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# Application of composite materials in underground mining industry – fore-shaft closing platform

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Abstract:

According to Polish law regulations, fore-shaft in underground mines in process of its liquidation must be either filled with bulk material or closed with double-deck platform on its top. As liquidation by closing is cheaper and easier than filling, steel closing platforms are typically used for this purpose. However, steel price fluctuations due to COVID-19 pandemic together with rapid development of composite materials, make application of composite structure a tempting direction. The article presents a design of composite double-deck closing platform for fore-shaft liquidation in one of the collieries located in the eastern area of Silesian Coal Basin. Presented solution was thoroughly calculated and tested and then assembled in the mine. The aim of the research was to prove applicability of composite structures in underground mines with maintaining proper level of safety.

Keywords: composite materials, fore-shaft liquidation, shaft platform, mine liquidation

## 1. Introduction

Safety of vertical mine workings – shafts and fore-shafts – in underground mines is a key issue during their whole lifecycle – from sinking, through their operation, to liquidation. Every mine working may be a threat for work and public safety, even after its liquidation. Thus, the issue of mine workings liquidation process itself is a subject for strict law regulations and numerous research and articles, concerning liquidation planning and monitoring of the process, as well as effects of the liquidation [1-6]. The most frequently studied threats and issues connected with shaft and mine liquidation are -geological and hydrogeological [7-12], economic and social [13-16], environmental [17-20] and technological issues [4, 21-23].

Shaft liquidation, similarly to its sinking and maintenance, is extremely expensive, thus such decision is always thoroughly analyzed and process itself is meticulously planned. Similar case is a liquidation of fore-shafts, vertical mine workings of different functions, usually transport and ventilation, having no connection to the surface. However, due to smaller lengths and cross-section dimensions, scale effect occurs.

Law regulations in mining in Poland precisely regulate rules of shaft and fore-shaft liquidation. According to Geological and Mining Law Regulation, shaft or fore-shaft has to be filled with material suited for geological and hydrogeological conditions and natural hazards occurrence [1]. Ventilation type of the shaft has to be taken into consideration as well, such as its equipment and connections with other mine workings.

Due to character of fore-shafts, the Regulation provides different liquidation ways of these vertical workings. It allows for a closure of a fore-shaft using a two-deck platform on its top level together with its isolation from other existing mine workings. Isolation is realized using durable barriers constructed of non-combustible materials in mine workings connected with the fore-shaft on each level. However, such a method of fore-shaft liquidation requires expert's positive opinion.

Fore-shaft liquidation using closing platform is particularly common in operating underground mines, where only the area of the fore-shaft is closed, due to different reasons. The main reason of fore-shaft liquidation is its functionality loss. It might be also caused by significant damages of the fore-shaft lining to an extent that makes it uneconomical to repair. Shaft liquidation by its closure is, for obvious reasons, significantly cheaper than "traditional" solution, i.e. filling fore-shaft. It requires less material for platform and barrier construction instead of filling, and less man-hours for the process to be conducted. Closing platforms are usually made of steel, which is generally the most popular material in Polish mining industry, due to numerous advantages. However, steel does have some disadvantages.

The greatest disadvantage of steel, in terms of mining industry, is its significant weight and susceptibility to corrosion. Especially in the case of constructions or support in workings designed for a long period of time. Whereas its high weight might be a difficulty in case of transport to remote and inaccessible areas and workings, where ability to use suspended or floor railway is limited or even impossible. In such cases, even manual transport might be a problem, especially if transported elements are of significant sizes. It has to be considered an issue in terms of fore-shaft closing platforms, as liquidated fore-shafts are usually located in old and abandoned areas of the mine, where dimensions of workings' cross-sections are usually reduced. Thus, transport of platform's element and their assembling in conditions of limited space are usually the greatest problem in the process of fore-shaft liquidation [24].

A method for overcoming these problems includes composite materials. In recent years they are gaining popularity in almost every branch of engineering, such as civil engineering, mining, mechanics, aeronautics and so on [24, 25]. Composite materials can be made, using different methods and technics, from different components. Their strength parameters are similar to steel, with significantly lower weight. The process of composite elements allows for a great flexibility both in terms of composite strength parameters and in shape and dimensions of elements produced, since composite elements can be formed into almost any shape. Also, their treatment is easier than in the case of steel elements. The main disadvantage of composite materials is their price. However, in a long time period, application of composites instead of steel might become profitable. Moreover, high steel

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prices and their large fluctuations due to COVID-19 pandemic make composite materials more tempting for mines and other potential buyers [24, 26-29].

It should be also noted, that composite materials are already in common use in underground mines. However, they are rarely spotted as construction elements. Composite materials are usually used for mesh-wire lagging protecting roofs and sidewalls and in bolts [24, 26, 28, 29].

