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THE EFFECT OF PREVENTIVE CONSERVATION MEASURES ON THE TECHNICAL CONDITION OF A RELIGIOUS BUILDING LOCATED IN THE MINING AREA

WPLYW ZABEZPIECZEŃ PROFILAKTYCZNYCH NA STAN TECHNICZNY BUDYNKU SAKRALNEGO USYTUOWANEGO NA TERENIE GÓRNICZYM

The article presents the case study of a historical religious building located in the area of “Bogdanka” S.A. Coal Mine. As the building lacked adequate resistance to the expected effects of mining, the Mine undertook efforts so that it was fully protected against mining impacts before the commencement of mining operations. A preventive conservation system was used, consisting of an external stiffening reinforced concrete plate at the ground level and a system of steel tie rods established at the level of vault supports. The article assesses the effect of undertaken preventive conservation measures on the current technical condition of the building. The basis for the assessment was the extent of damage to the building confirmed after the occurrence of impacts from the performed mining operations combined with the analysis of ground deformation.

Keywords: preventive conservation of the building, mining damage, mining exploitation

W artykule przedstawiono przypadek zabytkowego budynku sakralnego, usytuowanego na terenie górniczym Kopalni LW „Bogdanka” S.A. Z powodu braku odpowiedniej odporności na prognozowane wpływy górnicze, staraniem Kopalni budynek ten został kompleksowo zabezpieczony profilaktycznie przeciw wpływom górniczym jeszcze przed rozpoczęciem eksploatacji. Zastosowano system zabezpieczeń profilaktycznych złożony z zewnętrznej żelbetowej tarczy usztywniającej w poziomie terenu oraz układu stalowych ściąągów, założonych w poziomie oparcia sklepień. W artykule dokonano oceny wpływu podjętych działań profilaktycznych na aktualny stan techniczny budynku. Podstawą oceny był zakres uszkodzeń budynku stwierdzony po ujawnieniu się wpływów od dokonanej eksploatacji górniczej, w powiązaniu z analizą deformacji terenu.

Słowa kluczowe: zabezpieczenia profilaktyczne budynku, szkody górnicze, eksploatacja górnicza

1. Introduction

The historical Orthodox Church of St. Nicholas in Dratów (Fig. 1) was located within the harmful impacts of mining exploitation carried out by the Lublin Coal Mine “Bogdanka” S.A. This building structure of traditional construction, lacked adequate resistance to the expected effects of mining activities. The Mine undertook efforts so that it was fully protected against mining impacts before the commencement of mining operations. The article assesses the effect of undertaken preventive conservation measures on the technical condition of the building after the occurrence of impacts from the performed mining operations. The basis for the assessment was the extent of damage to the building identified during the repeated survey of its technical condition, after the occurrence of impacts from the performed mining operations combined with the analysis of ground deformation. The first surveys of the church were carried out in 2002, that is before the commencement of mining exploitation.

2. Description of building construction

The orthodox church was built between 1888-1889 in the Russian style. It has a ground plan in the shape of a Greek cross, with an elongated chancel and three-sided sacristy. Despite its relatively small size, the building’s shape is fragmented and varied (Fig. 2 and 3). The total length of the building is 27.48 m and the maximum width is 16.05 m. The height of the building varies from 6.0 m (lateral extensions at the main entrance) to 25.5 m (the tower with the cross).

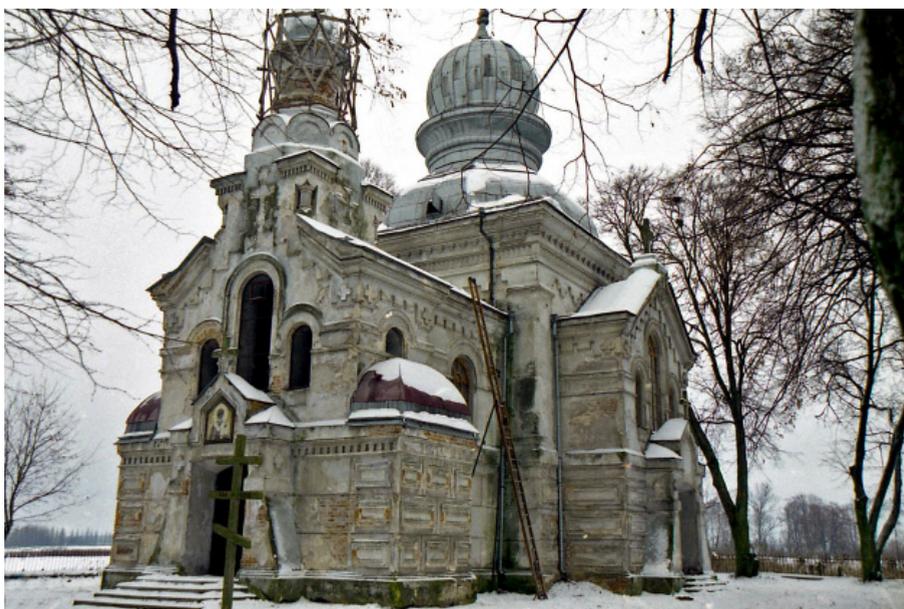


Fig. 1. The Orthodox Church in Dratów (as of 2002), the view from the south-west.

