Behavior of a Sandy Uniform Soil During the Jaltipan Earthquake, Mexico

Comportement d'un sable uniforme durant le tremblement de terre de Jaltipan, au Mexique

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Summary

In August 26, 1959, an earthquake of intensity VII on the modified Mercalli scale, occured in the south-coast region of the State of Veracruz, Mexico.

In Jáltipan, Minatitlán and Coatzacoalcos seismic action was most severe. In addition to damage sustained by various types of structures, the foundations of three buildings of the Naval Shipyard and of several sections of a nearby quay in the Coatzacoalcos River behaved in peculiar manner.

Soil exploration and tests carried out on undisturbed samples taken from the subsoil in Coatzacoalcos showed that the upper strata contained layers of fine uniform sand and silty sand, 10 m. thick. These materials lie on soft plastic clays or layers of sand and sandstones of marine origin.

After reviewing the bearing capacity of the soil and carefully examining foundation damage the author concludes that failures were caused by partial liquefaction of the sand and silt.

Sommaire

Le 26 août 1959, un tremblement de terre d'intensité VII de l'échelle Mercalli modifiée, eût lieu dans la région située le long de la cote sud de l'état de Veracruz.

A Jáltipan, Minatitlán et Coatzacoalcos, les effets sismiques fûrent les plus graves. On observa indépendemment des dégâts occasionés à de nombreuses structures de types variés, un comportement inhabituel des fondations de 3 édifices de l'arsenal et de plusieurs sections du quai construit le long du fleuve Coatzacoalcos.

Les sondages et les essais effectués sur échantillons « non remaniés » provenant du sous-sol de Coatzacoalcos, montrent que la formation supérieure est composée de couches de sable fin et uniforme et de sable limoneux sur 10 m d'épaisseur, ces matériaux reposent sur des couches d'argile plastique ou des dépôts de sables et grès d'origine marine.

Dans cet article, sont présentés les résultats des essais effectués et les observations des ruptures des fondations. Après avoir étudié de nouvean la capacité portante du sol et soigneusement observé les dégâts causés aux fondations, il semble que le motif de ces ruptures, doit être attribué à une liquéfaction partielle des couches de sable et de sable limoneux.

In order to investigate the damage caused by the Jáltipan Earthquake on a number of buildings in the Coatzacoalcos-Minatitlán-Jáltipan region (Fig. 1), the Institute of Engineering of the University of México undertook local soil exploration. The author gives laboratory data and conclusions about the probable causes of foundation failures that affected several structures at Coatzacoalcos.