The article presents an example of composite materials application for construction of fore-shaft closing platform. This construction was designed for conditions of underground coal mine located in the Silesian Coal Basin.

## 2. Geological and mining conditions in the vicinity of the inter-level fore-shaft

### 2.1. Fore-shaft parameters

The inter-level ventilation shaft is located in the north-eastern part of the Mysłowice-Wesoła colliery, located in the east of the Silesian Coal Basin. The fore-shaft was sunk in 1990s using traditional drill and blast mining method. It connects levels 465 and 665 m and its total length is 202.15 m. Parameters of the fore-shaft are presented in Table 1.

**Table 1.** Inter-level fore-shaft parameters

| Parameter | Value |
|---|---|
| Top level depth | 182.50 m below sea level |
| Bottom level depth | 384.65 m below sea level |
| Total length | 202.15 m |
| Diameter | 4.5 m |
| Function | Ventilation - upcast |
| Equipment | Ladder compartment<br>Compressed-air pipeline ϕ150 mm<br>Downcast water pipeline ϕ150 mm<br>Goaf reconsolidation medium pipeline ϕ185 mm<br>Methane pipeline ϕ325 mm |

The fore-shaft has following connections with mine workings:

– at the level 465 m (depth: 492.1 m) – double-sided inlet directed south and north,
– at the level 664 m (depth: 699.2 m) – single inlet directed west.

The fore-shaft is protected with single-layer lining of variable thickness, made of concrete blocks. According to the original project of the lining BSz1 concrete blocks of class [30-31] and M12 class mortar. The fore-shaft lining is presented in Fig. 1. Its parameters are as follows:

– 492.1 ÷ 496.6 m – concrete blocks lining with thickness of 0.58 m (two blocks thick),
– 496.6 ÷ 699.2 m – concrete blocks lining with thickness of 0.44 m (1.5 blocks thick),
– in the sections located in coal seams the thickness of the lining equals 0.74 m (2.5 blocks thick).

