INCREASING SUSTAINABILITY THROUGH CONSOLIDATION WORKS AND DEGRADATION STABILISATION OF THE ROMANIAN ORTHODOX CATHEDRAL IN GHELAR

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Abstract
The aim of the paper is to present the study conducted at the Romanian Orthodox Cathedral in Ghelari, Hunedoara District. The construction works started in 1939 with: the selection of the location, works for the consolidation of the foundations, superstructure and of the foundation land in the area, in the '80, partially done.
Ghelari is a commune in the district of Hunedoara, situated at an altitude of 760m, in the Massif Poiana Ruscă. The soil is made of iron ore, siderite in depth and brown iron ore at the surface.
The iron ore extraction goes back in time to the Geto-Dacians. The mine Ghelar-Est was founded in 1969. The valleys are dry; the water level is under the bottom level- approx. 500m. The top level is at approx. 200m. The water lenses have 5-to- 5 m depth.
The damages at the Orthodox Cathedral are caused by the land subsidence in the area of the commune Ghelar. The phenomenon is caused by the mining exploitations works and the incomplete filling of the mine galleries.
The intervention studies conducted aimed to find a solution to stabilize or to attenuate the subsidence phenomena, by consolidating the building to increase the load bearing capacity for different subsidence levels at the cathedral built surface.

Keywords: *Ghelar, cathedral, damages, stabilization, consolidation*

INTRODUCTION

CAUSES OF THE DAMAGES

The underground workings for the ore extraction make big cavities in the underground ore, which after the removal of the proppings can lead to important movement of the land, such as the subsidence of the surface rocks. None of the filling operations of the mines can provide a complete filling of the cavities.
In percentages this can be of maximum 50-60% after the dry filling settlement or after the water loss following a hydraulic filling.
That is why the surface settling advances like a wave and it is usually smaller than the dug gallery, because the layers which break down increase their volume because of the soil loosening. By subsidence, the ground surface takes the shape of a plate called "cuvette" and expands on an area bigger than that of the underground exploitation.
The movements of the ground are both vertically and horizontally as the compression-subsidence wave advances. On the vertical direction, the size of the subsidence increases towards the middle of the depression area.

On the horizontal direction, in the adjoining area of the depression where the curve center of the depression curve is under the initial level of the ground, elongation and breaking efforts are produced. In the central area, where the there is the curve center compression efforts occur.
As the mining workings advance, the load stress changes, the horizontal efforts change their direction or they are even annulled in the middle areas of the depression.
The ground deformations caused by underground coal extractions last a long period of time and they continue long after the extraction works are completed.
The exceeding of the compression-subsidence maximum admitted values leads to the occurrence of damages in the use of the buildings situated in the subsistence bed.
Initially, a construction leans in the direction of the coal mining exploitation front, then after the front passes by the building, this starts leaning in the opposite direction. Sometimes, there are even situations in which the slopes are inverted.
The flexible buildings have a higher deformity level and they can follow the ground deformations without damages that could affect the strength capacity of the building. Unfortunately, the rigid buildings do not have this deformation capacity that is why there are several damages that can occur: cracks, structural breaks in the underground elements or in the above ground elements of the buildings.
The degradations of the structural elements are amplified every time a subsidence wave crosses the building.

