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EVALUATION OF LOAD CAPACITY OF SHAFT COLLAR SUBJECT TO UNINTENDED EXCEPTIONAL LOADS

OCENA NOŚNOŚCI GŁOWICY SZYBOWEJ PODDANEJ NIEZAMIERZONYM OBCIĄŻENIOM WYJĄTKOWYM

The article presents an evaluation of the technical conditions of the shaft collar as well as its load capacity in which the consequences of uncontrolled displacement of part of the ventilation drift could have caused additional stress to occur. On the basis of comprehensive diagnostic examination undertaken by the authors, a comprehensive analysis of the static resistance of the shaft collar, which takes into consideration the exceptional unintended load. Examinations as well as calculations carried out have allowed for the evaluation of the practical degree of danger for shaft objects (constructions) as well as their infrastructure.

Keywords: shaft collar, load evaluation, underground construction, construction diagnostics

Obiekty szybowe stanowią bardzo istotną rolę w całym procesie wydobywczym każdej kopalni. Ze względu na swoje znaczenie obiekty szybowe oraz ich infrastruktura wymagają szczególnego dozoru w zakresie ich stanu technicznego, który wpływa nie tylko na bezpieczeństwo ich użytkowników ale przede wszystkim na możliwość prowadzenia, niejednokrotnie w sposób ciągły, procesów technologicznych umożliwiających wydobycie. Nawet niewielkie zakłócenia w zakresie użytkowania obiektów szybowych mogą spowodować całkowity paraliż w zakresie prowadzonych prac eksploatacyjnych. Stąd istotnym jest utrzymywanie takich obiektów w odpowiednim stanie technicznym, co niejednokrotnie wymaga stałego monitoringu ich zachowania się pod wpływem działających na nie obciążeń statycznych jak i dynamicznych. W przypadku stwierdzenia jakichkolwiek nieprawidłowości mogących doprowadzić analizowane obiekty do awarii, należy podjąć natychmiastowe działania naprawcze umożliwiające ich prawidłowe użytkowanie. Brak odpowiednich działań naprawczych i zabezpieczających może skutkować katastrofą budowlaną o ogromnych zasięgu. W niniejszym artykule przedstawiono jeden z takich przypadków, gdzie w jednej z kopalni węgla kamiennego wskutek niekontrolowanego przemieszczenia się części lunety wentylacyjnej, która jednocześnie stanowiła posadowienie dla dwóch słupów ram budynku nadszybia, mogło dojść do powstania dodatkowych naprężeń w elementach głowicy szybowej oraz samej obudowy szybowej. Przeprowadzone przez autorów badania obejmujące opis i analizę stanu istniejącego wraz z dokumentacją fotograficzną oraz kontrolne obliczenia statyczno-wytrzymałościowe głowicy szybowej

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uwzględniające niezamierzone obciążenia wyjątkowe pozwoliły ocenić realny stopień zagrożenia dla obiektów szybowych oraz jego infrastruktury.

Na podstawie przeprowadzonej wizji lokalnej, która obejmowała swoim zakresem obszar bezpośredni wokół analizowanego szybu, kanału wentylacyjnego i głowicy szybowej, stwierdzono niewielkie przemieszczenia z rotacją części L-2 lunety wentylacyjnej zauważalne na łączeniach dylatacyjnych, pionowe pęknięcia na łączach dylatacyjnych poszczególnych części lunety wentylacyjnej, przemieszczenie pionowe części L-1 lunety wentylacyjnej względem głowicy szybowej. Na podstawie przeprowadzonej analizy uszkodzeń założono, że czynniki wywołujące przemieszczania się poszczególnych elementów kanału wentylacyjnego ustabilizowały się czego potwierdzeniem był brak uszkodzeń plomb. Dodatkowym potwierdzeniem stabilizacji ewentualnych zjawisk wywołujących przemieszczenia się kanału wentylacyjnego były wyniki prowadzonych cyklicznie pomiarów geodezyjnych wychyleń trzonu prowadniczego i wieży szybowej.