The seismic movement occurred at 8·30 a.m. Greenwich

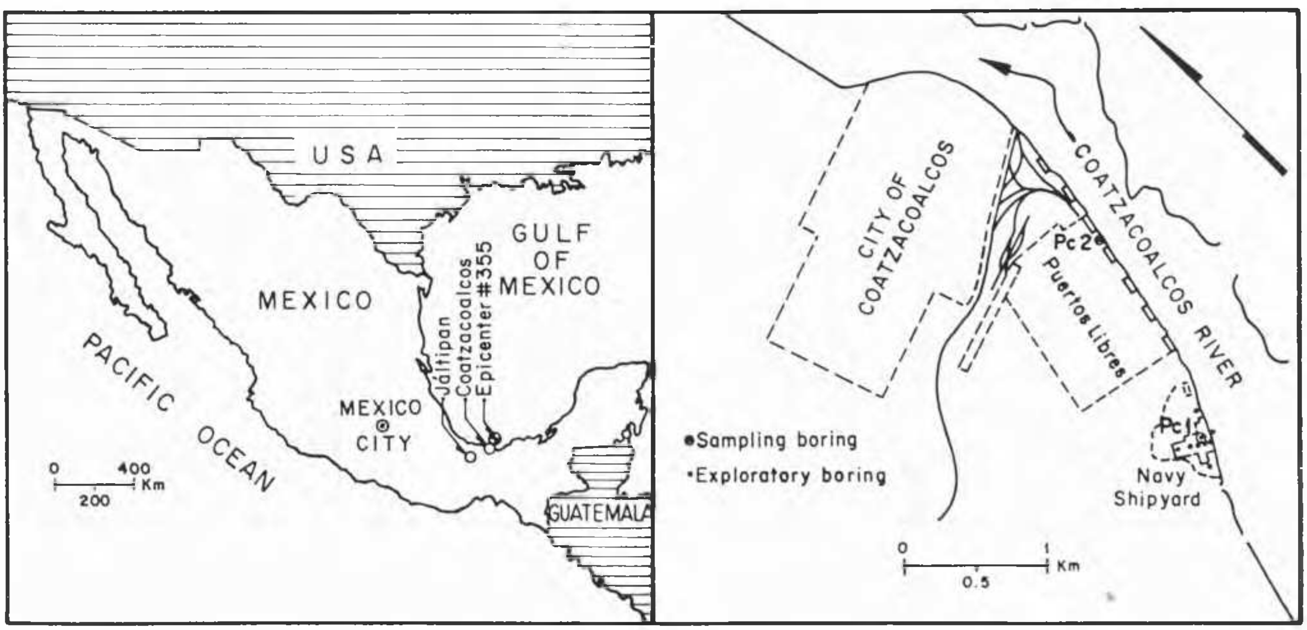

Fig. 1 General location, and site layout of Coatzacoalcos Veracruz.
Vue générale, indiquant les points où ont été effectués des sondages. Coatzacoalcos, Veracruz.

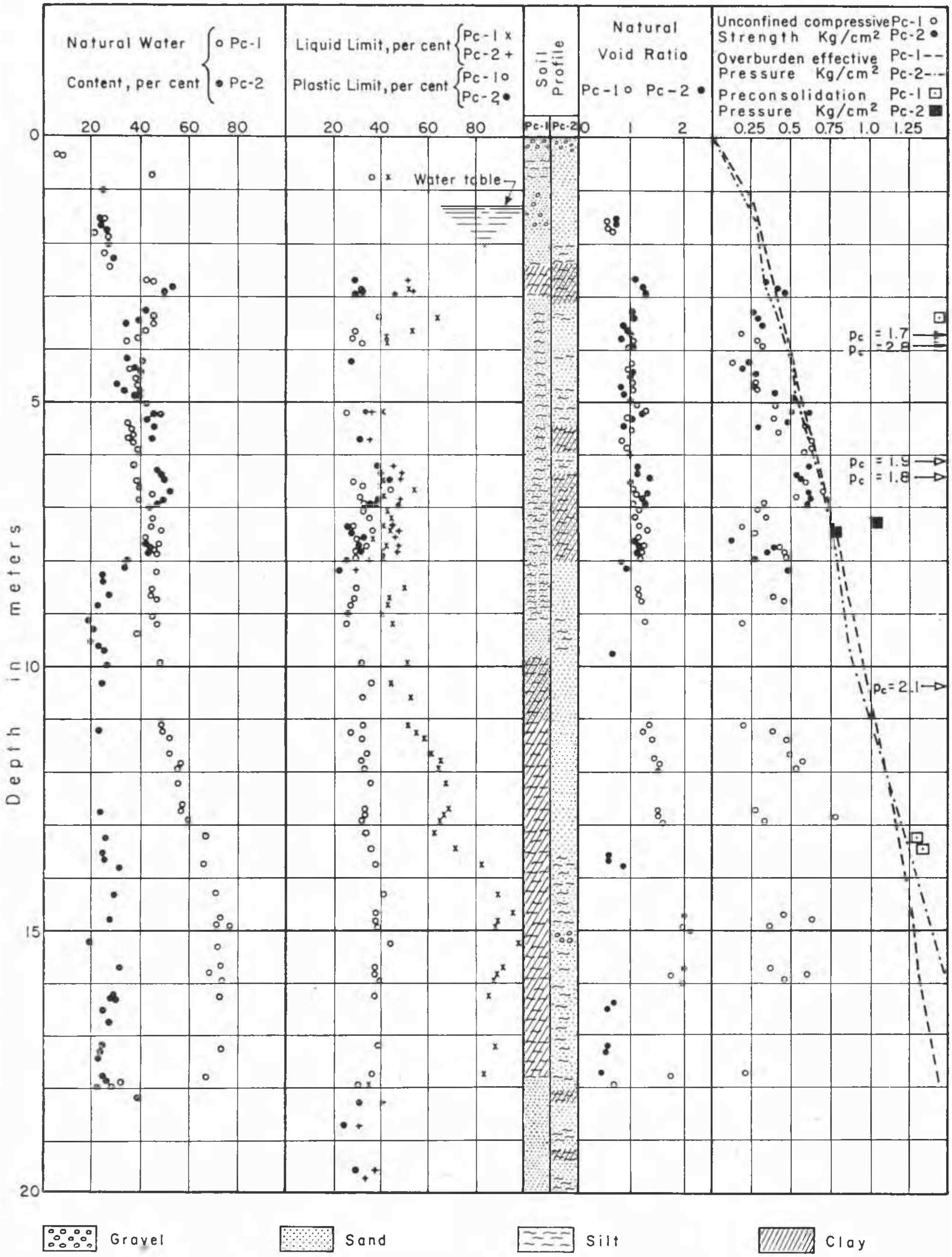

Fig. 2 Soil Profile, showing variation of mechanical properties with depth.