SHORT HISTORY AND INTERVENTIONS IN TIME

The location of the Romanian Orthodox Cathedral of Ghelar was chosen in 1939 when the local people started to collect the money contributions to build the cathedral.
The initial project was made by the Viennese eng. architect Neugebauer, employed by the Romanian state.
The works began on the 17^{th} of September 1939, being monitored not only by the engineers sent by Episcopacy but also by other engineers and architects, as well.
The Cathedral has a building surface of approx 37x21m, 12 m high from the pronaos, 15m from the altar, 18m at the 4 little towers, 27m in the cupola area, which partially covers the naos and 30m at the two big towers.
In 1976 the first fissures occurred in the structural construction elements of the orthodox cathedral, and in 1977 they became more evident.
Along the year 1981 there have been noticed damages at the dwellings in the area, which worsened in the next years.
With the intension of stopping the phenomena, consolidation actions were taken both for the consolidation of the cathedral ground and the cathedral itself, as well as for the dwellings in the area.
Land consolidation began on the basis of a directory project designed by INCERC Bucharest, but not entirely finalized. The consolidation solution consisted in making reinforced drillings, vertical and inclined at 30^o and $60^{o.}$
The real consolidation works began with the external foundations which were coated and under concreted. Then a high quality reinforced concrete girdle was made, in compliance with the project made by IP Hunedoara. These girdles were to be connected with "horizontal tunnels under the cathedral floor, reinforced and injected."
In April 1992 new cracks were noticed in the altar area, along the longitudinal direction from the altar. At that time the girdle was only half made. In August 1992, the girdle was completed the way it was designed, i.e. with interruptions at the stairs, because of the interdictions imposed by the parish.

In September 1994 and September 1995, respectively, there have been noticed new cracks in the consolidation concrete girdle.
On contract basis, INCERC Bucharest mounted marks on the cracks in the cathedral walls and monitored their advancement, from 1993 until 1995.
Likewise, some plaster marks were placed on the direction of the cracks. They were monitored for two years and showed that the cracks continued to grow. From 1978 until 2001, The Hunedoara Mining Enterprise, through its compartment Topo-Geo, monitored the compression-subsidence movements in the Ghelar area, according to Map-Plan -Station Observation, MERIZ-GHELARI.
The same, in 1999, The Design Institute –Deva SA designed the project: “Local Protection of some interiors of the Ghelar Cathedral”. Protection nets were put to protect both the paintings and the parishioners against the falling of the painting and of the masonry from the cracked area.

MATERIAL AND METHODS

DESCRIPTION OF THE BUILDING AND OF THE DAMAGES

The Cathedral has a building surface of approx. 37x21m, 12 m high from the pronaos, 15m from the altar, 18m at the 4 little towers, 27m in the cupola area, which partially covers the naos and 30m at the two big towers.
The Ghelar Cathedral is made up of a pronaos, next to which two side towers are placed, a naos provided with two apses and an altar placed between four other towers. At the entrance and at the side parts of the naos there are balconies, which reach the central area of the cupola.
Thus, the cathedral architecture built between 1936 and 1939, can be characterized as having a Neo-Byzantine style with Baroque influences in the solving of the details, of the windows and of the inner finishings with ample development; taking into consideration, probably, the financial resources they had at their disposal.
In the photos one can see the cathedral and the damages.

Fig.1. Main façade of the cathedral


Fig.2. Cracks/open joint fissures at columns
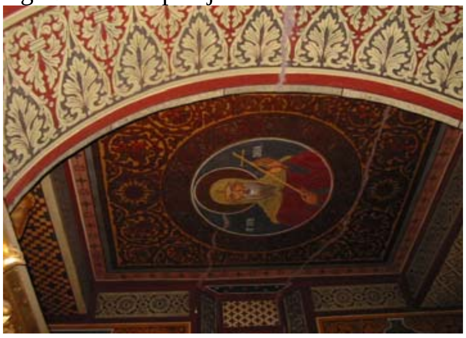
Fig.3. Cracks at arches and vaults

Fig.4. Cracks in the floor
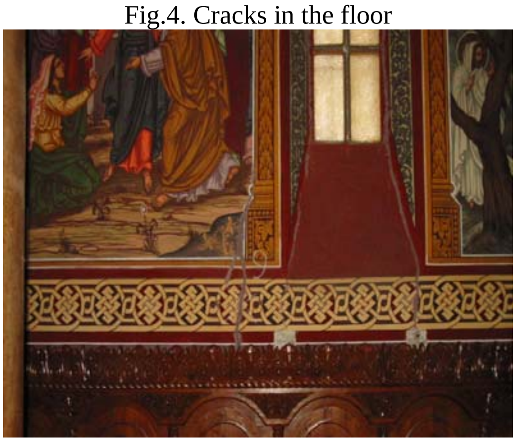
Fig.5. Cracks in parapet beams and walls

