TEST EMBANKMENTS ON TEXCOCO LAKE

REMBLAIS D'ESSAI DANS LE LAC DE TEXCOCO

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SYNOPSIS In this paper are presented the results of field measurements made on two instrumented test embankments which were built by the Ministry of Public Works over the Texcoco Lake, in order to obtain the necessary data for the design of the Peñón-Texcoco project, which is a direct road between this two points. The measurement program is being carried on, and in this paper it is only shown the data obtained in the approximately first 30 months of performance of the two embankments. It is included the information given by the leveling of surface witness, by Wilson inclinometers by settlement torpedos and by Casagrande and pneumatic piezometers. It is also shown the value of the shear strength determinated by vane shear tests performed during the measurement period.

An approach of a preliminary interpretation is made, giving special attention to those facts that do not clearly correlate with the established theory.

INTRODUCTION

The Ministry of Public Works had the necessity to project a direct road between Mexico City and Texcoco City over Texcoco Lake. The soil of this lake is formed by soft volcanic clay, (which means low shear resistances and high compressibility) with depths of hundreds of meters. The project involves the construction of a four line highway with an overall wide of 40 meters.

In order to obtain the necessary data for the design of this project, several Soil Mechanics studies and field research had to be made, being the result a cross section with a total cost of 7 millions pesos per kilometer with a safety factor in the order of 1.1 in the worst conditions. However, the present theories as well as the experience on the construction and the behavior of highway are considered unsuficient, so the results received are not to be trusted, specially those about the development of the settlements within time.

All this led to construct and investigate with the help of measurement instruments, the behavior of some sections or test embankments at a natural scale on the surface of the Texcoco Lake in those spots that were considered critic, in order to compare the results of the application of Soil Mechanics theories and the behavior of the full scale models. This paper pretends to describe all the investigation made with the indicated purposes, showing the results of a 30 months measurement program.

CHARACTERISTICS AND LOCATION OF THE TEST EMBANKMENTS

Based on 120 borings and laboratory analysis of more than 1,100 samples was located the most critical spot on which were to be made two test embankments, 120 meters long each one, slightly different, because it was also desirable to study two different alternatives with two different materials in order to establish an economical relation. So one of the embankments represents a road built with a light material of 1.0-1.1 tons per cubic meter, and the other one represents a road built with the conventional material of 1.8 tons per cubic meter. The first embankment is of course lighter, meanwhile the second one needs of two struts. General description of the foundation in this place shows that it is formed by a volcanic, soft, high compressibility clay (CH) that reachs a deepness superior to the significative to the project, as shown on Fig. # 1 and table # 1. Fig.#2 shows the cross section of the two constructed test embankments that were completed in December 1965.

INSTRUMENTATION

Both test embankments were instrumented as follows:

- 30 surface witnesses were placed and leveled to register the surface movements with precision levelings.
- one transverse line of Wilson Slope Indicator were placed at one of the thirds of the length of each embankment, from natural ground down to 15 meters. The line has 7 inclinometers going from the center line to 5 meters away from the toe of the embankment in the natural ground.
- one transverse line of vertical torpedos were placed in the other third of the length of each embankment with 7 observation points in the line that were able to register settlements as depth as 15 meters.
- one line of pneumatic piezometers in coincidence with the line of vertical torpedos, with 3 piezometric stations and 6 piezometers installed at 5, 10, 20 and 30 meters of depth. The pneumatic piezometers were completely built of plastic to avoid the corrosive effects of the water.
- one line of Casagrande Open Piezometers intercalated with the pneumatic piezometers at 5, 7 and 15 meters of depth.

DATA OBTAINED FROM THE READINGS

a) Surface level witnesses.

The data obtained from this witnesses is shown in Fig.# 3. It should be noticed the general symmetry of the settlement as well as the location of the maximum settlement displaced from the center of the embankment, perhaps due to the influence of the access road. It can also be noticed the tridimentional effect in the edges.

b) Inclinometers.

The data obtained from the inclinometers is reported in Fig.# 4, and it should be noticed that all the lectures are perfectly consistent in both embankments. It is very interesting to point out that the deformation outwards the center of the embankment after been very great became backward closing up again, due to what seems to be the consolidation effect of the soil under the center of the embankment, which in the time counteracted the tendency of lateral displacement of soil under loads.
The lateral movements are considered to be within tolerable magnitude in relation with the present and future stability of the embankment.

c) Vertical Deformimeters.

