

INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

<https://www.issmge.org/publications/online-library>

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Refoundation Research of Mexico's National Palace

Investigation de la Récimentation du Palais National à México

G. MORENO PECERO Professor of Civil Engineering, Universidad Nacional Autónoma de México. Chief of the Soil Mechanics Office. Geotechnique Department. D.G.S.T. Secretaria de Asentamientos-Humanos y Obras Públicas—México

SYNOPSIS The low strength and high deformation of the clayey soil of the Mexico City are well known. The withdrawal of subsoil water, in addition to the city supply demands, produce consolidation of the soil, creating a series of undesirable situations. One of the main problems to this concern is cracking of colonial time buildings, which being part of the country's history, require a careful maintenance. In order to preserve a building of such characteristics, a system to control soil deformations and prevent structure cracking was developed; this method consists in avoiding important water pressure changes in the soil, by injection of a relative small water amount at a relative high pressure into the bearing soil. Since 1977 up to present, this injection method has been carried out, observing the structure and the bearing soil behaviour. In the present paper, the research and related results are discussed.

FOREWORD

The typical characteristics of the clayey soils found in most of the urban area of Mexico City, and which in some occasion lead Professor Karl Terzaghi to qualify it as "The Soil Mechanics Paradise", still constitute a source of constant "problems", true privileged situations for the Soil Mechanics technicians. The clayey soil of Mexico City is very deformable and little resistant, as a result of the alteration of volcanic ashes which millions of years ago were thrown by the volcanos of the Valley of Mexico. This soil is still undergoing consolidation due to the reduction of its water pressure, as a consequence of the drawing out of subsoil water, by means of pumping, to complete the water supply for the City population consumption.

In several areas the soil has sunk as much as 8.0 meters. In general terms, the fact of having limited the dewatering of the soil, has reduced the rate of settlement, at least in the area of the National Palace (object of this paper), where nowadays, it has reduced to about 6 centimeters a year.

The National Palace, located in the historical center of the City, is a classical building from the Colonial Time. Its construction began in 1540; its surface is square, with 200 meters each side. Originally it had three floors, but in 1928, a fourth floor was added to it. From 1900 up to date, the settlements have been of about 6.0 meters, but what is still more important, is that considerable differential settlements have occurred. The dimensions of the differential settlements between the four corners and its center, which is more elevated, are shown on Table I.

The plumb measurements at 13 locations of the four structure facades suggest that, at present, the National Palace is out of plumb in

different directions and dimensions, varying from 18 milimeters up to 261 milimeters.

TABLE I

Corner formed by the streets:	Differential settlement with regard to the center of the National Palace (in meters)
Moneda and Plaza de la Constitución	2.03
Corregidora and Correo Mayor	2.65
Moneda and Correo Mayor	1.70
Corregidora and Plaza de la Constitución	1.65

The settlement process to which the Palace has been subject, basically in concern with the differential settlements, has produced a series of cracks. Mainly, the out of plumb is also a result of such a process.

Due to this situation, it appeared necessary to realize studies and to arrive to a solution in order to prevent the evolution of cracks and the out of plumb, which besides complying with the safety, economical and performance conditions, should not imply destructive measures (works) in concern with the National Palace structure, considering the historical value of this building.

STRUCTURAL CHARACTERISTICS OF THE NATIONAL PALACE

The National Palace is a relatively flexible structure, with a series of bearing walls, constituted by a conglomerate of sound igne

ous rock, porous igneous rock fragments (tezonle), and mortar; the columns are constituted by solid rock fragments; the roofs, of multiple cylindrical vaults, are constituted by grooved steel sheets, bearing on the steel beam flanges. At present it has four levels. In concern with the foundation, its structural characteristics are unknown; nevertheless, considering the data obtained from the neighbor historic constructions, dating from the same time as the National Palace, it can be said that its foundation is probably constituted by short lumber piles, 25 centimeters in diameter by 3 or 4 meters in length, which in some locations, is probably bearing on Aztec monument vestiges, and in other, on natural soil. Above the piles it is supposed to have a masonry base constituted by tezontle fragments (light stone with $\approx 1.1 \text{ Ton/m}^3$) with the idea of uniforming the distribution of the loads transmitted to the ground. According to this, it can be confirmed that both the superstructure as well as the foundation, may be considered flexible.

CHARACTERISTICS OF THE BEARING SOIL OF THE NATIONAL PALACE

The National Palace is located in what is known as the "lake zone"; the first 4 meters (upper stratum) is constituted by a filling material, mainly silts and sandy clays, with some fragments of light igneous rock; underlying this filling, the Mexico City typical clayey high plasticity soil is found, with soft to solid relative consistence, and an average depth of 34 meters, constituting the so called "Upper Clayey Formation" (FAS); underneath this stratum, the first solid layer is encountered, 4 to 5 meters in depth, constituted by silt and clay of a hard consistence and highly compact sands; finally, the soundings have detected the so called "Lower Clayey Formation" (FAI). A stratification profile of the three borings realized at the National Palace area are shown on Figure 1. The index and mechanical average characteristics of the existing soils are shown on Table II.

