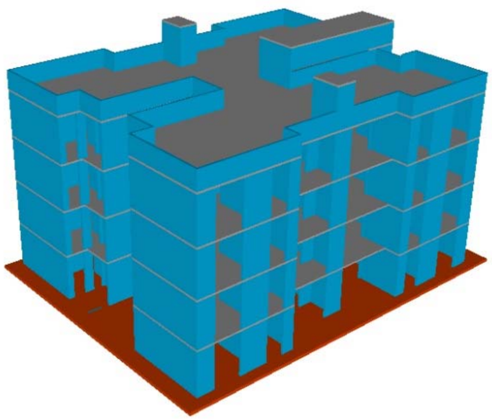
Case Study

Some of the project´s features

Results

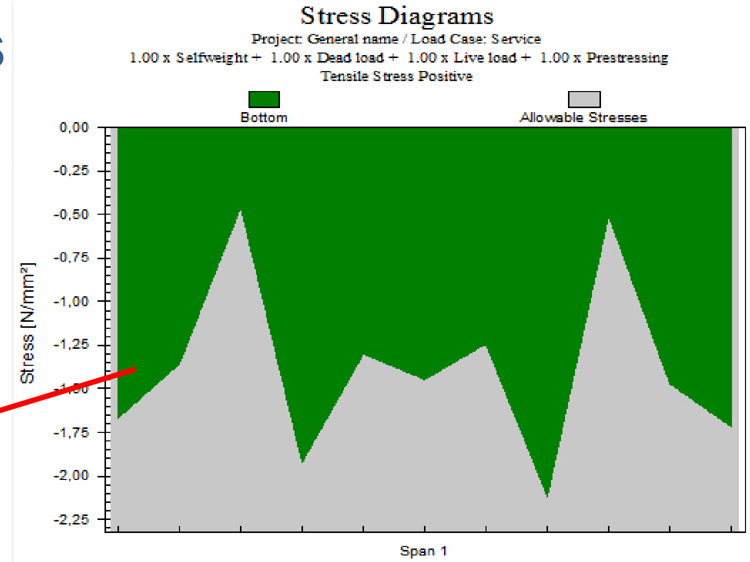
Post-Tensioned Raft Foundation

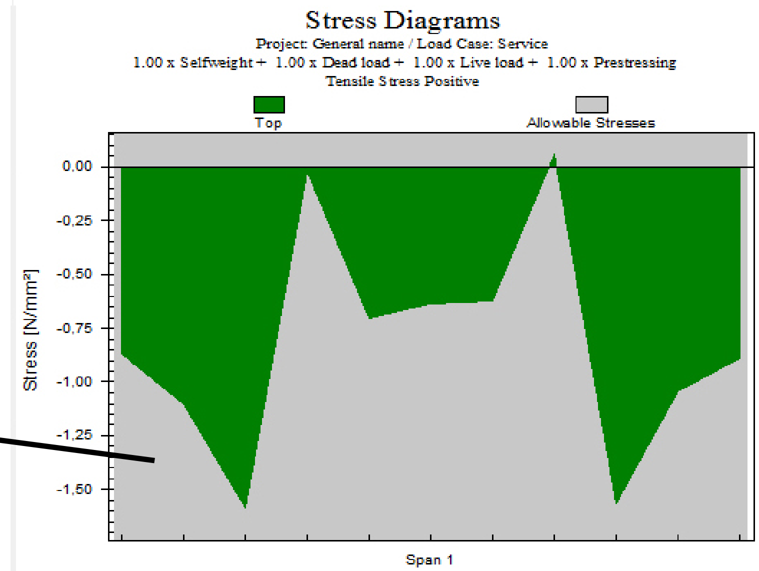
Top and Bottom Stresses with Allowable Values



