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Monitoring regional subsidence in Metropolitan Cathedral in Mexico City for its preservation as an architectural monument.

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ABSTRACT: The historical centre of Mexico City, where most of its historical monuments are located, has undergone for at least the last 150 years a continuous consolidation process due to the depletion of pore water caused by the exploitation of the aquifers that underlie its upper compressible strata. Extremely soft soils and regional subsidence have combined to induce damaging differential settlements in a large number of monuments built in the former lake area. Between 1989 and 2001, the Mexico City Cathedral underwent a rehabilitation program to remedy damage resulting from large-scale differential settlements caused by a combination of regional subsidence and the early settlements that occurred by self-weight. However, over time, the differential settlements began to accumulate again. Regional subsidence present in the area creates the need to continue monitoring the pore pressures and settlements that occur in the Metropolitan Cathedral, in order to evaluate their impact on the monument. This article presents an update of recent measurements performed in the Metropolitan Cathedral. Field measurements of pore pressures and settlements were carried out between 2021 and 2024, to monitor their evolution and their effect on the ancient monument. The results of these campaigns were interpreted to evaluate the current state of the site and what the future scenario could be if it were not intervened again with geotechnical solutions.

KEYWORDS: Soft soils, regional subsidence, differential settlements, field measurements, preservation of monuments.

1 INTRODUCTION

Most of the heritage monuments in Mexico City are located in the city centre, located in the so-called lake zone, which is made up of highly compressible clays with low shear strength. These characteristics bring about settlements that can reach significant magnitudes upon the application of surcharges or when its stress state is modified. Furthermore, these lacustrine clays have a significant creep component, which contributes to settlements that occur over time even without changes in its stress state. The effects of regional subsidence are most intensely felt in the lake zone. The phenomenon is caused by deep water pumping, whose influence on the clay is observed as settlements that can range from unimportant to significant. This imposes a constant and progressive settlement on all the urban structure, including historical monuments located in the lake area, which must be monitored to prevent settlements from reaching magnitudes that may eventually compromise the structural integrity many monuments. This paper presents the results of measurements to monitor the Metropolitan Cathedral of Mexico City, the analysis of field data, and a future projection of its integrity, based on the evolution of regional subsidence.

2 BACKGROUND

The Metropolitan Cathedral of Mexico City is part of a religious complex comprising the Sagrario Church, the Chapel of the Souls, and the Curia. This religious complex, without exception, has experienced differential settlement almost since the beginning of its construction. This article will focus on describing the characteristics of the Cathedral building, its behavior throughout its history, and the interventions carried out for its conservation.

2.1 *History of the Cathedral*

The Metropolitan Cathedral was built between 1571 and 1813 on an island elevated above the lake level, where a Mexica ceremonial center once stood. The Metropolitan Cathedral is composed of a central nave bounded by 16 columns and divided by the choir; two processional naves along the temple; two lateral chapel naves confined by the perimeter and perpendicular walls; a 65 m high central dome resting on four columns; and two 60 m high bell towers. All these elements are distributed over an area of 126.67 m long by 60.40 m wide, with an average height in the central nave of 25 m. The total weight of the Cathedral is 1.270 MN, which is transmitted to the ground as an average pressure of approximately 166 kPa (Ovando-Shelley and Santoyo Villa 2019).

Part of the Cathedral's foundation rests on pre-Hispanic remains (Figure 1). The Cathedral's initial foundation consisted of 22,500 short wooden piles driven into the clay, upon which a masonry platform measuring 140 m long and 70 m wide with an average thickness of 90 cm was placed. The masonry platform becomes thicker toward the south to compensate for the differential settlements that arose from its own weight at the beginning of its construction in that area. A grid of masonry beams measuring 3.5 m high, 2.5 m wide, and 127 m long was built on top of the platform to support the walls, pilasters, and columns (SEDUE, 1990).

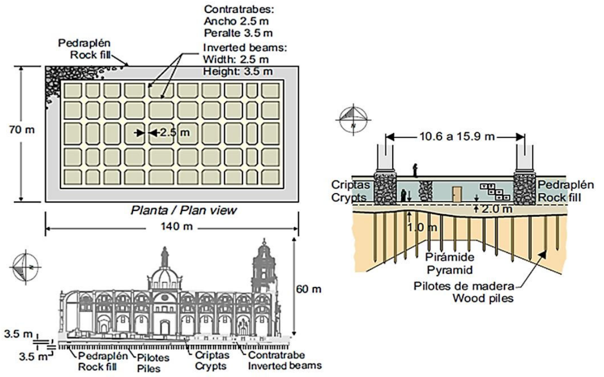

Figure 1. Foundation of the Metropolitan Cathedral (Ovando Shelley y Santoyo Villa, 2019).