Towards the center of the building, the National Palace is bearing on the ruins of the former Palace of the Aztec Emperor Moctezuma Xocoyotzin; this explains the fact that the perimeter of the building is settling more than its central part.

In order to come to know the stresses of the water in the bearing soil, nine piezometric stations were installed, eight at the perimeter of the structure and one at its center. A total of 39 piezometers were installed, 29 of the pneumatic type and 10 of the open type or Casagrande. In Table III the results obtained with the measurements of each piezometer are shown; the negative sign represents hydrostatic pressure and the positive sign, an excess of it.

In general it can be seen that there is a pressure decrease in the water with regard to the hydrostatic pressure. In previous piezometric readings close to the Palace the same trend was observed, especially within the first 25 m of depth (Piezometers installed by the Comi-

sion de Aguas del Valle de México). The average pressure decrease in the water with respect to the hydrostatic pressure is 0.134 Kg/cm^2 .

DISCUSSION OF THE SITUATION

As previously stated, the solution to be adopted to prevent new cracks in the Palace must duly fulfill the condition that no destructive works be done in the structure. Cracks are the result of differential subsidences in the bearing soil, and these, in turn, could be imputed to three different causes: the weight of the structure; the modification of the conditions of the bearing soil due to construction works near the Palace -i.e. the construction of the "Subway" and of a rainfalls collector 3.0 m of interior diameter along Moneda Street-, and the lowering of pressures in the water of the bearing soil due to its extraction through pumping in areas close to the Palace.

The first cause was eliminated as it implies the production of an excess of pressure in the water with respect to the hydrostatic pressure; as regards to the second cause, the examination of the subsidences time graphs of the different control points expressly placed in the Palace determined that in effect some movements in the structure had been produced during the construction of "Subway" and collector, but it was also observed that shortly after the conclusion of these works those movements had practically stopped, though not the settlement that had been present long before the aforementioned works. So, the third cause was the only remaining.

By employing the theory stated by Dr. Nabor Carrillo in his work "Influence of the Artesian Wells on the settlements of the City of Mexico", it was concluded that there must be a pressure decrease of 1.76 Kg/cm^2 to 1.33 Kg/cm^2 in the water to generate the total measured sinkings, and considering that thus far the decrease is of only 0.134 Kg/cm^2 it can be realized that it would be convenient to seek another solution tending to avoid that pressure decrease so as to practically reduce the sinkings, basically the differential ones.

SOLUTION PROPOSED

The recovery of the hydrostatic pressure through the nullification of the commented pressure decrease was intended via the injection of a water flow to the bearing soil at a depth of 7 to 25 m. Figs. 2 and 3 show a sketch of the injection system and a detail of an injection well, respectively. There are two injection wells, one located at the corner of Moneda and Plaza de la Constitución streets, and the other at the junction of Correo Mayor and Corregidora.

Through This theory it was intended to quantify the flow required to obtain the pressure increase in the water, as well as its variation in the course of time; based on the above and employing a simplification of Jacob's the following expression was obtained:

