

# Analysis of removal method of a 19<sup>th</sup> church's deflection

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**Abstract.** A historic mid-19<sup>th</sup> C. church building is located on the area affected by the impact of underground coal mining. In the past, the building was secured many times against an adverse effect of the mining area deformation by providing massive reinforced-concrete reinforcements. As uneven depressions have emerged, caused by underground coal mining, the structure has become vertically deflected by 39 mm/m in the eastern direction. With the building length of 51 m, the corners have been vertically displaced in relation to each other by 1.99 m. The existing deflection impedes the structure's usage, decreases its value and threatens the stability of its furnishings. The deflection should therefore be removed. Due to the building's historic character and the presence of massive reinforcements installed already during its operation, three scenarios of deflection rectification were assessed. After the assessment, a scenario was chosen where the building is detached with the use of hydraulic jacks in the floor level, and then straightened by uneven raising. The lifting height of the corners is up to 1.99 m. The article presents the results of the building model calculations and the reinforcements proposed for the time of straightening. It was assumed that the structure, with the total weight of 810,000 tonnes, will be straightened by means of 178 jacks. The outlined procedure will restore the building's architectural assets and value and will allow the church goers to use the church comfortably.

## 1 Introduction

An uneven depression of the land surface occurs on the areas where underground extraction of hard coal takes place. Building structures are becoming vertically deflected as a result of such depressions. Deflections reduce the comfort of a building's usage, decrease its value and often lead to its further damages [1]. The issue regards in particular historic buildings erected before hard coal exploitation began in their neighbourhood [2].

The article presents a neo-Gothic church building erected in the second half of the 19<sup>th</sup> C. The structure's vertical deflection in the eastern direction is 39 mm/m. As the impact of mining in the building's region began to emerge soon after it was erected, the edifice has been strengthened many times to mitigate the effects of land deformation induced by coal mining. Massive reinforced-concrete constructions below the floor and land level were installed in

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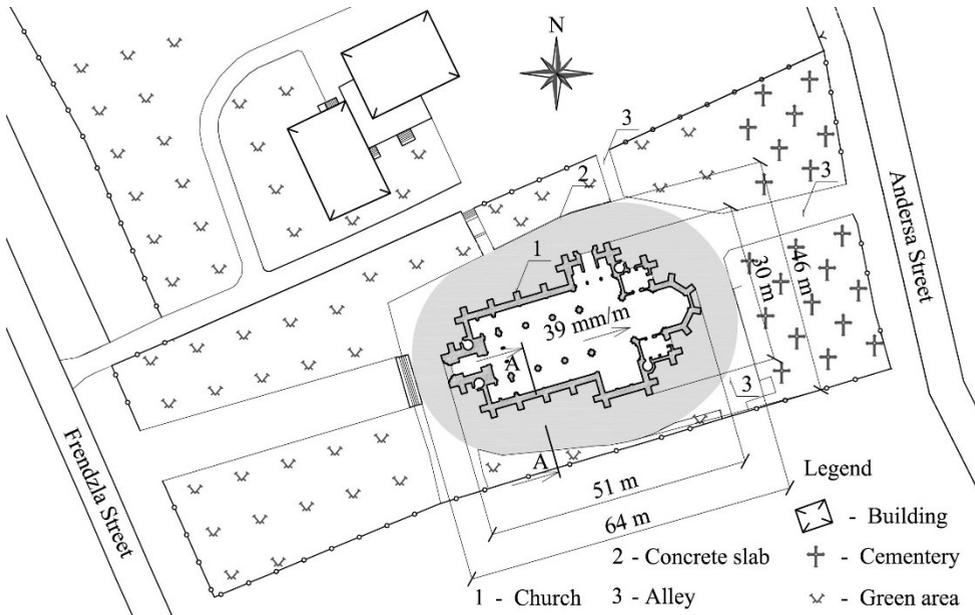
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particular [3]. A customised approach to the designing of structure deflection removal is required due to such reinforcements. The solutions successfully employed for rectifying a neo-Gothic church from 1896–1898 [4] or for 11-storey buildings [5] cannot be applied in a straightforward manner. A custom approach requires, especially, to analyse the concept of managing the existing reinforced-concrete reinforcements and to design temporary reinforcements and a deflection rectification technology.

## 2 Church building overview

### 2.1 Basic information about the building

The Holy Cross Church building is situated in Bytom-Miechowice and was erected in the neo-Gothic style in 1856–1864. It was built in the shape of the Latin cross. Its floor plan can be inscribed into a rectangle with a length of 51 m and width 30 m. The longer side coincides roughly with the east-west direction (Fig. 1). There is a tower in the western part of the church, finished in 1894, ended with a cross installed at the height of 58.2 m. A part of the building with a basement is situated on the opposite, eastern side of the building, with a presbytery extended by two sacristies. The church is attached to a reinforced-concrete slab with the length of 64 m (Fig. 1 - more details about the slab at the end of the chapter).