In 1976 the first fissures in the cathedral structural construction elements were noticed. They became more visible in 1977.
During the year 1981 there have been noticed fissures in the construction elements of the dwellings in close proximity; the phenomenon was intensified in the following years.
In April 1992 new cracks were observed, next to the altar, on the longitudinal direction of the cathedral.
In order to know, locate and monitor the deformation phenomena, the Topographic Station Merizi, was founded in 1978. It monitored the subsidence phenomena until 2001.
In 1995, when the studies were issued, the calculus of the topographic station pointed out the following parameters:

- total subsidence -9013mm;
- maximum subsidence velocity-79mm/day;
- maximum longitudinal displacement -12174mm
- maximum specific deformation -334mm/m;
- leaning interval -894mm/m.

The conclusions presented in the studies made by CEPROMIN and ICECOM- Bucharest and drawn by the research team from the CCIA Department of the Civil Engineering Faculty show that besides a slightly reduced evolution of the damages, in comparison with the previous years the phenomena, the situations and the damages observed also include:

- fissures and cracks in the brick vaults – at the heading stone, in the field, at the springings;
- fissures and cracks in the window-recesses between the windows of the exterior longitudinal walls, in the heads of the window, in the parapet beams, and in the cornice;
- fissures and cracks at the crossings, ramifications and at the corners between the bearing walls and other dividing elements and at the floor joints;
- shearing sections of the empty spaces between the windows and the external walls;
- fissures and cracks in the parapet beams of the inner balconies;
- fissures and cracks in the floors;
- fissures and cracks in the stairs: main, secondary, side and back, with the tendency to detach from the building;
- the left side pillar is very fissured and has the tendency to lose stability;
- fissures and cracks in the dividing walls, non-bearing walls;
- fissures and cracks at the ground floor and in the balconies;
- fissures and cracks with tendency of the detachment of the inner and outer masonry;
- The above mentioned damages have a relatively uniform distribution, but have the tendency to concentrate in the central area of the naos, with the cupola and the other adjacent areas, mainly towards the pronaos, practically jointing transversally the building in three parts.
- Changes in the position of the construction elements ratio to the implant milieu- *maximum subsidence level 800-1200mm, over the period 1978-2000, of the Cathedral perimeter.*
- Changes in the shape of the construction elements- *deformation of the stairs and pillars*;
- Changes in the protection degree, either from the sealing point of view or from the aesthetic point of view- *degradation of the stairs, of the interior paintings, parapet beams, floors, walls, etc.*

- Faults and degradations in the structural strength with implications over the safety of the construction elements or safety exploitation- *decrease of the bearing walls rigidity, fall of the masonry, decrease of the strength capacity of the wall structural strength.*

ANALYTICAL EVALUATION OF THE EVOLUTION STATE OF THE LAND DEFORMATION AND OF THE DAMAGES

The purpose of evaluation is to determine the dynamics of the land subsidence and of the opening of the fissures during the periods in which these values were measured.
Consequently it studies:

- the variation of the opening of the fissures, in the period 1993-1995, the at the ground floor and at the first floor of the Cathedral, after the girdler was made and the ground injected;
- the ground deformation dynamics over the period 1984-2000, for Profile 900 and in the period 1978-2000 for Profiles 200 and 1000, *all the three profiles outflanking the area of the commune Ghelari.*
- the land deformation state over the period 1978-2000, for Markers 205-206-207 on the Profile 200, markers that delimit the Cathedral longitudinally;
- the subsidence variation of the markers set on the southern side of the Cathedral- 4 pieces R2-5, from 1981-1990.

A comparative representation is shown in the graphs; therefore the following conclusions can be drawn:

- Starting from the year 1993, the velocity of the subsidence decreased, and from 1997 the values are approximately constant;
- The land consolidations in the period 1987-1988, practically had no effect on the land behaviour (as it was foreseen).