Z obudowy głowicy szybu oraz lunety wentylacyjnej pobrano 5 rdzeni, z których wycięto łącznie 11 próbek poddanych następnie badaniom wytrzymałościowym w prasie hydraulicznej. Na podstawie uzyskanych wyników badań laboratoryjnych stwierdzono, że parametry materiału kanału wentylacyjnego są znacznie gorsze od własności wytrzymałościowych materiału obudowy szybowej. Średnie wytrzymałości na ściskanie i rozciąganie materiału kanału wentylacyjnego wyniosły odpowiednio 12,07 MPa i 2,23 MPa. Natomiast średnie wytrzymałości na ściskanie i rozciąganie materiału obudowy szybowej wyniosły odpowiednio 25,42 MPa i 2,28 MPa.

Zaznaczyć należy, że ze względu na niewielką liczbę próbek uzyskane wartości wytrzymałości na ściskanie i rozciąganie materiału należy traktować jako szacunkowe. Ponadto podkreślić należy, że konstrukcja głowicy szybowej jak i kanału wentylacyjnego według archiwalnej dokumentacji wykonana zostało jako konstrukcja żelbetowa, zatem uzyskane wyniki nie można odnosić do wytrzymałości całej konstrukcji.

W celu określenia wpływu obciążenia pochodzącego od kanału wentylacyjnego na głowicę szybu zostały przeprowadzone obliczenia numeryczne metodą elementów skończonych przy użyciu programu Autodesk Robot Structural Analysis Professional 2013. Obliczenia te pozwoliły określić rozkład naprężeń w głowicy i obudowie szybowej wywołany obciążeniami oddziałującymi podczas normalnej eksploatacji w/w obiektów oraz obciążeniem wyjątkowym. Obliczenia te przeprowadzono w dwóch etapach:

- etap I – obejmujący głowicę szybową,
- etap II – obejmujący obudowę szybową.

Uzyskane wyniki rozkładu naprężeń normalnych w kierunkach x, y, z pozwoliły określić mapę zredukowanych naprężeń występujących w głowicy i obudowie szybowej według hipotezy niezmiennika tensora $I1$. W hipotezie tej pierwszy niezmiennik tensora wyznaczany jest ze wzoru:

$$I1 = \sigma_1 + \sigma_2 + \sigma_3 = +\sigma_{yy} + \sigma_{zz} \tag{1}$$

z kolei drugi niezmiennik jest równy:

$$I2 = 0{,}5[(\sigma_{xx} - p)^2 + (\sigma_{yy} - p)^2 + (\sigma_{zz} - p)^2] + \tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2 \tag{2}$$

gdzie: $p = I1/3$ – naprężenie średnie.

Na podstawie przeprowadzonych obliczeń stwierdzono, że maksymalne wartości zredukowanych naprężeń ściskających w głowicy szybowej nie przekraczają 1,35 MPa, natomiast maksymalne wartości zredukowanych naprężeń rozciągających wynoszą 3,21 MPa. Naprężenia rozciągające o tej wartości występują tylko lokalnie w miejscu oparcia kanału wentylacyjnego na głowicy szybowej.

W przypadku obudowy szybowej maksymalne wartości zredukowanych naprężeń ściskających wynoszą 1,1 MPa. Z kolei zredukowane wartości naprężeń rozciągających nie przekraczają 0,61 MPa. Należy podkreślić, że uzyskane wartości zredukowanych naprężeń zarówno ściskających jak i rozciągających nie przekroczyły wytrzymałości materiału z jakiego jest wykonana obudowa szybowa.

Na podstawie przeprowadzonej analizy obejmującej opis i ocenę stanu istniejącego wraz z dokumentacją fotograficzną oraz kontrolne obliczenia statyczno-wytrzymałościowe głowicy szybowej uwzględniające niezamierzone obciążenia wyjątkowe pozwoliły stwierdzić, że zarówno głowica jak i obudowa szybowa są w stanie przenieść dodatkowe obciążenie pochodzące od kanału wentylacyjnego. Należy jednak prowadzić stały monitoring przemieszczania się poszczególnych elementów kanału wentylacyjnego poprzez obserwację zamontowanych plomb oraz analizę wyników pomiarów geodezyjnych wychylenia trzonu prowadniczego i wieży szybowej. Zaleca się również prowadzenie stałego monitoringu odkształceń gruntu.