Calculated Stress

Allowable Stress

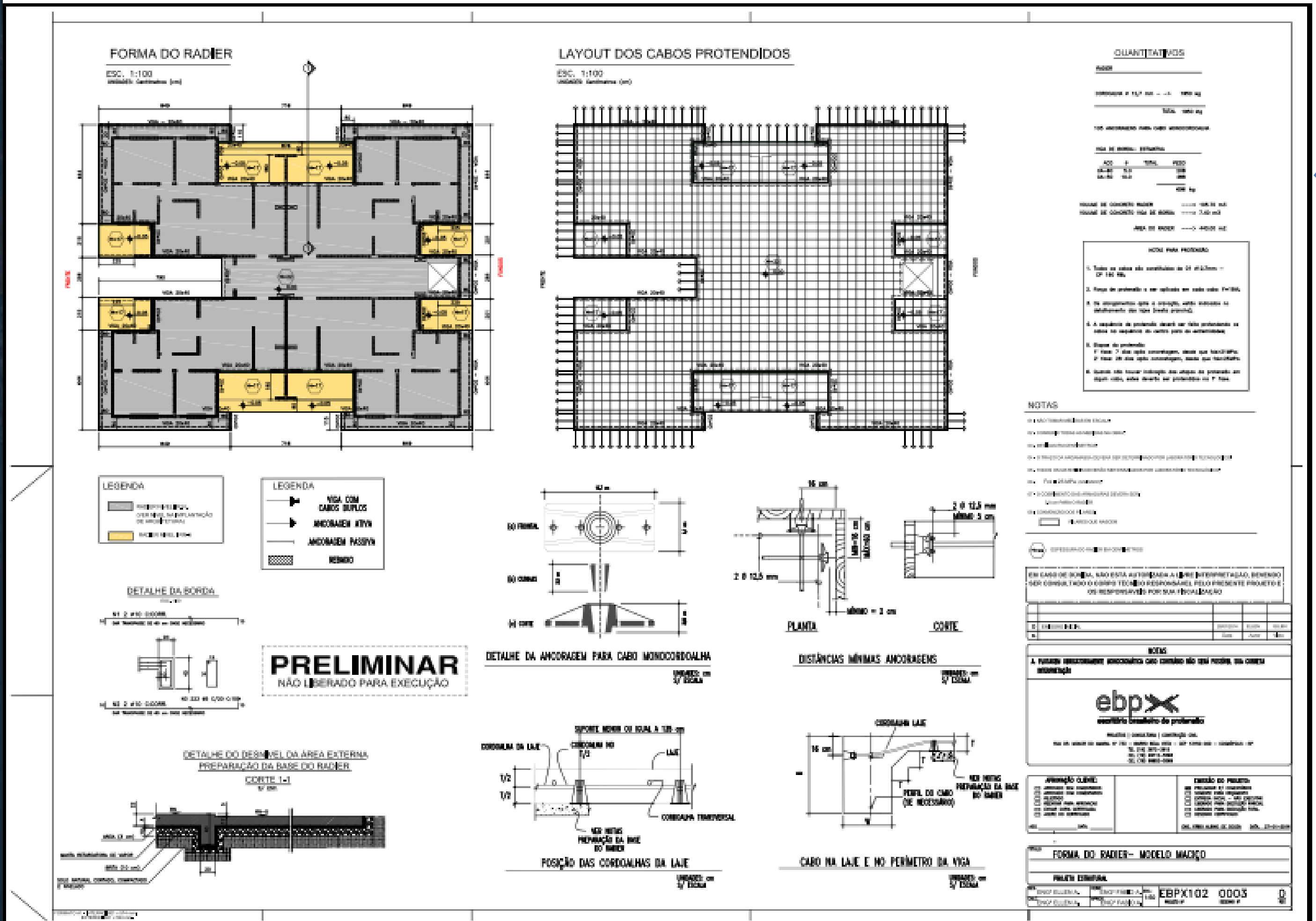




Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation



Raft Foundation

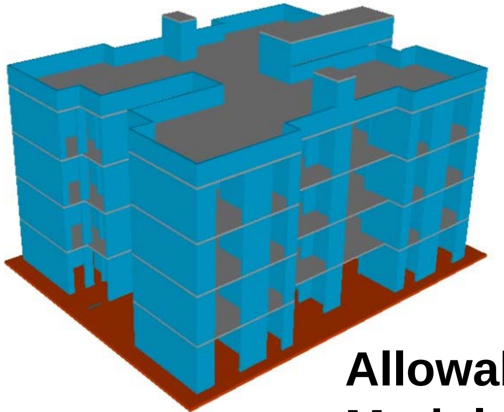
Preliminary Design – Post-Tensioned

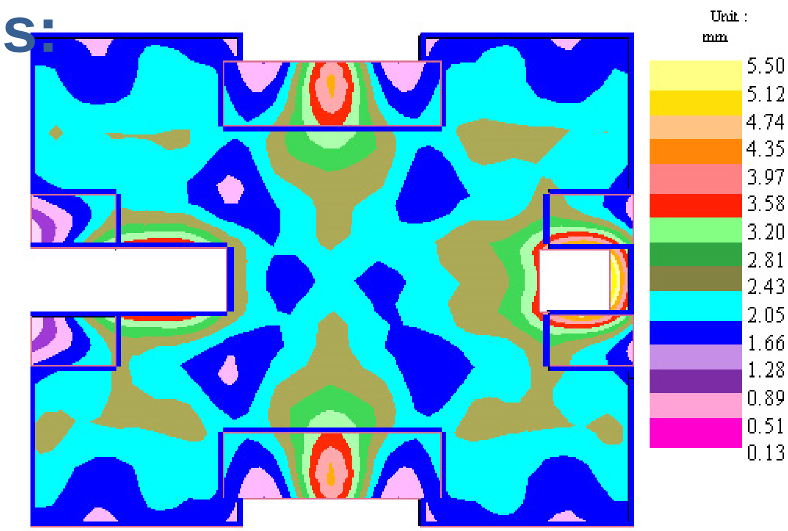
Case Study

Some of the project´s features:

Results

Reinforced Raft Foundation





Allowable Soil Bearing = 0.17 Mpa (1.7 kgf/cm^2)
