FOUNDATION FAILURES DURING THE COATZACOALCOS (MEXICO) EARTHQUAKE OF 26 AUGUST 1959

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INTRODUCTION

The general characteristics of the Coatzacoalcos-Jáltipan earthquake, which affected southeastern Mexico, are described in this paper. Also, descriptions are given of typical damages to structures. Some emphasis is placed on the comparative properties of the soils of the inland towns, of the marshy soils along the highway joining the towns of Minatitlán and Coatzacoalcos, and of the sandy soils on the margins of the Coatzacoalcos River. These properties are then correlated with the observed behavior of structures founded on these soils.

The earthquake occurred at about 8:30 A.M. Greenwich Time (2:30 A.M. Standard México Time) on 26 August 1959. Approximately 20 persons were killed. The material damages were considerable: 450 houses and huts, one school for 1200 students, two old churches, and one railroad station were destroyed or damaged beyond repair. The inland towns most affected were Jáltipan, Chinameca, Cosoleacaque, and Acayucan. The coastal city of Coatzacoalcos (Puerto México) was also affected: the installations of the Ministry of the Navy, and the docks and warehouses of the free port zone. all situated on the margins of the Coatzacoalcos River, suffered severe damage. The 35-Km strip of highway joining Coatzacoalcos and Minatitlán was heavily damaged by large and wide longitudinal cracks, with depths and widths up to two meters. This strip is located on marshy soil which settled badly with the earthquake.

From the engineering point of view, the earthquake made possible the study of failures in buildings founded on widely different soils. In the inland towns, the observed failures were typical of buildings founded on firm ground: the floor masses accelerated causing, in general, collapse of the supporting columns and walls. In Coatzacoalcos, however, most of the failures were due to failure of the soil: some buildings settled vertically about one meter, and suffered large horizontal displacements. At Coatzacoalcos, the margins of the river consist of a saturated, uniform fine sandy silt, to depths of about 11.0 meters. Under the vibrations of the shock this soil behaved much as a liquid, causing very sudden settlements of the buildings.

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It should be mentioned that a great deal of the damage occurred to shoddy constructions, to buildings and houses not designed for earthquakes, and to structures already weakened by previous earthquakes.

GEOPHYSICS AND GEOLOGY

The epicenter of the earthquake was located 35 km out at sea from Coatzacoalcos, at a point of latitude 18° 27' N, and longitude 94° 16' W, with a depth of focus of 15 to 20 Km. It corresponded to epicenter No. 355 of the Seismic Chart of Mexico (Fig. 1). It should be mentioned that from 1927 to 1958 four other earthquakes were registered with this same epicenter, the one of January 11, 1946 having an intensity of 7 (Modified Mercalli).[1] Another shock, of smaller intensity, was felt the following day, 27 August 1959, again with epicenter No. 355.

Typical seismographs from the Tacubaya Station (520 Km from the epicenter), from a 10 Kg apparatus, are shown in Figs. 2 and 3. Relatively large initial vibrations can be observed. This probably accounts for the low death rate, as the population was awakened and had time to vacate their homes before the maximum shocks arrived.

From the seismographs taken, the magnitude of the earthquake was established at about 6.5 (Richter), with variations depending on the seismological stations from which the determination was made. These ranged from a magnitude of 7.1 at the Veracruz Station (200 Km from epicenter), to 6.0 at the Puebla Station (400 Km from epicenter).

The maximum energy was manifested at Coatzacoalcos, and the maximum destruction at Jáltipan and neighboring towns. It is likely that the shock waves caused movements of local faults in the vicinity of Jáltipan, owing to the presence of salt domes and other irregularities.

The prevailing periods of motion on firm ground were estimated at 0.7 sec, and maximum ground accelerations ranged from 0.07 to 0.2 of gravity.

Figure 1 shows the major faults in Mexico. Most of the earthquake epicenters of Mexico are concentrated around them, and will be described briefly below. The general established movements at the faults are as shown by the arrows, due mostly to pressures that come from the north.

Pressure during the Tertiary caused the central portion of Mexico to be raised, and to slide. It also formed faulty masses in the Pacific Ocean. The San Andreas Fault runs north-south through the Gulf of California, and branches into three faults: Zacamboxo, Coast, and Pacific Faults (Fig. 1). Based on the depths of focus and alignements of epicenters, Figueroa[2] infers that these three branches are not really part of the San Andreas Fault, but form another deeper system. According also to Figueroa,[2] the Meso-american Trench (located recently in a more precise manner by Fisher and Schor of the Scripps Oceanographic Institution, La Jolla, California) is not the center of the movements in the Pacific. The Clarión Fault runs east-west, and was studied by Humboldt, and more recently by Mooser, Figueroa and Lorenzo.

