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REPAIR OF THE CHURCH OF LA PURISIMA CONCEPCION OF HUELVA (SPAIN) WITH JET-GROUTING, FOR DAMAGES CAUSED BY THE CONSTRUCTION OF DIAPHRAGM WALLS IN ITS PROXIMITY

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ABSTRACT

The Church of La Purísima Concepcion, raised in 1515 as the second parish of Huelva (Spain) has been affected by diverse natural disasters along its history.

The soil of Huelva is mainly mud, very soft and highly compressible.

In 1999 the works to build a residential building with four plants below the ground level affected the church and several buildings. Horizontal displacements of the sheet pile wall in top, overcame 12 cm. The settlements were higher to 5 cm.

The system of struts, with lengths over to 30 meters used to built the pile wall, was not the best one. Also, the diaphragm walls were designed short, and the dimensions of the element diaphragm wall were incorrect (wide 5 meters).

The foundation of the church has been repaired using the technology of jet-grouting, with columns of 15 and of 30 meters of depth and 0.75-0.80 m of diameter. Later, it was realized concrete slab to join all the heads of the columns of jet-grouting. Measurements of levelling have been realized to observe the movements of the church structure during the accomplishment of the jet-grouting.

THE BUILDING

The Church of La Purísima Concepción was raised in 1515 as the second parish in Huelva (Spain). Along its history the temple has been affected by diverse natural disasters like the earthquake of January 26, 1531, or the earthquake of November 1, 1755.

The original structure was of Mudejar arches that were remodeled in 1758, because of the damages caused by the earthquake of Lisbon, all the interior decoration and it façade were moved into a baroque style. In the XX century, a fire destroyed the ceiling of the church.

It is a basilica plant building with three aisle, and a structure of pillars and arches, that in their origin they were aimed, to subsequently remain hidden and transformed into semicircular.

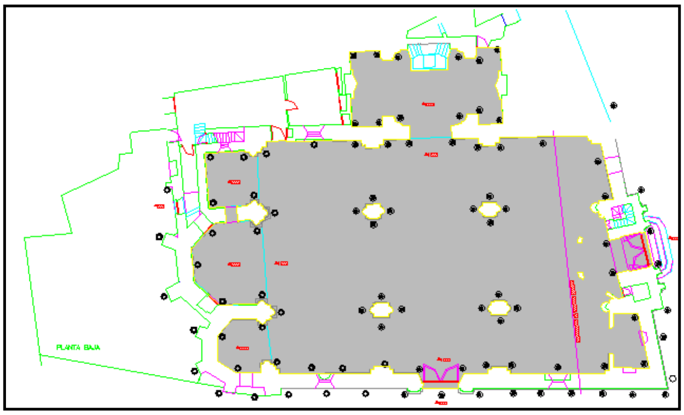

Fig. 1. Plant

THE SOIL

The coastal marsh that characterizes the soil zone is a composed, recent geological formation by an accumulation of fine-grained soils of marine origin, silt and clayey soils with fine layers of sands and seashells.

The subsoil in this zone of Huelva is composed by a layer of silt and clayey muds of very low resistance and high deformability, with a thickness of some 9 meters that is found on a layer of sand with layers of gravel. From 17 m of depth we found grey silt , with a thickness of 15 m and finally from the 28m of depth we find some marl clays. The water table was found at 3.20 meters

The cut of the soil that is obtained of the bores carried out is:

- Level I Backfill
- Level II Brown clayey silt with gravel
- Level III dark grey clay with shells
- Level IV Clayey Sand with gravel
- Level V Silt of variable plasticity
- Level VI Marl clay

