MATEC Web of Conferences **396**, 03002 (2024) https://doi.org/10.1051/matecconf/202439603002
WMCAUS 2023

Review of methods for deflected buildings located in mining area of Upper Silesia

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Abstract. The underground coal mining creates the post-mining void, which causes displacements of a massif, both above and under the void. One of the consequences of underground mining is a change in inclination of the surface area. Hence, buildings in the mining area are vertically deflected. This paper presents the procedure for constructions whose deflection was caused by underground coal mining in Upper Silesia. It describes the historical approach, theoretical analyses, and successful rectification processes performed by non-uniform elevation of buildings. The reviewed literature on procedures for deflected building, some of them observed by the author, and the concepts described in the literature lead to conclusions that the method guaranteeing the purpose of restoring the deflected building is rectification based on non-uniform elevation of jacks with pistons. The scope of other methods is limited to very special cases.

1 Introduction

The underground coal mining creates the post-mining void, which causes displacements of a massif, both above and under the void (Fig. 1). The surface area shows deformation in the shape of a depression basin, additionally some discontinuous deformations [1] and also ground vibrations can be observed. The depression basin is described by indicators of deformation of mining area [2], which include not only depression ($w_{\text{gór}}$), but also horizontal deformations, land surface curvature and a change in the land slope ($T_{\text{gór}}$). There are many predictive theories to determine indicators (geometrical and integral, stochastic, based on massif mechanics, and numerical models based on medium discretization). Particular attention should be paid to a methodology published in 1953 – the geometrical and integral methodology by S. Knoth, developed by W. Budryk, and currently known as Budryk-Knoth methodology. According to this theory, values $w_{\text{gór}}$ can be determined from two parameters describing massif deformations: a – operational parameters and β - an angle of impacts. Operational parameters specify the method of exploitation and elimination of voids with a thickness $g_{\text{śr}}$ ($a = w_{\text{gór-max}} / g_{\text{śr}}$). An angle of impacts characteristic for a type of massif is usually expressed as an angle tangent and is used to determine the related parameter of impact scattering r, which is also connected with the exploitation height and is equal to $H / tan\beta$, (Fig. 1).

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Other indicators of deformation (components of inclination, curvature, and deformation) are obtained by differentiating depressions $w_{\text{gór}}$ and components of horizontal displacements [3].

Deflection of buildings T_{obj} is usually associated with a change in inclination of the mining area $T_{\text{gór}}$. According to recent tests, such an assumption is a too far reaching simplification because deflections T_{obj} also affect other factors, e.g. horizontal deformations [4] and factors other than caused by geological and mining conditions. They include stiffness of soil below the building and seasonal changes in mechanical characteristics of some types of ground, as well as the foundation method of a building. Additionally, deflection of a building in the mining area is also significantly affected by the applied structural solution. Differences between $\mathbf{T}_{\text{obj}}$ and $\mathbf{T}_{\text{gór}}$ cannot be interpreted as scattering, which means that the values T_{obj} and $T_{\text{gór}}$ cannot be considered as equivalents.

Deflection is a defect, which impairs operation of buildings [5], underestimates their value, and in extreme situations can lead to structural collapses [6]. Methods of eliminating deflections by lowering a part situated higher above the ground and elevating a part situated lower have been employed in redeveloped mining areas in Silesia. Such troublesome deflections used to be minimized by introducing changes into buildings.

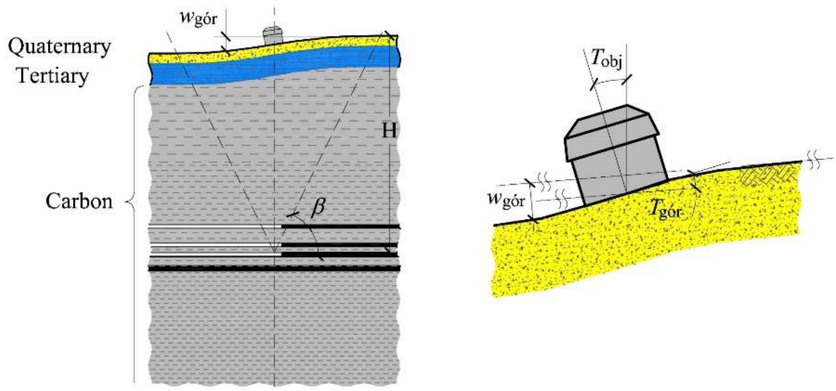


Fig. 1. Layers of tertiary and quaternary carboniferous near the mining area, its depression ($w_{\text{gór}}$), inclination ($T_{\text{gór}}$), and deflection of constructions (T_{obj}).

