sciendo

CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2021; 31 (4): 0087-0111
DOI: 10.2478/ceer-2021-0051
Original Research Article

REPAIR AND RENOVATION OF THE HISTORIC CHURCH IN RUDA ŚLĄSKA AFTER MANY FAILURES CAUSED BY MINING EXPLOITATION

Łukasz DROBIEC[1]
Silesian University of Technology, Faculty of Civil Engineering, Gliwice, Poland

Abstract

This paper describes a case of the church, which for nearly 70 years was exposed to the impact of 26 mining exploitations conducted under the church or very close to the church at different depths. These caused damage in the form of superficial cracks of vaults and walls as well as the loosening of the front layer of stone façade of towers. The construction has been preserved due to the continuous monitoring and numerous repairs and renovations. Currently, there is no mining exploitation under the church.

Keywords: damage to masonry structures, repairs of historic buildings, effects of mining exploitation

1. INTRODUCTION

Masonry towers and vaults in churches are specific examples of masonry structures. Towers are particularly exposed to atmospheric conditions, their inspections are difficult due to poor access, and their repairs are expensive and require good organization [1, 20, 23]. Besides atmospheric impact, masonry towers are also exposed to other factors. The most common factors include [3, 7, 15, 22, 26, 27]:

- processes of natural aging of materials,

[1] Corresponding author: Silesian University of Technology, Faculty of Civil Engineering, Akademicka 5, 44-100 Gliwice, Poland; lukasz.drobiec@polsl.pl, tel. +48322371127

- environmental impact,
- impact of bell action,
- impact of mining exploitation,
- lack of maintenance works and ad-hoc repairs,
- errors made during repairs.

All these factors can cause damage, and the majority of them are also responsible for vault damage. Harmful effects on walls are often caused by a set of factors. Sometimes just one factor induces a series of damage [7, 17, 19, 21, 24]. Damage is usually observed as:

- cracks,
- damage to masonry units and joints,
- spalling of parts of mortar and masonry units,
- spalling of the front layer of masonry.

Masonry towers are usually built from two layers. Front layers are usually stone blocks or special ceramic blocks with the shaped front plane, sometimes they are glazed. Even walls made of ordinary brick can be divided into front elements (usually of higher strength, often perforated) and internal elements. It can be troublesome while analysing causes of damage and planning the method of effective repair. Defining causes of damage is fundamental for the proper selection of strengthening and repairing methods of such constructions. The evaluation should be always accompanied by a thorough factual analysis [16]. For this purpose, non-destructive tests are performed [6, 13, 14, 25, 29, 30]. In recent years advanced numerical methods have been more commonly used. They are based on based computing technique, which provides more detailed analysis of structures [2, 18, 28].

2. CHARACTERISTICS OF HISTORIC MASONRY WALLS

Old masonry units were usually laid in lime mortar. They are characterized by high porosity and good capillary properties. Hence, joints function as drains that carry off water and salt solutions from masonry units [4, 31]. Therefore, mortars are exposed to destructive action of salt (crystallization) and water (freezing) and are often damaged. Lime mortars are also prone to (sulphuric, nitric) acids polluting atmosphere. The above factors gradually destroy mortars in external layers of walls, which can be observed as their granular disintegration and loosening. Consequently, masonry units can fall out.

Masonry is a composite composed of masonry units joined together with mortar [5]. The main loads exerted on masonry towers are compressive loads caused by self-weight, thermal effects generating tension, and wind loads (in-plane bending). However, self weight generates the greatest internal forces. The loaded area of the masonry is deformed. It is specified by the numerical value ε – a quotient of shortening Δh to the masonry height h. A wall is the most durable when its two components cooperate to take the load, that is, when the relative deformation ε corresponds to a similar stress value in mortar and brick [9, 10, 31]. This condition is met in the walls for medieval bricks and lime mortar. A similar situation is observed for much harder and stiffener machine-made bricks (19^{th} and 20^{th} centuries) and mortar of similar properties. In the case of big differences in deformability of masonry units and mortar in the wall, the complex state of stresses is created.

Fig. 1 presents the graph of stress-strain relationship for the medieval and machine-made brick, lime and cement mortars, and old and modern walls. This figure indicates that the masonry made of medieval bricks laid in lime mortar is strained at least five times more than the modern wall under the same load [31]. Lime mortar generally "flows" at relatively low stresses. Machine-made bricks, cement mortar, and the wall built from these components are subjected to relatively small strains, elastic ones, within the same range of stresses. The wall laid in cement mortar under gradual loading is strained and returns to its original size while in the unloaded state. Deformation of the same wall, but laid in lime mortar is generally irreversible as if "recording" the history of the deformation process. These properties should be considered while planning repair works of masonry towers of churches.

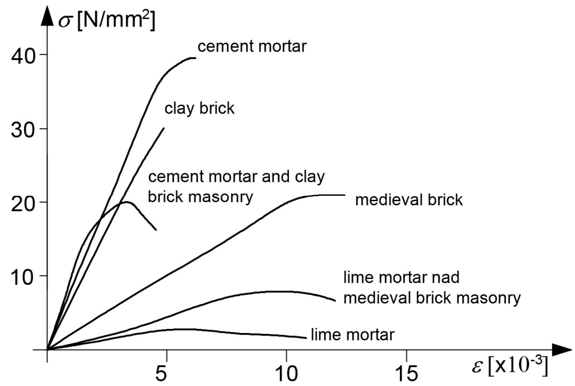

Fig. 1. Deformations of old and modern mortar, bricks and masonry

Damaged masonry towers of churches are usually repaired by [1, 8, 11, 12, 20] rebricking, crack stapling, striking of joints, and anchoring. Vaults are repaired by injecting, superficial strengthening, and crack stapling [8, 17, 19, 24].

