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Moving and Straightening the Building Segment

To cite this article: Krzysztof Gromysz 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 052026

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Moving and Straightening the Building Segment

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Abstract. The segments of buildings located on areas where the impact of underground mining is seen are subject to mutual displacements. For poorly designed or executed expansion joints, the direct interaction of the neighbouring segments occurs (compression and closing down of the expansion joint). Such compression has led, in many cases, to a threat to the safety of residents, to building failures and to significant property losses. The subject of the publication is a multi-family dwelling building consisting of two semi-detached segments. Each segment is provided with a complete basement and has two aboveground floors. Due to the acting mining area curvature and compression horizontal deformations, the direct interaction of the neighbouring segments occurred in the expansion joint on the ceiling level above the last floor. In addition, due to uneven vertical displacement of mining land, the building has deflected vertically, which has considerably reduced the comfort of its use. One building segment was moved by 300 mm versus the other segment to avoid a building failure caused by direct interaction. Moreover, the comfort of building use was restored by straightening the building through uneven raising. The segment was displaced vertically and horizontally in four phases, during which mobile supports were installed, and the structure was moved in the horizontal direction and raised unevenly. All the designed works, that were individually designed, are presented in this publication. The works carried out have prevented a building failure and restored the comfort of building use.

1. Introduction

Underground coal mining causes land surface deformations characterised by the four basic parameters: depression – W , horizontal deformation – ε , radius of curvature– R and sloping T (Figure 1). As a consequence, the distance between segments of buildings is changed and their mutual rotation occurs. This may lead to a building failure in buildings with wrongly designed or constructed expansion joints. For example, [1] shows a failure of a multi-segment, ten-floor building made of large panels. Due to the wrongly shaped and located expansion joint, two segments were interacting with each other directly (compression in the expansion joint). The actual load-bearing capacity of the walls, upon which the ceiling was rested, was lost. The emergency protection procedures presented in [1], and then time- and cost-intensive renovation have allowed to avoid an advancing disaster and to use the structure again. A case is presented in [2, 3], where the lines of five-floor residential segments, built with the traditional technology, have their expansion joints closed down. Because the segments are interacting with each other, a failure of the structures' longitudinal walls took place during the occurrence of horizontal mining area deformations of the compression character. The extent of damages in this case was so large that a decision was made to disassemble the damaged buildings.

A mutual interaction of segments located on mining area is a very frequent phenomenon. Multi-segment buildings subject to the impact of mining are being constantly observed for this reason and on-



going actions are taken to ensure the safety of building users and to prevent the occurrence of substantial property losses.

The publication presents a residential building consisting of two twin segments. When the impact caused by the successive coal exploitation revealed, the segments were closed down in the expansion joint on the level of the last floor (direct interaction of the segments) as a result of a joint effect of the mining area curvature and horizontal deformations of compression character (Figure 1). Moreover, the body of the segments was deformed and vertically deflected as a result of underground headings exploitation, which made the usage more difficult. It was decided to move the segments apart to avoid a building failure caused by the direct interaction of the segments. In addition, to enable the further correct use of the deflected segment, it was decided to straighten the segment.

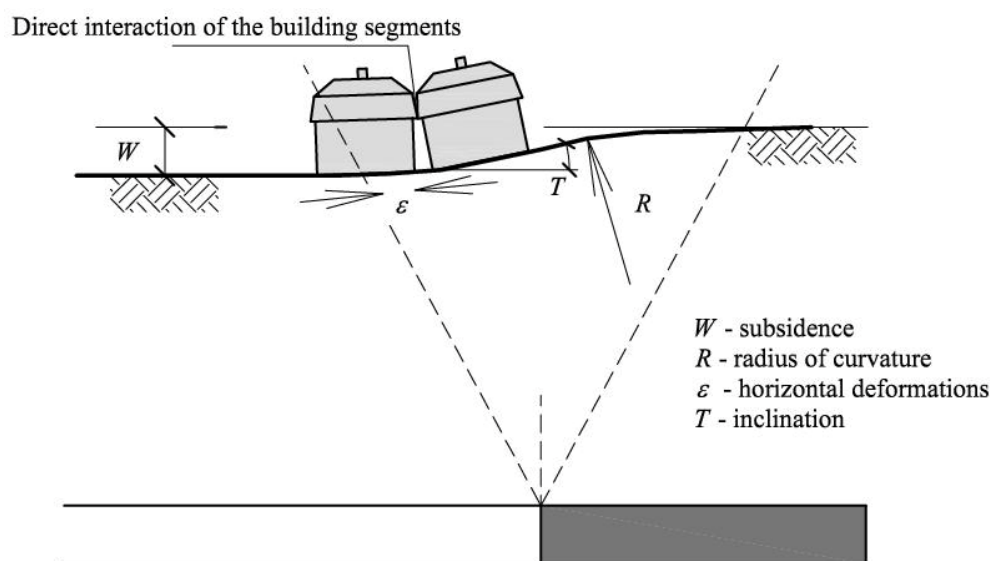


Figure 1. Direct interaction of the segments (compression and closing down of the expansion joint) as a result of mining land curvature ($1/R$) and horizontal deformations (ϵ)

