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TECHNICAL NOTE

EXAMPLE OF THE APPLICATION OF JET GROUTING TO THE NEUTRALISATION OF GEOTECHNICAL HAZARD IN SHAFT STRUCTURES

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Abstract: The article presents a geotechnical hazard neutralisation technology for shaft structures. The diagnosis of problems with uncontrolled subsidence of the ventilation duct provided by the authors enabled the development of a schedule of works required for the protection and reinforcement of foundation soil in the shaft area. The technology of protection works was selected after the analysis of the technical condition of shaft structures as well as hydrological and geomechanical conditions. Due to the closeness of the shaft lining, it was necessary to form grout columns using jet grouting and low-pressure grouting technologies. The article presents the issues related to the selected technology and its application to the neutralisation of the emergent geotechnical hazard. The method of performance of recommended works was also described together with their impact on the technical condition of structures discussed as well as their functionality and usage.

Key words: *jet grouting, shaft, mining construction, structure diagnostics*

1. INTRODUCTION

Shaft structures are crucial for the safe and economically effective operation of mines. Due to their importance, they require periodical inspections regarding their technical condition. Downtimes in the operation of shaft structures lead to severe limitations in production works. This is the reason why continuous monitoring of their behaviour in reaction to applied static and dynamic loads is of vital importance. In case any irregularities which could potentially damage the structures being analysed are found, remedial measures must be taken immediately to secure their operating order. A situation of this type occurred in one of the Silesian coal mines – subsidence of the ventilation duct in the area of the shaft due to the instability of foundation soil. The dislocation of the segments of the ventilation duct resulted in additional uncontrolled impact on the shaft collar. The multiparameter analysis by the authors helped to assess the current strain on the affected shaft structure elements and enabled the development of a schedule of works required for the protection and reinforcement of foundation soil in the shaft area. Due to the closeness of the shaft lining, the works related to the reinforcement of the ground were performed using jet grouting and low-pressure grouting technologies.

2. TECHNICAL DESCRIPTION OF THE SHAFT COLLAR AND VENTILATION DUCT

The initial shape of the shaft collar was difficult to verify, due to the lack of appropriate documentation. In the 1970's, a ventilation duct in its current form was made – this may have resulted in the need to retrofit the final collar with pipe and cable duct inlets. The old shaft collar was partly disassembled and a new reinforced concrete structure was erected. The new shaft collar structure rests directly on the brick shaft lining, with local thickness of 2 m. The method of resting the collar on the shaft lining is presented in Fig. 1. The shaft working consists of two parts. The first segment (L-1) is directly adjacent to the shaft collar and is raised at a 30° angle towards the second, horizontal segment – L-2. The segments of the ventilation duct and the shaft collar are separated by

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movement joints. Due to the high water content in the local soil and its low physical and mechanical properties, the ventilation duct was constructed using the ground freezing method. The segments of the ventilation duct are made of reinforced concrete.

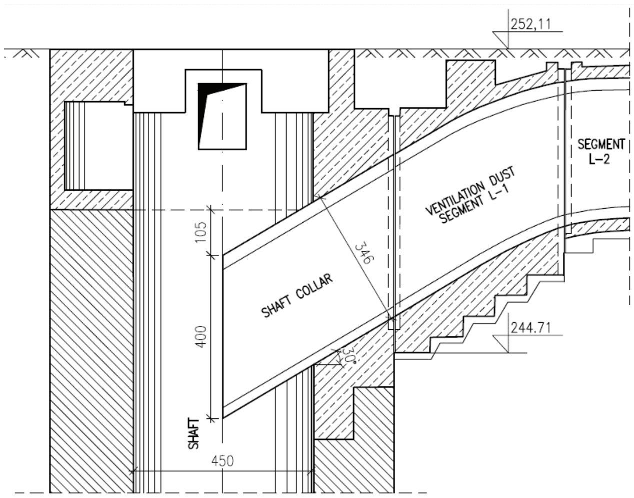

Fig. 1. Longitudinal section drawing of the ventilation duct and shaft collar

After the dislocation of the ventilation duct, a site inspection was performed, including the immediate area around the shaft, ventilation duct and the shaft top building. As a result of the displacement of the first segment of the ventilation duct in relation to the shaft collar, a possibility of additional loads affecting the shaft lining was found. These loads were not taken into account in the initial design. The research conducted by the authors included the analysis of the current condition as well as control static and strength calculations helped to assess the real hazard to shaft structures and infrastructure. It was shown that further subsidence of the ventilation duct may lead to damaging the shaft structures. Immediate protection of the ventilation duct against further subsidence was recommended [2].