2.2 *Rescue and conservation works on the Cathedral*

Between 1989 and 2001, Mexico City's Metropolitan Cathedral underwent a rehabilitation program to reverse the damage caused by the accumulation of large-scale differential settlements, initially produced by its own weight and, over the decades, as a result of subsoil consolidation resulting from the overexploitation of deep aquifers.

To correct the differential settlements, the underexcavation method was implemented at the Metropolitan Cathedral and the Sagrario Church between August 1993 and June 1998. This technique consisted of controlled extraction of the soil supporting the foundation in elevated areas through horizontal or inclined drilling. This technique accelerated the descent of the hard subsoil relative to the softer areas, thereby significantly reversing the differential settlements.

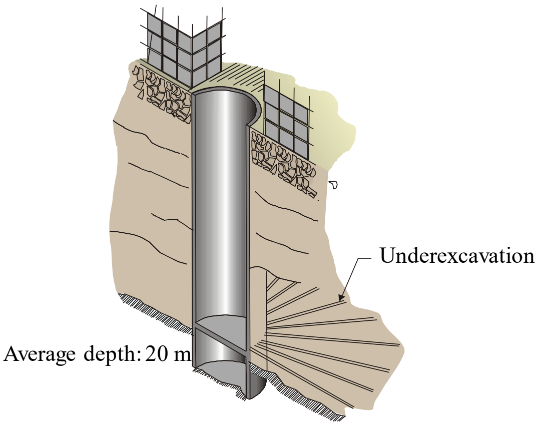

Figure 2. Shaft for the underexcavation process in the Metropolitan Cathedral, (Ovando Shelley y Santoyo Villa, 2019).

Once the expected re-leveling was achieved through underexcavation, between 1998 and 2000, mortar injection by hydraulic fracturing was implemented as a preventive technique for soil hardening. The mortar rigid inclusions sought to eliminate or mitigate compressibility differences due to the soil's loading history, which, among other factors, generated settlement differentials. This procedure was based on clay hardening studies and techniques carried out at the Palace of Fine Arts in Mexico City (Santoyo Villa and Ovando Shelley, 2008). Mortar rigid inclusions into the soil modified the differential settlement pattern and achieved a significant decrease in the annual settlement rate.

The preservation of a large part of the religious complex to the present day is due to the repairs, conservation, and restoration work it has undergone over more than 300 years. For example, in 1938, the seminary was demolished as a measure to relieve pressure on the eastern side. Attempts to underpin it included driving 25cm diameter wooden piles and reinforcing the parish floor with a slab of concrete supported by a grid of steel beams. Between 1960 and 1964 concrete piles were driven in 1m increments. Finally, 390 control piles were installed to reduce the work on the cathedral's foundation and as a corrective measure for differential settlements between the Cathedral within the structure itself and the surrounding ground.

2.3 *Geotechnical conditions*

The stratigraphic sequence on which the Metropolitan Cathedral rests corresponds to the typical stratigraphy of the lacustrine zone of the Valley of Mexico, which is an ordered sequence of soft clay strata separated by hard lenses of silty-sandy material (Figure 3).

This sequence begins with the Superficial Crust (SC), which, in the specific case of the Cathedral, is composed of a fill consisting of archaeological remains, followed by soft soil with lenses of dried aeolian material that form a dry crust. Beneath the superficial crust is the Upper Clay Formation (UCF), composed of soft to very soft lacustrine clay of high compressibility, a product of the deposition and physicochemical alteration of alluvial materials and volcanic ash. Below the UCF is the Hard Layer (HL), composed of a deposit of sandy silt mixed with some clay. The consistency of this layer is hard, a product of the cementation and compaction of its materials. Underlying the HL is the Lower Clay Formation (LCF), a unit composed of a sequence of clay strata of lower compressibility than the UCF, with intercalations hard lenses of silty sand. Finally, the Deep Deposits (DD) are located, a unit composed of a series of silty alluvial sands and gravels cemented with hard clays and calcium carbonate.