**Fig. 1.** The church building is positioned in relation to alleys, cemetery and green area; the section A-A is in Fig. 2

The main entrance to the church leads through the tower and through a porch inside the tower. The central part of the building accommodates the main nave and two side naves separated with two rows of brick columns with the section of 0.87/0.87 m and height of 9.3 m. A vaulted ceiling of the main nave is 15.11 m over the floor. A single-nave transept is situated between the presbytery and the naves. Side entrances are provided in the northern wall of the building. Vaulted ceilings above this part of the church are distinct for the same height as above the main nave. A small tower, so-called bell tower, can be found in the roof, over the point where the transept crosses the main nave.

All the above-ground walls of the building are made of full brick. Their thickness at the level of the presbytery floor is 1.16 m, in the naves - 1.28 m, and in the transept - 1.38 m. The tower walls at the floor level are up to 2 m thick. The wall thickness of the naves, presbytery and tower is not constant and decreases along with the height. The naves' walls in the foundation level of the vaulted ceilings and of the tower at the level + 32 m are 1.0 m thick. All the external walls are furnished with buttresses with their width at the floor level of 1.2 m and length of 1.43 m. A plinth is formed outside all the walls, at a height of 0.98 m. Vaulted ceilings above the naves, presbytery and apse are constructed as semi-circular crossed and ribbed ceilings made of full brick (ribs) and of cavity brick (vault cells). A cross-section of the main ribs is similar to a rectangle dimensioned 0.65 m/0.91 m. The vault cells supported on the ribs are 0.24 m thick.

The church is founded on 2 m wide foundation walls made of stone and brick. The uncoverings (see Fig. 3) and measurements made show that the base of such walls is 4.40 m below the floor level. A roof structure over the church is made of a wooden frame with a double suspension system. The roof is covered with zinc-plated sheeting laid on full boarding.

A cemetery is located in the eastern part of the building, 7 m from the presbytery. It is very important - due to the adopted method of removing the building deflection - that a reinforced-concrete slab attached to the building is situated in the cemetery limits from the church side (Fig. 1). Alleys used by pedestrians are situated between the cemetery and the presbytery and around the church, directly by its walls (Fig. 1). Vehicles move along the alleys during bigger events or during funerals.

## 2.2 Land deformation in the building's region

The land upon which the church building is placed is subject to constant deformations caused by underground mining of hard coal. The voids created in the exhausted coal deposits are tightening, hence non-uniform land depressions and deformations are caused in the land. The first underground exploitations affecting the structure were conducted already at the end of the 19th century. There is no accurate information about land deformations which occurred in the proximity of the structure before the end of World War II (until 1945 the church area belonged to Prussia and then to Germany). Records say that 11 beds were exploited after 1945, mainly with longwall caving. Extraction was carried out at the depth of 270 m to 820 m, and the extracted beds were 1.5 m to 2.2 m thick. A bed with a total thickness of about 21 m was exhausted. It can be pointed out, by analysing the effects of extraction after 1945, that the church building after this date was lowered by 16.90 m in the tower area to 18.85 m in the presbytery area.

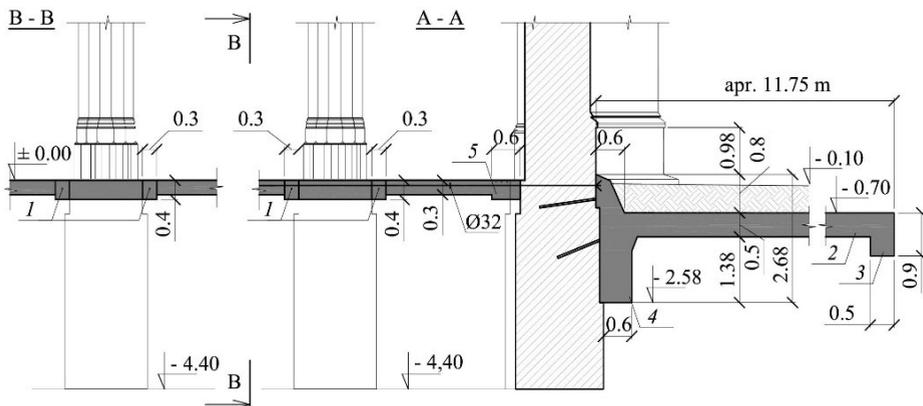
## 2.3 Existing building reinforcements

The building has been damaged due to mining exploitation conducted more than ten times in its adjacency and due to considerable land deformations caused by such exploitation. The building was repaired provisionally many times for this reason. In fact, it has been repaired incessantly since 1955. During such repairs, walls were mainly reconstructed, cracks in vaulted ceilings and columns were filled with resins and the roof covering was replaced. Urgent protection and remedial works were also conducted for such historic components as stained-glass windows, stone elements of the façades, sculptures and others.