The Clipperton fracture zone has been studied recently by Menard and Fisher.[3] They define the Tehuantepec Ridge bending sharply towards the Isthmus of Tehuantepec. This ridge probably continues inland through the Isthmus, because the epicenters there are aligned in that general direction, including epicenter No. 355 of the Coatzacoalcos earthquake.

An approximate geological sketch of the zone where most of the damage occurred is shown in Fig. 4. The crust beneath Jáltipan and vicinity contains salt domes - salt that has been squeezed out to the surface by internal pressures. The domes are surrounded by some consolidated Miocene formations.

During the Tertiary, the coast line reached Minatitlán, as shown in the figure. As time elapsed, the coast line receded to its present position. Sand dunes formed as it receded, the ground being quite flat, and the zone became a marsh that has been partly filled in since. Coatzacoalcos is founded on a mixture of sand dunes, filled marsh, and Coatzacoalcos River deposits.

MECHANICAL PROPERTIES OF THE SOILS

In this section, descriptions are given from the point of view of soil mechanics, of the main characteristics of the materials in the subsoil of two zones affected by the earthquake, Coatzacoalcos, along the left margin of the river, and Jáltipan. The observed behavior of structures during the shock was markedly different in each zone, as will be described in the following sections.

Coatzacoalcos

Undisturbed samples were obtained by means of continuous borings from the surface to 18 m depth. The results of standard laboratory tests are shown in the logs of Fig. 5.

The simplified stratigraphic profile is as follows: from the surface to about 2.50 m, medium sands with some gravel and sea shells, not too compact (void ratio = 0.6). From 2.50 to 11.0 m depth, fine uniform sandy silts in loose state, with void ratios that increase slightly with depth, from 1.0 to 1.2; these silts have natural water contents approximately constant and equal to about 40 percent, liquid limits that range from 40 to 45 percent, and plasticity indexes from 7 to 20; they are completely saturated, their unconfined compressive strength varies from 0.12 to 0.65 Kg/cm^2, and their sensitivity from 1.5 to 3.0. The specific gravity of solids is about 2.75. It is to be noted that sandy silts have a considerable amount of biotite, and organic matter in some layers. Between depths of 10.0 to 18.0 m, the silty materials change gradually into clayey materials. The layer at a depth of 14.7 m consists of a marine clay with a soft consistency and high plasticity; its unconfined compressive strength varies from 0.4 to 0.6 Kg/cm^2, and its liquid and plastic limits are almost constant and equal, respectively, to 85 and 40 percent. The layers at about 18.0 m depth consist of sands, and below this elevation, of sandstones of marine origin.

The plasticity chart and granulometric curves of the soils sampled are shown in Fig. 6. The sandy silt group is clearly defined in the plasticity chart. Its uniform grain size is shown in the curves. It is known that in a loose state, soils with these characteristics have a tendency to liquefaction when they are under actions that disturb their unstable structural equilibrium. Based on these facts, it was concluded that the sharp and large movements of the structures along the left margin of the Coatzacoalcos River (described in more detail in the following sections) were due to partial liquefaction of the layers of uniform sandy silt.

Jáltipan

An open pit excavation was made in the center of town, to a depth of 6 m, and undisturbed samples were obtained. The subsoil in this region consists of large deposits of volcanic sand, partially weathered, and having veins of clayey materials.

The results of tests made on two specimens at depths of 2.5 and 5.5 m are shown in Fig. 7. The natural water content of these materials is about 13 percent, with liquid limit of about 19 percent, plastic limit of 15 percent, and degree of saturation varying from 47 to 76 percent. The average unconfined compressive strength is 0.6 Kg/cm^2. Several triaxial tests were made without varying the natural water content of the soil. The corresponding failure envelopes are also shown in Fig. 7. It is seen that the angle of internal friction varies between 24 and 29 degrees, with a cohesion of 0.2 Kg/cm^2. Using these values, and a mean unit weight of 1.90 Ton/m^3, and applying the Terzaghi formulas,[4] it was estimated that the allowable bearing capacity of the soil was of 12 Ton/m^2, with a factor of safety of 3.0 for long footings at least 1 m wide, and founded at a depth of at least 1 meter. The usual type of building in this town has probably bearing pressures much smaller than the above estimate. This fact is consistent with the behavior of buildings in the region during the earthquake, in that no foundation failures were observed in Jáltipan and vicinity.