2. Building description

The building consists of two segments provided with a full basement: the eastern and western segment (Figure 2). The structure features two aboveground floors and is used for residential and office purposes. The basement plan of each segment is rectangular, with the dimensions of 9.74 m $\times$ 11.38 m, and the ground floor and first floor plan can be inscribed into a rectangle with the side length of 9.78 m and 14.08 m. The building height, counting from the ground level to the roof edge, is 8.79 m (Figure 3). The structure is founded 1.15 m below the ground level on reinforced concrete foundation footings with a height of 0.35 m and a width of 0.40 m to 0.60 m. The bearing walls of the segments, with a thickness of 0.25 m to 0.38 m, are made of full brick on cement and lime mortar. The ceilings of the both segments are made of 0.14 m thick reinforced concrete monolithic slabs, rested on the walls through ring beams with the section of 0.25 m $\times$ 0.25 m. The flat roof is not ventilated, with a slag insulation layer provided on the ceiling over the first floor, onto which a concrete screed was laid, covered with roofing paper. The maximum expansion joint width between the segments was 100 mm on the basement flooring level. However, the working range of the expansion joint on the ceiling level over the ground floor was exhausted and the segments were directly interacting (the compressions of the segments in the expansion joint – Figure 3). In addition, due to uneven subsidence of mining area, the structure became vertically deflected. The following are the measured deflection components of the eastern segment: 24.4 mm/m

towards a shorter side of the segment and 11.0 mm/m towards a longer side (Figure 2). The value of the resultant segment deflection was hence $(24.4^2 + 11^2)^{0.5} = 26.8$ mm/m. The deflection was burdensome [4] and it was decided to remove it by the uneven raising of the eastern segment [5]. The western segment was also vertically deflected but the flooring sloping had already been removed earlier by levelling the floors. The plans of the building segments are shown in Figure 2, where the basement plan for the eastern segment is shown, and the ground floor plan for the western segment.