A typical data obtained from settlement torpedos in one of the test embankment is shown in Fig.# 5. It seems to be important to see how the settlement decreases with depth. In connection with this matter, Fig.# 6 shows the theorical stress distribution under the embankment obtained from the application of Boussinesq Theory. It should be noticed that the contribution of load to settlement with depth was smaller in reality than could be predicted from the theory, happening the same lateraly. It can also be observed that the rate of settlement seems to diminish faster in the upper levels.

d) Pneumatic Piezometers.

Fig.# 7 shows a typical information obtained from one station of piezometers placed under the test embankments; the other gives a very similar information. The interpretation of this data is very difficult and seems to be very little conclusive; for example, it registers a constant excess from the hydrostatic pressure which is difficult to correlate with the high settlement of the structure. In general terms, it is concluded that pneumatic piezometer gives unreliable information in this type of work, eventhoug a reasonable care was taken in its installation, operation and lecture techniques.

e) Open Piezometer.

The observations reported in Fig.# 8 are not conclusive because these instruments were installed 6 months later.
They seem to indicate that the phenomena of variation in the pore pressure is very low at high depths (15 m.).

f) Vane shear test.

An investigation of the shear strenght of the natural ground was carried on using the vane shear test, they were performed approximately 30 months after the construction of the embankments, using an instrument designed by the Engineering Institute of the National University. The obtained values were compared with the original values applying a relationship proposed by Marsal and Mazari (reference # 1) in which it is stated that for the clays of the Mexico City Valley the shear strenght determinated by the vane shear test is given by:

$$\tau_f = \frac{q_u}{1.5}$$

Whith this equation it was obtained an initial value of 1.5 Ton/m2 and a second value of 2.5 Ton/m2 30 months later. This significant rise in the shear strenght value can be atributed to the consolidation process of the soils under the embankment. It should be noticed that the addition to the shear strenght is practicly uniform in all the depth explored. Fig. # 9 justifys the last statement. Other tests performed at the toe of the embankment and in a vertical axis gave 1.7 Ton/m2 shear resistance in relation with an original value of 1.5 Ton/m2.

DATA INTERPRETATION

The following statements seems to be based in the information obtained from the measure equipment.

a) The shear strenght determinated by a vane shear test has increased with the time, an stability analysis shows that the safety factor has risen from 1.1 to 1.25 in 30 months as an effect of consolidation.

b) The settlement decreases rapidly with depth to smaller values than those indicated by the traditional theories based in the Boussinesq analysis.

c) The rate of vertical deformation also decreases rapidly with the depth, but in the other hand, in the lower levels, this rate of deformation tends to stand still, meanwhile in the upper levels it disappears more rapidly.

d) The largest lateral deformations ocoured at a depths between 5 and 7 m. smaller than those expected.

e) It can be seen in Fig.# 10 that the consolidation path obtained up to day in both embankments indicates that primary consolidation has not yet occur. This and the fact that significant secondary consolidation effects are expected, lead to the need of continuing with the measure program.

f) Fig. # 11 shows the evolution of the settlement velocity. It decreases very quickly at the beginning but now it is becoming almost constant. Fig. # 12 shows the relation between the consolidation degree and time. It should be noted that for 30 months the primary consolidation degree should have been 73%; it means 2.40 meters of total theoretical settlement, much higher than the real settlement which is about 1.00 meter. The same ideas are handled in the Fig.# 13 showing that the real settlement in the center line at the base of the embankment is the 38% of the theoretical settlement at the same period while at a depth of 15 m. it is about the 23%. All these facts indicate that the settlements are much lower than those we had calculated and that the consolidation effects are dissipating very quickly with the depth.

FINAL COMENT

All the information obtained from the measure program in comparison with the original ideas related with the Peñón-Texcoco project and based on the theories available, makes evident the necessity of complementation between the theory and field research based in measures made in test embankments.

Only in this way will be possible to obtain a realistic approach of the behavior of soils on which can be based an objetive project.