Profil du sol, indiquant la variation des propriétés mécaniques avec la profondeur.

Standard Time on August 26·1959. The epicentre was located in the Gulf of Mexico, 35 km from Coatzacoalcos in latitude 18°27′ N and longitude 94°16′ W; its depth of focus was about 20 km.

According to seismograms obtained from several stations, the intensity of movement was 6·5 on the Richter scale. The prevailing period of motion on firm ground was estimated at 0·7 sec. and maximum ground accelerations ranged between 0·07 and 0·2 g.

In Coatzacoalcos, heavy structural and foundation damage was observed, while in Jáltipan only the first type of destructive effect was recorded. In the former town, the upper layers of subsoil are mainly composed of loose sandy silts, below which layers is soft marine clay or medium sand. On the other hand, in Jáltipan the soil consists of deep deposits of well graded volcanic sand, somewhat weathered and with pockets of clay; its shear strength was determined by triaxial tests at constant moisture content and was $0{\cdot}2 + \sigma' \tan 25°$ (kg per sq. cm)

Exploration and Sampling Borings

The exploratory boreholes near Coatzacoalcos were concentrated on the left bank of the river, where port installations have been constructed and where most of the foundation damage occured. Two continuous sampling borings 20 m deep and several exploratory borings using a standard spoon were drilled; the location of these borings is shown in Fig. 1. Undisturbed samples were obtained by means of thin wall samplers of 2 in. and 5 in. diameter.

Laboratory tests

At the laboratory tests were carried out with undisturbed samples from borings Pc-1 and Pc-2 : Specific gravity of the solids, natural moisture content, liquid and plastic limits, initial void ration and unconfined compressive strength were measured. The results of these tests are shown in Figs. 2, 3 and 4 with the soil profile. Grain-size analyses were also performed on samples representative of the subsoil; Fig. 3 shows some of the grain-size curves. This diagram also includes a plasticity chart and ranges of activity for both the silty and clayey soils. With some of the 5 in. diameter specimens, consolidation tests were carried out, and preconsolidation pressures thus obtained are plotted in Fig. 2.

Soil Profile

According to Fig. 2, the formations present in sample boring Pc-1 are as follows :

From the ground surface to El. —2·5 m, layers of medium to fine clean sand, with void ratios of about 0·6, moisture content varying from 20 to 25 per cent and specific gravities of 2·66 are found. These layers are interbedded with some silty ones. The ground water table was 1·3 m deep.

Between El. —2·5 and E. —6·7 m, there is a uniform layer of loose sand; void ratios are practically constant and equal to unity, water contents about 30 or 40 per cent. Except for a few specimens, these materials are not plastic. Unconfined compressive strengths range between 0·2 and 0·6 kg/cm^2, and specific gravity is of the order of 2·70.

From El. —6.7 to El. —9.0 m, sandy silts with void ratios of 1·1 to 1·2 are predominant. Water contents are of 45 per cent; liquid limits of about the same magnitude, and plastic limits of 30 per cent on the average. The unconfined compressive strength changes erraticaly between 0.2 and 0.7 kg per sq. cm. It has to be noted that these materials have an appreciable amount of biotite, organic matter, and some seashells.

A layer of clean medium sand 0·9 m thick lies below El. —9·0 m.