Apart from provisional repairs, the building was strengthened three times. First, ties were mounted underneath the church interior floor in 1955 – 1958. These are reinforced-concrete components with their cross-section (b/h) of 0.3 / 0.4 m, reinforced with a single bar with the diameter of 32 mm (*I* - Fig. 2). The ties are aligned parallel to the church axis and

perpendicular to this axis in such a way that each pillar is embraced by such components (Fig. 2, cross-sections A - A and B - B).

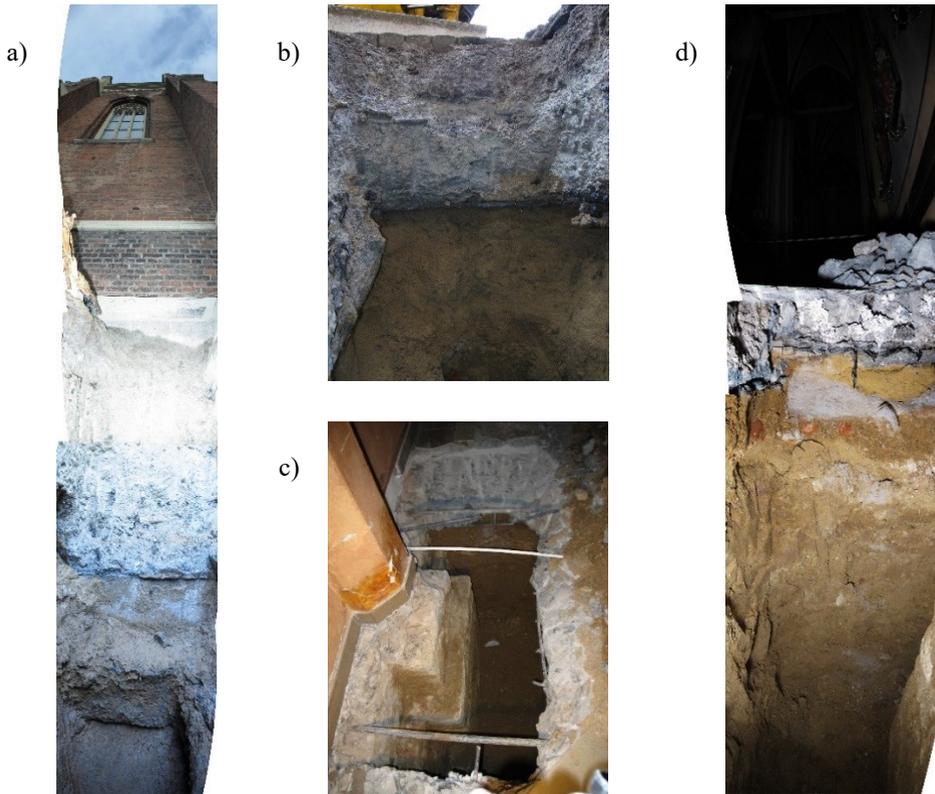
Such strengthening has proved to be unsatisfactory when subsequent effects of mining have emerged [3]. Another reinforcement, installed outside the building under the ground level and under the floor inside the building, was thus executed in the mid-80's of the 20th c. A 0.5 m thick and 6 m to 16 m wide reinforced-concrete slab was constructed outside, at a depth 0.8 m below the ground level (2 - Fig. 2 and 2 - Fig. 1). The slab runs around the church and has an oval shape in the outline, which can be inscribed into a rectangle with the sides' length of 64 m and 46 m (Fig. 1). From outside, the slab is ended with a groin with the cross-section of 0.9 m / 0.5 m (3 - Fig. 2). From the side of the church, the slab is ended with a reinforced-concrete ring with a height of 2.68 m and width of 0.6 m (4 - Fig. 2). Moreover, inside the church under the floor, along the walls, a reinforced-concrete ring with the cross-section (b/h) of 0.6 m / 0.4 m was built in (5 - Fig. 2) and the hollows between the ties (made in 1955 - 1958) were concreted. The reinforcements described above were inventoried based on the uncoverings made outside and inside the building. For such uncoverings, boreholes had to be performed in a 0.5 m thick reinforced-concrete slab outside the building (Fig. 3 a,b) and a concrete layer had to be broken up between the ties installed inside under the floor (Fig. 3 c,d). The elements dismantled during uncoverings were restored.



**Fig. 2.** Building reinforcement outside the structure, below the ground level and reinforcement under the floor (position of cross-section A - A is shown in Fig. 1); 1 - reinforced-concrete ties reinforced with bar with diameter of 32 mm, 2 - reinforced-concrete slab, 3 - reinforced-concrete groin, 4-reinforced-concrete ring outside the building, 5 - reinforced-concrete ring inside the building.