3. GEOTECHNICAL CONDITIONS

The area discussed is a morphological part of the Rybnik Plateau with diversified vertical relief, resulting from an erosion dissection of the weak loess top formations by flowing waters. As a result of the mining activity, the terrain was elevated to the level of 250.5 mamsl in the southern part and 252.7 mamsl in the northern part.

The whole area is located within the confines of the protective pillar created for shaft structures.

Six geotechnical layers were distinguished in the foundation soil of the area:

- Layer I – uncontrolled embankments near the surface, composed of loose material from the mining activity (shale, claystones, sandstones) mixed with slag, clay, sand as well as wood, brick and concrete rubble and industrial waste,
- Layer II – holocene fluvial formations represented by organic alluvions and humic soils in a high-plastic state (not found in the immediate area of the ventilation duct),
- Layer III – non-cohesive fluvioglacial soils – pebbles, sandy gravels and sands in a medium-compacted state $I_D = 0.45$, occurring in the form of lenses,
- Layer IV – low-plastic soils with the plasticity of $I_L = 0.14$,
- Layer V – plastic soils with the plasticity of $I_L = 0.31$,
- Layer VI – high-plastic soils with the plasticity of $I_L = 0.68$.

Fig. 2. Vertical displacement on the joint of the L-1 segment of the ventilation duct with shaft collar, from the shaft's side

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Layers IV, V and VI are composed of eolian formations in water, occurring as interlayers of silts, sandy silts and silty clays, with laminae of silty and fine sands.

The aquifer is connected to the sand and gravel layer deposited among silty clays and silts with low permeability. The roof of water-bearing soils was drilled to the depths of 4.3 m (247.5 mamsl) to 10.2 m (241.2 mamsl). The groundwater table has stabilised at elevations from 246.2 to 248.4 mamsl. Groundwater is also present in the interbeddings of sands and as drains in clay-silt soils with low permeability.

Groundwater shows weak to medium signs of sulphuric aggressiveness towards concrete.

Soils in layers II, IV, V, VI are classified as non-consolidated, type "C". They are characterised by high structural sensitivity, and low resistance to dynamic loads. The thixotropic properties of these soils and the fluctuations in the groundwater level resulted in their loosening and decreased consolidation. The draining effect of the shaft enabled the movement of water and suffosion transport of small soil particles. The processes described led to the deterioration of the physical and mechanical properties of the soils and resulted in the subsidence of shaft structures. The detrimental geotechnical processes present in the shaft area were described in detail in studies [1], [4].

4. GEODETIC SURVEY

The administrator of the structure has performed systematic geodetic surveys of the shaft area over the years. The analysis of the results of such surveys shows the largest vertical displacement in the first segment of the ventilation duct (L-1). The total displacement in the period from November 2010 to April 2011 was 3.1 cm. The analysis of the surveys also shows that the subsidence process was most intensive in the spring of 2010 (Fig. 3).

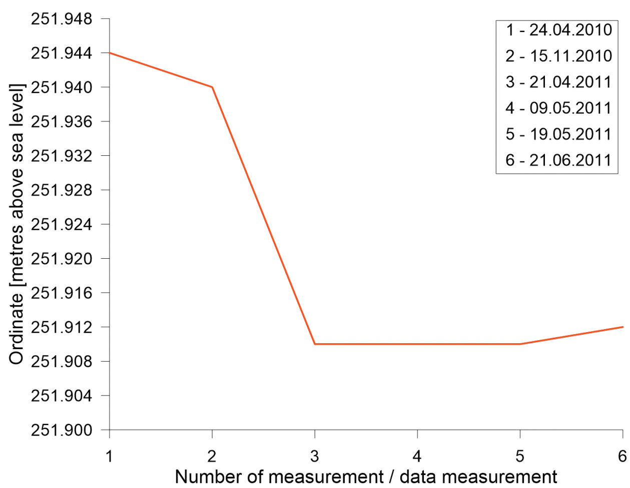

Fig. 3. Measurement point levels in the L-1 segment of the ventilation duct

The results of geodetic surveys show that the factors contributing to the displacement of the segments of the ventilation duct have stabilised. However, due to the geotechnical conditions, further subsidence cannot be excluded.