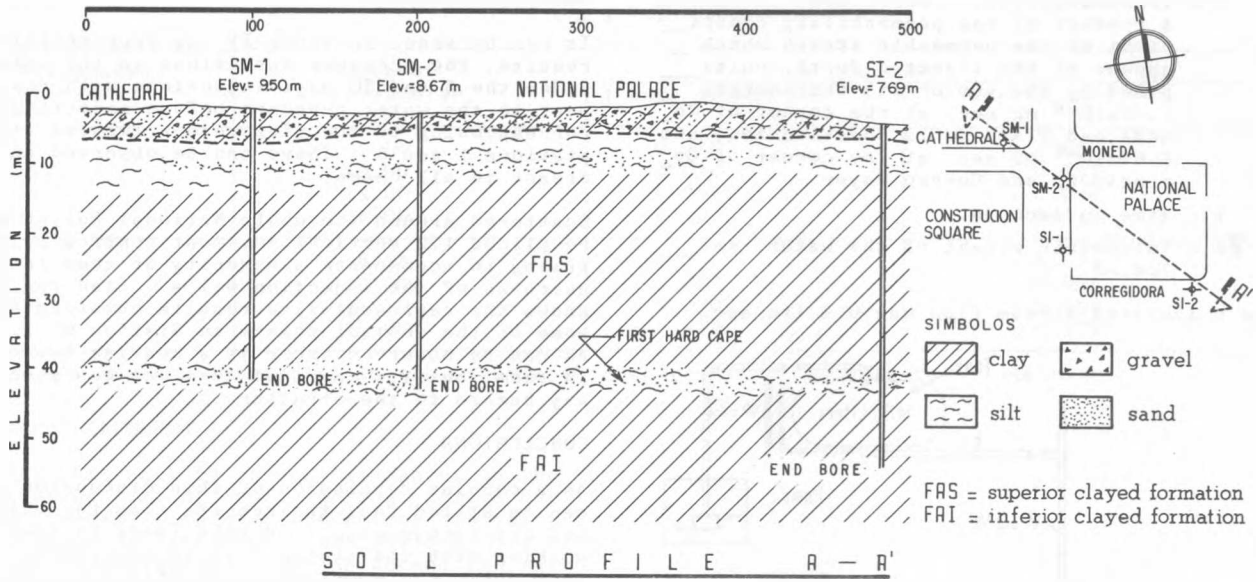


Figure 1

T A B L E I I

	W %		LL %		LP %		QuTon/m2		γ _m (Ton/m3)		k cm/seg	m _v cm2/kg
	1	2	1	2	1	2	1	2	1	2		
MS	63.2	19.89	82.8	31.0	41.4	8.8	9.3	2.7	1.58	0.11	0.277	1.345
FAS	206	77.74	285.3	102.5	66.2	19.3	9.1	3.7	1.25	0.14	0.433	6.07
CD	106.8	68.57	179.6	65.3	48.2	15.4	41.7	57.7	1.32	0.13	0.396	1.96

MS - Upper or surface stratum
 FAS- Upper Clayey Formation
 CD - Solid layer

1 Mean value
 2 Standard deviation

W - Natural moisture content
 LL- Liquid limit
 LP- Plastic limit

q_u- simple compression strength
 γ_m - specific gravity with natural moisture

k - permeability coefficient x10⁻⁸
 m_v- compressive modulus x10⁻²

T A B L E I I I

Difference of the theoretical hydrostatic pressure to the pressure measured in the water, in Kg/cm2

Depth	Piezometric stations								
	1	2	3	4	5	6	7	8	9
10 m.	-0.02	-0.05	-0.07	-0.13	+0.01	-0.10	-----	+0.02	-0.05
15 m.	+0.07	+0.04	+0.48	-0.06	-0.10	+0.05	+0.10	-0.07	-0.31
25 m.	-0.13	-0.12	-0.22	-0.18	-0.02	-0.29	+0.12	-----	-0.37
35 m.									-0.27
55 m.									-2.19

$$Q = \frac{4 \pi u}{2.30 \gamma_o \left[\frac{1}{T_1} \log \frac{2.25 T_1}{S r_1^2} t + \frac{1}{T_2} \log \frac{2.25 T_2}{S r_2^2} t \right]}$$

where:

Q = Stream flow to be injected, in m3/sec.
 r=r₁=r₂=Distance from the point where the recovery of the pressure to the injection

wells is evaluated.

$$u = \frac{r^2 S}{4 T t}$$

S = Storage coefficient. A 1x10⁻⁵ value is given, according to the data obtained by Ing. Ignacio Sáinz Ortiz in the case of the injection wells made at Mixcoac, in the City of Mexico.

T = Transmissibility coefficient in $m^2/sec.$
 A product of the permeability coefficient of the permeable strata which appear at the injected depth, multiplied by the sum of its thicknesses.
 $1.99 \times 10^{-6} m^2/sec.$ at the corner of Moneda and Plaza de la Constitución, and $3.69 \times 10^{-6} m^2/sec.$ at the corner of Corregidora and Correo Mayor

t = Time in seconds.

γ_o = Volumetric weight of the water, in $Ton/m^3.$

The calculated stream flow was 0.4 lts/sec.

