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Analysis of the sensitivity of the support unit static parameters to the changes in the inclination angle of a roof bar

The article presents how the changes in the inclination angle of a roof bar impact the static load of the support unit elements. The change of this angle is the result of adapting geometrical features of the support unit to an unparallel roof and floor of the excavation. On the basis of low, middle and high support units it was found out that minor changes in the inclination angle of the roof bar result in significant changes in the load-bearing capacity of the support unit and the values of forces in the joints of the support development mechanism.

key words*: mining, mechanization, powered suport, load-bearing capacity of the support unit*

1. INTRODUCTION

Both in the process of the powered support unit design and its testing, it is assumed that the upper plate of the roof bar is parallel to the floor of the excavation. This assumption makes it easier to conduct bench testing. Additionally, it enables to compare technical parameters, such as: load-bearing capacity of the support unit, or internal forces for support units with different geometrical features.

The roof bar development mechanism enables to have an unparallel arrangement of the roof bar and the floor bar of the support unit. This is particularly useful in the excavation conditions, as it allows to adapt the geometrical form of the unit to the unparallel features of the roof and floor. Thanks to that, the pressure of the roof onto the roof bar can be distributed over the whole surface of the bar, not only on its one edge. Thus the inclination angle of the roof bar in the support unit set in the excavation, treated as a relative angle between the floor and the upper plate of the roof bar, can be different from zero.

Due to weak conditioning of the system of balance equations of the powered support unit [6], a minor change in the inclination angle of the roof bar, which causes a relatively unsignificant change in the geometrical features of the unit, may result in a considerable change in the values of inner forces determined from the balance equations.

The subject of this paper is the analysis of changes in the inclination angle of the roof bar and their impact on the load-bearing capacity of the support unit and on forces transmitted by hinge-type joints of its elements.

2. STATIC DIAGRAM

The considered geometrical model of the support unit was presented in Fig. 1. The geometrical quantities of the support unit, which depend on the application height of the support unit, are the following angles: α_1, α_2, α_3, α_5, α_6, and the following lenghts of sections: l_1, l_3, s_C. The remaining dimensions in Fig. 1 are constant.

In balance equations the inclination angle α_4 of the roof bar is a known quantity. The balance of the support unit was considered in the whole range of its application heights and angles α_4 which change in the range of $-5° \le \alpha_4 \le +5°$. Assuming the variability range of the angle α_4, a commonly accepted range of the roof bar inclination angle was considered. This angle results from selecting powered support units with respect to certain geological and mining conditions.

The considered static diagrams of the roof bar and the shield system can be seen in Fig. 2 and 3. The inclination angle α_4 of the roof bar against the floor was taken into account in the diagram in Fig. 2, where the given angles are the inclination angles of the prop and the roof bar abutment against the upper plate of the roof bar, not against the floor (Fig. 1). Similarly, Fig. 3 features the following angles: inclination angle of the roof bar abutment and the A_H and A_V components of the force in the hinge connecting the roof bar with the shield system, determined against the upper plate of the shield system.