3. DESCRIPTION OF THE CHURCH BUILDING

The Holy Trinity Church in Ruda Śląska - Kochłowice was designed by Ludwig Schneider. Its construction began on 18 April 1900 and the foundation stone was consecrated on 15 July. The main builder of the church was the master bricklayer Fedor Wieczorek from Królewska Huta (nowadays Chorzów). The church was built over two years. It was consecrated on 17 October 1902. The church had six bells, five of them were installed on the south tower, and one bell in a ridge turret. The church is presented in Fig. 2.

The church had Neo-romanesque architecture with Neo-gothic elements. It is an oriented construction with the cruciform floor plan, with a chancel and the arms of a transept ended with apses. Two-floor annexes are adjoining the chancel from the north and the south. The spacious ridge turret is on the roof, above the intersection of the nave and the transept. At the west end of the church, there are two six-floor towers covered with pointed octagonal steeple arcs. The chancel is flanked by turrets, whose height is close to the height of the nave. On the south tower, there are clocks.

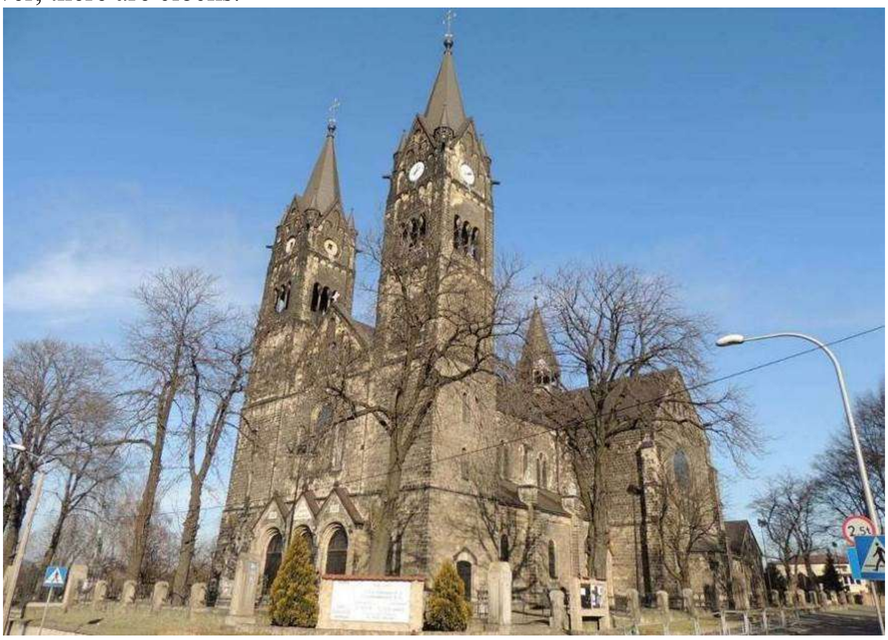

Fig. 2. The church – a view from the north-west side, March 2015

The construction is 57 m long and 21 m wide in the nave. The church width at the east side (including dormers of auxiliary altars) is 37.64 m, and its width at the west side (between the outermost towers) is 25.37 m. The nave is 23,0 m high, and the tower height is 52.85 m. The foundation depth from the floor level is 3.0 m below ground level. The floor space of the church is ca. 12 000 m^2, and the total internal volume is 23 600 m^3.
There are three Neo-Romanesque portals in the triaxial elevation with two towers. The area of a three-nave building with the chancel that ends with a semi-circular apse is within a cross vault. Stained glass and statues of four Evangelists are in the church. There are also oil paintings of St. Barbara, the Immaculate Mother of God, alter paintings of the Hole Trinity, and the Sacred Heart of Jesus. The stained glass was ordered in the Mayer Company from Munich, statues of the Evangelists in Wrocław, and pipe organs were ordered in the Schlag und Söhne Company in Świdnica. The alter paintings of the Hole Trinity, the Sacred Heart of Jesus and the paintings of St. Barbara and the Immaculate Mother of God were works of Julian Wałdawski from Wrocław, who also painted way of the Cross. The church has a capacity of 5 000 people.
Its walls and the towers are made of two layers. The internal layer is made of bricks of different thickness (adjusted to the height in the tower), and the external layer made of stone (sandstone). Stone blocks have a thickness from 10 to ca. 30 cm, a height of 30 cm, and a width from 30 to 60 cm.
Dimensions of the tower plan are ca. 7.0 x 6.6 m. The tower thickness at the ground floor is 1.33 m. At the level of the entrance to the choir section, the wall thickness is reduced to ca. 1.0 m in central areas of the towers. Thickness in their corners is practically the same which resulted in pilasters.
The roof system is made of timber. Above the nave, there is a clasped purlin roof with three posts, the end posts are inclined, and the vertical post is on the stretcher construction. Both towers have couple of roofs. The roof above the nave, the transept and the towers are made of metal sheet.

