TECHNICAL TRANSACTIONS | **CZASOPISMO TECHNICZNE**
CIVIL ENGINEERING | BUDOWNICTWO

2-B/2014

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REPAIR PROCESS IN THE PITHEAD BUILDING AND ITS INFRASTRUCTURE AS AN EXAMPLE OF REPAIR WORKS IN INDUSTRIAL FACILITIES

PROCESY REMONTOWE W BUDYNKU NADSZYBIA ORAZ JEGO INFRASTRUKTURY JAKO PRZYKŁAD REALIZACJI ROBÓT REMONTOWYCH W OBIEKTACH PRZEMYSŁOWYCH

A b s t r a c t

This article presents the technological issues of carrying out repair works on a pithead building in Upper Silesia. The problems diagnosed by the authors and connected with the uncontrolled settling of the pithead building and neighbouring facilities caused the need for developing a repair works schedule that enabled its continuous operation. The paper also presents a method for the implementation of the recommended works and their impact on the technical condition of this object, its functionality and operation.

Keywords: repairs, diagnostics, jet grouting

S t r e s z c z e n i e

W artykule przedstawiono problematykę technologii wykonania oraz przeprowadzenia prac naprawczych budynku nadszybia w jednej z kopalń węgla kamiennego znajdującej się na terenie Górnego Śląska. Zdiagnozowane przez autorów pracy problemy związane z niekontrolowanym osiadaniem budynku nadszybia oraz obiektów sąsiadujących pozwoliły opracować program prac naprawczych umożliwiających ich dalszą eksploatację. W pracy przedstawiono także sposób realizacji zaleconych prac oraz ich wpływ na stan techniczny omawianego obiektu oraz jego funkcjonalność i użytkowanie.

Słowa kluczowe: prace naprawcze, diagnostyka, jet grouting

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1. Introduction

Buildings located within mining plants are interesting examples of industrial facilities. Their technical condition affects not only the safety of their users but, above all, the ability to conduct, often continuously, the technological processes of excavation. Even small disruptions in the operation of a pithead facility may result in a total stoppage in mining activities. It is therefore important to maintain such facilities in good condition, which often requires continuous monitoring of their behaviour under the influence of static and dynamic loads acting upon them. In case of any irregularities which could lead such facilities to the state of structural failure, immediate repair actions leading to their proper operation should be carried out. Such a situation was recorded at a coal mine located in Upper Silesia. In this mine, as a result of uncontrolled displacement of the ventilation duct which also served as a foundation for two poles of the pithead building, there may have been additional tension in the structural elements of the building. Research carried out by the authors, which included the description and analysis of the current state of the structure, along with photographic documentation, static and strength control calculations that took the forced uneven settling of the foundations into account, as well as an analysis of the results, conclusions and recommendations for further operation of the building, which allowed for developing a repair schedule.

2. General characteristics of the pithead building

The building in question is located in a former swampy area, which has been evened out using made ground. The pithead building was also designed to house a ventilation exhaust. The pithead included two depression chambers for trolleys transporting auxiliary material, an airlock for the staff and a leisure facility. With the transformation of the shaft into a downcast shaft, the conditions were changed for the building, thus changing its depression load. The total area of the pithead building is 350.10 m^2, and the total volume is 3.127.00 m^3.

According to geotechnical documentation, the area around the pithead building is filled with man made ground consisting of slag, brick, stone, clay and sand, down to the depth of 2.00 m. Below is a layer of sand dust and clay with a thickness of 1.00 to 2.00 m. Below that, there are low- and medium-cohesion soils consisting of dusts and dusty plastic clay. The last layer includes ground water of low aggressiveness.

The main load-bearing structure of the building is made of a single-nave, single-storey steel frames hinge-joined with the foundation every 6.0 m. The walls are made of prefabricated reinforced concrete slabs welded to the structural columns using suitable fasteners. The roof structure is made of typical prefabricated A-4/K ceiling slabs supported by the rafters of the framework. A general view of the support structure of the pithead building and the building itself are shown in Figure 1.