Słowa kluczowe: głowica szybowa, ocena nośności, budownictwo górnicze, diagnostyka konstrukcji

1. Introduction

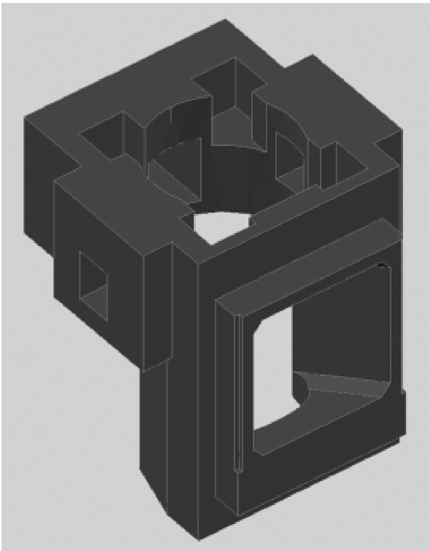
Shaft objects form a very essential role in the whole extraction process of every mine. Due to their significance shaft objects and their infrastructure require specific supervision in the scope of technical condition, which not only influences safety of users but, above all, the possibility of continually carrying out technological processes which enable mining extraction. Even slight interference in the scope of using shafts objects can cause complete paralysis in the area of current mining operations. For this reason, it is essential to maintain such objects in appropriate technical condition which requires continuous monitoring of its behavior under the influence of static and dynamic loads. In case of any abnormalities which could lead to breakdowns of the analyzed objects, it is necessary to carry out immediate remedial action enabling proper operational use. The lack of appropriate corrective and protective action can lead to a construction breakdown of enormous extent, as shown in Fig. 1.

Fig. 1. Construction failure on a shaft object caused by the lack of corrective action

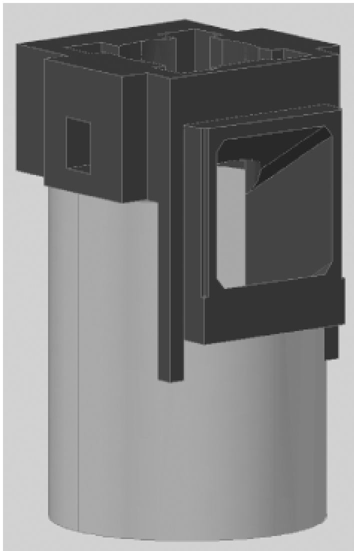
A similar situation, though of a lesser extent, was recorded in one of the coal mines located in Upper Silesia. In the coal mine in question the consequence of uncontrolled displacement of part of the ventilation telescope, which simultaneously formed the foundation for two frame posts of the shaft brow building, could have caused additional stress in the elements of the shaft collar as well as the shaft support structure itself. Research carried out by the authors covering the description and analysis of the current condition together with photographic records and calculations of the static resistance of the shaft collar taking into consideration the unintended exceptional load, allowed for the evaluation of the practical degree of danger for shaft objects as well as their infrastructure.

2. Characteristics of a shaft collar and ventilation drift

The original shape of the shaft collar was difficult to define due to the lack of appropriate documentation in this respect. Construction of the ventilation drift in its present form was carried out in the 1970s, which could have caused the necessity to ultimately upgrade the shaft collar with pipe-cable duct inlets. For this purpose, a partial demolition of the old collar was carried out, after which a new reinforced concrete construction was built, as presented in Fig. 2.2, the geometry of which is presented in Fig. 2a. The new construction of the shaft collar is based directly on the bricklaying of the shaft support structure, which in this place has a thickness of about 20 m. The method in which the collar is placed on the shaft support structure is presented in Fig. 2b.



a



b

Fig. 2. General view of the shaft collar a) Geometry of the reinforced concrete construction of the shaft collar b) Method of placing the shaft collar on the shaft support structure

The ventilation telescope consists of two parts. The first part (L-1) is directly adjacent to the shaft collar at an angle of 30° and rises to the second level of part L-2. Individual parts of the ventilation telescope as well as the shaft collar have been dilated from each other. Due to wet rocks of low physical and mechanical parameters covering this area, construction of the ventilation drift was carried out using the freezing method. Individual parts of the ventilation drift, just as in the case of the shaft collar, have been carried out with a reinforced concrete construction.