4. MINING EXPLOITATION

The exploitation of coal seams under the church began in 1941. The first exploited seam 502/1 of 6.0 m thickness was at the depth of 605 m within a distance of 386 m from the church. Then, in the 1970s, the coal seams 405/1, 510/2, 504 and 506 of 1.8-2.6 m thickness were exploited. In the years 1977-1988 the seams 504, 507 and 510/1 that were located directly under the church and the very close seam 506 were exploited. They had a thickness of 1.8-2.5 m and they were at the depth of 745, 777, and 795 m respectively. Generally, 26 coal seams were exploited in the surroundings of the church in the years 1941-2010.

Surveying inspections of the impact of mining exploitations on the church shape (based on benchmarks in the walls) began in 1979. The terrain and building deformations observed up to now are the following:

- subsidence of the building:
  - from 3.05 to 3.5 m in the period of 09.1979÷09.2008,
  - from 0.175 to 0.28 m in the period of 05.2006÷09.2008.
- calculated maximum inclination was 20 mm/m and was noticed between the benchmarks in the apse.
- horizontal deformations:
  - calculated on the basis of measured length of external sides of the church walls in the period of 09.1979÷10.2008 were equal to +4.85 mm/m and were found in the south-west wall of the transept.
  - the maximum horizontal deformation in the period 05.1989÷10.2008 was +7.5 mm/m on the south side of the building.

A significant increase in tensile forces in the church and its surroundings was observed in the years 2004÷2005. At that time the western edge of the exploited coal seam was running under the south-west corner of the church. This mining operation also activated a fault in the seam 405, placed directly under the church. Edges of four exploited coal seams placed under the church, and the fault weakened the massif and caused shearing, and consequently the formation of non-continuous deformations (three vertical discontinuities). The exploitation was predicted to lower the walls by 0.138÷0.241 m to September 2008. In fact, the subsidence was slightly greater 0.281 m due to active non-continuous deformations. Also, deflection of the church towers was measured. Within six years deflection of the towers changed its value and direction. The north tower inclined by 5.39 promille towards the south, and then by 1.49 promille towards the east, whereas the south tower inclined by 1.17 promille towards the west, and then by 2.75 promille towards the south.

5. PROTECTION OF THE BUILDING AGAINST MINING EFFECTS, OBSERVED DAMAGE AND REPAIR WORKS

The church building was not originally protected against the effects of mining exploitation. First minor damages to the building were noticed in 1936, and the serious damage was found in the late 1970s which resulted in installing benchmarks for the survey inspection. The damaged walls and vaults were repaired on 23 June 1980. The repair works included rebricking of external walls and lintels of arch windows, and injection of cracks on the vaults with epoxy resin. In 1986÷1987, the reinforced concrete apron of 1.0 x 1.0 m cross-section was performed at the elevation of -2.20 m below ground level (Fig. 3). The concrete apron was reinforced with 20 rebars of 32 mm in diameter (18G2 class) in the longitudinal direction, and transversely with 16 rebars of 32 mm in diameter (18G2 class). Inside the church, the apron was connected with transverse tie rods placed on the axis of the posts. Over the tie rods in the transept area, the reinforced concrete slab (diaphragm) was performed.

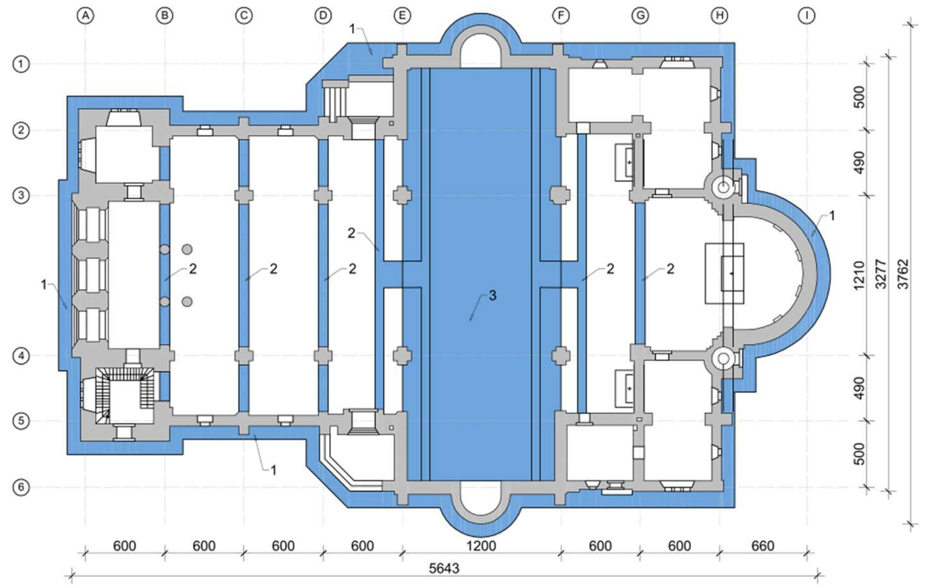

Fig. 3. Strengthening of the church horizontal foundation in the years 1986-1987: 1 – reinforced concrete apron, 2 – reinforced concrete tie rods, 3 – reinforced concrete slab over tie rods

The post heads were horizontally stiffened (level of +8.6 m) above the floor level. This stiffening using longitudinal and transverse tie rods/flying shores was a part of the works performed in the years 1986÷1987. These flying shores were made of two C-shaped beams 2xUPN240. Additionally, the vaults of the main nave were stiffened at the level of post heads in aisles, the vestry and chapel rooms using rigid two-branch tendons and the system of longitudinal and transverse slender tie rods. Also the vaults of the transept and the nave were protected with slender cross tie rods made of steel. Above this protection, steel cords were stretched to fix the safety net (Fig. 4). Photographs illustrating strengthening works are presented in Fig. 5.

