SALVAGING THE CAPILLA DE LAS ÁNIMAS IN MEXICO CITY

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SUMMARY

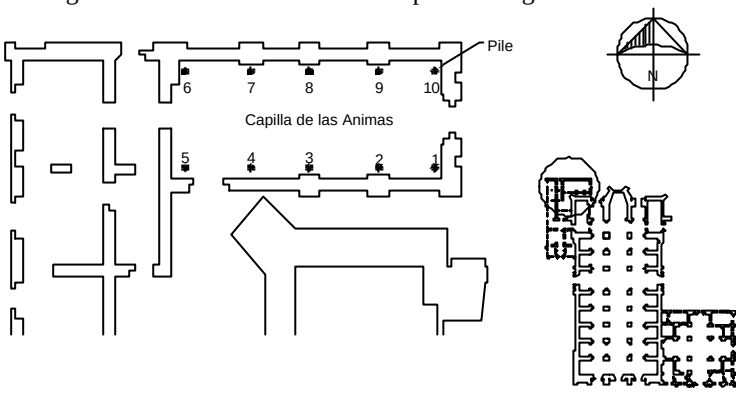
The Capilla de las Ánimas, a chapel built in Mexico City within the Metropolitan Cathedral's atrium, was damaged by differential settlements. The Chapel was underpinned in 1991 to prevent it from suffering additional damage while the Cathedral was being underexcavated. The original underpinning project was modified later, when several unexpected factors that affected it were eliminated.

1. INTRODUCTION

The Capilla de las Ánimas in Mexico City is a single nave vaulted chapel built in 1725 on the northwestern portion of the Metropolitan Cathedral's atrium, (Figure 1). It is 19.54 m long, 9.31 m wide and 9.25 m tall. Regional subsidence induced differential settlements in the chapel, starting on the mid XIXth century which resulted in severe tilting and cracking. Damages accumulated during the XXth century and, in the early 70's, an underground train was built along its northern wall, only a few tens of centimetres away from it, which resulted in further damages to the chapel. Underexcavation of the Metropolitan Cathedral, which was designed to induce settlements of almost one metre in the vicinity of the Chapel, would have damaged it even more [1]. Given its inherent structural weaknesses, the survival of the chapel could only be guaranteed by isolating it from the displacement fields generated while underexcavating the Cathedral.

The site is underlain by very soft and compressible soils, i.e. Mexico City clays, which at the site have water contents ranging from 180 to 250 %. Heterogeneous fills, including the remains

of prehispanic buildings and masonry from the Cathedral's foundation footings and raft, form the uppermost materials down to a depth of 13 m; a layer of desiccated soils, three metres thick follows, mainly clayey silts. The softest and most compressible clays are found between depths 16 to almost 38 m. A hard stratum, identified locally as the first hard layer is then found; it is more than 4 m thick and is formed by silty fine sands and pumitic gravels. Another soft clay deposit 10 m thick follows, the second clay formation. Finally, deep alluvial deposits lie at the bottom of the significant strata. Detailed descriptions of geotechnical conditions in Mexico



City can be found elsewhere [2].

Figure 1 : Location the Capilla de las Animas

The Chapel was underpinned with ten point bearing piles provided with control mechanisms for correcting tilts and differential settlements. The piles were driven down to the first hard layer and were provided with external deformable sleeves to avoid the effects of down drag forces on the shafts produced by regional subsidence and by subsidence induced by underexcavation in the Cathedral. Reinforced concrete beams were required to allow the installation of the piles. A plan showing the distribution of piles is also given in Figure 1; details of the control devices and the friction sleeve are illustrated in Figure 2. The underpinning project was carried out in the first half of 1991.

