Panel report: Geotechnical conditions in Buenos Aires City

Rapport de spécialistes: Conditions geotechniques dans la ville de Buenos Aires

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In accordance with the geotechnical characteristics of the foundation subsoil, Buenos Aires City can be divided in two main zones:

- The first one, which covers the principal urban area of the city, presents in the upper levels, deposits belonging to Pleistocene. These deposits include silty and clayey soils, preconsolidated by desiccation with layers or lenses of cemented soils by calcareous impregnation. The total thickness of these sedimentary deposits is about 25 to 45 m; this part of the profile is the locally so called "Formación Pampeano".
- In the second one, principally located along the Riachuelo Valley soft deposits of clays and plastic silty clayey soils, and/or loose to medium sandy soils, are found that are included in the locally named PostPampeano formation belonging to the Holocene.

Underlying these formation the "Puelches" fine and dense sands that correspond to the Pliocene Period are found. Into these dense sands there is a layer or stratum of plastic clayey silt or silty clay, a very plastic soil, approximately 10 m or

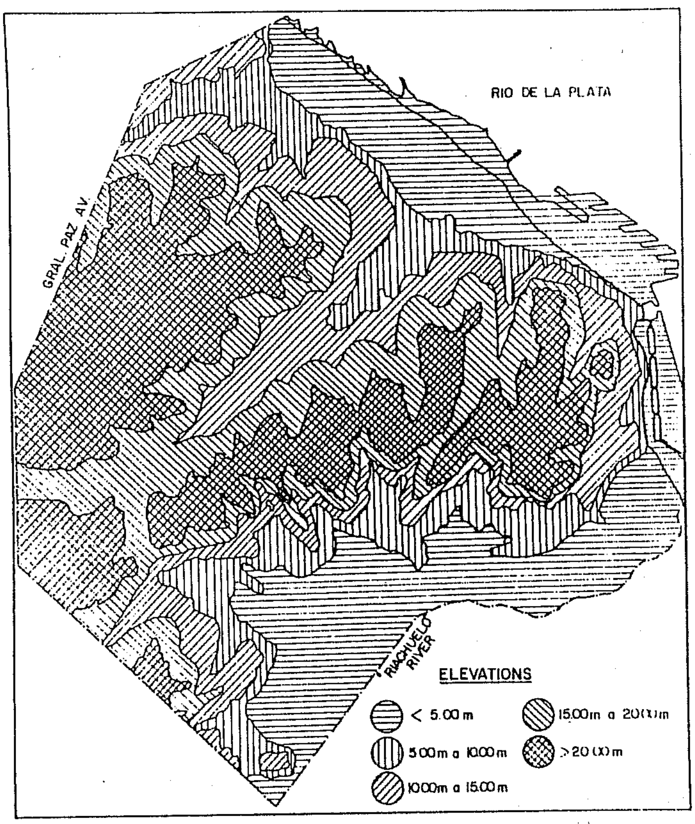

Fig 1.- Buenos Aires City plan showing the ground elevation. For elevation < 5 m, the natural elevation corresponds to the Post Pampeano Formation.

a little thicker. This greenish gray or blueish clays are very stiff and generally normally consolidated under the loads imposted by the biggest thickness of the

