Forecast of influences of exploitation conducted in rock mass degraded by the previous activity of the “Bobrek” Coal Mine on the building of historical church in Miechowice

Ryszard Mielimąka and Franciszek Plewa
Faculty of Mining and Geology, Silesian University of Technology in Gliwice, Akademicka 2, 44-100 Gliwice, Poland
ryszard.mielimaka@polsl.pl

Abstract. This paper presents the method of performing forecast of the influence of exploitation planned in seam 503 by the “Bobrek” Unit of “Bobrek-Piekary” Coal Mine on the Holy Cross Church in Bytom - Miechowice. It contains the analysis of church construction and history of its renovations, geological and mining conditions in the church area as well as deformations it underwent as a result of mining exploitation conducted so far. Forecast of influences of planned exploitation was performed with the use of EDBJ program, a formula for subsidences by J. Bialek, applying the best local values of parameters of this formula in the sense of the least-squares method. The analyzes presented herein were used to assess the possibility of conducting planned exploitation in the context of protecting this church.

1. Introduction
Forecast of planned exploitation influence on an important public facility of historical character must exhibit considerable credibility due to the need of maintaining the safety of use of such object and preserving its historical values. This is particularly important in the case when this protected object has already been subjected to deformations resulting from long-term, multi-seam mining exploitation conducted in its vicinity. In such case, before performing forecast of influences, it is necessary to put under careful analysis:

- geological conditions in its area,
- previous mining exploitation having an effect on this object,
- construction of the object, its protective measures against the influences of mining exploitation and history of its renovations,
- the size of previous influences of exploitation which it took over on the basis of results of geodetic observations carried out in the object itself and in its vicinity, as well as re-forecasts of influences of previous exploitation.

Forecast of influences of planned exploitation on a protected object is usually performed with the use of geometrical-integral theory formulas utilizing parameters determined locally by fitting subsidences measured in its area to theoretical subsidences by means of the least-squares method. The use of such parameters is of particular importance in the case of rock mass that is already significantly degraded by previous mining exploitation, because at that time one has to deal with a significant random factor in measured subsidence troughs [1, 2]. Forecast of influences performed this way may
be the basis for assessing the possibility of taking over forecasted deformations by the protected object.

This article demonstrates the way of performing forecast of planned exploitation influences on a historical protected object. This is presented on the example of the Holy Cross Church in Bytom-Miechowice, which will be subjected to influences of the exploitation of seam 503 conducted by the “Bobrek” Unit of “Bobrek-Piekary” Coal Mine.

2. Description of Church construction

The Holy Cross Church in Miechowice, located in Bytom-Miechowice at 42 Ks. Jana Frenzla Str., was built in the years 1856-1865 in the neo-Gothic style. It is a brick building made of solid bricks on lime mortar. Finishings and decorative elements are made of sandstone (figure 1).

![Figure 1. View of the church from the western (a) and eastern side (b).](image-url)

Plan of the church is organized on a Latin cross-shaped view with the following overall dimensions: church length 51.70 m, width in the transept 30.30 m. In ground floor level the view of the church consists of a main nave with adjoining side naves (northern and southern) in its western part. Main nave crosses with transept, which limits the side naves. In the further part of the church there is a presbytery with a width of main nave. It is adjointed by two sacristies. On the eastern side the presbytery is adjointed by a polygonal apse. The church has a partial basement – under apse and presbytery there is a crypt and boiler room.

Naves of the church are covered with cross-rib vaults. Transept, presbytery and apse – with a star-shaped vault with ribs. Main nave has a span of 8.60 m (in the axes of columns) and side naves are 4.60 m each. Transept is covered with vaults with columns spaced 8.50 m away from each other. In the longitudinal direction vaults are repeated four times counting from the entrance (western side). The axial spacing of supports in this direction is about 5.35 m. Main nave is extended by the presbytery (by about 6.00 m), and then by the apse (by 5.20 m). In the axes of columns there are arches in longitudinal and transverse direction. Vaults placed on arches are at the highest point above the ground +15.2 m high in main nave, transept and presbytery, and +13.2 m high in side naves. Presbytery has been separated from apse by a gable wall with richly decorated attic. On the transversal extension of arches along the entire height of side walls there are buttresses with width of 0.95 m and length of 1.42 m. In the side walls of the church and apse there are large ogival windows with stone traceries.

