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Individual-portal support with a pre-tensioned canopy for a coal mine roadway junction

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Abstract: This paper presents an alternative model of individual-portal support structure with a pre-tensioned canopy for coal mine roadway junctions in the geological and mining conditions of underground mines in Vietnam. The aim of the research is to determine the bearing capacity of the individual-portal support structure with various configuration. For this purpose, an analysis of the rock mass behaviour around the three-way roadway junction was carried out using the difference element method-based programme (FLAC3D). Additionally, other analysis of the bearing capacity of the selected individual-portal support structure was also conducted using the finite element method-based programme (COSMOS/M). The geological and mining conditions of Vietnamese mines were taken into account during performing these analyses. Based on the results, the optimal individual-portal support structure was proposed for the roadway junctions driven in the geological and mining conditions of underground mines in Vietnam.

Keywords: portal support; coal mine roadway; bearing capacity; pre-tensioned cable; numerical modelling.

1 Introduction

Effective underground mining operation requires driving a significant number of roadways with a total length of several hundred kilometres. These roadways connect with each other in many places in the form of junctions (intersections). These junctions require the application of special support adapted to the geometry of junctions, dimension of the roadways and the expected loads from rock mass (Bednarek et al., 2024; Jendryś et al., 2020; Xie et al., 2020; Duży and Cholewa, 2019; Majcherczyk et al., 2014). One of many solutions for the coal mine roadway junction is a support structure based on a frame made of beams with attached steel elements. Such a support is called portal, frame or after the names of manufacturers (e.g. Heintzmann, Łabędy). The Central Mining Institute has been designing this type of support for 30 years (Rotkegel, 2017; Stałęga, 2001). During this time, over 400 original support solutions were developed and installed in specific places at the mine sites (Rotkegel, 2011; Rotkegel, 2017). In the case of a three-way junction, portal support commonly consists of two cantilevers located above the line of roadway junction, connected to each other by a main roof beam (Fig. 1). In general, the frame structure is supplemented with special steel elements connected to the main beams. Spatial sketches of such a typical support are shown in Figure 2, while exemplary implementations are shown in Figure 3.

In Vietnam, a support structure consisting of steel I-beams is applied for three-way junctions. It has been widely used in the past in many underground mines such as Mao Khe, Nam Mau and Vang Danh (Tran et al., 2018; Duong et al., 2020). This solution has many advantages: a simple structure, material costs are much lower compared to those of other portal support structures and providing a wider space for underground mining operations. However, this solution still has some drawbacks: the steel

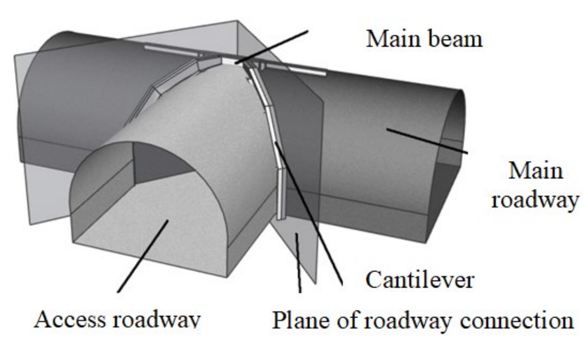

Figure 1: Assumptions in the design of roadway junction supports (Rotkegel, 2013).

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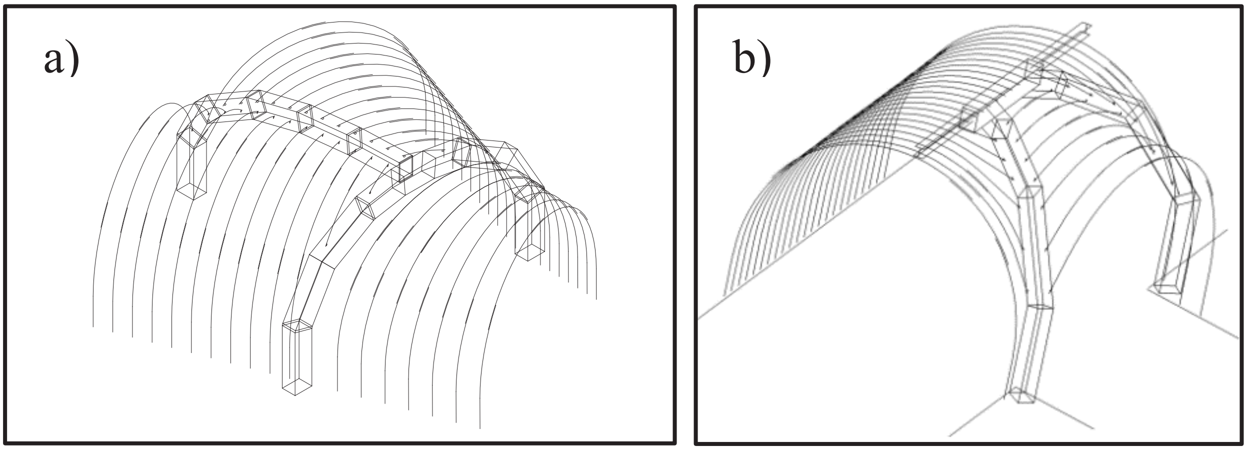


Figure 2: Spatial sketches of typical portal supports for three-way junctions: (a) at an acute angle and (b) at a right angle (Rotkegel, 2015).

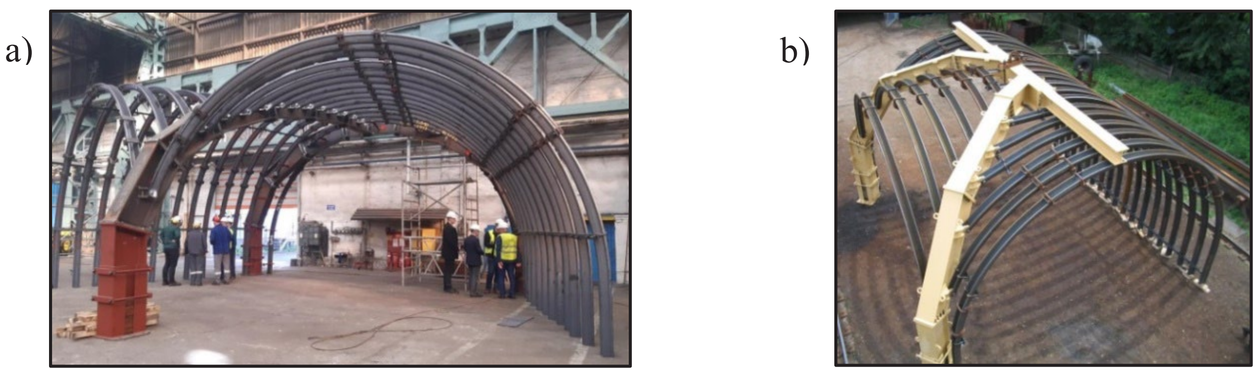


Figure 3: Examples of portal support implementation for three-way junctions: (a) at an acute angle and (b) at a right angle (Rotkegel, 2015).

elements are leaned on the structure, which causes the total load on the main beams to be significantly high. In conditions of increased load from the rock mass (e.g. deep coal mine), the application of such a structure will not meet the load-bearing requirements. If steel beams with greater bending resistance are used, the size and total weight of the structure will increase, making the structure more expensive and difficult to assemble. Therefore, an alternative solution was proposed in order to minimise the mentioned limits, which involved strengthening the structure canopy with pre-tensioned cables (Fig. 4).

This research aims to determine the bearing capacity of the proposed portal support structure with various configurations. To achieve this goal, the state of rock mass around the three-way junction and the bearing capacity of the support structures were examined. All analyses were performed using numerical modelling, taking typical geological and mining conditions of Vietnamese mines into consideration. Based on the results, the possibility of applying the proposed portal support for the geological and mining conditions of coal mines in Vietnam was discussed. The optimal structure of the portal support was also proposed for three-way roadway junctions.

2 Selected examples of individual-portal support applied in Polish underground mines

In Polish coal mines, the individual-portal support is often applied in coal mine roadway junctions, where the access roadway should connect with the main one, preferably at an angle close to right angle, and its dimensions should be relatively small. This means the structure support has a short length. Such portal support can be made from a flat frame screwed from simple elements, creating a rectangular shape (a roof beam on two columns) or a polygon on an arch (simple beams twisted at an angle). A common solution is to make the portal in the form of specially profiled rectangular steel frame made of different profiles (U, V or SWP). Figure 5 shows examples of portal

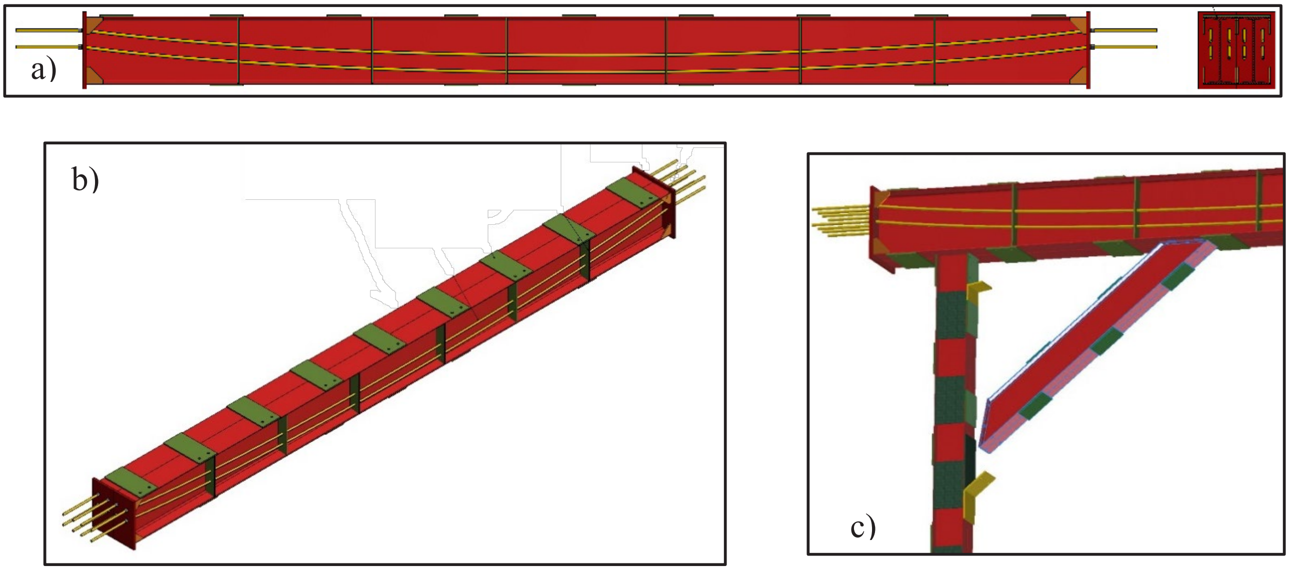


Figure 4: Support structure made of steel I-beams with the canopy reinforced by pre-tensioned cables: (a) cross section of canopy, (b) canopy with pre-tensioned cables and (c) position of canopy attached with column legs.