Columns in gable walls in axis 3 are suspended on struts due to the lack of space on the foundation (shaft head building). In axis D, two frame columns in axes 3 and 4 are supported by a ventilation duct section separated by movement joints and constructed to transfer the load from the frames. The plinth in the form of a clinker brick wall on cement mortar is laid on prefabricated ground beams supported by foundations. The foundations were made as a group for the individual columns interconnected with safety beams that secure the

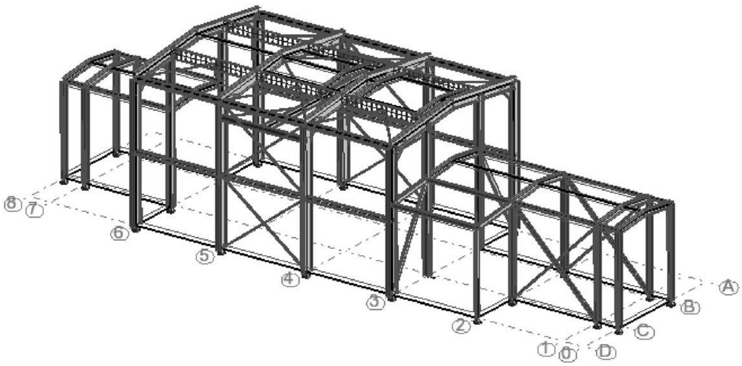

Fig. 1. Supporting structure of the pithead building

foundations against excessive horizontal displacement. The foundations are placed 1.5 m below ground level, with only the previously mentioned pillars of the framework in the axis D. Axes 3 and 4 transfer the loads to the ground via the stair structure of the ventilation duct on which they are placed. The solution adopted for the foundation of the pithead building allows for independent operation of individual groups of foundations.

3. Evaluation of the technical condition of the pithead building

In July 2011, site visits were conducted, which included the direct area around the shaft, the ventilation duct and the pithead building. The observations and measurements of the geometric dimensions of the facility included an assessment of the technical condition of the building. Based on the site inspection, the following conclusions were made:

- damaged floor in the area of load-bearing columns support on the ventilation shaft,
- damaged hinged joints of the framework column in axes D and 3 with the foundation, displaced J-bolt in relation to the ventilation shaft,
- damaged curtain wall in axes D and 3 – vertical slots,
- damaged infill in the curtain wall in axes D and 3,
- damaged external reinforced concrete wall panels – debonding and slight vertical and horizontal displacement,
- loosening of wall elements from the building's plinths,
- damaged wall corner of a pithead building addition,
- slight displacement with rotating ventilation shaft, noticeable in expansion joints,
- lack of progress in expansion joints loosening based on installed infills,
- vertical displacement ventilation shaft in relation to the shaft head.

It was concluded that this damage may have been caused by uncontrolled displacement and rotation of the individual parts of the ventilation shaft. This would have been caused by the method of setting the pithead building, which included supporting the framework columns in axes 3 and 4 on the section of the ventilation shaft surrounded by movement joints. The in fills allowed for constant monitoring of the possible acceleration of the loosening of observed slits and damages. It was also concluded that the factors which caused the displacement of individual elements of the ventilation shaft have stabilised, which was proven by the lack of damage on the seals and the results of systematic geodesic measurements.

During site inspections, no damage was found in the joints of main or auxiliary elements. The steel components were properly protected against corrosion and the measurements did not show any dimensional deviations from the designed values.

4. Evaluation of the current carrying capacity and serviceability of the pithead building

Assessment of the current technical state allowed for static and strength calculations to be carried out for the pithead building. Calculations were performed in a calculation program using Finite Element Method and included:

- building a computational model based on the available archival documentation and the inventory of current state,
- the determination of internal forces in structural elements,
- the determination of deformations and displacements,
- inspection to check the load capacity of selected, representative steel components.

Based on the inspection and available technical documentation, a computational model for the pithead building was constructed. The model takes the geometric characteristics of the individual components and their interconnections into account. A summary of loads in this analysis was performed in accordance with current standards and regulations [1–6]. In the case of wind and snow loads, changes resulting from the amendment of the provisions of code were also taken into account. Due to the change in the function of the ventilation shaft from exhaust to downcast, the air depression load was omitted in the loads. The model also takes the uneven settling of the foundation of the pithead building into account. As a result of the uneven settling of the supports of the pithead structure, the forces and deflections are distributed differently in the main elements of the structure. The values of internal forces and torques in steel columns and beams are thus altered. The calculations do not take the stiffness of both the wall and roof elements into account, which, significantly increase the structure's rigidity due to the permanent nature of their joints.