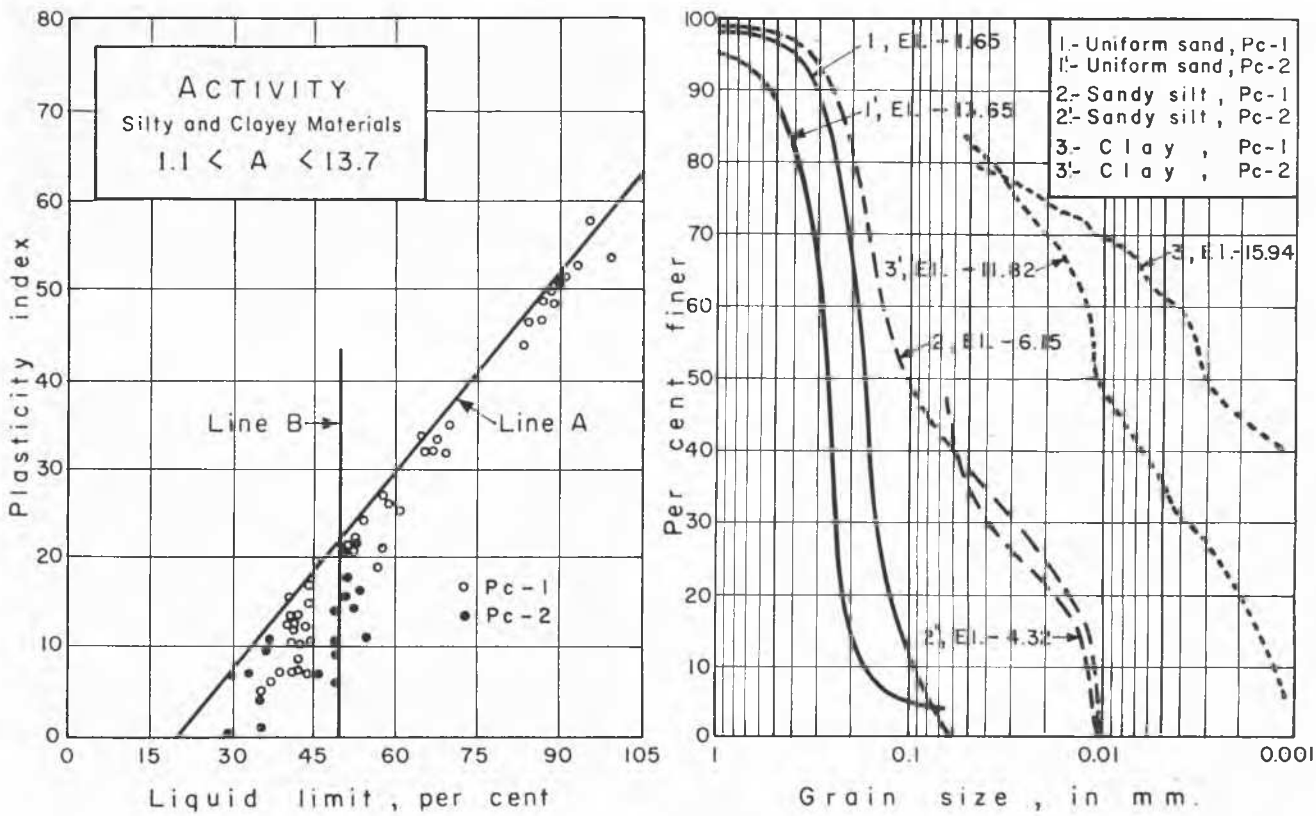

Fig. 3 Plasticity chart and activities of silty and clayey materials; grain-size curves.
Diagramme de la plasticité et de l'activité des matériaux limoneux et argileux ; courbes granulométriques.