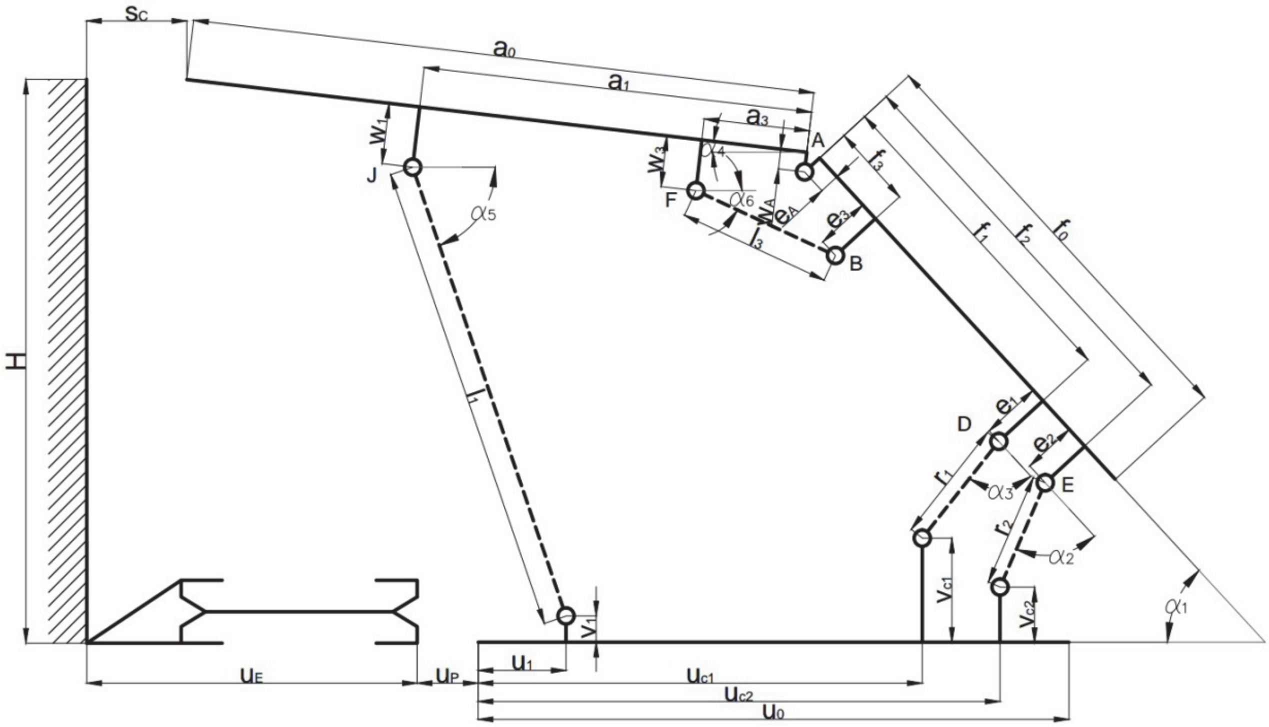

Fig. 1. Geometrical model of the support unit adopted in the calculations [3]

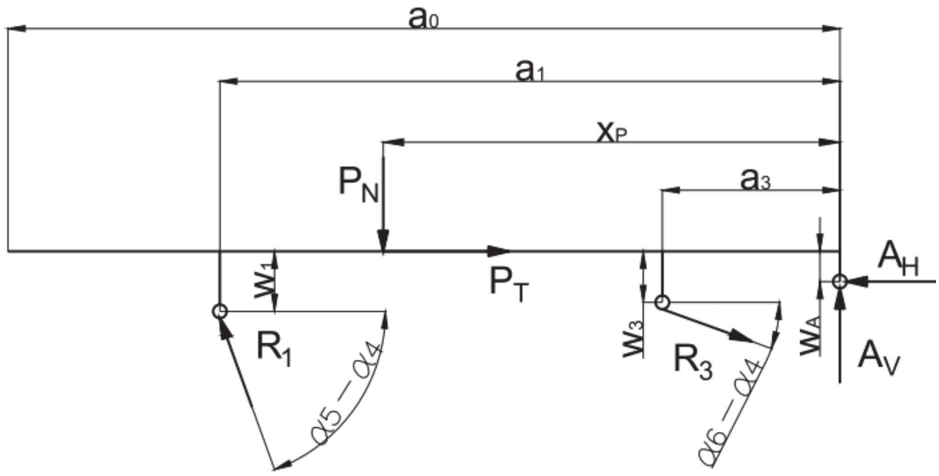

Fig. 2. Static diagram of the roof bar [3]

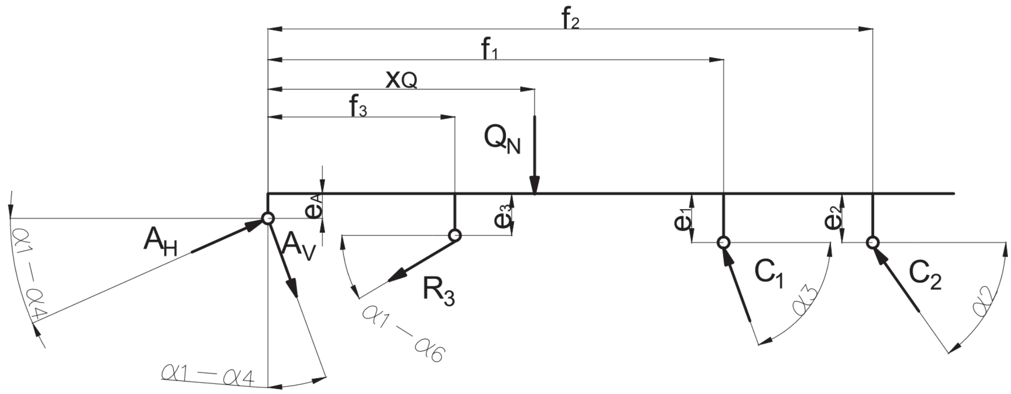

Fig. 3. Static diagram of the shield system

While drawing the static diagram of the roof bar and the shield system, the following facilitating assumptions were adopted:

– the impact of the roof onto the roof bar was modelled by means of a concentrated force with the following components: P_N (treated as the load bearing capacity of the support unit) – a normal one to the upper plate of the roof bar, and a tangent one – P_T, treated as a friction force and characterized by the friction coefficient $\mu = 0.3$;
– the pressure of the cave-in onto the shield was assumed in the form of a concentrated force Q_N = 600 kN, perpendicular to the surface of the shield and applied in the point determined by the co-ordinate $x_Q = 0{,}5f_2$. The friction force of the cave-in rocks against the shield was treated as insignificantly small, taking into account different directions of the cave-in shifts against the shield system which occur during the pressure of the support unit.

In addition, the load of the basic elements of the units presented in Fig. 2 and 3 are the following inner forces:

– R_1 – force in the prop,
– R_3 – force in the roof bar abutment,
– C_1, C_2 – forces in the joints of the lemniscate mechanism of the roof bar development,
– A_H – force component in the hinge connecting the roof bar with the shield system, tangent to the upper plate of the roof bar,
– A_V – force component in the hinge connecting the roof bar with the shield system, normal to the upper plate of the roof bar.