Table 1 shows the values of maximum cross-forces, as well as maximum tension values in the structural elements. Figure 2 shows an example of a graph of maximum torque M_y.

Analysing the values of maximum tension obtained, we can conclude that they do not cause maximum effort in the steel profiles. Stress with approx. values of 150.0 MPa should be safely transferred by the structural components used.

Table 2 shows maximum displacement values for the structural nodes of the pithead building in the limit state of usability.

Table 1

The maximum values of internal forces and stresses occurring in the structural elements of the pithead building

	F_X [kN]	F_Y [kN]	F_Z [kN]	M_X [kNm]	M_Y [kNm]	M_Z [kNm]	σ_{max} [MPa]	σ_{min} [MPa]
MAX	843.91	16.25	123.62	0.17	654.40	27.99	152.23	145.08
Rod	73	31	73	65	73	124	52	123
Node	61	12	62	54	62	88	35	73
MIN	–210.55	–31.11	–272.36	–0.22	–654.40	–3.29	–146.17	–146.17
Rod	77	46	75	64	75	65	132	132
Node	66	31	62	54	62	58	63	63

Table 2

The maximum values of displacements of structural nodes in the pithead building

	U_X [cm]	U_Y [cm]	U_Z [cm]	R_X [rad]	R_Y [rad]	R_Z [rad]
MAX	0.0	4.4	0.0	0.005	0.012	0.005
Node	4	10	4	55	54	41
MIN	–4.0	–1.6	–3.6	–0.008	–0.007	–0.001
Node	62	56	85	12	87	55

A maximum displacement value of 4.4 cm was obtained in node no. 10 of the structure, which is located in axes 6 and D in the joint between the column and the beam. Due to the fact that the stiffness of both the wall and roof elements were not taken into account, and their permanent joint with the structure significantly increases the overall stiffness, the real registered displacements should be lower. It should be further emphasised, that the forced settling of the foundations related to the settling of a section of the ventilation shaft is a decisive factor causing the deformations. Calculated deformations, taking the additional stiffening of certain panel elements of walls and roof into account, should be safely transferred by the structure in question.

Based on these calculations, it can be concluded that no limit state in those elements is exceeded. However, further settling of the ventilation shaft, as well as the foundations in axes C and D in the southern part of the pithead building, should be limited. Further settlement growth will significantly reduce the load capacity of the main structural elements and can lead to exceeding the limit states of load capacity and serviceability of the building. Due to the positive experience of the mine with foundation reinforcement in this area using micro-piles, the previously used solutions should be adapted to protect the foundations of the

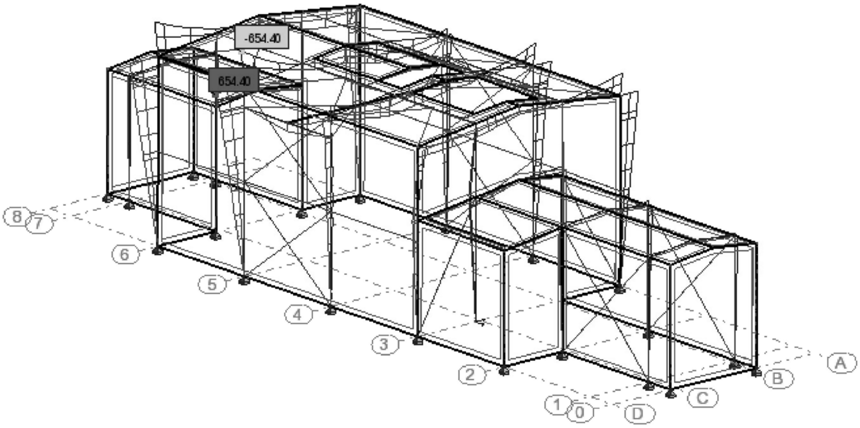

Fig. 2. Graph of maximum torque M_y of the pithead building structure

pithead building. The use of appropriate technology to reinforce the foundations would also allow for the rectification of the facility.

5. Repair works on the pithead building

The diagnosed issues connected with the uncontrolled settling of the pithead building and neighbouring facilities necessitated the development of a repair project which allowed for its continuous operation. To this end, "Georem" Sp. z o.o. engineering company developed a project [7], which included strengthening of the existing foundations of the pithead building, the construction of heaters, reinforcing the floors near technological channels in the buildings, as well as the ground adjacent to the ventilation shaft. All repair works were carried out in autumn of 2012 and included the following execute:

- site preparation where the works would be conducted,
- 5 geotechnical holes on the outside of the buildings,
- 3 geotechnical holes inside the ventilation duct,
- injection columns under the existing foundations,
- injection columns in the immediate vicinity of technology channels,
- vertical barrier in the immediate vicinity of the existing duct,
- low pressure injection under the duct's base plate,
- organising the work area.