Modulus of soil reaction = 2.00 – 3.00 kgf/cm^3

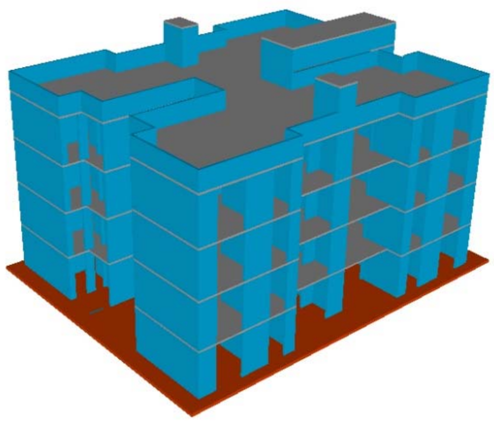
Load Combination	Minimum Displacement (mm)	Maximum Displacement (mm)	Minimum Soil Pressure - MPa	Maximum Soil Pressure - MPa
Service (TL)	0.09	3.93	0.01	0.12
Strength (DLO)	0.12	5.50	0.02	0.17
Cracked Sustained Load	0.09	4.54	0.01	0.14

Case Study

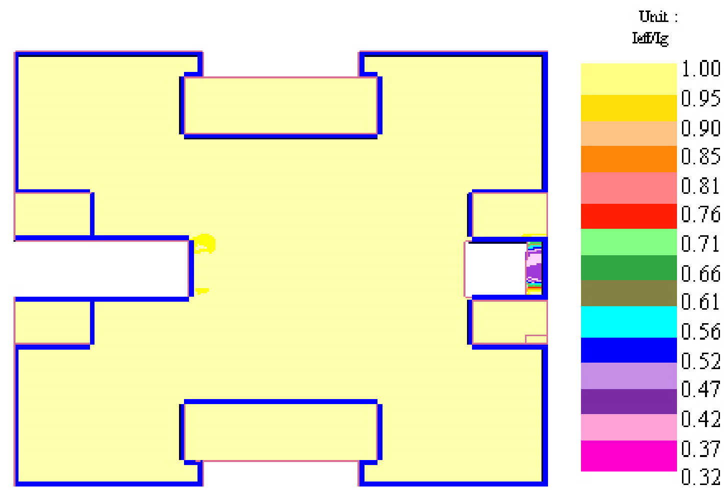
Some of the project´s features:

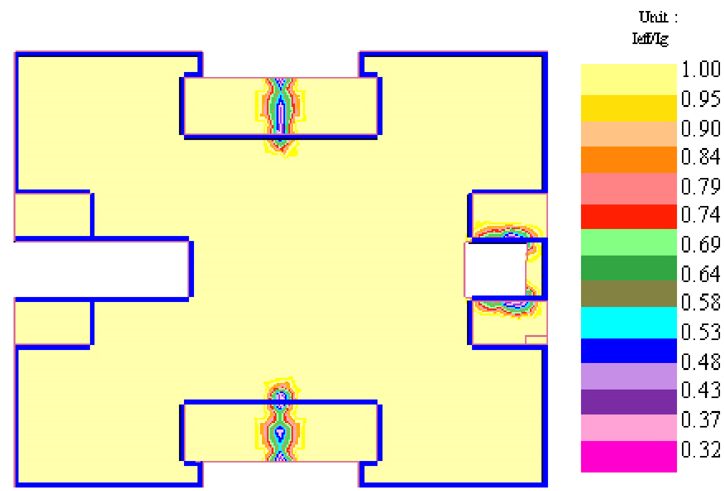
Results

Reinforced Raft Foundation



Reduced Rotational Stiffness About XX and YY

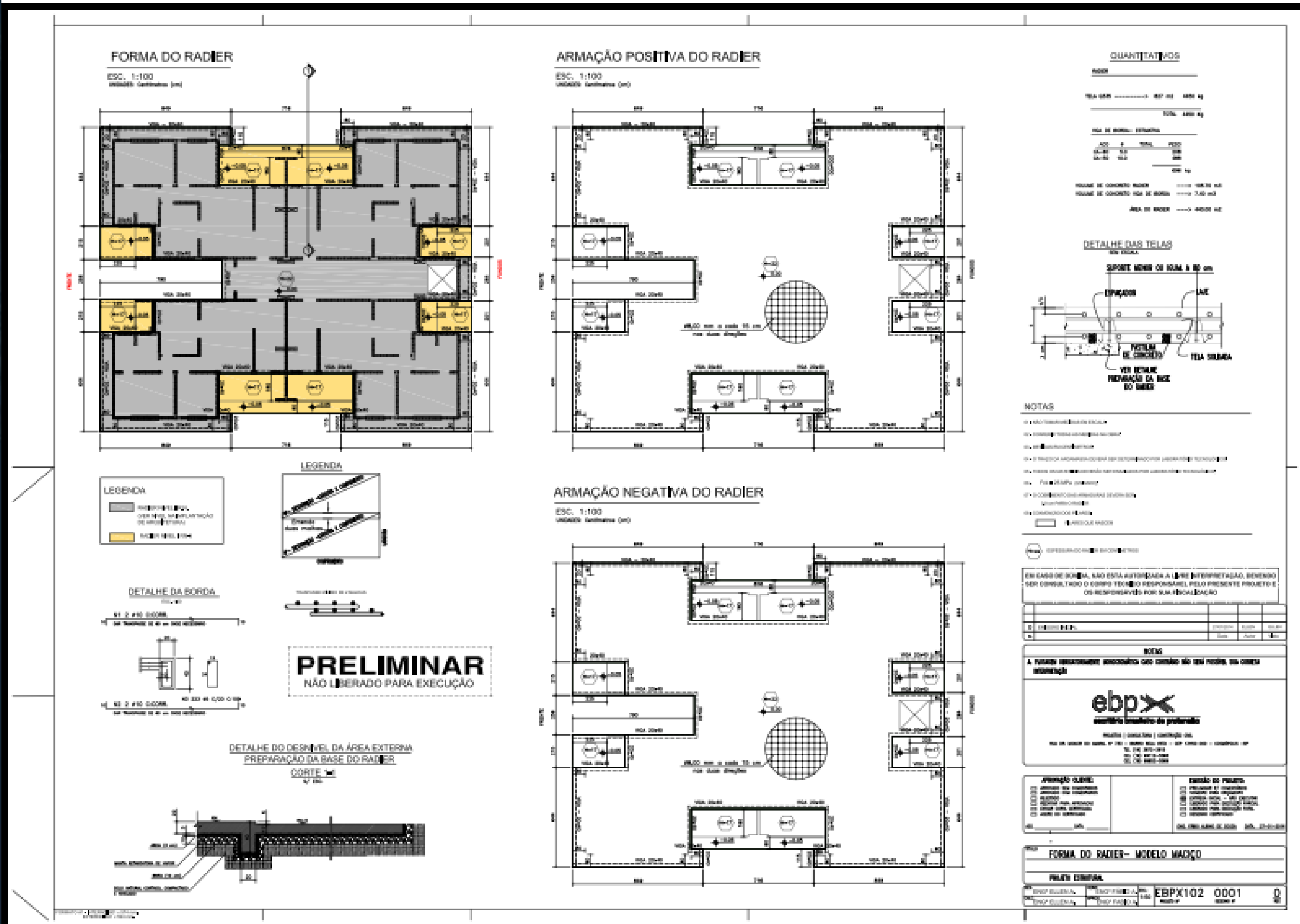




Case Study

Some of the project´s features:

Design of Post-Tensioned Raft and Piled Raft Foundation



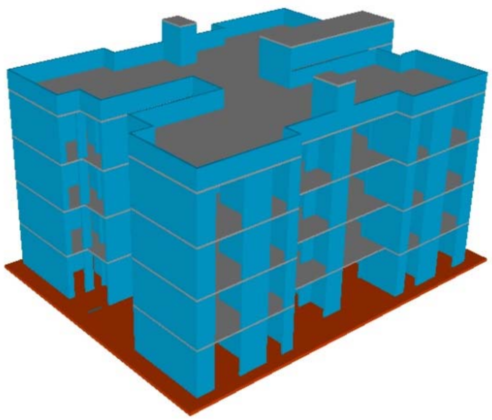
Raft Foundation

Preliminary Design – Reinforced Concrete

Case Study

Some of the project´s features:

Summary



Design Reference	SOG Area (m^3)	SOG Volume (m^3)	Weight Rebar (kg)	Weight Tendon (kg)	Rate Rebar (kg/m^3)	Rate Tendon (kg/m^3)
Reinforced Concrete	432.86	99.68	4,404	-----------	44.19	-----------
Post-Tensioned + Reinforced Concrete	432.86	99.68	1,402	1,216	14.07	12.20