DESCRIPTION OF TYPICAL DAMAGE

Photographs of damaged structures are shown in Figs. 8 through 19. They are divided into three groups: Figs. 8 through 11 show damaged structures in the inland towns of Jáltipan and vicinity. Figs. 12 and 13 are photographs of the highway joining Minatitlán and Coatzacoalcos; and Figs. 14 through 19 show damaged structures on the left margin of the Coatzacoalcos River.

As mentioned previously, the inland towns have soils with good bearing capacity, and the damage was typical of structures where the floor masses accelerated, causing collapse of the walls and columns. Fig. 8 shows the tower of the Acayucan church, about 20 Km southwest of Jáltipan. The top of the tower contained heavy bells suspended from I-beams attached to the walls. These masses accelerated with the earthquake causing complete destruction of the top portion of the tower, and heavy cracking in the rest of it. Figs. 9 and 10 are photographs of two concrete columns of a school building in Jáltipan. The roof slab accelerated leading to collapse of the columns. The displacement of the roof relative to the column can be clearly seen. Fig. 11 is a house in Cosoleacaque, located between Minatitlán and Coatzacoalcos, just beyond the marshes. As can be seen in the figure, the walls are of brick and mortar, coated with stucco. The roof is a reinforced concrete slab supported along the walls. Again, the roof slab accelerated and caused damage to the walls.

Figure 12 shows a portion of the Minatitlán-Coatzacoalcos Highway, 15 Km from Coatzacoalcos. This highway is built on marshy ground. The shock waves traveling through the marsh had their maximum effect on this very stiff strip, as compared to the adyacent ground. The settlement of the crown, and the lateral displacement of the shoulders of the road can be seen in the figure. Large longitudinal cracks formed along the highway. Fig. 13 shows another portion of it just outside Coatzacoalcos. The bridge in the background is one of the entrance bridges into town. Heavy cracking can be observed in the highway, as well as settlement of the highway relative to the bridge. The bridge is founded on piles that rest on a consolidated layer of soil, about 20 m deep, and did not suffer any structural damage. It should be noted that the railings on the bridge were originally inclined.

Figures 14 and 15 are from the free port zone of Coatzacoalcos. All the warehouses, piers, and docks suffered severe damages. Fig. 14 is a photograph of Warehouse No. 2. The Coatzacoalcos River is on the right. The vertical settlement and large horizontal movement of the warehouse can be clearly noted. Fig. 15 shows a sectioned dock with a railroad track. The rails were displaced about one meter with respect to each other. The very large movements of structures in this zone can only be explained by large movements of the subsoil.

Figures 16 and 17 show two aspects of the shipyards of the Ministry of the Navy installations at Coatzacoalcos. The large settlements of the columns can be clearly seen ir the photographs. Fig. 17 shows that the column settled about 0.8 m with respect to the floor slab. Also from the Ministry of the Navy installations are the two photographs of a repair shop that settled about 1 meter (Figs. 18 and 19). The Coatzacoalcos River is in the background of Fig. 18. The top portion of the repair shop is shown in Fig. 19. Cracking in the bricks and beams is obviously due to a sudden settlement, and not to horizontal acceleration.

FINAL COMMENTS

The earthquake offered the opportunity of studying the behavior of structures founded on soils with and without good bearing capacity. Most of the damaged structures located on the bank of the Coatzacoalcos River (the installations of the Ministry of the Navy, and the Free Port Zone) were founded on footings to depths of not more than 10 meters. Properties of these soils correspond to those shown in Figs. 5 and 6, that is, they are saturated, very uniform, with void ratios close to unity, and of a very unstable structure. A soil of this type, under the action of repeated vibrations, becomes partially liquified, as has been shown by Mogami[5] for sands and loams. This explains the sudden settlements and large movements of buildings during the earthquake, and means that a structure will suffer a foundation failure before the structure itself fails due to the earthquake loads. This is an important consideration for the aseismic design of a structure founded on these soils, since the designer will have to take into consideration the behavior of the soil under dynamic loading, besides considering the dynamic loads on the structure.

On the other hand, the failures of structures in the inland towns were in the structures themselves. The failures in this case were due to lack of consideration of the earthquake forces in the design, to poor construction techniques, or to the fact that some structures, like the old churches, were already weakened by previous earthquakes, which occur frequently in this region.