The reinforcement mounted in the 80's of the 20th century has fulfilled its function by taking over horizontal deformations of mining land. The distance between the tops of the nave columns was however changing due to the impact of the mining land curvature, which threatened the stability of vaulted ceilings. Hence, steel reinforcements on the foundation level of vaulted ceilings on the walls and columns at a height of 9.3 m over the floor level, were installed at the turn of the 20<sup>th</sup> and 21<sup>st</sup> century (see Fig. 9).

The most severe church damage currently is its eastward deflection by 39 mm/m. The deflection hinders to use the building and threatens the stability of some of the ornamental elements on the façades, especially on the attic.



**Fig. 3.** Uncoverings made to take an inventory of reinforcements and building foundation (uncoverings were made in the place of the cross-section A - A from Fig. 1): a), b) reinforcement situated outside, below the ground level, c), d) reinforcement situated inside under the floor.

### 3 Analysis of deflection removal method

Due to the structure's large floor plan and its construction it was assumed that the building deflection would be removed (rectified) by uneven raising with jacks. The process consists in tearing the building in the horizontal plane and then lifting the part of the building situated over the detachment plane until the part of the building being lifted is reinstated to its vertical position. After the completion of rectification, the eastern edge of the building is situated higher, and the western part remains at the same level. Another rectification method, where ground is removed from underneath the part of the building situated higher [6, 7], would have led to considerable, inadmissible, relative displacements of the church construction elements having low rigidity.

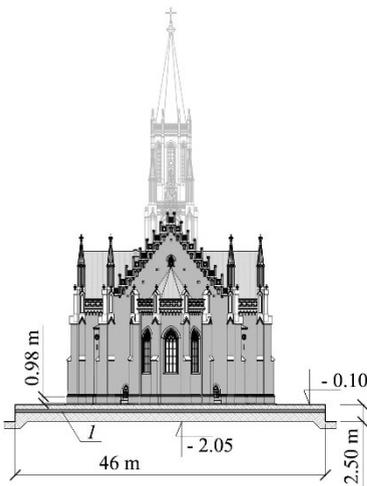
Three scenarios of uneven building lifting were considered. In the first scenario, the building is raised together with reinforced-concrete reinforcements situated under the church floor and below the ground level outside the building. A neo-Gothic church building was straightened this way, for instance [4]. However, for the structure covered by this work, as a result of such a procedure, the eastern edge of the reinforced-concrete slab - representing an external church reinforcement - would have been 2.5 m (64 m × 39 mm/m) above the ground level situated directly by the cemetery (Fig. 1). A 2.5 m high wall would then be created in the eastern part of the building (Fig. 4a), which would impede the traffic of pedestrians and vehicles around the building. This scenario was rejected for those reasons, although, as

mentioned above, such procedure would have been favourable for constructional reasons and technically feasible [4].

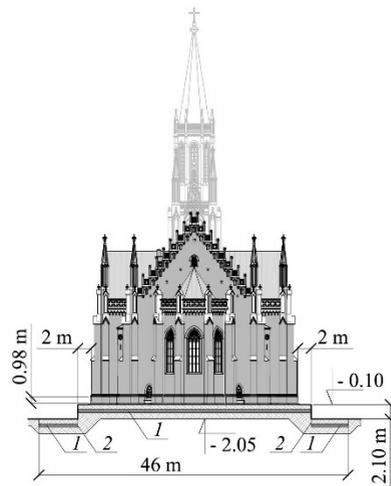
Another considered scenario was uneven raising of the church building together with a separated part of the reinforced-concrete slab outside. It was assumed for this aim that, reinforced-concrete reinforcement would be cut at a distance of 2 m from the edge of the building (Fig. 4b). This way, the plan of the reinforced-concrete slab attached to the church walls could be inscribed into a 55 m long (51 m + 4 m) and 34 m wide (30 m + 4 m) rectangle. The church building, with part of the slab contiguous to the building, would be lifted unevenly in the considered scenario. Up to 2.1 m (55 m × 39 mm/m) high wall would thus be formed around the church in the eastern part – Fig. 4b. Such a wall would however greatly interfere with the historic character of the structure and its surroundings. As a result, this scenario was also rejected.

The third considered scenario of rectifying the building deflection is to detach it, in the floor level of naves and presbytery, and then to lift unevenly only the above-ground part of the building situated above the detachment plane. In this scenario, all the reinforcement components situated below the floor and the ground level are not lifted and no interference with their construction takes place. The eastern edge of the building is raised by 1.99 m (51 m × 39 mm/m) with such procedure. As a result, the height of the plinth, which originally was constant and was 0.98 m, will increase from 0.98 m in the western side to 2.97 m in the eastern side (Fig. 5). A vertical position of the front entrance to the church, leading through a tower, will not change when the deflection is eliminated. Additional stairs and ramps will be provided by the side entrance to the building leading through a transept and by entrances to the sacristy.