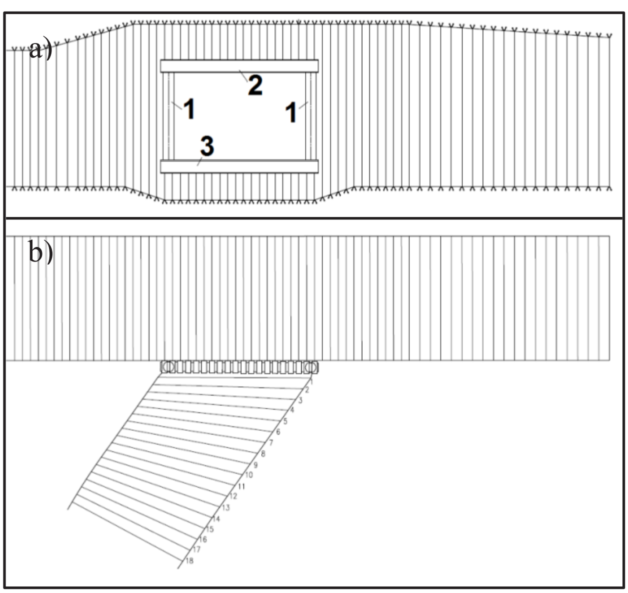


Figure 5. Example of support for the roadway junction in the form of a rectangular portal: (a) cross section and (b) top view (1 – column legs, 2 – canopy, 3 – floor base).

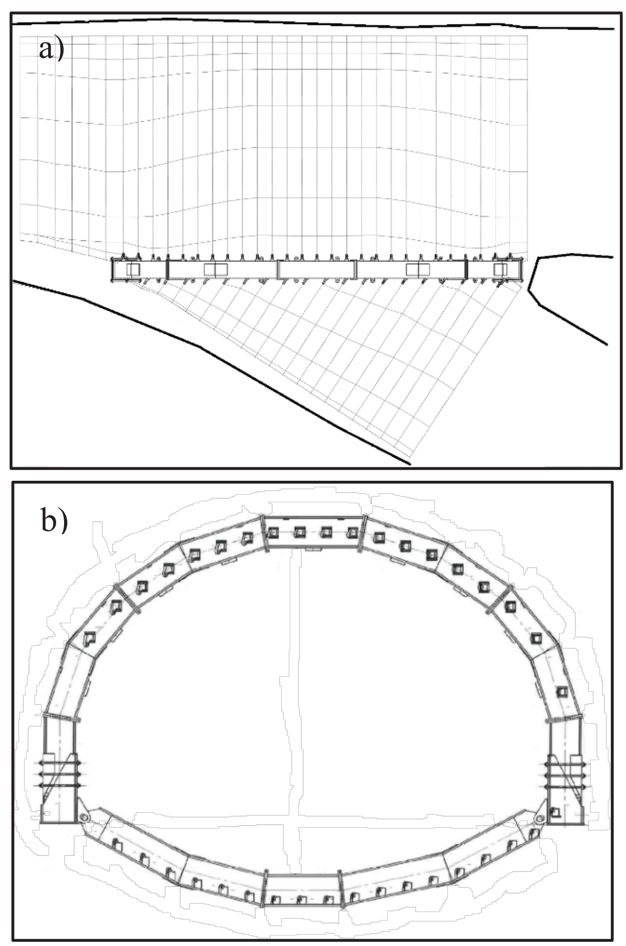


Figure 6: Example of polygonal portal made in the form of an arch – a support construction designed for the Bogdanka coal mine: (a) top view and (b) cross section.

support made in the form of a simple canopy beam on two column legs, and Figure 6 shows a polygonal portal support.

In many cases, individual-portal supports are made in the form of special steel frames built in double or triple layers. Most often, these are rectangular steel support, additionally reinforced with steel arches. An example of such an implementation for the Chwałowice coal mine is shown in Figure 7.

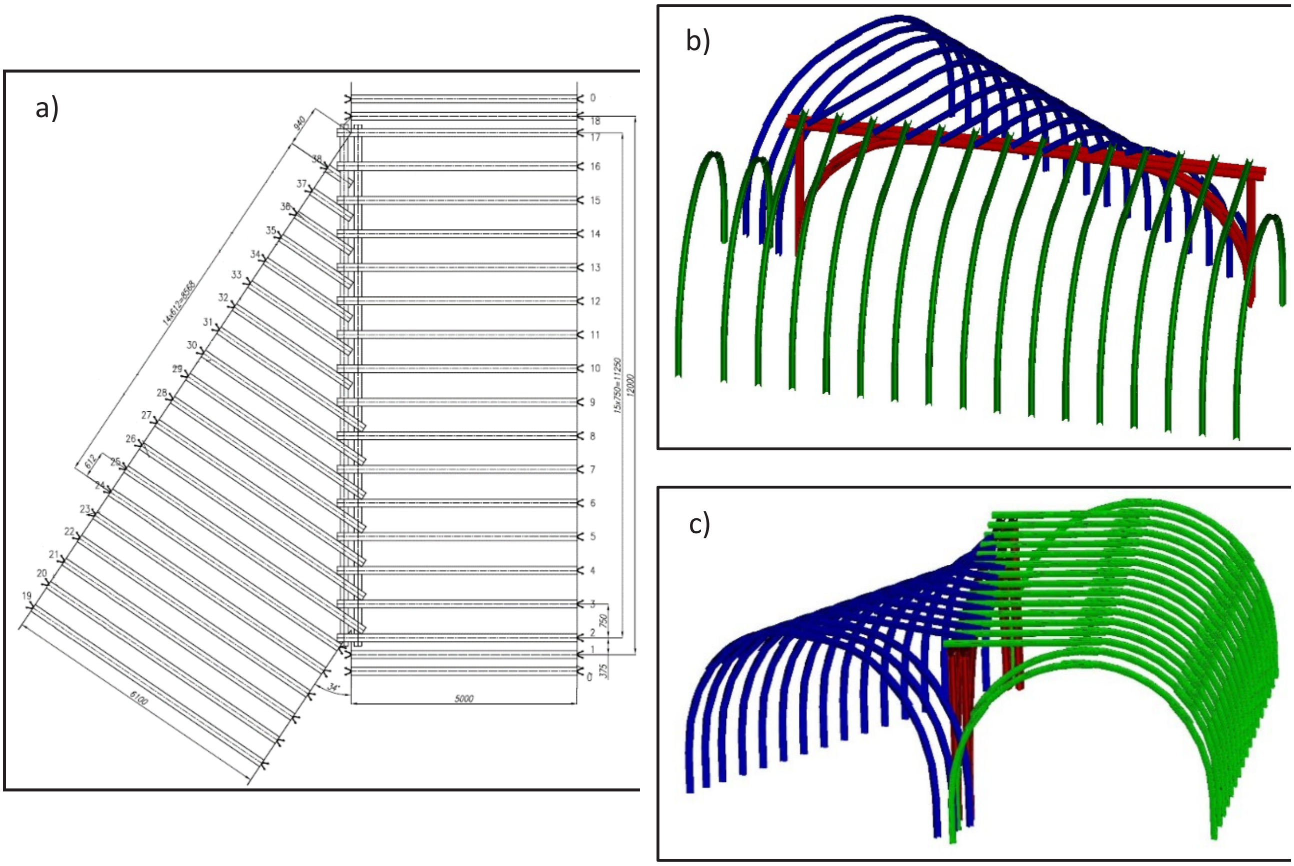


Figure 7: The three-way roadway junction support is based on a portal made of the V profile steel frames: (a) top view and (b and c) cross section.

3 Analysis of rock mass behaviour around the three-way roadway junction

The numerical analysis of the strain-stress state of the rock mass around the three-way connection of roadways was carried out using a computer program based on the finite difference method – FLAC3D v.5 (Itasca, 2012), taking the geological and mining conditions of Vietnamese UG coal mines into account. The underground coal mining in Vietnam is characterised by a shallow mining depth of 300–500 m, thick coal seams and presence of numerous faults and folds. The rock mass consists of hard rocks such as sandstone, mudstone, claystone and coal, which have a compressive strength from 30 MPa to 120 MPa (Nguyen and Niedbalski, 2016; Mijał, 2018; Niedbalski et al., 2018; Duong et al., 2019; Nguyen et al., 2020; Nguyen et al., 2021; Duong et al., 2023).

3.1 Model description

Numerical models represent the typical geo-mining conditions of UG coal mining in Vietnam as mentioned above. All numerical models were fixed at the top, bottom and two sides in appropriate directions (perpendicular to individual planes). The numerical models had dimensions of 60×120×40 m and were divided into approx. 320,000 elements (Fig. 8). The models were originally developed as elastic to achieve the primary stress state. Then, the displacements and velocity vectors were zeroed. In the next step, the 'null' model was assigned to the zones which corresponded to the roadways, and then, the model was recalculated.

It is assumed that two coal mine roadways (main roadway and access roadway) connect each other in a three-way junction at an angle of 30, 60 and 90 degrees. Typical coal mine roadway in Vietnamese coal mines characterised a cross section of arch with an area of 14.8 m^2 (5.0×3.8 m). Figure 9 shows the model with the geometry of the excavations and their connection method.

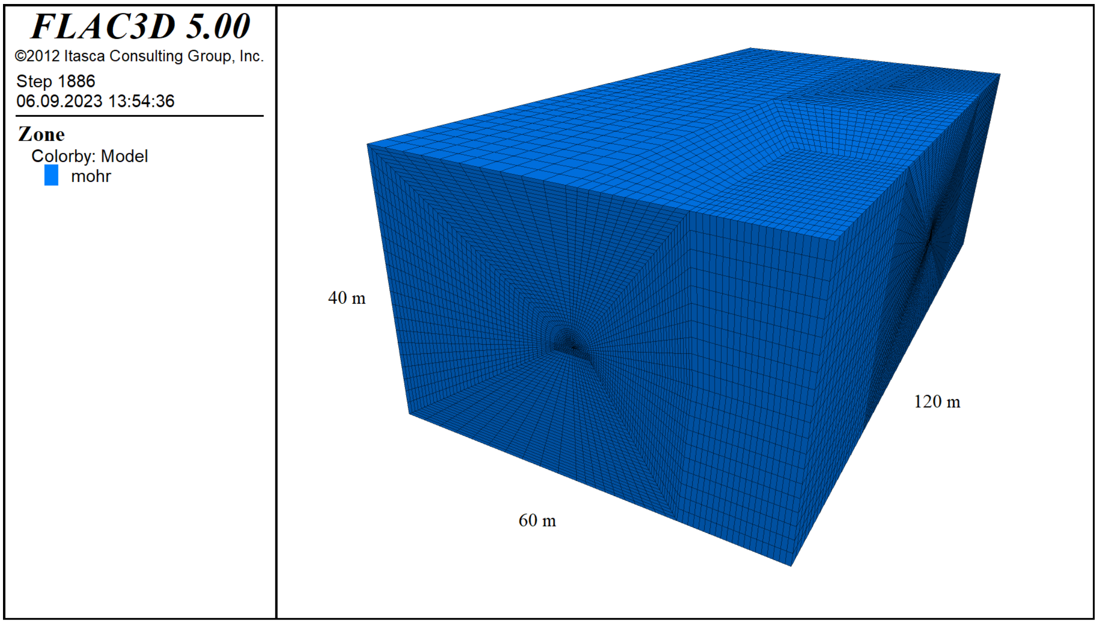


Figure 8: Numerical model of rock mass in FLAC3D.