The roof of a rafter-and-truss structure is placed on external walls and on the extension of internal columns. The surface of the roof is multi-hipped – gable along the main axis of the church and gable over transept. The roof over apse is multi-hipped. At the point where ridges of main nave and transept
cross there is an octagonal spirelet with a height of about 13.2 m. Its spire is at the height of +36.1 m. The roof is covered with copper sheet on full boarding.

Tower of the church is made of brick on the projection of a square. Dimensions of the tower in axes on the ground floor level are about 5.25 m. Projection of the tower partially enters the light of the first span of main nave from the western side. From the level of +28.45 m, the projection of the tower changes shape to octagonal. The brick part of the tower ends at a height of +40.18 m. Above there is a wooden pyramidal roof structure that reaches a height of +53.90 m. It is topped by the spire with a cross. The roof is covered with copper sheet.

As part of major renovations of the church that took place after damage caused by the exploitation of subsequent seams, a number of works have been carried out to increase the church’s resistance to the influences of mining exploitation and to ensure the safety of its use. The most important of them include:

a. after damages that occurred until the end of 1953:
   • making benches of ferroconcrete under the floor in longitudinal and transverse direction to the church axis with pillars to transfer compressive and tensile forces,
   • making ferroconcrete beams in the transept at the level of + 5.00 m to protect the vault of transept from compression,
   • making steel tie rods at the level of column capitals in longitudinal and transverse direction,
   • making steel tie-rods in external walls at the level of column capitals.

b. in the year 1976 making a horizontal ferroconcrete shield in the shape of an ellipse stiffening the church floor at the ground floor level,

c. the following works after the year 2000:
   • laying plastic mesh and applying a gypsum plaster on the upper surface of vaults,
   • applying rigid struts between heads of the pillars simultaneously with the already used tie-rods protecting the vaults against the influence of concave curvature and introduction of diagonal tie-rods,
   • introduction of ferroconcrete diaphragm to secure the crypt under presbytery and apse against the influence of compressions and against displacements of the column supporting the palm vault.
   • dismantling an attic of the wall between presbytery and apse up to the presbytery roof level due to its large deflection.

Inspection of object’s damage carried out in April 2017 [3] showed scratches in walls and vaults as well as in places after earlier rebuildings present mainly in the eastern part of the church. The width of most of the scratches did not exceed a few millimeters.

3. Geological and mining conditions

The “Bobrek” Unit of “Bobrek-Piekary” Coal Mine is located within the Bytom Trough. In the range of recognition, rock mass is built of layers of overburden belonging to Quaternary and Triassic as well as Carboniferous forming the deposit. Triassic and Quaternary deposits reach a total thickness of 185 – 260 m.

Quaternary is represented by gravels, sands, loams, slits, mudstones and clays with pebbles and rock blocks, interbedded with sands. In the area of the Holy Cross Church the thickness of Quaternary layers equals to about 10 m.

Triassic formation, deposited in the form of a trough on Carboniferous, is represented by bunter sandstone and shellbearing limestone. From lithological point of view, it is dominated by limestones, dolomites and marls as well as loams with interbeddings of sand and sandstone. In the floor part of ore-bearing dolomites, there is a zinc-lead ore deposit, which was the subject of mining exploitation but not in the immediate vicinity of the church. The thickness of Triassic formations ranges from 60 m in the south to 200 m in the north.

Deposits of productive Carboniferous are represented in this area by Ruda layers (group of seams 400 from seam 404 to seam 419), saddle layers (group of seams 500 from seam 501 to seam 510) and
Poręba layers. These deposits are composed of interbedded layers of claystones, siltstones, sandstones and coal seams. The thickness of Ruda layers is approx. 570 m, and of saddle layers – approx. 240 m.