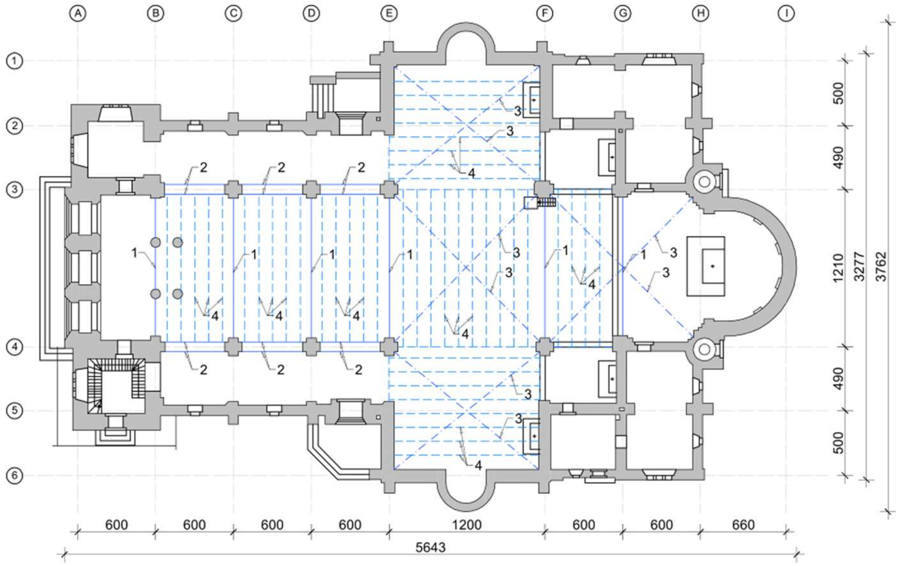

Fig. 4. Horizontal strengthening of the church at the level of +8.6 m in the years 1986-1987: 1 – tie rods 2x UPN240, 2 – tie rods 2xUPN100, 3 – slender steel tie rods ϕ32, 4 – cords to stretch the net protecting people inside the church

Fig. 5. Strengthening performed in the years 1986-1987: internal tie rods (left) and reinforcement of reinforced concrete slab (right)

The repair works for new cracks and fractures developed in the walls and vaults of the church began in 2002. Their width was up to 18 mm. However, no cracks were observed in the towers. After injecting the cracks with epoxy resin, the church was plastered and painted wall decorations were restored. New damages were formed directly after finishing the works. At first, cracks were observed in the arches of the main wall. They were so big (with the width up to 20 mm – Fig. 6 and 7) that they posed a risk of falling out of the masonry units. Thus, it was recommended to wedge the arches and ribs of the vaults (Fig. 8 and 9) and to support them locally with arch centerings adjusted to their geometry.

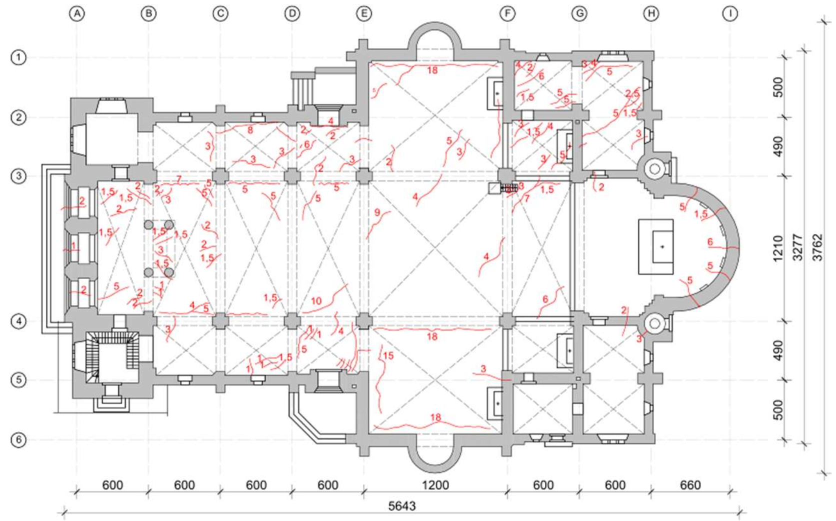

Fig. 6. Cracks found in 2003

Fig. 7. Cracks of the elevation found in 2003

Fig. 8. Damage to the arch and wood wedges driven in the place of cracking (2003)

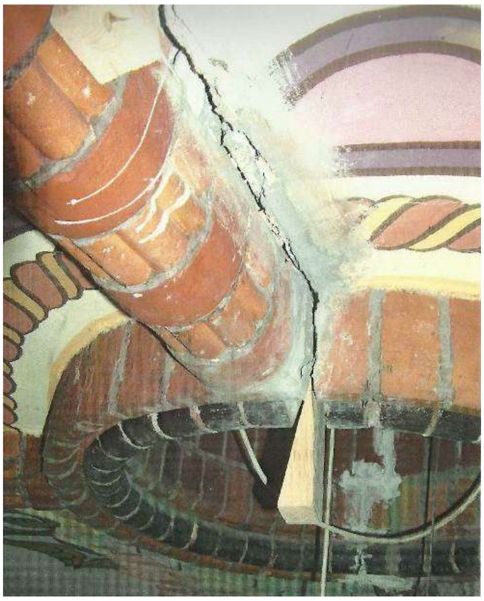

Fig. 9. Damaged area near the vault ribs and wood wedges driven in the place of cracking (2003)

Damage to some tendons of the protection installed at the height +8.6 m occurred parallel with cracking of the arches. Edge plates of anchorages were damaged, loosening of some tie rods was found, and others were stressed. Then, two bricks fell out of bottom parts of the vaults. It was related to mining-induced tremors. The cracks were again repaired by injection.