As suggested by Prof. G. Housner[6], this was probably a case where the extremely soft subsoil attenuated the ground accelerations rather than amplified them. This would partly explain why more destruction was observed in Jáltipan than in Coatzacoalcos, in regions where the soil had greater bearing capacity than along the margins of the river. The soft subsoil along the margins might have acted as a damper for the ground vibrations.

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6. G. Housner, personal comunication.

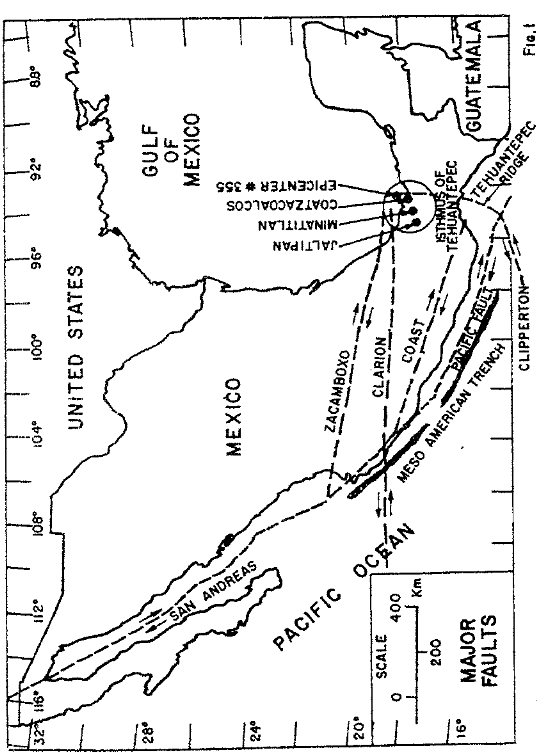

Fig. 1

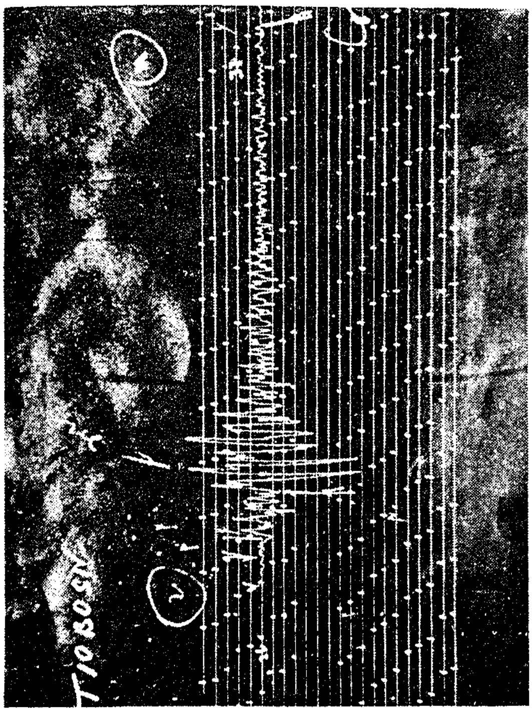

FIG. 2. SEISMOGRAM FROM THE TACUBAYA STATION (N-S COMPONENT)

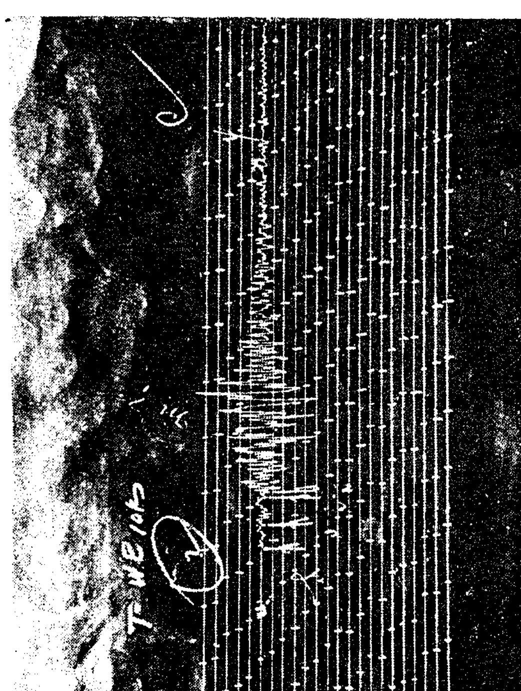

FIG. 3. SEISMOGRAM FROM THE TACUBAYA STATION (E-W COMPONENT)