Case Study

Conclusion – Raft Foundation

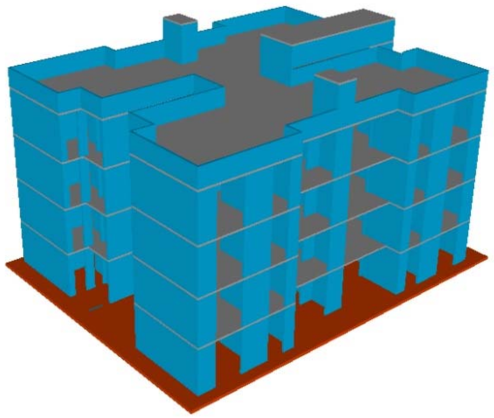
The summary data are very interesting and deserve the following comments.

1-. **In Brazil the ratio of tendon cost x rebar cost is 1.5 and it is a competitive value.**

2-) Calculating it we have 1,216*1.5 = 1,824 +1,402 = **3,227 kg – Steel.** The economy of using post tensioned slab-on-ground is (4,404 – 3,227) = **1,177 kg – Steel/ slab-on-ground**.

3-) **26.7% would be saved.**

4-) It is noticed that in this case **almost 2 full foundations could be saved** which would result in much higher profit. When we overlook at all the work involved in these two foundations that could be saved the benefits are much better.