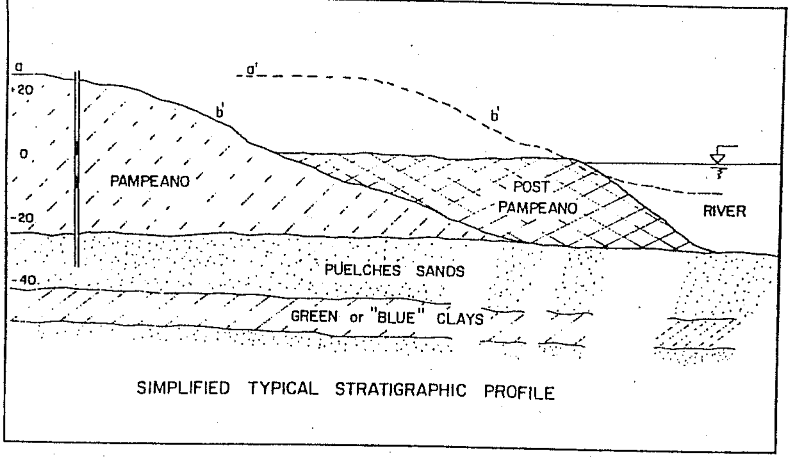

Fig. 2.- Simplified typical stratigraphic profile of the Pampeano Formation near rivers Paraná, de La Plata and Riachuelo (horizontally not in scale).-