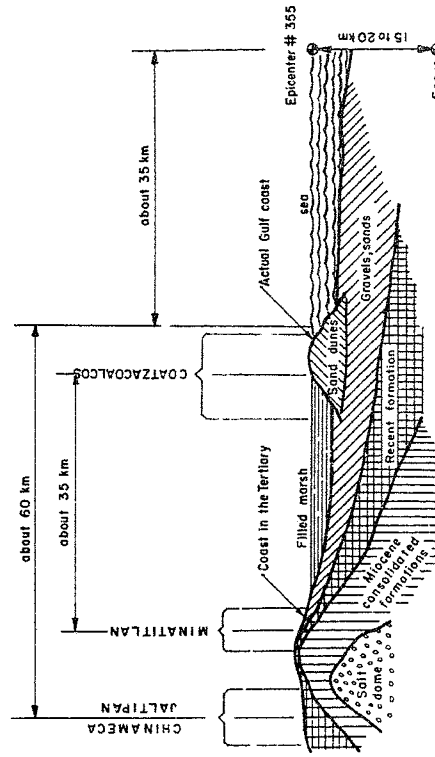

FIG. 4. GEOLOGICAL SKETCH OF ZONE

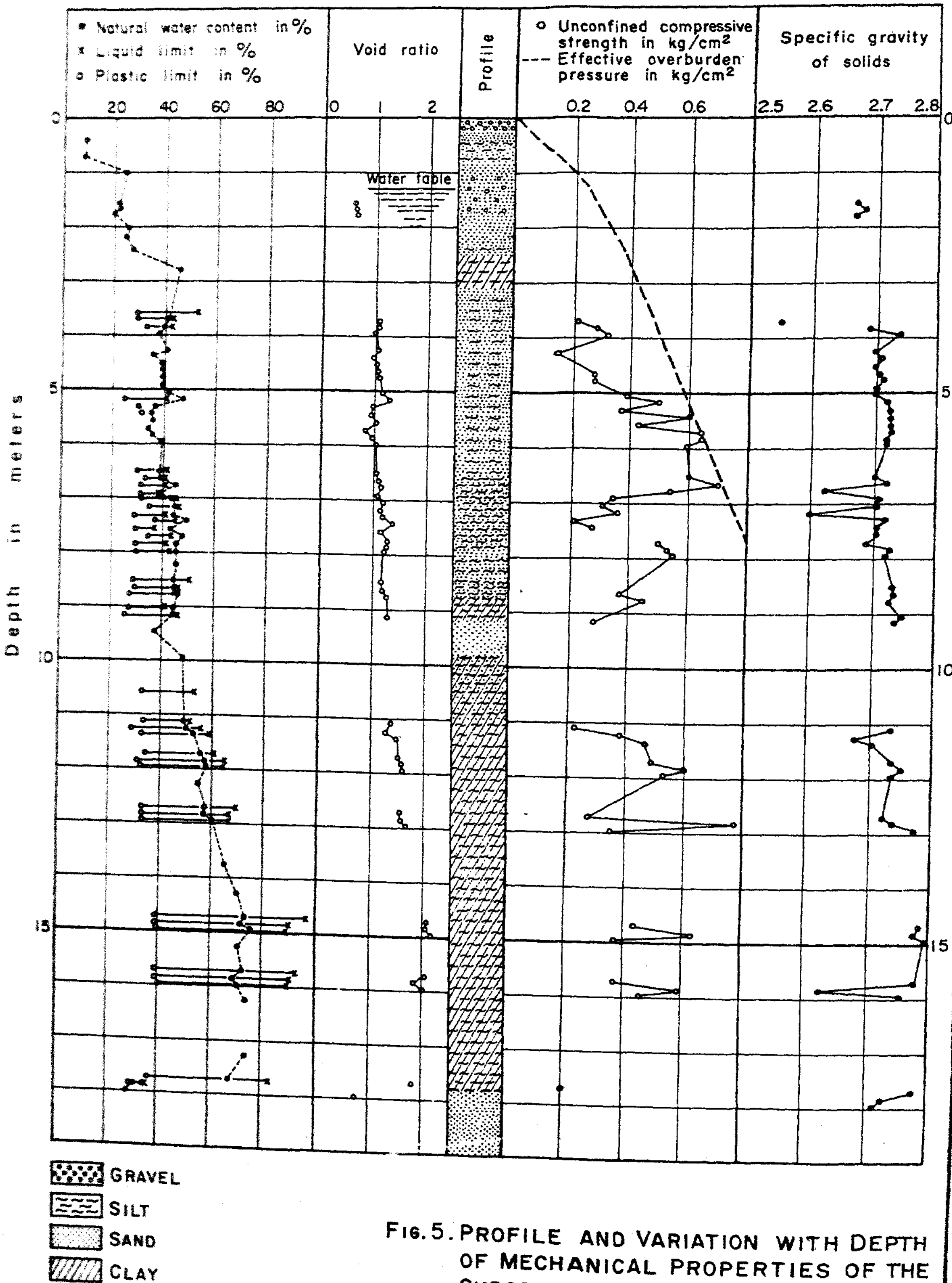

FIG. 5. PROFILE AND VARIATION WITH DEPTH OF MECHANICAL PROPERTIES OF THE SUBSOIL AT COATZACOALCOS.