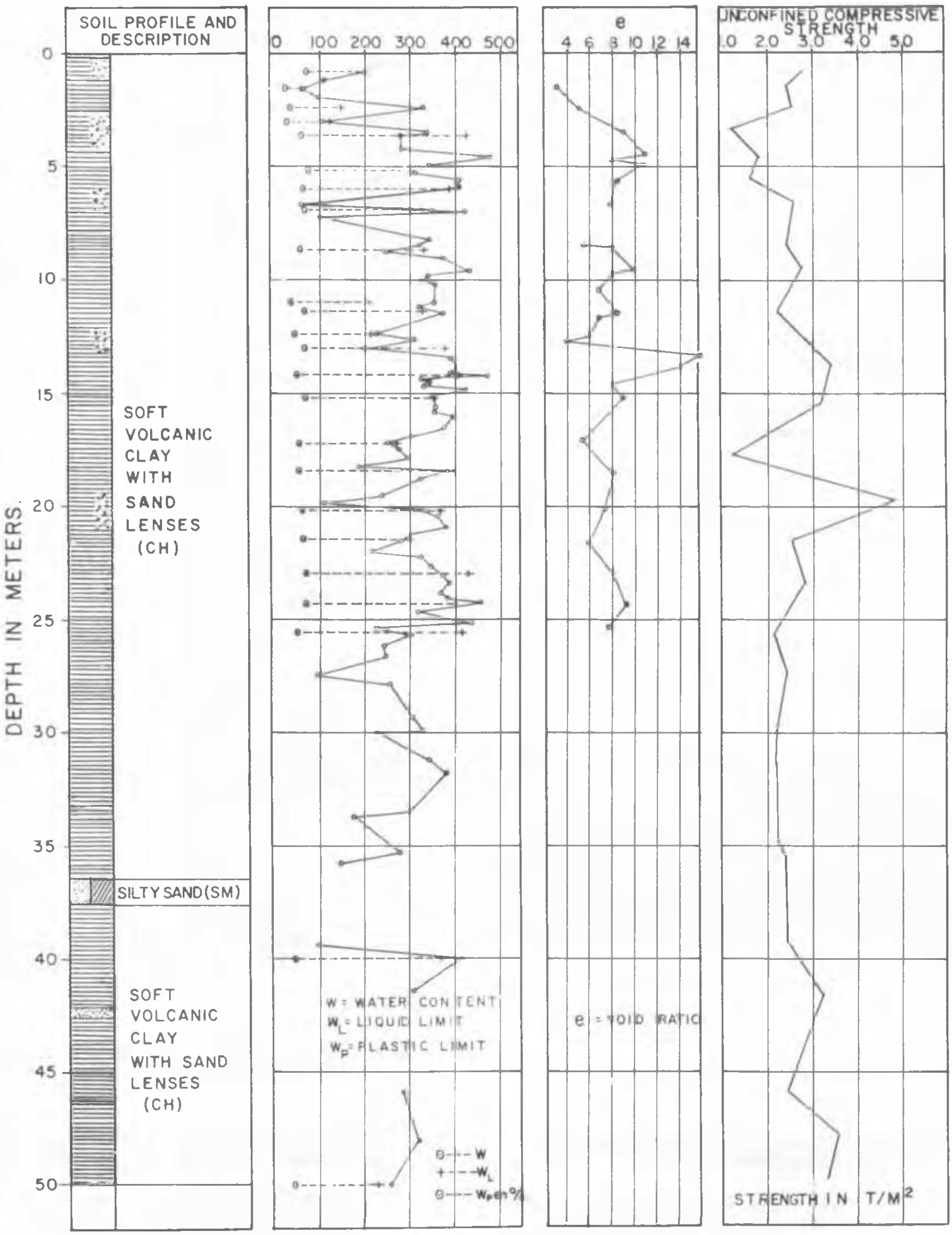


FIG. 1 - SOIL PROFILE AND RESULTS OF SOIL TESTS BEFORE CONSTRUCTION.

Depth (m)	m_v (cm²/Kg)	p (Kg/cm²)	C_u (Kg/cm²)	γ (T/m³)	G
4.60	0.53	0.56	0.18	1.30	2.47
6.40	0.52	0.50	0.21	1.15	2.67
8.60	0.45	0.62	0.25	1.18	2.36
11.50	0.54	0.60	0.20	1.18	2.36
12.80	0.47	0.70	0.11	1.18	2.36
13.50	0.47	0.60	0.19	1.20	2.35
16.00	0.41	0.56	0.10	1.25	2.35
24.00	0.44	0.54	0.14	1.15	2.31
27.00	0.27	0.80	0.16	1.15	2.30
29.60	0.37	0.64	0.18	1.16	2.35
35.60	0.12	1.51	0.24	1.19	2.40
41.70	0.14	1.48	0.32	1.17	2.33
48.20	0.20	1.16	0.36	1.14	2.33

m_v - Maximum Values of the Coefficient of volume compressibility.

