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FOUNDATIONS IN DOWNTOWN SÃO PAULO (BRAZIL)

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SYNOPSIS

A brief description of subsoil conditions in downtown São Paulo is presented, followed by a general presentation of the foundation types that have been used. Finally, as examples of actual application of these foundation types in this city, the description of the main features connected with the foundations of five large buildings is presented.

a) SUBSOIL CONDITIONS IN THE CENTRAL DISTRICT OF THE CITY OF SÃO PAULO.

The subsoil of the downtown section of the City of São Paulo is formed in descending sequence, of alternating clay and sand layers near the surface, followed by sand layers overlying bedrock.

The clay layers have thicknesses varying from a few decimeters to a few meters. These layers are in general stiff, but they may also occur in medium and hard consistency, less often soft. Their color is yellow and/or violet (when soft, medium or stiff) and light gray (when hard). These clays plot a little above the A-line in A. Casagrande's plasticity chart. Above a certain elevation, in the city of São Paulo, a layer of porous red clay, of low bearing capacity occurs. However, this layer is to be encountered only in a relatively small section of the business district.

The underlying sand layers are extremely variable. Their predominating texture is medium, but they alternate with layers and lenses of fine and coarse sand erratically distributed. Their clay content is generally low, but irregularly distributed clay lenses or lenses of very clayey sand are found. They are locally found in a loose state but from depths of about 30 m on down they are generally coarse and compact (resistance to penetration x) over 20 blows per 30 cm penetration). These are waterbearing layers, groundwater being almost always at several locally independent levels, on account of the above mentioned clay layers and lenses in the sand mass. Samples of these sands have been obtained down to about 25 m, from 6"casing borings by means of the Ivanoff sampler showing a void ratio of the order of 0.70.

Decomposed rock has been exceptionally located, in one case, in the business district, at a depth of about 30 m. (This was the only case in the business district where foundation loads were transmitted to it). In other locations in downtown São Paulo, borings to depths of the order of 70 m did not reach bedrock.

The city topography is very irregular. In the valley sections the upper clays do not occur, and are substituted by soft organic soil, followed by the previously described sand layers overlying bedrock.

b) FOUNDATIONS IN SÃO PAULO.

Up to about 1920 important foundation problems were not encountered, for only light masonry or steel frame buildings, two or three stories tall, at the most, were constructed. Small spread footings or wooden piles took care of the loads. Reinforced concrete only came into general use in about 1920, when the construction of heavier and taller buildings started. The rate of building construction has steadily increased up to present days.

The far greater building loads of today has called for more accurate control of foundation design and construction.

In cases where high bearing-capacity layers are found near the surface, mat or spread footing foundations are used. The underlying layers are generally firm. This has been proved by numerous settlement observations which demonstrate that settlement problems are not important in this city. Maximum settlements so far observed are of the order of 5 cm, with the exception of one case.

In cases where the upper layers are weak, or excavation is objectionable due to groundwater conditions, the following most important types of foundations have been resorted to: a) precast concrete piles (loads up to 80 t have been used); b) cast-in-place reinforced concrete (Franki) piles, pre-excavated or not, as may be the case (90 t loads are common); c) compressed air caissons (loads up to 1800 t have been used); d) caissons excavated in the open when groundwater conditions permit.

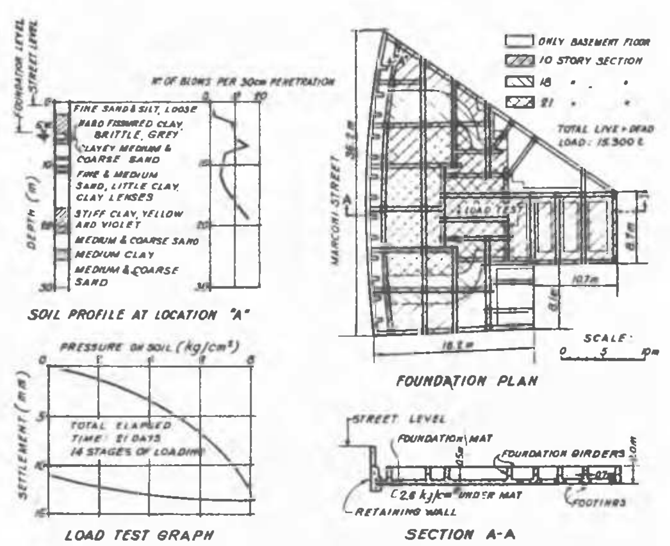
c) TYPICAL CASES OF FOUNDATIONS.