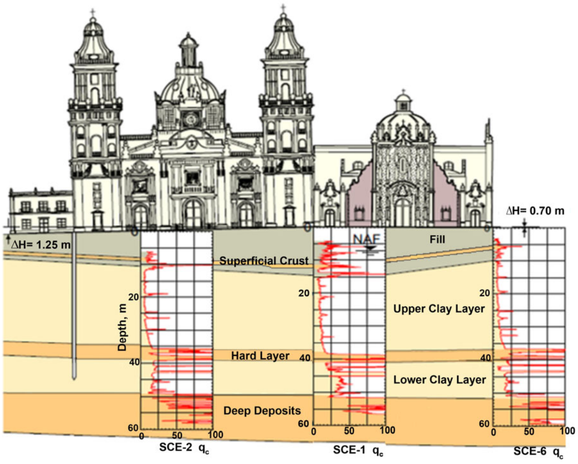

Figure 3. Stratigraphic sequence under the Metropolitan Cathedral, (Ovando Shelley and Santoyo Villa, 2019).

3 CURRENT STATE OF THE METROPOLITAN CATHEDRAL

Monitoring settlements and pore pressure drawdown continued throughout the first decade of the 21st century. Subsequently, due to a lack of funding, settlement and pore pressure measurements were discontinued, maintenance work ceased, and automatic monitoring of structural performance was suspended.

3.1 *Pore pressure and settlement measurements in the Cathedral area*

Monitoring of pore pressures in the Metropolitan Cathedral both in the perimeter of the building and in the crypt area was resumed in 2023 (Figure 5). The piezometric stations installed around the Cathedral perimeter were in a state of disrepair, making it impossible to open several instruments to take water level readings during the initial survey. Hence a project to restore the functionality of these instruments was carried out in 2024 after which it became possible to obtain new readings from the majority of the piezometers comprising piezometric stations PS-04, PS-03, PS-07, and PS-02, located along the perimeter of the Cathedral (Figure 4). Unfortunately, the piezometer that provided pore pressure data at the UCF and LCF levels (PS-01) was buried during remodeling works in the atrium area. Consequently, it is no longer possible to continue the valuable measurements recorded at this station between 1990 and 1999.

The settlement measurements were carried out by the structural experts from the Institute of Engineering, UNAM, which began working on structural restoration in 2017 following the earthquake that struck Mexico City that same year. This allowed for the reactivation of automated monitoring of structural performance and the recording of settlements by taking readings from the benchmarks (Figure 4). In addition, Figure 4 shows the location of the geotechnical soundings performed in the years 1989, 1990 and 2021.

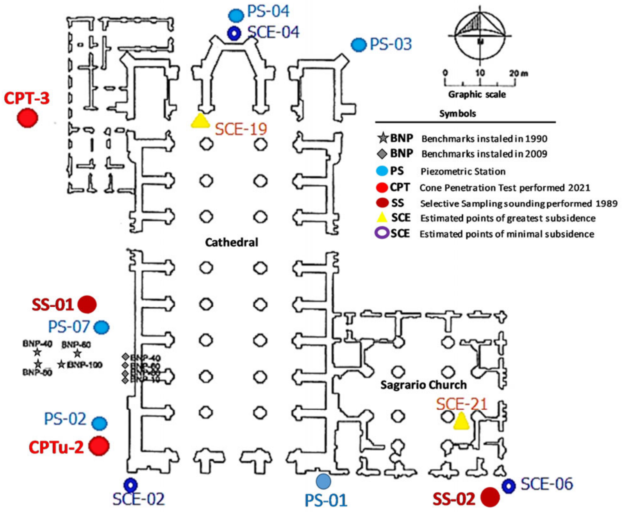

Figure 4. Location plan of piezometric stations, benchmarks, and geotechnical soundings.

3.2 Analysis *of the results of field measurements and site visits*

Figure 5 shows the records of pore pressure distributions in the Upper Clay Formation (UCF) and Lower Clay Formation (LCF) measured at piezometer PS-01 between 1990 and 1999. The same figure also includes the most recent measurements from piezometer CTPu-02 (2021) and from PS-02, PS-07, and PS-04, recorded in 2025.