Carboniferous layers fall beneath the Miechowice District towards the south, to the bottom of the Bytom trough, at an angle of up to 10 degrees.

Mining exploitation of hard coal deposit under the church in Miechowice District encompassed 11 layers (in 9 seams) including 9 layers exploited with a fall of roof. The depth of this exploitation ranged from 270 m (seam 406/4) to 820 m (seam 510), and the height of longwalls ranged from 1.5 m to 2.2 m.

The main way of exploitation was the longwall system with a fall of roof. At the beginning, in upper-Ruda seams (406/4 - 409) dry backfill was used (in the years 1948 - 1954) while from 1965 onwards the prevailing method of exploitation became the one with a fall of roof. Also – to a small extent – hydraulic backfill was used (in seams 418 and 501).

In 2017, the exploitation is carried out in seam 503 with longwalls 5 and 6.

The exploitation schedule influencing deformations of the church building is shown in Table 1, which contains data on exploitation time and roof management system.

Figure 2 shows the location of the edges of exploitation fields extracted from the year 1965 in individual seams – in relation to the Holy Cross Church.

Table 1. Schedule of accomplished exploitation in the area of the Holy Cross Church in Miechowice.

| Years of exploitation | 1948 | 1951 | 1966 | 1976 | 1978 | 1983 | 1989 | 1993 | 2000 | 2003 | 2013 |
|-----------------------|------|------|------|------|------|------|------|------|------|------|------|
| Seam                  | 406/4| 407/2| 414/3| 418  | 419  | 501  | 507   | 509   | 509  | 510   |
| System of exploitation| Dry backfill | Dry backfill | Fall of roof | Fall of roof | Fall of roof | Fall of roof | Fall of roof | Fall of roof | Fall of roof | Fall of roof |

Figure 2. The location of the edges of exploitation fields.

4. The influence of accomplished exploitation on the church building

4.1. The influence of accomplished exploitation in the light of geodetic measurements

Systematic geodetic observations of deformations of the church and its surroundings have been conducted since the year 1965. They include elevation and linear measurements of the measurement.
network consisting of points located on the walls, pillars and the ferroconcrete band around the church building. Moreover, levelling measurements of the floor are performed inside the church.

The results of geodetic measurements allow to state that the western part of the church building (in the area of portal) has decreased since the year 1927 by 19.40 m (figure 3). A significant increase of subsidences began after the year 1965 in connection with the exploitation of lower- Ruda seams (414/3, 418 and 419).

Summary values of subsidences from 15.01.2014 to 28.02.2017 range from 1628 mm to 2003 mm, while the increase in the difference of subsidences over the length of the church amounts to 68 mm.

The levelling measurement of the church floor made on 15.02.2017 shows that inclinations along the length of the church are generally directed eastward and range from 13.2 mm/m to 35.3 mm/m. In the perpendicular direction they run to the north and amount up to 5.7 mm/m.

Vectors of the church tower deflection, according to the last measurement performed on 28.02.2017, amount to:

- at an altitude of 59.3 m – 17.9 mm/m to the east and 5.2 mm/m to the north (the resultant deflection vector is 18.6 mm/m),
- at an altitude of 28.8 m – 23.0 mm/m to the east and 3.5 mm/m to the north (the resultant deflection vector is 23.3 mm/m).

Subsidences of points in a concrete slab (band) are identical as in the case of points on the church building. The largest subsidence for the period from 14.05.2013 to 03.01.2017 occurred in the eastern part of the band, where it reached almost 2.0 m. In the western part, the subsidences amount to 1.45 – 1.55 m. Correspondingly, the remaining deformation indicators amount to:

- the largest inclinations of ± 12.0 mm/m in the western part of the church,
- the extreme horizontal deformations in time from +1.6 mm/m to -1.2 mm/m in its eastern part.

The analysis of measured deformations indicates that damages to the church building result mainly from the developing of terrain curvatures, because the band made of ferroconcrete limits the influence of horizontal deformations on this object.