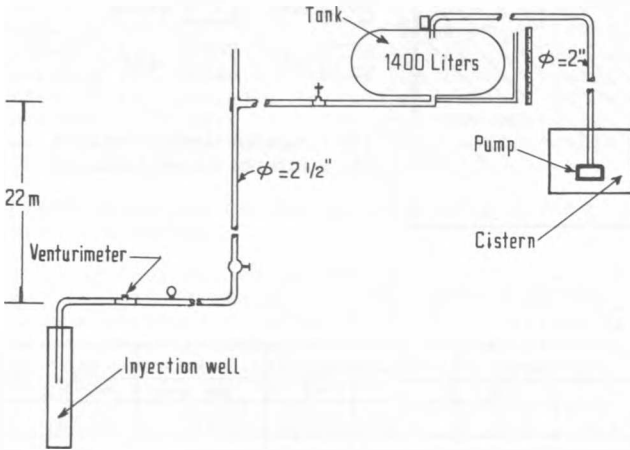


Figure 2

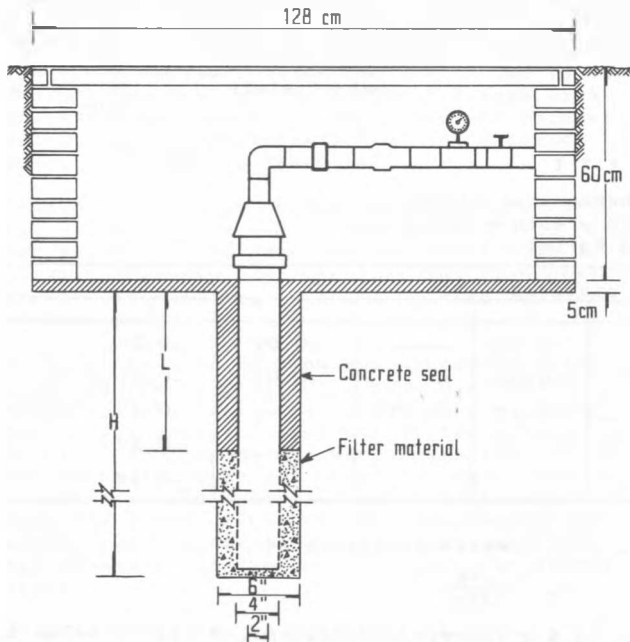


Figure 3

RESULTS OBTAINED

It can be seen, in Table IV, as representative results, the pressure variations in the water under the 3 and 30 days injections with respect to the water pressure before injecting, corresponding to the piezometers located at stations 1 and 5. There can be observed an increase in all cases.

Scattered around the whole National Palace were placed 172 vertical movement control points, trying to accommodate a majority of them in the nearness of the injection wells. Also Fig. 4 shows the representative results obtained from some of the control points in Station N° 1. As can be observed there is a heaving tendency in them, but its magnitude does not represent any hazard to the structure.

CONCLUSIONS:

As a concise conclusion of this discussion it can be stated that the results thus far obtained are encouraging, and this leads to keep on working with the system. It is considered that the most important implication is that it does not lie principally in the relatively positive results obtained at the National Palace, but in the future possibility that this method be implanted as trying to diminish the sinking of the soft soils in the city of Mexico through high pressure injections of small amounts of water in it, water which can be obtained from the same subsoil. No reverse results are apparently expected due to the extraction of a certain amount of water from the soil at a certain time, if that water is to be once more injected into the soil.

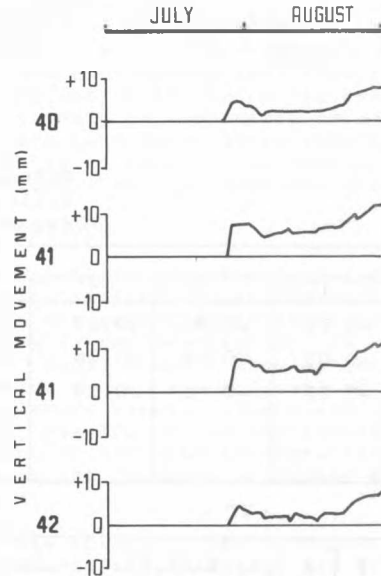


Figure 4

T A B L E I V

Piezometric Station.	Depth of Piezometer (m)	p (Kg/cm ²)	
		3 days injection	30 days injection
1	7.00	+ 0.030	+ 0.028
	10.00	+ 0.031	+ 0.037
	15.00	+ 0.027	+ 0.040
	25.00	+ 0.027	+ 0.090
5	6.15	+ 0.097	+ 0.058
	10.00	+ 0.040	+ 0.088
	15.00	+ 0.096	+ 0.097
	25.00	+ 0.259	+ 0.175

p = Pressure variation in the water with respect to its value before injection.

ACKNOWLEDGMENT

May this work be an acknowledgment to the outstanding work of Prof. and Eng. Carlos Escalante Portas, with whom the author had the privilege to collaborate at the start of the outlined investigation. At his decease the author remained in charge of the project. Especial acknowledgment to the authorities of the Ministry of Human Settlements and Public Works of Mexico for your support and financing for this investigation.

REFERENCES

- Carrillo, N. (1969). The settlement of the Mexico City. Texcoco Project. Mexico
- Davis, S.N. and de Wiest R. (1971). Ariel Editorial, Barcelona, Spain
- Marsal, R.J. and Mazari, M. (1969). The subsoil of the Mexico City. Engineering Institute. UNAM. Second Edition.
- Ministry of Finance and Public Credit. (1976). National Palace. Mexico
- Sainz, O.I. (1963). Artificial Infiltration in the Valley of Mexico. Ministry of Hydraulic Resources.