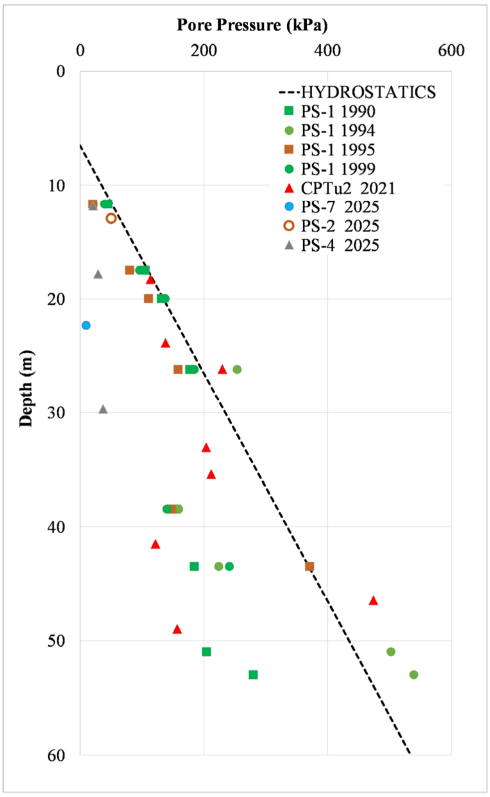

Figure 5. Evolution of pore pressure with depth.

Figure 5 also illustrates the effect of regional subsidence on pore pressure within the subsoil. The dataset covers a rather large time interval showing how pore pressures decline gradually but consistently over time. It can also be observed that the greatest drawdowns occur below approximately 30 m of depth, while a tendency to maintain hydrostatic conditions is observed down to about 15 m.

Finally, some piezometric records appear to exceed the hydrostatic condition. These values correspond to measurements obtained from instruments located at depths of 27 m, 52 m, and 54 m in borehole EP-01 taken in 1994, and from readings at depths of 26 m and 47 readings, these may have been influenced by the restoration and conservation works carried out at the Cathedral, such as the installation of rigid inclusions and the underexcavation process. The anomalous readings from 2021 may be possibly due to the insufficient time allowed for pore pressure dissipation after the installation of the piezometers.

To simulate the regional subsidence, pore pressure decays were used to determine the drawdown rates in and around the the Metropolitan Cathedral (Figure 6).

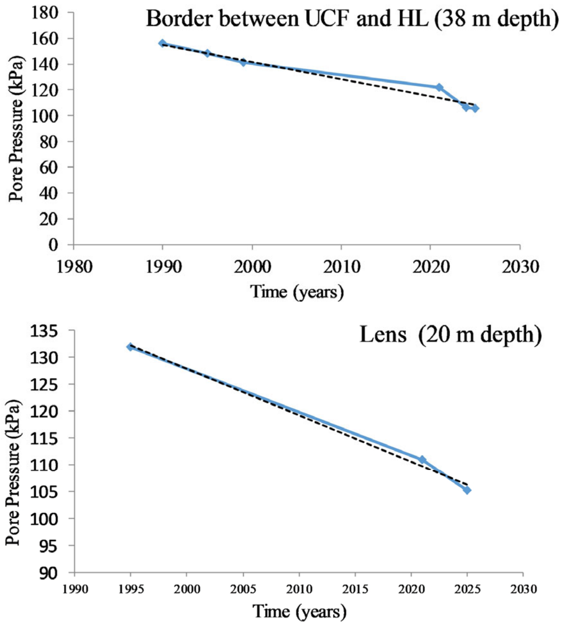

Figure 6. Pore pressure drawdown rates.

In 2021, an estimate was made of the pore pressure decay rates at the boundary between the draining strata and the clayey formations in the study area, based on the analysis of pore pressure records from 1990 to 1999 from station PS-01 (Blanch, 1999), located near the south facade in front of the east tower, and from a pore pressure dissipation survey (CPTu-02) conducted in 2021 in the area (Figure 4).

The drawdown rate at the boundary between the UCF and the HL was 1.062 kPa/year. Finally, the rate at which pore water pressure declined between 1990 and 2021 at the boundary between the LCF and the DD was 1.540 kPa/year.

With the information obtained from the rehabilitated piezometric stations, the drawdown rate at the boundary between the UCF and the HL was updated, from 1,062 kPa/year to 1,323 kPa/year. The rate of the LCF with the DD could not be updated because the deeper piezometers no longer exist. However, the remaining measurements revealed the behavior of pore pressure in a lens at a depth of 20 m, where pore pressure decreases at a rate of 0.86kPa/year.

As part of the instrumentation system, four deep benchmarks were installed at depths of 40 m, 60 m, 80 m, and 100 m. These instruments enable the monitoring of the deformation of the clay strata and the deeper deposits resulting from regional subsidence. Figure 7 shows settlements recorded by these benchmarks up to 2024.