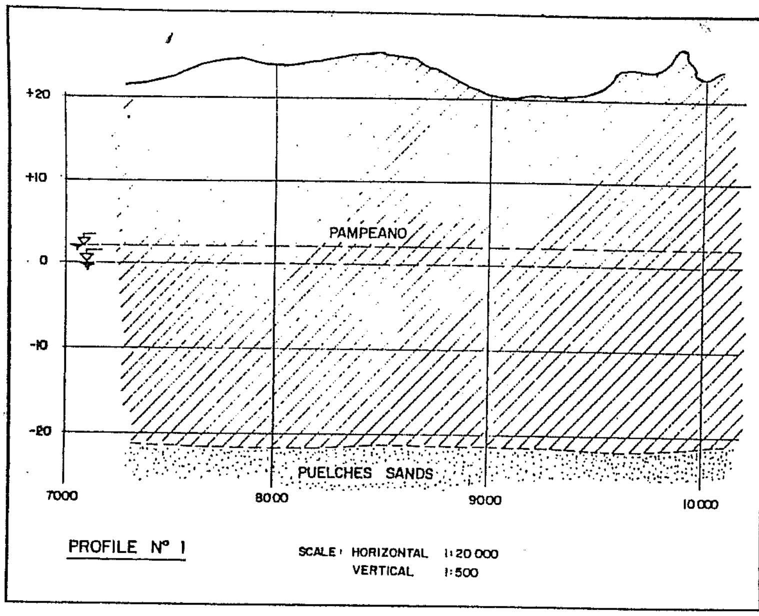

Fig. 3.- Typical profile through the Pampeano Formation.-

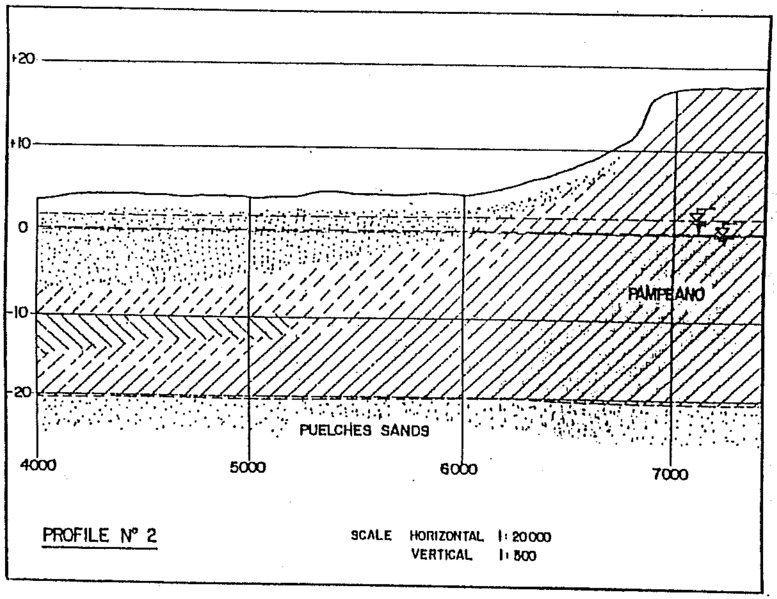

Fig. 4.- Typical profile through the Pampeano and Post Pampeano Formations.-

Pampeano profile.
It is generally accepted that the lower part of the pampeano profile was formed by deposition of particles transported by the wind in a fluvial environment ; instead, it is considered that the upper part was built by eolic deposition subsequently transported and redeposited under water; this later environment transformed locally the structural characteristics of the particles; that is why, they are denominated as "modified and redeposited loess". The alternate action of wet and dry environment, of local erosion, of redeposition and dessication while raising the formation, finally produced strata almost 60 m thick in some locations near the city.
The presence of calcium carbonate in form of nodules, and calcium oxides as impregnation of matrix, produced cemented zones of the profile; its strength and thick strata are variables with a discontinuous appearence of lenses of 0,5 to 1,5/2,0 m thick.
It can be conceived that soils were redeposited and desiccated below relatively small thick layers; the high values of suction generated interparticles equivalent high pressures and produced the decreasing of volume. If we were to use some expression to link effective pressures with suction - as has been done for instance

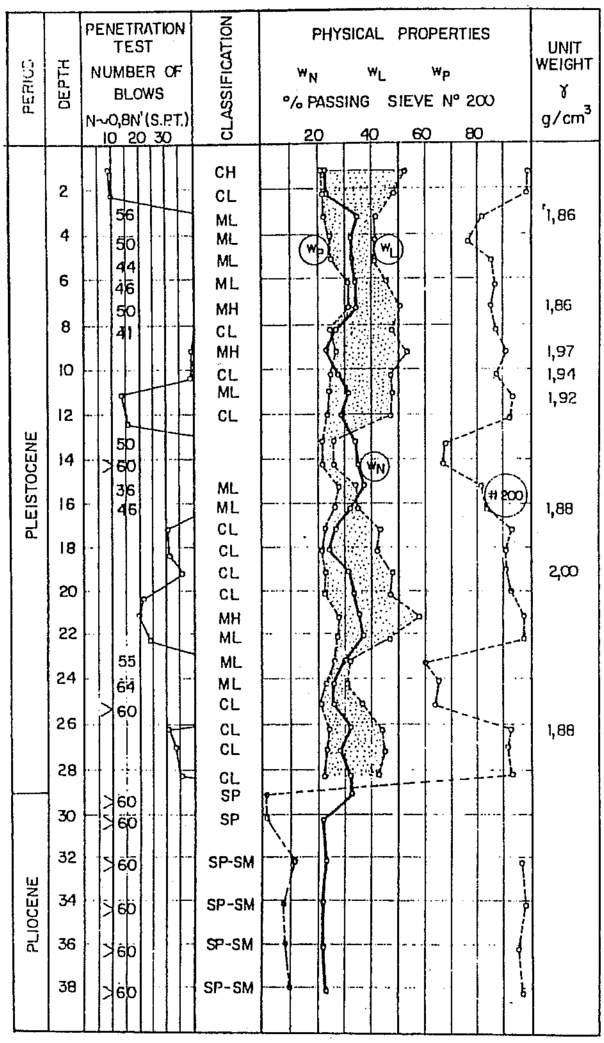

Fig. 5.- Pampeano Formation. Typical field and laboratory test results .-

by Bishop or more recently by Freudlund, and if we were to admit the sequential alternance of redeposition - desiccation - wetting acting during all the time of deposit formation, it would be possible to conceive that in the past pressures as high as 5 to 10 kg/cm2 were developed. A ratio value of effective stresses in between $K_o \cong (1-\sin\phi')$ and 1 can be expected if during the process of formation the mass of soil maintains its continuity or has very small little fissures.
Instead, if the drying process were developed in a period of time that produces

an important cracking and consequently loss of lateral confining pressures, the additional vertical load action may produce a Kcrit. condition by lateral expansion. On the other hand if in this cracking condition, it were possible to fill the vertical fissures with mixtures of soil with some cement material, a later process of wetting or flooding may produce, if the filling has reached sufficient strength, a vertical expansion that raises the value $\sigma'h/\sigma'v$ up to 1 or higher and an inclusive near failure due to vertical expansion combined with null lateral strains.