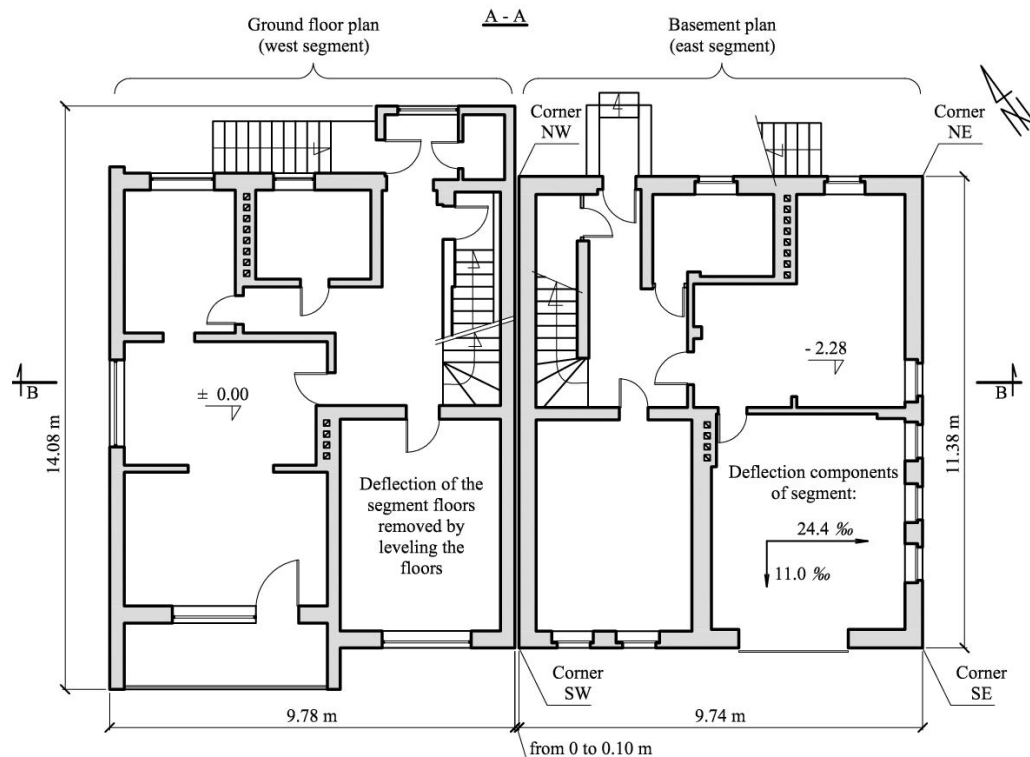


Figure 2. Plan of residential building consisting of two twin segments

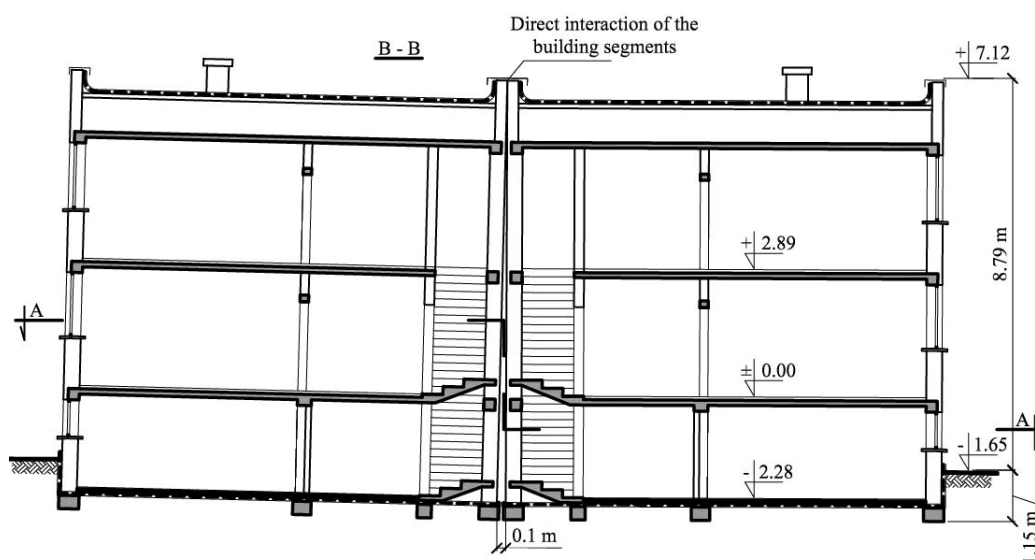


Figure 3. Cross-section of building with the marked area of direct interaction of segments in the expansion joint

3. Handling procedure adopted for the building

As shown above, the eastern segment was deflected vertically in the south-east direction (Figure 2). Moreover, the eastern and western segment were in contact on the ceiling level over the first floor (direct interaction of segments in the expansion joint – Figure 3). The relative position of the structures did not allow, therefore, to straighten the eastern segment without moving it in prior. The following sequence of works was programmed for this reason. It was planned to first move the eastern segment towards the shorter side of its plan, and then to straighten it.

For this reason, for the programmed change of the segment position, it was first planned to move the structure in the horizontal direction, and then to straighten it by uneven raising. In order to prepare the segment for moving, mobile supports had to be installed in its walls. For this purpose, the structure had to be lifted evenly first, and then lowered onto the supports. Accordingly, to straighten the structure, it had to be lifted unevenly using hydraulic jacks. It was thus assumed that the same set of jacks will be used both, for raising the building evenly to install mobile supports, and for straightening. Consequently, four phases of segment displacement were envisaged, marked with successive Roman numerals.

The building basement walls were detached in the first phase on the 0.35 m level over the basement flooring, and then the building part situated over the detachment plane was evenly raised by $\Delta h_I = 180$ mm upwards. Mobile supports could have been mounted into the so formed space in the walls. Then, in the second phase, the aboveground part of the segment was lowered by 100 mm ($\Delta h_{II} = -100$ mm) and rested on the mobile supports. In the third phase, the segment was moved evenly horizontally by 300 mm ($\Delta l = 300$ mm). In the last, fourth phase (phase IV), the segment was raised unevenly in such a way that the structure has reached its vertical position. Each corner of the segment was therefore displaced by a different value. The height of uneven raising of the structure corners resulted from the direction and value of structure deflection. As a consequence, the following are the raising height values of the individual corners (see Figure 2) in this phase: NW corner – $\Delta h_{IV} = 0$, NE corner – $\Delta h_{IV} = 24.4 \cdot 9.4 = 238$ mm, SW corner – $\Delta h_{IV} = 11.04 \cdot 11.8 = 125$ mm, SE corner – $\Delta h_{IV} = 24.4 \cdot 9.74 + 11.04 \cdot 11.8 = 363$ mm. Table 1 lists the designed vertical and horizontal displacements of four segment corners in particular phases. In addition, total displacements in vertical (Δh) and horizontal (Δl) direction are shown in the table 1 and in Figure 5.

Figure 4a shows a building plan before displacing the eastern segment and Figure 4b a building plan after displacing the segment and after the completed renovation.