The proposed high-pressure jet injection was the technology used to strengthen the foundations of the ground, a tried and tested method used for thirty years. It was moved from to Japan to Europe in the 1970 's. This technology is characterized by three specific features which are useful in applications relating to strengthening the foundations of buildings. Jet grouting technology provides the possibility of drilling small diameter foundations (about 100–150 mm). From a relatively small diameter drilling pile, the creation of a substantial diameter pile can be achieved. These features together with using drilling equipment with a small footprint allow for the effective implementation of the consolidation work in almost all technical conditions, even from a basement not exceeding 1.5 meters in depth. It should be emphasized that in the analyzed case, jet grouting technology enabled the implementation of all repair processes without any major disturbances in the use of the building headroom, which was a main assumption for the selection of technologies for strengthening the ground and foundations.

In order to strengthen the ground below the existing spot footing and continuous footing, columns with a diameter of 60 cm and the length of 7.5 to 10.0 m were designed. Prior to forming the columns, re bores were carried out on the existing foundations.

In order to strengthen the subsoil in the immediate vicinity of the technological channels, columns with a diameter of 60 cm and the length of 4.0 m were designed.

To prevent the excessive settling of the duct, a vertical iris was designed using columns with a diameter of 80 cm and the length of 8.0 to 10.0 m. Additionally, in order to strengthen the subsoil directly beneath the base plate of the duct, holes were made for low-pressure injection (classic injection).

The jet grouting technology used filled any voids, caverns and loose material that could appear in the ground, e.g. as a result of ground water.

5.1. Column injection molding technology

Column injection involves drilling holes in the soil and the formation of column shafts using the kinetic energy of a stream flowing out of a nozzle, which hews and fills the ground with the injected grout using the rotation and the concurrent upwards and downwards motion of the drilling tool. Cement grout made of cement is most widely used as the injected medium.

In this case, injection columns with a diameter of 60 cm and 80 cm were designed at proper working levels. Working level adjustment maintained the level of column bases while the designed geometry below the foundation outline were also maintained.

For works safety reasons, control cross cuts were made prior to drilling in order to locate existing underground installations. In the event of a conflict between existing installations with the designed columns, the colliding installations should be moved or the geometry of injection works should be changed.

The works preceding the drilling and injection included:

- control cross cuts in order to locate the underground development,
- performing optional demolitions in order to access the drilling locations and preparing the working level for column construction (drilling level),
- starting the works on 60 cm and 80 cm columns.

The columns were constructed in the following order:

- drilling holes through floors, walls, building foundations,
- drilling holes in the ground to the proposed depth,
- constructing the columns by jet grouting.

To perform the injection work according to the technology described, specialist equipment was used. The basic elements of this equipment are:

- drilling with equipment (head injection, injection line, monitor injection, jets),
- high rotary mixer,
- slow rotary mixer,
- high-pressure injection pump,

- manometer,
- scales to measure the density of the cement paste.

The transport of materials and equipment was made by commonly available transport sources which were adopted to carry the certain goods.

During the realization of repair works the control studies were conducted. These studies included:

- materials used for the column injection,
- inject work and their compliance with the design documentation,
- strength of the cement-soil compressive,
- diameter made of columns.

5.2. Technology of low pressure injection

In order to reinforce the ground directly below the foundations of the ventilation duct, low-pressure (classic) injection was used for the purpose of eliminating any possible loosening, washouts or caverns. For this purpose, holes with a diameter of 50 mm were drilled vertically through the base plate every 0.75 × 2.3 m with a displacement every second row.

The injection procedure should be conducted using packers. Grout injection was carried out sequentially in the adjacent holes until a significant leakage in the next hole was noticed or the injection pressure increased to a pre set value. Drilled holes were treated as safety valves in the event of a pressure increase above the permissible value. The maximum injection pressure measured directly in the hole was P_{max} = 0.2 MPa. In the case of high absorbency of the soil, characterised by a lack of grout flow in the adjacent holes, injection should be discontinued and restarted after 24 hours.