The classic Coulomb-Mohr (elastic-plastic) model was used to perform numerical calculations. An example of rock mechanical parameters describing the rock mass in the Cam Pha coal basin, Vietnam, is presented in Table 1. Hypothetically, the original horizontal stress is equal to the vertical stress. The value of the primary stress was calculated hydrostatically from a depth of up to 500 m (approx. 12 MPa).

3.2 Result analysis

The results of numerical calculations were presented in the form of displacement maps and plasticity indicators (failure zone) of the rock mass around the roadway junction. Based on the results, critical zones of the rock mass around the roadway junction were determined. Figures 10–14 show the vertical displacement of the rock mass around the main roadway and the access roadway. In general, it can be seen that the vertical displacement on the roof and floor is greater when these roadways are connected at a decreasing angle. In the main roadway, a zone of greater vertical displacement can be observed on the access side and an increase in vertical displacement is noticed when the connection angle is reduced (Figs. 10 and 11). However, in the access roadway, the maximum vertical displacement is located at the connection line with the main roadway (Figs. 12 and 13).

Figure 14 shows the failure zone of the rock mass around the three-way roadway junction. It can be seen that when the roadways are connected at an angle of 90 and 60 degrees, the size of rock mass failure zones is slightly different. However, in the case of an angle of 30 degrees, the size of the failure zone is clearly larger (Fig. 14a). The same situation is observed in the access roadway. Additionally, the largest size of the rock mass failure zone is located above the connection line between the roadways (Fig. 14b). This is confirmed by the vertical displacement results presented in Figures 12 and 13.

3.3 Determination of the critical area of the rock mass around the coal mine roadway junction

Based on the results, it can be concluded that behaviour of the rock mass around the roadway junction depends on the configuration of their connection. In all connection types, the greatest displacement and size of the rock mass failure zone can be observed at the connection line between the roadways. In the case of configuration connection on a smaller angle (acute angle), there is a greater displacement and size of the rock mass failure zone around the connection in comparison to the case of configuration connection on a larger angle. This means that the rock mass load on the support is greater at the connection line and at a smaller connection angle. This

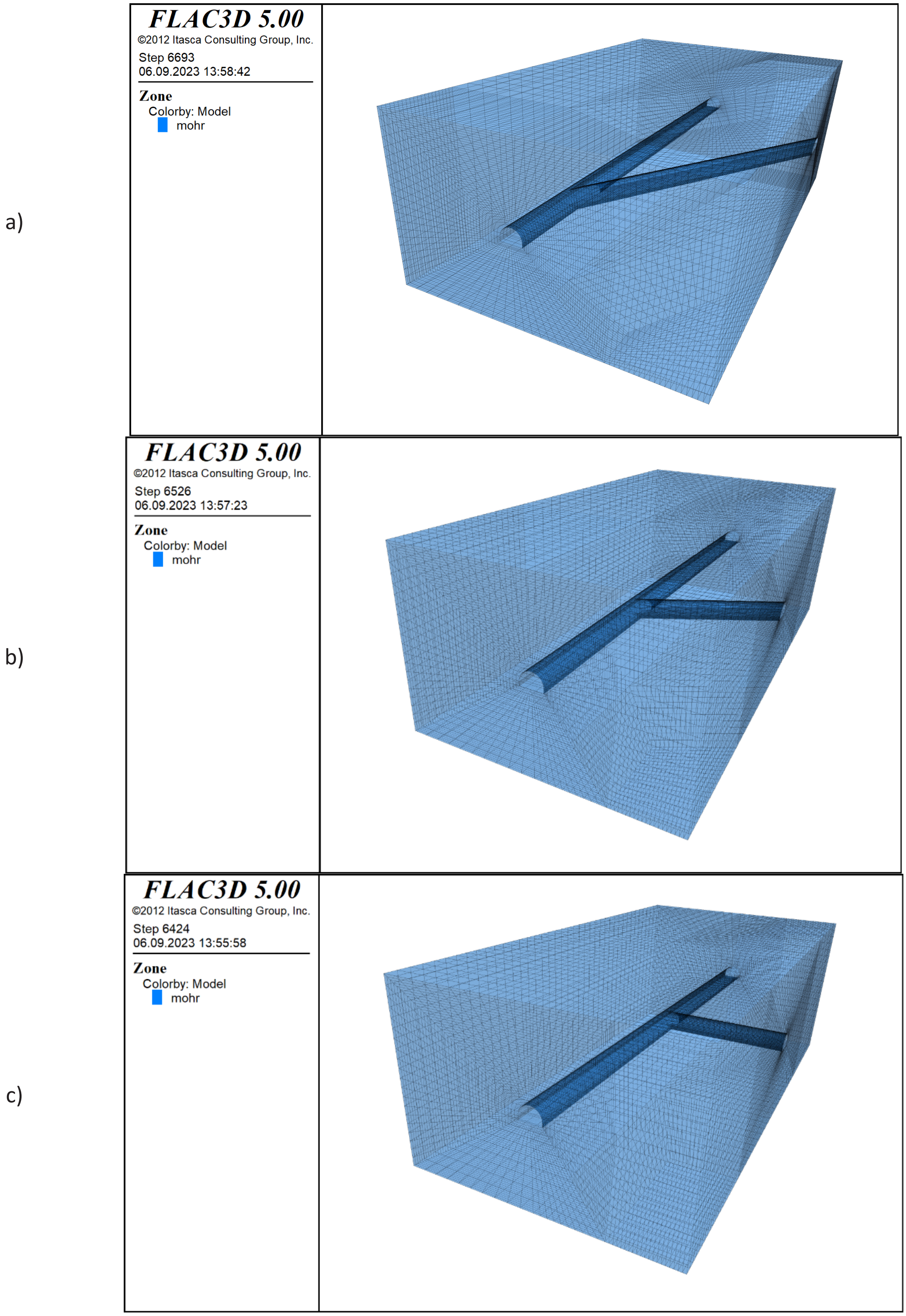


Figure 9: Numerical model of the coal mine roadway and the configuration of their connection at different angles: (a) 30°, (b) 60° and (c) 90°.

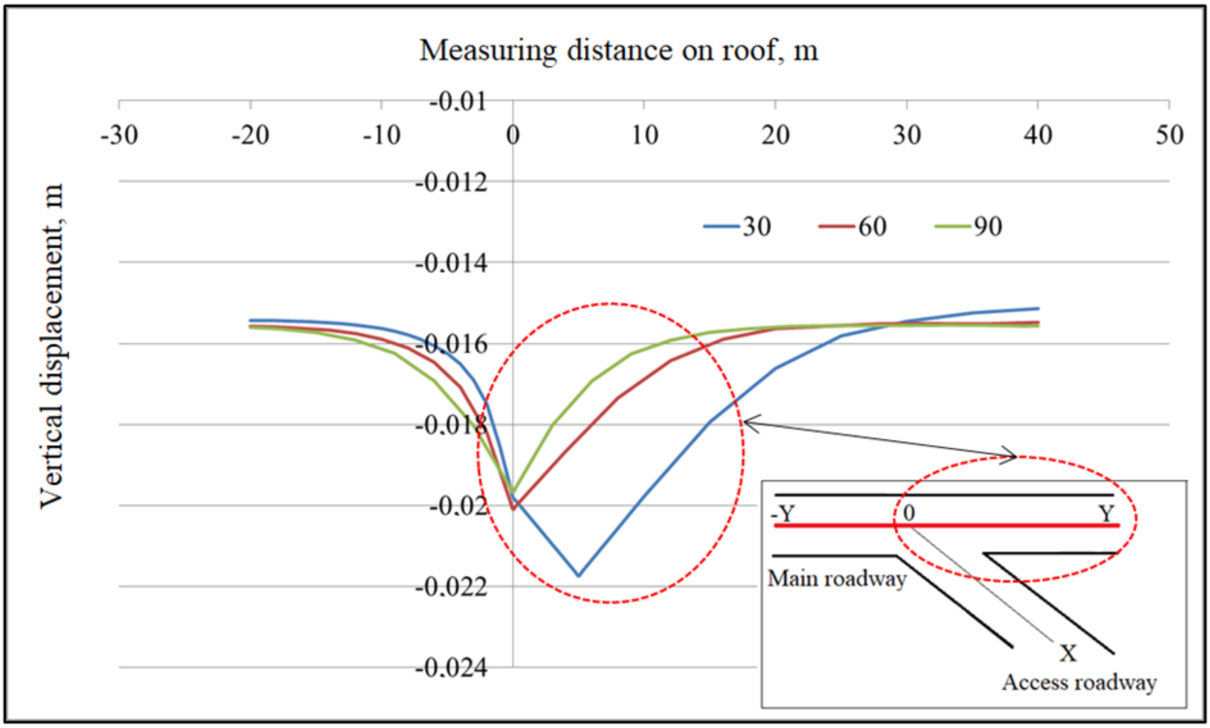


Figure 10: Vertical displacement of roof rock in the main roadway.

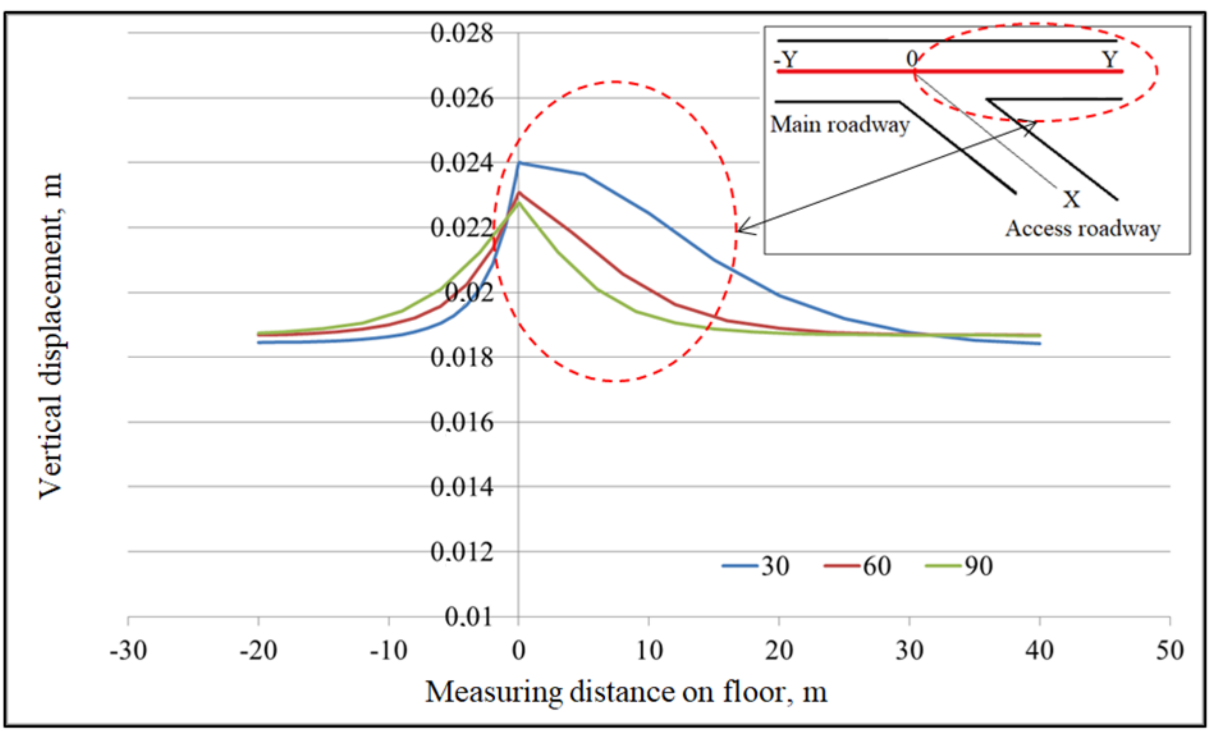


Figure 11: Vertical displacement of floor rock in the main roadway.