The preconsolidation of the lower soil layers of the profile, that probably were sedimented under water in a fluvial environment, can be explained due to the action of the drawdown of water table, capillary effects and suction due to the evapora - tion process. Anyway, it seems to be clear that de preconsolidation ratio to the present time must be lowering with the depth. Taking into account that the tertiary clays appear to be normally consolidated under long time loads, the strength of the pampeano soils - those that exibit high void ratios even without appreciable cementation - only can be explained due to an overconsolidation phenomenon as was described before.

The skeleton strength in the portion of the profile where the structure is open, but very stiff to very hard, is due to cement acting among particles. These cemented strata or lenses are locally named "tosca" soil. When the cementation is very hard the triaxial resistance under a confining pressure of 1 kg/cm2 is between

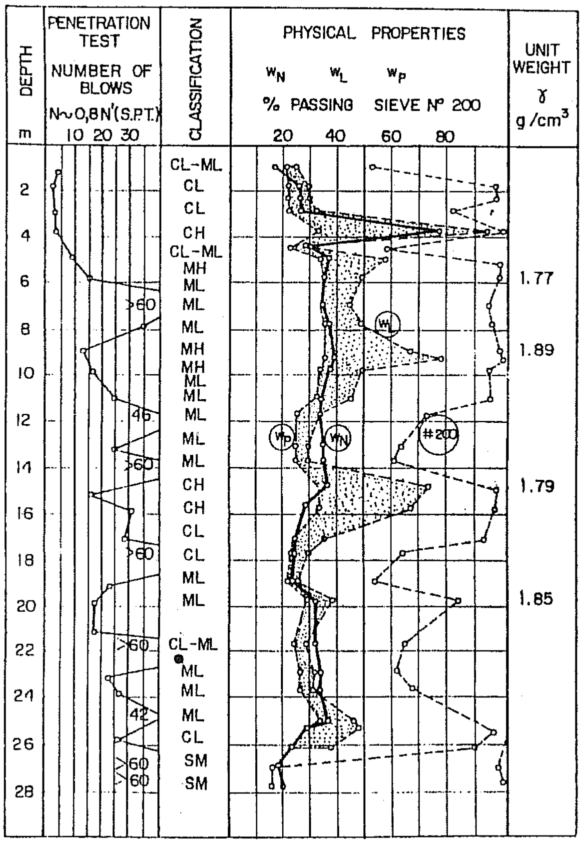

Fig. 6.- Pampeano Formation. Other typical sounding. Note the alternance of the cemented strata or lenses .-

10 to 20 kg/cm2. Due to variability of cementation, it is common to obtain values comprised between the latter lower value and 5 kg/cm2, and, when the clayed silty matrix is not cemented the strength falls down to about 2 kg/cm2. In this case the strength of the skeleton particles is caused only by the preconsolidation shown before.

The local investigation performed to obtain samples from the ground and the N' values, usually include as a routine standard dynamic penetration tests using a 2½" inside diameter sampling tube with a thin shoe and plastic liners. For any condi - tion this procedure permits to get a preliminary idea of soil resistance using correlations with the N - SPT values. It also provides sufficient quantity of soils to determine the natural water content, the physical properties and the granulometric characteristics. When the soils are not cemented, their relatively low sensitivity allows to perfor triaxial tests and their results are considered only as an rough index of the actual strength of the material. Additionally, when the degree of saturation is less than 100% the multiple stage technique is used to estimate the undrained intercept cohesion c_u and friction ϕ_u values. However, when it is required to perform rigorous studies to investigate the actual stress - strain - strength relationships, block samples are recovered from open pits or deep shafts. Many times, a Denison type double wall sampler. at least 5" in dia - meter, has been successfully used.