The following description of the foundations of five buildings recently completed or under construction in São Paulo will serve as typical examples of the above cited foundation types. Figures 1 to 5 present in simplified form the most important features connected with the foundations of these buildings. As in the case of all buildings constructed in this city nowadays, they are of reinforced concrete.

Building A

This is a 21-story building located in that part of the business district of best foundation soil, where hard clays or compact clayey sands are found near the surface. Soil exploration consisted of four 2" casing exploratory borings to about 30 m depth with measurement of penetration resistance, and one 6" casing boring with undisturbed sampling. A load test was made at the proposed foundation level (-5 m from street level). Soil underneath the test plate was a clayey silty fine sand, compact, friable, fissured, grey in color. Natural water content was of the order of 30%; liquid limit of 55%, plasticity index of 25. Unconfined compression tests on prisms of 5 x 5 x 12.5 cm showed premature rupture at 2 kg/cm^2. The foundation consists of a reinforced concrete mat. A better distribution of column loads upon this mat is achieved by foundation girders connecting all columns. In the back part of the building (10 floors) spread footings underneath girders, all inter-

x) - Penetration of a split-spoon sampler 37 mm $\varnothing_i$ 46 mm $\varnothing_e$, with blows of a 60 kg weight falling 75 cm.



BUILDING A

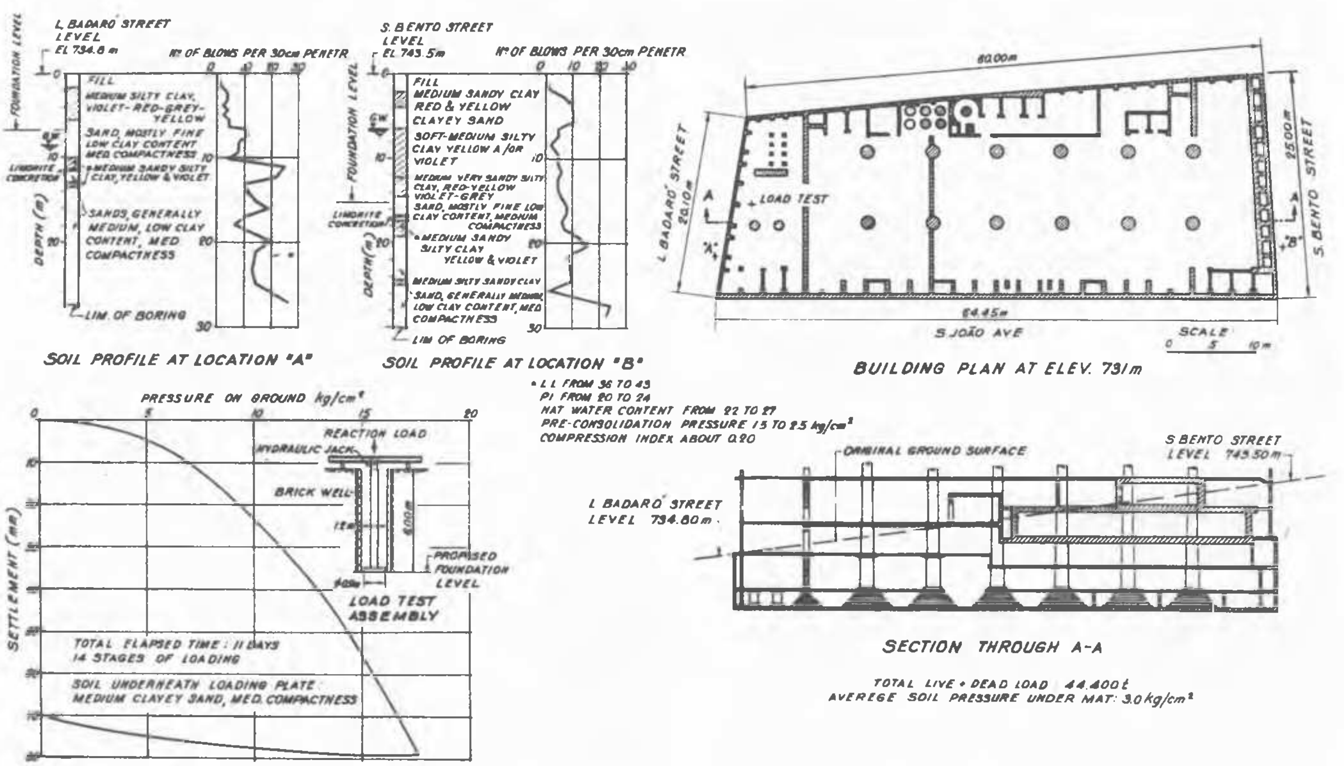
FIG. 1