The calculus made were introduced in an Excel file and shown graphically for the periods 1981-1990 and 1978-2000. In fact the entire measuring period.
At the time when the building expertise was made by the research team of the Faculty of Civil Engineering, the following things were noticed:

- in the central area of the subsidence "cuvette" the phenomenon was stabilized, but not finished, reaching in the year 2000 at approx. 2600mm;
- in the Cathedral area the subsidence phenomenon continued, according to the readings, with the same rhythm until 1993 Still until the year 2000, the phenomenon began to stabilize, (but not entirely*)*, fact also confirmed by the readings of the fissure openings or by the state of the plaster markers;
- the fact that the subsidence phenomena continued after the completion of the cathedral consolidation, is confirmed by the occurrence, in the period 1992-1995, of fissures in the concrete of the girdlers. They were distributed at intervals and the openings were much smaller than the ones existing in the masonry structure of the cathedral.

The occurrence of the fissures in the concrete of the girdles shows that they are still working, so the consolidation solution adopted is efficient, but insufficient.
The measuring of the evolution of the opening of the fissures and of the cracks was made by setting certain markers on the construction elements.
The markers were made of two metal markers placed on both sides of the identified fissures. Markers are at 25cm apart.
The markers were made of brass, pasted with cianofix or mortar with glue, placed along the fissure.

The regular measurements monitored the evolution in time of the opening of the fissures. The conclusions, for the period 1994-1995, were drawn by CEPROMIN having as beneficiary the Ministry of Research and Technology.

The measurements made in the period 1994-1995, showed the evolutions of the fissures at maximum values:

- at the ground floor of the Cathedral 0.382mm;
- at the first floor of the Cathedral 0.340mm;

The markers made of plaster mortar showed at the date of the expertise, detachments and fissures, which took place along a period of almost 10 years.

RESULTS AND DISCUSSION

CONSOLIDATION SOLUTIONS PROPOSED

Taking into consideration the damages presented, consisting mainly of fissures in the strength elements of the walls and of the platform made of vaults supported by masonry arches, the previous projects mainly intended the following:

- To level of the unequal compressions and the unequal subsidence of the foundations by consolidation works at the Cathedral. First by making a 'rigid corset', by coatings and underconcreting the outer foundations and by making a high quality concrete support- girdler, in conformity with the project made in collaboration with CPJ Giurgiu, IP Hunedoara, INCERC Bucharest, I.P.E.G. Deva, CPJ Alba. The girdles were to be connected by horizontal tunnels under the church floor, reinforced and injected in a subsequent variant- action not made.
- The anchorage of the metal fittings of the concrete girdle was to be made as leaned reinforced drilling, because of the interruption of the girdle at the stairs and because of the girdle continuity brakeage. At the back of the Cathedral, the girdle follows the stairs contour, thus diminishing the girdle effect, the stairs being tied to the building and they do not tie the construction itself. In fact it was made only an anchorage in the ground of the girdle metal fittings.
- The construction, under the Cathedral, of a double curve vault, made of calcareous rock, injected and reinforced for solidification. The project was made by INCERC Bucharest in collaboration with IPJ Alba and CPJ Giurgiu. The injection technology used was set by ICITPLCIM (CEPROMIN)-Deva. They used aluminum expansive cement to ensure the non deformation in horizontal and vertical plans.

The vault will have at the end a thickness of 15m at the heading stone and of 30m at the springing. Thus it is prevented the shattering of the fissured calcareous rock from under the vault, which acts as a corset, by an inverted bearing wall, bottom limited by the lowest level of reinforced injections. The springing of the vaults under the shape of a spur has the following role:

- It anchors the vault assembly and the church infrastructure that it supports to the inferior rock in a whole unitary entity non deformable, taking into account the huge size of the vault;

At the cathedral, there were made 61 reinforced injections, out of the 118 stipulated in the project made by INCERC- Bucharest, at 15m depth, without making the vault under the construction, as stipulated, and without anchoring the metal fittings to the girdle in the ground.