Injections were considered completed when pressure increased above the preset value P_{max} = 0.2 MPa with minimal absorbency of the grout.

5.3. Executive recommendations and notes

Before drilling and injection could start, existing soil development networks had to be precisely located. In the event of a collision with planned works, the placement of columns had to be adjusted. Regulatory distances from injections to foreign devices had to be maintained.

All devices and installations, or their parts, that were located in the vicinity of the works had to be turned off, stripped of all hazardous factors and successfully secured against accidental launch and appropriately marked.

Prior to the commencement of works related to grout injection, 8 geotechnical holes had to be drilled to prove the assumptions concerning the soil. In the case of any deviations in relation to the assumptions, appropriate design and work decisions had to be made and agreed upon with the designers.

The works associated with drilling down to the predetermined depth had to be carried out using cement grout. Due to the occurrence of cohesive soil in the substrate, wet scrubber drilling was inadvisable.

During the injection works in the direct vicinity of existing channels, their technical condition had to be checked first to secure them against filling with technological dump. If necessary, piping had to be laid in the section in direct contact with the technological channel.

After the designed works have been completed, as-built documentation had to be compiled.

6. Evaluation of the effectiveness of made the repair process

Mine engineers have been making geodesic measurements near the pithead building for many years. Measuring points were placed both on the building and on its floors. The geodesic monitoring allowed for determining both the past displacement of measurement points and the effectiveness of the repair process carried out. The measurements obtained show that the largest vertical displacements prior to repairs occurred in the direct vicinity of the resting place of the column in axes D and 3 on the ventilation duct. Total displacement at this point was 3.1 cm. Slightly smaller displacements of 1.6–1.9 cm were recorded at points located in the vicinity of the wall in axes B and 1–2, as well as C and 1–2, and at a point in the vicinity of the foundation shaft tower brace. Other displacement measuring points did not exceed 1.0 cm, and extra points installed after finding displacement of the ventilation duct showed no significant changes.

Fig. 3 is an exemplary diagram of vertical displacements recorded at measuring point No. 78, located on the wall in the immediate vicinity of the resting place of the column on the ventilation duct. It should be noted that significant displacements of 2.4 cm at this point were recorded directly before the repair works commenced (18.09.2012). As a result of the repair process, the displacements have stabilised and are currently not hazardous to the pithead building. It should be emphasised that similar relationships have been recorded at other measuring points.

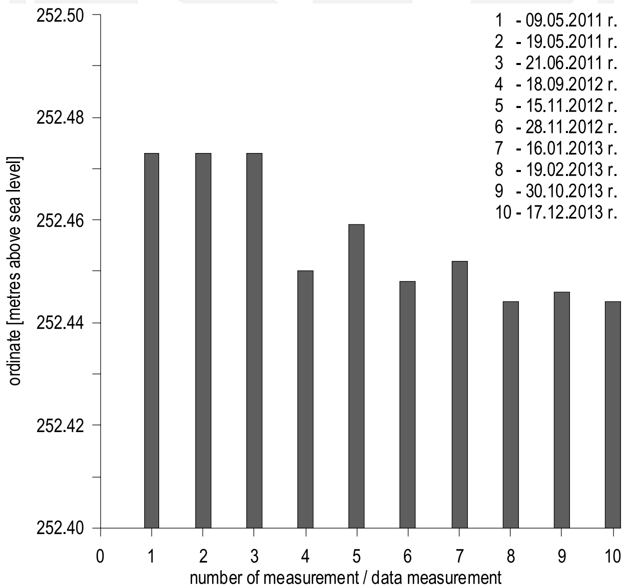

Fig. 3. Vertical displacements of measuring point no. 78

7. Conclusions

Repair works to industrial facilities, not unlike other facilities, is a complex issue. When designing and performing such tasks, one should take a number of factors that may hinder their performance into account. The correct assessment of current technical conditions, taking real condition of the structure and the factors causing the loads into account seems very important. The example of repair works using jet injection technology presented in this article points to the desirability of this type of solution, particularly in situations where work has to be carried out quickly. This technology guarantees safety of the structure as well as minor interference to the environment object. It should also be noted that all repair works were carried out without causing any major disruptions to the operation of the mine. Previous positive experiences related to the use of jet grouting technology for repair works on industrial facilities show great potential.

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