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Underpinning large buildings on Mexico City soft clays

Reprise en sous-oeuvre de grands bâtiments sur les argiles molles de Mexico

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ABSTRACT: Mexico City is known for the high compressibility of its lacustrine clays. The area is also affected by a general subsidence phenomenon and by frequent seismic events. These conditions have an influence on the behavior of buildings foundations. Many constructions present large settlements or tilting. In some cases, deep foundations present a conspicuous apparent protruding with respect to the surrounding ground. This paper deals with two underpinning techniques that have been proposed for large airport terminal buildings in Mexico City. The first case refers to a long building presenting uneven settlements due to the variation of the thickness of the clay layers close to a volcanic hill. In order to avoid further differential settlements, a series of cast in place concrete inclusions will be installed along the building. The second case refers to a building with point bearing piles cast in place down to a depth of 60m. In 15 years, the foundation has presented an apparent protruding of about 1.5m that interferes with the operation of the terminal. In this case, the current foundation will be replaced by a partially compensated box-type foundation that will be built performing underground excavation allowing continuous operation of the building. The upper part of the piles will be demolished while the lower part will be kept and contribute to reduce settlements through negative skin friction. In both cases the geotechnical and structural numerical analyses performed to define the design of the new foundation and the construction procedure are presented.

RÉSUMÉ : La ville de Mexico est connue pour ses argiles lacustres extrêmement compressibles. La zone est par ailleurs sujette a un phénomène de subsidence génerale et à de fréquents séismes. Ces conditions affectent le comportement des fondations des édifices. De nombreux bâtiments présentent des inclinaisons et des tassements importants. Dans certains cas, les fondations profondes présentent une émergence apparente par rapport au terrain environnant. Cette communication présente deux techniques de reprise en sous oeuvre qui ont été proposées pour de grands bâtiments de l´aéroport de Mexico. La première concerne un édifice de grande longueur qui a présenté des tassements différentiels dus aux variations d´épaisseur des couches d´argiles a proximité d´une colline volcanique. Afin de controler ces tassements, on installera une serie d´inclusions le long du bâtiment. La seconde technique sera appliquée a un édifice fondé sur des puits reposant sur une couche résistante a une profondeur de 60m. Sur une période 15 ans, les fondations ont présenté une émergence apparente de l´ordre de 1.5m qui constitue une gêne considérable pour l´opération de la terminale aéroportuaire. Dans ce cas, les fondations sur puits seront remplacées par un caisson partiellement compensé qui sera mis en place sans suspendre le fonctionnement de l´édifice. La partie supérieure des puits sera démolie mais leur partie inférieure continuera à travailler par frottement négatif. Dans les deux cas, on présente les modèles de structure et géotechnique qui ont permis de réaliser la conception des nouvelles fondations et la définition du procédé de construction.

KEYWORDS: lacustrine clays, subsidence, settlements, tilting, inclusions.

1 INTRODUCTION

The two terminal buildings of International Airport of Mexico City (AICM) are located in the lacustrine geotechnical zone (Zona III) of the city (Auvinet *et al*., 2017). Both buildings have presented some of the problems that are affect many structures built in this area: regional subsidence due to deep water pumping and pronounced site effects during earthquakes. The differential settlements that have been registered in both terminal buildings have led to inappropriate conditions for the technical personal as well as for users of the airport.

In Terminal 1 (T1), the regional subsidence and proximity of the geological structure known as “Peñón de los Baños” (PB) induce differential settlements (figures 1 and 2). Those settlements generate visible tilting of the buildings and disorders in the arrangement of the structural elements weakening their stability in seismic conditions (figure 3).

In Terminal 2 (T2), regional subsidence induces apparent protruding of buildings founded on cast-in-place piles resting on deep deposits (figure 4). These building are now working in conditions different from those considered in the original project (figure 5). Furthermore, protruding of these buildings originate communication problems between contiguous constructions with different foundation system such as the north and south piers and the entrance ramps resting respectively on friction piles and box type surficial foundations that follows the regional subsidence (figure 6).

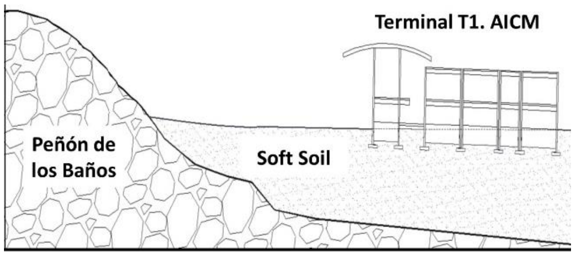

Figure 1. Differential settlements in Terminal T1.