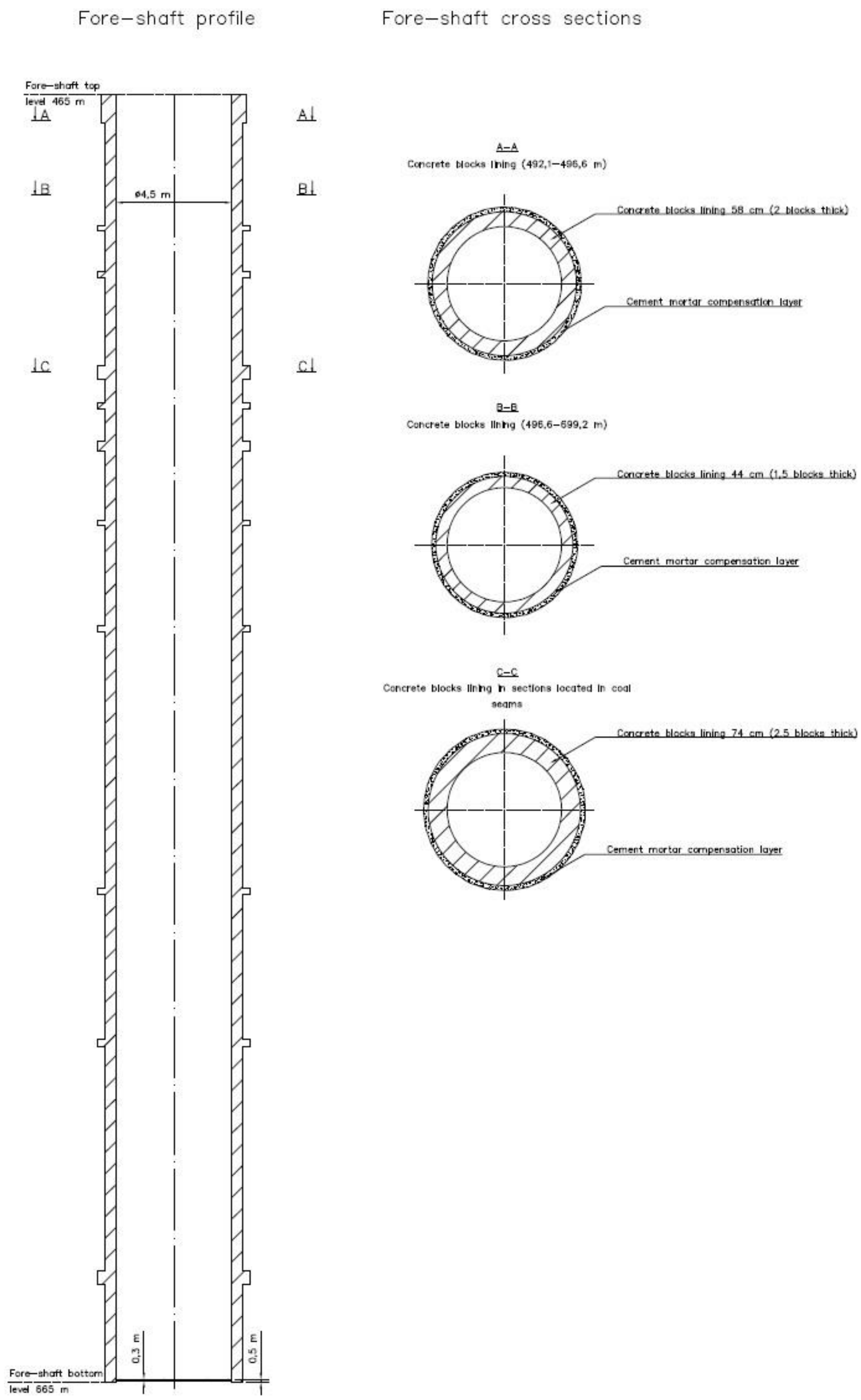


**Fig. 1.** Inter-level ventilation fore-shaft lining

Due to significant fore-shaft lining damages in the vicinity of the inlet at the level 465 m, the following repair work was carried out in 2007:

- fore-shaft lining replacement on the length of 6 m below the level of 465 m,
- replacement of steel protections in the inlet at the level of 465 m,
- reconstruction of the lining above the fore-shaft collar,
- reconstruction of the drift at the level of 465 m.

Before the reconstruction of the drift, floor heave reaching 1.0÷1.5 m occurred in this area. According to the data gathered by the mine staff, similar phenomenon can be spotted in the drift currently.

## 2.2. Geological and hydrogeological conditions in the vicinity of the inter-level fore-shaft

Vicinity of the fore-shaft comprises basically two formations:

- mudstone formation – between the depth of 0 and 72 m; comprising layers of shale, mudstone, coal seams and sandstone;
- sandstone formation – between the depth of 72 and 202 m; comprising layers of sandstone, sandy shale and coal seams.

In the vicinity of the level 665 m layers of shale, coal and sandstone occur.

In the upper part of geological profile (in the vicinity of the level 465 m) numerous coal seams occur, however their thickness rarely exceeds 1 m. Only exceptions are seams 405/1 at the depth of 42.8 m with thickness of 1.8 m and 416 at the depth of 171 m and thickness of 2.0 m. No tectonic faults were found in the profile of the fore-shaft, however rock layers located between the depth of 117 and 143 m are fractured.

Rock mass in the area of the fore-shaft is dewatered by roadways located at the levels 465 and 665 m. The only water and gas horizons occur at the depth interval of 120÷143 m. Thus, water and gas inflows into the fore-shaft are connected with fractured rock layers. There is no water inflow at the bottom level of the fore-shaft. However, it should be noted that local water inflows from behind the shaft lining occur in the fore-shaft.

Intense longwall exploitation of seams 349, 401, 405/1, 405/2 and 510 was carried out in the vicinity of the inter-level ventilation shaft, both before and after it was sunk. Coal seams 349, 401, 405/1 and 405/2 were exploited using longwall caving. Thickness of mined seams varies between 1.2 and 2.6 m. Minimal horizontal distance between the fore-shaft and longwall was 130 m east and 40 m west, both in the seam 349, exploited between 1974 and 1978, located about 150 m above the fore-shaft top level.

Exploitation of the seam 510 is worth noting. It was carried out between 1999 and 2011 using longwall caving. The seam 510 is located from 15 to 30 m below the fore-shaft bottom level and the closest longwall was located in the distance of 110 m from the fore-shaft. Thickness of the seam 510 is 2.2÷3.5 m.

It can be assumed, that coal mining in the vicinity of the inter-level ventilation fore-shaft, especially exploitation of the seam 510 negatively affected lining of the fore-shaft. Effects of this influence were reconstructions of the shaft and neighbouring workings.

# 3. Composite closing platform

Composite closing platform was designed for liquidation of inter-level ventilation fore-shaft by closing its top at the level of 465 m. The other elements of the fore-shaft closure are explosion-proof barriers made of fast-curing binder. Due to high convergence of workings of the level of 465 m transport of the platform is impossible. Thus, the platform was designed as a bolted joint construction. It can be assembled in any chosen place and it was designed to be transported through the fore-shaft using a winder installed above the fore-shaft top.

## 3.1. Platform characteristics

Designed platform consists of two decks. The first one of them is located directly on the top of the fore-shaft, fully covering it. The other deck is situated 500 mm above the lower deck to which it is assembled. Both decks form bolt-connected and compact space frame.

The platform consists of the following elements:

- supporting structure,
- locks,
- cover,
- mountings and joints.