ing borings, to about 30 m depth. The lot slopes with a difference in elevation of about nine meters over its greater length. Subsoil consists of medium-soft and medium clay layers alternating with sand layers near the surface (down to depths from 10 to 20 m). Continuing downward, sand layers, generally medium, and with low clay content, predominate. One load test was made at the proposed foundation level with a Ø 0.9 m test plate. The foundation consists of a reinforced concrete mat 0.5 m thick upon which rest the column footings. The average soil pressure underneath this mat will be 3.0 kg/cm^2

Only about ten percent of the load is applied. Maximum settlement to date is 6 mm (measured by precision water level using a deep underground bench-mark).

<u>Hotel São Paulo Building</u>

This is a 20-story building located in one of the valley sections. At these locations the superficial layers are very weak and the groundwater level is very close to the surface. The lot slopes with a maximum difference in elevation of 3 meters. Five exploratory 2" casing borings were made to a depth of about 30 m. The foundation consists of Franki piles without pre-excavation, all driven to about same elevation.



"BANCO DO BRASIL" BUILDING

FIG. 2

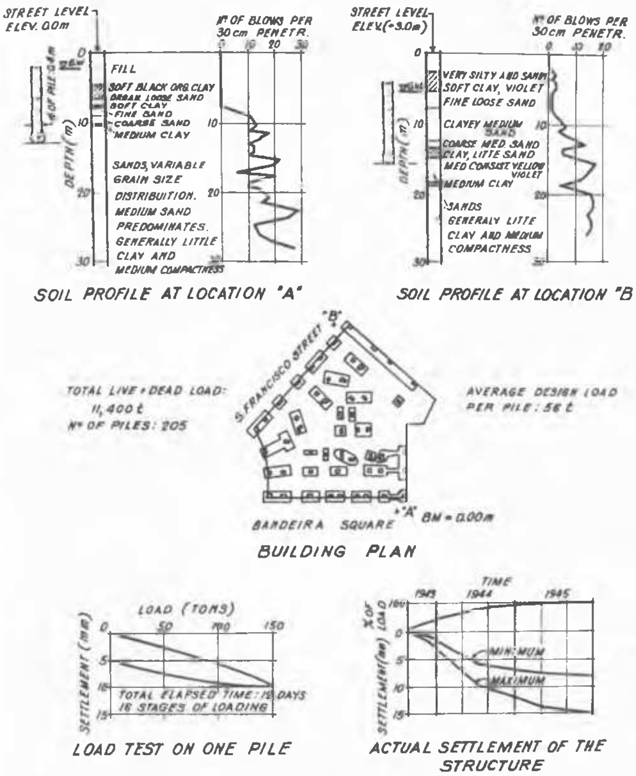
connected, were used. The average soil pressure at the front area is 2.6 kg/cm^2. The total load of the building has been effective now for several months. Maximum settlement to date is 1.5 cm (measured by precision water level using deep underground B.M.).

<u>Banco do Brasil Building</u>

This is a large bank building, under construction, to be 25 stories high and 125 m high from lowest street level, and occupies an area of about 1,500 m^2. Soil exploration consisted of three 2" casing and three 6" casing borings, to about 30 m depth.