Source: Barycz et al., 2002

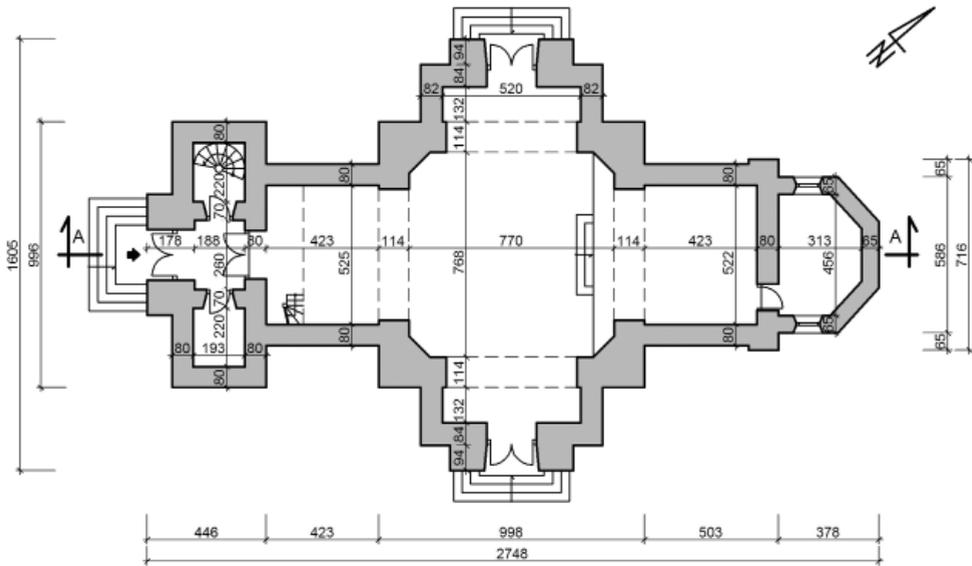


Fig. 2. Projection of the church building at the level of $\pm 0,00$ m.

Source: Barycz et al., 2002

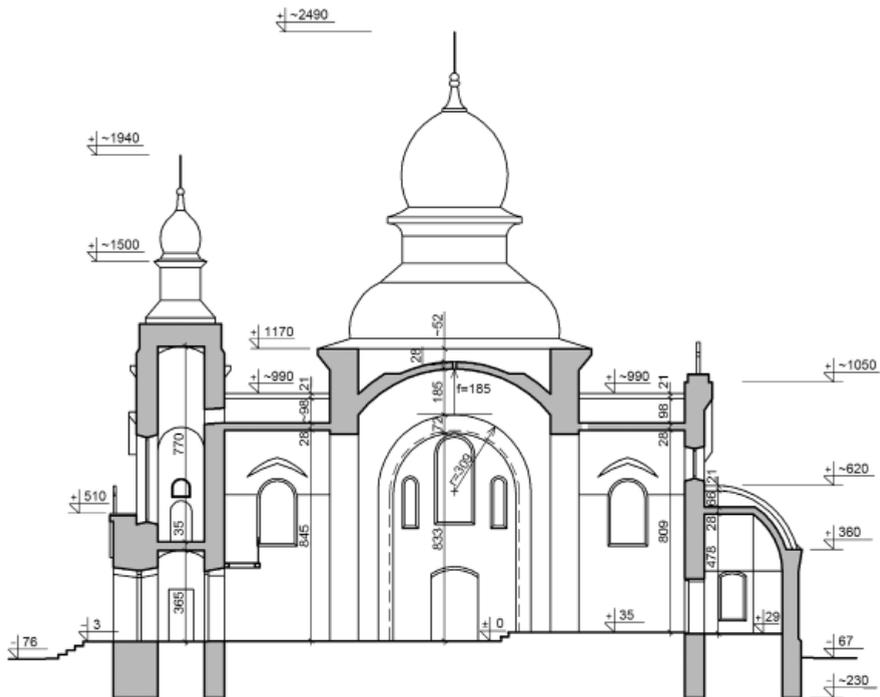


Fig. 3. Longitudinal section A-A of the church building.