3. Hydrological conditions in the shaft area

In the area of the quaternary layers of the analyzed shaft there is one water-bearing level in sand and gravel in the free surface of water. In the area of the shaft the quaternary water-bearing level is +248.0 m above sea level. This level is of low abundance in water and its efficiency is to 0.5 m^3/min.

In the lower deposing layers of Miocene loam, insert dust from heavily watered sand and gravel is present to a depth of approximately 27.0 m. However, there is no data on the abundance of these levels. Deeper layers are filled with water impermeable and hard plasticity loams. Residual coal at a depth of approximately 46.0 meters is very irregular. The roof layers are formed by sandstone waste and conglomerate. During shaft sinking, large inflows of water, in the order of 3.0 m^3/min, were found at this level. Carboniferous and tertiary layers were heavily watered during initial exploration and have currently been seriously depleted as a result of a high concentration of mining operations.

There were no inflows at the level of 200 m. However, at the level of 400 m there is a modest total inflow of 1.0 m^3/min. The level of 600 m is barely recognizable and layers of sandstone and conglomerates linger on seams 507 to 510 and are heavily watered.

Carboniferous waters are highly mineralized and in relation to concrete and mortar have an average aggression taking into account the catalytic impact of various compounds on the crystallography of cement.

4. Geology and Engineering and the impact of mining on the shaft support structure

Engineering and geological examinations carried out in the area of the shaft between 1971 and 1972, allowed for the distinction of three geotechnical levels in over layers of different parameters and a series of carbon, as follows:

- Level I – to a depth of about 7.0 m, which form the quaternary, hard plasticity dust interlayers with clay sanding plasticity,
- Level II – consisting of sand and gravel which is averagely concentrated, waterlogged and prone to soaking,
- Level III – composed of hard plasticity Miocene loams with local pockets of dust, waterlogged with sand of a quicksand characteristic with a thickness of 20.0 m,
- Level IV – which forms a complex of firm carboniferous rocks of ore and anticline formed from sandstone, sandy shale and coal layers.

On the basis of mining and geological documentation for the analyzed shaft, it can be stated that both the shaft and objects by the shaft are protected by a pillar securing these objects from the effects of mining damage larger than for category II. In another case there could be additional stress around the shaft depending on the depth of mining activity around the pillar, as was widely presented by Majcherczyk and Lubryka (2003).

5. Macroscopic evaluation of the shaft collar and the ventilation duct and associated damage

On the basis of a local inspection which in its scope included the area directly around the shaft, the ventilation duct and shaft collar, stated:

- slight displacement of the rotating part of the L-2 ventilation drift noticeable on expansion joints – Fig. 3a,
- vertical cracks on the expansion joints and of individual parts of the ventilation drift,
- lack of progress on the delamination of expansion joints on the basis of installed seals – Fig. 3b,
- displacement of the vertical part of the L-1 ventilation drift relative to the shaft collar – Fig. 4,
- no damage to the shaft collar in the breakout location under the ventilation telescope,
- loosening of wall elements in shaft top undermining the new ground beam,
- damage to the shaft top corner of the wall of the building.

a b

Fig. 3. Recorded damage a) displacement of ventilation head, b) view of the installed seal

Fig. 4. Registered displacement of ventilation drift relative to the shaft support structure

On the basis of observation carried out it was found that the resulting damage could have been caused by uncontrolled displacement and rotation of the individual parts of the ventilation drift. The placed seals allowed for constant monitoring of the possible increase in the rate of delamination of the registered cracks and damage. On the basis of the analysis of damage it was assumed that factors triggering the displacement of individual elements of the ventilation duct stabilized, which was confirmed by the lack of damage to the seals. Additional confirmation of the stabilization of possible effects causing displacement of the ventilation duct were the results of periodic surveying of shaft deflection guides and hoist tower. Table 1 lists the results of measurements of a given year, which clearly shows the lack of effects causing further displacement of the rock mass in this area or that this phenomena is of a relatively small range. The obtained results of the guide shaft deflection and hoist tower are within the limits of the margin of error.