Case Study

Conclusion – Piled Raft Foundation

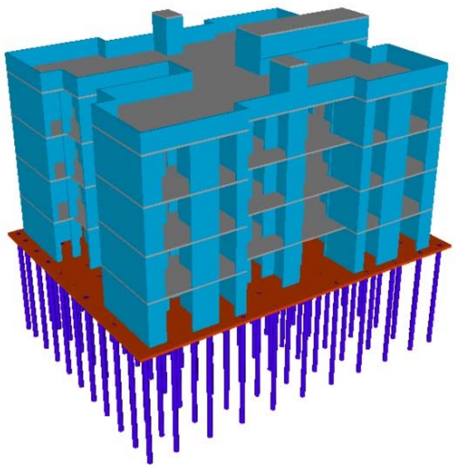
The summary data are very interesting and deserve the following comments.

1-. **In Brazil the ratio of tendon cost x rebar cost is 1.5 and it is a competitive value.**

2-) Calculating it we have 1,207*1.5 = 1,810 +1,790 = **3,600 kg – Steel.** The economy of using post tensioned slab-on-ground is (4,250 – 3,600) = **650 kg – Steel/ slab-on-ground**.

3-) **15.3% would be saved.**

4-) It is noticed that in this case **almost 1 full foundations could be saved.**



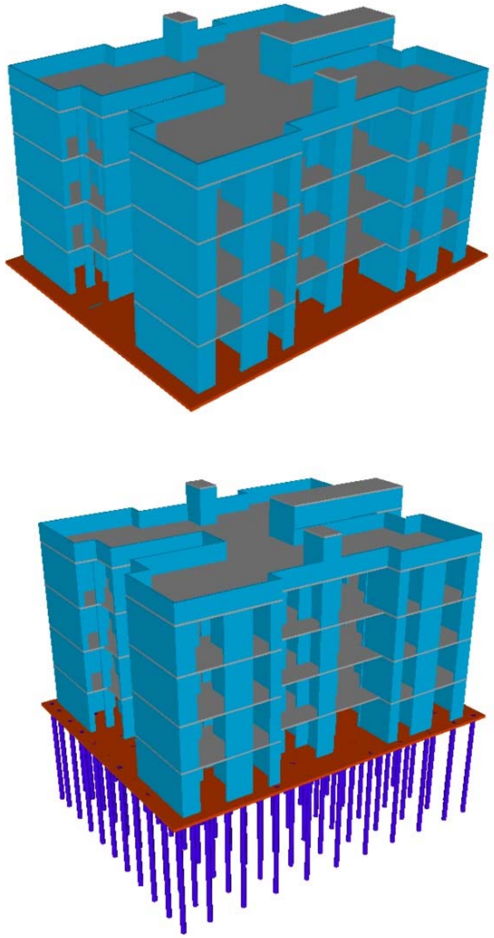
Case Study

Conclusion

The summary data are very interesting and deserve the following comments.

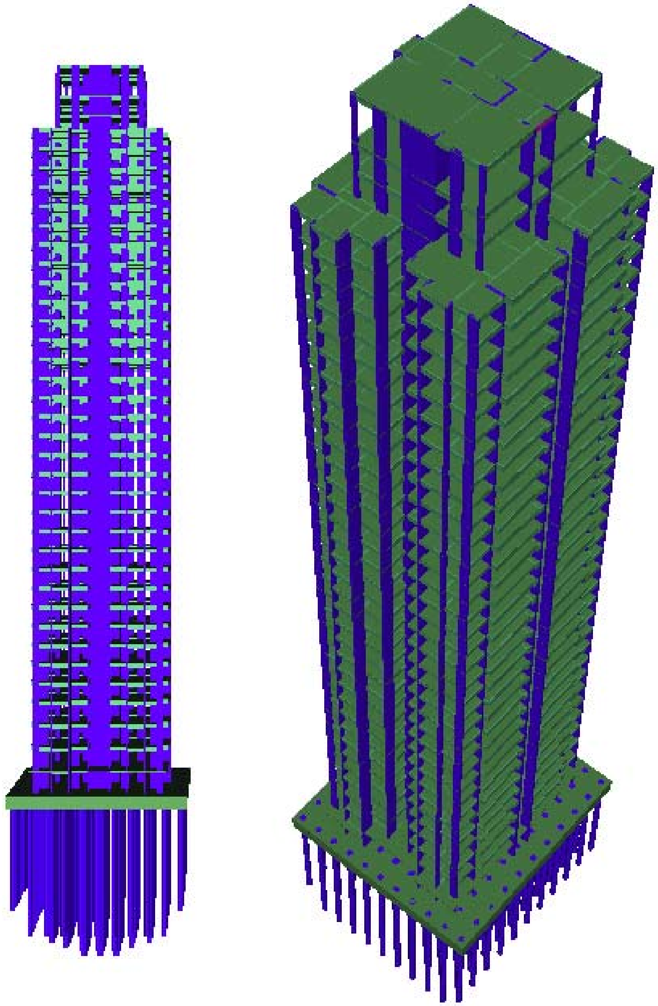
Almost 3 full foundations could be saved.