Table 1. Values of vertical and horizontal displacements of the eastern segment in individual phases

Displacement phase	Vertical displacements of segment corners Δh_i (i = I, II, IV)				Horizontal displacement of segment Δl
	NW corner (jack 1)	NE corner (jack 5)	SW corner (jack 28)	SE corner (jack 33)	
I	180	180	180	180	---
II	- 100	- 100	- 100	- 100	---
III	---	---	---	---	300
IV	0	238	125	363	---
Total displacement	80	318	205	443	300

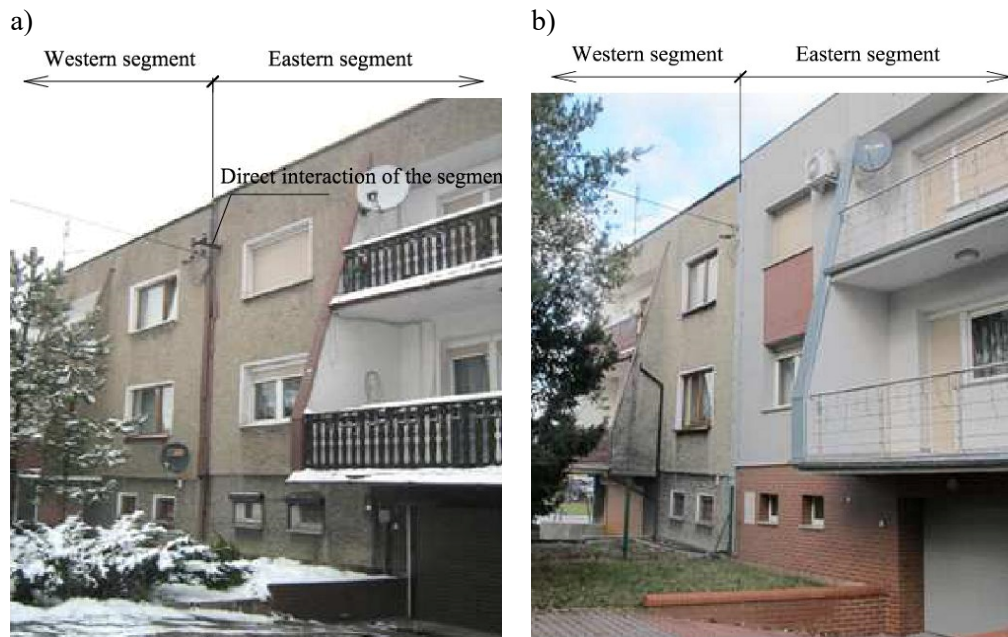


Figure 4. Residential building consisting of two segments - view from the south: a) eastern segment before displacement, b) eastern segment after displacement and completed renovation

4. Progress of construction and building works

Building works for the eastern segment of the building were designed and performed based on the adopted handling procedure. An outer stairway to the building and a stairway from the basement to the ground floor were disassembled in the first place; the building was also uncovered and the upper surface of foundation footings was exposed. The depth of excavation was 0.73 m, and width was 1.94 m. A building reinforcement was then executed over the planned detachment plane of the building on the 1.93 m level (0.35 m above the flooring). The reinforcement was made of [160 steel sections running horizontally (Figure 5). In the first place, the sections were mounted from both sides to the bearing walls and joined through the walls with M20 bolts spaced every 800 mm. The bolts were guided through openings with a diameter of 22 mm made in the bearing walls and in the sections. For the wall near the expansion joint, as there was no access to this wall from the side of the adjacent segment, only one section was mounted, running inside the building, which was mounted to the wall with adhesive anchors with a diameter of 20 mm. Then, stiffening elements, also made of [160, were mounted in the corners to the sections mounted on the walls. The role of the elements was to ensure the stiffness of the walls of the building part above the detachment plane during structure displacement. In addition, the elements were transferring horizontal forces onto the building walls, with such forces being applied to the reinforcement when moving the structure in the horizontal direction. Some elements were added to the reinforcement running along the outer eastern wall, and turnbuckles causing a horizontal force during movement were fitted to such elements in the subsequent stages of works. Additionally, elements interworking with the guiding elements installed in the next phase were fitted to the reinforcement running along the outer northern and southern walls.

After providing a steel reinforcement over the designed detachment plane of the segment, foundation walls of the building - running in the direction perpendicular to the direction of the designed structure displacement - were widened. The widening was performed by adding concrete footings with the width of 300 mm and height of 350 mm to the existing foundations. The added concrete strip foundations were joined with the existing ones with bars with a diameter of 20 mm bonded every 800 mm to the existing foundations, and then the bars were concreted in the widening (Figure 6). Drawing elements were