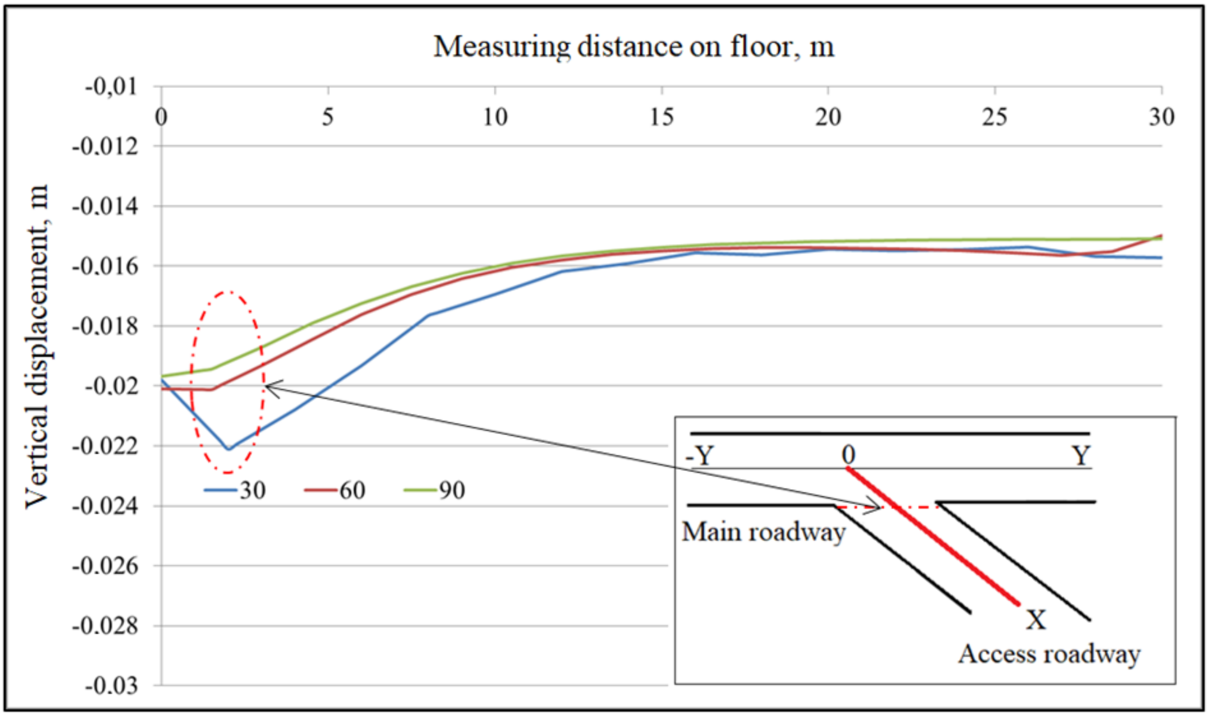


Figure 12: Vertical displacement of roof rock in the access roadway.

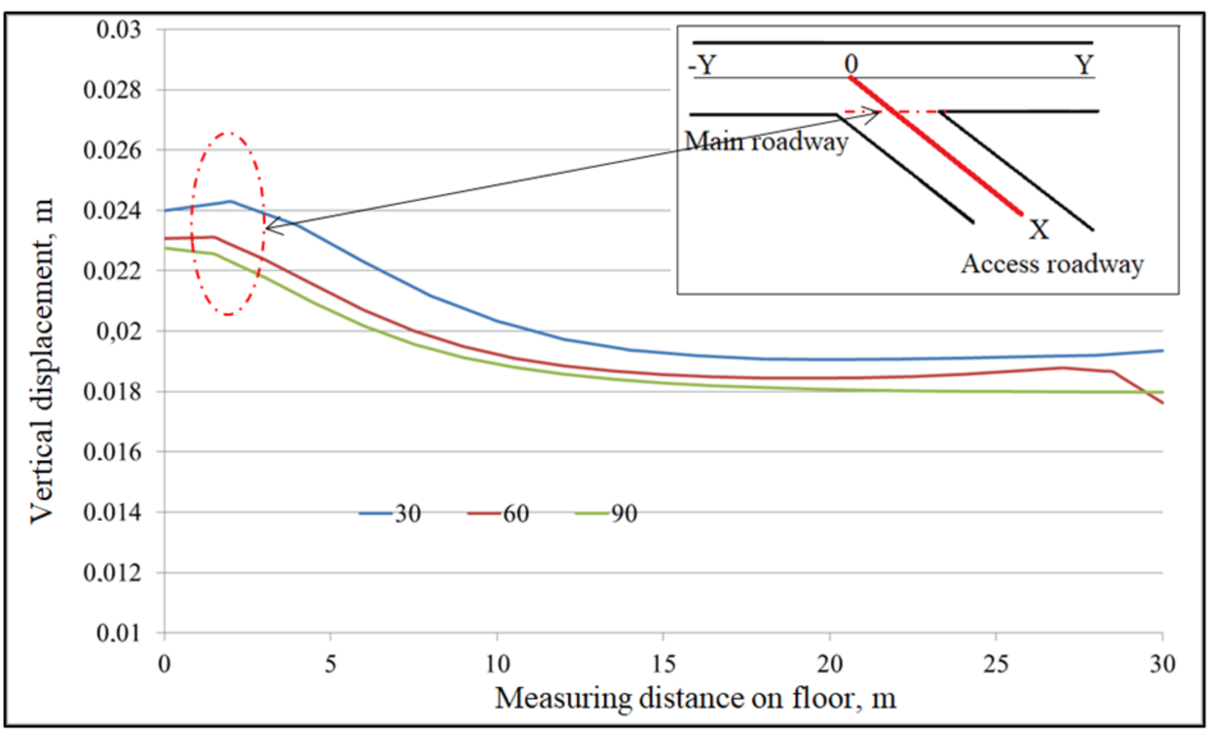


Figure 13: Vertical displacement of floor rock in the access roadway.

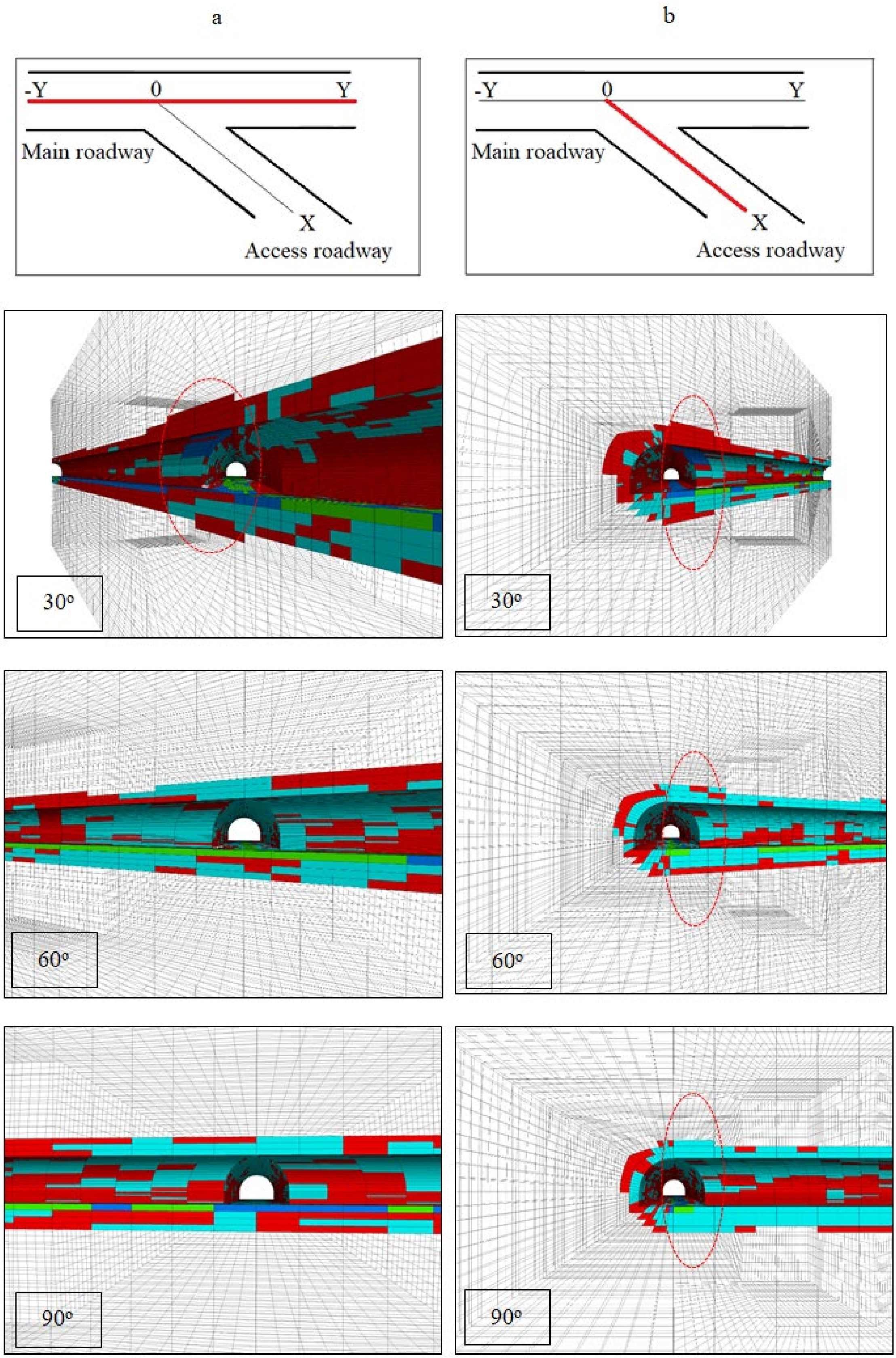


Figure 14: Failure zone of rock mass around the three-way roadway junction: (a) along the main roadway and (b) along the access roadway.

Table 1: Mechanical parameters of rock mass in the Cam Pha coal basin, Vietnam.

Rock type	Bulk modulus, K (GPa)	Shear modulus, G (GPa)	Friction angle φ (deg.)	Cohesion c (MPa)	Tensile strength R_t (MPa)	Density ρ (kg/m^3)
Sandstone	3.94	2.58	32	4.0	1.20	2500
Mudstone	2.33	1.40	30	2.0	0.56	2700
Claystone	1.67	1.00	28	1.2	0.25	2600
Coal	1.25	0.58	25	0.8	0.10	1400

has been confirmed by others (Hoek et al., 1995; Hsiao et al., 2009; Rotkegel, 2017; Liu et al., 2017; Siad et al., 2023). Attention should be paid to the case of weak rock (deformation and strength parameters are relatively lower) or a greater depth of coal mine roadways (rock mass load on support is relatively higher), and values of displacements and the size of the failure zone of the rock mass around junction would be much greater as shown in Figures 10–14. As a consequence, the load on the support will be higher, which affects the stability of the roadways (Bednarek and Majcherczyk, 2020; Majcherczyk et al., 2018; Wang et al., 2015). In such a case, special reinforcement (support) for the connection zone (e.g. the construction of steel I-beams reinforced with pre-tensioned canopy by cables) is required to maintain and improve the stability of the roadways and their connection.