Source: Barycz et al., 2002

The church building has a traditional construction. The walls, up to about 80 cm thick, are made of ceramic solid brick and lime mortar. The structure is placed on brick continuous footing at a depth of about 1.6 m below the ground level.

The nave, chancel and extreme parts of the transept are covered with a brick barrel vault, 28 cm thick. The height of the walls to the vault abutment is 5.75 m above the zero level, and the height of the vault at the keystone is 8.35 m. The wooden, rafter-collar beam roof structure is based on longitudinal walls, at the level of 8.0 m. The height measured to the roof ridge is about 9.90 m.

The rectangular central part opens to the four sides with four circular arches. These arches are a support for the single-surface sail vault covering the whole structure. The dome, which is a section of the flattened sphere, is made of brick, and has a thickness of 43 cm at the abutment and 28 cm above it. Parts of the walls, rising above the arches, support the wooden roof structure (domed roof with eight slopes, topped with an onion dome). The height measured to the top of the onion dome is approximately 23.30 m.

In the south-western part of the nave there is a porch covered with a cross-shaped vaulted ceiling. Over the porch, there is the bell tower with a height of about 18.4 m, topped with a much smaller onion dome.

Window openings are vaulted with semicircle-shaped lintels, except for the window openings of the sacristy, closed with segmented arch lintels. Segmented arch lintels are also used in the door openings.

A detailed survey of the technical condition of the structure, carried out in December 2001, before the planned mining activities (Barycz et al., 2002), revealed no significant damage to the masonry load-bearing structure of the church building which could pose a threat to its security, but only minor scratches occurring near the keystones of all the brick arches of the roof covering and the window openings. Taking into consideration the natural wear and tear (moisture, corrosion and loss of plaster, etc.), the condition of the structure was assessed as average (in a 6-point scale: very good, good, fair, average, bad and very bad, e.g. Wodyński, 2007; Rusek, 2009).

3. Preventive conservation measures

Due to the exploitation of the walls 10/1, 9/1, 8/1 in the seam 382 planned for the years 2002-2010, as well as the planned exploitation in the seam 385/2 after the year 2010, it was necessary to implement measures for preventive conservation of the church building. The exploitation was to be carried out by the longwall system with the caving method, and the nearest exploitation field was to be located at a distance of about 150 m northeast of the analyzed object. Because of the location of the building outside the field and outside the mining area, the greatest deformation rates were expected after the occurrence of impacts from the performed mining operations and they were expected to be: $\varepsilon = +3.86$ mm/m, $R = 47$ km, $T = 4.25$ mm/m (Barycz et al., 2002).

The following factors were taken into account while deciding about the scope of the necessary preventive measures:

- unique and historical character of the building (in 1989 this orthodox church was entered into the register of monuments for the province of Lublin under the number A/986),
- minimal natural resistance of the structure to the effects of mining impacts, established on the basis of a detailed analysis.

Bearing these facts in mind, in the technical expertise (Barycz et al., 2002) it was decided to implement a comprehensive preventive conservation against mining impacts. A system was used,

consisting of an external stiffening reinforced concrete plate at the ground level and a system of steel tie rods established at the level of vault supports.

The task of the plate was to receive all the horizontal surface deformations and to ensure geometric invariance of the horizontal projection of the building at the ground level. The plate was designed as a wide reinforced concrete band embracing the whole projection of the church building and a directly adjacent to the external walls. The plate was composed of three basic elements combined into one monolithic whole (Fig. 4):

- reinforced concrete slab, 20 cm thick,
- inner reinforced concrete ring beam with cross-sectional dimensions of 60×155 cm,
- outer reinforced concrete perimeter ring beam with cross-sectional dimensions of 40×60 cm.

In the sections where the inner reinforced concrete ring beam runs at a certain distance from the wall (e.g. in the inner corners), the space between it and the foundation wall was filled with concrete during the concreting of the ring beam. Therefore, the inner ring beam (or the concrete spacer) adheres tightly to the foundation walls of the structure, at their entire height. In addition to the concrete adhesion to the masonry wall, the connection of the ring beam with the foundation walls is ensured by steel anchors $\phi 20$ mm, embedded in these walls every 0.5 m. Due to its considerable structural height and the resulting rigidity, the inner ring beam also stiffens the structure in the vertical direction, thus partially protecting it as a whole against deformation resulting from the curvature of the area. The outer edge of the plate is stiffened with a perimeter ring beam, which in a plan has the shape of a convex polygon. To execute all the elements of the plate, concrete B20 was used, with F100 degree of frost resistance and W4 water resistance, as well as stainless steel of A-II class and 18G2 type.

