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Restoration project of vernacular architecture affected for ground subsidence: A case study in Juslibol Church (Zaragoza, Spain)

Alberto Gracia[1], F. Javier Torrijo[2,3], Miguel A. Pérez[1]
[1]CTA, Consultores Técnicos Asociados, S.A.P., agracia@cta-consultores.com, mperez@cta-consultores.com; [2]Research Centre PEGASO, Universitat Politècnica de València, fratorec@trr.upv.es; [3]Department of Geological and Geotechnical Engineering, Universitat Politècnica de València, fratorec@trr.upv.es

Topic: T4.1. Conservation and restoration projects of vernacular architecture.

Abstract
At the request of the Archbishopric of Zaragoza, an exhaustive study of the situation of the parish church dedicated to the Assumption of Our Lady (18th century) in Juslibol (Zaragoza) has been carried out since 2011. It was built between 1758 and 1784. The church was built on a hillside with a medium-low slope, excavating in a loose colluvial soil formed by silt-clay materials with fragments of marl-gypsum rock. and pebbles of gravel and sand from the terrace deposits located in the highest part of the slope. Once the plot was leveled, the ground would be prepared and the foundation elements would be excavated (apparently continuous trenches) according to the design of the projected building floor plan. This church has suffered for many years from deformation and settling problems caused by the combination of several especially unfavorable factors, such as: the poor quality of the support ground, its sloped location halfway up the hillside, and leaks-filtrations from a supply network, and especially sanitation, which have favored processes of dissolution-undermining of the land below the foundations. The part facing south, including the tower, registered differential settlements with respect to the part further into the hillside. Once this situation was assessed, it was underpinned by means of jet-grouting columns and, apparently, the measure was effective. However, the cracks now observed are not explained within a differential settlement process.

Keywords: *church; sloped; settlements; leaks-filtrations; gypsum; expansive salts.*

1. Analysis of the problem

Situation on the hillside

Expanding the study area, it can be seen that the problem does not fit only the church. One aspect that had not been sufficiently dealt with until now is the situation of the recognized deformations in the church, in relation to the existing cracks and deformations in the environment closest to it. From the scheme of the cracks recognized in the pavement of the surrounding streets, and the square that is in front of the main door. These are arranged towards the upper part of the slope, in consecutive discharge arches, which give meaning to the idea of a descending flow that fits well with the morphology of the cone or ejection fan of the primitive ravine.

It can be said that the problem that affects the church, in terms of the movements that it is registering at this time, has its origin in a much broader scope, which includes at least part of the slope that corresponds to the old cone of dejection of the ravine that is located right at the head.

The first discharge arch (1) is obtained by correlating the cracks observed in the pavement of the street, just at the corner of the church, in front of the tower. These seem to be directly linked to the emptying of the lot on the other side of the street.

Fig. 1. Location plan. Situation and morphological analysis of the cracks on aerial photography (Source: ©2018 Google).

Fig. 2. Location plan. Situation and morphological analysis of the cracks on aerial photography (Source: *Investigation report for the assessment of problems in the subsoil of the juslibol church (Zaragoza)*, 2014).

Arches 2 and 3 are obtained by correlating the open cracks in the sidewalk (now repaired), which continue to cross the church's street and apparently continue along the low wall of the square, towards a more open area.

Arches 4 and 5 are the ones that project towards the interior of the hurch. From the square they are easily recognizable. One of the cracks crosses it in the middle and goes through the centre of the front door. The other (5) can be seen from the square, on the corner next to the house, breaking the low wall on the church's street in 2-3 places, and projecting towards its façade where it is very evident on the wall and especially in the stone oculus. Both cracks project through the interior of the church itself, exiting through the main altar. In his case, number 3 affects the sacristy and the adjoining house (currently being demolished).