The supporting structure is entirely made of C-shape composite profiles NKG2006010. Profiles were connected using angle mountings and bolts. The locks are also made of NKG2006010 C-shape profile. They are designed to prevent movements of the platform, placed on the fore-shaft top. They

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are inserted into slots made in the fore-shaft lining and assembled to it at the distance of 200 mm. Cover is made of composite open grille (NKG type) with eyelet of 30 x 30 cm and thickness of 38 mm. Anti-slip grilles are assembled to both platform decks.

The only non-composite elements of the platform are steel mountings and joints. The mountings are used to connect the cover with supporting structure and connect elements to each other. Mountings and joints are made of S235JR type steel. All steel elements were galvanized. A diagram of the platform is shown in Fig. 2.

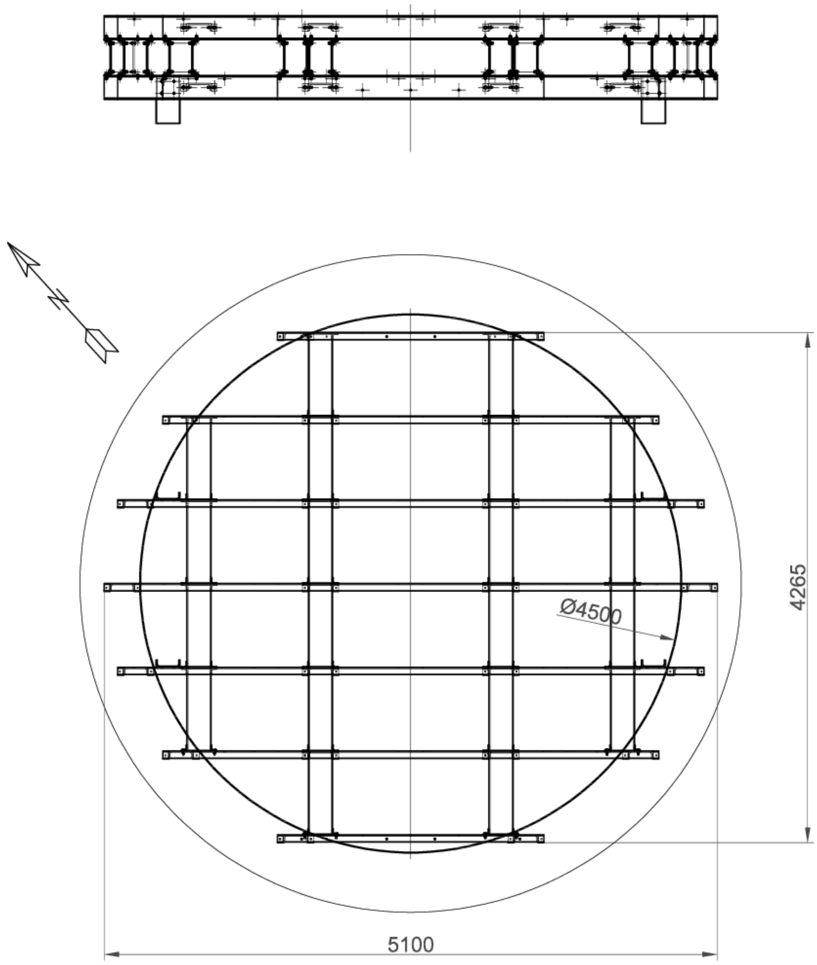


**Fig. 2.** A diagram of the platform construction

## 3.2. Calculations

The decks of the platform were designed for maximum load of 250 kg/m$^2$. Calculation tests of the platform were conducted with factor of safety n ≥ 6. Stress limit for composite elements, made of NKG material with tensile strength $R_m$ = 340 MPa, was assumed as:

$$k = \frac{Rm}{n} = \frac{340}{6} = 56.6\ MPa \qquad (1)$$

Static analysis was conducted using Autodesk Robot Structural Analysis Professional (RSAPRO) 2018 software. A general scheme of the platform is presented in Fig. 3. It was assumed that supporting structure is made of C-shape profiles C200 NKG C2006010 (Fig. 4). Technical characteristics of the profile is presented in Table 2. Table 3 presents strength and material parameters of the NKG material.