A sudden increase in the width of existing, but repaired cracks and the formation of new ones were observed since 2005 (Fig. 10-12). Non-continuous deformations occurred as pockets on the stone paved area around the church (the pit with the deflection of 12 cm).

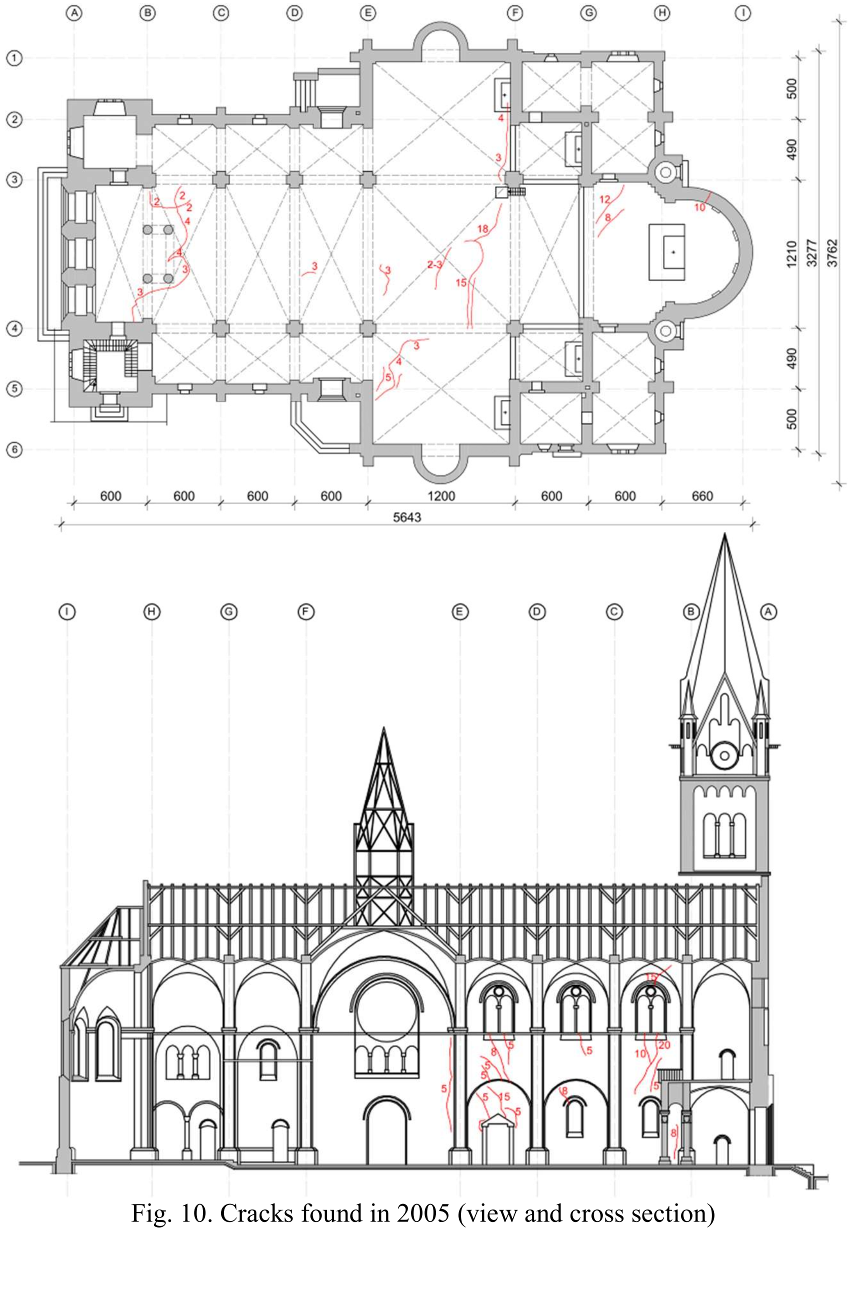

Fig. 10. Cracks found in 2005 (view and cross section)

The church floor repaired by injection and overlaying was considerably cracked (the width up to 20 mm). New cracks (some with displacement) were formed in the walls and the vaults. Cracks on the stone elevation of the towers, loss and cracking of grouts were observed for the first time.
Another repair works of the church were conducted in the years 2005-2006. The vaults and walls were again injected. Additionally, a protective coating of the vault was applied from the top using the PCC technology. Floors, plaster and painted wall decorations were repaired.
In May 2008, new cracks were found in the walls and the vaults. The research and development paper and another report were prepared in 2009. Besides cracks in the walls and the vaults, the following issues were noticed: local debonding of vaults from the attic, damaged external stairs to the main entrance, cracking of reinforced concrete apron, and the subsidence of the paving stone from the west and the east side. These damages were repaired until 2010.
At night-time 2/3.07.2016, a part of the wall of ca. 12 m^2 was loosened in the west elevation of the south tower at the height of ca. 30 m above the ground level, in the place of damage observed in 2005 (Fig. 11 and 12) and fell down destroying an information board and the paving stones. The tower wall in this place is composed of two layers, the internal layer is made of bricks and the external layer made of stone (sandstone). Both layers are overlapped and bonded with lime mortar. Five stone blocks with the arch ornament were loosened. Each block was 63 cm high, ca. 92÷93 cm wide and differed in their thickness. Their thickness varied from 10 to 20 cm. Also stone blocks of the cornice, one whole layer of stone blocks above the cornice, and parts of two other layers were loosened. Debonding of single masonry units in the buttresses of both towers was also found. The loose masonry units fell down at the west side of the tower. They destroyed the noticeboard and caused the deflection of 7 cm in the stone paved-area.
Insect nests were found in both towers, in the spandrel area, in the wall crevices. Bees nested were in the south tower, and wasps nested in the north tower. After the damage to the front wall, the fire service removed the loose masonry units and mortar from the debonding zone on 3 July, 2016. The area around both towers was fenced. The loose masonry units were removed, and temporary centering of the wall facing was performed where debonding was noticed (Fig. 13). The inspection of the second tower indicated significant debonding of the wall facing and high probability of the occurrence of the similar situation (Fig. 14).