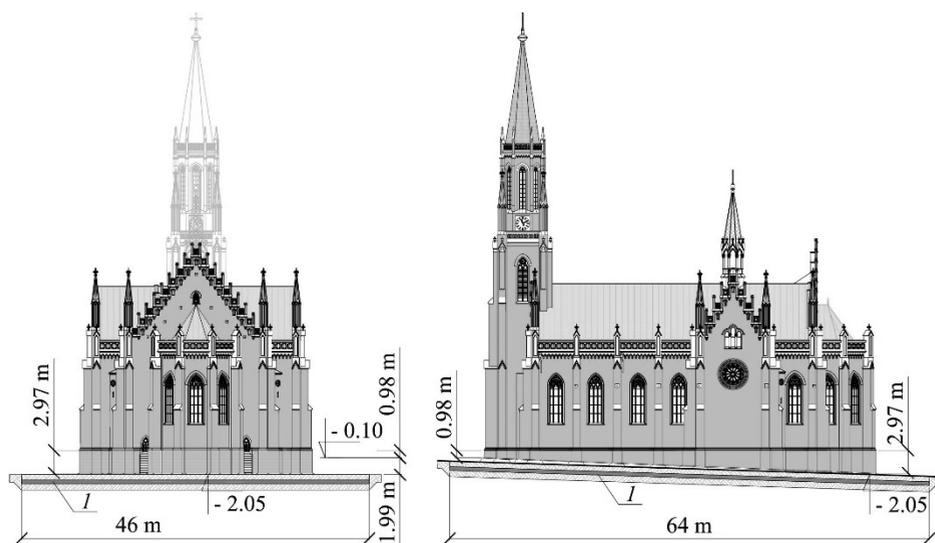
a)



b)



**Fig. 4.** Alternative methods of uneven raising of the church building – view of eastern façade: a) a scenario where the building is straightened with the whole reinforced-concrete reinforcement, b) a scenario with deflection removal from part of the reinforced-concrete slab, after its cutting at the distance of 2 m from the wall edge; *I* – reinforced-concrete slab with the thickness of 0.5 m, 2-the cutting surface of the reinforced-concrete slab.



**Fig. 5.** Adopted method of uneven raising of the church building: *I* – reinforced-concrete with the thickness of 0.5 m.

## 4 Adopted design solutions

### 4.1 Calculation analysis

A calculation analysis was undertaken to check the correctness of the adopted solutions. A building model was developed for this aim, whose geometry matches the real object. The model represents an above-ground part of the structure over the floor, i.e. such to be unevenly raised. The model uses surface elements (panels) and bars (Fig. 6). 308 panels were used to represent the geometry of walls and buttresses. 1,694 panels were used to represent the geometry of vault cells of vaulted ceilings. The bar elements were used for representation of brick columns, ribs of vaulted ceilings and steel reinforcements running in the foundation level of vaulted ceilings on the walls. The ribs themselves were modelled with 721 bars. The discretisation of surface elements, modelling the walls into finite elements with the dimensions of approx. 0.3 / 0.3 m, was performed in the calculations. The dimension of finite elements, into which surface elements modelling the vault cells of vaulted ceilings were divided, is approx. 0.25 / 0.25 m. The stiffness of the wooden roof structure was omitted in the model due to its negligible role in the stiffness of the whole building. The roof weight was however applied to the elements modelling the walls in the place where the load from the roof in reality is transmitted onto the building. The overall roof structure weight is 1,074 kN. The determined mean load of the wall, with the weight transmitted from the roof, equals 15 kN/m. However, the values of vertical forces transmitted from the roof to the brick columns vary between 40 kN to 60 kN. An elastic model of the brick wall material was used in calculations with the following values:  $f_k = 3.653$  MPa (compressive strength),  $E_0 = 3653$  MPa (elasticity modulus),  $\nu = 0.2$  (Poisson's ratio),  $K = 1000$  MPa (Kirchoff's modulus),  $\gamma = 1.80$  kN/m<sup>3</sup> (unit weight). The following was used for the vault cells of vaulted ceilings made of hollow brick, respectively:  $f_k = 1.750$  MPa,  $E_0 = 1.750$  MPa,  $\nu = 0.2$ ,  $K = 1.000$  MPa,  $\gamma = 1.20$  kN/m<sup>3</sup>. The loads resulting from the weight of walls and vaulted ceilings were generated automatically by software. The total calculated weight of the raised part of the structure, determined based on the model calculations, is 79,417 kN.