![Figure 3](image_url). Subsidences of benchmark no. 429 located on the western side of the church from the year 1927 [4].

4.2. The influence of accomplished exploitation in the light of re-forecast of influences

Re-forecast of influences on the Holy Cross Church area was performed for exploitation accomplished since the year 1965 (exploitation in seams: 414/2, 414/3, 418, 419, 501, 503, 504, 506, 507wg, 507wd, 509wg, 509wd, 510wg and 510wd – figure 2).
The analysis of influences shows that exploitation conducted since the year 1965 by the “Bobrek” Unit caused deformations of the church building with the following values:

- increase in subsidences – from approx. 16.90 m on the western side to approx. 17.50 m – on the eastern side,
- increase in inclinations – from approx. 12.5 mm/m on the eastern side to approx. 16.3 mm/m on the western side; these amounts fall within the IV and V inclination categories,
- increase in main deformations – from approx. -6.70 mm/m on the eastern side to about -8.7 mm/m on the western side,
- increase in main curvatures – from approx. +70.8 m$^{-1}10^6$ (radius of curvature 14.1 km) on the eastern side to approx. +97.2 m$^{-1}10^6$ (radius of curvature 10.3 km) on the western side.

5. Determination of local parameters of the theory of influences

The values of parameters $a$, $\tan \beta$ and $A_{obr}$ of the formula for subsidences by J. Białek [5, 6] necessary to evaluate the influences caused by the planned exploitation of the “Bobrek” Coal Mine on the Holy Cross Church in Miechowice, were determined using the EDBJT program, developed in the Department of Deposits Exploitation of the Silesian University of Technology [7, 8]. The values of these parameters are determined by minimizing the residual variance of measured subsidences and the ones calculated theoretically.

Calculations were performed with the use of subsidences of wall benchmarks on the church building which were measured in the period from 15.01.2014 to 28.02.2017.

During the measurement period, twin longwalls with cavings were extracted in seam 510wd: 30a and 31a. Currently, the “Bobrek” Mine conducts exploitation of twin longwalls with cavings, 5 and 6, in seam 503. The location of the edge of this exploitation in relation to the church building is shown in figure 4.

![Figure 4](image-url)

**Figure 4.** Location of the edges of longwalls extracted in the period from 15.01.2014 to 28.02.2017 in seams 510wd and 503 in relation to the Holy Cross Church building.

Longwalls 30a and 31a in seam 510wd were under exploitation from March 2013 to March 2015 and from June 2013 to July 2015 respectively. These longwalls, exploited in the north-south direction, were set up at an average depth of about 800 m. Their heights were 2.1 m in the panel length sections located in the vicinity of the church building (sections: 30aII with the panel length of about 490 m and
31aII with the panel length of about 460 m) and 2.4 m in the remaining panel length sections (sections: 30aI with the panel length of about 480 m, 30aIII with the panel length of about 200 m, 31aI with the panel length of about 400 m, 31aIII with the panel length of about 280 m).

Exploitation of longwalls 5 and 6, extracted from north to south in seam 503, was commenced on 01.03.2016 and on 01.09.2016 respectively. Until 28.02.2017 longwall 5, located on the eastern side of the church building, reached the panel length of about 670 m and on that day its front was about 40 m south of the church building, while longwall 6 was extracted to the panel length of about 275 m, i.e. its front was situated approximately 265 m north of this building. Longwall 5, to the panel length of about 390 m, was exploited to a height of 2.3 m (section 5I), while on the further panel length the height of exploitation gate was reduced to 2.0 m (section 5II). The height of longwall 6 on the previously extracted section was 2.3 m. The extracted sections of longwalls 5 and 6 are set up at an average depth of approximately 670 m.

As a result of calculations with the EDBJT program, the following values of theory of influences parameters have been determined:
- parameter $\tan \beta = 2.80$;
- subsidence coefficient $a = 0.96$;
- peripheral parameter $A_{\text{obs}} = 0.07$.

Matching of theoretical subsidences to the measured ones is characterized by a standard deviation $\sigma = 30.2$ mm and a coefficient of correlation $R = 0.9942$.