Table 1. Soil Parameters

DEPTH.	GEOCISA	RODIO	INTECSA
0-2,10 Level I	γ = 19 kN/m^3 ϕ' = 20º c' = 10 kPa N =2 N.F. 2,00	γ = 19 kN/m^3 ϕ' = 28º c' = 0 kPa N.F. 2,10	γ =19 KN/m^3 c' = 0
2,1-7,8 Level II	γ =19 kN/m^3 ϕ' = 22º c' = 15 kPa N = 5	γ = 19 kN/m^3 ϕ' = 22º c' = 15 kPa	γ = 19 kN/m^3 c' = 150 kPa
7,8-11,0 Level III	γ=19,5 kN/m^3 ϕ' = 19º c' = 5 kPa N = 6	γ=19,5 kN/m^3 ϕ' = 22º c' = 15 kPa	γ=19,5kN/m^3 c' = 150 kPa
11,0-14,0 Level IV	γ = 20 kN/m^3 ϕ' = 25º c' = 20 kPa N = 40	γ = 20 kN/m^3 ϕ' = 30º c' = 10 kPa	γ=20,0 N/m^3 c' = 100 kPa
14,0-23,0 Level V LL=52% PL=25% PI=27%	γ=20,5 kN/m^3 ϕ' = 29º c' = 35 kPa N = 25	γ=20,5 kN/m^3 ϕ' = 30º c' = 20 kPa	γ=20,5kN/m^3 c' = 100 kPa
23,0-30,0 Level VI	γ=20,8 kN/m^3 ϕ' = 28º c' = 70 kPa N = 45	γ=20,5 kN/m^3 ϕ' = 28º c' = 70 kPa	γ=20,5 N/m^3 c' = 700 kPa

The parameters of the soil used by the different people had been very different according to the work they were doing, existing variations in some of them, as is the case of the effective cohesion of the soil, of to 10 times its value.

Fig. 2. Bore holes machine working inside the church

ORIGIN AND CAUSES OF THE DAMAGES

Near the Church of the Conception a residential building was being built with four plants bellow the ground level. They were building a sheet pile wall in the boundary of the new building and it began to be executed in the summer of 1998.

While building the sheet pile wall began to appear damages in the church, derived from the displacements of the same, because the rows of trust that were placed were not enough to guarantee the absence of movements, that went sensitively bigger than movements calculated in the project.

In a first moment were detected a series of damages in the Church and in the next parochial buildings, consisting fundamentally in cracks of different importance inside the parochial buildings. The controls placed, in the Church as in the surrounding buildings, appeared broken, what corroborated the lack of stabilization of them mentioned movements.

According to Rodio, the movements of the walls would oscillate among the 11.83 mm at 6,50 meters of depth when they excavated to 7 meters and the 18.65 mm at 9 m of depth when the excavation reached 12 meters. These calculations were carried out with limit states methods and the deformations of the walls were deduced from them, so these are totally fictitious.

We have calculated the movements by the method of the finite elements and considering the real parameters of the soil and the different phases of the construction of the walls and the placement of the anchorages, movements in the heads of the walls are between 10 and 12 cm, ten times over them calculated by the methods of limit state.

The 23-11-98 the first damages were detected, cracks in the parochial buildings of the Church of the Conception. The works of excavation the underground plants were at the second phase and proceeded to stress the trust of the 2º level.

The cracks in December of 1998 had advanced to a greater distance from the excavation.

The struts that were placed to avoid the movements of the walls suffered very important elastic shortage, because of fundamentally of the inflexibility of their nods. The diagonals of the struts were fixed to the main cords by a screw, which does not permit to guarantee the fixing among these two elements, should calculate like an pinned fix.

The depth of penetration of the wall was not enough, as they do not reach conveniently in the layer of marls, producing water filtrations to the building.

Fig. 3. Pinned fix detail.

Because of the irregular geometry of solar, the bracing supports were not arranged perpendicular to the walls, but are placed in angles even in 41º, what complicates clearly the transmission of efforts and the efficacy of the pre-stressed. Besides the lengths of many of the support are next to the 30m. The wall was built in very long parts in many cases, longer than the 5 meters.

Because of the movements of the walls there had been differential settlements in the supports of the church, and the parochial buildings, and many cracks appeared in the walls.