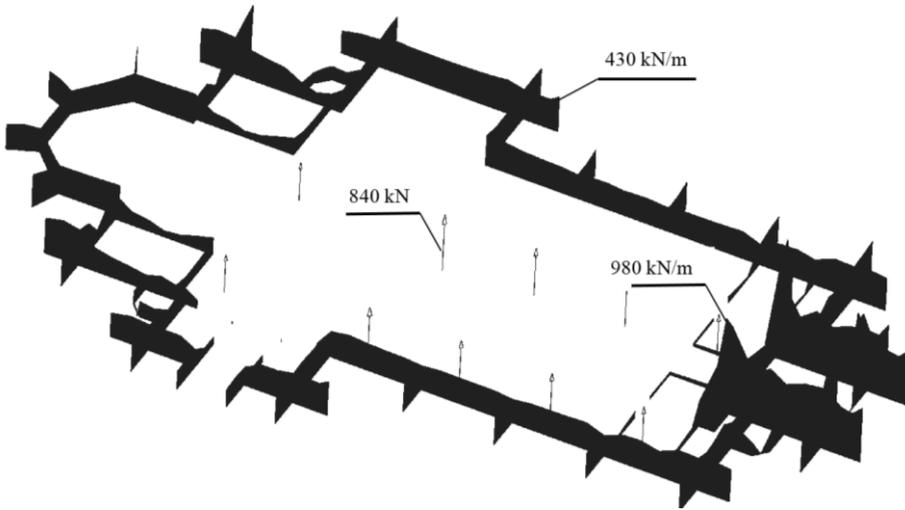
The calculations were carried out in two stages.

- a)
- b)

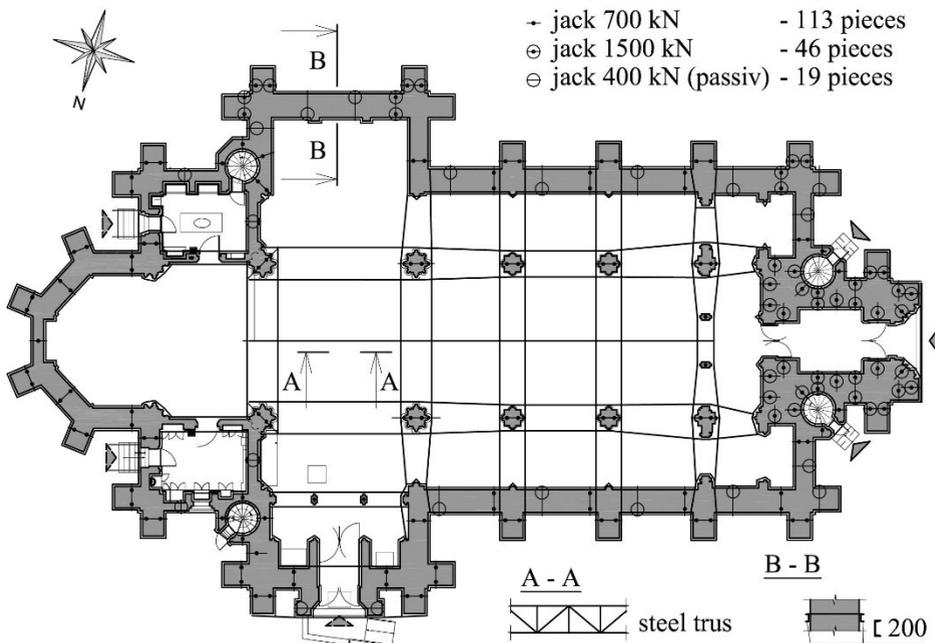
**Fig. 6.** Church building model observed: a) from the top b) from the bottom.

It was assumed in the first stage that the walls and columns are mounted in the level of the proposed building detachment (level 0.00). A distribution of reactions, transferred from the above-ground part of the church onto the foundation walls, was obtained for such scheme (Fig. 7). Maximum reactions in the linear supports of nave walls amount to 430 kN/m and in linear supports of the tower walls to 980 kN/m. On the other hand, maximum reactions in the brick columns of the building amount to 840 kN. When the distributions of reactions were known, the jacks were started to be positioned. It was assumed that for uneven building lifting, jacks working in two modes, active and passive, will be used. Upward displacement of the building will be forced with jacks. The jacks will be installed in brick columns, pilasters and in parts of walls with no door and window openings. A force with the constant value of 50 kN will be excited in passive jacks. The jacks will be mounted in walls in the region of window openings. The task of passive actuators will be only to balance the weight of some of the walls situated under window openings. 113 active jacks with the load carrying capacity of 700 kN, 46 active jacks with the load carrying capacity of 1500 kN and 19 passive jacks were proposed for removing the building's deflection (Fig. 8). The jacks with the greatest load carrying capacity were mounted mainly under the tower.

A situation was shown in the second stage of calculations, where the above-ground part of the church building rests on jacks. A force with the value of 50 kN, directed downwards, was therefore applied in the place of the proposed installation of jacks. This load equals to the constant value of the force exerted by passive jacks on the construction being lifted. Hinge supports were however mounted in the installation place of active jacks. It was revealed that reactions in all active jacks are smaller than their load carrying capacity.