4 Analysis of the bearing capacity of individual portal with a pre-tensioned canopy

4.1 Model description

The bearing capacity analysis of the rectangular support structure with pre-tensioned canopy (Fig. 4) was carried out using the finite element method (FEM) using the program COSMOS/M v.2.8. (SRAC, 1999). Three variants of the load on the canopy made of two I-beams propped up at the ends with a length of 5.5 m were analysed. In the first variant, a concentrated load acting on the canopy centre was assumed (a one-point load), in the second – a two-point load, and in the third – a load distributed evenly along entire length of the canopy. Figure 15 shows the calculation diagrams of the support structure with a simple canopy made of two I-beams. Dimensions of the I-beam are presented in Figure 16.

4.2 Model verification

In the first stage of numerical analyses, simulations were performed using simple beam elements (BEAM), which were given cross-sectional parameters corresponding to a beam made of a single I-beam. Figure 17 shows a model of a simple canopy.

The outcomes, including model deformations, support reactions and internal forces, were converted by the programme into reduced stresses. In the meantime, analytical calculations were performed to compare to the results of the numerical analysis. The maximum values of bending moments (*Mg*) and the maximum beam deflection (*f*) were determined. These values for individual loading patterns are presented in Table 2.

The reduced stress following the Huber-von Mises-Hencky hypothesis using the formula:

$$\sigma_{red} = \sqrt{\left(\frac{M_g}{W_x} + \frac{N}{A}\right)^2 + 3 \cdot \left(\frac{T}{A}\right)^2} \tag{1}$$

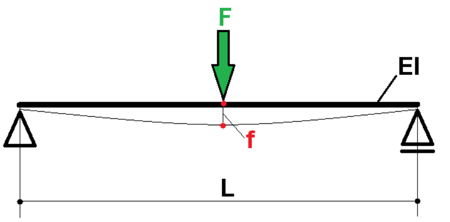
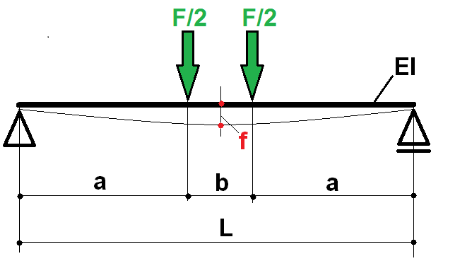
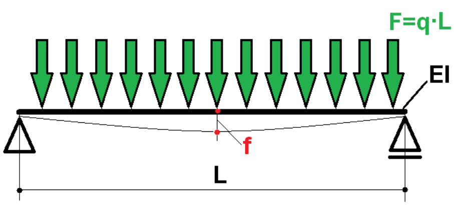
where Mg is the bending moment, Nm; Wx is the cross-section modulus index, m^3; N is the axial force, N; A is the cross-sectional area, m^2 and T is the transverse force, N.

The maximum stress values occur in the centre of the beam's length, where the shear forces become zero, and the axial forces for the analysed loading patterns throughout the beam are zero. Therefore, the above relationship reduces to the formula:

$$\sigma_{max} = \frac{Mg_{max}}{W_x} \tag{2}$$

For the calculations, the beam length is $L = 5.5$ m, Young's modulus $E = 200$ GPa, moment of inertia of the beam section (double I-beam) $Ix = 47000$ cm^4 and the bending strength index of the section $Wx = 2350$ cm^3. Additionally,

Table 2: Maximum values of bending moments *Mg* and beam deflections *f* for individual loading patterns according to analytical calculations.

	$Mg_{max} = \frac{FL}{4}$	$f = \frac{FL^3}{48EI}$
	$Mg_{max} = Fa$	$f = \frac{Fa(8a^2 + 12ab + 3b^2)}{24EI}$
	$Mg_{max} = \frac{FL}{8}$	$f = \frac{5FL^3}{384EI}$

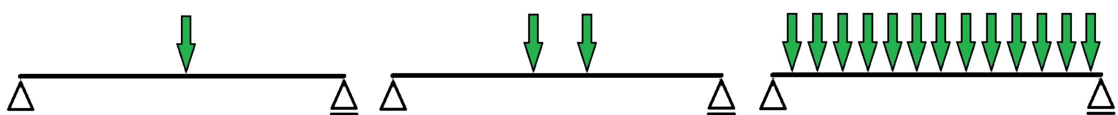


Figure 15: Load patterns for the canopy beam.

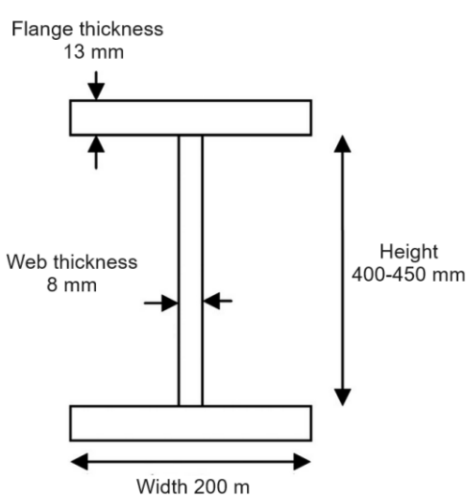


Figure 16: Dimensions of I-beam adopted for modelling.

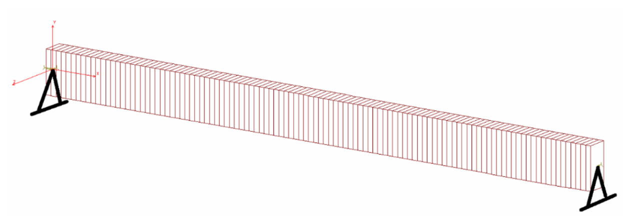


Figure 17: Model of canopy made of a simple I-beam – Beam model.

in the second loading scheme, it was assumed that the dimensions a = 2.05 m and b = 1.4 m.

The results of analytical and numerical calculations were completely consistent. Maximum values of reduced stresses were 292.5 MPa (one-point load), 218.1 MPa (two-point load) and 146.3 MPa (evenly distributed load). Maximum values of beam deflections were 18.44 mm, 16.80 mm and 11.52 mm, respectively.

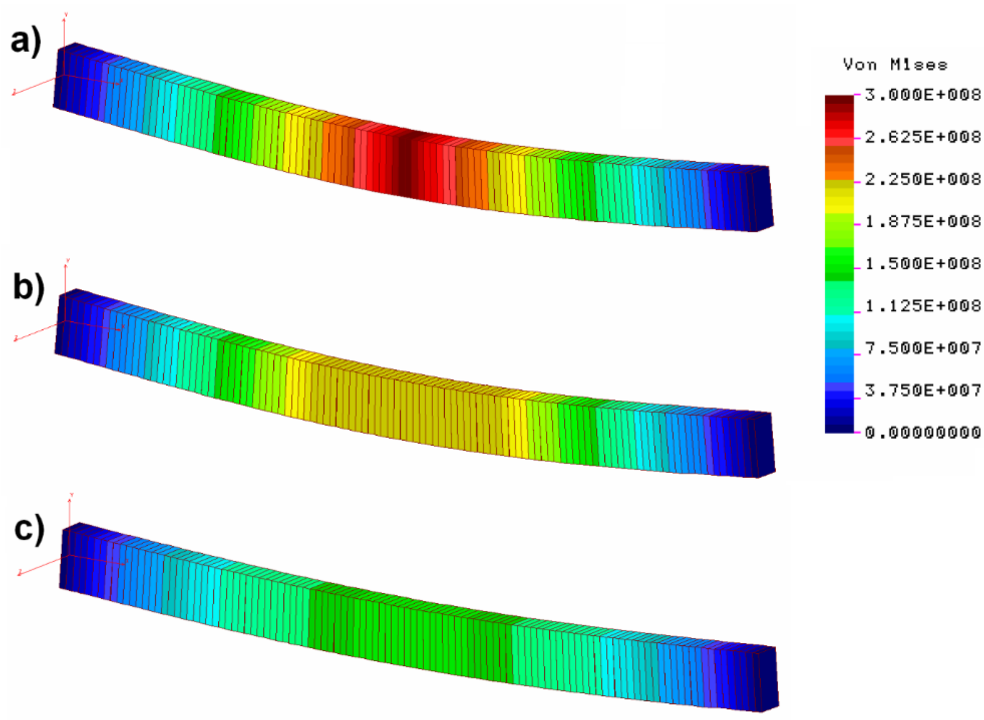


Figure 18: Distribution of reduced stresses (Pa) in the beam model of a canopy made of a single I-beam for various load patterns: (a) one-point load, (b) two-point load and (c) evenly distributed load.

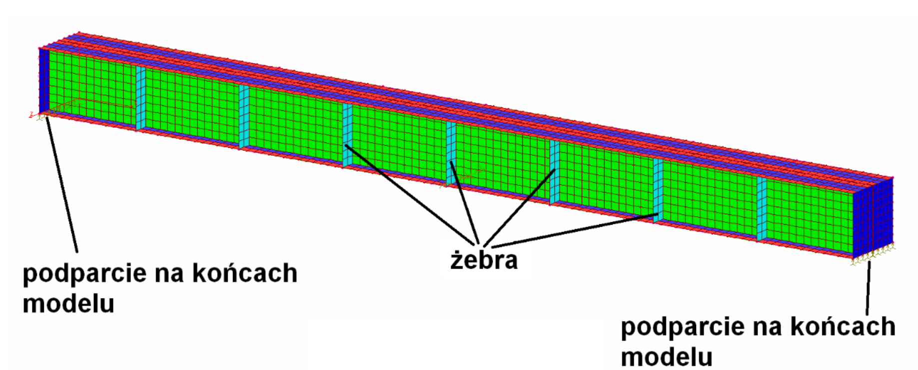


Figure 19: Model of a canopy made of two I-beams with additional ribs – Shell model.

This is due to the simplification of the analysis with a simple beam propped and loaded in its longitudinal axis. Figure 18 shows the distribution of reduced stresses depending on the pattern of loading of the canopy beam.

4.3 Calculation variants

Due to a good agreement between analytical results and numerical results and the possibility of simultaneously taking a number of factors into consideration, further calculations were performed by numerical modelling. Simulations were carried out for models of a canopy made of two I-beam elements with additional elements in the form of pre-tensioned cables. It is assumed that a canopy is pre-tensioned by four 18-mm cables in line. As before, three load patterns were analysed. Figure 19 shows a model of a canopy made of two I-beams with only additional ribs, while Figures 20 and 21 show a canopy model made of two I-beams with additional ribs and different configurations of pre-tensioned cables.

Such simulations were repeated for different heights of I-beam. Summary of calculation variants is shown in Figure 22.