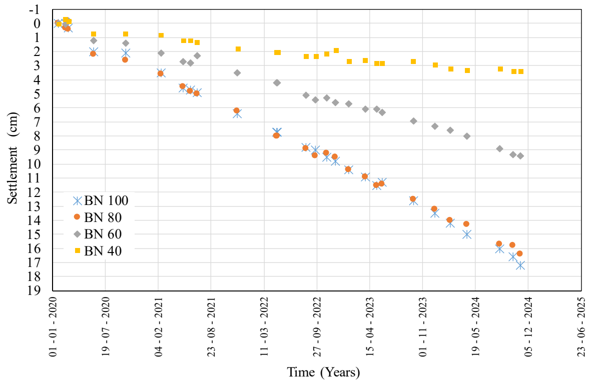

Figure 7. Evolution of settlements recorded by the benchmarks over time.

Recorded settlements show a continuous increase over time and some variations in the rate at which they occur, as well as variations in their behavior with depth. The current total settlement rate is 7.5cm/year.

3.3 *Assessment of the integrity of the Cathedral*

Field observations and analysis of measurements demonstrate that regional subsidence is ongoing at the site. This has gradually caused the apparent emergence and silting of some piezometers. Furthermore, over time, piezometric stations 1 and 5 were lost, making it impossible to monitor pore pressures along the entire UCF and LCF, since the piezometers that provided information on the LCF and its boundary with both the HL and the DD were located on EP-01.

In 2021, the largest differential settlements were located between the northwest part of the Cathedral and the southwest (Bell Tower) and southeast (Sagrario Church) corners, reaching 70°cm and 55°cm respectively. This differential is gradually increasing and is growing with the regional subsidence, which is advancing at a rate of approximately 7.2 cm/year. If it continues to worsen, it will exacerbate the damage listed in this paragraph and compromise the integrity of the Cathedral complex and the safety of parishioners.

Currently, the main structural damage observed in the religious complex is cracking, dislocation of structural elements, and material degradation. This damage can be classified into two groups: those that compromise the structural safety of the building, and those that do not affect structural elements but nevertheless represent a detriment to the heritage. The damage and deterioration have four main causes: differential settlement, earthquakes, environmental factors, and lack of maintenance.

4 FUTURE PROJECTION OF THE CATHEDRAL'S INTEGRITY

The evolution of regional subsidence has gradually induced additional differential settlements erasing some of the corrections achieved with underexcavation and mortar rigid inclusions, albeit at a much slower rate than previously. Regional subsidence will continue to induce additional differential settlements in the foreseeable future and will further deteriorate the monument if no measures are taken to mitigate or prevent it.

4.1 *Evolution of regional subsidence over the next 20 years*

A review and analysis of the condition of the Cathedral complex was initiated in 2021. As part of this study, estimates of the evolution of regional subsidence at the site were made. Unfortunately, laboratory tests for geotechnical characterization were not available, and the decision was made to use the results of the SS-1 and SS-2 sampling surveys conducted in 1990 (Figure 4). This can be done because the regional subsidence slightly affects the compressibility properties along the virgin consolidation line, so they were assumed to be constant (Ovando and Ossa, 2007). To determine the value of the viscosity parameter (ψ), the C_c/C_α ratio was considered, which, according to Mesri et al. (1975), has a value of 0.35 for the clays of the Valley of Mexico. To establish the stratigraphy of the area, two electric cone soundings ejecutados en 2021 were used, CPTu-2 and CPT-3 (Figure 4). From the analysis and contrast of the 2021 cones with the 1990 cones (SEDUE, 1990) it was possible to measure the reduction in the thickness of the compressible clayey strata that had experienced during this time and thus use the available 1990 cones were used to update their stratigraphic configuration, considering the detected reduction. Once the soil characterization had been completed, the modeling of the regional subsidence phenomenon at the site was carried out.

Nabor Carrillo (1948) was the first to explain the phenomenon of regional subsidence in Mexico City as a consolidation process and the first to modeling it, based on Terzaghi's consolidation theory (1923). Subsequently, the work of Marsal and Mazari (1959) confirmed Carrillo's findings (1959). This interpretation enables the modeling of pore pressure drawdowns, caused by regional groundwater extraction, as the dissipation of excess pore pressures within a consolidation framework, along with the corresponding settlements. The consolidation model employed for these estimations corresponds to the Elastoviscoplastic (EVP) model proposed by Yin and Graham (1989,1996). This is a one-dimensional model that, in estimating total deformations, accounts for the elastoviscoplastic behavior of soils characteristics exhibited by the clays of the Valley of Mexico. The governing equations are presented below:

$$c_v \frac{\partial^2 u}{\partial z^2} = \frac{\partial u}{\partial t} - \frac{1}{m_v} g(u, \varepsilon_z) \tag{1}$$

$$\frac{\partial \varepsilon_z}{\partial t} = -m_v \frac{\partial u}{\partial t} + g(u, \varepsilon_z) \tag{2}$$

$$g(u, \varepsilon_z) = \frac{\psi / v_o}{t_o} exp\left[-(\varepsilon_z - {\varepsilon_{zo}}^{vp}) \frac{v_o}{\psi}\right] \left(\frac{\sigma'_z}{\sigma'_{z0}}\right)^{\frac{\lambda}{\psi}} \tag{3}$$

where c_v is the coefficient of consolidation associated the reduction in soil volume due to the expulsion of pore water from the soil matrix and it is estimated with the following equation:

$$c_v = \frac{k}{m_v \gamma_w} \tag{4}$$

where k is the permeability, γ_w is the volumetric weight of water and m_v is the coefficient of volumetric compressibility of the soil (m^2/kN) and equal to:

$$m_v = \partial \varepsilon_z / \partial \sigma'_z = (\kappa / v_0)/(\sigma'_z) \tag{5}$$

where v_o is the specific volume of the soil, σ'_z is the effective stress and κ is the slope of the elastic section of the compressibility curve.

$$\psi / v_0 = C_\alpha / 2.3 \tag{6}$$

where C_α is the slope of the logarithm of time versus strain curve and λ is the slope of the virgin section of the compressibility curve.

Expressions 1 and 2 form a system of nonlinear differential equations that are numerically integrated in this work using the finite difference method.

To simulate pore pressure drawdowns in permeable strata confining compressible clayey soils, time-varying boundary conditions are introduced (Ovando and Ossa, 2004). These boundary conditions are represented as drawdown rates, which are described by time-dependent polynomials (Eqs 7 and 8). To obtain the rates (V_s, V_i), pore pressure measurements taken in the field during the available time period are processed.

$$u(0,t) = u(0,0) - (V_s * t) \tag{7}$$

$$u(2H,t) = u(2H,0) - (V_i * t) \tag{8}$$

where, $2H$ is the thickness of the clay stratum considered, t it is time and V_s, V_i, are the pore pressure drawdown rates at the upper and lower boundaries of the clayey stratum.

The rate at which pore water pressure decreases depends on several uncertain factors. These include the depth and spatial distribution of the pumping wells, as well as the pumping regimes (operating schedules, extraction rates, and applied suction). Additionally, the response is influenced by the properties of the subsurface materials affected by pumping, particularly their compressibility and permeability. Consequently, it is challenging to accurately predict, through analytical means, the future evolution of pore pressure drawdown rates.

As an illustrative example, Figure 8 presents the evolution of pore pressure at point SCE-6, derived from the regional subsidence modeling.

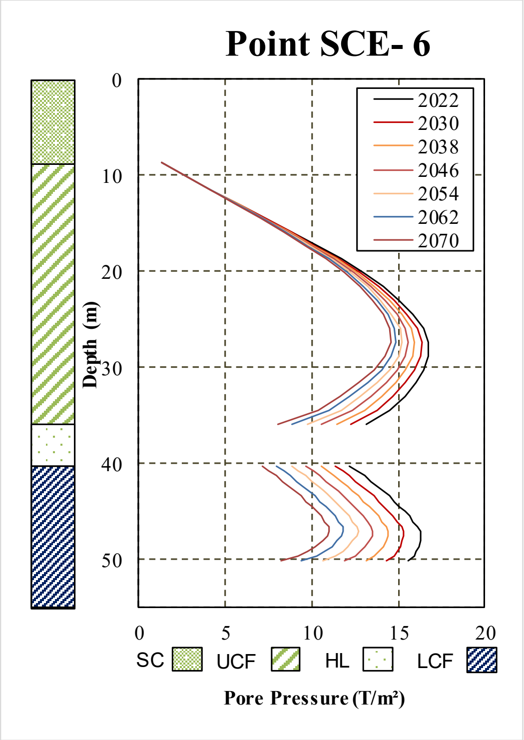

Figure 8. Estimation of the evolution of the pore pressure at point SCE-6.