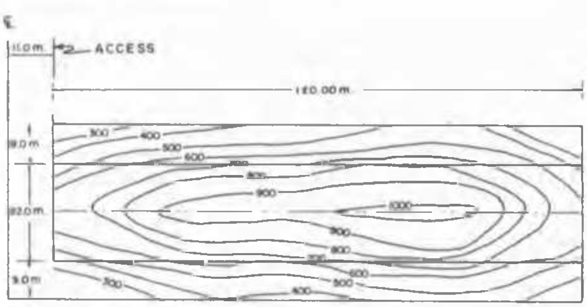
γ - Unit weight.

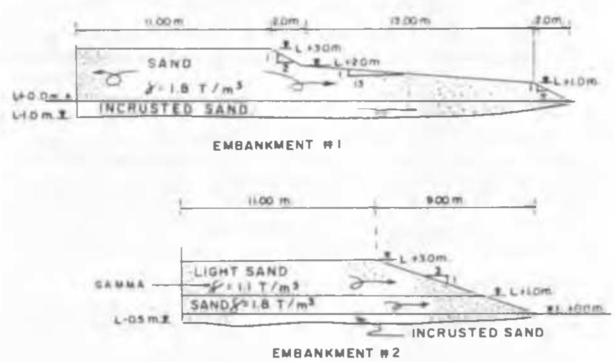
p - Maximum consolidation pressure.

G - Density of solids.

C_u - Cohesion on unconfined triaxial test.

TABLE 1.- MECHANIC PROPERTIES OF THE SOILS





NOTE : THE LEVEL +0.0 m. IS THE NATURAL GROUND LEVEL AND ALSO THE WATER TABLE LEVEL

FIG. 2. GEOMETRIC SECTIONS OF THE RIGHT HALF OF THE TEST EMBANKMENTS.

FIG. 3. SETTLEMENTS (IN M.M.) FROM JANUARY 3rd 1966 TO NOVEMBER 8th, 1968 IN EMBANKMENT # 2

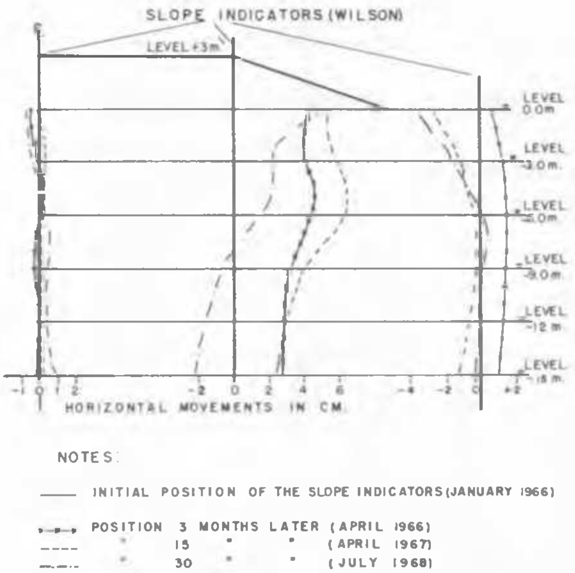


FIG. 4.- DATA FROM SLOPE INDICATORS IN EMBANKMENT # 2.

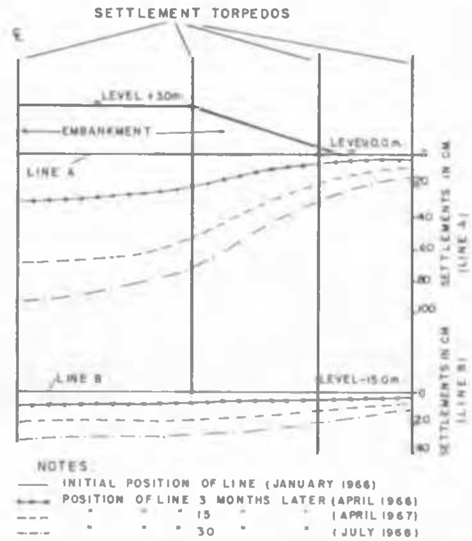


FIG. 5.- DATA FROM SETTLEMENT TORPEDOS IN EMBANKMENT # 2.