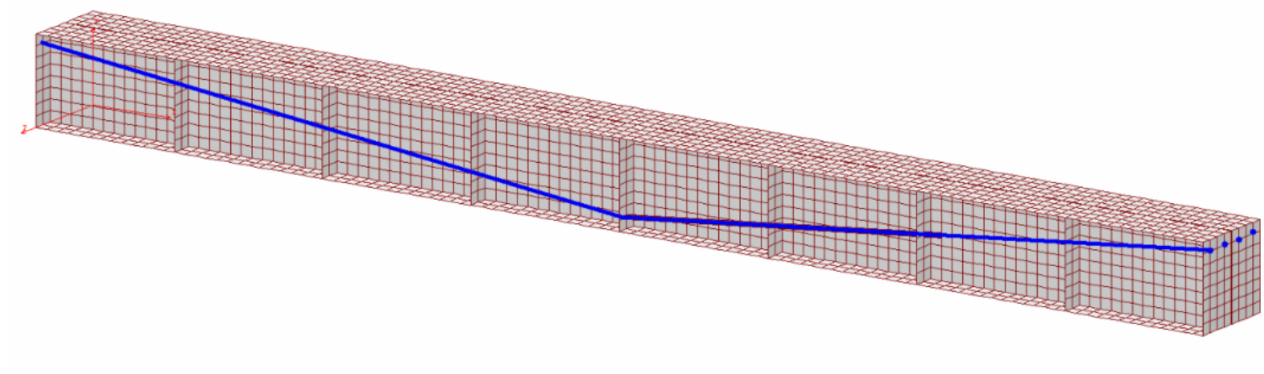


Figure 20: Model of a canopy made of two I-beams with one line of cables (*Shell model + 4 cables*).

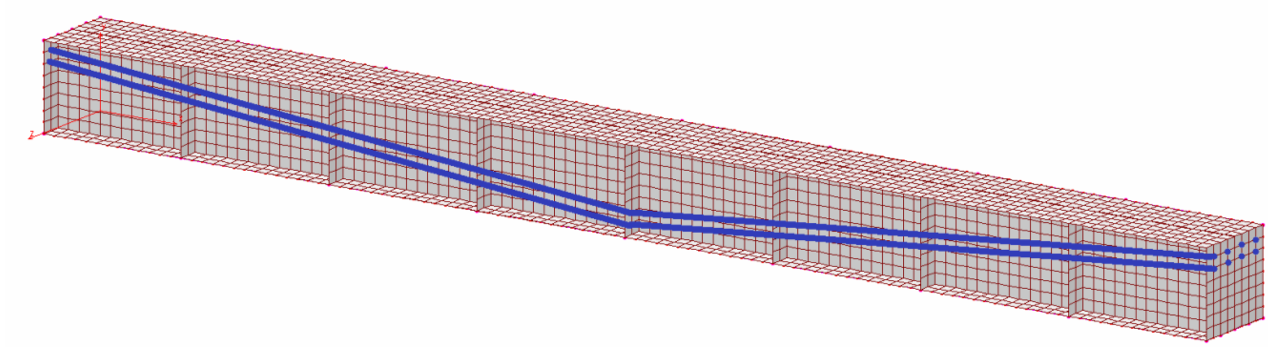


Figure 21: Model of a canopy made of two I-beams with two lines of cables (*Shell model + 8 cables*).

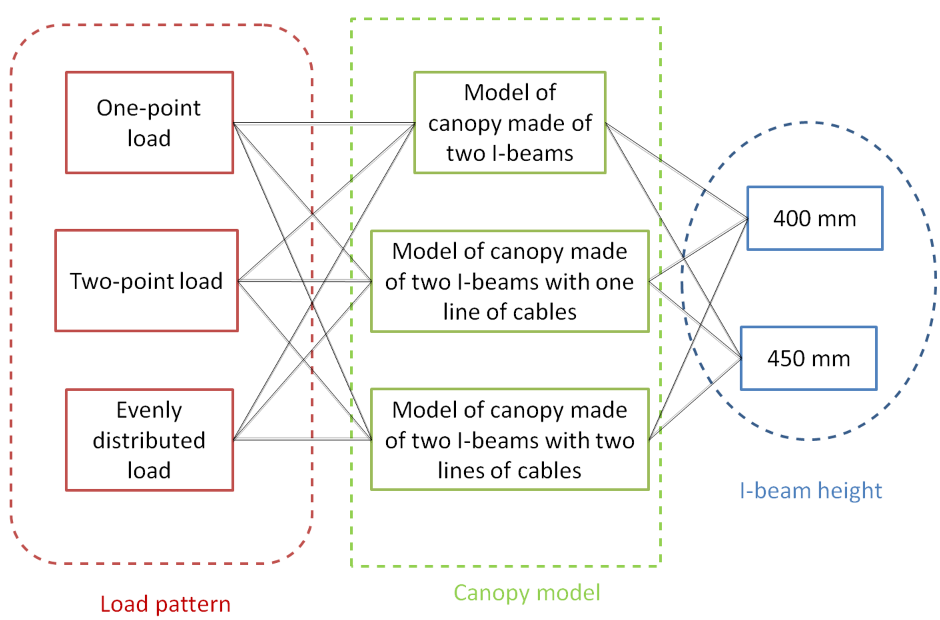


Figure 22: Calculation variants.

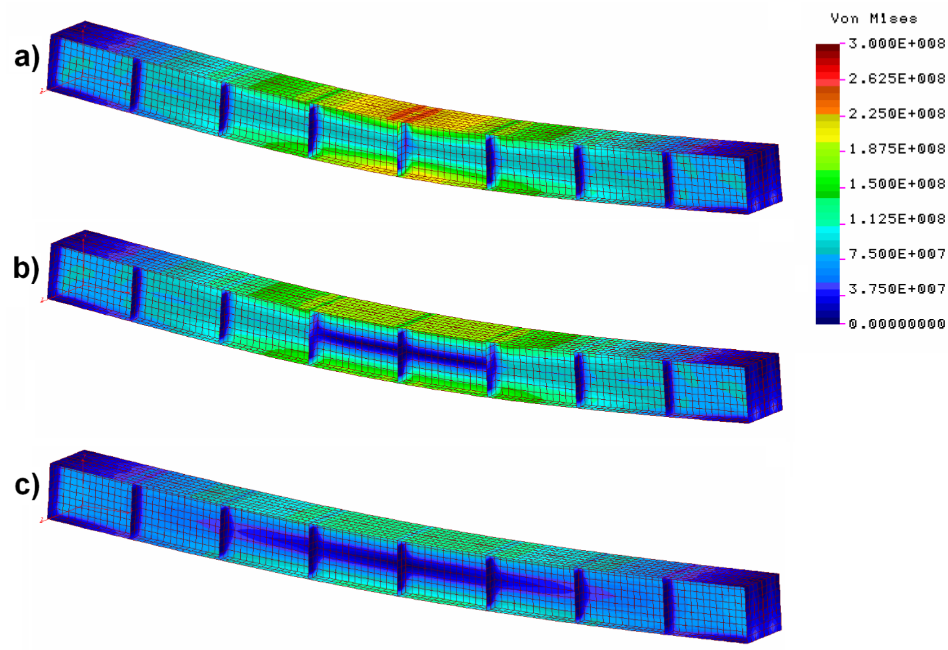
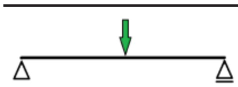
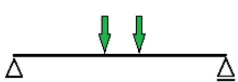
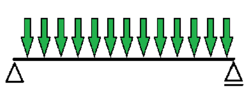


Figure 23: Map of reduced stresses (Pa) in a model of a canopy made of two I-beams: (a) one-point load, (b) two-point load and (c) evenly distributed load (*loading force – 500 kN*).

Table 3: Comparison of results of the bearing capacity analyses for the shell model and the beam model.

Load pattern	Shell model		Beam model	
	Max. reduced stress, *σred*, MPa	Max. deflection, *f*, mm	Max. reduced stress, *σred*, MPa	Max. deflection, *f*, mm
	258.21	15.91	292.5	18.44
	189.90	14.13	218.1	16.80
	118.87	9.72	146.3	11.52

4.4 Result analysis and discussion

The results of the numerical calculations are presented in the form of the maximum deflection and the maximum reduced stresses of the canopy. Figure 23 presents an example of reduced stresses in a model of a canopy made of two I-beams subjected to a load of 500 kN. (Estimated maximum value of load can act on the support in the geo-mining condition of the Cam Pha coal basin.)

As noted, the reduced stress and deflection values in the shell model (Fig. 19) are clearly lower than those in the beam model (Fig. 17). In the shell model, the reduced stress and deflection values constitute approx. 85% of the reduced stress and deflection values in the beam model (Table 3). This is due to different prop and load patterns of the canopy. As mentioned earlier, the beam model is propped and loaded in the neutral line (in the longitudinal axis of the canopy). However, the shell model is propped at the lower surface of the I-beam and loaded on the upper surface. Moreover, the shell model includes ribs that stiffen the canopy cross section.

Figures 24 and 25 present numerical values for individual calculation variants. It can be noted that the use of pre-tensioned cable in most cases causes a slight increase in the maximum reduced stresses in the canopy (by approx. 8%) and a reduction in deflections by 10–15%.

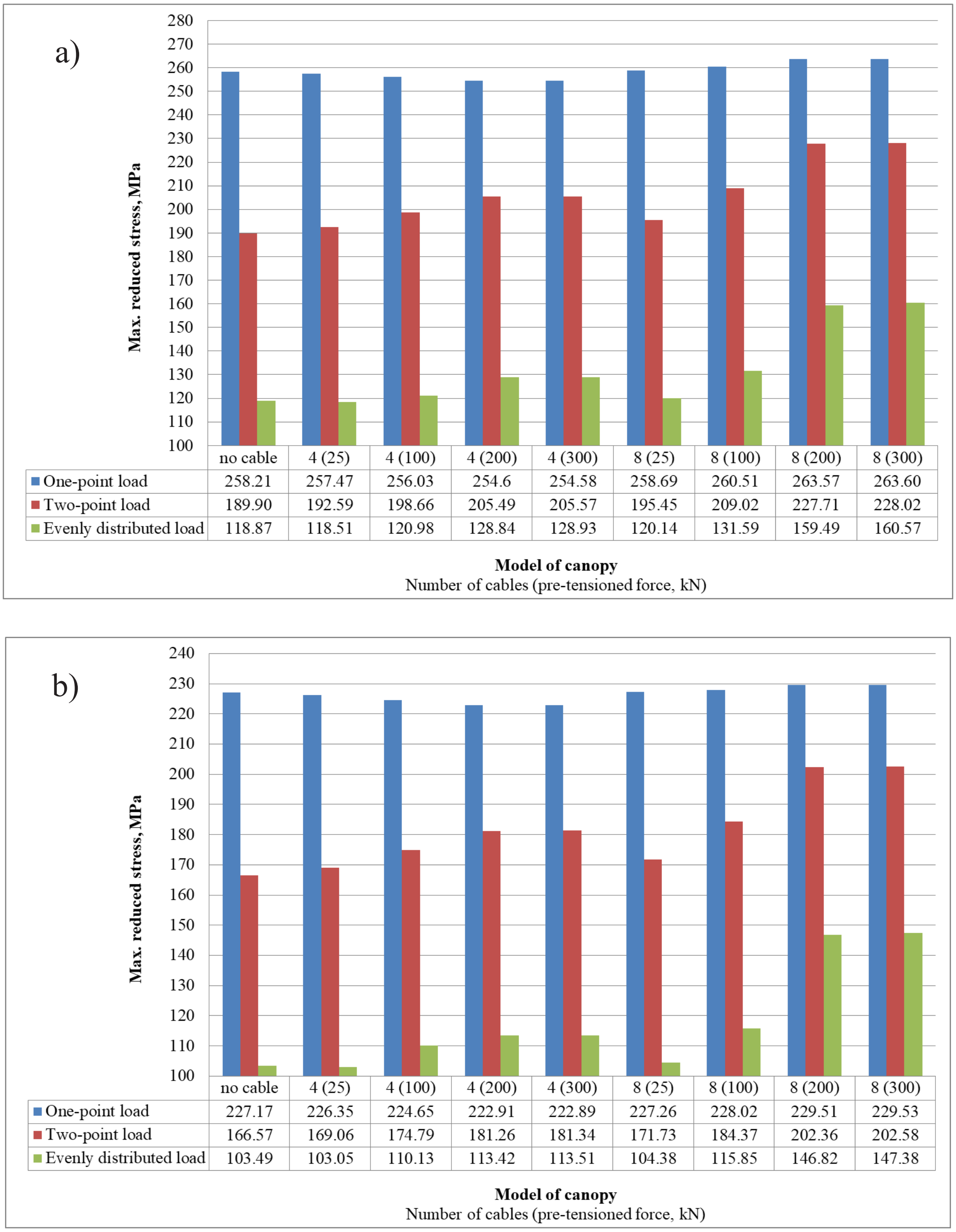


Figure 24: Maximum values of reduced stress of canopy for individual calculation variants: (a) 400-mm I-beam and (b) 450-mm I-beam (*loading force – 500 kN*).