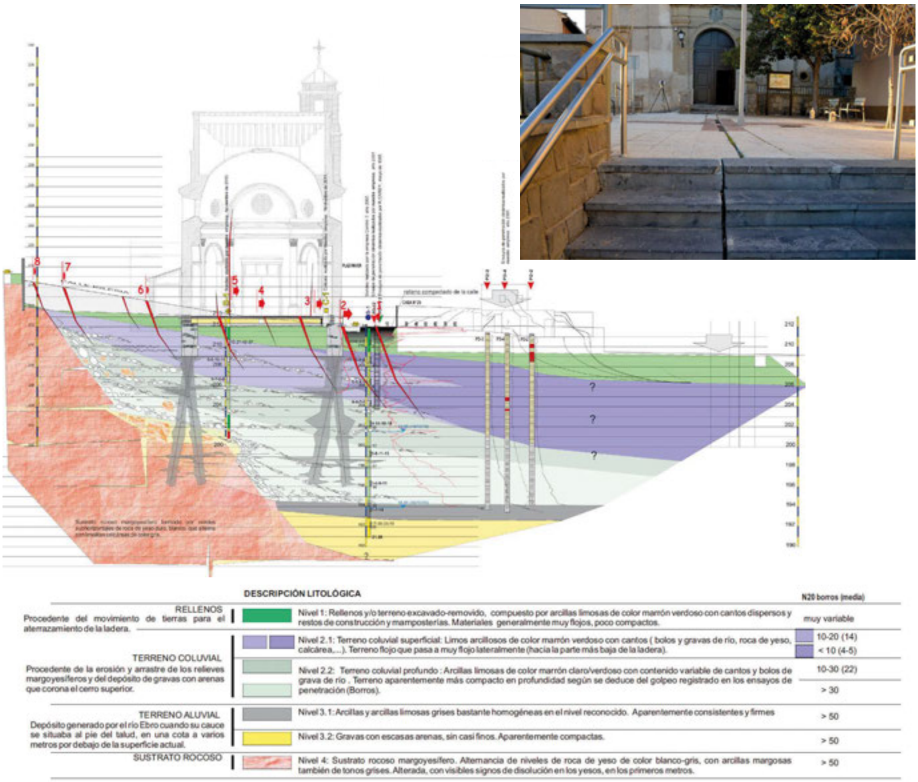

Fig. 3. Geotechnical correlation profile of all available information. (Source: *Investigation report for the assessment of problems in the subsoil of the Juslibol church (Zaragoza)*, 2014). In the photograph it can be seen the crack number 4 recognisable in the square that is in front of the main door.

Cracks 6, 7 and 8 apparently only affect the street and the old parish house, forming discharge arches towards the lower part of the slope, with the same design.

At present, it is concluded that: the process is still active. Either because the situation of the sanitation network has not been sufficiently resolved, due to deficiencies and leaks from the supply network (in the examination of February 7th, 2018, it was possible to observe, in the manhole on the corner of the church; church' street with "Calle Mayor", which was full of water). Or due to the inertia of the process in which the leaks have already established a trend and favoured channels for the infiltration of riverbed waters coming from the upper areas of the slope and/or non-localized leaks in supply and sanitation.

Fig. 4. Interior view of the church (Source: The authors, February 2022).

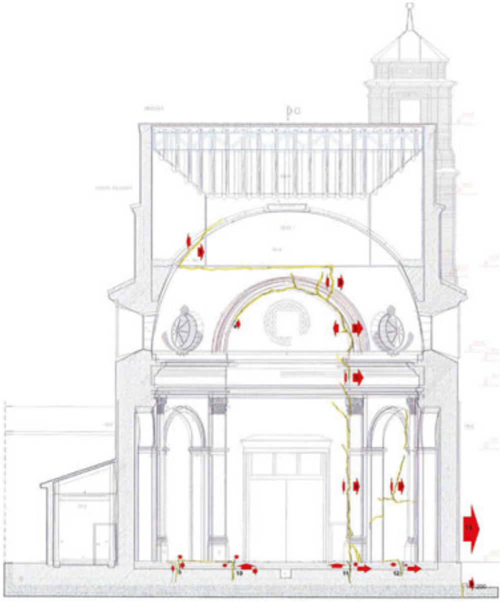

Fig. 5. Schematic profile of the main cracks and fissures that can be seen inside the church. The position and magnitude of the arrows express the apparent movement that the recognized deformation has developed. In the photograph, you can recognize some of the cracks in the part of the altar-presbytery.