**Fig. 7.** Distribution of reactions transferred onto the foundation walls at the level of  $\pm 0.00$  m.



**Fig. 8.** Proposed reinforcement and layout of jacks.

#### 4.2 Adopted constructional solutions

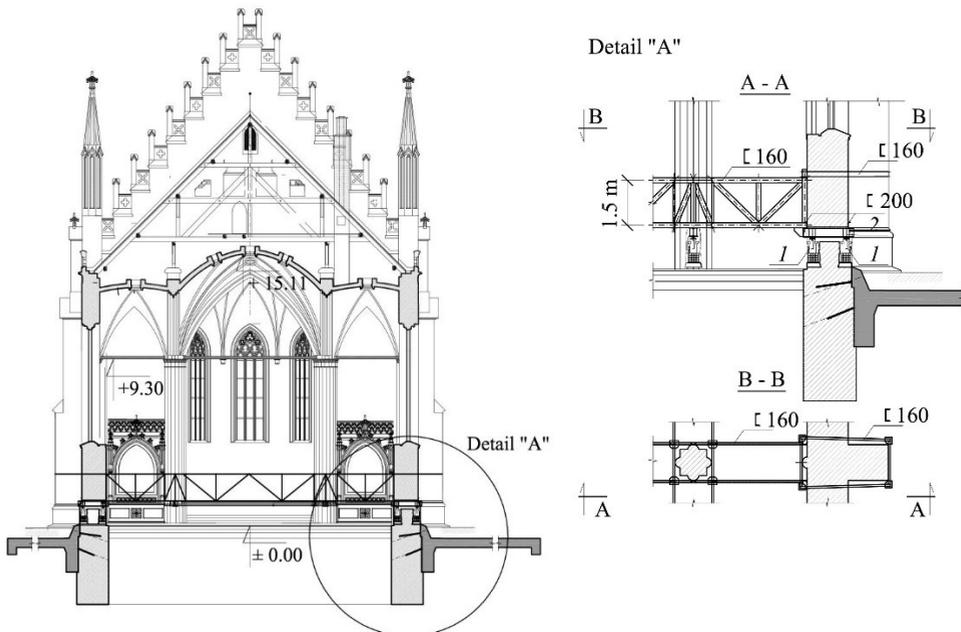
The church should be strengthened prior to the start of uneven raising. Two types of steel reinforcements were adopted: a configuration of I 200 profiles running on two sides by the walls and elements in the form of trusses led inside the building parallel and perpendicular to the axes of naves (Fig. 8).

The role of the reinforcement in the form of I 200 profiles, running by the walls, is to secure the walls against the arch-action in the case where the building rests on jacks. The

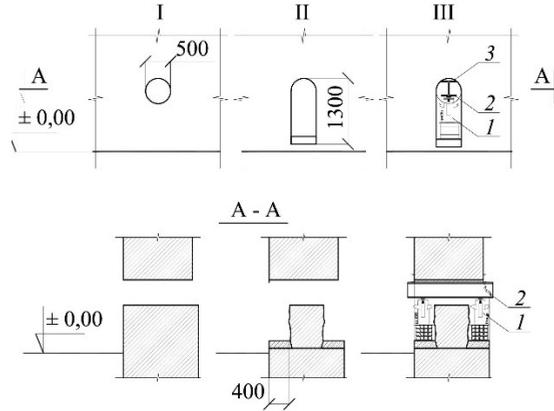
interlinked profiles are hence acting as lintels. The truss elements though, ensure the stability of the construction's elements during uneven raising. Their role, therefore, is in particular to reduce the buckling length of the brick columns separating the naves when they rest on jacks. The truss elements will also transmit forces caused by second-order effects. Second-order effects will arise due to the eccentric transmission of the load by jacks and as a result of material inhomogeneities of the brick columns. In such case, each of the columns, on the detachment level, from four sides, will be connected with reinforcements represented by truss elements.

Jacks with the piston stroke of 200 mm will be used for deflection removal. The height of uneven raising of the structure is however up to 1990 mm. Given the above, the jacks need to be periodically underlain with cubic elements forming stacks. For this reason, active jacks will be mounted in the walls and in the columns in pairs. This will allow, during deflection removal, to operate more conveniently the supports consisting of jacks and of a stack of cubic elements [8]. Forces from each pair of jacks will be transmitted onto the brick construction of walls and columns by means of steel elements made of rolled HEB profiles. The profiles will go through the entire thickness of the walls (Fig. 9). The following installation method was devised to limit disassembly works for installation of jacks and HEB profiles in walls and columns.