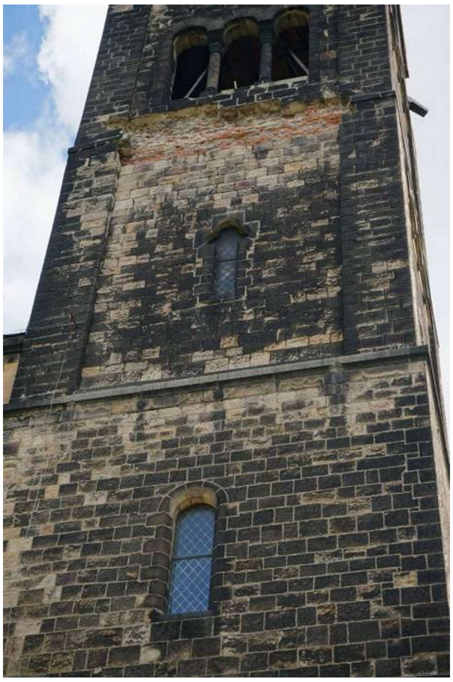

Fig. 11. View of damaged west elevation of the south tower

Fig. 12. Damage detail of the west elevation of the south tower

Fig. 13. Temporary protection of the debonding zone

Fig. 14. North tower. Loss in joints, cracks in stone works, bumps in masonry units and the cornice

The following repair and restoration works were conducted in 2017-2019:

- Damage repair in the failure zone. The repair works consisted of rebricking of the wall facing and the parts of the remaining wall. They aimed at keeping as many original masonry units as possible. Unfortunately, the stone blocks with the arch ornament broke into pieces. Thus, they had to be copied. The new stone elements were selected regarding the colour, the size, and the strength. The applied mortar was the system mortar for the historic buildings, similar to the original one.
- Crack repairs in the tower masonry. The cracks were stitched with stainless steel anchors placed in bed joints. Mineral injections were applied to the cracks.
- Masonry anchorage. All stone blocks with the arch ornament were anchored to the brick masonry using stainless steel anchors based on chemical anchors. Two anchors were used per one unit. Additionally, selected elements of the cornice and walls were anchored. Over 400 anchors were used in each tower.
- Removal of secondary pointing with cement mortar.
- Cleaning of the wall face. The wall was cleaned using the mixed method, that is, manual and blast cleaning.
- Restoration of joints and stone impregnation. Joints were restored using the ready product - the mineral mortar with resin to add flexibility. Joint colours were agreed with the Provincial Monument Conservator. The colour of uncleaned stones was unified, impregnated with siloxane products that reduce stone absorption.

Individual stages of the works are presented in Fig. 15-22. The church elevation before and after the restoration works is compared in Fig. 23 and 24, and the restored interior of the church is presented in Fig. 25.