To ensure invariable support for the vault arches construction of the roofing, anchoring of the walls was used (Fig. 5). For this purpose, on the outer side of the walls at the level of +6.00 m, steel tie rods $\phi 30$ mm in grooves were mounted. The nave with the bell tower, the central part (without the extreme parts of the transept) and the chancel were secured by this system.

All the conservation works were carried out in late 2002 and early 2003, based on the technical project (Szczepaniak and Wach, 2002), prepared pursuant to the concept presented in (Barycz et al., 2002). After the completion of the works, a thorough renovation of the facade of the building was carried out, together with replacement of the roofing, guttering and flashing (Fig. 6).

4. The effect of mining operation

4.1. The operation performed in the vicinity of the church building

Starting from the year 2002, to the north-east of the church building, mining exploitation was conducted in the seam 382, in the walls 10/1, 9/1, 8/1, 7/1, 6/1. The extraction was carried out by the longwall system with the caving method. The length of the longwalls in this region was 300 m, and life face was about 3000 m. With the advance of the face works, simultaneous elimination of longwall galleries was performed. The mining operation was carried out in the south-eastern direction with a lift. The depth of the seam ranged from 920 m (at the northern boundary) to 820 m (at the southern edges of the walls). The slope of the seam was low and it did not exceed 4‰. The average thickness of the longwalls was 2.7 m. The exploitation was