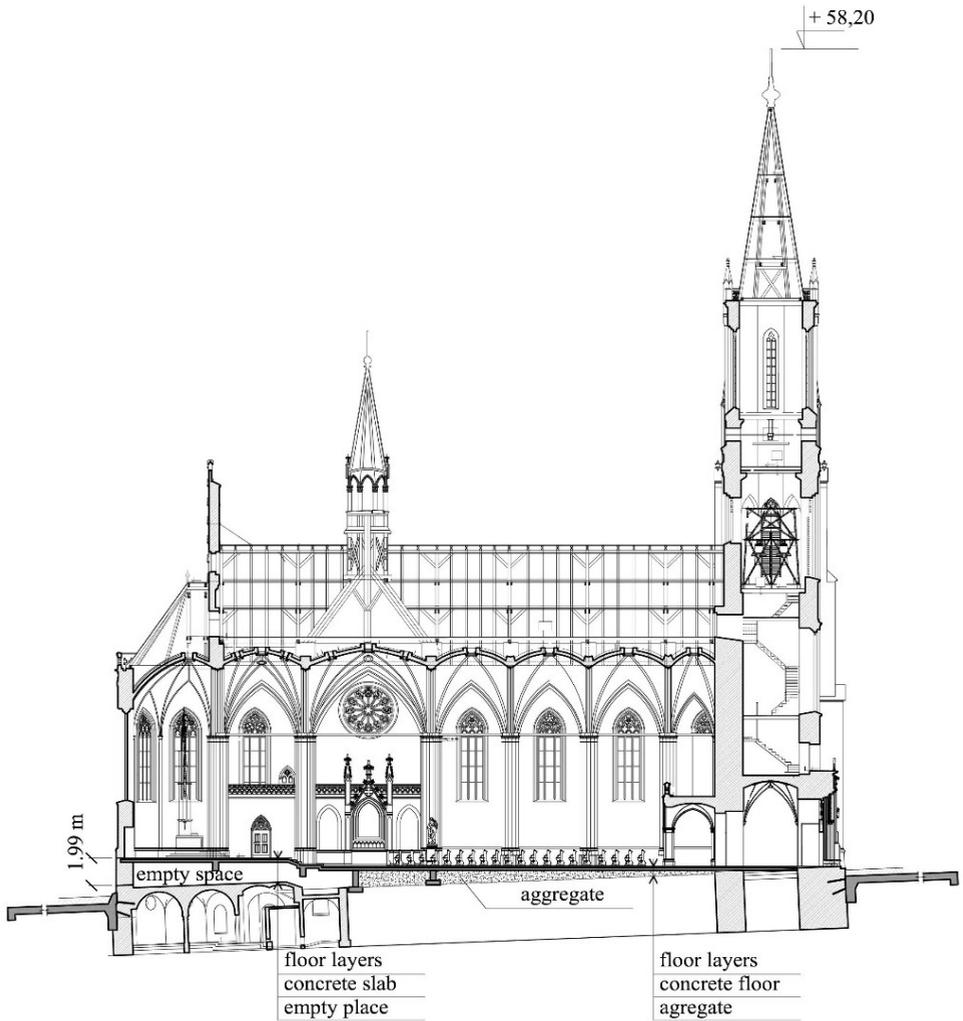
An opening with a diameter of 500 mm will be drilled through the entire thickness of the wall in the first place (Phase I - Fig. 10). Then, in the outer parts of the wall, the opening will be expanded by elongation to the floor level in such a manner that jacks are placed there from both sides (Phase II - Fig. 10). Part of the wall thickness will then be enlarged only, ca. 400 mm from each side. Then (Phase III - Fig. 10) an HEB profile will be inserted into the opening and lifted with jacks to the opening edge. The space between the circular part of the opening and the HEB profile will be filled with mortar. In order to stabilise the position, the HEB profile will be welded to a reinforcement consisting of 200 profiles.



**Fig. 9.** Reinforcement with a truss and a method of transmitting a force from the jacks onto the walls; 1 – jack, 2 – HEB profile.



**Fig. 10.** Phases of jacks' installation in the walls (I, II, III); 1 – jack, 2 - rolled HEB profile, 3-layer of mortar.



**Fig. 11.** Building cross-section after straightening.

The reinforcements described are temporary and will be dismantled after removal of the structure's deflection. After straightening, the walls in the presbytery will be elevated by up to 1.99 m. A new reinforced-concrete ceiling will be constructed to counterbalance the floor level in the church presbytery and in the part of the transept (Fig. 11). The ceiling in the presbyterial part will be rested on outer walls. In doing so, the original ceiling over the basement part will not be loaded. A hollow will be formed between the existing ceramic ceiling and the new reinforced-concrete ceiling. A new reinforced-concrete floor will be created on the remaining part of the church.

## 5 Summary

A historic, neo-Gothic church from the second half of the 19th century is vertically deflected. With the average deflection of 39 mm/m and the structure length of 51 m, the height difference inside the church, resulting from its deflection, is 1.99 m. Provided inside the building, under the floor, and outside, below the land level, are massive reinforced-concrete reinforcements executed in the half of the 20th century to reduce the mining land deformations carried onto the above-ground part of the building.

The proposed method of rectifying the church building's deflection considers its complicated floor plan and the fact that reinforced-concrete reinforcements exist. For the time of straightening, the structure will be additionally reinforced by installing trusses and beams in the lifted part. The calculations conducted reveal that the total weight of the structure is 79,417 kN. The structure will hence be straightened with 178 jacks with the load carrying capacity of 700 kN and 1500 kN.

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