Removal of Deflection and Reconstruction of Foundations of the Historic Museum Building

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Abstract. The displacements and forces were measured and analysed in the jacks on which the structure was rested during the complex renovation. The building was deflected from the vertical and its foundations were damaged. The renovation consisted in lifting the above-ground part of the structure and removing its deflection and then replacing the foundations. The building subject to renovation and investigations dates back to 1902; it is a historical structure and serves as a museum. The building is partially cellared, has two above-ground floors and a rectangular projection with 10.3 m and 10.7 m long sides. The building was vertically deflected by 31 mm/m. 27 hydraulic jacks were installed in order to remove the deflection in the axes of the cellar and foundation walls. With their help, the building was torn apart and then straightened by uneven lifting. After the rectification, the weight of the building was transferred onto a new system of supports transferring the load directly to the ground outside the foundations and the jacks located in the walls’ axes were dismounted. This made it possible to demolish the old stone foundations which were in very poor technical condition. New reinforced concrete strip foundations and foundation walls made of concrete blocks were made in their place. The forces and displacements in the jacks were continuously measured during the rectification. The article presents these measurements and establishes the relationships between the forces in the jacks and the displacements of the elevated building. The scope of the renovation and the innovative structural solutions applied in the construction of the foundations are also presented. The renovation of the deflected structure allowed to avoid demolition of the historic building and its re-assembly. Moreover, with the presented procedure, no damage was caused to the structure’s elements that were being lifted. The measurements of forces and displacements made it possible to determine the parameters of the straightened building.

1. Introduction

Historic wooden buildings are usually placed on foundations made of slag and stone. The durability of such foundation often proves to be insufficient [1]. In addition, the deflection of building structures due to uneven land subsidence is seen in the area affected by mining exploitation [2] [3]. It is caused by the tightening of the voids left after underground exploitation [4], [5] and even by the exploitation of natural underground water reservoirs [6]. In such case, structure renovation is usually done by its disassembly, construction of the new foundation and then rebuilding the structure in the vertical position [7]. Such procedure causes, however, irreversible changes to historic buildings’ construction. A much more advantageous solution is to perform renovation in such a way as to avoid disassembly of a vertically deflected structure. Unconventional solutions should then be designed and executed. This includes the removal of the structure's deflection and construction of new foundations underneath the existing
structure. Such procedure interferes with the original constructional solution as little as possible and allows to preserve the original value of the renovated structure.

The subject of the investigations discussed in this article is the process of renovation of the historic museum building, which consists in removing the structure's deflection and constructing new foundations underneath it. During the deflection removal process, which consisted of uneven lifting, the values of the forces occurring in the jacks and piston extensions of the jacks were recorded. The data obtained made it possible to estimate the parameters of the system.

2. Building description
The building subject to the renovation and investigations dates back to 1902. It is a historic structure and serves as a museum. Eva von Tiele-Winckler, a German Protestant deacon and charity activist [8] [9], lived and worked there until the 1930s. Currently, the building houses an exhibition on the activities of the female diaconate from Miechowice.

The building is partially cellared, has two above-ground floors and a rectangular projection with 10.3 m and 10.7 m long sides. Its height above the ground level is 7.2 m. The cellar walls (Fig. 1) are 0.42 m thick and are solid brick and the walls of the above-ground floors are made of wooden logs 0.18 m thick (Fig. 2). The roof structure is made of a wooden formwork covered with ceramic roof tiles. The foundation level of the cellar walls is about 2.5 m below the ground floor and the foundation level of the non-cellared part is 1.0 m below the floor. The non-cellared part was rested on strip foundations made of stone and slag with the section of 0.65 m × 0.65 (Fig. 3). These foundations have been severely damaged due to changes in soil moisture caused by the land subsidence and deformation.

There is continuous underground hard coal mining exploitation conducted in the area of the building. The voids created in the excavated coal deposits are subject to tightening, hence non-uniform land depressions and deformations are occurring in the land. The first underground mining exploitations affecting the structure were conducted already at the beginning of the 20th century. There is no accurate information about land deformations which occurred in the proximity of the structure before the end of World War II. The area on which the structure is located belonged before 1945 to Germany, and is now located in Poland. The documented hard coal mining exploitation after 1945 was carried out in a dozen long walls, mostly by a roof rocks cave-in. Exploitation was carried out at the depth of 270 m to 790 m, and the extracted seams were 2.4 m thick. The building's deflection of 31 mm/m occurred as a result of the mining exploitation. The deflection component value in the southern direction was 29 mm/m and 10 mm/m in the eastern direction. Renovation was designed in order to remove this deflection, which consisted of uneven lifting of the above-ground part of the structure with a value from 67 mm to 367 mm (Fig. 4).