2 Rectification by lowering a part situated higher above the ground

Rectification by lowering a building part, which is situated higher above the ground, usually consists in removing soil from below the building, which reduces its load-bearing capacity, and consequently provides subsidence of the building parts situated higher above the ground. Soil can be removed with drilling rigs by performing horizontal holes below the foundation (Fig. 2). However, effectiveness of this method is limited. The majority of modern buildings in mining area have a layer of compacted soil underneath. Even a dense grid of holes in such a ground often does not guarantee deformation of underlying soil due to counteraction of internal friction forces initiated by response to loading with self-weight of the building. Hence, drill holes are reasonable for cohesive soil with low modulus of elasticity. However, this method turned out to be ineffective for quaternary cohesive soil in Silesia and compacted loose soil.

Therefore, a more invasive technique of removing soil from below a part of the building located higher above the ground was used in the 1980s in the area of the then Rybnicki Okręg Węglowy (Rybnik Coal Area) in Silesia. This technique consisted in removing soil by layers [7], [8].

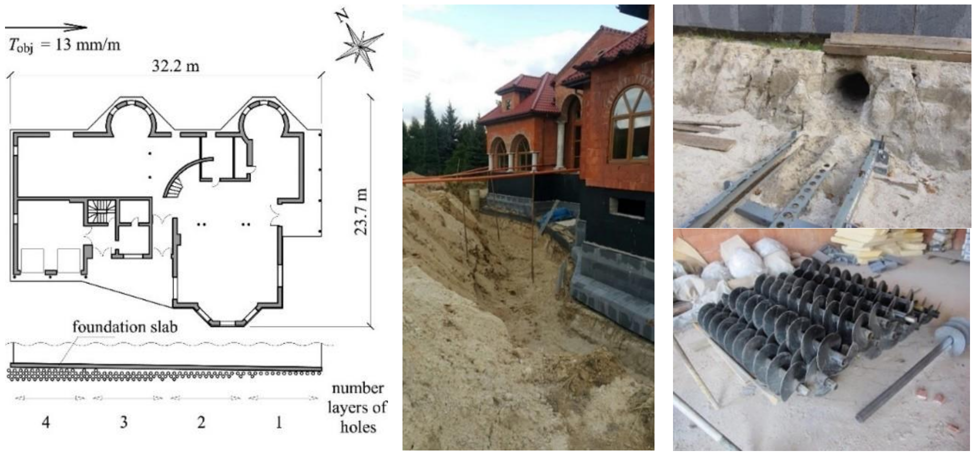


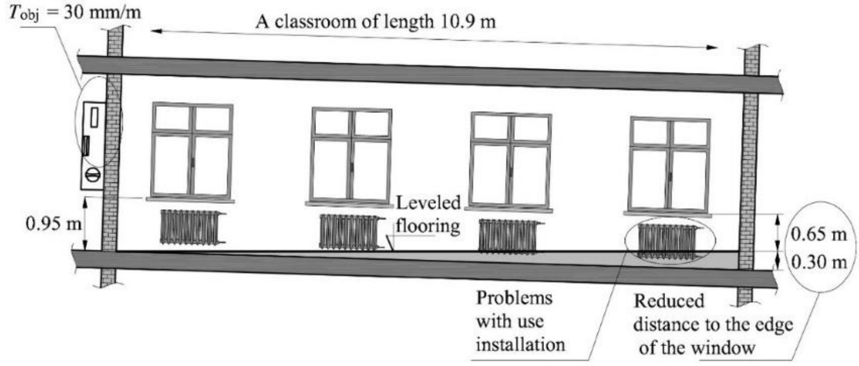
Fig. 2. Removal of soil from below the foundation with the method of drill holes

