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FOUNDATIONS ON EXPANSIVE SOILS IN MEXICO

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ABSTRACT

Mexico has a considerable number of regions covered by expansive soils (12% of the total country area). One of these regions, named as “Cienega de Chapala”, is located in the state of Jalisco; the morphology of this region is mostly volcanic where plains and basins are found among volcanic formations. Plains and basins contain a variety of rocks mixed with volcanic ashes. The soil is formed by alluvial and lacustrine lands arranged in layers where the expansivity of superficial layers range from medium to high. This work describes two cases to illustrate typical problems originated by subsoil displacements. These displacements are produced by changes in soil humidity conditions that generate volumetric changes in such expansive soils. Both cases are educational facilities (i.e., college buildings) that have been seriously damaged by subsoil volumetric changes. This document also describes the soil characteristics, the buildings state before any rehabilitation work, the analysis performed, the obtained results, the solutions proposed, and the first findings about the buildings state after the rehabilitation works.

INTRODUCTION

Mexico has a considerable number of regions covered by expansive soils having 12% of the total surface of the country. One of these regions, called “Ciénega de Chapala”, is located in the Jalisco State. The morphology of this region corresponds to a predominant volcanic zone where plains and river basins are opened between the volcanic formations composed of rocks mixed with volcanic ashes. The soil is composed of alluvial and lacustrine materials in ordered layers which contain superficial materials with expansibility varying from medium to high, high plasticity dark clays or medium plasticity clayed silties or silty clays (shales).

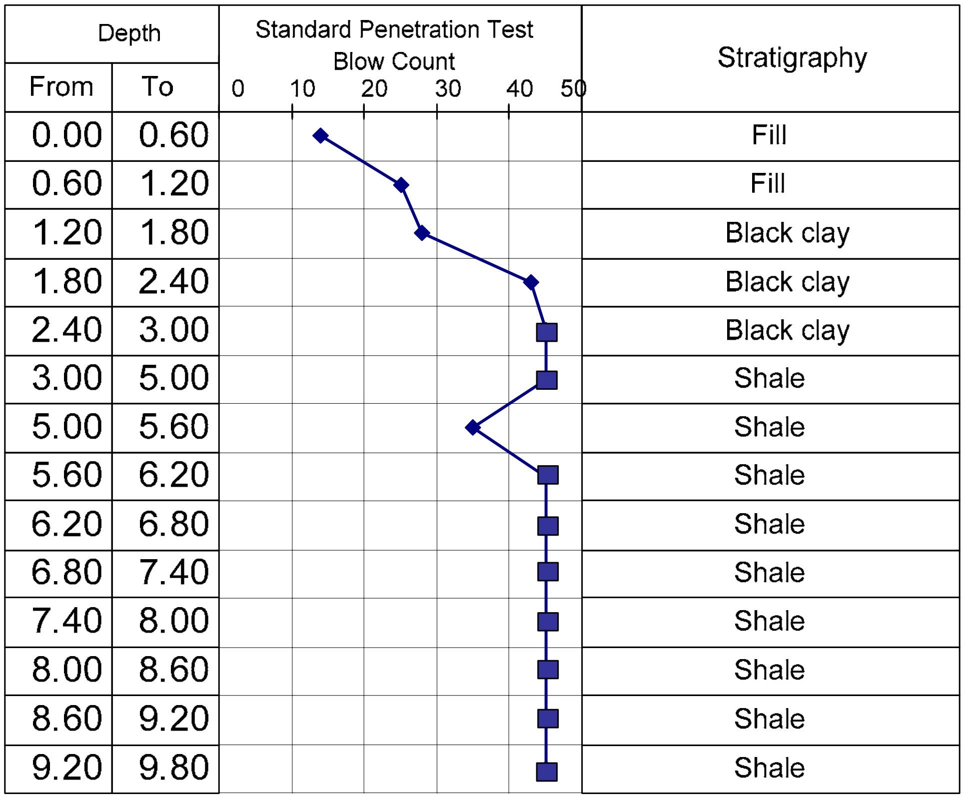
This work describes two cases showing similar behavior where they are two educative centers having one or two levels buildings. These buildings have been damaged seriously by the volumetric changes of the expansive subsoil located where the building were constructed. In both cases, the damages appeared from the building operation beginning and the risks worsened during the rain season.

In both cases, the geotechnical studies were limited in scope with consequences such that they were not able to prevent the problems that have appeared during the building operation. Given the previous circumstance, the causes of the undergone deterioration are mainly originated by the constructive process where the high susceptibility of the subsoil materials to the moisture variations or its fragility was not protected before the soil disturbing.