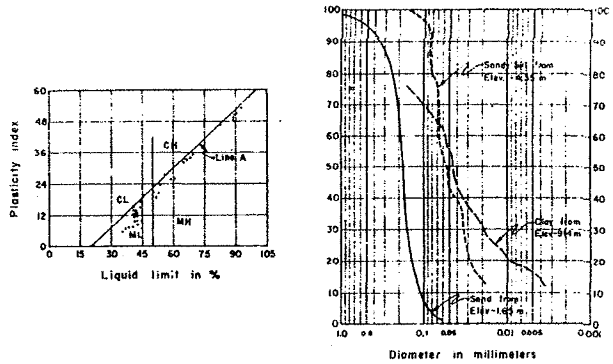

FIG. 6. PLASTICITY CHART AND GRAIN-SIZE DISTRIBUTION OF SOILS FROM COATZACOALCOS.

Sample elevation in m	Natural water content in %	Void ratio	Specific gravity	Degree of saturation in %	Liquid limit in %	Plastic limit in %	Plasticity index
-2.30 to -2.60	13	0.58	2.66	60	20.2	18.2	2.0
-5.20 to -5.50	12	0.59	2.65	54	18.8	14.7	4.1

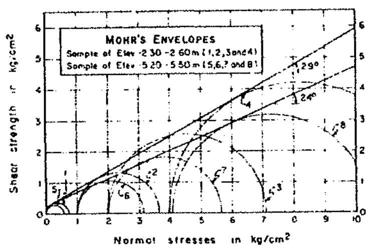

FIG. 7. MECHANICAL PROPERTIES OF THE JALTIPAN SOILS.