The drilling, the injection and the reinforcement were to be made in four execution stages:

- drilling the openings that were to be injected with aluminum expansive cement;

- injecting the openings and the fissured rocks implicitly, in compliance with the technology designed by ICITPLCIM Deva;
- redrilling the injected openings and the introduction of the reinforcement for the consolidation of the calcareous rocks, injected in the previous stage;
- reinjecting the drillings to ensure the co-working of the retrofitting with the injected rock.
- Making some tunnels under the Cathedral floor, which were to be injected and reinforced, thus making the transversal connection with the reinforced concrete girdlers placed on the outer walls- not constructed.
- Making some injections with epoxy mortar into the fissures of the structural walls, after finding out the efficiency of the measures foreseen for the consolidation of the land and of the cathedral and for the stabilization of the subsidence land phenomena.
- "Local protection of some inner parts of the Orthodox Church –Gelar", protection nets being mounted to protect both the paintings and the parishioners against the falling of the painting and of the masonry from the cracked area- work completed.

In view of a deep consolidation of the Monumental Complex of the Ghelari commune, a first consolidation directory project was made, but the Orthodox Parish from Ghelari did not agree**,** because the girdler at the plinth level was to cross the main entrance and the side entrances.

The Ghelari Parish had the following requests:

- the church entrances are not to be affected;
- to increase the number of the drillings by making a third drilling chain around the cathedral.

A second directory project consisted in filling in the reinforced drillings, increasing their length and the alteration of the angles. Thus drillings were designed, which make with the vertical angles of 0^0, 25^0, 35^0, 45^0 and 75^0.

An additional idea was to make, under the cathedral, a double curve vault out of calcareous rock, injected for solidification and reinforced, with a technology designed by I.P.E.G. Deva, using aluminum expansive cement, to ensure the non deformation in horizontal and vertical plans.

- Finally, the vault will have a thickness of 15m at the heading stone and of 30m at the springing. Thus it can be prevented the shattering of the fissured calcareous rock from under the vault, which acts as a corset, by an inverted bearing wall, bottom limited by the lowest level of reinforced injections. The springing of the vaults as spurs has the following role:
- It anchors the vault assembly and the church infrastructure that it supports to the inferior rock in a whole unitary entity non deformable, under the huge size of the vault;
- It connects the fissured calcareous massif from under the vault, which acts as inverted bearing wall, limited at intrados by the inferior level of the reinforced injections.

The drilling, the injection and the reinforcement were to be made in four stages of execution:

- drilling the openings that were to be injected with aluminum expansive cement;
- injecting the openings and implicitly the fissured rocks in compliance with the technology designed by ICITPLCIM (CEPROMIN) Deva;
- redrilling the injected openings and the introduction of the reinforcement for the consolidation of calcareous rocks, injected in the previous stage;

- reinjecting the drillings to ensure the co-working of the reinforcement with the injected rock.

The reinforcement of the 92mm diameter drilling, with length ranging from 15 and 30m, is done with steel concrete PC 60, steel spiral type OB 37 with a diameter of 6Φ20 with hoop reinforcement of Φ6/12cm

The girdle projected in Variant I, as continuous along the contour cathedral, was designed as interrupted at the main and secondary stairs, in Variant III, the reinforcement of the girdle was to be ground anchored, in drillings, with two 15cm strands crossed with the strands with embedded ends at the other part of the girdle, with leaning angle of 60^{0} against the vertical

In the next stage they considered making some tunnels under the Cathedral floor, which were to be injected and reinforced, thus making the transversal connection of the reinforced concrete girdlers, placed on the outer walls- not constructed.

Likewise, in a subsequent stage they planned making some epoxy mortar injections into the fissures of the structural walls, after finding out the efficiency of the measures foreseen for the consolidation of the ground and of the cathedral and for the stabilization of the subsidence phenomena.

Works foreseen and executed:

- At the building expertise the following works were completed: the perimetral girdle with the under-concreting of the foundation, but with interruptions of the girdle at the main and side secondary stairs, and at the back stairs, the girdle following the contour of the stairs-finished in 1992;
- There have been made some drillings, injected and reinforced, 61(for the cathedral) and 7 more for the Old Church (work started in 1987 and finished in 1988), out of 118 stipulated in the INCERC project –Variant III.