The settlements resulting from the modeling of pore water pressure drawdown within the analyzed soil deposits (UCF and LCF) range from 0.471°m to 1.486°m over the next 50 years. This will occur at a settlement rate ranging from 1.928 to 4.19°cm/year in the first few years and decreasing from 1.345 to 2.84°cm/year within 50 years. These results are associated with existing records of the percentages contributed by each of the clayey formations to the total settlement at the surface. At the time of these estimates, the settlement rate of UCF and LCF accounted for 43% of the total settlement rate at the study site; the remaining 57% corresponded to the contribution of DD located below 100 m.

In the 2021 analysis, variations in the percentages of DD contributions were considered. The first scenario corresponds to the DD contributing 45% and therefore the settlement rates of the UCF and LCF for the first years are estimated between 3.505 and 7.625°cm/year, while by 2070 they are estimated to decrease between 2.445 and 5.164°cm/year. Considering that the DD contributes 65%, then the settlement rates of the UCF and LCF in the first years would vary between 5.507 and 1.982°cm/year, while in 50 years they would vary between 3.843 and 8.114°cm/year.

It should be emphasized that, for any of these scenarios, the newly computed differential settlements must be added to those measured in 2021.

The points where the maximum and minimum settlements were identified through the analyses with which will settlement patterns can be established. The points of highest settlement correspond to the southwest corner (SCE-02) at the foot of the Cathedral bell tower, the area of the Cathedral apse (SCE-04), and the southeast corner (SCE-06), which corresponds to the east corner of the Sagrario Church facade (Figure 4). The points of minimal settlement correspond to a point near the reference column for the topographies in the northwest section of the Metropolitan Cathedral (SCE-19) and a point in the center of the Sagrario Church, leaning toward its east side (SCE-21). Estimated differentials settlements will accumulate over the next 50 years, ranging from 15 cm to 80 cm. These differentials could occur in locations close to the points where the greatest subsidence was estimated.

Using records from the benchmarks taken between 2019 and 2024, the settlement rate in the area was updated, showing a slight increase from 7.2 to 7.5 cm/year.

4.2 *Recommendations to avoid damage to the cathedral*

The first step in proposing any intervention on the Cathedral building is to properly monitor the heritage property. From a geotechnical perspective, it is important to detect settlement patterns, quantify the intensity of regional subsidence in the area, and the contribution of each clay layer to the total settlement recorded on the surface.

To obtain this information, it is necessary to continue monitoring the rehabilitated piezometers. This requires maintaining the stations in good condition, which includes cleaning the covers, oiling the screws, and monitoring the emergence of the pipes that conform each piezometer.

It is also essential to conduct and interpret high-precision topographic measurements in order to obtain a detailed understanding of the settlement behavior within the Cathedral structure. Furthermore, the monitoring of benchmarks must continue to quantify the relative contribution of each clay layer to the overall settlement, as well as to determine the cumulative subsidence rate in the area. Based on this information, it is possible to evaluate the current rate of regional subsidence affecting the surroundings of the Cathedral complex. A thorough assessment of the current condition of the installed piles is of critical importance in order to identify those that are performing adequately and those that may require maintenance or intervention.

It is recommended to carry out a thorough geotechnical field and laboratory investigations throughout the whole Cathedral complex, to characterized the present condition of the subsoil in terms of both index and mechanical properties, as well as updating the stratigraphic thicknesses across different zones of the site.

Based on the results of the forthcoming geotechnical study, subsequent analyses may be conducted, encompassing distinct sectors within the entire site. The settlement projections will be computed at selected reference points, as defined in coordination with the team of structural engineering specialists.

With the results of this study, and in coordination with the structural engineering expert group, it will be possible to propose a solution to address the problems resulting from the accumulation of differential settlements

The objective is to prevent, or mitigate the accumulation of new differential settlements and to ensure that the structural stability of the Cathedral complex is not compromised by ongoing regional subsidence.

5 CONCLUSIONS

Site visits carried out between 2023 and 2025 to review the state of the piezometric stations, and the effort to access the majority of piezometers still available for monitoring, resulted in updated pore pressure drawdown rates, which increased from 1,062 kPa/year to 1,323 kPa/year at the border between the UCF and the HL. The velocity at the border between the LCF and the DD was not updated due to the lack of active instruments at that depth. With the remaining measurements determined that in a lens at 20 m depth, the pore pressure decreases at a rate of 0.86 kPa/year. From the periodic measurements of the benchmarks, the settlement velocity for the area was updated, which slightly increased from 7.2 to 7.5 cm/year.