5. REINFORCEMENT OF THE FOUNDATION OF SHAFT STRUCTURES

The diagnosed problems with uncontrolled subsidence of the ventilation duct required the development of a schedule of remedial measures for further safe operation of the shaft. Due to the closeness of the shaft lining, the works related to the reinforcement of the ground were performed using the jet grouting technology. The decisive factors in the selection of this technology were the quickest possible neutralisation of the hazard and a lack of additional negative impact on shaft lining.

The technology of making grout columns involves drilling boreholes in the foundation soil and forming column shanks by using the kinetic energy of a nozzle jet which, during the rotation movement and together with the up and down movements of the drilling tools, breaks the foundation soil and fills it with grout. The injected medium is usually cement grout.

The requirement to maintain the safety of the reinforced structures is an important aspect of working in proximity to shaft structures. The jet grouting technology is characterised by a lack of dynamic impacts which would pose a potential threat to the stability of the reinforced structures. Low-diameter bore perforations through the reinforced structures may be drilled without impact or made with low-impact jackhammers to maintain the safety of the structures [3].

Pressures used in the jet grouting technology are individually selected to match the reinforced structure. The energy of the grout jet is used to break the soil structure in a controllable manner and does not result in negative impact outside the specified area. Grouting works are performed with an open borehole, preventing any type of pressure on the adjacent rock mass apart from the column formation. Excessive grout, mixed with soil, flows freely to the surface forming the so-called technological discharge.

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Taking into account the possibility of controlling the penetration range of the grout jet, the jet grouting technology can be successfully applied to the reinforcement of the foundation soil for structures located near the shaft lining. It also provides the possibility of a quick neutralisation of the emergent hazard, which was a key factor in the case of the condition of imminent failure described.

6. GROUT COLUMNS FORMATION TECHNOLOGY

The analysis of the construction of shaft structures, their technical condition, the structure of the foundation soil and its processes revealed the need to perform rock mass petrification works. Due to the closeness of the shaft lining, it was necessary to form grout columns using jet grouting technology. The calculation of the number and strength of grout columns was based on the guidelines mentioned in the study [5]. For calculation purposes, it was assumed that the total load-bearing capacity of the columns is transmitted to the ground by side surface friction and, additionally, base resistance in case the piles are located in cohesive soil in a low-plastic state. In order to protect the first segment of the ventilation duct against further excessive subsidence, the formation of columns with 60 cm in diameter and 10.0 m in length was proposed. For the next segment, it was suggested to provide a vertical wall made of columns with a diameter of 80 cm and length from 8.0 to 10.0 m. Additionally, in order to fill any potential remaining voids, caverns and loose areas in the soil under the foundation plate of the working, boreholes were made for low-pressure grouting. Low-pressure grouting required the application of borehole seals. The grout was successively injected into boreholes until there was visible grout spillage into the next borehole or the injection pressure was raised to a given value. The boreholes provided safety valves in case the pressure exceeded the allowable value [6]. The location of grout columns is presented in Fig. 4.