This is due to the additional load on the canopy with compressive forces generated by the pre-tensioned cables. However, this is associated with the plasticity of the cables as a result of exceeding the yield point (Re = 700 MPa was assumed in the simulations). The optimal pre-tensioned force of approx. 200 kN is considered a suitable value to maintain the structural integrity of the canopy and prevent the cable from exceeding its yield strength (Fig. 26). Moreover, significant concentration stress values also occurred at the cable ends in the connections with beams. This situation can be observed in Figure 27.

Comparing the results presented in Figures 24 and 25, it should be noted that a better effect (lower reduced stresses and deflections) can be achieved by using a slightly higher profile of I-beam (450 mm instead of 400 mm) than by using pre-tensioned cables. It seems that

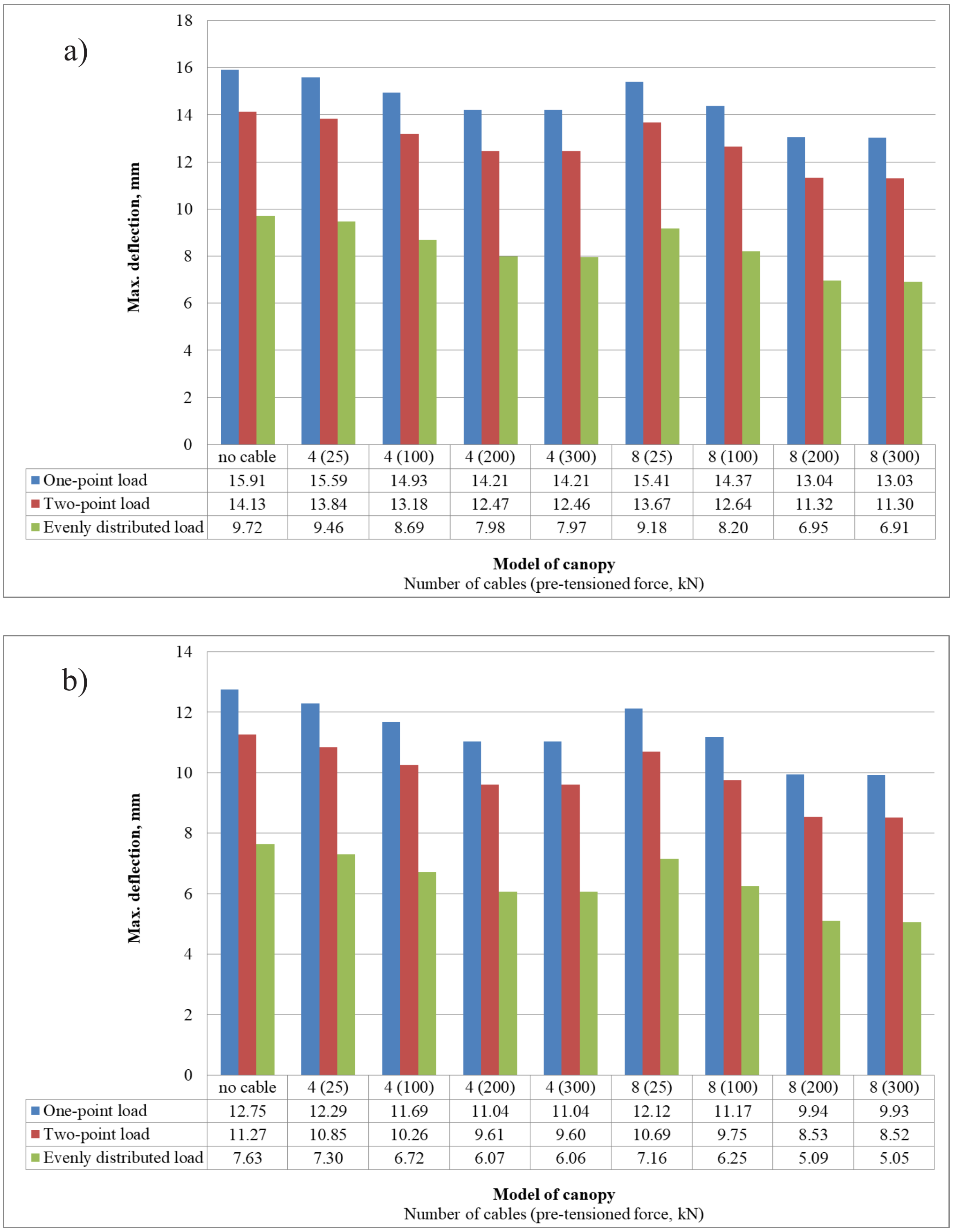
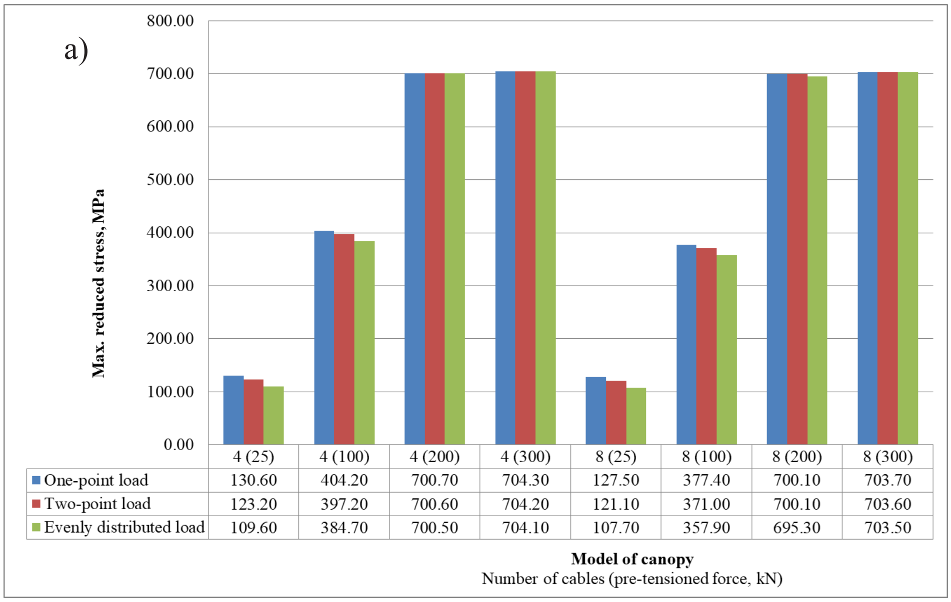


Figure 25: Maximum values of canopy deflection for individual calculation variants: (a) 400-mm I-beam and (b) 450-mm I-beam (*loading force – 500 kN*).

such a solution is simple to produce and implement, and therefore, it is cheaper.

5 Conclusions

Alternative models of individual-portal support structure were proposed for the geological and mining conditions of underground coal mines in Vietnam. In order to determine the bearing capacity of the proposed individual-portal support structure, numerical analyses were performed considering the typical geological and mining conditions of Vietnamese coal mines. An analysis of the rock mass behaviour around the three-way junction was carried out using FLAC3D, and then, an analysis of the bearing capacity state of the proposed individual-portal support structure was examined using COSMOS/M. Based on



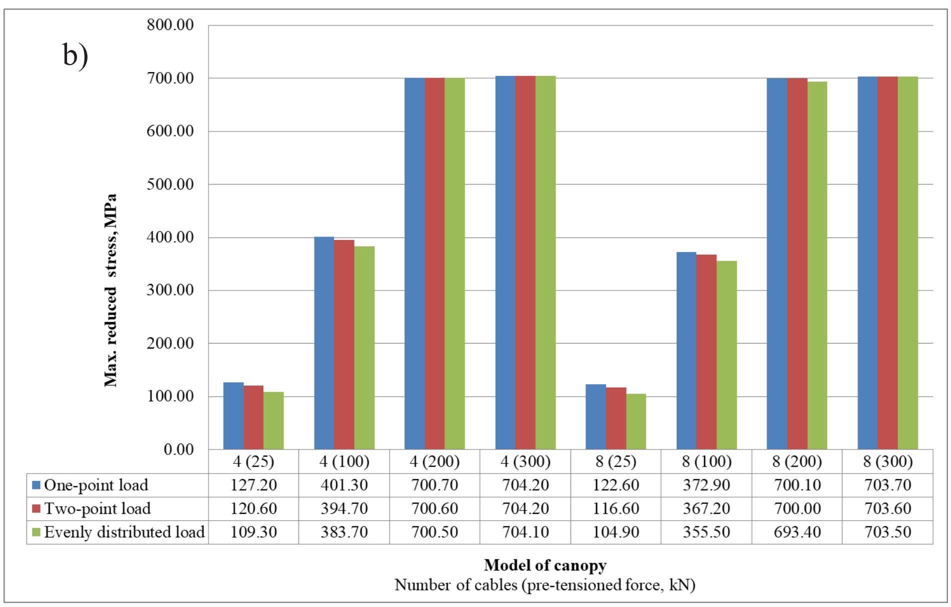


Figure 26: Maximum values of reduced stress of cables for individual calculation variants: (a) 400-mm I-beam and (b) 450-mm I-beam (*yield strength of steel – 700 MPa*)

the obtained results, the following conclusions can be formulated:

- The results of the analysis of the behaviour of the rock mass around the coal mine roadways and their connections indicate that the greatest displacement and size of the failure zone of the rock mass occur at the connection between the roadways. The smaller the connecting angle, the greater the displacement and size of the rock mass failure zone around their connection. Therefore, the expected load on the support is greater at the junction of the roadways and especially on a smaller angle of the roadway connection. This has also been confirmed by other research and practical experience.
- Support structure for the three-way junction based on a rectangular portal with a canopy pre-tensioned by cables is an interesting construction solution. The results of the bearing capacity analysis of the rectangular support structure indicate that the application of additional pre-tensioned cables allows for higher bearing capacity while maintaining the designed cross section of