The protruding problem became especially conspicuous during the September 19th 2017 earthquake (figure 7).

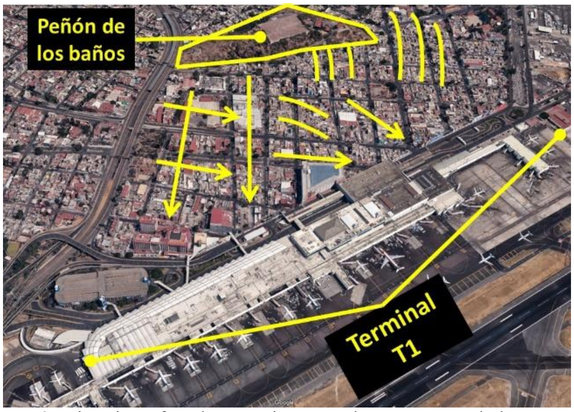

Figure 2. Direction of settlements in areas close to Peñón de los Baños.

Figure 3. Uncoupling of structural elements.

Figure 4. Apparent protruding of the parking building, Terminal T2

Figure 5. Loss of contact between the raft and the ground.

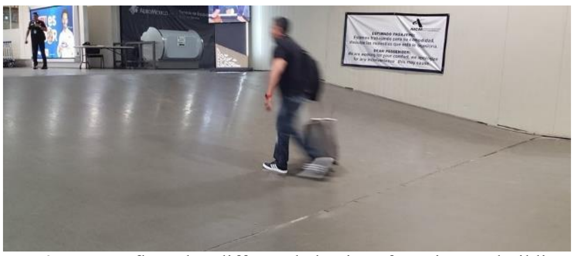

Figure 6. Uneven floor due different behavior of contiguous buildings.

Figure 7. Sudden increase of differential settlement between entrance ramp and main building during 2017 earthquake

2 PROPOSALS FOR UNDERPINNING FOUNDATIONS OF AICM TERMINALS T1 AND T2 BUILDINGS.

2.1 *Proposal for Terminal T1*

The solution consists of installing one or several rows of cast-in-place inclusions (Auvinet and Rodríguez, 2006) along the Terminal buildings on the opposite side with respect to Peñón de los Baños (i.e. on the runways side), (figures 7 and 8).

The number and dimensions of the inclusions (diameter, length and spacing) are assessed with the aim of mitigating the transversal differential settlements of the buildings, associated with the interference between regional subsidence and Peñón de los Baños.

Geotechnical analyses allow evaluating the short and long term interaction between ground, inclusions and structure as well as the possible effects on existing neighboring structures, apron, runways, etc. (figure 8).

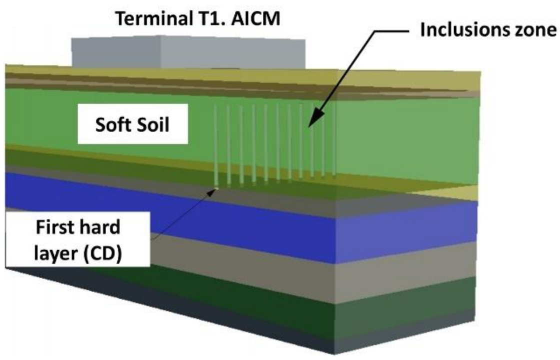

Figure 7. Rows of inclusions for improvement of the behavior of several buildings of Terminal T1.

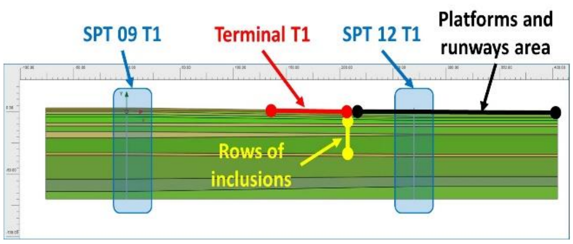

Figure 8. Numerical analyses aimed at defining the number and characteristics of inclusions.

The numerical analyses of the long term expected behavior of the Terminal T1 without any reinforcement of the soil indicate that the additional transversal differential settlement with respect to the present condition could reach 30cm (figure 9).