Water-moisture content in the subsoil.

The phreatic level of the area is located at a depth of the order of -18.00 m. Apparently, it is associated with the coarse detrital materials of level "C" (sandy gravel from the lower terrace of the Ebro), as it has high permeability due to its high intergranular porosity. This water table is permanent and its vertical oscillations are closely linked to those suffered by the free aquifer of the Ebro river alluvial.

However, in measurements obtained in the drilling carried out, it was found that the level fluctuates a lot in this area. Specifically, in the surroundings of the church, it has been recorded at -4.00 meters from the mouth of a drilling carried out next to the south wall, taking street level as a reference. Even admitting the presence of "hanging" aquifer levels, associated with layers of greater relative permeability intercalated within the colluvial deposit, it is clearly anomalous.

The most obvious explanation relates these groundwater contributions to the frequent presence of leaks in the supply network, but, above all, from an old and defective sanitation network. The former are detected relatively early as they affect supply. But the sanitation ones remain undetected for years. Only when a sinkhole appears in the street or a façade wall or the corner of a house comes down.

One thing to keep in mind in relation to the process studied here, is that related to the abundant mud found in the layer of river bowls that was placed at the end of the underpinning and repair work on the church carried out in 1997. In the test pit carried out in November 2011, the aforementioned bowls were extracted, completely impregnated with very wet mud. This mud has necessarily had to be "injected" into this layer of bowls by a stream of water.

In addition to the normal contributions, the surface runoff accumulated by the receiving basin of the entire ravine located at the head (more than 10,000 square metres), is captured in the highest streets and channelled through the sanitation pipe (40 cm long) that goes down the street of the church. Considering the flow at times of heavy rains (storms), the relative slope (high) and the poor quality of the sanitation network in certain sections where the installation is already very old and defective (see Roads and Water Reports), it is easy to deduce the result.

It is immediate to correlate that, at certain times of intense rains, underground water infiltration occurs from the sanitation network itself, at very considerable pressures, as shown by the deep sinkholes that have been recorded for years. The water "injected" under pressure through broken pipes or with poorly placed joints, undermines loose soil that dissolves, disperses and relocates, often affecting the foundations of the closest buildings.

It cannot be a coincidence that in recent years there have been a significant number of breakdowns with chasms in the ground, located in an environment very close to the sanitation network and among them, in the high streets located just above the church.

The sanitation network around the church is made up of asbestos-cement pipes that in recent years it has been replaced by more resistant plastic-PVC pipes. However, if we look at the previous photographs, it is very clear that the very ditches that were used to lay the sanitation pipes are visibly undermined and through them, and down the slope, there is a circulation of underground water contributions with drag of materials.

Fig. 6. Supporting the previous argument, it is especially relevant to observe in the two photographs 5 and 6, the holes or highly washed areas that appeared next to the manhole and collector (indicated with an arrow). These have been filled with rubble from the excavation itself, to later proceed to pour the sealing concrete of the connection socket of the new collector with the manhole. These two points would be connected and present a clear continuity parallel to the collector and apparently towards the lower part of the church's street.

Growth of expansive salts.

As already mentioned, the differential settlement problems that had affected the building for years determined that, in 1997, it was underpinned by cement injections using the jet-grouting system. It was injected from inside and outside the church to a relative depth of -14 meters. Apparently, a sulphur resistant cement was used.

However, very few years later, deformations began to be registered that fundamentally affected the floor of the church. This began to rise forming an inner ring; a meter or so from the walls, reaching to break the floor. Control of these deformations has been carried out for more than ten years and it has been verified that it maintains a fairly constant progression. The registered relative ascents reach more than 15cm.