In this method chain on gears driven by motor and equipped with a cutting unit is put under the building, at a depth of ca. 0.5 m below the foundation base. Moving chain removed soil by layers of ca. 65 mm thick under the building part located above the ground, which restored the building to the vertical position. The drive mechanism consists of: cutting chain, hydraulic motor, chain adjuster, and speed controllers. The device driving chain was moving along specially built track at the bottom of the excavation. Foundation layers of buildings, which were rectified were classified as quaternary and tertiary deposits, whereas sand and sandy soil were directly under the buildings. Rectification required many preparatory works on possession of area around the building to dig excavations and install devices there. Despite strengthening, superficial cracks were formed during rectification. Therefore, steel strengthening with greater section was used in other building. The rectified buildings were below the original level of the ground and infrastructure, which impaired their normal operation. This method was used for three single-family houses with load-bearing wall structures, built at the turn of 1970s and 1980s, which had been previously deflected from 62.2 mm/m to 118 mm/m due to mining exploitation under them.

To avoid serious damages to the buildings during removal of soil from below them, the concept was developed to rectify vertically deflected building by drilling holes on the surface area, at an angle of 45^0 [9]. In that way the drill holes were to be arranged in the system crossing in the plane of flares, leaving triangular sectors of undisturbed soil at edges. After rectification of the building, it was required to fill gaps in soil with concrete to keep its position. It was one of many projects consisting in removing soil from below the building, which did not provide an expected result. In the 1980s and 1990s, the methods of rectification based on removing soil were specified in the literature as the “gravitational and drilling” methods.

3 Attempts to restore comfort of vertically deflected building

The above methods of rectification were used in individual cases over the history of hard coal mining in Poland. Until rectification based on non-uniform elevation was introduced, which is presented in the next chapter, the comfort of operating buildings was restoring by levelling selected elements of a building, particularly floor, using various technical solutions. For concrete floor, new floor layers were placed on existing floor (Fig. 3a). For timber floor, existing floors were often removed covering top surfaces of wooden beams, on which triangular elements were nailed to obtain the horizontal level, and then these beams were again covered (Fig. 3b). However, such solutions led to impaired operation of those building. For example, in a classroom with a length of 10.9 m, levelling the floor of inclination of 30 mm/m lowered the window sill level from 0.95 m to 0.65 m (Fig. 3a). Moreover, there were some inconveniences of using installations, that is, radiators were below the floor level (Fig. 3c). From present perspective, such alterations introduced into the buildings de facto damaged them. Improvements that did not seriously interfere with the building structure were to fit vertically deflected windows, doors (Fig. 4), cabinets (Fig. 5a), building steps inside rooms (Fig. 5b) etc.



a)

b)

c)

Fig. 3. Examples of consequences of levelling floor: a) changes in a classroom, b) lowered distance between the floor and the window edge, c) problems with using central heating system.

Fig. 4. An example of windows and doors in deflected buildings.

a) b)

Fig. 5. Organisation of interiors with inclined floor: a) built-in wardrobe, b) steps inside a room

The main method procedure for deflected buildings was however compensation paid for a building or its removal. Despite significantly impaired operation of such buildings, many of them were still in use. Nowadays, this situation has changed due to continuous development of rectification methods.

4 Rectification by elevating a part situated higher above the ground

In recent decades deflected buildings in Silesia have been rectified by elevating lower parts using jacks. As the method develops, it is applied in structures of increasing weight and complex structural solutions. The discussed method consists in installing jacks in walls or poles at the lower floor, dividing the building into two parts - the one kept on the ground, and another one non-uniformly elevated. Foundation, foundation walls, or fragments of basement walls based on foundation are a part of the building kept on the ground. However, there are special circumstances where a building is elevated also with foundation, and then the part kept on the ground is composed of elements prepared to resist reaction from the jacks. These elements can be stacks of elements pressed into ground, reinforced concrete piles [10], or reinforcement of foundations increasing foundation support. Division of the building into two parts means for masonry structure horizontal tearing of the building caused by appropriate force inputs in jacks inside the walls, and for reinforced concrete structures crushing or cutting elements with cutters. As the extension of the jack pistons is limited, it is often necessary to place stacks of elements under them.

In practice, two types of hydraulic jacks are applied: membrane and piston jacks. Membrane jacks are made of sheet in a disc shape, so supplied oil increases its height under pressure [11]. In this method jacks are membranes filled with oil with an initial height of 60 mm and a diameter of 520 mm (Fig. 6). Due to specially adjusted shape of jacks, their height is increased by 60 mm after filling with oil. In the discussed method, the jacks are centrally feed from one oil pump, and controlled by oil pressure forced individually in each jack. Application of these jacks requires the substantial width of the support equal to 0.6 m. Moreover, the operational range of theses jacks is 0.06 m, which makes this solution ineffective and requires a wide range of preparatory works. Examples of structures providing the required width of the support for a building based on beam foundation are shown in Fig. 6. Detail in Fig. 6 illustrates the system of two jacks arranged one on another, which increases their operational range.