SUBSOIL CHARACTERISTICS

The results of previous and subsequent subsoil explorations in the buildings are shown in the stratigraphic profile in Fig. 1. This figure shows the next key information:

- The subsoil superior part is composed of more or less compact urbanization fillings with depth varying from 0.0 to 1.20m.
- The next layer is composed of black clay deposits with consistency and plasticity varying from medium to high and medium expansibility; this layer has a thickness varying from 1.20 to 4.20m. The volumetric changes that this layer suffered, according its natural moisture conditions, caused the damages that have been detected in the buildings.
- From the previous layer and down to the deepest sounding (10.2 m), the materials found included clayed silties and silty clays (shales) of color dark coffee to beige containing organic material, with medium plasticity, medium compressibility and with variable natural moisture.
- The phreatic water level was not in fount at the maximum depth exploration (10.2m).



Blow count > 45

Fig.1 Typical soil profile.

Additionally, the expansive soil layers were identified using laboratory index tests such as the Casagrande classification criterion. Fig. 2 shows the location of these soils on the plasticity letter where three clays are classified as high plasticity (CH), five clayed silties are classified as medium plasticity (MH), and the rest, sandy clay, is classified as medium plasticity (CL).

In addition, the index test results were used to apply three classification criteria for expansive soils. Table 1 shows the results where it is observed that, according to the O'Neill and Poormoayed Criterion (1980), seven samples correspond to expansive soils and two are stable. Next, according to the Bureau of Reclamation Criteria (1959), four are expansive, two collapsible, two marginal and one stable. Finally, according to the Chen Criteria (1988), four have high potential expansion, three have a very high, one has medium and the rest have low potential of expansion. From the previous information analysis thing which can be seen that three different criteria identified five soil samples with a very high expansive potential.

On the other hand, only two undisturbed samples could be tested with the odometer. Both samples correspond to high plasticity clays, showing the pressure of expansion values 5.88 kPa and 33.30 kPa. These values do not correspond to the pressures that have deteriorated to the affected buildings.

The test performed to the samples taken from the shales shown that their expansion potential is very low. Although, results showed a special characteristic, that its resistance varies remarkably due to the water content changes: when they have a small amount of water they behaves as hard rock, whereas when increasing its content of water they behavior is transformed into plastic rock.

Finally, the fact that the ground water table is not found discards the possibility that underground waters exist and affect the behavior of the buildings.

BUILDING BEHAVIOR

The educative centers have buildings with one or two levels with reinforced concrete structures including foundations, columns, walls, ceilings, and floors. Additionally some masonry walls are included. The foundations depth varied from 1.60 to 3.0m, some of them are placed on embankments constructed during the urbanization works. Some of the buildings included drainage works, such as subdrain, vertical moisture barriers, etc.

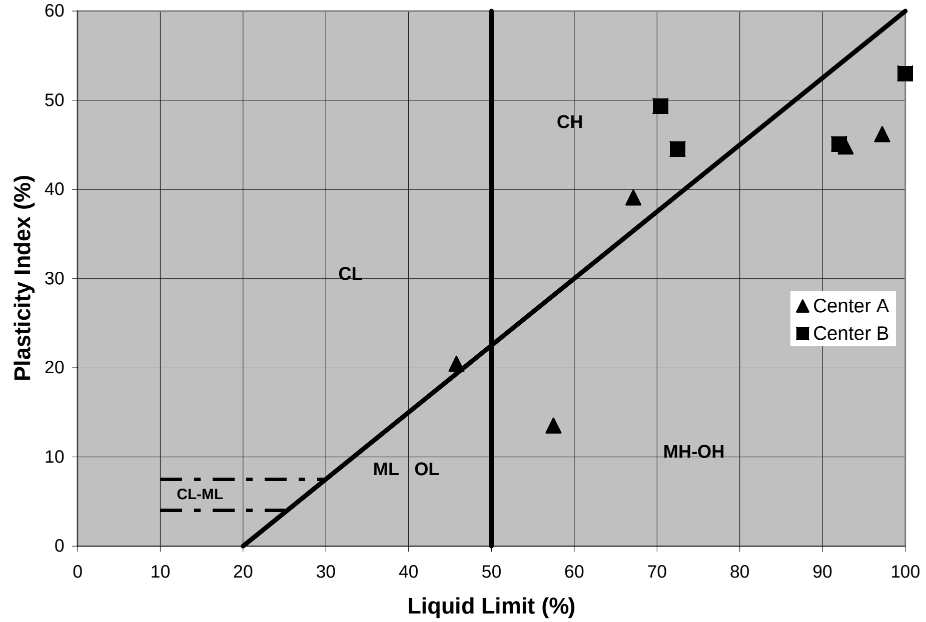


Fig.2 Location of typical expansive soils in the Casagrande plasticity chart.