The determined values of parameters are local values that can be used only in forecasts of mining exploitation influences on the church building and the surface of terrain in its area.

Values of theory parameters determined on the basis of subsidences of selected points positioned on the church are significantly higher than their values assumed by the “Bobrek” Coal Mine in forecasts of mining exploitation influences on the terrain surface and objects. This phenomenon is present due to the fact that the extraction of discussed longwalls took place in rock mass that was already significantly disintegrated by the previous mining exploitation. In such conditions, the subsidence troughs that emerge on the terrain surface are characterized by a large value of random factor, which means that local inclinations of slopes may be significantly greater than those calculated theoretically with the use of parameter values determined for entire profiles of these troughs.

6. Planned exploitation and its influence on the church building

In the area of the Holy Cross Church in Bytom the “Bobrek” Coal Mine conducts exploitation of longwalls 5 and 6 in seam 503. Longwall 5 was launched in March 2016, longwall 6 in September 2016. Target panel length of longwall 5 is 1309 m, and longwall 6 – 950 m. Depth of exploitation amounts to 670 – 700 m.

Considering the protection of surface during the exploitation of longwalls 5 and 6, it is planned to use mining prevention of limiting the height of longwall 5 to 2.0 m on the 500-meter-long section of panel length (counting from the beginning of longwall on the panel length from 390 to 890 m) and longwall 6 on the section of panel length from 340 m to 950 m. In addition, the speed of front of longwalls 5 and 6 on the panel length from 390 m to the end of longwalls should not exceed 4 m/day (figure 5).

Forecast of exploitation influences of longwalls 5 and 6 in seam 503 was performed with EDBJT program, using formulas of S. Knothe – W. Budryk theory with extensions proposed by J. Bialek – the theory parameter values were determined for the Holy Cross Church area.

The analysis of forecast of influences results allows us to state that exploitation of longwalls 5 and 6 will cause the church to suffer deformations with the following values:
- subsidences – from 1374 mm on the western side of the church to 1643 mm on the eastern side of the church,
- final changes in inclinations – from 3.80 mm/m on the eastern side of the church to 6.70 mm/m on the western side of the church; these values fall within the IV and V inclination categories,
• main tensile deformations extreme in time – from 2.93 mm/m on the southern side of the church to 3.05 mm/m on the western side of the church; these values fall within category II and on the border of categories II and III of horizontal deformations,
• main compressive deformations extreme in time – from -3.54 mm/m on the western side of the church to -4.12 mm/m on the southern side of the church; these values fall within category III of horizontal deformations,
• main negative curvatures extreme in time – from -42.5 m⁻¹¹⁰⁶ (radius of curvature 23.5 km) on the western side of the church to -43.6 m⁻¹¹⁰⁶ (radius of curvature 22.9 km) on the northern side of the church; these values fall within the range of category I of curvatures,
• main positive curvatures extreme in time – from 46.6 m⁻¹¹⁰⁶ (radius of curvature 21.4 km) on the western side of the church to approx. 66.4 m⁻¹¹⁰⁶ (radius of curvature 16.6 km) at the central point of the church; these values fall within the range of category I and II of curvatures.

Figure 5. Location of the exploitation edges of longwalls 5 and 6 in seam 503 in relation to the church building

7. Conclusions
Analyses concerning the influences of accomplished and planned exploitation of the “Bobrek” Coal Mine on the historical Holy Cross Church in Bytom – Miechowice, included in this paper, allow formulation of the following general statements:
1. In the past, the church was subjected to the influence of long-term, multi-level mining exploitation, which led to numerous damages, that were successively repaired. During major renovations, the church's construction was strengthened by installing a steel grate in the level of vault support (column heads) and a ferroconcrete shield with ferroconcrete tie-rods below the church floor.
2. The analysis of the results of cyclic geodetic measurements conducted at points placed on the walls and pillars of the church, and also on a ferroconcrete band around the church revealed, that damages occurring in this building are mainly caused by curvatures emerging as a result of mining exploitation in its area. Stiffening the ground floor of the church with a ferroconcrete shield together
with ferroconcrete tie-rods significantly limited the influence of horizontal deformations on this object.