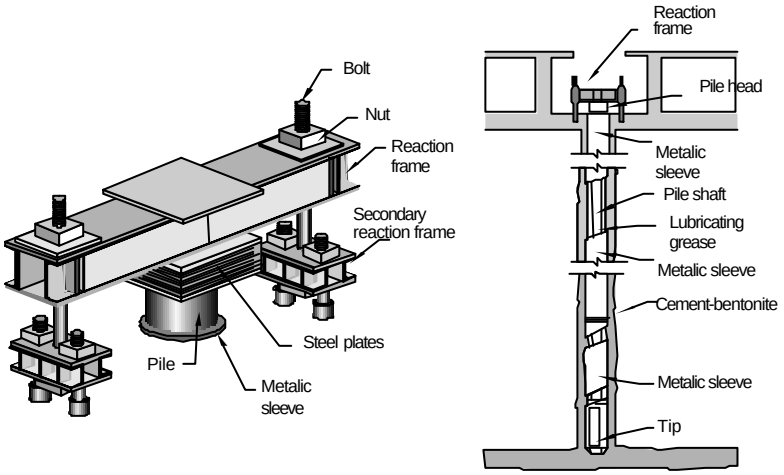


Figure 2 : Pile with anti-friction sleeve and control device in its head

There are no instrumental records of the Chapel's behaviour before August 1994, i.e. one year after underexcavation began in the Metropolitan Cathedral. However, it was apparent that fissures and cracks along its southern wall were growing continually. Plumb lines installed after that date showed that the chapel tilted 0.84 % towards its south west corner between August, 1994, and September, 1995. Convergence measurements with extensometers also showed that the lateral walls were opening and that their upper parts were tilting at a higher rate. Finally, topographical levellings at the level of the new concrete foundation beams indicated that the south wall settled at a higher rate than the wall in the north side, as seen in Figure 3. Settlement rates along the northern wall averaged 13 cm/year whilst the average rate along the south side was 15.7 cm/year. Maximum settlement rates were observed at the south east corner. Underexcavation in the Cathedral stopped temporarily between 17 April and 14 July, 1995, and differential settlement rates in the Chapel became almost negligible over this period. However, when underexcavation started again, settlement rates rose slightly and equalled 13.7 and 16 cm/year along the north and south walls, respectively.

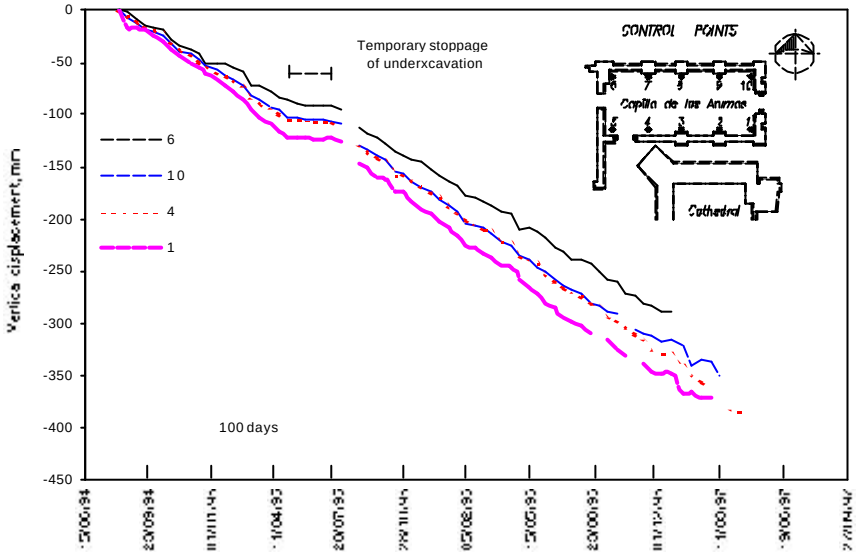


Figure 3 Evolution of differential settlements before modifying foundation

2. REMEDIAL WORKS

The behaviour of the Chapel was clearly unacceptable and, as a first remedial measure, the vault was braced with tensors, which reduced the rates at which the walls were opening. At the same time, major excavations around and under the Chapel started in order to verify the state of the foundation beams built in 1991. While excavating the Chapel, portions of the Cathedral's foundations were found, revealing that the Chapel had been partially built on top of them; in fact, some of the concrete beams had been cast directly on and around the Cathedral's foundations. Archaeological investigations also showed that the remains of an Aztec structure that formed part of a prehispanic ball court also contributed to induce damages in the Chapel.

Lastly, the chapel's northern wall was found to be lying directly on part of the Milan walls used in the underground train tunnel.

Observational data indicated that as the Cathedral's apse subsided due to underexcavation, it pulled the Chapel through the links formed between the 1991 concrete elements and the Cathedral's XVIth century masonry footings and raft. The basculating action towards the Southeast corner was enhanced by restrictions to displacements imposed on the north west corner by the underground tunnel's internal wall. Inspection of the pile heads and the analysis of their displacements relative to the floor did not suggest that a bearing capacity failure had or was going to occur.

As excavation went on, the concrete beams were detached from the Cathedral's footings and raft and, along the north wall, from the underground's Milan wall. After a thorough revision of each of the ten pile heads and their reaction frames it was decided to increase the capacity of the frames. The chapel was then detached from the piles and supported on a temporary steel structure, while the new reaction frames were installed. It was also found that the concrete beams were also underdesigned. As they were being retrofitted, it was discovered that many large spaces in them had no concrete. Specifically, concrete in the two perpendicular beams reaching the south east corner was missing.

Isolation of the Chapel was achieved by means of a line of injection wells along the north wall. Water injected through these wells moistened the clay below the north wall thus reducing its capacity for transmitting shear stresses thus allowing the Chapel and the underground tunnel to move independently. The wells were drilled at one-metre intervals down to the depth at which the Cathedral was being underexcavated in that zone (18 m). The sides of the retrofitted foundation beams were also covered with two layers of lubricated polystyrene plaques, placed along the north, east and west walls. A schematic view of the elements described here is given in Figure 4.