Figure 1. Cellar floor plan of the building (section A-A is shown in Figure 3)
Figure 2. Ground floor plan (section A-A is shown in Figure 3)

Figure 3. Cross section
Figure 4. Components of the building's deflection and designed heights of the corners’ lifting

3. Removal of the building's deflection

The deflection of the building was removed by uneven lifting of its above-ground part, the ceiling above the cellars and a part of the cellar walls above the detachment plane. The south-western corner was raised highest, by 367 mm (Fig. 4). 27 piston hydraulic jacks were installed into load-bearing walls of the cellar and into wooden log walls of the building in order to raise the structure; Figure 5a shows the location of the jacks. The building was torn apart with their help. The horizontal detachment ran at the terrain level (− 0.26 m) and divided the structure into two parts: the unevenly lifted part and the part remaining in the ground. The unevenly lifted part was situated above the detachment plane and the part remaining in the ground was situated below the plane. Some of the cellar walls below the detachment plane remained in the ground (Fig. 5b) along with the foundation benches, on which the non-cellared part was placed (Fig. 5c). Uneven lifting consisted of applying displacements to the individual pistons of the jacks. Due to the fact that the extension of the jack pistons was limited to 200 mm, it was necessary to install a stack of wooden parallelepiped elements under some of them (Fig. 5d). The final extension of a given piston was equal to the height to which the building had to be lifted in the place of installation of the jacks. Bringing the building to the desired position was designed in four cycles.

The pistons of all the jacks were extended (u) during each cycle. The building was moving upwards and the values of forces (Q) in the jacks were changing as a result of pistons’ extension. The values u and Q were registered during the rectification in each piston and were recorded every 1.5 sec. Examples of such records are shown in Figures 6 and 7. The entire rectification process took 150 minutes and the piston stroke speed, in one cycle, was about 1.8 mm per minute. Figure 6 shows the curves corresponding to the two jacks with numbers 11 and 17 installed into the cellar walls. Figure 7 shows the curves corresponding to the two jacks with numbers 7 and 26 installed into the external log wall. The four cycles of the applied piston extensions can be distinguished in the figures. The first cycle occurred at the time from t₁ to t₂, the second from t₃ to t₄, the third from t₅ to t₆ and the fourth from t₇ to t₈. The values of the applied piston extensions corresponding to particular cycles were determined as ∆u₁₂, ∆u₃₄, ∆u₅₆, ∆u₇₈ and their corresponding increase in forces as ∆Q₁₂, ∆Q₃₄, ∆Q₅₆, ∆Q₇₈. These values are shown in Figures 6 and 7 and are listed in Tables 1 and 2. The values ∆u depended on the position of the jack and the cycle and ranged from 16.29 mm to 122.92 mm. The change ∆Q in the force value Q corresponding to the change ∆u depends on the jack installation place. For the jacks installed in the cellar walls, the change is from 2.56 kN to 23.98 kN. On the other hand, it is much smaller and ranges from 0 to 3.45 kN for the jacks installed in the wooden log walls. The difference in the value of ∆Q increments may result from different stiffness of the cellared and non-cellared part of the building. The cellared part is much stiffer, so forcing a change in its position requires more force.
Figure 5. Jacks installed the building walls: a) arrangement of the jacks, b) jacks installed in the cellar wall, c) jacks installed in the external log wall, d) building resting on the jacks