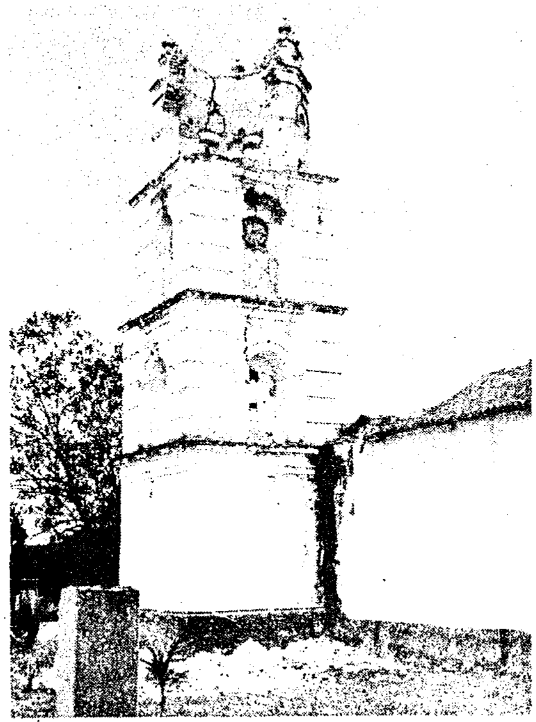

FIG. 8. CHURCH TOWER IN ACAYUCAN

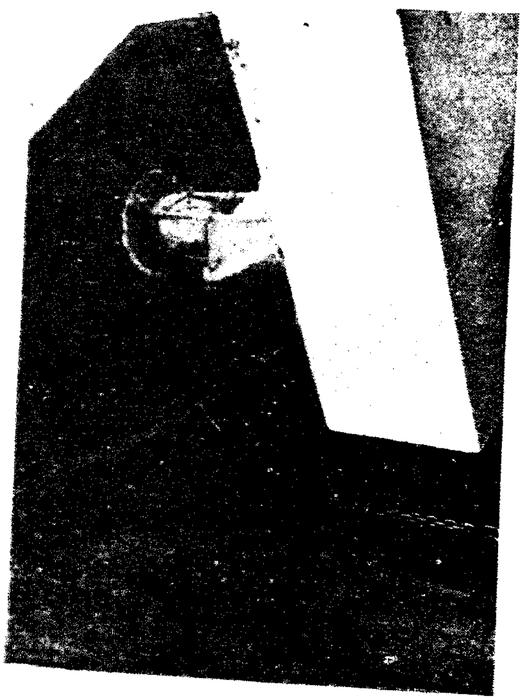

FIG. 9. SCHOOL BUILDING IN JALTIPAN

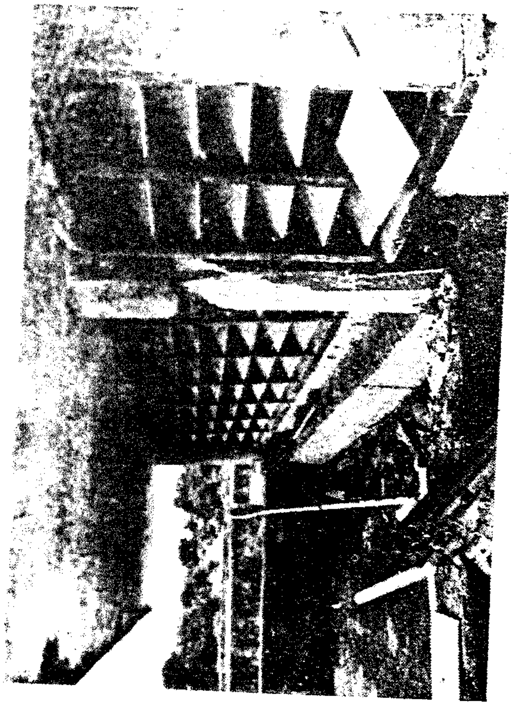

FIG. 10. SCHOOL BUILDING IN JALTIPAN

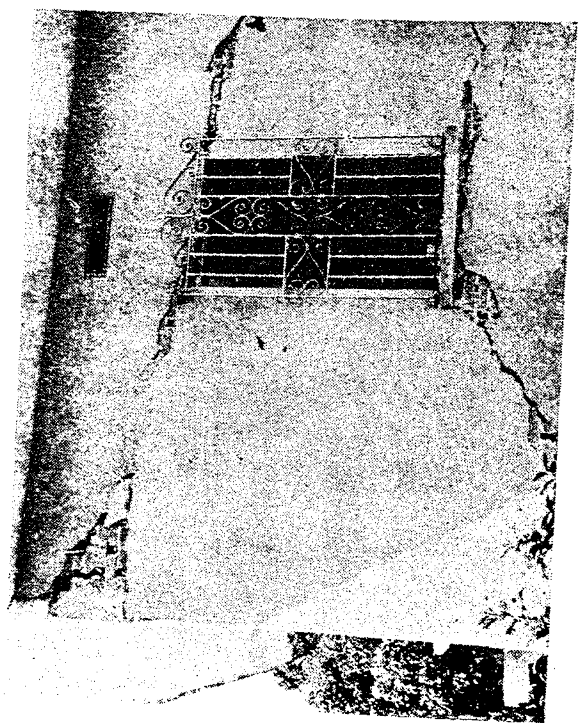

FIG. 11. HOUSE IN COSOLEACAQUE

FIG. 12. HIGHWAY BETWEEN MINATITLAN AND COATZACOALCOS

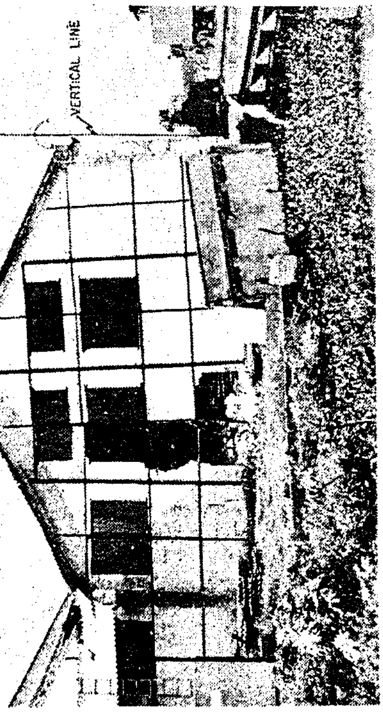

FIG. 14. WAREHOUSE Nº 2. FREE PORT ZONE IN COATZACOALCOS

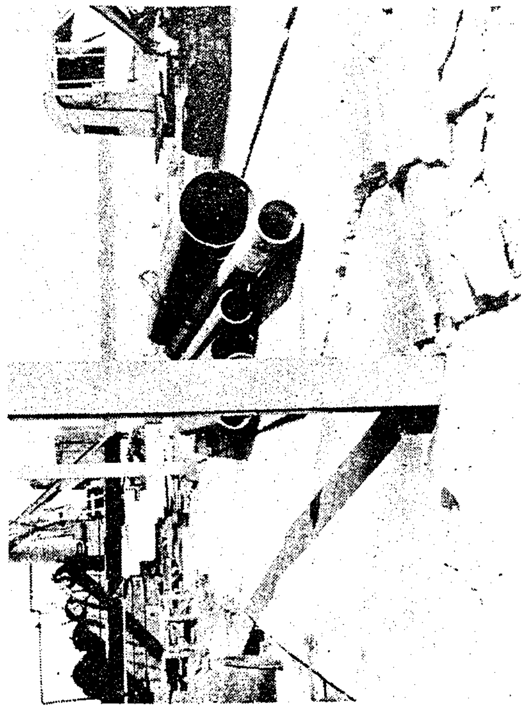