TABLE 1

Results of deflection measurements of the hoist tower

Date of measurement	Average incidental deflection of the hoist tower	Permissible deflection of the hoist tower
18.03.2010 r.	41,60 mm	47,00 mm
22.04.2010 r.	39,10 mm	47,00 mm
26.05.2010 r.	38,70 mm	47,00 mm
15.11.2010 r.	37,20 mm	47,00 mm
21.04.2011 r.	39,10 mm	47,00 mm

7. The results of core samples taken from the support structure

Five core samples were taken from the shaft collar support structure and ventilation drift, the location of which is marked in Fig. 5. A total of eleven samples were cut from the cores and subsequently tested for durability in a hydraulic press. The results obtained are shown in Table 2.

TABLE 2

Results of laboratory tests of samples taken from the shaft brickwork

Sample no.	Compression strength [MPa]	Tension strength [MPa]
1/1	11.58	–
1/2	–	1.79
2/1	–	2.68
2/2	12.57	–
3/1	26.84	–
3/2	–	1.75
4/1	29.61	–
4/2	–	2.50
5/1	23.12	–
5/2	–	2.58
5/3	22.10	–

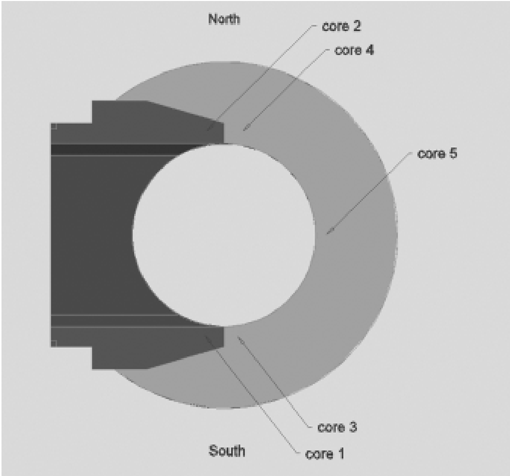


Fig. 5. Location of core drilling taken

Based on the results of laboratory tests, it was stated that the material parameters of the ventilation duct are substantially worse than the resistance properties of the material of the shaft support structure. Average compression and tension resistance of the ventilation duct material amounted to 12.07 MPa and 2.23 MPa, respectively. In contrast, the average compression and tension strength of the shaft support structure material amounted to 25.42 MPa and 2.28 MPa.

It should be noted that due to the small number of samples obtained, strength values on compression and expansion of the material should be treated as estimates. In addition, it should be noted that the design of the shaft collar and the ventilation duct according to archival documentation was carried out as a reinforced concrete structure, so the results obtained cannot be extrapolated to the strength of the whole structure.

8. Evaluation of the current load capacity and stability of the shaft collar

The analyzed construction consists of the shaft collar leaning directly on the shaft support structure. The shaft collar was made of a monolithic reinforced concrete element; however, the shaft has a brick structure support based on cement mortar. The ventilation duct, made of reinforced concrete segments, adjoins the shaft collar with a mutual dilatation from each other (Fig. 6). As a result of displacement of the first segment of the ventilation telescope relative to the shaft collar, it was stated that the possibility of transferring the additional load was not taken into consideration during the design stage. Due to the lack of accurate data in respect of the displacement of the ventilation drift segment and condition of the soil underneath the base plate, calculation of the most adverse case impact of the ventilation drift to the shaft collar had to be accepted. It was assumed that as a result of subsidence and rotation, the first segment of the ventilation drift would transfer horizontal loads to the shaft collar only via the face of the floor slab.