3. Parameters of the theory of influences determined on the basis of matching theoretical subsidences to subsidences measured in the area of the church are significantly larger than those commonly accepted. Because of considerable and diverse disturbance of rock mass the value of parameter $a$ can locally become close to 1.0 and the value of parameter $\tan \beta$ may get close to 3.0. Therefore, it is not appropriate to perform the forecast of influences for important buildings using standard parameter values because it significantly increases error of the determined deformation values.

4. The stiffening of the church on the ground floor level fulfills its task and is beneficial in terms of assessing the possibility of taking over influences of exploiting seam 503 with walls 5 and 6 situated at a depth of approximately 700 m by this building. With such depth of exploitation extreme curvatures in fact fall within one category higher than extreme horizontal deformations.

5. In terms of protecting the church building and heavily built-up terrain surface in its area it is important to conduct mining prevention of reducing the height of longwalls 5 and 6 in a substantial part of their panel lengths to 2.0 m as well as limiting their daily progress to a maximum of 4.0 m and maintaining its stability. This way of conducting mining exploitation will significantly reduce the size and increments of deformations on the terrain surface.

6. Numerical analysis of exploitation of longwalls 5 and 6 in seam 503 influence on the church construction performed at the Faculty of Civil Engineering of the Silesian University of Technology [9] showed the possibility of emergence of further scratches in the church structure. These scratches will not pose a threat to this structure due to steel reinforcement located in the level of vault supports.

References

[1] Mielimąka R 2009 Wpływ kolejności i kierunku eksploatacji prowadzonej frontami ścianowymi na deformacje terenu górniczego (Gliwice: Wydawnictwo Politechniki Śląskiej)

[2] Strzałkowski P 2010 Forecasts of mine-induced land deformations in consideration of the variability of the parameter describing the process kinematics Archives of Mining Science 55/4 pp 865-72.

[3] Szojda L, Kubicza J and Kotala B 2017 Analiza numeryczna wielokrotnych eksploatacji pokładów węgla na murowaną konstrukcję sklepień kościoła Konferencja Naukowo-Szkoleniowa „XIV Dni Miernictwa Górniczego i Ochrony Obiektów Budowlanych na Terenach Górniczych” Ustron 27-29 września 2017

[4] Kowalski A 2017 Ekspertyza górnico-budowlana dotycząca wpływu zwiększenia wybiegu ściany nr 6 w pokładzie 503 przez Węglokoks – Kraj KWK Bobrek-Piekary na obiekty zabudowy powierzchni w szczególności kościoła pod wezwaniem Św. Krzyża w Bytomiu Miechowicach GIG Katowice

[5] Białek J 2003 Algorytmy i programy komputerowe do prognozowania deformacji terenu górniczego (Gliwice: Wydawnictwo Politechniki Śląskiej)

[6] Białek J 1991 Opis nieustalonej fazy obniżeń terenu górniczego z uwzględnieniem asymetrii wpływów końcowych Zeszyty Naukowe Pol. Śl. seria Górniczto 194

[7] Białek J and Mielimąka R 1999 Możliwości zwiększenia dokładności prognoz deformacji terenu górniczego wykonanych przy użyciu powszechnie stosowanych programów komputerowych Zeszyty Naukowe Pol. Śl. seria Górniczto 239

[8] Białek J and Mielimąka R 2001 Próba weryfikacji parametrów teorii prognozowania wpływów eksploatacji na teren górniczy Zeszyty Naukowe Pol. Śl. seria Górniczto 250 pp 69-79

[9] Kotala B, Mielimąka R and Szojda L 2017 Ekspertyza górnico-budowlana dotycząca wpływu zwiększenia wybiegu ściany 6 w pokładzie 503 na budynek kościoła pw. Świętego Krzyża przy ulicy Frenzla 42 w Bytomiu Politechnika Śląska Gliwice