provided in the next step outside the building from the eastern side (Figure 7), and guiding elements were provided from the northern and southern side (Figure 8). Each of the five drawing elements consisted of a concrete foundation, with the cross-section of 300/700 mm and a length of 1100 mm, and of a steel construction made of $\angle 160$ sections anchored in the concrete foundation. Turnbuckles were fitted to the steel construction, using which a horizontal force was generated, transmitted from the drawing elements to the steel reinforcement and to the building. Six guiding elements were mounted on the both sides of the building – three along the northern wall and three along the southern wall (Figure 5). The elements consisted of a concrete foundation with the cross-section of 300/500 mm and a length of 800 mm, and of an anchored steel construction forming a triangle (Figure 8). The purpose of such elements was to ensure horizontal movement of the building along a straight line. 33 hydraulic jacks were then installed in the building basement walls. 33 openings, with the dimensions of 600 mm $\times$ 500 mm, were driven through the walls under the reinforcement. The 20/500/500 plates were mounted in the openings (Figure 6), by joining them by welding with the reinforcement running along the walls, and then hydraulic jacks with the piston diameter of 120 mm were placed on the foundations. The structure was detached by generating a pressure of 10 MPa to 16 MPa, and the detachment plane was running on the level of the lower foot of the reinforcement. The building was then raised by $\Delta h_1 = 180$ mm (Figure 6), which was achieved by applying the same displacement value in all the jacks.

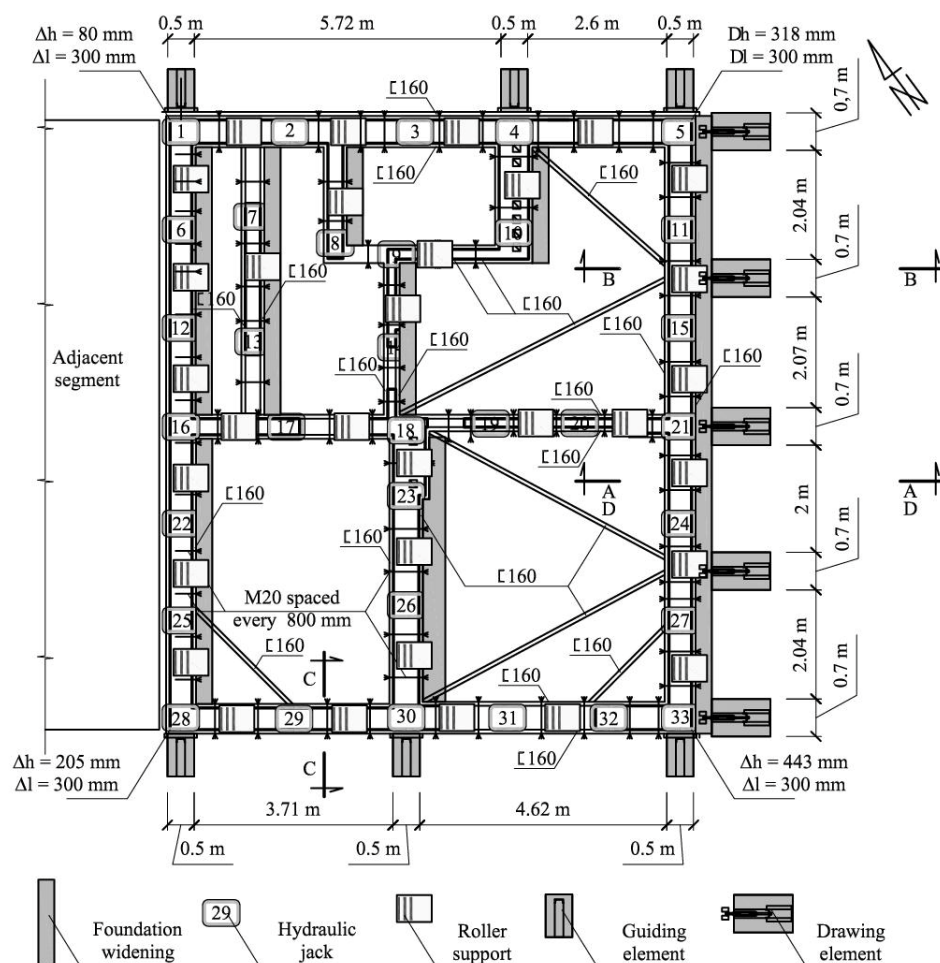


Figure 5. Plan of reinforced walls of the eastern segment; Δl – horizontal displacement of the building, Δh – total vertical displacement of corners; sections A – A, B – B, C – C and D – D are given in Figures 6 – 9

The structure situation in this position was stabilised by activating mechanical protection of the jacks. 32 roller supports were then started to be installed, onto which the structure was moving in the horizontal direction. Each support was made of two plates: a top plate dimensioned 20/500/500 and a bottom plate dimensioned 10/500/650 and three bars (rollers) with a diameter of 50 mm (Figure 7). The top plate of the roller support was joined with the building reinforcement using [160 running in the vertical direction (Figure 7). The total height of the mobile support was therefore 80 mm. When a concrete grout has set, on which a bottom plate of the support (the plate dimensioned 10/500/650 - Figure 7) was seated, the structure was lowered evenly by $\Delta h_{II} = -100$ mm with jacks, and it was placed onto the roller supports. The structure was then stabilised in this position, preventing horizontal movement in the supports, and the jacks were removed. The turnbuckles, with their one end connected in prior to anchoring blocks, were mounted with the other end to a reinforcement made of [160 mounted on the segment walls.