Table 1. Expansibility results for the tested specimens

Specimens	Depth (m)	Classification SUCS	Expansibility Criteria		
			O'Neill and Poormoayed	Bureau of Reclamation	Chen
1 A	1.90	CH	Expansive	Marginal	High
2 A	2.70	CH	Expansive	Marginal	High
3 A	2.40	MH	Expansive	Expansive	High
4 A	3.20	MH	Expansive	Expansive	High
1 B	1.90	MH	Stable	Collapsible	Low
2 B	2.50	CL	Stable	Collapsible	Medium
3 B	2.10	MH	Expansive	Expansive	Very High
4 B	2.70	MH	Expansive	Expansive	Very High
5 B	3.50	CH	Expansive	Expansive	Very High

Damages produced by the volumetric changes of the subsoil began to appear in the damaged buildings at the beginning of their operation. The damage increased during the rain season due to changes in the expansive soils moisture conditions. After this rain period, the damage diminishes but the magnitude of the deterioration was increased. The main damages presented in the building after three years in operation are:

- Swelling of the floors with cracks in all directions; the deteriorations have caused problems in door operation, frames, and windows (Fig. 3).
- Displacement by swelling of the construction joints of floors (ground floor) with distortions throughout the joint and also atrophies to the door operation, frames, and windows.
- Vertical cracks in inner walls from the joint between columns and the wall, which deformed window frames, ironworks, and doors (Fig. 4). These damages are originated by the vertical movement which generated vertical cracks in facade walls, and columns.

Fig.3 Cracking and deformation on the floor.

- Slab deteriorations of walking areas had strong cracks, distortions, openings of the construction joints, etc., in a dual phenomenon that combines settlements with expansions.

All the described deteriorations were generated during the time of operation (three years) of these buildings until they affected seriously the building operation.

DAMAGE CAUSES

The study to find the causes of damages started after performing geotechnical borings. A preliminary revision allowed to identify that the damages were originated by moisture fluctuations of the soil sub-superficial layer. These fluctuations caused volumetric changes in the layer. The pre-construction geotechnical studies were not able to totally foresee the phenomena since the resistance measures obtained with the standard penetration test showed values varying from medium to high: the superficial layers showed bearing capacity greater than 294.3 kPa for the foundation depth (1.6 to 3.0 m). These results were used to support the project recommendations that were created based on the season conditions where the pre-construction studies were performed (winter – spring) having low pluvial precipitation.

The moisture fluctuations could be caused by two different sources: first, failures in the hydraulic and sanitary installations; second, filtrations originated by the presence of some superficial or underground water flow, since water zones with artesian pressure exist (springs) that emerge in some locations. The running offs can be either from natural origin due to bordering flows to the site or induced by terrene urbanization works and the construction of foundations. This last one could cause the drying or the disturbing of the expansive layer, making it more dangerous.

The water filtration through failures in the hydraulic and/or sanitary installations was detected in some points in each building, but the number of them was not enough to explain the totality of damages, since the deteriorations are distributed randomly, including relatively distant places from where hydraulic and/or sanitary facilities exist.

In relation to the existence of natural water flows, the zones around the buildings were carefully inspected trying to identify either some superficial or underground draining formed by rainwater that could affect the buildings. There was not indication that something could cause a water flow. Furthermore, the results of the geotechnical borings performed in both sites did not reach the phreatic water level within 10.0