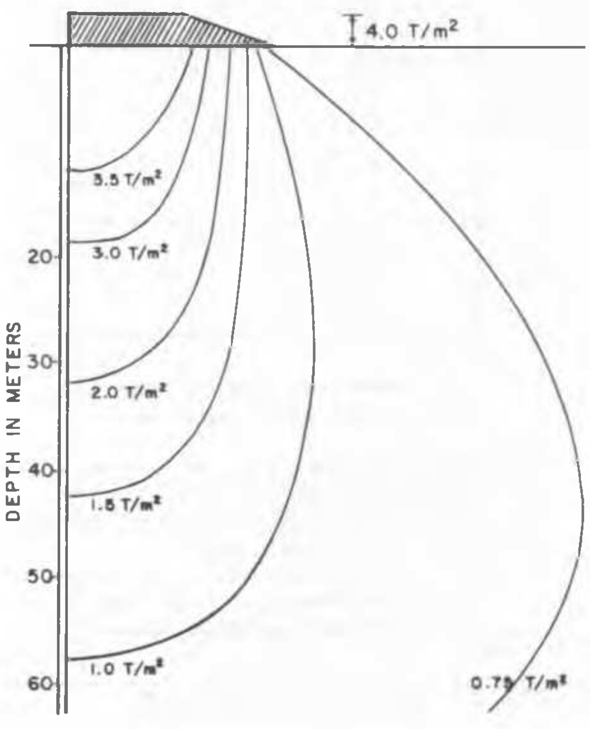


FIG. 6.- THEORETICAL STRESS DISTRIBUTION UNDER EMBANKMENT # 2.

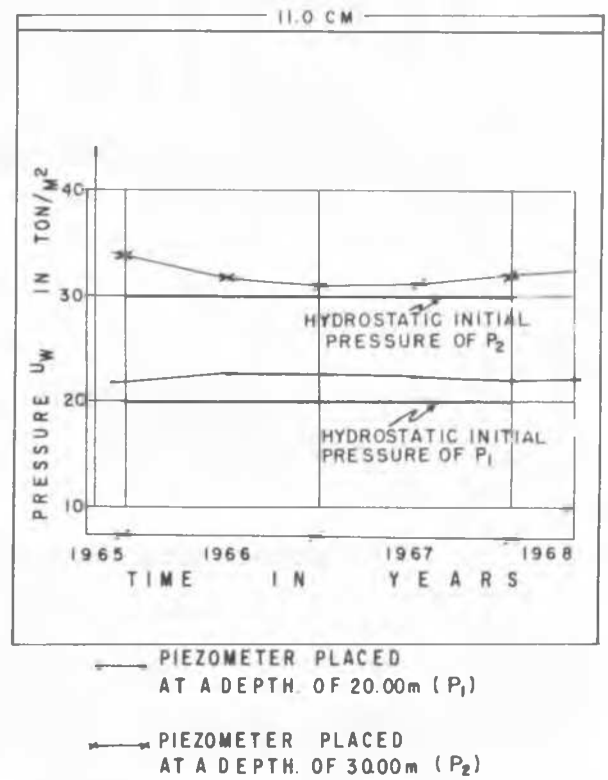


FIG. 7.- PIEZOMETRIC MEASURES - (PNEUMATIC PIEZOMETERS)