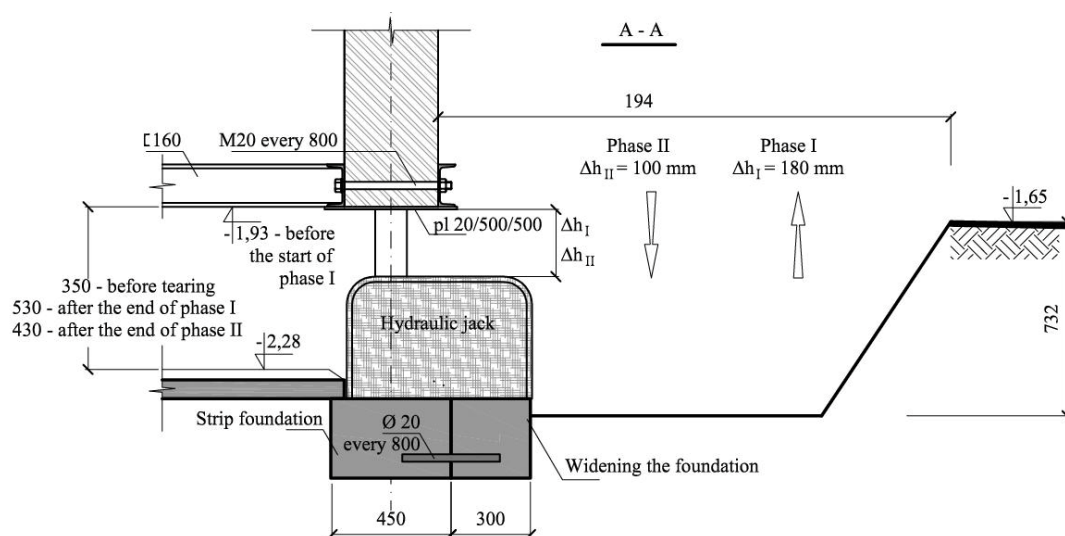


Figure 6. Hydraulic jack installed in the building wall during even raising of the building (phase I, $\Delta hI = 180$ mm) and during lowering (phase II, $\Delta hII = -100$ mm); location of A – A section is shown in Figure 5

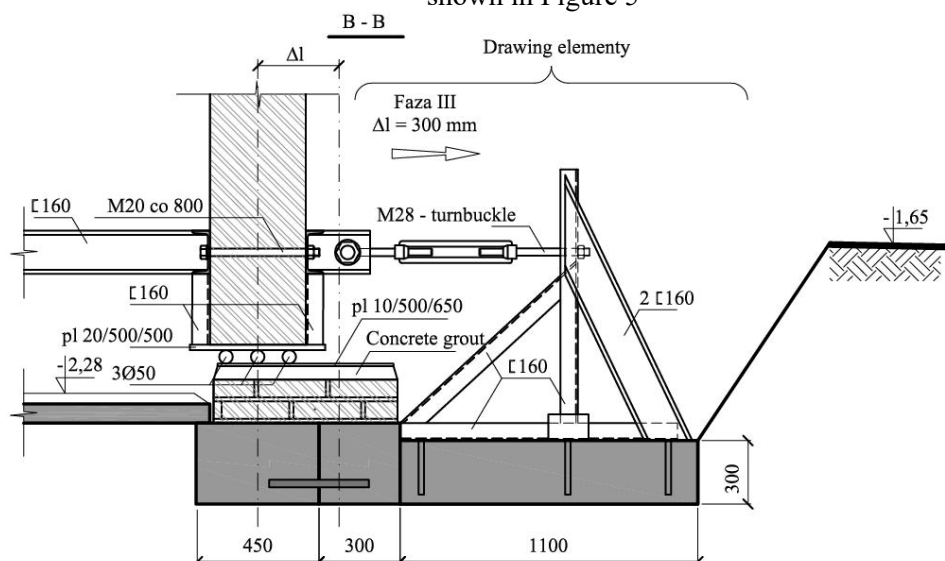


Figure 7. Drawing element during building displacement in horizontal direction (phase III, $\Delta l = 300$ mm); location of section B – B shown in Figure 5

Building movement in the horizontal direction by the value $\Delta l = 300$ mm was forced by generating forces in five turnbuckles at the same time. When the segment was placed in a new location over the widened foundation, the structure was stabilised by blocking its movement in the supports and 33 hydraulic jacks were started to be installed again. The jacks were installed in the same places where they stayed during even raising of the building, except that they were shifted by 300 mm in relation to the building part (Figure 9).