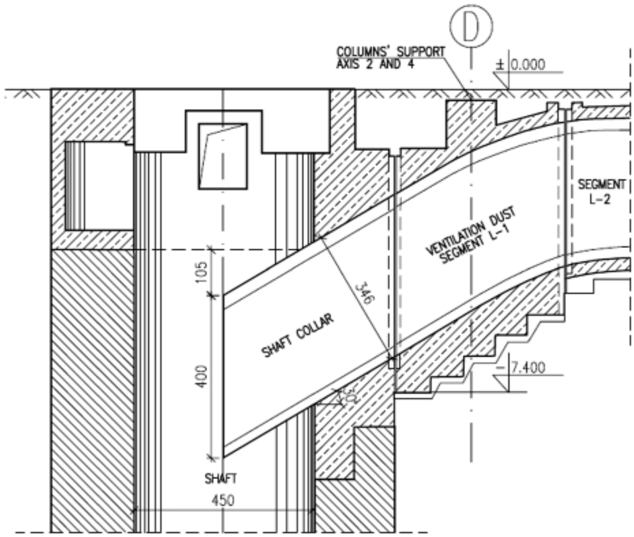


Fig. 6. Longitudinal section through the ventilation duct and shaft collar

On the basis of analysis carried out in respect of the static impact on a segment of the ventilation drift, exceptional loads working on the shaft collar were designated, which took into consideration:

- reaction of the main support pillars of the shaft top building,
- weight load from the bare weight of the construction of the first segment of the ventilation drift,
- technological load,
- surcharged load.

In order to determine the effect of the load deriving from the ventilation duct at the shaft collar numerical calculations were carried out with the finite element method using the Autodesk Robot Structural Analysis Professional 2013 program. The finite element method, alongside analytical methods (Bulychev, 2008), is commonly used both for the design of these types of objects as well as to analyze their behavior under the influence of various factors (Reś, 2009).

These calculations enabled determination of stress patterns in the collar as well as in the shaft support structure induced by loads during normal mining operations of the aforementioned objects as well as in the event of an exceptional load. These calculations were carried out in two stages:

- Stage I – encompassing the shaft collar
- Stage II – encompassing the shaft support structure.

The results of normal stress patterns obtained in the *x*, *y*, *z* directions enabled the possibility of determining the map of reduced stress occurring in the collar and shaft support structure according to the tensor invariant I1 hypothesis. In the first hypothesis the invariant tensor is determined by the following formula:

$$I1 = \sigma_1 + \sigma_2 + \sigma_3 = +\sigma_{yy} + \sigma_{zz} \quad (1)$$

in turn, the second invariant is equal to:

$$I2 = 0{,}5[(\sigma_{xx} - p)^2 + (\sigma_{yy} - p)^2 + (\sigma_{zz} - p)^2] + \tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2 \quad (2)$$

whereby: $p = I1/3$ – is mean stress.

Distribution of reduced stress during normal exploitation operation and exceptional load for the shaft collar is shown in Fig. 7 and the shaft support structure in Fig. 8

On the basis of calculations, it was ascertained that the maximum value of the reduced compressive stress in the shaft collar does not exceed 1.35 MPa and that the reduced value of the maximum tensile stress is 3.21 MPa. The tensile stress of this value occurs only locally at the place of support of the ventilation channel on the shaft collar.

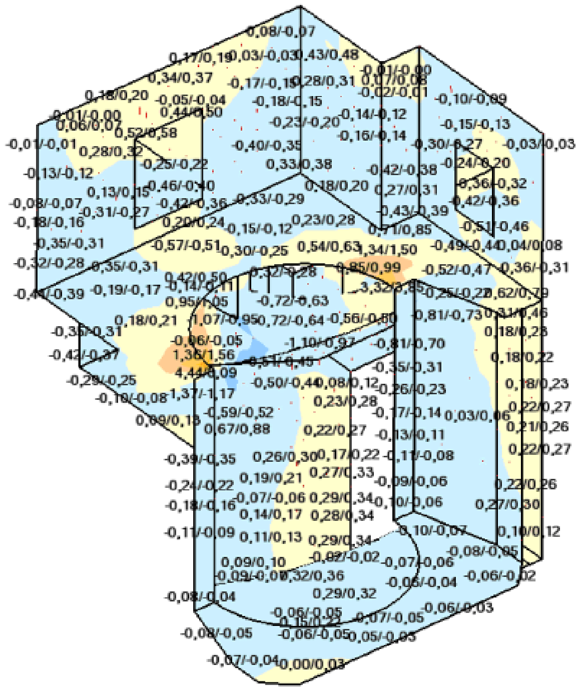


Fig. 7. Map of the reduced normal stress [MPa] occurring in the collar
– a view from the side of the shaft

In the case of the shaft support structure the maximum value of the reduced compressive stress is 1.1 MPa. In turn, the reduced tensile stress values do not exceed 0.61 MPa. It should be emphasized that the values obtained for both the reduced compressive stress and the tensile stress do not exceed the strength of the material from which the shaft support structure is made.