Due to the great variability of cementation it is not unfrequent to obtain a wide range of results. Values of c_u between 0,5 to 2 kg/cm2 and ϕ_u between 10º to 25º are common. Due to the macroporous structure of these soils, and perhaps to some rest of loessian structure that can be seen in the form of small vertical holes into the undisturbed mass, the vertical permeability is higher than the horizontal. In dewatering problems - where the predominant permeability is the horizontal - the coefficient of permeability values obtained is in the order of 10^{-4} to 10^{-5} cm/seg. These particular characteristics of the macro structure of these soils permit to understand why samples obtained below phreatic level, when tested in the triaxial chamber without back pressure, appears as non saturated due

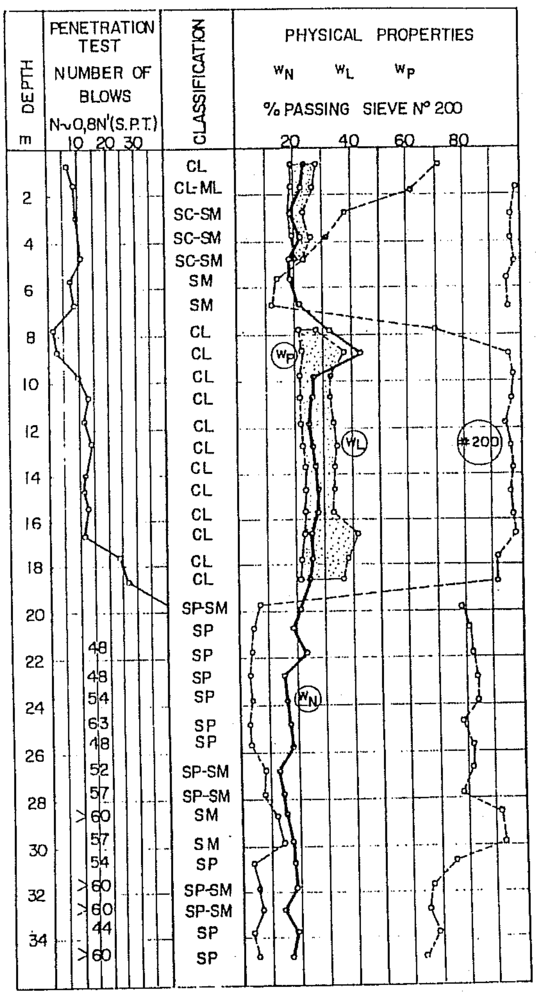

Fig. 7.- Transition: Pampeano and Post Pampeano Formation.-

to the loss of water from the holes. This high capacity of drainage - more remarked in "tosca" soil - has permitted to design foundations using shear parameters obtained from averaging results of triaxial tests with partially drained samples. Taking into account that the soil skeleton has relativelly low deformability, this method to design foundation gives results in accordance with actual small deforma- tion of structures. When these are shallow foundations - individual, combined and

continuous footings - the allowable pressure commonly used are 2 to 6 kg/cm2; for rafts the usual values are of the order of 3 to 5 kg/cm2. The uniaxial consolidation test results, obtained from conventional oedometers or using the triaxial chamber following prefixed stress paths, when they are introduced into calculations, generally overestimate the actual settlement of the structures. This is true due to the difficulties to obtain undisturbed samples of inhomogeneouslly cemented soils. On the other hand, it is very difficult to apply "in situ" - to this type of soil formation - exploration devices as static or dynamic penetrometers, dilatometers, and so on, due to the presence of cemented lenses or strata that prevent to advance with the measure tool. That is why exploration methods as wash boring combined with standard penetration tests of samplers to allow to recover representative samples of soil, sistematically are so widely used.
Shallow foundations are generally used in this pampeano formation; however the architectonic trend to concentrate loads on small numbers of columns can force the use of piles. In these cases generally bored piles - designed up to 2,20 m in diameter and 1.800 Tn of allowable axial load - are commonly employed. The concrete structures of high expressways in B.A. rest on bored piles or cilinders of circular or rectangular cross section.
In zones where the presence of soft soils (postpampeano) overlaying the very stiff pampeano formation require piles, these piles rest on or are built through these preconsolidated inhomoginuouslly cemented soils. Many times, and due to requirements of design loads, the tips of the piles must enter the dense puelches sands. Hence, the pampeano soil-pile interaction has been carefully studied.
Commonlly, the shaft friction is considered of the same value of undrained cohesion c_u for soils without cementation; when this cementation exists, a reduction factor less than one is applied. For bored piles it is generally necessary to take into consideration the peripherical remolding of soil and the probable use of concrete with high water/cement ratio. For this type of piles the values of friction adopted to design are generally minimized. When the piles are above the water table, additives are used with the concrete to improve the shaft behaviour when it is necessary to inclrease the frictional resistance along the shaft. The shear parameters obtained from drained and consolidated-undrained triaxial tests performed under high stress level are commonly used to estimate the point resistance. When highly cemented soils are loaded heavely, the value of shear parameters must be reduced; in this case a ϕ' value of 30º seems satisfactory. In the knowledge of the author the greatest point resistance at failure into "tosca" is about 100 and 120 kg/cm2. When are used driven piles with displacement of soil always the "refusal" are reached in the "tosca" soil.