Drillings and reconnaissance test pits have been carried out inside and outside the church. In them, along with the remains of the cement grout injections, massive-looking materials with saline efflorescence and a gray-white colour have been recognized. Apparently "growing" from the cement inclusions themselves.

Analyses have been carried out in a specialized laboratory (Laboratory for Building Quality of the Government of Aragon) and the majority contents, within the two samples tested, of Ettringite and Thaumasite have been identified by means of X-ray refraction.

In the pit, it can be seen how these massive-looking materials, in their apparent growth, come to "force" the upper levels, generating pressures that deform the layer of gravel and pebbles and contribute to raising the floor, cracking it (Figure 8). The entire floor of the church presents deformations, with up to 15 cm of relative elevation, in an annular environment parallel to the interior perimeter of the sill.

Fig. 7. Pit nº2, (interior). Next to the foundation wall of the Church. The fractured concrete floor and the foundation are recognizable. In the second photograph, detail of the deformations of the floor. Cracks are recognized in the base of the wall due to fundamentally vertical component thrusts.

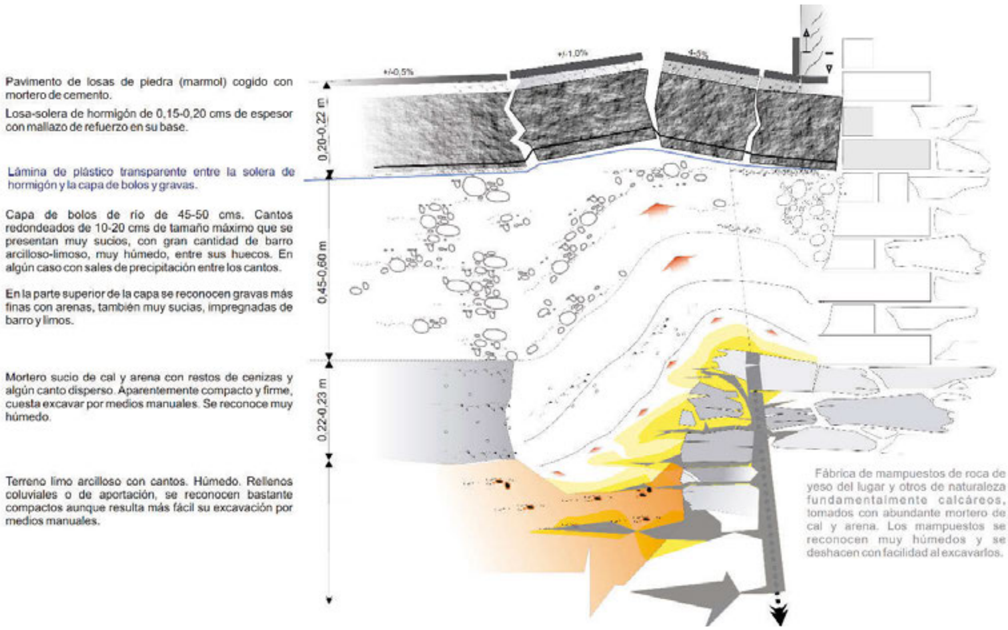

Fig. 8. Outlined explanatory diagram of the situation observed during the excavation of pit 2. The figure includes the cement grout injections, which were injected-infiltrated between the gypsum rock masonry of the very foundation of the Church walls. These gypsum rock fragments are sometimes recognized as broken and displaced; enclosed within a grey-whitish mass (in yellow).