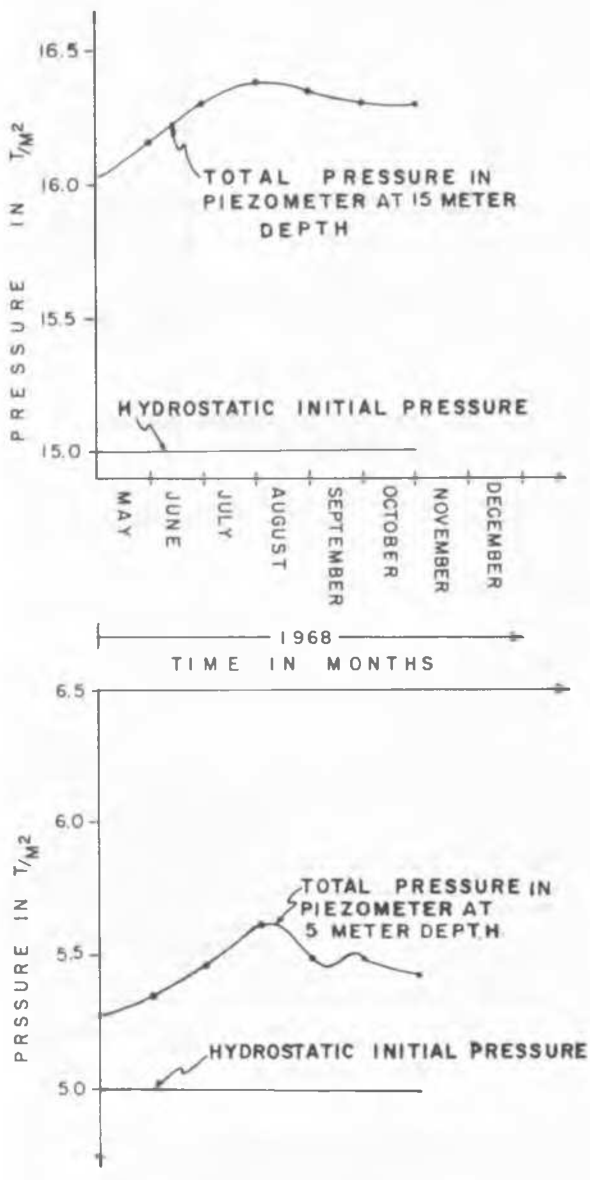


FIG. 8.- PIEZOMETRIC MEASURES - (CASAGRANDE PIEZOMETERS)