At present, piston hydraulic jacks are the most effective tool for rectification. Taking into account the method of oil feeding, currently used jacks can be divided into jacks fed from a central pump or an internal pump. The jack fed with oil from the central pump is composed of a body based on parallelepiped elements, a piston, and a system of valves. Oil from the external pump is fed under pressure to the jack. An electronic pressure sensor, which measures oil during rectification, is in an electric control box placed between the pump and the valves. The jack body has an outer diameter of 209 mm and a height of 440 mm. A nominal extension of the piston with a diameter of 169 mm is 200 mm.

The jack fed from the internal pump contains the oil pump. A diameter of its body is 130 mm, and its height is 300 mm. The jack body, the oil pump, the solenoid valve, and oil tank are inside the frame with a length of 655 mm and a height of 370 mm. Regardless of the supply, jacks belong to one computer-controlled system.

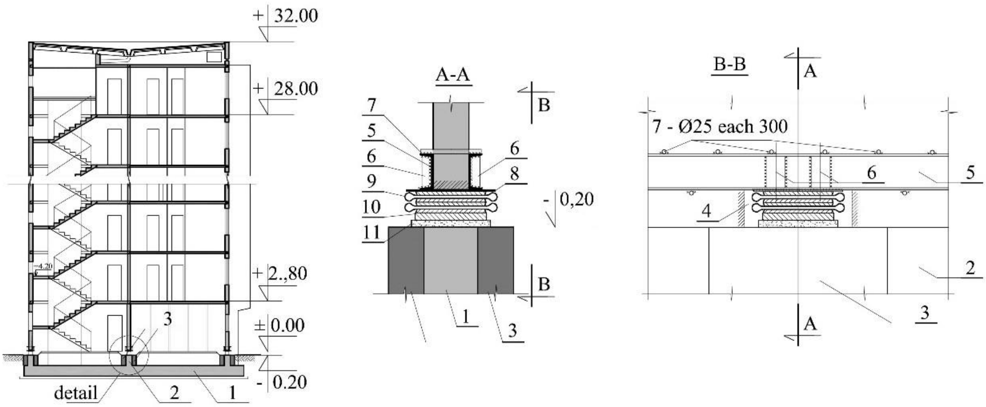


Fig. 6. Rectification of a building with membrane jacks; *1* – foundation slab, *2* – foundation rib, *3* – widening of the foundation rib, *4* – hole in the wall 600/220, *5* – [200, *6* - ∟ 75x75x8 mm, *7* – ϕ 25, *8* – plate 600x600x20 mm, *9* – membrane jacks, *10* – wooden spacer, *11* – steel hoop filled with sand

Fig. 7. Membrane jacks.

The application of jacks fed from individual pumps is presented for a rectified single-family house with a rectangular floor plan with sides of 10.29 m and 9.55 m, and a height is 8.85 m from floor in the basement to the roof ridge (Fig. 8). It was rectified with 31 jacks built into the basement walls, and the tearing plane was 1.15 m above the level of basement floor. The north-eastern corner was elevated the most, by 1312 mm. To ensure stability of the building during rectification, special steel guide structures were installed inside, and the south-eastern corner during elevation continuously acted on the corner kept on the ground. In this way friction forces counteracted relative displacements of the part to the horizontal direction. A building during rectification is presented in Fig. 9a, and the jacks in load-bearing internal walls are shown in Fig. 9b.