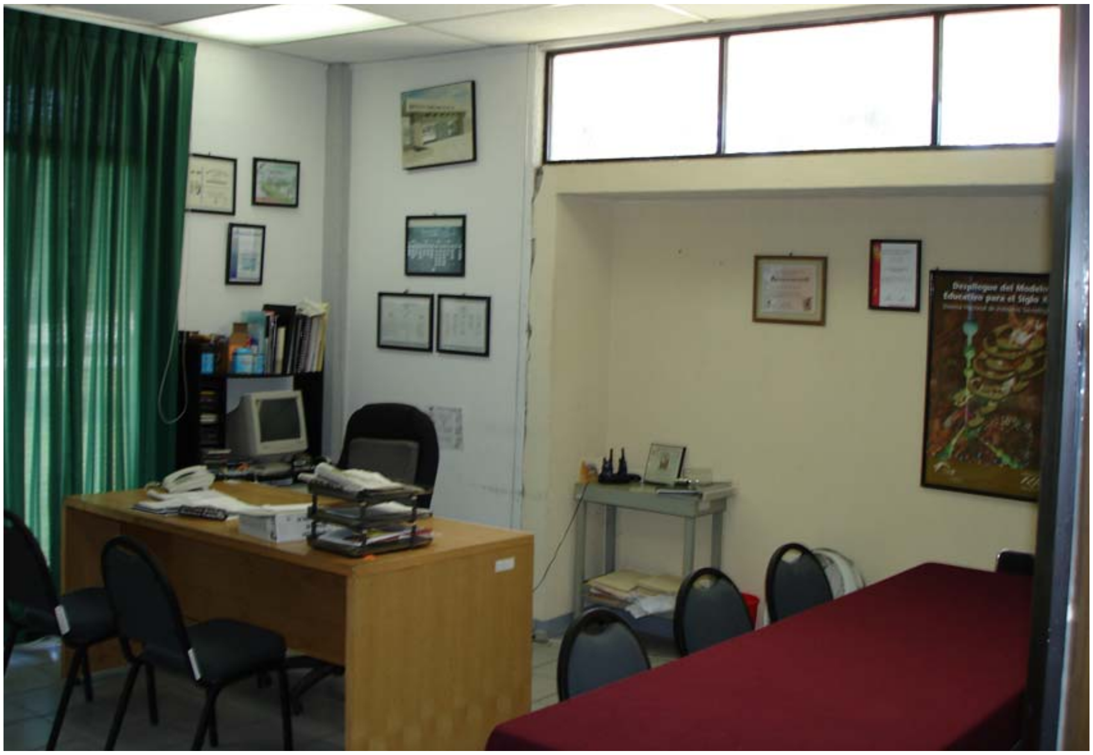


Fig.4 Vertical cracking joint between the wall and the column in the library cubicle.

m of depth. Then, there were no evidences that underground water flows were the cause that affected the subsoil moisture conditions.

Finally, each site was reviewed carefully and there was found rainwater concentrations in the garden and walking areas due to the bad land leveling. These rainwater concentrations produced filtrations into the subsoil under the buildings and then, incrementing the water content in the foundation level. In addition, evidences of excessive irrigation were located during the regular operation of one of the educative centers, which constituted another water source for the subsoil.

CONCLUSIONS

The analysis results indicated that these educative centers were based on lands that contained a stratus with thickness varying from 1.20 to 4.20m which is composed of expansive clays. These clays are, by nature, very susceptible to changes in moisture. The deteriorations that buildings have shown are mainly generated by the seasonal moisture variations that affected the clays during the rain season that caused the expansion of such layer with the damages already described.

The main causes of the observed damages started from the constructive process by the lack of an adequate project where it did not consider the protection of the subsoil materials high susceptibility to the moisture increment or its fragility before the soil disturbing. In addition to the previous problems, a bad terrain leveling that concentrates puddles of superficial rainwater drainings in zones around the buildings which produced water infiltrations into the buildings foundations.

Other sources of expansive layers humidification are the failures in hydraulic and sanitary facilities as well as the regular garden irrigation, where evidences of excessive irrigation were found.

Important information is that results did not find the ground water table within 10.0 m depth. This information supports the argument that the problems were not originated by underground waters. Additionally, superficial land drainings in surrounding terrains, that could alter the conditions of moisture of the subsoil, were not detected.

RECOMMENDATIONS

The problems of soil expansion generated by the result of fluctuations in their water content combined with heterogeneous subsoil conditions caused the expansion phenomenon. The solution to address this problem is based on