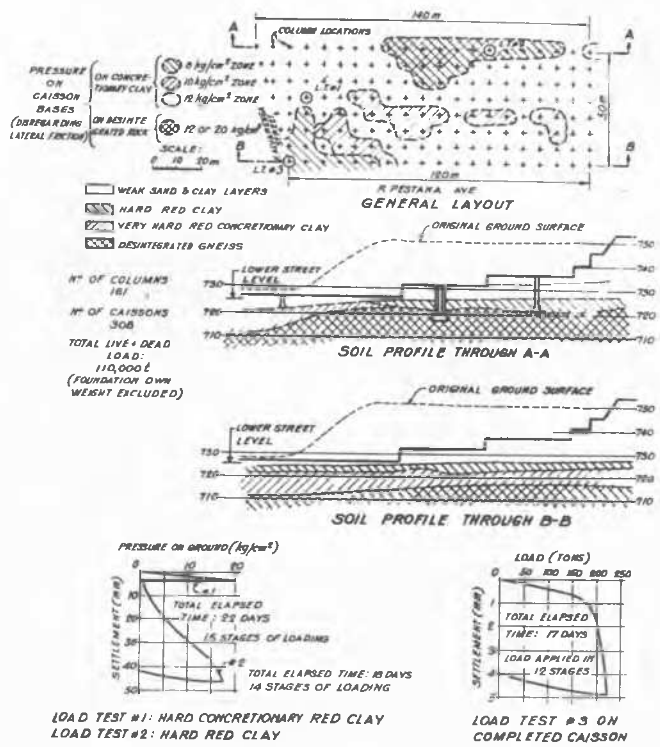
<u>Sotto Mayor Building</u>

This is a 20-story building. Three 2" casing and three 6" casing borings were made. Subsoil consists of a 3 m superficial layer of clay, medium in consistency, followed by relatively weak sand layers down to about 14 m below street level, and from this depth on down, compact sands. (Depth 0 in soil profile in fig. no. 4 corresponds to bottom of excavation of clay overburden). Foundation consists of compressed air reinforced concrete caissons with enlarged bases. One load test



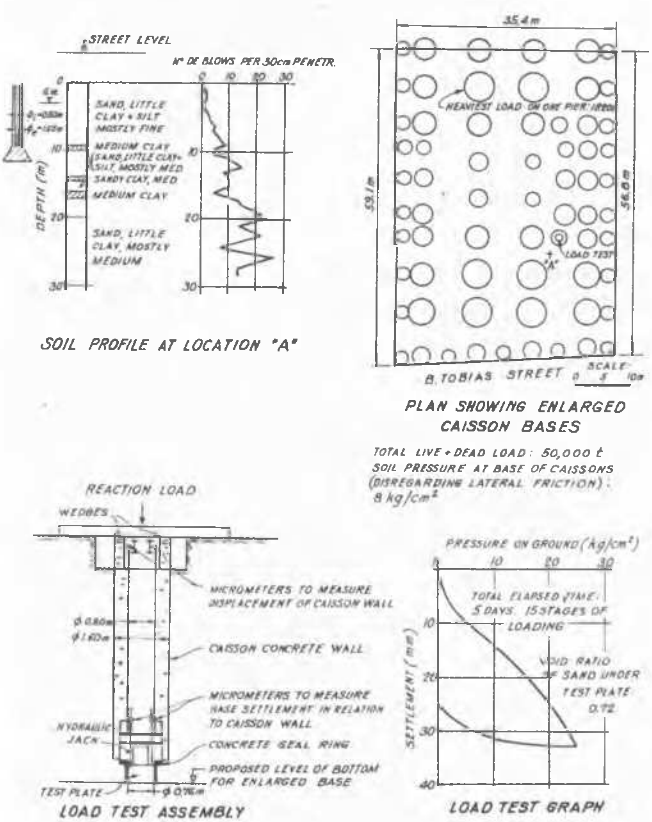
"HOTEL SÃO PAULO" BUILDING

FIG. 3



"SECRETARIA DA FAZENDA" BUILDING

FIG. 5



"SOTTO MAYOR" BUILDING

FIG. 4

was made at the proposed elevation of the caisson bases. This load test was made by loading the soil at the bottom of a caisson before the enlargement of its base. Only the soil at the bottom was loaded, that is, no lateral friction was mobilized. For the installation of the load test the compressed air operation was discontinued when excavation reached the proposed level. Open air pumping was resorted to during load test assembling. A pressure of 2.5 kg/cm^2 was first applied to the soil and a settlement of 13 mm was recorded. The soil was then unloaded and the test started again with the results shown in fig. 4. The loosening up of the soil due to open - air pumping was believed to account for these higher deformations at low stages of loading. The building is almost completed and settlements are under 1 cm (observed by the contractor with an optical level using a B.M. on an old building).

Secretaria da Fazenda Building

This is a monumental public building, now under construction, with about 6,000 m^2 of horizontal projection, 20 stories, and is to be 120 m high from lowest street level. Its total weight will be 110,000 tons.