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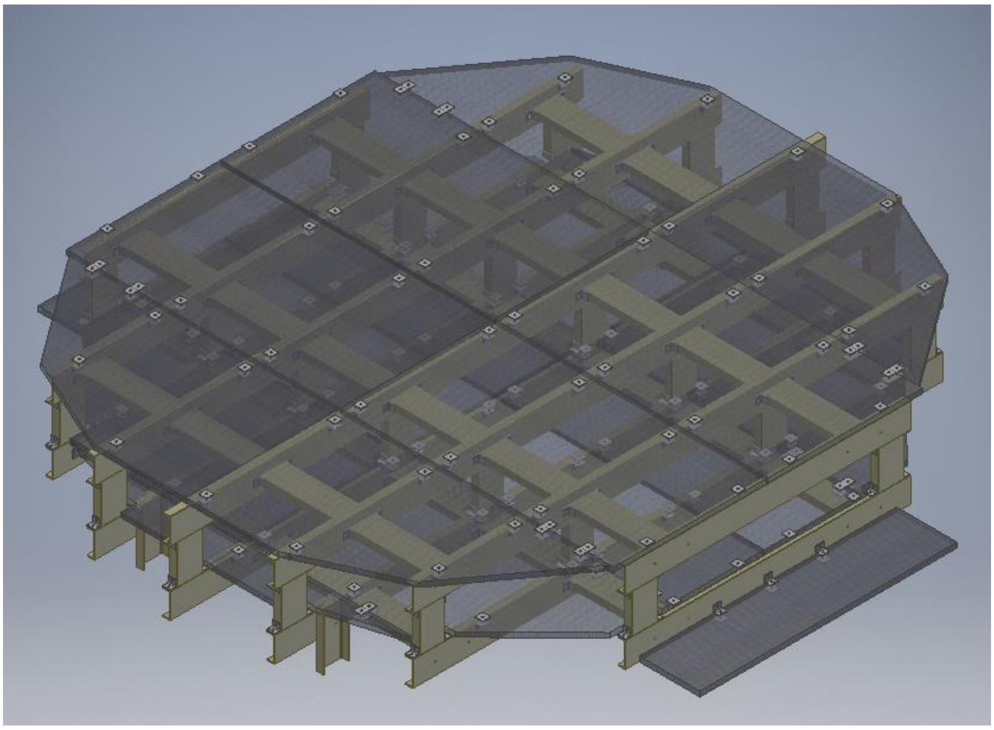

**Fig. 3.** A general scheme of the fore-shaft closing platform

**Table 2.** Technical characteristics of composite C-shape profile (supplier's data, according to [32])

| Mark | A, mm | B, mm | C, mm | D, mm | E, mm | Weight, kg/m |
|---|---|---|---|---|---|---|
| NKG C60505 | 60 | 50 | 5 | 2 | 7 | 0.85 |
| NKG C100405 | 100 | 40 | 5 | 6 | 8 | 1.8 |
| NKG C150506 | 100 | 50 | 6 | 8 | 2 | 1.9 |
| NKG C2006010 | 200 | 60 | 10 | 10 | 4 | 3.6 |
| NKG C2508015 | 250 | 80 | 15 | 15 | 2 | 8.0 |
| NKG C3009020 | 300 | 90 | 20 | 20 | 1 | 9.5 |
| NKG C35010025 | 350 | 100 | 25 | 25 | 1 | 11.0 |
| NKG C38012530 | 380 | 125 | 30 | 30 | 1 | 12.4 |

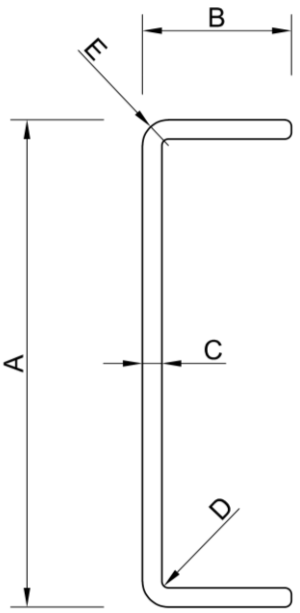


**Fig. 4.** Composite C-shape profile

**Table 3.** Parameters of the NKG composite material (supplier's data)

| Property | Test method | Value | Unit |
|---|---|---|---|
| Specific weight | ISO 1183/ASTM D 792 | 1.75 – 1.90 | $g/cm^3$ |
| Tensile strength | EN ISO 527-4 | 340 – 500 | MPa |
| Compressive strength | EN ISO 14126 | 350 – 400 | MPa |
| Shear strength | EN ISO 14130 | 25 – 30 | MPa |
| Flexural strength | EN ISO 14125 | 500 – 550 | MPa |
| Flexural modulus | EN ISO 14125 | 20 – 25 | GPa |

A truss model of the platform was developed and maximum stress was checked for the typical load for platforms in underground mines, which is equal P = 2.5 $kN/m^2$ and deadweight, including covers, which is equal Qp = 1 $kN/m^2$. All the loads act on the top deck of the platform. A truss model of the platform is presented in Fig. 5. It comprises a lattice, which is a combination of two platform decks, connected with C-profiles. Forces Pz, acting on the construction, are P = 2.5 $kN/m^2$ and Qp = 1 $kN/m^2$ and area of the platform's cross section is 15.9 $m^2$. The forces acting on the platform's construction are shown in Fig. 6.