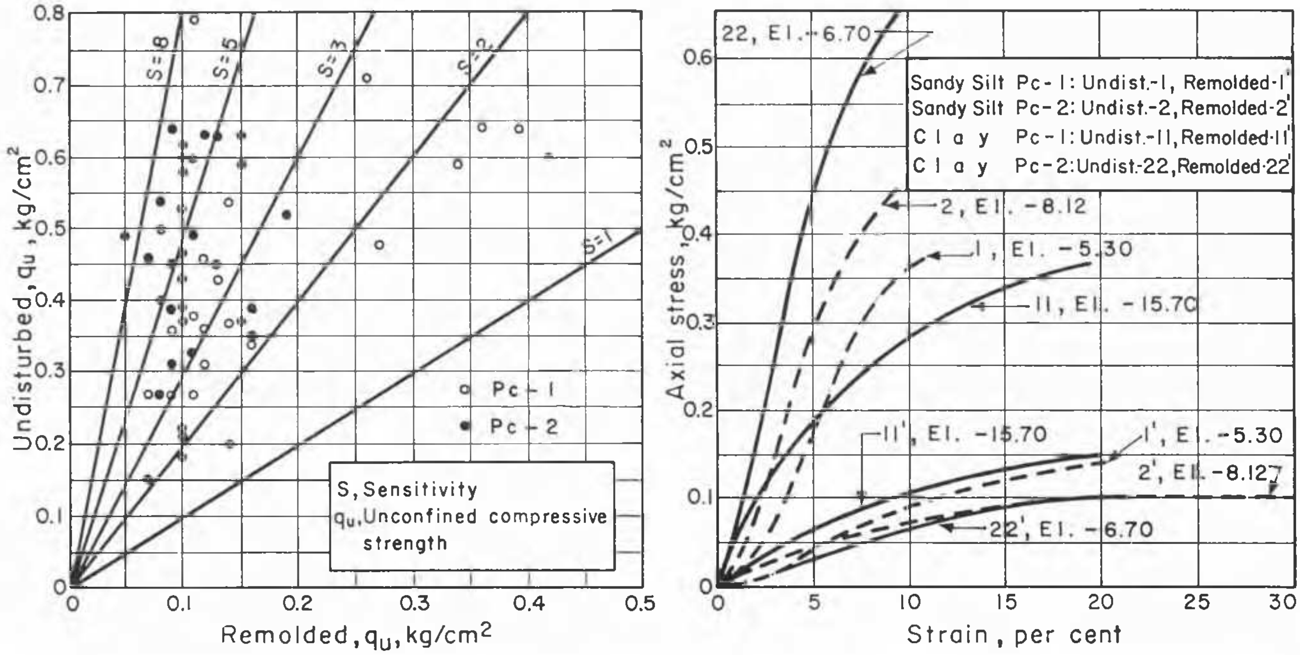

Fig. 4 Stress-Strain Curves of silty and clayey materials (unconfined compression test); sensitivities.
Diagrammes contraintes-déformations des matériaux limoneux et argileux (essai de compression simple). Sensibilité.

Between El. —9·9 and —17·8 m, sandy silts and clays are found, their plasticity increasing with depth. Moisture contents vary from 50 to 75 per cent and liquid limits are much higher than the natural moisture content, reaching values of 90 per cent, while plastic limits are under 40. Unconfined compressive strengths range from 0·2 and to 0·8 kg/per sq. cm, the sensitivity varying from 2 to 8. Specific gravities are greater than 2·70. Activities fall between 1·1 and 13·7 (See Figs. 3 and 4).

Below El. —17·8 m, there are compact sands and sandstones of marine origin.

In Fig. 2 the results of tests performed on samples from boring Pc-2 are presented; the soil profile is also shown. In comparing information from boring Pc-2 with that of Pc-1, it will be observed that there are important differences below El. —8·0 m. In boring Pc-2, below that elevation there is a thick fine silty sand deposit, having a natural moisture content of about 50 per cent, and void ratios of 0·4 to 0·9· Exploratory boreholes drilled at different points near Coatzacoalcos indicate that the subsoil is of erratic type.

Fig. 5 Collapse of column footings in the Naval Shipyard.
Rupture de l'assise des colonnes dans l'arsenal.

Silty sand and silt materials

These soils deserve special attention. They are non-plastic materials, and in a rather loose state, judging from their natural void ratios. Besides, as can be seen in Fig. 3, their grain sizes are quite uniform. These properties are characteristic of materials that, when subjected to a shock like that produced by an earthquake, are susceptible to structural collapse (2). A large mass of this type of soil can undergo rapid displacement, behaving as a liquid. In some cases, this phenomenon is local and limited to zones where maximum shear stresses occur.

Foundation failures

Two types of failure were observed in the Coatzacoalcos region next to the river; both of them are indicative of a partial liquefaction process taking place in the silty sand layers, particularly those between El. —2·5 and El. —6·7 m :

(a) A sudden settlement of the order of about one metre in the columns of the Naval Shipyard and the walls of the Machine Shop (Figs. 5 and 6).

Fig. 6 Subsidence of a continuous wall footing, Naval Machine Shop.
Élévation du radiet continu de l'entrepôt de l'asenal.

(b) Relative horizontal displacements between sections of the "Puertos Libres" quay (Fig. 7).

Fig. 7 Relative displacement of two sections of the Puertos Libres Quay.
Déplacement relatif de deux sections du quai « Puertos Libres ».

Both types of movement were a consequence of the August 26, 1959 earthquake.

The metal roof of the Naval Shipyard is supported on concrete columns which, in turn, rest on spread footings 1 metre square at a depth of 0·8 m.

The walls of the Machine Shop are founded on continuous footings 0·9 m wide at a depth of 0·8 m.

The Puertos Libres quay sections are formed by a metallic substructure resting on tubular steel piles, 20 cm in diameter, with an enlarged helical toe. The length of these piles is not exactly known, but it is greater than 10 m.

It is worth noting that the Shipyard construction was completed in 1956, and that no signs of disturbance were observed before the Jåltipan Earthquake. The Puertos Libres quay was built in 1910 and its behaviour was satisfactory until August 26, 1959.

Conclusion

Taking into account the features of the sandy silt layers in the subsoil at Coatzacoalcos, it has been concluded that the foundation failures result from partial liquefaction of those materials, induced by seismic action.

Phenomena very similar to the one described above, but on a much larger scale, have taken place recently in the Valdivia region as a consequence of the severe earthquake that struck southern Chile during May 21 and 22, 1960.

Acknowledgements

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