The damages caused by the movements of the walls by failures of the provisional struts have been increased by the modifications of the water table, and the changes in the soil parameters.

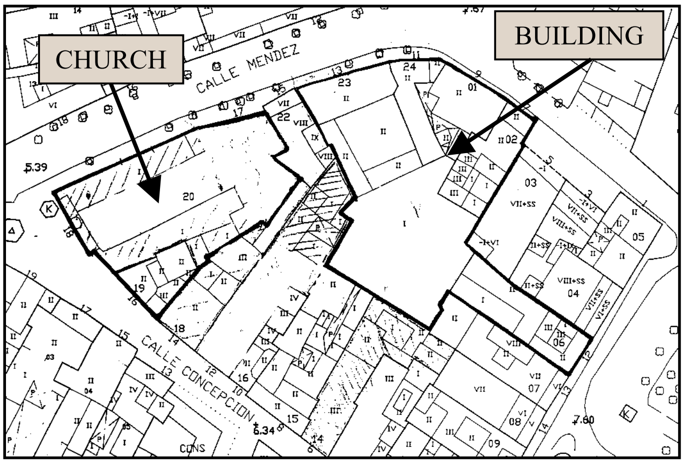

Fig.4. Situation

Fig 5. Bracing support.

During the building of the sheet pile walls was necessary to move water from the excavation, which changed the moisture content in the soil under the Church. The construction of the walls to the 24 meters changed the journey of the subterranean run-off of water originated in the hill, and it has increased the water table in the sidewalk of the building. The measure of the water table carried out a descent of it in the tube placed in the interior of the church, while in the tube placed in the sidewalk of the new building has verified the elevation of the mentioned level.

THE REPAIR

The repair of the Church consisted in "Jet Grouting" (J-1) all around the church. The system consists essentially in the cement grouted with very high pressures breaking the adjacent soil, at the same time that is mixed with the whitewash of cement grouted and whose result is a column of cemented soil. The employed columns have a length of 15 and 30 meters and a diameter of 70-80 cm.

Fig. 6. Jet-grouting column.

The inclination of the columns went of 7º in the perimeter of the temple and of 15º in the four central pillars. 65 columns of 15 meters they were carried out and 31 of 30 meters.

To verify the admissible load of the piles used the boards of Michel Bustamante.

The 8-9 first meters do not have practically any resistance (the number of blows is lower in many zones to 2). We consider 6 meters of bulb grouted (type IRS from 9 to 15 ml). The medium value of the number of blows is of N = 10.

For this value we consider a frictional resistance of 0,15 Mpa, according to the figure 17 of the article of Bustamante (1986). For clay + silt. Type of injection AL. 1. We consider 150 kPa.

We consider that the 60 cm of the diameter of the column already is the diameter Ds. It is the equivalent to consider α = 1.

$$Q_l = \pi * D_s * L_s * q_s \qquad (1)$$

$$Q_l = 3{,}1416 * (1{,}0 * 0{,}6).6 * 150 kPa = 16963{,}46 kN \qquad (2)$$

$$Qp = Ap * kp * pi = 0{,}3^2 * 3{,}1416 * 1{,}6 * 650 = 294 kN \qquad (3)$$

The relation among the point and the shaft resistance is of the 17,33%, according with what says Bustamante in its article (of the 15 al 20%).

$$Qadm = (Ql + Qp) / F = 1696{,}46 + 294 / 3 = 663{,}49 kN \qquad (4)$$

It agrees to consider a coefficient of efficacy of 0,7 for the group effect, for which the admissible load of a column of 60 cm, will be of 464,44 kN.

Two lengths of columns have been used, whose admissible loads would be the following:

Table 2

LENGTH(m)	**QS**	**QP**	**Q_{HUN}**	**Q_{ADM}(kN)**
15	1696,46	294	1990,46	663,49
30	5937,61	294	6231,61	2077,20

Once we calculated the columns, were adopted the following injection rules:

- Holes of 2" by the ones that the whitewash of cement leaves, mixed 1/1.
- Volume of admission 4 kN/ml.
- Grouting pressure 40 MPa.
- Volume injected 100 l/min.
- Velocity of rotation 16-18 rpm or Steps of 4cm each 9 seconds.
- Armed with high bars of steel resistance DW36.
- Cement type 42.5 R SR.