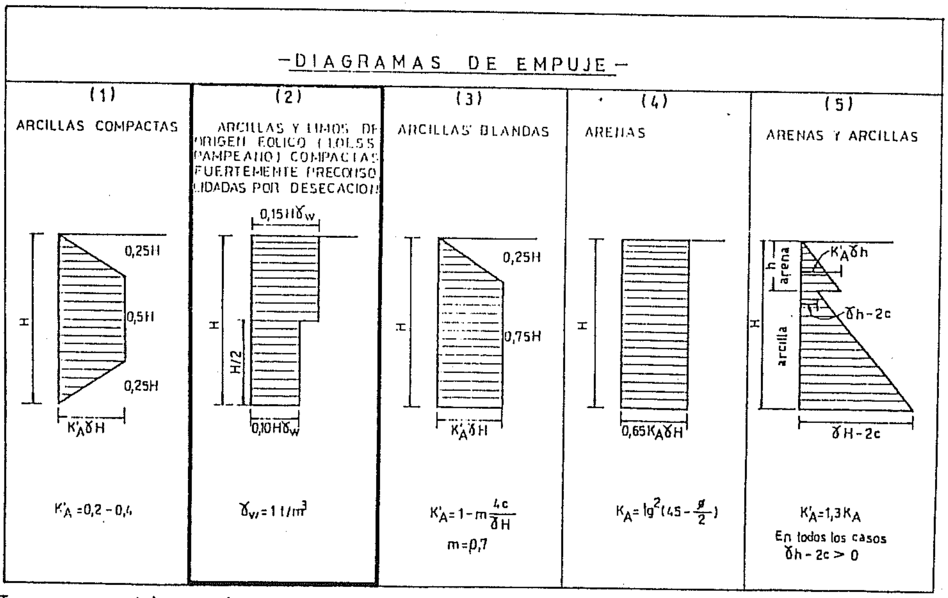

Fig. 8.- Horizontal pressures diagrams used for retaining structures. The(2) number correspond to the Pampeano: Stiff silts and clays from eolian origin hardly preconsolidated by desiccation.-

In connection with open excavation, for retaining temporary structures design we use a total pressure diagram with some particularities: a) its magnitude is equal to the pressure produced by an equivalent fluid with $\gamma_{eq} = 1/4 . \gamma_w$; b) the distribution of the horizontal pressures presents two rectangular blocks of H/2