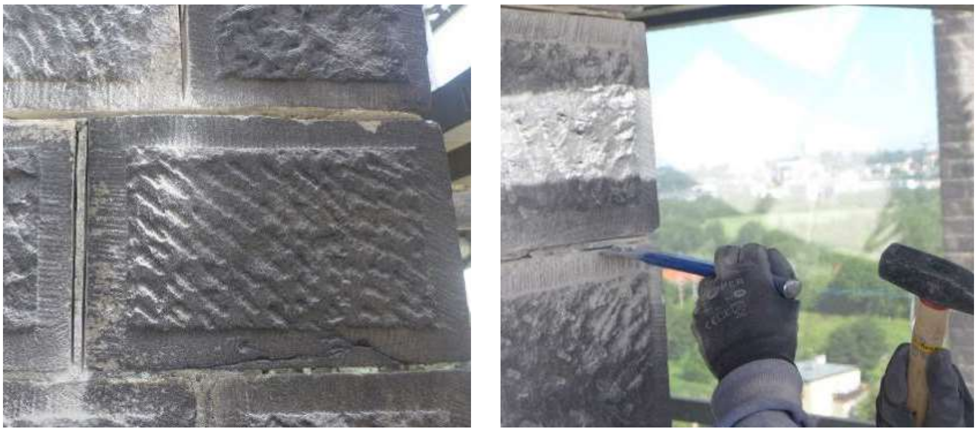

Fig. 15. Removal of secondary pointing

Fig. 16. New masonry units

Fig. 17. Cleaned elevation and removed secondary pointing

Fig. 18. Cleaned elevation and removed secondary pointing

Fig. 19. Anchorage of loose elements

Fig. 20. Anchors for bed joints

Fig. 21. Anchorage of new cornice elements in the failure zone

Fig. 22. Restored failure zone in the south tower

Fig. 23. The church towers before and after the renovation

Fig. 24. The church towers before and after the renovation

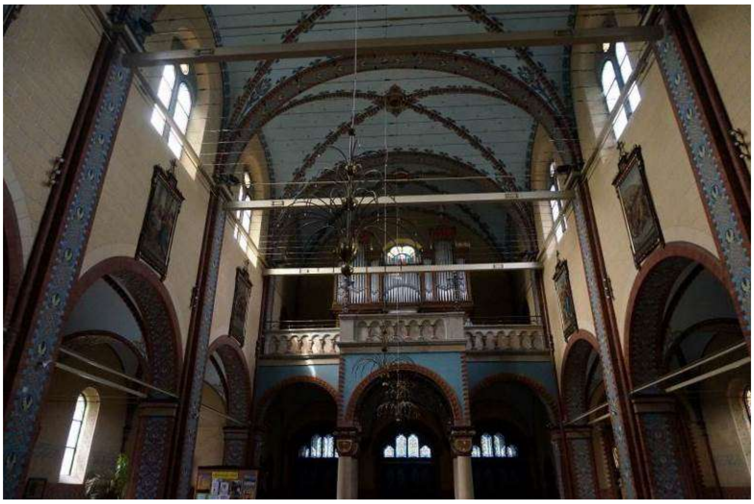

Fig. 25. View of the church after renovation

The mosaic above the entrance (Fig. 26) and the stairs leading to the main entrance (Fig. 27) were renewed. The chancel and the east elevation are currently being renovated (Fig. 28). As in the case of the towers, loose masonry units are additionally anchored.

Fig. 26. Renewed mosaic above the main entrance

Fig. 27. Renewed stairs and the main entrance

Fig. 28. Renovation of the chancel and the east elevation

6. CONCLUSIONS

Repair works of historic structures, particularly vaults and walls of church towers, are difficult. The works are especially complicated when the causes of damage cannot be eliminated and the repairs are performed bearing in mind that other works interfering in the historic structures will be required at some time. The Holy Trinity Church in Ruda Śląska - Kochłowice is just such a case. Exploitation of 26 coal seams under the church or in its direct vicinity within 70 years resulted in the continuous formation of new damages and opening of repaired cracks. Fortunately, the church has overcome these effects due to continuous renovation and repair works. Nowadays, there is no mining exploitation under the church.

REFERENCES

1. Calvo-Serrano, MA, Castillejo-González, IL, Montes-Tubío, F and Mercader-Moyano, P 2020. The Church Tower of Santiago Apóstol in Montilla: An Eco-Sustainable Rehabilitation Proposal. *Sustainability* **12.**

2. Ciesielski, R 1988. Nowe możliwości analizy i diagnostyki budowli zabytkowych *[New possibilities of analysing and diagnosing historic buildings]*. *Inżynieria i Budownictwo* **9**, 470- 476. (in Polish).
3. Ciesielski, R 1998. *Obciążenia wyjątkowe budowli zabytkowych [Exceptional load on architectural monuments]*. IV Konferencja Naukowo-Techniczna: Inżynieryjne Problemy Odnowy Staromiejskich Zespołów Zabytkowych Rew-Inż. *[4th Science and Technology Conference: Engineering Problems of Renewal of Old Town Historic Complexes of Buildings Rew-Inż]* Kraków, 1998, Volume 1, 135-148. (in Polish).
4. Domasłowski, W and Łukaszewicz, JW 1996. Problemy konserwacji murów ceglanych *[Problems with restoration of brick walls]*. *Ochrona Zabytków* **195**, 351-358. (in Polish).
5. Drobiec, Ł, Jasiński, R and Piekarczyk, A 2013. Konstrukcje Murowe według Eurokodu 6 i norm związanych *[Masonry structures according to Eurocode 6 and related standards]*. Volume 1. Warszawa, PWN Publishing House. (in Polish).
6. Drobiec, Ł, Jasiński, R and Mazur, W 2020. The Use of Non-Destructive Testing (NDT) to Detect Bed Joint Reinforcement in AAC Masonry. *Applied Sciences*, **10**.
7. Drobiec, Ł 2007. Przyczyny uszkodzeń murów *[Causes of masonry damage]*. XXII Ogólnopolska Konferencja – Warsztat Pracy Projektanta Konstrukcji *[22nd Polish Conference - Workshop of Structure Designers]*, Szczyrk, 7-10 March 2007, Volume I, 105-147. (in Polish).
8. Drobiec, Ł 2015. Naprawa rys i wzmocnienia murowanych ścian *[Repairs of cracks and strengthening of masonry walls]*. XXX Jubileuszowe Ogólnopolskie Warsztaty Pracy Projektanta Konstrukcji, *[30th Polish Jubilee Workshop of Structure Designers]* Szczyrk 25-28 March 2015, Volume I, *323-398.*
9. Drobiec, Ł 2017. Limitation of cracking in AAC masonry under the window zone. *Mauerwerk* **21**, 332-342.
10. Drobiec, Ł 2019. Analysis of AAC walls subjected to vertical. *Mauerwerk* **23**, 387-403.
11. Drobiec, Ł 2020. Behaviour of stitching bars in the masonry wall. In: *Brick and Block Masonry – From Historical to Sustainable Masonry*. Taylor and Francis Group. London, s. 979-986.
12. Drobiec, Ł, Jasiński, R and Kubica, J 2008. Strengthening of cracked compressed masonry using different types of reinforcement located in the bed joints. *ACEE Architecture, Civil Engineering, Environment*, **4**, 39-48.
13. Gentile, C and Saisi, A 2007. Ambient vibration testing of historic masonry towers for structural identification and damage assessment, *Construction and Building Materials* **21**, 1311–1321.