FIG. 16. SHIPYARD. INSTALLATIONS OF THE MINISTRY OF THE NAVY IN COATZACOALCOS

FIG. 13. BRIDGE OUTSIDE COATZACOALCOS IN THE MINATITLAN-COATZACOALCOS HIGHWAY

FIG. 15. DOCK IN FREE PORT ZONE OF COATZACOALCOS

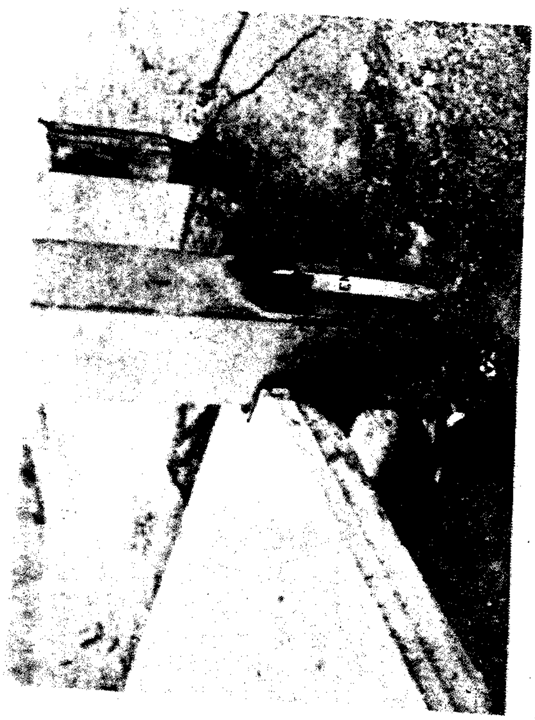

Fig 17. DETAIL OF COLUMN SETTLEMENT, SHIPYARD, INSTALLATIONS OF THE MINISTRY OF THE NAVY IN COATZACOALCOS

Fig. 18. REPAIR SHOP. INSTALLATIONS OF THE MINISTRY OF THE NAVY, COATZACOALCOS

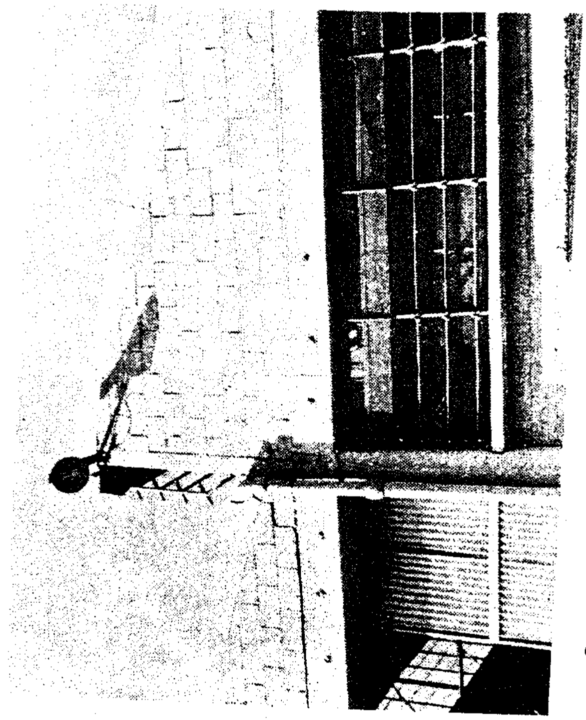

Fig. 19. REPAIR SHOP. INSTALLATIONS OF THE MINISTRY OF THE NAVY, COATZACOALCOS