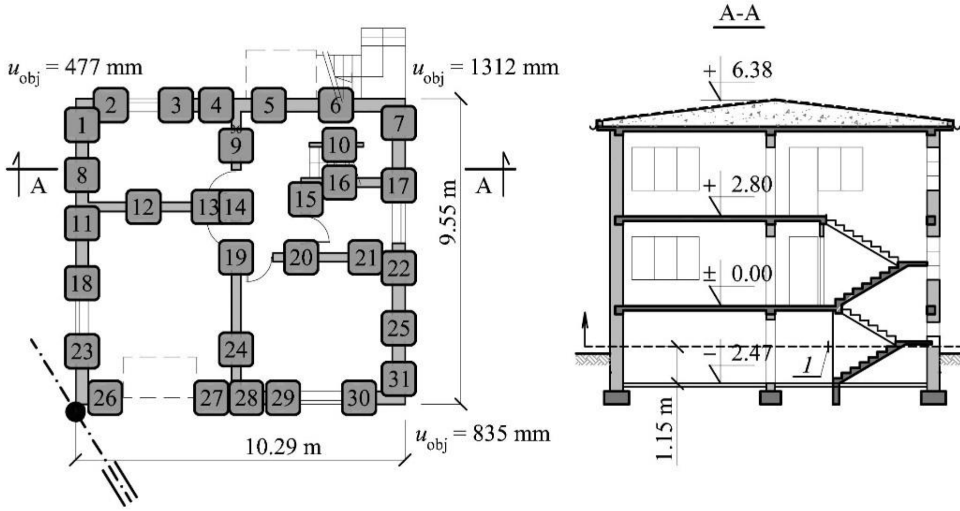


Fig. 8. A rectified two-storey building; *1* – tearing plane of the building.

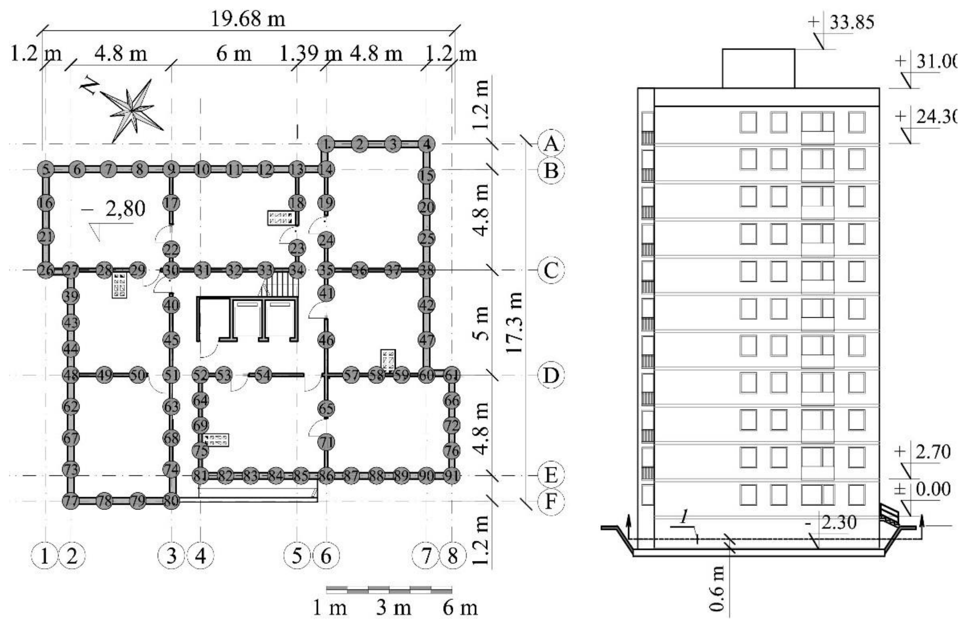
a) b)

Fig. 9. A building during rectification: a) a photo, b) jacks in internal walls.

Application of jacks fed from one central pump is described for rectification of an 11-storey building whose floor plan can be fitted into the rectangle with a side length of 19.68 m and 17.30 m (Fig. 10a). The building is 36.15 m high from the level of basement floor to the elevator room (Fig. 10b). The building foundation is made from reinforced concrete footing with a thickness of 0.40 cm and various width of: 1.00 m below the external walls, 1.2 m below the internal walls, and 2.55 m below the system of two load-bearing internal walls (walls along axes 3, 4 and walls along axes 5, 6). The basement has monolithic load-bearing walls made of reinforced concrete with a thickness of 0.30 m for external walls and from 0.15 m to 0.2 m for internal walls. External load-bearing walls in floors over ground level had a thickness of 0.3 m, and a thickness of internal walls was 0.15 m. They were built in 1975 in the slipform construction technique from concrete with pumice powder used in Silesia at that time. Rectification was based on 91 jacks in load-bearing walls of basements, based directly on wall footing. The tearing plane of the building was 0.6 m above the level of the basement floor.