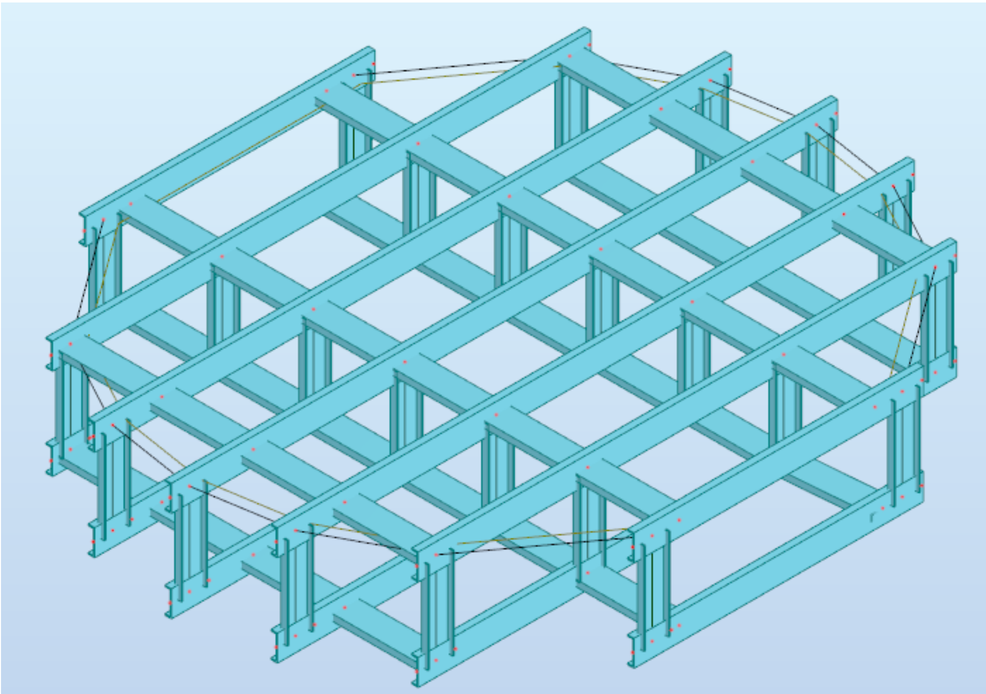

**Fig. 5.** Truss model of the fore-shaft closing platform developed in ROBOT software

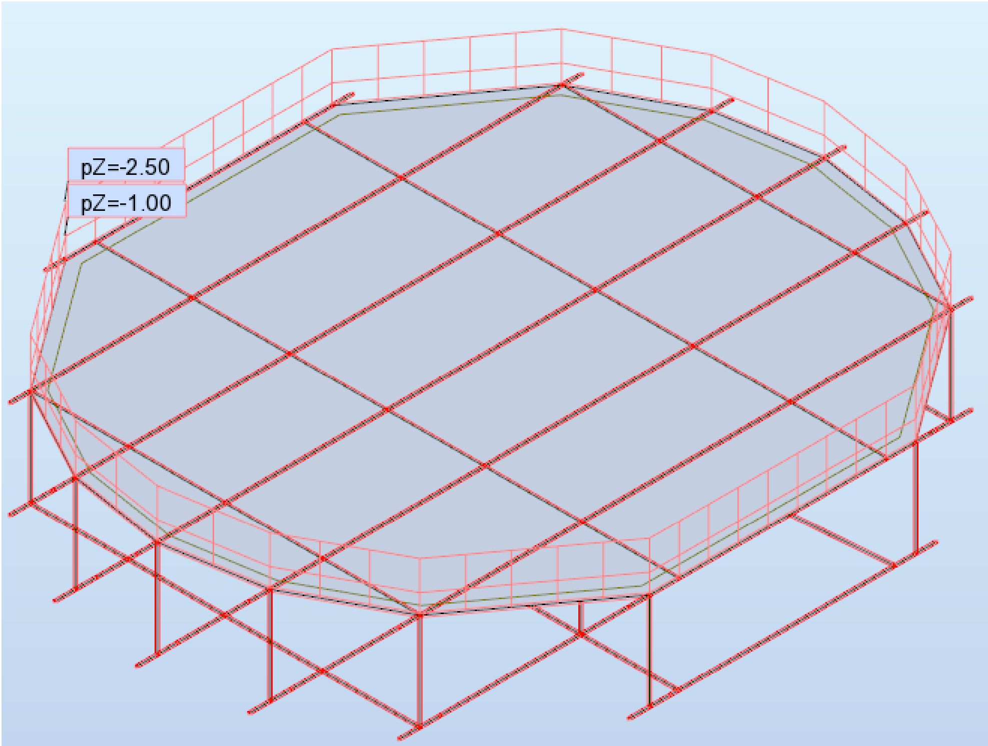


**Fig. 6.** Forces acting on the model (units: kN/m$^2$)

Stress in construction's elements was calculated basing on acting forces, comprising the deadweight multiplied by confidence factor kc = 1.3. Results revealed that maximum stress value is 18.41 MPa (Fig. 7). Moreover, stress in construction's fulcrums is between 12 and 14 MPa. Other stress values do not exceed 4 MPa.