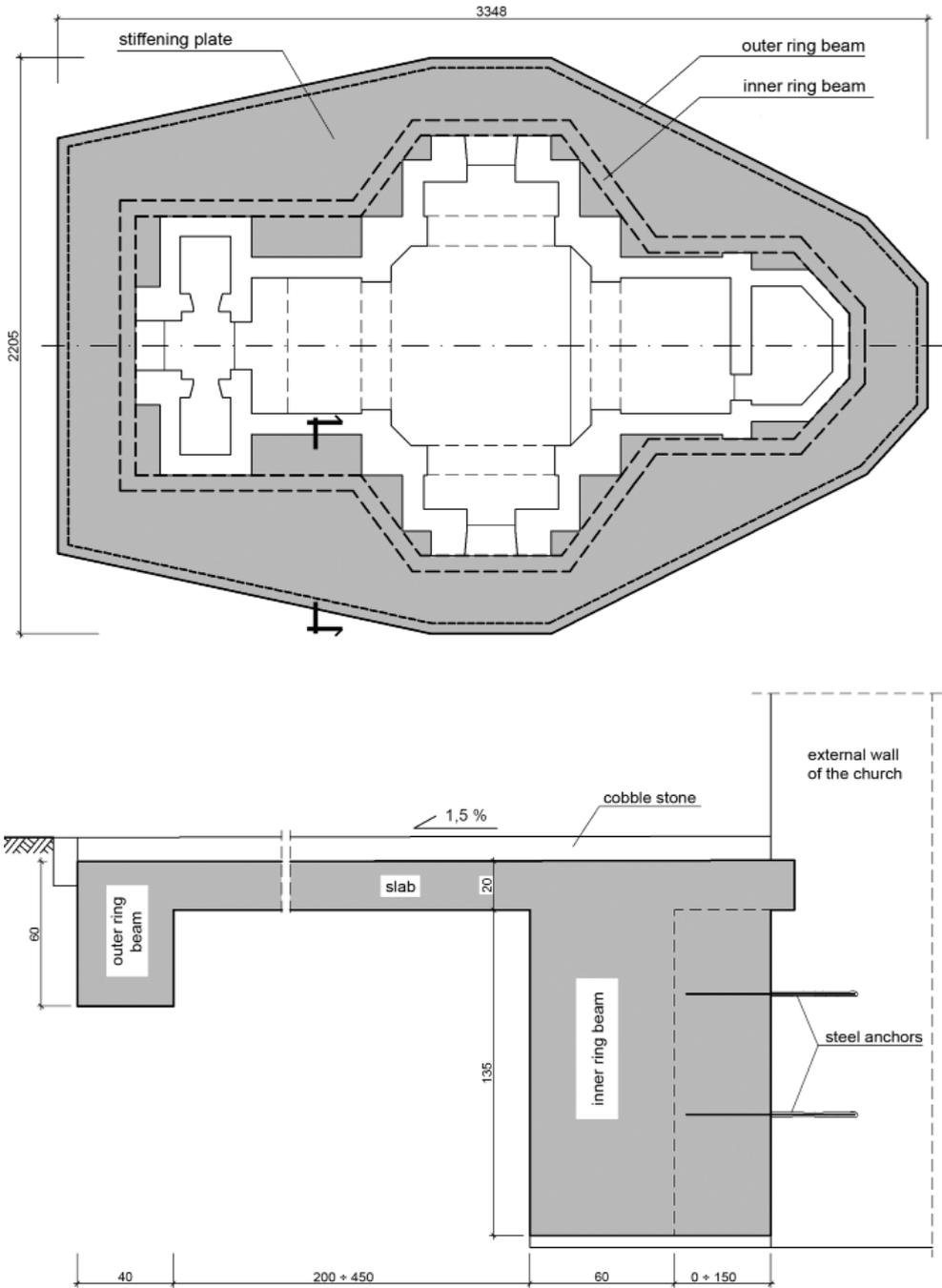


Fig. 4. Scheme of preventive conservation of the structure with reinforced concrete stiffening plate – a horizontal projection and cross section of the stiffening plate.
 Source: Own study based on Szczepaniak and Wach, 2002

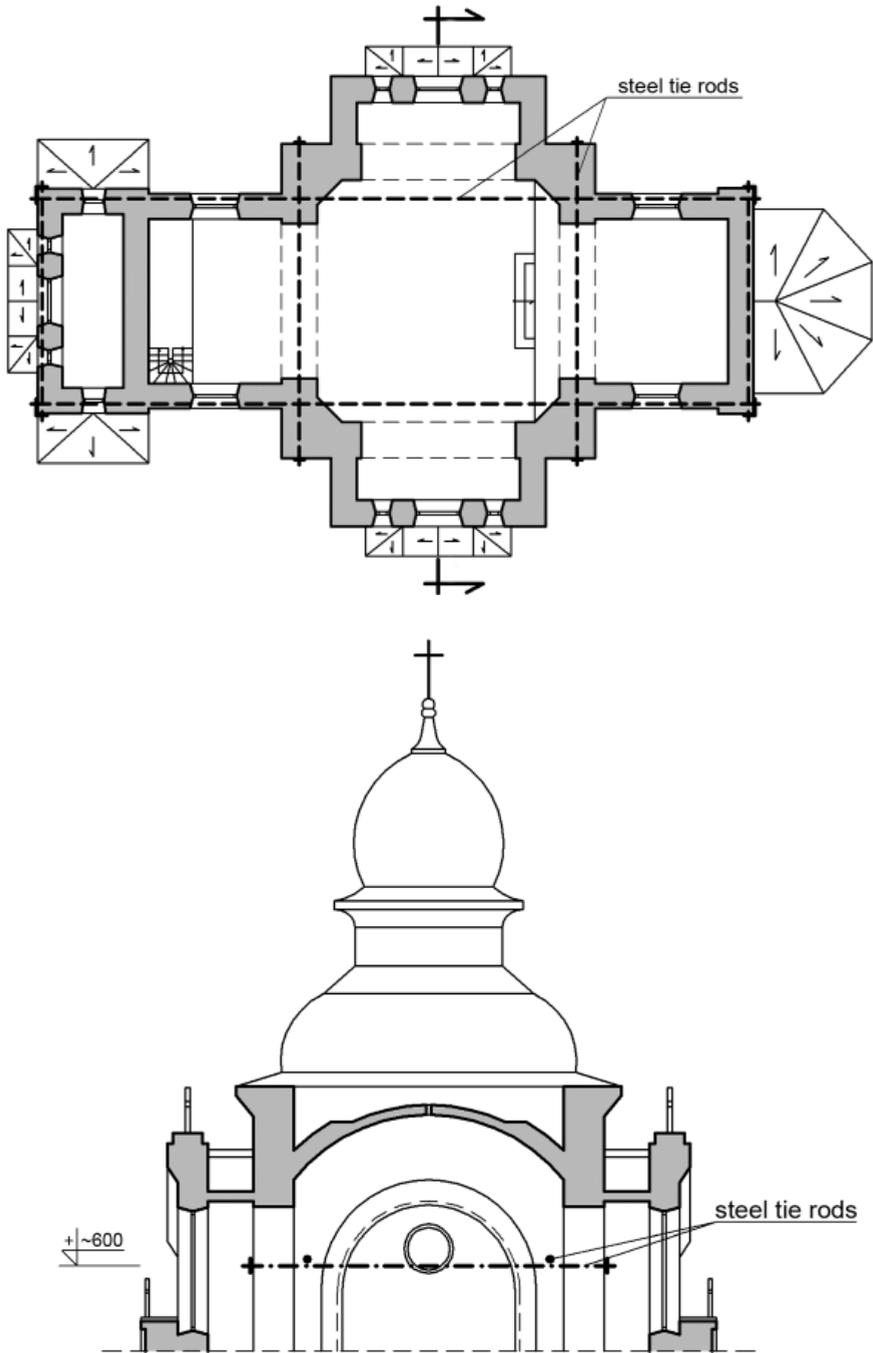


Fig. 5. Arrangement scheme of steel tie rods (anchoring) at the level of +6.00 m – a horizontal projection and cross section of the stiffening plate.