Works foreseen and not executed:

- Not all the drillings, injected and reinforced were made. Their inventory can be found at the work executants, and in the documentation made by the site foreman- Inspection Data Sheet- Minutes, Consolidation Works-Ghelari, 1987-1988;
- The tunnels under the cathedral ground floor, which were to connect the reinforced concrete girdles, were not made.
- The epoxy mortar injections into the fissures of the structural walls were not made.

Following the intervention state observed, the subsequent intervention proposals for the new Cathedral were made:

Minimal Variant:

- resumption /continuation of the monitoring of the land behaviour in Ghelari, by doing topographic measurements by the Meriz-Ghelari Station
- resumption /continuation of the measurements of the openings of the fissures/cracks on the markers mounted inside and outside the Cathedral, including the stone fence that surrounds the complex;
- total realization of the reinforced injections, in compliance with Variant III, designed by INCERC Bucharest in collaboration with IPJ Alba and CPJ Giurgiu and with the injection technology cf. project symbol 75/214 designed by ICITPLCIM- Deva. 61 injected drillings were made out of 118 foreseen in the INCERC Bucharest project, at depth of 15m, without making the vault under the building, foreseen in the project and without anchoring the reinforcement to the girdler in the ground. There are going to be executed the drillings, injected and reinforced, type A and B, in compliance with the Project 622-1986 designed by CPJ Giurgiu.

- making some horizontal tunnels, reinforced and injected, under the cathedral floor, to connect the longitudinal girdlers transversally, in compliance with Variant III, designed by INCERC Bucharest and IPJ Giurgiu;
- monitoring the building behaviour for approx. 1 year after the completion of this stage , and if the fissures continue to open Stage III is to be applied;

In case the stabilization of the subsidence phenomenon and that of fissures opening is confirmed by:

- TOPO measurements of the Meriz-Ghelari Station;
- measurements of the openings of the existing markers;

the following measures are foreseen:

- making epoxy mortars injections in the fissures/cracks of the structural strength of the cathedral , the technology being adapted in compliance with the Technical Instructions indicative C 149-87;
- Coating the stanchions of the external walls, placed outside, reinforced with welded nets, with quotes ranging from +0.20 to +8.85. Nets are to be anchored to walls with reinforcement clamps inserted in the drillings, injected subsequently with cement paste under pressure.

Maximal Variant:

- Making the continuity of the girdlers and the under-concreting of the foundations at the side stairs and the secondary back stairs.
- Making the continuity of the girdlers and the under-concreting of the foundations at the main stairs of the cathedral main entrance.
- Making an exterior girdler semi-embedded, perimetral, at +8.85-9.30m, from the level floor of the cathedral, the reinforced girdler, anchored in the masonry of the external walls by “reinforced plots in drillings subsequently injected”.
- making some internal cross–ties for every perimetral arch of the central cupola of the naos, solution also presented in Project Variant I, designed by CPJ Alba in 1980-Pl. B2. Perforations made for the introduction of the cross –ties are to be injected with cement paste under pressure;
- The repair of the fissures, main stairs and secondary stairs, by epoxy mortar injections.

The interventions foreseen had in view also the intention to maintain the exterior architecture of the church, VARIANT III, by placing the internal cross –ties in MAXIMAL VARIANT, situation when there are no other intervention possibilities. It is worth mentioning that in the international practice of the church consolidations, the use of interior cross-ties is frequently used, if all the other intervention possibilities are excluded.
We have to mention that both variants are compulsory and that the staging has the purpose to prioritize the order of the consolidation works.

CONCLUSIONS

The studies and the solutions given in the Technical Expertise by the research team of the CCIA Department of the Civil Engineering Faculty of Timisoara, were materialized in the design of the intervention works by CEPROMIN Deva and the execution was made by SC CIF DEVA SA.
In the autumn of 2006, the intervention works at the cathedral were completed and accepted entirely. The next step is the execution of the intervention works at the dwellings in Ghelar, monitoring the behaviour in service of the buildings with the reactivation of the Topographic Station Merizi-Ghelar to monitor the land behaviour in the area.

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