USD 25,000 saved.



Coming Soon

TIKUNA´S TOWER – MANAUS



Post-Tensioned Raft Foundation
Some of the project´s features:

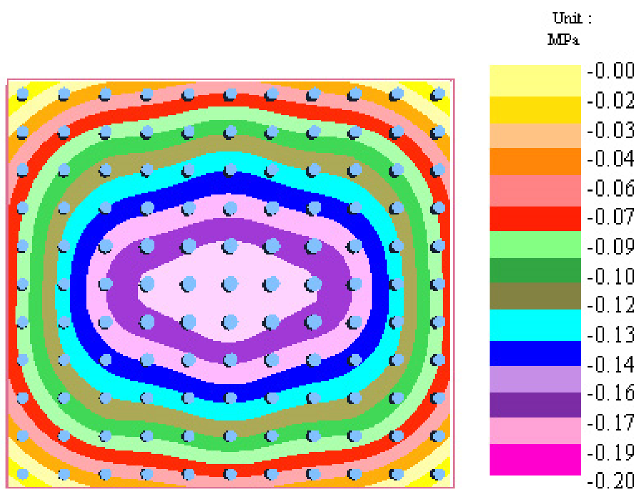
- **36 Floor Stories**
- **112 meters high**
- **14,100 m^2**

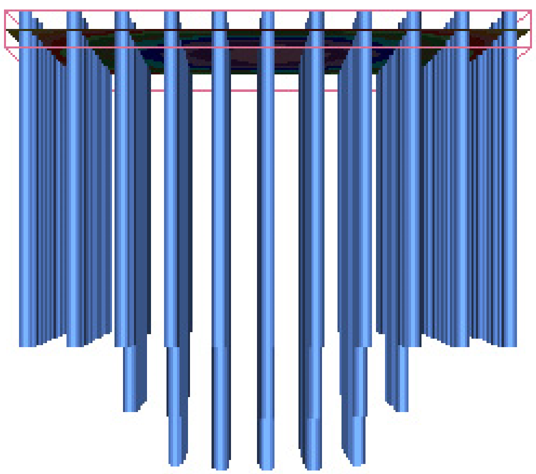
- **Coefficient Gamma Z (Brazilian Parameter)**
- **Gamma Z (X) = 1.18**
- **Gamma Z (Y) = 1.11**

- **P-Delta**
- **Wind (X) = 13.49%**
- **Wind (Y) = 7.95%**

Coming Soon

TIKUNA´S TOWER – MANAUS





Post-Tensioned Raft Foundation
Some of the project´s features:

- **Column with maximum load = 28,450 kN**

- **Horizontal Displacement**
- **Displacement X = 3.70 cm**
- **Displacement Y = 2.60 cm**

- **Total Auger Piles = 121**
- **External Ring (outer) = 80 cm -> 18 meters**
- **Internal Ring (inner) = 90 cm – 100 cm -> 25 meters**

- **Slab Thickness = 2.50 meters**

Questions and /or Comments

OBRIGADO!!!!

Thank you !!!