Source: Own study based on Szczepaniak and Wach, 2002



Fig. 6. The Orthodox Church in Dratów (as of 2014), the view from the south.
Source: Own study

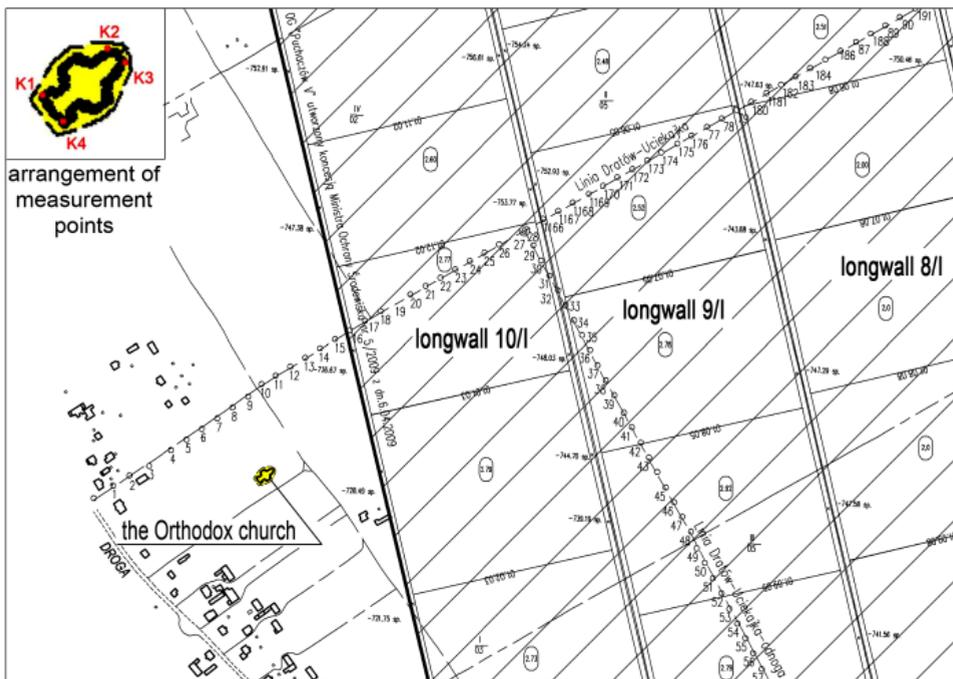


Fig. 7. Location of panels and a measuring line relative to the church, as well as distribution of calculation points at the building structure.
Source: Data regarding..., 2014

commenced in July 2002 with the 10/1 wall, which was located to the north-east of the church building (Fig. 7). The exploitation front pace ranged from 5 to 11 m per day. While analyzing the impact of consecutive walls on the surface deformation in the area of the church, it should be emphasized that only the longwalls 10/1 and 9/1 affected the deformation in this area. Assuming that the average range of direct impact is about 750 m, it can be concluded that the mining operation carried out after October 2005 had no effect on the surface deformation in the vicinity of the church.

4.2. Geodetic observations conducted in the vicinity of the church building

In the area of Dratów, there are two fixed observation lines: Dratów-Uciekajka and Dratów-Uciekajka branchline. Dratów-Uciekajka will be the subject of further analysis, due to its advantageous location with respect to the panels. This is a line that runs north of the church building, at a distance of about 90 m. The measurement line includes 145 permanently marked reference points. The average distance between the points is about 25 m. The leveling measurements on the line began in 2002. Subsequent measurements were performed in the years 2003, 2006, 2007 and 2008. Since 2010, the leveling has been performed at annual intervals. The observations carried out along this line made it possible to trace the process of surface deformation (Fig. 8).