Ten borings were made to disclose the general picture of the subsoil and then 57 more were made, as foundation construction went on, to detail the conditions that departed from the anticipated ones. The irregularity of subsoil conditions at the site made such a great number of borings necessary.

As an exception, in downtown São Paulo, bedrock is relatively shallow. This is the first case in central São Paulo of a building partially founded on decomposed rock (gneiss). Throughout almost the entire area a very hard layer of iron-oxide concretionary red clay overlies the bedrock. Thin layers of such concretions, having the appearance of a rolled steel sheet, are to the found here and there in the São Paulo soil. At the site of this building, however, this layer of concretionary clay is exceptionally thick and widespread. On top of the concretionary clay appears a hard red clay, not concretionary. There is no clear boundary between this clay and the concretionary one. Continuing to the surface, clayey sands, with thin layers of medium clay are found. The void ratio of the concretionary clay is of the order of 0.5. Its compressive strength from unconfined compression tests showed very erratic results due to the nature of the material itself (from 1.5 to 35 kg/cm^2). The void ratio of the red hard clay varies from 0.50 to 0.65; pre-consolidation load from 7 to 10 kg/cm^2; liquid limit from 35 to 40; plasticity index from 15 to 20, natural water content, approximately 20%.

As a criterion for the judgement of the state of compactness of the desintegrated rock, the progress of the 2" casing hand operated wash boring for 10 minutes operation was adopted. This corresponds to about 300 strokes of the cutting tool falling about 30 cm. It was observed that for a progress under 40 cm per 10 minutes operation the state of the rock was such that compressed air tools were needed for its excavation.

Foundation for this building consisted of caissons with enlarged bases resting either on the concretionary clay or on the decomposed rock. To each column corresponds, depending on its load, one, two, three or four caisson cylinders, with only one enlarged base in all cases. The heaviest load on one column is 1,653 t. These caissons were mechanically (except for the concretionary clay and for the base enlargement) excavated in the open, as a steel cylinder (Ø 0.9 m) was pushed down. This steel cylinder was withdrawn as the caisson was concreted. The pressure at the base of caissons (neglecting lateral friction) varies from 8 to 20 kg/cm^2.

Three load tests were made. No. 1 and 2 were soil load tests at the level of the caisson bases, respectively on concretionary clay and hard red clay. A Ø 0.8 m plate was used in all of them. Load test No. 3 was made on a completed caisson resting on concretionary clay. Load test No. 2, on hard red clay was made in anticipation of founding the caissons, in the upper part of the lot, on that layer. Groundwater conditions, however, would make difficult the hand excavation for the enlargement of the bases. It was found much easier to go through the red clay with mechanical excavation down to the concretionary clay thereby sealing off the water.

The building is now under construction. A deep underground B.M., and reference points, have been established. Very small settlements are anticipated.

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FOUNDATIONS FOR MASTS OF STEVEDORE TRAINING SHIP

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At the beginning of World War II, the U.S. Navy had no organized groups specially trained for loading and unloading cargoes in combat zones. In 1942, the Navy Department gave the Bureau of Yards and Docks the task of organizing stevedore battalions, known as "special" battalions, under the "seabee" program, in order to handle the acute problem of unloading cargo from ships in the forward areas.

A stevedore training station was established at Camp Rousseau in the U.S. Naval Advance Base Depot at Port Hueneme, California, which is 65 miles north of Los Angeles. Training of stevedores in cargo handling was conducted on a land ship which was built of masts, booms and gear of a standard Liberty Ship. The ship was built with two masts with two hatches for each mast, and with an upper deck and a hold approximating shipboard conditions.

The design and construction of the concrete foundations for the full-size steel masts and erection of the masts on the foundations constituted some of the most interesting and difficult features of this project.

Fig. 1 shows a crane placing a mast on the concrete foundation. On a Liberty Ship these masts are welded and securely fastened to the structural frame of the ship. For the training ship built on land, a concrete foundation and pedestal to carry the mast had to be designed and built.

A close-up view of the concrete base is given in Fig. 2, taken at the time the mast was set in a steel ring in the base. The reinforced concrete foundation of spread footing type was designed to carry the dead weight of the mast and booms, wind load on the mast, and a live load of 10 tons applied at the end of one boom when horizontal. The ship was built inland about one-half mile from the harbor in order to conserve valuable harbor frontage for berthing of regular ships. No soil problems at the water's edge were involved, but the site selected had a clay soil which had low bearing capacity wher