of height; the upper portion has a constant $p_h = 0{,}15\,\gamma_w.H$ and $p_h = 0{,}1\,\gamma_w.H$ in the lower one. Hence, 60% of the total earth pressure acts on the upper half of the cut, and the 40% on the lower part. The resultant P is located 0,55.H above the bottom of the excavation. As we know, for stiff fissured clays Terzaghi & Peck suggested a total earth pressure that can be asimilate to $P = \frac{1}{2}\,\gamma_{eq}.H^2$ with $\gamma_{eq} \cong \frac{1}{2}\,\gamma_w$ if the structure can be kept to a minimun and the construction time were short. If this were not the case, $\gamma_{eq} \cong \gamma_w$. In all cases the application point of the force P is at the middle of the cut. It can be observed that for preconsolidated by desiccation soils of Buenos Aires the earth pressure diagram gives at least half the value that can be expected using the conventional diagram as presented by T&P. Apparently, for excavation with $H > H_{max} = 8c/3\gamma.tg(45º+\phi/2)$ the earth pressure is greater than the values obtained using the previus commented diagram. Theoretically if the horizontal displacements are null the magnitude of earth pressures should be similar to the K_o condition. For $K_o \rightarrow K_A$, $\gamma_{eq} \rightarrow \frac{1}{2}$; for $K_A < K_o < 1$, $\gamma_{eq} \rightarrow 1$.
For excavation with H approximatelly equal to H_c, when reinforced concrete piles are used as passive tiebacks, it es better to use as total earth pressure $P = \frac{1}{2}.\eta.\gamma_w.H^2$ distributing the greater unit pressures on the upper half of the cut. Piles are designed using the allowable stress on the concrete and steel for $\eta \leq \frac{1}{2}$, but using $\eta \leq 1$ for yielding strength values of these materials.
The construction of big underground conduits for sanitary purposes has permitted to observe the bahaviour of these soils in tunnel circular excavation with a diameter around 3 to 5 m. Generally, it is possible to make the excavation in form partly manual or with some kind of milling machine. When the roof is into or immidiately below cemented non fissured soils, it is possible to advance without significative temporary support structures. Instead, when working into preconsolidated formation without cementation - especially in highly fissure zones or with little K ratio, it is necessary to use a temporary support structure. The thrust is small but the instability appears in the correspondence with the crown where the development of chimenys or fall of block is common.
To finish, the Post-Pampeano --Holocene -- can reach around 30 to 35 m thickness; into the urban areas this stratigraphic condition appears principally in corres - pondence with the Riachuelo Valley, but generally with less thickness. Out of the

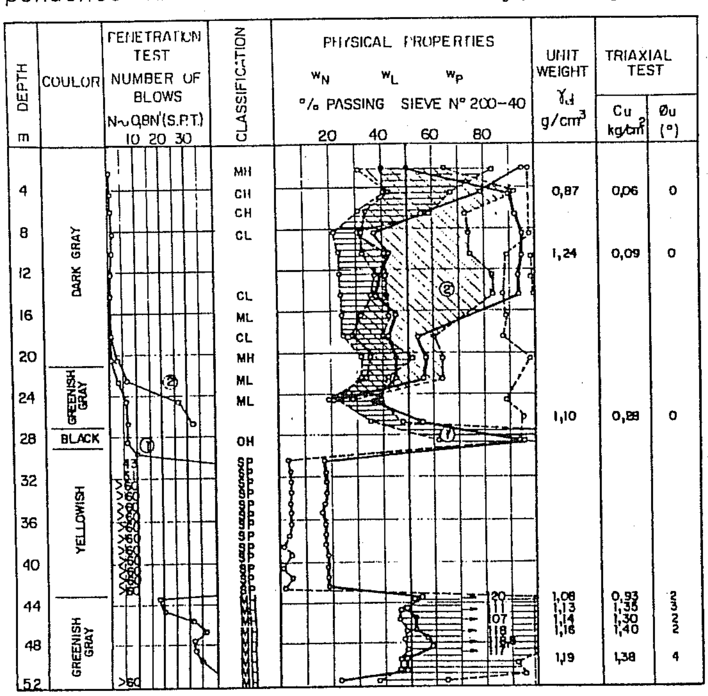

Fig. 9.- Post Pampeano. Typical results showing the PostPampeano overlying a thin layer of Pampeano, the Puelches dense sands and the tertiary greenish or "blue" clay layer.-