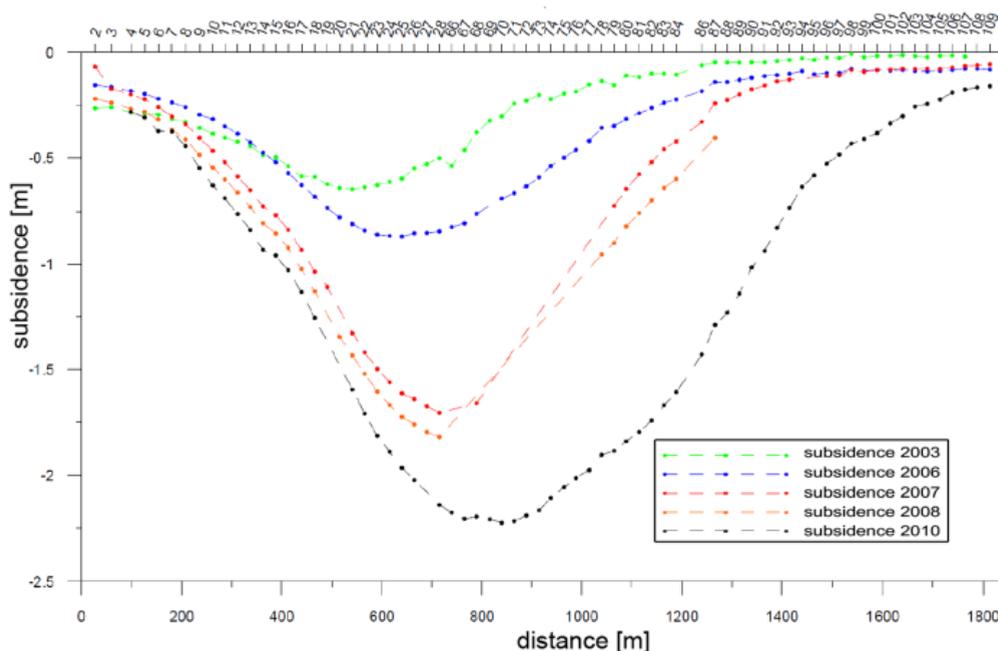


Fig. 8. Profiles of the measured surface subsidence along Dratów-Uciekajka observation line.

Source: Own study

The dynamics of the rock mass deformation rise was low. A slight subsidence began to appear on the surface after the extraction of the first wall, while the full subsidence basin was formed upon completion of mining operations in all three longwalls. The determined subsidence reached the maximum value of 2.223 m.

4.3. Determining continuous surface deformation for the church building structure

The measured identified subsidence made it possible to determine the parameters of the Knothe theory for this area. Then, they were used in the modeling process of surface deformation that occurred under the church. Dynamic deformation field was defined based on the Knothe theory. The specified parameters adopted for the modeling are as follows:

- the exploitation coefficient $a = 0.80$,
- the tangent of the angle of main impact range $\operatorname{tg}\beta = 1,80$,
- global time coefficient $c = 2.0$ [1/year]
- horizontal displacement coefficient $B = 0.4$ r.

The calculations were conducted at four points (K1, K2, K3, K4), located at the corners of the church building (see Fig. 7).

The analysis of continuous surface deformations in time showed that in the period from November 2002 to October 2005 the dynamics of displacement field under the church was the largest (Fig. 9).

When analyzing the values of maximum ratios of the surface deformation that occurred under the church building, it should be noted that the maximum subsidence reached 0.5 meters (cf. Tab. 1). The maximum slope of the ground surface under the church building was $T_{max} = 3.67$ mm/m. The direction of the maximum slope was in line with the x-axis (the horizontal axis in a mathematical coordinate system). The maximum tensile loads of the area surface occurred at about 300 meters to the outside of the exploitation field. It was the area located west of the church building. Therefore, larger tensile loads occurred around the western part of the structure (calculation points K1 and K4). Horizontal strains reached the maximum of $\varepsilon_{max} = 2.86$ mm/m. The direction of the maximum main strains was deflected by 15 gon relative to the direction of the x-axis. The angle of the church axis relative to the direction of the x-axis was 42 gon. Maximum directional strains are tensile strains, which were $\varepsilon_{alfa} = 2.66$ mm/m. The direction of the main strains was similar to the direction of the longitudinal axis of the structure.

TABLE 1

The values of indicators of deformation in the 2002-2012

| Point no. | W [m] | T_{max} [mm/m] | K_{g1} [1/km] | K_{g2} [1/km] | $\varepsilon_{g1} = \varepsilon_{max}$ [mm/m] | ε_{g2} [mm/m] | ε_{alfa} [mm/m] |
|-----------|--------------|---------------------|--------------------|--------------------|--|------------------------------|--------------------------------|
| K1 | 0,409 | 3,25 | 0,0001 | -0,0159 | 2,86 | -0,02 | 2,66 |
| K2 | 0,488 | 3,61 | 0,0005 | -0,0151 | 2,72 | -0,09 | 2,53 |
| K3 | 0,503 | 3,67 | 0,0007 | -0,0149 | 2,68 | -0,13 | 2,49 |
| K4 | 0,422 | 3,31 | 0,0001 | -0,0158 | 2,85 | -0,02 | 2,65 |