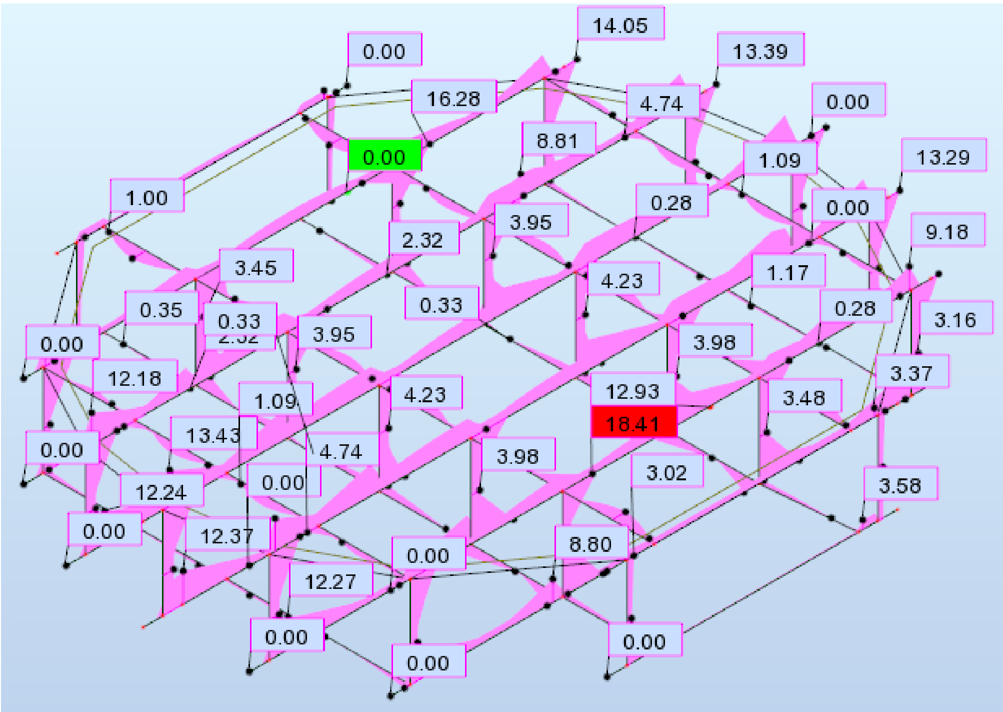


**Fig. 7.** Values of stress calculated (units: MPa)

Analysis of obtained results reveals that values of construction's stress are significantly smaller than the stress limit value, equal to 56.6. MPa. Values of support reactions are presented in Fig. 8 and in Table 4. Maximum value of support reaction is equal to 6.2 kN, with almost no bending moments.