Analyses were performed considering that the tip of the inclusions would rest on the first hard layer encountered in the soil profile (CD). It was checked that the inclusions would not punch this layer when submitted to downdrag forces due to regional subsidence. Different diameters, length and spacing were tested to define the best inclusions characteristics for soil improvement. Finally, a 40cm diameter, a length of 24m and a spacing between inclusions of 3m were considered as the set of parameters leading to the best geotechnical and structural behavior of the buildings. Figure 9 shows the expected long term differential settlement of Terminal T1 buildings in the analysis zone. The orange and blue lines correspond to long term differential settlements with and without inclusions respectively.

Figure 9. Differential settlements of Terminal 1 buildings in the analysis zone with and without inclusions.

Structural analyses corresponding to this behavior are beyond the scope of this paper.

2.2 *Proposal for Terminal T2*

In this case, the pile foundation resting at a depth of 60m will be replaced by a partially compensated box-type foundation that will be built performing underground excavation allowing continuous operation of the building (figure 10). The piles will be disconnected from the structure (figures 11 and 12), but will be taken advantage of as negative skin friction piers to control settlement. The new foundation will be allowed to follow the regional subsidence and will no longer protrude with respect to the surrounding ground and adjacent surficial and friction piles foundations.

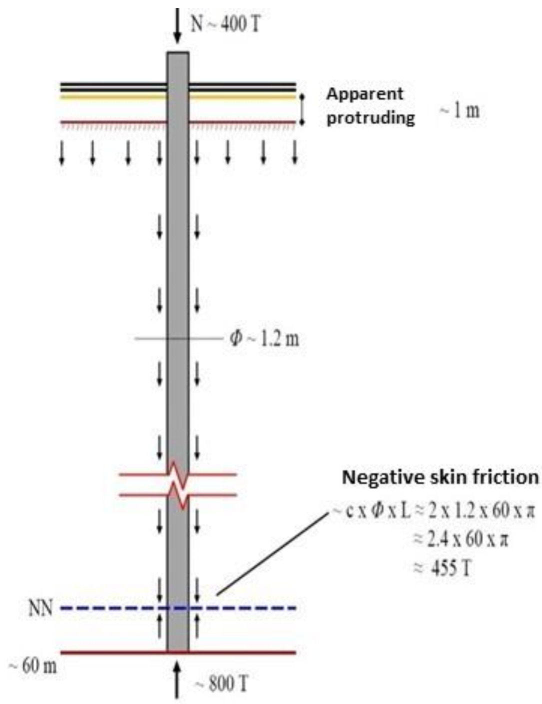

Figure 10. Current foundation on piles resting at a depth of 60m

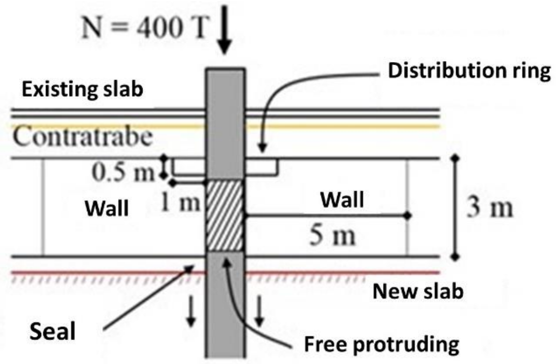

Figure 11. Underpinning (cross section)

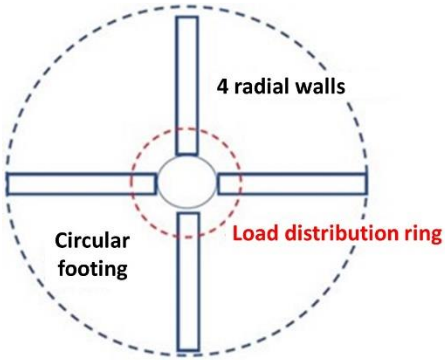

Figure 12. Underpinning system (plan view)

The stages of the underpinning process will be as follows:

- Excavation about 3m deep below the raft of the current foundation. Note that a void more than 1m high already exists between the raft and the ground due to the foundation protruding. The excavation will require bilge pumping.
- Construction of a new concrete raft on the bottom of the excavation. As part of this raft, circular footings will be built around the piles with radial and circular reinforcement. A small circular space will be left between the footing and the pile to allow for relative displacements. Simultaneously, a perimeter wall will be built to form a general box-type concrete foundation.
- Construction of a load distribution ring around the upper part of each pile.
- Construction of four radial walls ~5m long below the foundation beams connecting the piles. These walls will take over the load transmitted to the pile and transfer it to the new footing/raft. They will also be able to absorb shear forces during earthquakes.
- Chopping off of pile sections about 2.5 m high following a symmetrical sequence. The liberated piles are then able to penetrate through the new raft and the foundation as a whole is thus able to follow the regional subsidence. The space between pile and footing is sealed with flexible impervious material to prevent the phreatic water seeping into the foundation. The negative skin friction developed on the piles contributes to the control of settlements.

Figure 13 presents schematically the most typical structural configuration of the sites where the solution will be implemented (Case 1). The solution can be applied as such to a large number of piles. In the case of clusters of piles with an irregular shape, the solution can be easily adapted but requires a detailed design. Seven different cases were identified (figure 14)

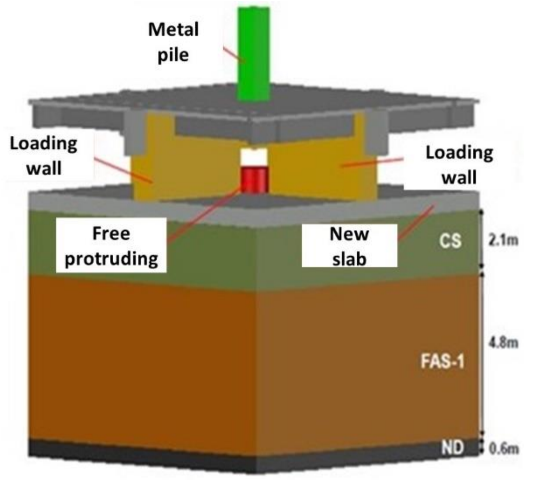

Figure 13. Excavation about 3m deep below the current raft.

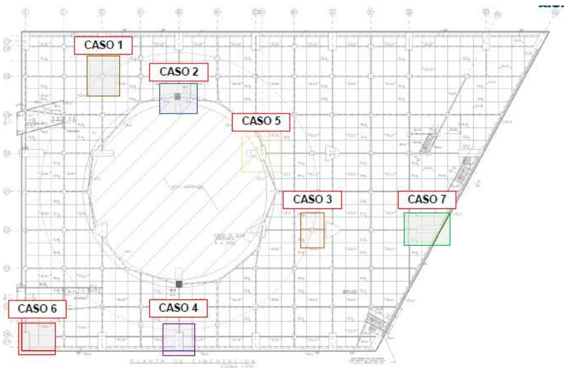

Figure 14. Different structural configurations found below main building of Terminal T2.

3 CONCLUSIONS

3.1 *Terminal T1*

The conceptual solution consists of installing longitudinal rows of inclusions along the buildings, on the runways side. These inclusions will rest on a hard layer. Their optimal dimensions and spacing can be determined using a numerical model. They should improve the behavior of Terminal T1 buildings without affecting neighboring structures.

A reduction of the differential settlements of T1 buildings due to regional subsidence close to the Peñon de los Baños hill is expected.

Construction of inclusions is quick and can be easily performed by local companies with experience in this field. The solution can be considered as robust but will require a continuous evaluation based on thorough instrumentation of the buildings and surrounding areas.

3.2 *Terminal T2*

The proposed solution consists of substituting the current foundation on cast-in-place piles down to a depth of 60m, by a box type foundation, taking advantage of the piles as elements disconnected from the structure but still able to work as negative skin friction piles reducing the settlements of the structure. The building will be able to follow the regional subsidence and will no longer protrude with respect to surrounding ground and adjacent structures with surficial or friction pile foundation.

The long publicized problem of Terminal 2 main building protruding will thus be definitively solved.

An important advantage of this solution is that it can be implemented without suspending operation of Terminal 2 and with minimal interferences with other activities in the airport. The only visible part of the operation will be the lateral entrances to perform the excavation and bring the required construction materials. A large number of local companies would be prepared to carry on this work since the so called "Top down" technique is commonly used for building large buildings in Mexico City. The radial walls around each pile will provide a high degree of seismic safety during and after the construction.

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