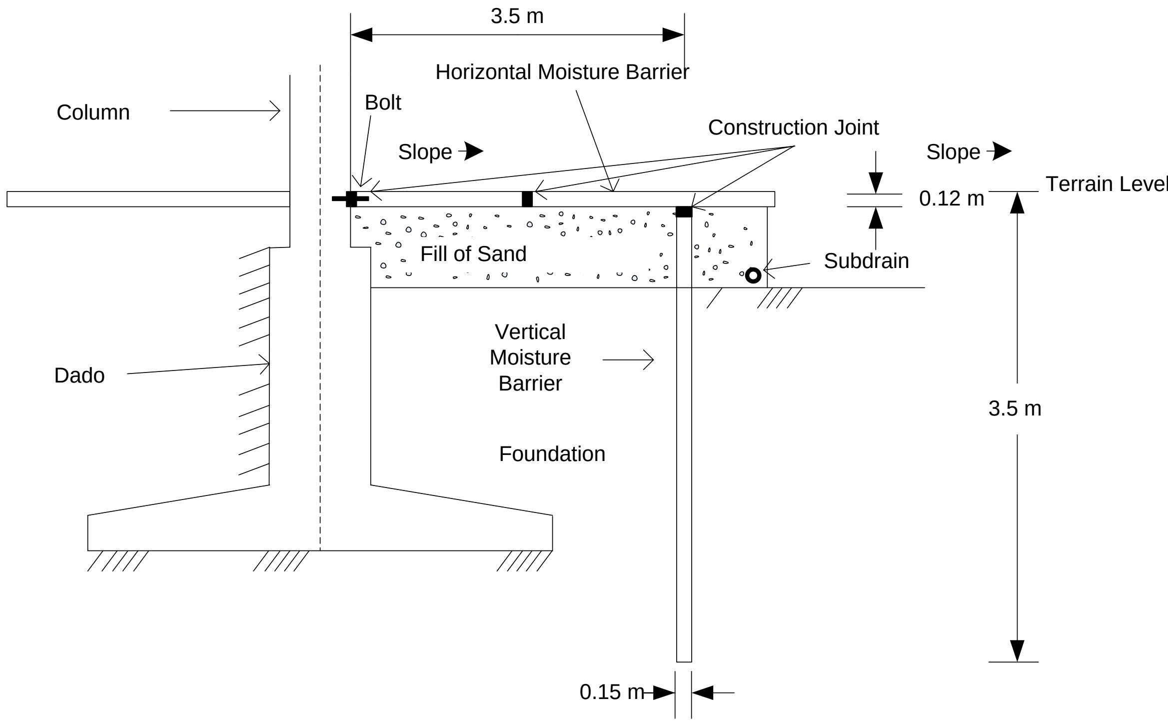


Fig. 5 Protection structures using the vertical and horizontal moisture barriers system.

reducing the moisture fluctuations and achieving moisture equilibrium in the foundation level. Next, the solutions proposed to reduce the problem are described.

One solution, which has been used successfully in the affected buildings, is the use of the horizontal and vertical moisture barrier system. This system offers a feasible solution since its basic principle is that they move outside the building the moisture from the foundations and floor borders. Another advantage of this system is that they reduce the seasonal variations of the subsoil water content located directly under the building, avoiding additional damages. This solution was selected after reviewing other alternatives and considering its cost medium and reduced maintenance (Fig. 5).

In order to enable a better and efficient operation of the horizontal and vertical moisture barrier system, it is necessary to avoid as much as possible the superficial water deposits that can cause rainwater infiltration. Then, it is necessary to modify the slope in green areas, walking areas, etc., so that these buildings emerge from the land and they do not store water. Additionally, it is necessary to design the channels and culverts that are required to take the rainwater to places where it could be eliminated.

For the areas that lack of vegetation, it was recommended to cover them with a layer of vegetal soil and to develop grass and small bushes. These actions will stabilize the soil reducing the erosion. When the vegetation is appropriately developed, soils will have better structure and better operation, since the vegetation absorbs infiltrated water and the water is returned to the atmosphere by the phenomenon called evapotranspiration.

For the hydraulic and sanitary installations, it was recommended to perform a continuous and periodic monitoring to detect and to repair to any failure or damage that might appear.

In additional, complementary works were recommended including periodic monitoring of the physical damages in the buildings, reviews of slops of pluvial water and the implementation of irrigation by aspersion in the green areas eliminating another source of infiltration.

It was recommended that the previous five actions were performed simultaneously to start the reduction of moisture variations under the buildings; at the same time, it was recommended to inspect damages in the buildings, especially distortions in damaged iron works. The “cosmetic” repairs of cracks and deformations in floors and walls must be postponed until the described conditions become stabilized.

PRESENT CONDITIONS

Some of the recommendations described here have been delayed given the budgetary conditions of year 2007 (To the date October 2007). Nevertheless, the task of leveling of the land has been implemented and it has diminished the impact of the damages originated by the rain season (June to September of the 2007) compared with the previous year. It has been planned to implement the additional recommendations described here during 2008 including a periodic monitoring of the buildings.

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