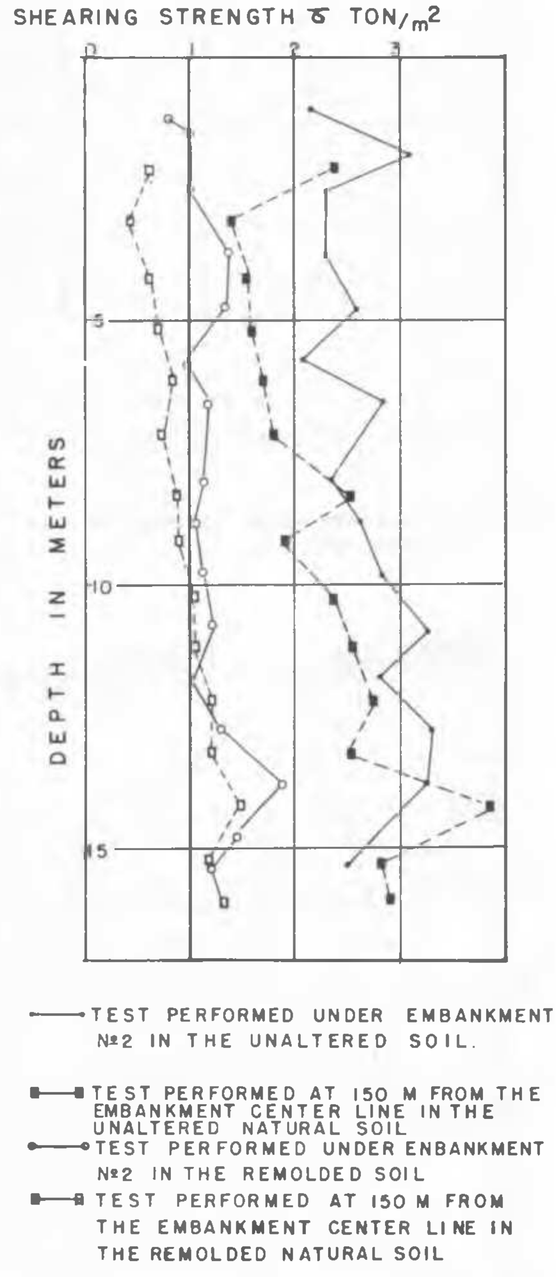


FIG. 9.- DATA FROM VANE SHEAR TEST

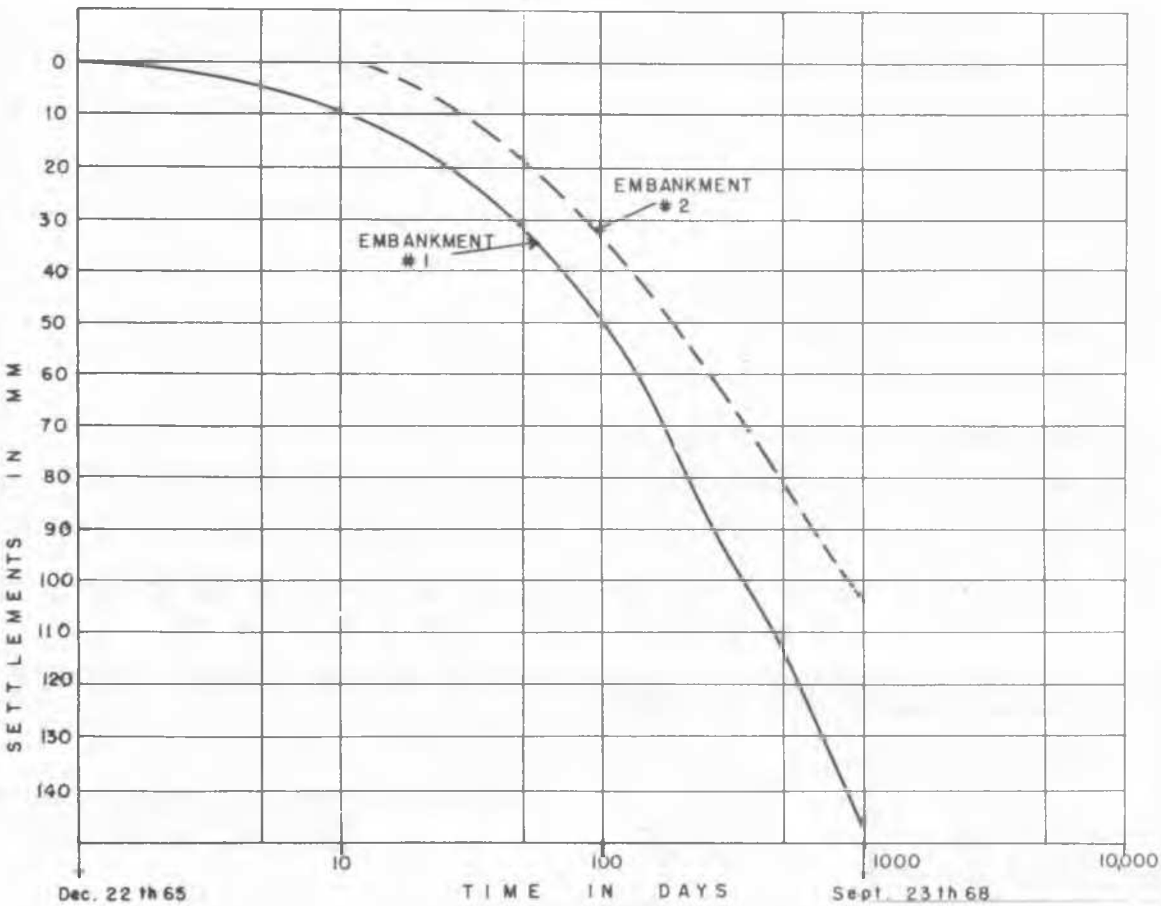


FIG. 10.- EMBANKMENT CONSOLIDATION

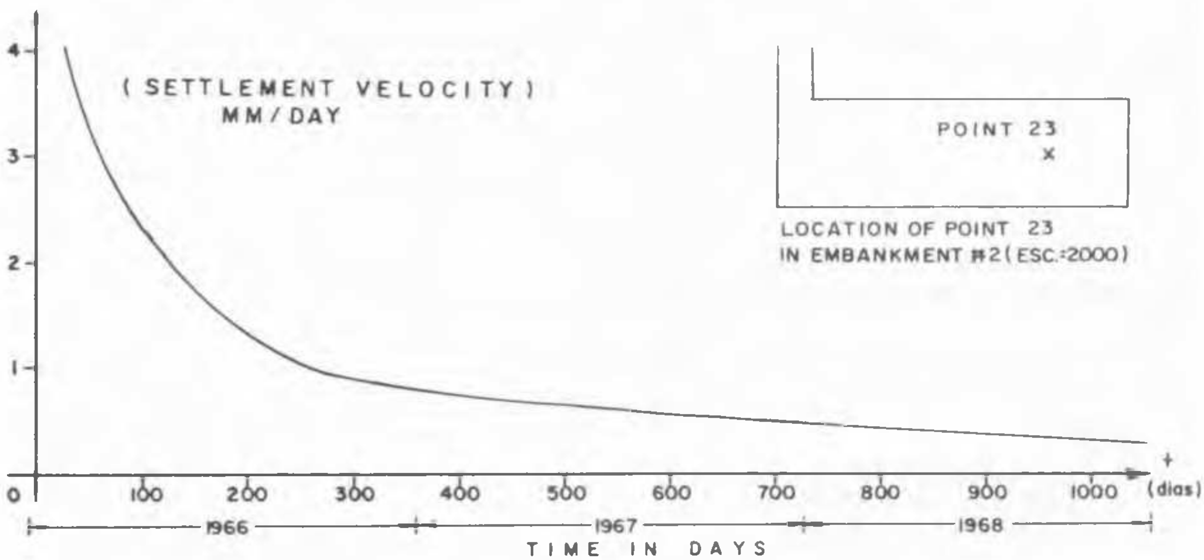


FIG. 11.- GRAPHIC OF SETTLEMENT VELOCITY VERSUS TIME OF THE MAXIMUM SETTLEMENT POINT IN EMBANKMENT # 2.