City it is common to find it along the valleys formed by the rivers that drain transversally the high terrace of Pampeano toward the Paraná or La Plata rivers. In the upper portion of the profile it is common to meet loose fine silty sands strata or lenses interbedded or within soft clays or plastic silts. The lower portion of the strata is generally constituted by soft plastic clays or very

plastic silts probably of marine origin.
This deposits are normally consolidated and force the use of deep foundation to support important structures. These foundation are generally piles resting on, or into the underlying pampeano formation or within the puelches fine dense sands ; the latter condition is common when the thickness of the soft soils is very large. The mechanical behaviour of this modern soft clayey deposits is well interpreted and can be predicted using similar approaches as developed for normally consoli - dated clay deposist widely studied in Soil Mechanics.

I wish to show you some slides of a great open excavation made in La Plata City near Buenos Aires City. The formation is the Pampeano. The water table is lower than the normal condition due to pumping to obtain fresh water for population

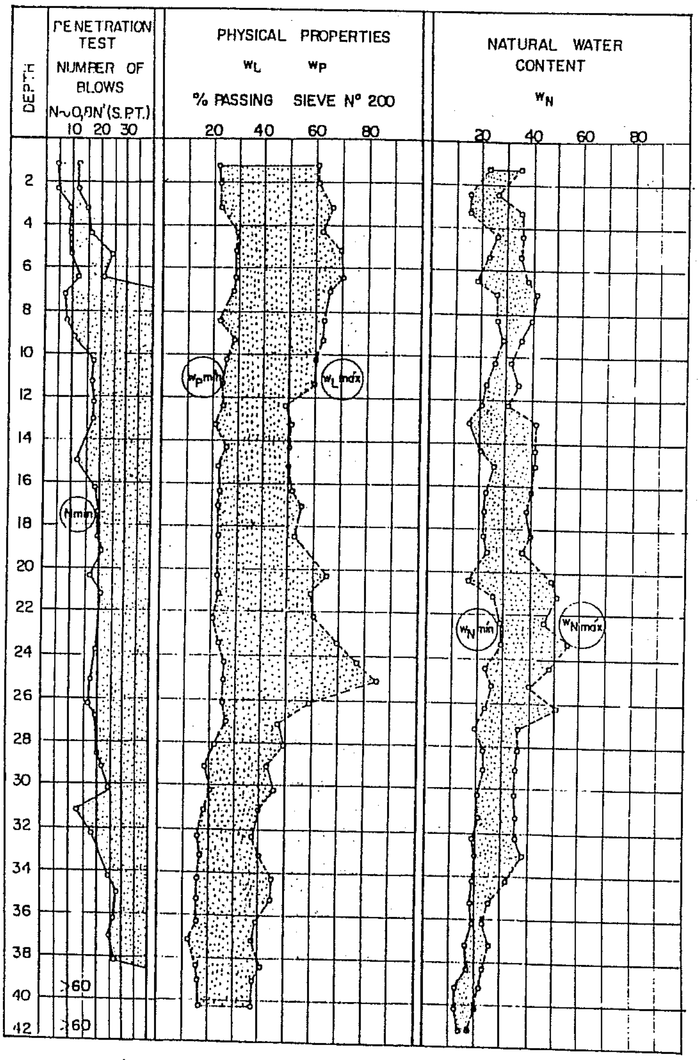

Fig. 10.- Typical Pampeano profile at La Plata City near Buenos Aires City, where a very big square excavation about 22 - 24 m depth was made.-

consumption. The depth of excavation reaches about 24 m, forming a square of 115 m width. Small bored piles were used - 35 cm in diameter - located almost horizontally connected to vertical cast in place reinforced beams, at the same time that the excavation advanced, 2,5 m apart, and connected between them with shotcrete reinforced with a ligth steel mesh, 3" thick. This temporary support system, conveniently connected to the structure of the building, integrate the final support structure. This solution requires only a small machine with a helicoidal auger.