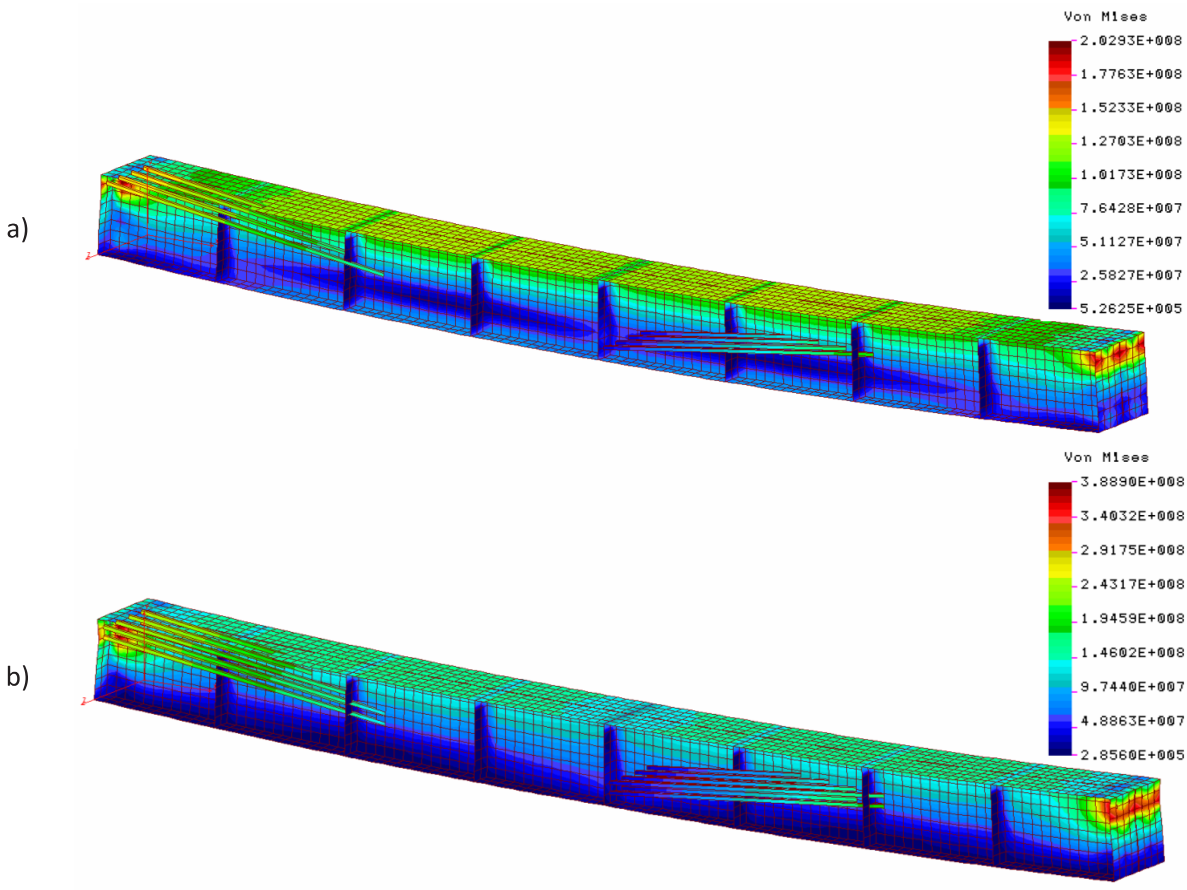


Figure 27: Concentration of stresses (Pa) in the area of cable connections (canopy model made of two 400-mm I-beams with evenly distributed load of 500 kN, pre-tensioned force of cable of 200 kN): (a) one line of cables – 4 cables and (b) two lines of cables – 8 cables.

canopy. However, this requires additional costs on implementation of cables, their connections to beam and ribs, as well as the need for control of tensioning cable process. For the case study given in this research, the maximum pre-tensioned force for cables should not exceed a value of 200 kN to ensure a potential maximum bearing capacity of the canopy while ensuring that cable plasticity does not cross its yield strength.

– If there is no need to reduce the height of the cross section of the canopy, a simple solution may be to just apply larger profiles, replacing 400 mm I-beams by 450 mm or larger I-beams.
– It is suggested to carry out the in-situ tests on the proposed individual-portal support structure with a canopy pre-tensioned by cables in order to determine its actual bearing capacity. The results would be valuable for verifying the modelling results and optimising the individual-portal support structure for the geological and mining conditions of Vietnamese underground mines.
– It is also suggested to examine the mentioned portal-frame support structures or polygonal portals, which are successively used in Poland and Germany for the geo-mining of coal mine in Vietnam.

References

[1] Bednarek, Ł., Małkowski, P., Niedbalski, Z., Mucha, K. (2024). Steel Arch and Rock Bolt Support in Terms of the Gateroad Stability Maintaining behind the Longwall Face. Appl. Sci., 14, 3594. https://doi.org/10.3390/app14093594

[2] Bednarek, Ł., Majcherczyk, T. (2020). An analysis of rock mass characteristics which influence the choice of support. Geomech. Eng., 21(4), 371-377. https://doi.org/10.12989/gae.2020.21.4.371

[3] Duong, D.H., Dao, H.Q., Turek, M., Koteras, A. (2019). The status and prospect of mining technology in Vietnam underground coal mines. Inżynieria Mineralna – Journal of the Polish Mineral Engineering Society, 21(2), 146-154. https://doi.org/10.29227/IM-2019-02-68

[4] Duong, D.H., Nguyen, V.D., Nguyen, D.Q. (2020). Study on application of steel beams combined with pre-stressed cables

against preparation road T-junction in underground coal mines of VINACOMIN. Mining Technology Bulletin, Institute of Mining Science and Technology - IMSAT, Hanoi. (in Vietnamese).

[5] Duong, D.H., Dao, H.Q., Phan, V.V., Ngo, V.T. (2023). Status and prospects of fully mechanized mining technology in Vietnam coal mines from 2005 to 2020, Journal of Sustainable Mining. 22(2). https://doi.org/10.46873/2300-3960.1383

[6] Duży, S., Cholewa, M. (2019). Assessment of the risk of loss of stability of the steel arch support of the underground excavations. IOP Conf. Ser.: Earth Environ. Sci. 261 012008

[7] Hoek, E., Kaiser, P.K., Bawden, W.F. (1995). Support of Underground Excavation in Hard Rock, Balkema, Rotterdam.

[8] Hsiao, F.Y., Wang, C.L., Chern, J.C. (2009). Numerical simulation of rock deformation for support design in tunnel intersection area, Tunnelling and Underground Space Technology, 24(1), 14-21. https://doi.org/10.1016/j.tust.2008.01.003

[9] Itasca Consulting Group Inc., Minneapolis. FLAC3D, Version 5.0, (2012). Software available at www.itascacg.com

[10] Jendryś, M., Duży, S., Dyduch, G. (2020). Analysis of Stress-Strain States in the Vicinity of Mining Excavations in a Rock Mass with Variable Mechanical Properties. *Energies*, *13*, 5567. https://doi.org/10.3390/en13215567

[11] Majcherczyk, T., Niedbalski, Z., Bednarek, Ł. (2018). Stability Assessment of Mining Excavations: The Impact of Large Depths. Studia Geotechnica et Mechanica, 40(3), 180 – 187. https://doi.org/10.2478/sgem-2018-0021

[12] Majcherczyk, T., Niedbalski, Z., Małkowski, P., Bednarek, Ł. (2014). Analysis of Yielding Steel Arch Support with Rock Bolts in Mine Roadways Stability Aspect. Arch. Min. Sci., 59(3), 641–654. https://doi.org/10.2478/amsc-2014-0045

[13] Liu, H., Li, S., Li, L., Zhang, Q. (2017). Study on deformation behaviour at intersection of adit and major tunnel in railway. KSCE J Civ Eng, 21, 2459–2466. https://doi.org/10.1007/s12205-017-2128-y

[14] Mijał, W. (2018). Coal Mining and Coal Preparation in Vietnam. Inżynieria Mineralna – Journal of the Polish Mineral Engineering Society, 1(41), 275-286 (2018). https://doi.org/10.29227/IM-2018-01-40

[15] Nguyen, P.M.V., Rotkegel, M., Do Van, H. (2020). Analysis of Behaviour of the Steel Arch Support in the Geological and MiningConditions of the Cam Pha Coal Basin, Vietnam. Arch. Min. Sci. 65, 551–567. https://doi.org/10.24425/ams.2020.134134

[16] Nguyen, Q.N., Nguyen, V.H., Pham, T.P. Chu, T.K.L. (2021). Current Status of Coal Mining and Some Highlights in the 2030 Development Plan of Coal Industry in Vietnam. Inżynieria Mineralna, 1(2). https://doi.org/10.29227/IM-2021-02-34

[17] Niedbalski, Z., Nguyen, P.M.V., Widzyk-Capehart, E. (2018). Geomechanical Assessments of Simultaneous Operation in the Case of Transition from Open Pit to Underground Mine in Vietnam. E3S Web of Conferences 35(3):01001. https://doi.org/10.1051/e3sconf/20183501001

[18] Nguyen, P.M.V., Niedbalski Z. (2016). Numerical modeling of open pit (OP) to underground (UG) transition in coal mining. Stud. Geotech. Mech., 38(3), 35–48. https://doi.org/10.1515/sgem-2016-0023

[19] Rotkegel, M. (2011). Influence of the shape of portal support of working junctions on its stress state. New Techniques and Technologies in Mining ed. ByVolodymyr Bondarenko, Irina Kovalevska, Roman Dychkovskiy. Edition 1st Edition, CRC Press, 207-212.

[20] Rotkegel, M. (2015). Selected examples of unconventional structures of portal support for roadway branches and intersections. Przegląd Górniczy 5/2015, 86-95, Katowice. (in Polish)

[21] Rotkegel, M. (2017). Method of designing portal-frame supports for junctions of coal mine roadway. Central Mining Institute, Katowice. (in Polish)

[22] Siad, I., Akchiche, M., Spyridis, P. (2023). Numerical Simulation of the Effect of Cross Passage Excavation on Surface Settlement. Geotech Geol Eng, 41, 4071–4082. https://doi.org/10.1007/s10706-023-02508-3

[23] Stałęga, S. (2001). Theoretical and research background for designing frame structures of supports for intersections and branches of coal mine roadway. Prace Naukowe GIG. Nr. 845. Katowice. (in Polish)

[24] Structural Research and Analysis Corporation (1999): COSMOS/M User's Guide. Los Angeles.

[25] Tran, T.M., Do, Q.T., Nguyen, Q.H., Pham, Q.N., Nguyen, V.D. (2018). Method of support design for underground construction). Hanoi University of Science and Technology, ISBN: 9786049504457. (in Vietnamese).

[26] Wang, H.W., Jiang, Y.D., Xue, S., Shen, B.T., Wang, C., Lv, J.G., Yang, T. (2015). Assessment of excavation damaged zone around roadways under dynamic pressure induced by an active mining process. Int. J. Rock Mech. Min. Sci., 77, 265–277. https://doi.org/10.1016/j.ijrmms.2015.03.032

[27] Xie, S.R., Pan, H., Chen, D.D., Zeng, J.C., Song, H.Z., Cheng, Q., Xiao, H.B., Yan, Z.Q., Li, Y.H. (2020). Stability analysis of integral load-bearing structure of surrounding rock of gob-side entry retention with flexible concrete formwork. Tunn. Undergr. Space Technol., 103, 103492. https://doi.org/10.1016/j.tust.2020.103492