In a first moment, we made some columns for testing the results and we checked the penetration of the fluid in the interior of the soil.

The penetration of a pressured fluid in coherent soil can produce a drag of particles, collapse by saturation of unstable layers or even the heave in foundations, if we apply strong pressures near its level of support. Nevertheless, in incoherent or little cohesive soils, it can produce exactly the contrary effect when you begin to grout and you can produce settlements.

Later, if it is introduced a portion of whitewash is when begin to be produced the heaven. It is then when the soil has managed to stabilize, or is quite next to it.

Before begin any grouting was carried out a leveling of the building and of the environment, to be able to control the possible movements induced by it, as well as the monitoring of the cracks of the arches and in the different walls. Also there were placed horizontal struts among heads of pillars in the two directions, by means of a steel cables, giving them stability to the church.

Fig. 7. Struts among head of pillars.

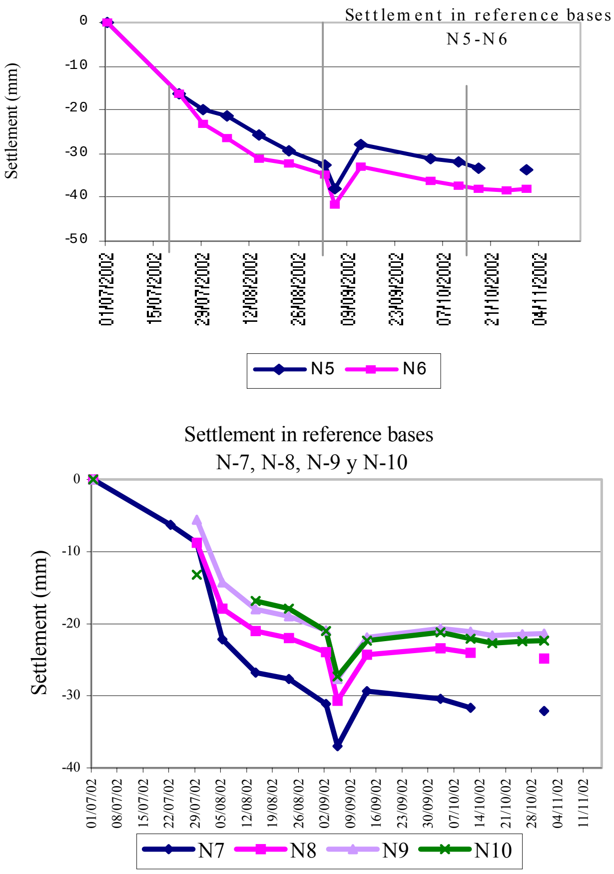

Fig 8. Settlements in reference bases.

The measured heaves went of 9 mm maximum in some points, oscillating most of them, around 1-2 mm, as we can see in the graphics (fig. 8).

After finishing with the injection it was excavated to a depth of 1,10 meters, being filled with gravel and compacting the 40 lower centimeters. A PVC sheet was placed above the gravel and a concrete slab was built, with a surrounding beam to tie the heads of all the columns of Jet of the interior of the church.

Fig 9. Crypts

In some zones the excavation was made by hand because they found three crypts in the presbytery and an under the chapel of the Vera Cruz, in which human remainders were found. Their vaults are straight tube with circular guideline, built with a solid thread of a foot brick received with lime mortar.

Finally the cracks of the arches were repaired, sealing them with a lime mortar with acrylic resin and sewing them with stainless steel rods fixed with epoxi resin. The most important cracks were rebuilt all their length, reorganizing the crack and replacing the solid brick received with lime mortar and white cement.

Fig 10. Concrete slab.

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