Recent measurements of pore pressures from piezometric stations and benchmarks settlements shows how regional subsidence is evolving in the area. When comparing these measurements with estimates made in 2021, they show that, despite the lack of recent laboratory tests, calibrations were properly achieved that currently reflect the what is presently happening in the field. However, the time used for the comparison is rather small, just 3 years, so monitoring of pore pressure settlements and drawdowns must be continued, as this will provide an indication of the actual evolution of regional subsidence in the area and whether the predictions made by the models agree with actual measurements.

The estimates of the evolution of regional subsidence presented here were made based on limited recent field information, two electric cone tests executed in 2021. By comparing them with the electric cone soundings available from 1990, it was possible to measure the reduction in thickness that the clayey strata had experienced during this time and thus update the stratigraphic configuration of the available cones from 1990, taking into account the detected reduction. Furthermore, the study sites were characterized using laboratory tests from the SS-1 and SS-2 performed in 1990, assuming that compressibility remains constant along the virgin consolidation line. Therefore, to improve the results of the estimates made, a thorough field exploration is required to obtain samples for laboratory testing to verify the compressibility and viscosity values used. Also, more cone penetration tests are required to confirm the change in the thickness of the clayey strata and the increase in their resistance at the cone tip.

If this new geotechnical exploration campaign is carried out, further analyses can be conducted to validate or adjust the current time estimates available for implementing conservation measures for the Cathedral, or to determine whether the mitigation actions against differential settlements should be undertaken promptly.

It is important to recognize that the ongoing evolution of regional subsidence at the Metropolitan Cathedral has progressively induced additional differential settlements, diminishing some of the improvements previously achieved through underexcavation and rigid mortar inclusions, albeit at a substantially slower rate than before.

Given the certainty that regional subsidence will continue to evolve at the site—thereby increasing the current differential settlements of the Cathedral—and combined with the effects of future seismic activity, it is expected that the monument will experience further deterioration. This process will exacerbate cracking, displacement of structural elements, and material degradation, ultimately compromising the structural integrity of the Cathedral complex and the safety of parishioners.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Carrillo, N (1948) “Influence of artesian wells in the sinking of Mexico City”. *Proc. Second International Conference on Soil Mechanics and Foundation Engineering, Rotterdam.*

Blanch, I. (1999) “Hundimento regional del centro histórico de la ciudad de México: situacion actual y predicciones”. *Tesis de Licenciatura, Universidad Politecnica de Cataluña.*

Marsal, R.J. y Mazari, M. (1959). The Subsoil of Mexico City. *Contribution to the First Panamerican Conference on Soil Mechanics and Foundation Engineering*, Ciudad de México, México.

Mesri, G., 2001. Primary compression and secondary compression. *In: Proceedings of the Symposium on Soil Behavior and Soft Ground Construction*. Geotechnical Special Publication No. 119:122-166, ASCE.

Ovando, E and Ossa, A (2004) “Modelo elasto-viscoplástico para la consolidación de los suelos y su aplicación al hundimiento regional de la ciudad de México”. *Memorias XXII Reunión Nacional de Mecánica de Suelos, Vol. 1, 291-299.* Guadalajara, México.

Ovando-Shelley, E., Santoyo, E. (2019). Correction of Differential Settlements in Mexico City’s Metropolitan Cathedral and Sagrario Church. *CRC Press*.

Ovando, E., Romo, M., & Ossa, A. (2007). The sinking of Mexico city: Its effects on soil properties and seismic response. Soil Dynamics and Earthquake Engineering, 27, 333-343, Mexico.

Santoyo Villa, E., and Ovando Shelley, E. (2008). Catedral y Sagrario de la Ciudad de México. *TGC*, Ciudad de México.

SEDUE (1990). *Estudio de las Cimentaciones de la Catedral y el Sagrario Metropolitanos de la Ciudad de México*.

Terzaghi, K. (1923). “Die berechnung der durchlassigkeitsziffer des tones aus dem verlauf der hydrodynamischen spannungserscheinungen”. *Sitznugshrichte Akademie Wissen. Wien of Mathem. Naturw. Kl. pp. 125–138.*

Yin J.H and Graham J (1989) Viscous–elastic–plastic modelling of one-dimensional time-dependent behaviour of clays. *Canadian Geotechnical Journal 26(2): 199–209.*

Yin, J. H and Graham, J (1996) Elastic visco-plastic modelling of one-dimensional consolidation. *Geotechnique, 46(3):515-527.*