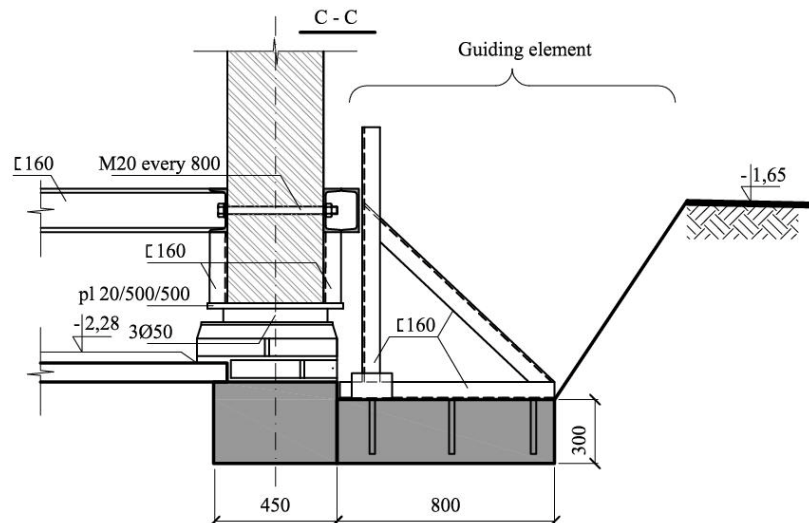


Figure 8 Guiding element; location of section C - C is shown in Figure 5

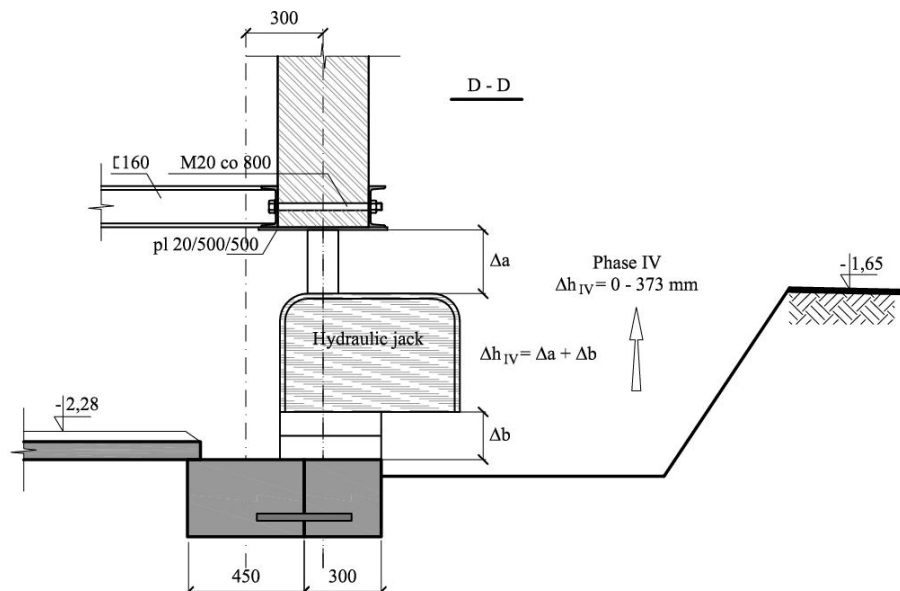


Figure 9. Hydraulic jack installed in the building wall during uneven raising of the building (phase IV, Δh_{IV} , of 0 to 363 mm); location of section D – D is shown in Figure 5

The structure was lifted unevenly after installing the jacks. A different displacement value Δh_{IV} was applied in each jack, from zero for jack number 1 to 363 mm for jack number 33. Building deflection was removed this way, with the resultant of 26.8 mm/m. The building position was stabilised with mechanical interlocks of the jacks and with additional supports made of hard wood. Figure 10 shows: a

guiding element, drawing elements, the expansion joint after segment displacement in the horizontal direction and a hydraulic jack during uneven lifting. Restoration works of walls were started after completing structure displacement works. First, the remaining bearing walls of the structure situated below the reinforcement were demolished, and then were rebuilt in the new location of the segment. Reconstruction was carried out in two stages. The fragments of the walls between the jacks were constructed in the first stage.