The described rectification of vertically deflected buildings has been tested and implemented since the middle of the 1990s [12] and is used for more and more complex structures. Examples of designing an elevation height of the building and determining the reliable deflection and organization of construction works are described in, inter alias.

Rectification planned for a building part kept on the ground and the elevated part is based on meeting limit states in these elements. One of the most important issues is to adopt a model of the rectified structure, which indicates the method of forced displacements during rectification [13] and is used to determine characteristics of these models [14].



a) b)

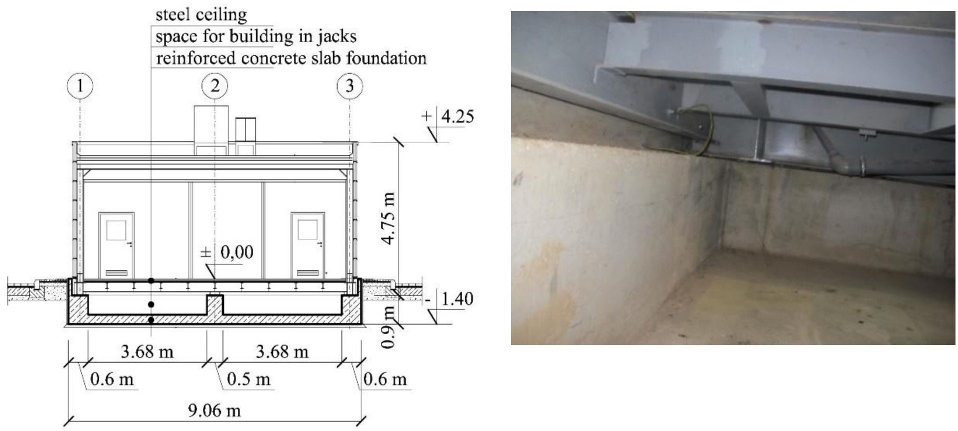
Fig. 10. An example of 11-storey building under rectification: a) floor plan, b) elevation; *1* – tearing plane of the building.

a) b)

Fig. 11. Hydraulic jacks with piston fed from the central oil pump: a) jacks built into internal walls, b) jacks in the external wall.

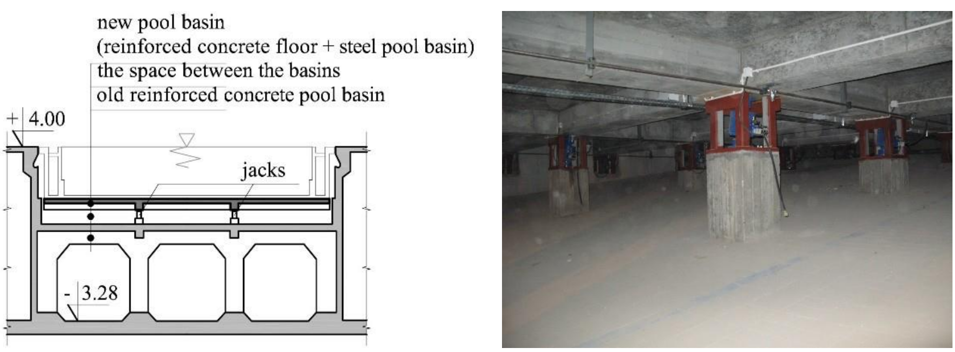
5 Adaptation of buildings for multiple rectification

For some structures in areas, whose inclinations are subjected to changes during their operational life, technical solutions are specified to facilitate the future rectification based on non-uniform elevation. For example, the design stage of fuel filling stations in the mining area assumes that all elements of this structure will be ready for rectification. A mini mall with a rectangular floor plan of 14.23 m x 13.03 m and a height of 4.25 m was designed as steel structure, including self-supporting floor. The structure is placed on reinforced concrete slab with a thickness of 0.3 m and up- stand beams with section (*b*/*h*) of 0.5/0.9 m (Fig. 12a). The steel structure of the building was fixed to these beams. The space between the foundation slabs was prepared for installing jacks during rectification (Fig. 12b). The similar procedure was performed for the canopy and fuel dispensers.



a) b)

Fig. 12. The mini mall at the fuel filling station in the mining area adapted to future rectification: a) cross-section of the building, b) space between foundation slab and steel floor for installing jacks



a) b)

Fig. 13. Adaptation of modernized swimming pool basin for rectification: a) cross-section, b) jacks installed between the old basin and a slab of the new basin.