14. Gentile, C, Saisi, A and Cabboi, A 2015. Structural Identification of a Masonry Tower Based on Operational Modal Analysis. International Journal of Architectural Heritage **9**, 98-100.
15. Ivorra, S and Pallares, FJ 2006. Dynamic investigation on a masonry bell tower, *Engineering Structures* **25**, 660–667.
16. Janowski, Z 1988. Nośność i trwałość konstrukcji murowych w obiektach zabytkowych *[Load capacity and durability of masonry structures in architectural monuments]*. IV Konferencja Naukowo-Techniczna. Inżynieryjne Problemy Odnowy Staromiejskich Zespołów Zabytkowych Rew-Inż. *[4th Science and Technology Conference: Engineering Problems of Renewal of Old Town Historic Complexes of Buildings Rew-Inż]* Kraków, 23-40. (in Polish).
17. Jasieńko, J, Łodygowski, T and Rapp, P 2006. Naprawa, konserwacja i wzmacnianie wybranych, zabytkowych konstrukcji ceglanych *[Repair, maintenance and strengthening works of selected historic brick buildings].* Wrocław, Dolnośląskie Wydawnictwo Edukacyjne. (in Polish).
18. Kujawa, M, Lubowiecka, I and Szymczak, C 2020. Finite element modelling of a historic church structure in the context of a masonry damage analysis. *Engineering Failure Analysis* **107**.
19. Małyszko, L and Orłowicz, R 2000. Konstrukcje murowe. Zarysowania i naprawy *[Masonry structures. Cracks and repairs]*. Olsztyn, Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego. (in Polish).
20. Mason, JA 2008. Strengthening of a Historic Unreinforced Masonry Church Tower. *Practice Periodical on Structural Design and Construction* **13.**
21. Mazzolani, FM and Mandara, A 2002. Modern trends in the use of special metals for the improvement of historical and monumental structures. *Engineering Structures* **24**, 43–856.
22. Mosoarca, M, Keller, AI and Bocan, C 2019. Failure analysis of church towers and roof structures due to high wind velocities. *Engineering Failure Analysis* **100**, 76–87.
23. Mosoarca, M, Keller, AI, Petrus, C and Racolta. 2017. Failure analysis of historical buildings due to climate change, *Engineering Failure Analysis* **82**, 666–680.
24. Nowak, R and Orłowicz, R 2020. Testing of Chosen Masonry Arched Lintels. International Journal of Architectural Heritage.
25. Nowak, R, Orłowicz, R and Rutkowski, R 2020. Use of TLS (LiDAR) for Building Diagnostics with the Example of a Historic Building in Karlino. Buildings **10**.
26. Orłowicz, R, Małyszko, L and Kindracki, J 1999. Morfologia uszkodzeń ścian i elementów wykończenia w konstrukcjach murowych *[Morphology of damage to walls and finish elements in masonry structures]*. XIV

Ogólnopolska Konferencja Warsztat Pracy Projektanta Konstrukcji *[14th Polish Conference - Workshop of Structure Designer]*, Volume 1, part 2, pp. 167-192 (in Polish).

27. Pająk, Z, Kubica, J, Starosolski, W and Drobiec, Ł 1998. Problemy zabezpieczenia na wpływy górnicze i pogórnicze obiektów sakralnych *[Problems concerning protection of religious facilities against mining and post-mining impact]*. IV Konferencja Naukowo-Techniczna Inżynieryjne Problemy Odnowy Staromiejskich Zespołów Zabytkowych „REW-INŻ. [*4th Science and Technology Conference: Engineering Problems of Renewal of Old Town Historic Complexes of Buildings REW-INŻ]* KRAKÓW 98", 21-23 May 1998, pp. 171-178. (in Polish).
28. Pirchio, D et al. 2021. Integrated framework to structurally model unreinforced masonry Italian medieval churches from photogrammetry to finite element model analysis through heritage building information modelling. *Engineering Structures* **241**.
29. Rucka, M, Wojtczak, E and Zielińska, M. Interpolation methods in GPR tomographic imaging of linear and volume anomalies for cultural heritage diagnostics. *Measurement* **154**.
30. Runkiewicz, L and Rodzik, W 1990. Badania nieniszczące wytrzymałości murowanych obiektów zabytkowych *[Non-destructive testing of the strength of historic masonry buildings]*. *Inżynieria i Budownictwo* **47**, 50- 52.
31. Tajchman, J and Najder, T 2006. Cement, beton i żelbet w zabytkach architektury – wady i zalety (wprowadzenie do problematyki konserwatorskiej) *[Cement, concrete and reinforced concrete in architectural monuments - pros and cons (an introduction into the conservation issues)]*. XXI Ogólnopolska Konferencja – Warsztat Pracy Projektanta Konstrukcji *[21st Polish Conference - Workshop of Structure Designers]*, Szczyrk, 8-11 March 2006, Volume III, 145- 213. (in Polish).

Editor received the manuscript: 03.06.2021