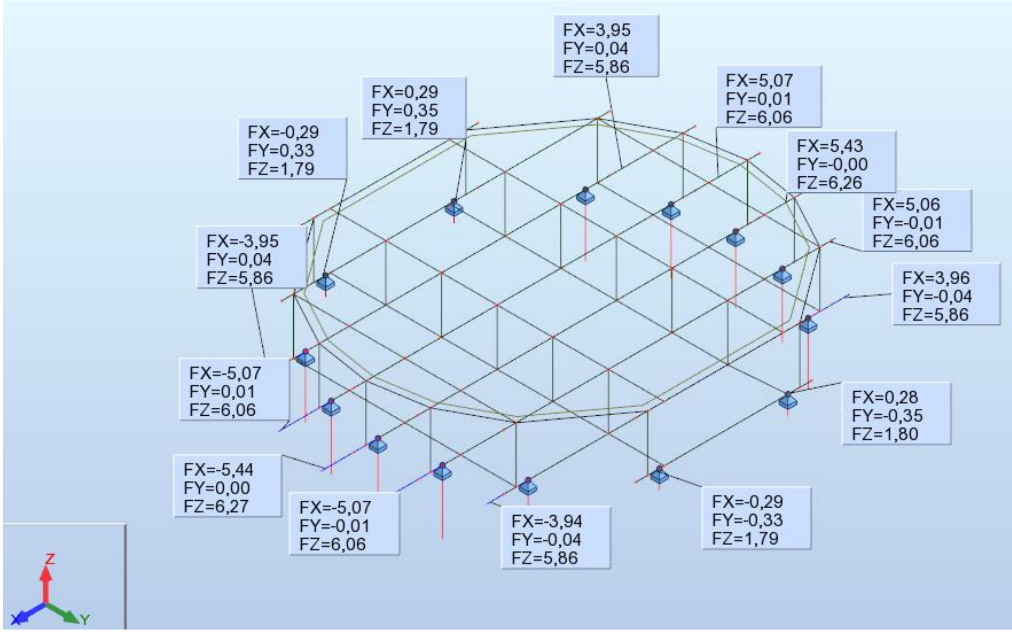


**Fig. 8.** Values of support reactions (units: kN)

**Table 4.** Values of support reactions

| Node/case | FX, kN | FY, kN | FZ, kN | MX, kNm | MY, kNm | MZ, kNm |
|---|---|---|---|---|---|---|
| 133/3 (K) | -3.95 | 0.04 | 5.86 | 0.00 | 0.00 | 0.00 |
| 134/3 (K) | -0.29 | 0.33 | 1.79 | 0.00 | 0.00 | 0.00 |
| 135/3 (K) | -5.07 | 0.01 | 6.06 | 0.00 | 0.00 | 0.00 |
| 136/3 (K) | -5.44 | 0.00 | 6.27 | 0.00 | 0.00 | 0.00 |
| 137/3 (K) | -5.07 | -0.01 | 6.06 | 0.00 | 0.00 | 0.00 |
| 138/3 (K) | -3.94 | -0.04 | 5.86 | 0.00 | 0.00 | 0.00 |
| 139/3 (K) | -0.29 | -0.33 | 1.79 | 0.00 | 0.00 | 0.00 |
| 140/3 (K) | 0.28 | -0.35 | 1.80 | 0.00 | 0.00 | 0.00 |
| 141/3 (K) | 3.96 | -0.04 | 5.86 | 0.00 | 0.00 | 0.00 |
| 142/3 (K) | 5.06 | -0.01 | 6.06 | 0.00 | 0.00 | 0.00 |
| 143/3 (K) | 5.43 | -0.00 | 6.26 | 0.00 | 0.00 | 0.00 |
| 144/3 (K) | 5.07 | 0.01 | 6.06 | 0.00 | 0.00 | 0.00 |
| 145/3 (K) | 3.95 | 0.04 | 5.86 | 0.00 | 0.00 | 0.00 |
| 146/3 (K) | 0.29 | 0.35 | 1.79 | 0.00 | 0.00 | 0.00 |

Then it can be concluded that the designed supporting structure is able to bear acting loads with maintaining the factor of safety $n \geq 6$.

## 4. Conclusions

The presented composite platform, designed and constructed for interlevel ventilation fore-shaft liquidation, meets safety requirements, in terms of material requirements (composite materials comply with legal safety requirements) and construction, which is confirmed by calculations presented in the previous section. It is absolutely crucial, as safety requirements must be fulfilled, to positively evaluate designed solution of fore-shaft liquidation, both during the process of liquidation itself and after it is finished.

An application of composite materials for a construction of the presented solution generates additional benefits, comparing to traditional steel platforms. Primarily, composites are resistant to aggressive atmosphere, contrary to steel. Estimated lifetime of composite platform greatly exceeds lifetime of steel constructions. In the presented case, it was significant to facilitate transport of the platform’s elements and their assembly. Another important factor was lower weight of the composite material. It was caused by significant degradation of neighbouring mine workings, causing in their cross-sections’ dimensions limitation. It should be noted, that it is a common problem in liquidated underground mine areas and workings.

The greatest disadvantage of composite materials is their high price. However, it should be taken into consideration that purchase price of the material is not tantamount to overall cost of production and maintenance of construction for underground mining, such as numerous types of platforms, including closing platforms for fore-shaft liquidation. In times of COVID-19 pandemic it is extremely hard to perform precise comparative analysis of steel and composite construction production costs, due to high and unstable steel prices. Moreover, the comparison of these costs should take into consideration not only costs of the material, but also transport costs, including both transport from the producer or supplier to the mine and underground transport or anti-corrosion protection costs, which is not necessary in the case of composite constructions. In the case of fore-shaft closing platforms maintenance costs are negligible, but they should be taken into account in the case of other structures. For now, it is difficult to conduct a fully reliable comparison due to lack of composite constructions in underground mines. However, comparing steel and composite elements that are already in use in mines (such as mesh-wire lagging and bolts), maintenance costs of composite structures are expected to be lower than in the case of steel constructions.

Other disadvantages of composite materials include problems concerning connecting elements with bolts and lack of experience in underground composite applications. Such a situation might cause resistance of miners or management of underground mines, however this attitude has changed recently.

Comparing pros and cons of composite materials in structures for underground mining and observing the market of composite materials, a number of composite constructions in the mining industry is expected to increase. It should be considered the right direction of development, especially due to practical and financial factors.

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