7. ASSESSMENT OF THE EFFECTIVENESS OF REMEDIAL MEASURES

Continuous surveying monitoring enabled the determination of the current dislocations of measurement points as well as the assessment of the effectiveness of foundation soil reinforcement works. The results of the measurements show that due to the remedial measures provided, the dislocations have stabilised and do not pose further threat to shaft structures. Figure 5 shows an example diagram of vertical dislocations registered at the measurement point located in immediate proximity of the first segment of

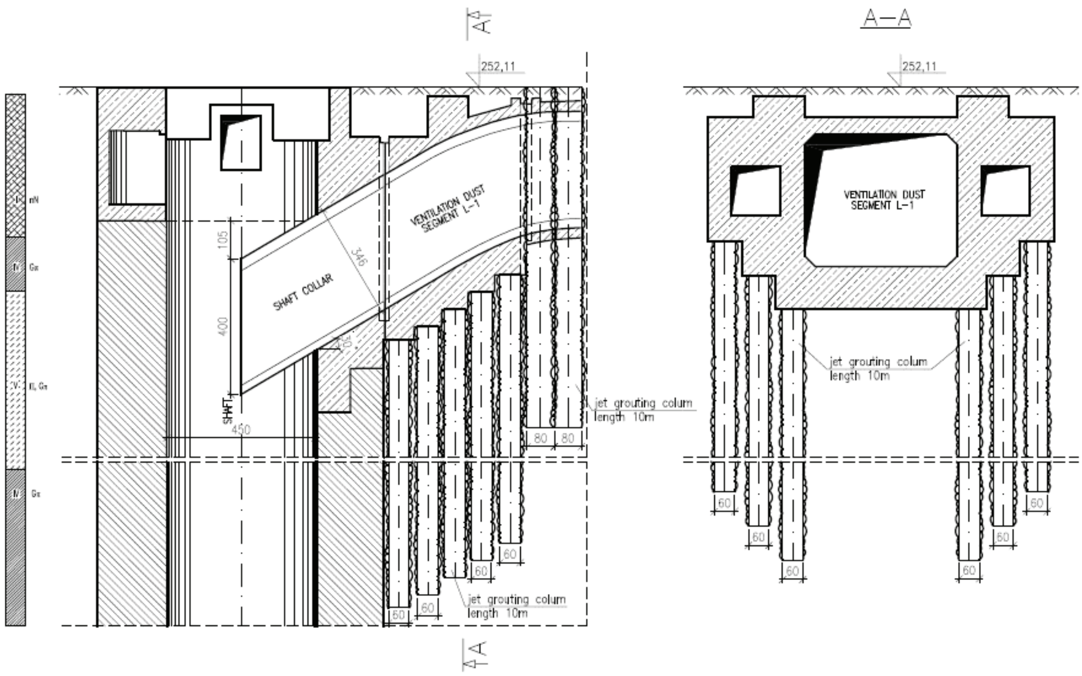

Fig. 4. Location of grout columns

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the ventilation duct. Similar dependences were found for the remaining measurement points.

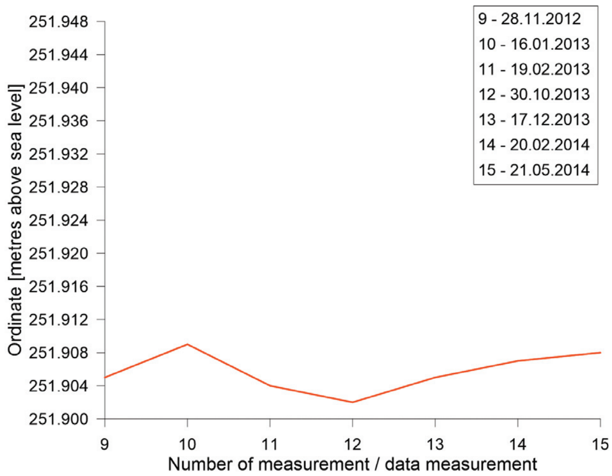

Fig. 5. Measurement point levels in the L-1 segment of the ventilation duct after the reinforcement of the foundation soil

8. CONCLUSION

Remedial measures for shaft structures are a complex issue. During engineering and carrying out this type of works, a number of factors which may prevent their performance needs to be taken into account. A correct assessment of the current technical condition is vital and needs to include actual operation conditions of the structure and geological and engineering diagnosis. The example of foundation soil reinforcement with jet grouting presented in the article proves the efficacy of this type of solutions, especially in situations when the works need to be performed immediately, safely and with minimum impact. The grout columns filled the empty spaces in the soil and created a barrier preventing further soil degradation in the area of the shaft structures.

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