And during repair works in the indoor swimming pool in the mining area, a decision was made to adapt the new basin for rectification. Elements of the new basin were designed within the existing one (Fig. 13a). New elements included a reinforced concrete slab and partly self-supporting basin made of stainless steel, which was placed on this slab. A system of 48 hydraulic jacks was installed between the bottom of the old basin and the new slab (Fig. 13b). The plan for adapting the foundation of a historic church for multiple rectification by performing reinforced concrete grid underneath is described in [15].

Since the 1970s, other solutions than non-uniform elevation have been analysed for potential use for rectification of buildings. The paper [16] described, inter alias, the possible use of the solution proposed in the 1930s, which consisted in placing the bottom foundation slab in reinforced concrete bund filled with fine sand. Water under pressure was to be forced into the space between the slab and the bund to restore the horizontal position. On the other hand, the paper [17] referred to the method of rectification with jacks placed in the horizontal heading drilled under the building, where the lower part was elevated, and the higher part was lowered. That paper also referred to the possibility of constructing the foundation from two parts. Its upper part was a low pyramid with a vertex headed downwards and based on the bottom part (the central foundation). Screws with nuts were to be placed in one side of the pyramid. By adjusting the screw length, the building was to be kept in the required horizontal position regardless of ground inclination. The building was on the pyramid base. The paper [18] indicated that adaptation of high buildings for rectification required foundations in the form of double reinforced concrete floating foundation arranged on one another to install “hydraulic and thermal” jacks between them. On the other hand, the best solution for multi-storey buildings was the double foundation framework [19]. Foundation on reinforced concrete slabs, arranged on reinforced concrete wells was found appropriate for rectifying single-family houses and resisting horizontal deformations from the mining area [20]. A new trend in testing multiple rectification of buildings was presented in the paper [21], where it was suggested to form the foundation from two interacting parts with a layer of film and grease between them.

The problem of multiple rectification of vertically deflected winding towers, whose load-bearing system was composed of four poles, was presented in [22]. After analysing six methods, which could be potentially used for rectifying the tower with a height of 100 m, the method with hydraulic jacks was finally suggested. It was recommended to construct the bottom part of each pole in the form of three branches. Each of them should be based on the system of two foundations, arranged on one another. Moreover, the top part of each foundation should provide space for installing jacks. The current knowledge of rectification indicates that the theoretical assumptions made in that paper are incorrect, particularly those associating excitation with extension of jack pistons. Moreover, the concept was defined that multiple rectifications could be performed in many directions to compensate the behaviour of connections in the supports. However, practice shows that when the deflection direction is set mainly slender buildings are further subjected to deflection in one direction when, often regardless of the direction of imposed actions

6 Conclusion

The reviewed literature on procedures for deflected building, some of them observed by the author, and the concepts described in the literature lead to conclusions that the method guaranteeing the purpose of restoring the deflected building to its vertical position is rectification based on non-uniform elevation of jacks with pistons. The test results presented in this paper are used for rational designing of rectification. The scope of other methods is limited to very special cases.

References

1. Whittaker, B.N.; Reddish, D.J. *Subsidence. Occurrence, Prediction and Control*; Developments in Geotechnical Engineering; Elsevier: Amsterdam - Oxford - New York - Tokyo, 1989; ISBN 0-444-87274-4.
2. Kratzsch, H. *Mining Subsidence Engineeting*; Springer-Verlag: Berlin, Heiderberg, New York, 1983;
3. Orwat, J. Mining Exploitation Forecasted Effects Caused by a Hard Coal Extraction from a Thick Seam. *J. Phys.: Conf. Ser.* **2020**, *1426*, 012017, doi:10.1088/1742-6596/1426/1/012017.