Figure 6. Forced piston extensions ($\Delta u$) and corresponding force changes ($\Delta Q$) in selected jacks installed in cellar walls: a) jack no. 11, b) jack no. 17
Table 1. Pistons’ extension values (Δu) and corresponding changes in forces (ΔQ) in jacks no. 11 and 17

|   | Jack 11  |   | Jack 17  |   |
|---|----------|---|----------|---|
|   | ΔQ(t_i)  | Δu(t_i) | ΔQ/Δu   | ΔQ(t_i)  | Δu(t_i) | ΔQ/Δu   |
| 1 | 3.62 kN  | 37.44 mm | 0.097 MN/m | 2.56 kN  | 70.80 mm | 0.036 MN/m |
| 2 | 5.40 kN  | 16.29 mm | 0.331 MN/m | 6.83 kN  | 31.50 mm | 0.217 MN/m |
| 3 | 7.96 kN  | 41.79 mm | 0.190 MN/m | 23.98 kN | 80.77 mm | 0.297 MN/m |
| 4 | 4.09 kN  | 25.00 mm | 0.164 MN/m | 14.89 kN | 48.34 mm | 0.308 MN/m |

mean ΔQ/Δu 0.176 mean ΔQ/Δu 0.215

Figure 7. Forced pistons’ extensions (Δu) and corresponding changes in forces (ΔQ) in selected jacks installed in external walls made of wooden logs: a) jack no. 7, b) jack no. 26

The stiffness of a system consisting of the building part to be lifted, the part remaining in the ground and the jacks can be measured by dividing the change in the force value in the jacks to the appropriate forcing (ΔQ/Δu). These values were determined in Tables 1 and 2 for the four jacks under analysis and for the four forcing cycles. The quotient ΔQ/Δu for the jacks installed in the cellar walls ranges from 0.036 MN/m to 0.308. The value of this quotient, on the other hand, corresponding to the installation place of the jacks in walls made of wooden logs, is lower and spans from 0 to 0.047. This confirms the thesis that the rigidity of the structure has an effect on the value of the force increase.
### Table 2. Pistons’ extension values ($\Delta u$) and corresponding changes in forces ($\Delta Q$) in jacks no. 7 and 26

| $i$ | $\Delta Q_{(i+1)}$ | $\Delta u_{(i+1)}$ | $\Delta Q/\Delta u$ | $\Delta Q_{(i+1)}$ | $\Delta u_{(i+1)}$ | $\Delta Q/\Delta u$ |
|-----|--------------------|--------------------|---------------------|--------------------|--------------------|---------------------|
| 1   | 0                  | 36.08              | 0       | 2.07                | 112.44             | 0.018               |
| 2   | 0                  | 14.64              | 0       | 1.38                | 47.94              | 0.029               |
| 3   | 1.37               | 37.54              | 0.036   | 2.06                | 122.92             | 0.017               |
| 4   | 0.69               | 22.46              | 0.031   | 3.45                | 73.57              | 0.047               |

mean $\Delta Q/\Delta u$ 0.017  mean $\Delta Q/\Delta u$ 0.028

### 4. Construction of new foundations

The strip foundations under the non-cellared part of the building were started to be replaced after the rectification. New supports were made for the raised part of the building to gain access to the existing strip foundations which are in poor technical condition. The supports were not in the axis of the walls and carried the load directly to the ground, outside the foundations. A sketch of this support is shown in Figure 8c and in the photograph in Figure 9a. The jacks installed in the axis of the walls were removed and the old foundations were dismantled after transferring the weight of the structure onto these supports. The ground under the building was then compacted and the new building foundation was made. It consists of reinforced concrete strip foundations and a foundation wall made of concrete blocks. A sketch of this solution is shown in Figure 8d and in photographs in Figure 9b and 9c. In the last stage, the building was lowered onto the prepared foundation (Fig. 9d).

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**Figure 8.** Phases of lifting the building and of constructing the new foundations: a) the building resting on the old foundations, b) a jack installed into an external log wall, c) the raised part of the building resting on supports not located in the axis of the wall and transferring the load to the ground outside the building, d) new foundation of the building
5. Conclusions
The traditional way of dealing with vertically deflected wooden buildings, where foundations need to be additionally repaired, consists in dismantling them and then rebuilding them on newly constructed foundations. An alternative procedure presented in the article proposes to remove the structure deflection by uneven lifting and replacing the foundations under the existing structure. No damages to the building were caused with this method. In addition, the even lifting of parts of the building allowed to avoid their troublesome dismantling and then restoration in a new location.

It was found based on the measurements of pistons extensions and the values of forces in the jacks used for uneven lifting, that the stiffness of the building in the jack installation place depends on the
type of the structure. The stiffness of the cellared section is about ten times higher than that of the non-cellared part of the building.

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