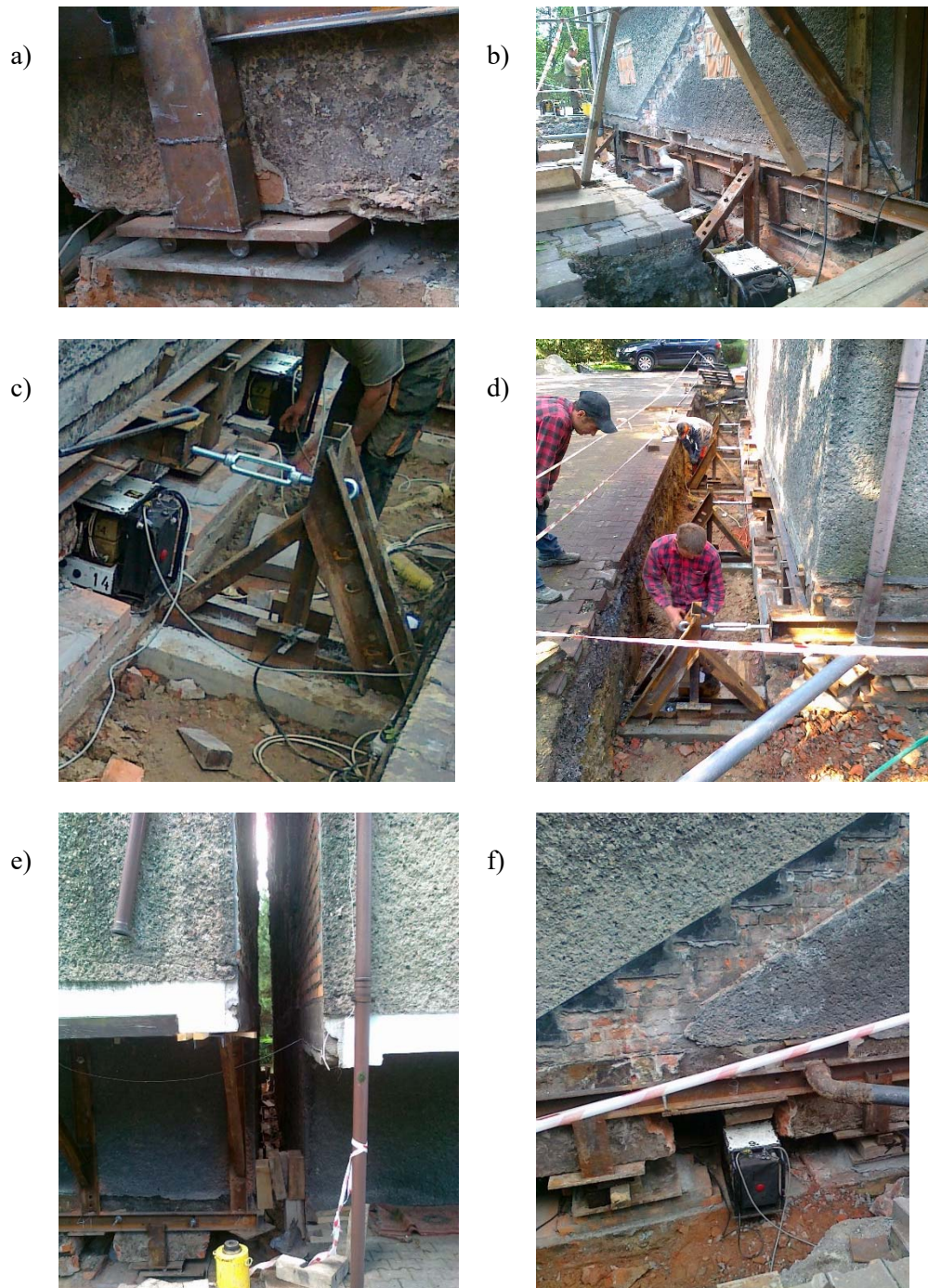


Figure 10. Works in the building: a) roller support, b) guiding element, c), d) drawing elements, e) expansion joint in segment displacement in horizontal direction, f) hydraulic jack during uneven lifting

In the second stage, after reaching the bearing capacity by the newly constructed parts of walls and after dismounting the jacks, walls were constructed in the spaces of the removed jacks. Stairways leading to the building and from the basement to the ground floor were then restored, and works connected with the building structure were completed this way. The following was disassembled as part of remaining works: steel reinforcements and drawing and guiding elements, as well as constructional restoration works. The appearance of the façade was unified by constructing a new stub wall and plastering the segment (Figure 4b). The works described were carried out over three months. Currently, the area where the building is situated is calm and no subsoil deformations occur.

5. Conclusions

If it is found that the operating range of an expansion joint between segments in a building founded on mining land is finishing, immediate actions should be taken to prevent a building failure. One of the ways is to move one segment in relation to the adjacent segment. In the presented procedure, roller supports were installed in the walls and drawing elements outside the building. Building movement in the horizontal direction was forced by tightening turnbuckles. Segment deflection was also removed in the presented case through its uneven lifting with hydraulic jacks. The building was displaced vertically and horizontally in four phases, during which roller supports were installed, the structure was shifted in the vertical direction and lifted unevenly. All the designed works were completed, and the individual stages are presented in this publication. The described undertaken works have prevented a building failure and restored the comfort of building use.

Acknowledgements

The author thanks the management and personnel of MPL company from Katowice for cooperation in implementation of the works presented in the article.

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