Source: Own study

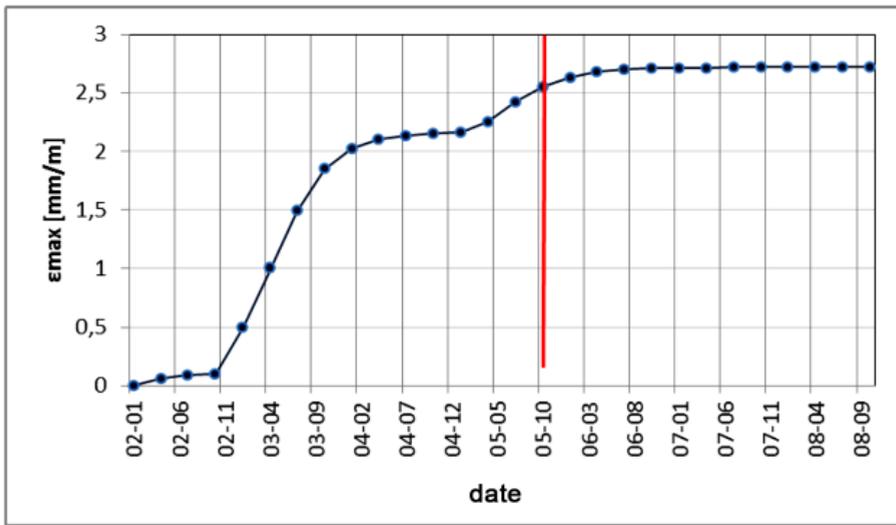


Fig. 9. Development of horizontal deformations at the point K2 in time.

Source: Own study

5. Assessment of the current technical condition of the structure

In April 2014, the authors carried out a repeated survey of the technical condition of the church building.

Since the interior of the building had not been renovated, a comparison of the status quo with the condition observed in 2001 was made. Detailed examination revealed the existence of exactly the same damage as before. These included scratches and minor cracks of the arches (buttresses) crowning the chancel, of the nave and the transept, as well as of the lintel bows over window and door openings. Their width usually did not exceed 0.5 mm, and only in two cases it reached 1 mm (e.g. Fig. 10, 11). Scratches of the lintels over side entrances to the church (in the transept gable walls) run up until they reach the window openings located above. Inside the building, traces of dampness of the walls, exfoliation of paint coatings and corrosion of plaster occurring in the places of leaks (mostly old) caused by the leaking roof were found. It should be emphasized that there were no new cracks or scratches, and the width of the existing ones remained unchanged.

There were no cracks found in the facade, which was renovated after the completion of the preventive conservation works. Few scratches of the window lintels, occurring before the renovation, did not renew themselves. The only damage, currently visible from the outside, are local shrinkage scratches of the plaster of irregular course, as well as local dampness and corrosion of the plaster caused by inaccurate performance of roofing and flashing works. The overall condition of the object was assessed as fair (in a 6-point scale – Wodyński, 2007).

During the on-site inspection, evidence was found demonstrating the occurrence of mining impacts in the area. They resulted in significant cracks of structural elements of the fence



Fig. 10. Scratches of the arch crowning the nave from the side of the main entrance (unchanged).
Source: Own study



Fig. 11. A scratch, 1 mm wide (the largest in the building) extending from the door lintel to the window above the western entrance (unchanged).
Source: Own study

around the building, both in its brick and stone foundations and in steel elements above the ground (e.g. Fig. 12). It may be argued that in the event of a failure to carry out preventive conservation works, or in the case of a less decisive action in this regard, the walls and vaults of the church building would crack as well.



Fig. 12. One of the cracks in the construction of the fence around the church building on the north-east side (present situation).

Source: Own study

The confirmation of the occurrence of mining impacts in the vicinity of the church (based on surveying conducted in 2002 and 2014), is tilting of the structure by up to 3 mm/m in the north-east direction, that is towards the exploited longwalls of the seam 382, which is consistent with the calculation values presented in Table 1.

6. Conclusions

when defining resistance of a building structure to mining impacts, we assume that it will safely “receive” effects of mining in the form of continuous surface deformations of a certain category of threat, while allowing for the occurrence of minor damage that does not pose a threat to users. Thanks to the undertaken preventive conservation measures with respect to the church building, it was possible not only to meet the safety requirements, but also to avoid any damage to the structure associated with the performed mining exploitation. The current condition of the building demonstrates the effectiveness of these preventive measures.

Preventive conservation measures in the form of using an external reinforced concrete stiffening plate were never subject to a wider discussion in the context of their effectiveness in the technical literature. The example presented in this article proves that this type of a solution could be successfully applied in protecting buildings with a complex floor plan against the harmful effects of mining.

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