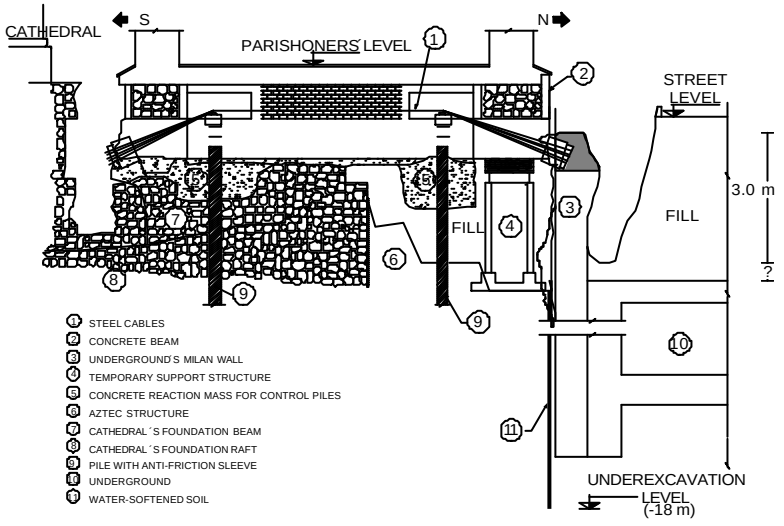


Figure 4 : Typical cross section below the Capilla de las Ánimas

Upon the conclusion of the remedial works, the Chapel was jacked along the south wall in order to reduce partially its inclination. Using the temporary steel structure as support, hydraulic jacks were placed under the south wall, which was raised gradually in small increments. As a result, the south wall rose a total of 9 cm and its inclination towards the Southeast reduced an average 1.08 %.

The graph in Figure 5 shows the evolution of differential settlements at the level of the concrete foundation beams, from 5 May, 1997 to 2 May, 2000. The sharp change in the levels of the control points near the south wall in early May 1997, is due to the jacking of the Chapel. Thereafter, when the piles were attached to the structure, settlements were mainly due to consolidation of the second clay formation, lying below the first hard layer. Settlement rates have been nearly equal after November 1998. The average value is 3.5 cm/year, roughly 50% of the total regional subsidence rate in that zone. This value closely matches the historical rate of settlement deduced from deep benchmark measurements [3].

The thickness and the compressibility of the second clay formation under the Chapel are not uniform and additional differential settlements due to further consolidation of the second clay formation produced by pore pressure reductions brought about by deep well pumping will occur in the future. Whenever necessary, they will be kept under check relevelling the Chapel by operating selectively the piles´control devices.

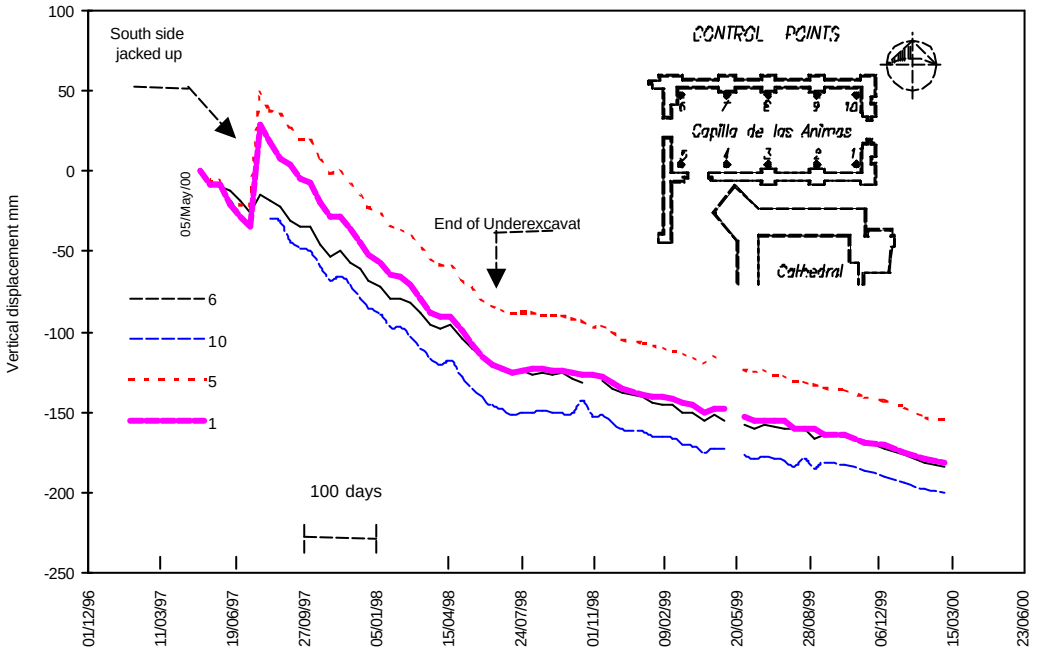


Figure 5: Differential settlements after jacking-up the south side

3. CONCLUSIONS

The Capilla de las Ánimas, built in the north west corner of Mexico City's Metropolitan Cathedral was underpinned in 1991 with point bearing piles. The original underpinning project was modified when it was discovered, while excavating the Chapel, that it had been partially built on top of the Cathedral's foundation and that the chapel's northern wall was found to be lying directly on part of the Milan walls used in the underground. The concrete foundation beams were cast directly on some of the Cathedral's masonry footings and foundation raft. It was also discovered that some of the concrete beams had been cast improperly. When the corrective intervention in the Chapel's foundation finished, it was jacked to reduce its inclination. Instrumental observations show that the efforts for salvaging All Souls Chapel have been successful.

4. REFERENCES

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