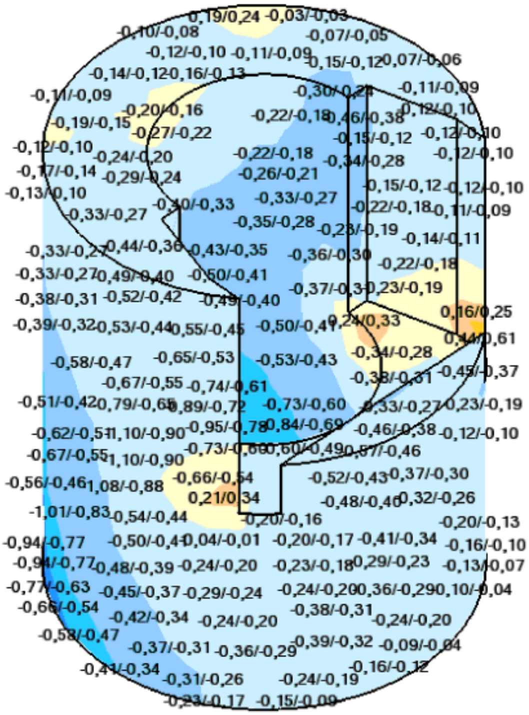


Fig. 8. Map of the reduced normal stress [MPa] occurring in the shaft support structure – view from the canal shaft

9. Conclusions

On the basis of analysis including a description and evaluation of the existing situation in respect of photographic documentation and control calculations as well as the static-strength of the shaft collar taking into account the exceptional load, it has been possible to draw the following conclusions:

1. The additional load on the shaft collar was caused by the weight of the one of the parts of the ventilation drift, which moves uncontrollably as a result of instability of the subsoil. This may be caused by e.g. tunneling, excessive consolidation of soil, or a change of water conditions in the vicinity of the shaft. These phenomena have been widely presented, amongst others, by Wiłun (2010) and Pisarczyk (2001).
2. Result reports of surveys of the guide shaft deflection and hoist tower clearly indicate the lack of any occurrence causing further displacement of the rock mass in this region or that it has a relatively small range. It can be assumed that the factors causing the displacement of the various components of the ventilation duct have stabilized, which in turn is confirmed by the lack of damage to the seals.
3. The maximum value of compressive stress in the reduced shaft collar has been determined on the basis of numerical calculations and did not exceed 1.35 MPa and occur locally at

the base of the shaft collar of the shaft support structure. The maximum value of reduced tensile stress in the analyzed element is 3.21 MPa and occurs only locally at the site of the ventilation channel on the back of the shaft collar. It should be noted that the shaft collar was made as a reinforced concrete structure and the location where tensile stress was applied and steel inserts have been used – in the form of a reinforced concrete bar.

4. Based on the results of numerical calculations it can be concluded that the critical stress in the shaft support structure is compressive stresses with a maximum value of 1.1 MPa. In turn, the reduced tensile stress value of the shaft in the support structure does not exceed 0.61 MPa. The obtained values of reduced stress, both compressive and tensile loads do not exceed the strength of the material from which the shaft support structure is made.
5. On the basis of the analysis carried out it can be concluded that both the collar and shaft support structure are able to transfer the additional load coming from the ventilation duct. It is necessary to carry out continuous monitoring of the displacement of individual elements of the ventilation duct installed by observing seals and the analysis of the results of surveys of the guide shaft deflection and hoist tower. It is also recommended to carry out constant monitoring of ground deformation by using special measures, which are described, amongst others, in the work of Gustkiewicz et al. (2004).

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