4. Orwat, J. Mining Terrain Curvatures Approximation Using the Polynomials and a Subsidence Trough Profile Fragmentation. *J. Phys.: Conf. Ser.* **2021**, *1781*, 012014, doi:10.1088/1742-6596/1781/1/012014.
5. Kijanka, M.; Kowalska, M. Inclined Buildings – Some Reasons and Solutions. *IOP Conf. Ser.: Mater. Sci. Eng.* **2017**, *245*, 022052, doi:10.1088/1757-899X/245/2/022052.
6. Puzrin, A.M.; Alonso, E.E.; Pinyol, N.M. Bearing Capacity Failure: Transcona Grain Elevator, Canada. In *Geomechanics of Failures*; Springer Netherlands: Dordrecht, 2010; pp. 67–84 ISBN 978-90-481-3530-1.
7. Motyczka, A.; Sitko, W.; Wyra, S. On the Basis of the Experiments Dealing with Straightening the Deflected Buildings by the Method of Cutting out Layers in the Ground Foundation (in Polish). In *Scientific Journals of the Silesian University of Technology*; Civil Engineering; Publishing House of the Silesian University of Technology: Gliwice, 1997; pp. 143–153.
8. Gromysz, K. Eliminating Structures Deflection by Removing Subsoil. In *International Scientific Conference. 70 Years of FCE STU*; Bratislava, 2008.
9. Gromysz, K. Methods of Removing Buildings Deflection Used in Poland. *IOP Conf. Ser.: Mater. Sci. Eng.* **2017**, *245*, 032096, doi:10.1088/1757-899X/245/3/032096.
10. Gromysz, K. Revitalisation of a Vertically Deflected Historical 16th Century Bell Tower. *IOP Conf. Ser.: Mater. Sci. Eng.* **2019**, *471*, 052025, doi:10.1088/1757-899X/471/5/052025.
11. Gromysz, K. Rectification an 11-Storey Vertically Deflected Residential Building. *Procedia Engineering* **2013**, *57*, 382–391, doi:10.1016/j.proeng.2013.04.050.
12. Gromysz, K. Repairs of Vertically Deflected Buildings. In *Iabse Colloquium*; Berlin, 1998; pp. 174–175.
13. Gromysz, K. Analysis of Parameters of a Rectified Tank on the Basis of In-Situ Tests. *Materials* **2021**, *14*, 3881, doi:10.3390/ma14143881.
14. Gromysz, K. In Situ Experimental Study on the Active Support Used for Building Rectification. *Materials* **2020**, *13*, 2015, doi:10.3390/ma13092015.
15. Gromysz, K. A Method of Protecting the Historic Wooden Church Building in Jankowice against Deformation of the Mining Area (in Polish). In *Environmental protection in the Mining Areas of Mining Mine in the Western Subregion of the Silesian Voivodship*; NOT, SITG: Rybnik, 2014; pp. 146–157.
16. Adamus, J. The Method of Preparing the Foundation for the Turbine Set for Tilt Rectification (in Polish). In *Proceedings of the 3rd IIM Scientific Conference*; Publishing house of the Częstochowa University of Technology: Częstochowa, 1983; pp. 15–19.
17. Kwiatek, J. A Method of Straightening Buildings and Structures Tilted from the Vertical (in Polish). In *Proceedings of the 3rd IIM Scientific Conference*; Publishing house of the Częstochowa University of Technology: Częstochowa, 1983; pp. 76–82.
18. Ledwoń, J.A. Adaptation of Skyscrapers to Rectify Excessive Tilts (in Polish). In *VI International Scientific and Technical Conference Metal Structures. Katowice 30.V.-2.VI.*; Katowice, 1979; Vol. 3, pp. 225–228.
19. Bołotow, J.; Słobodian, J.; Zotow, W.; Majewski, S.; Szojda, L. Securing Buildings with the Settlement Compensation Method (in Polish). In *Scientific and Technical Conference Building Failures. Szczecin - Międzyzdroje, 22 - 25 maja 1996*; pp. 535–541.

20. Niemiec, T.; Kozioł, E.; Fuchs, R. A Proposal for Single-Family Housing in Mining Areas (in Polish). In *Protection of mining areas of Jastrzębska and Rybnicka Spółka Węglowa mines*; Conference; NOT, SITG, 1997; pp. 201–208.
21. Szojda, L.; Nowak, K. New Possibilities of Straightening Buildings Exposed to Mining Influences (in Polish). *Inżyniera i Budownictwo* **2021**, *77*, 450–452.
22. Mita, M. Preparation for Rectification of a Steel Hoisting Tower with a Machine on Top (in Polish). In *Proceedings of the 3rd IIM Scientific Conference*; Czestochowa University of Technology: Częstochowa, 1983; pp. 116–126.