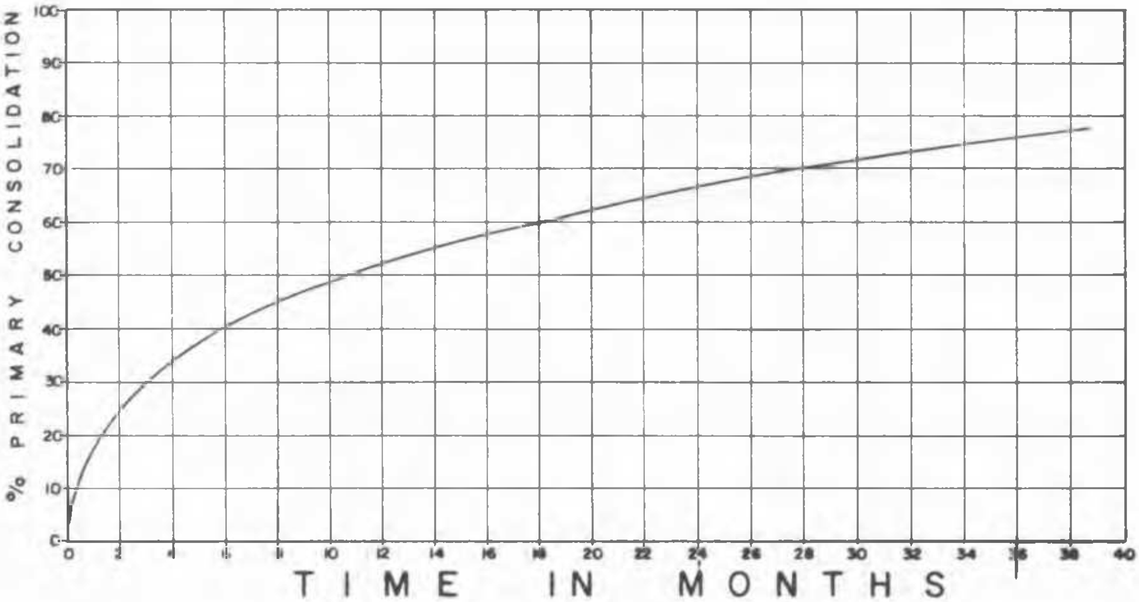


FIG. 12.- VARIATION OF THE SETTLEMENTS VERSUS TIME, CONSIDERING THE EFFECT OF PRIMARY CONSOLIDATION FOR LOAD INCREMENTS LOWER THAN 5 TON/M^2.

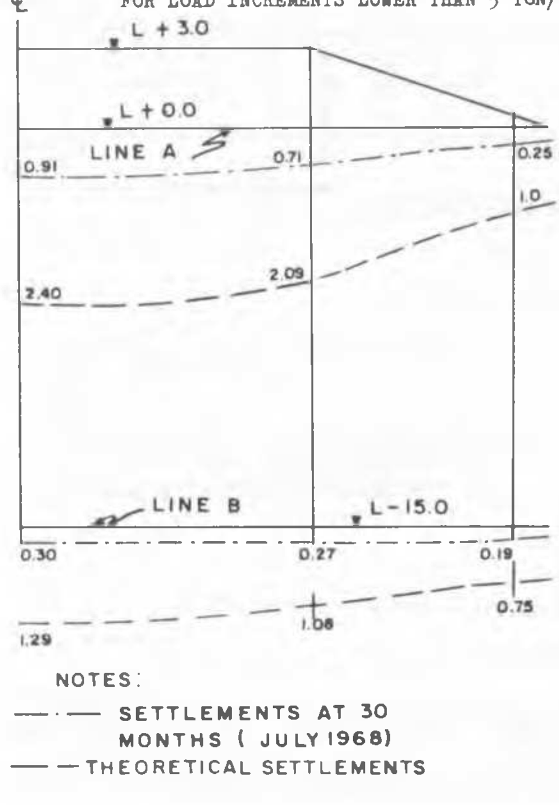


FIG. 13.- COMPARISON BETWEEN THE ACTUAL AND THE TOTAL THEORETICAL SETTLEMENTS.

Reference 1.- Marsal R. J., Mazari M. September 1959 "El Subsuelo de la Ciudad de México" Eng. Inst. U.N.A.M.