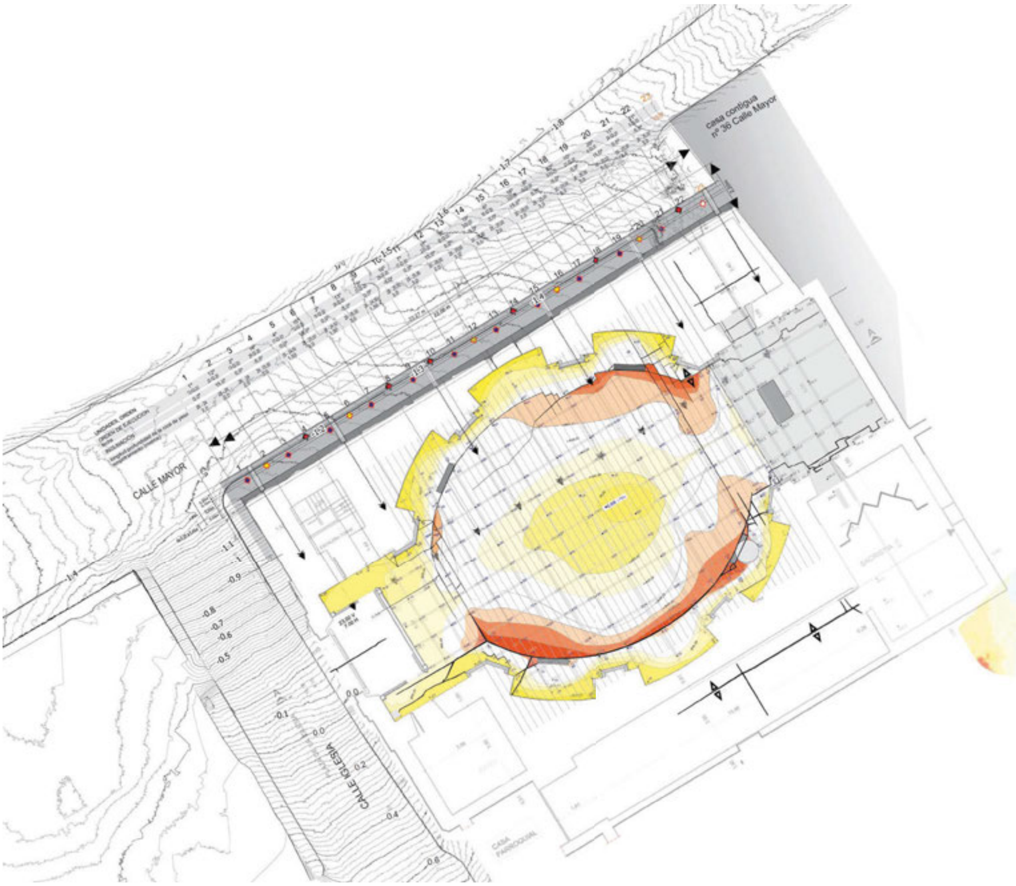

Fig. 9. Plan layout of the areas that register the greatest deformations in the floor of the church. Carried out by means of a self-levelling precision laser level, it registers the relative elevations of the floor.

2. Preliminary conclusions of the observations made

1) The cracks and fissures have a typology compatible with fundamentally horizontal relative displacements between the lateral walls (longitudinal) in an apparent direction towards the lower part of the slope. They do not indicate movements due to differential seating in the vertical.

2) Such movements have their most probable cause from pressures of hydrostatic origin of underground water infiltrated in the slope. Considering the geological-geotechnical model, the contributions that have been infiltrating fundamentally from a very defective sanitation network have generated these pressures. The inertia of the process maintains, even after partially repairing that network, the dynamics of efforts and has configured a trend that does not seem to stop.

3) The phenomenon of raising the ground of the Church seems to have a different origin. Most likely related to the growth of expanding salts under the floor. Throughout the interior perimeter, coinciding with the injections of jet-grouting carried out in the underpinning carried out in 1997.

4) Both processes are probably related and complement each other.

5) The terrain configuration; very loose towards the lower part of the slope, it favours the descent-deformation process of the colluvial land itself towards the south; towards the river valley. The cracks that affect this entire area, after performing their lateral correlation, begin to register from the upper part of the slope ("Alta" Street), so it is not a punctual effect that is concentrated in the church building. Traction cracks are also recognized from the south wall of it.

6) The process of apparent expansion that produces the lifting of the floor of the church, may also be acting laterally, favouring thrusts that contribute to "opening" the cracks in the transverse direction of the building. However, this stress system is not recorded in the longitudinal direction.