Some forces marked in Fig. 2 and 3 are known in balance equations: force – R_1 in the prop, force – R_3 in the roof bar abutment, and the cave-in pressure on the shield – Q_N. The remaining forces and the co-ordinate – x_P of the application point of the roof impact onto the roof bar are determined based on the conditions of balance between the roof bar and the shield. Thus, the values of the above mentioned quantities depend on the inclination angle α_4 of the roof bar. The obtained system of balance equations between the roof bar and the shield system was solved with the use of a computer program developed by one of the authors in the MATLAB environment. The applied algorithm has been described in details in [3].

3. HOW THE CHANGES IN THE ROOF BAR INCLINATION ANGLE IMPACT SELECTED STATIC PARAMETERS OF THE SUPPORT UNIT

An analysis was conducted on the sensitivity of support unit static parameters to the changes in the roof bar inclination angle. The analysis was carried out based on: a unit for low beds with the application height range of 0.95 – 1.7m, marked AA; a unit marked BB designed for medium beds with the application height range of 1.3 – 3.4m and a section marked CC with the application height range of 2.2-4.4m.

The following parameters were analyzed: load-bearing capacity of the support unit – P_N, force $A(A_H, A_V)$ in the bolt which connects the roof bar with the shield system, and forces C_1 and C_2 in joints.

Figure 4 presents charts illustrating changes in the load-bearing capacity of the AA unit in the whole height range of its application. An increase in the inclination angle of the roof bar causes a decrease in the load-bearing capacity value. This trend refers to all considered units in the whole ranges of their application heights. Usually, the impact of the changes in the inclination angle is the biggest for the smallest height of the support unit application. In the case of units for low beds, the load-bearing capacity of a unit whose roof bar is inclined at the angle of $\alpha_4 = 5°$ can be smaller by even 34% than the load-bearing capacity of a unit with a horizontal roof bar.

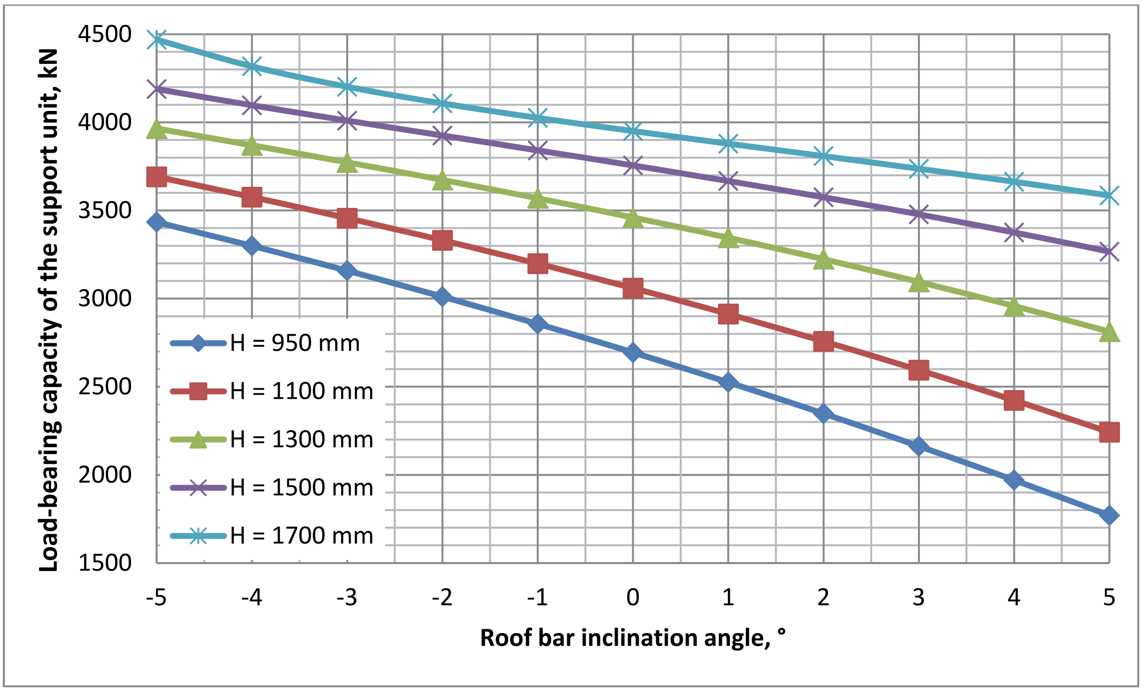

Fig. 4. Change in the load-bearing capacity of the AA unit in the function of the roof bar inclination angle [3]

In the case of the BB unit an analogical change of the load-bearing capacity is about 15%, while for the CC unit – 14%. In the case of the CC unit the inclination of the roof bar causes the biggest change in the load-bearing capacity P_N for the application height equal to 4,400 mm (Fig. 5), not for the smallest application height.

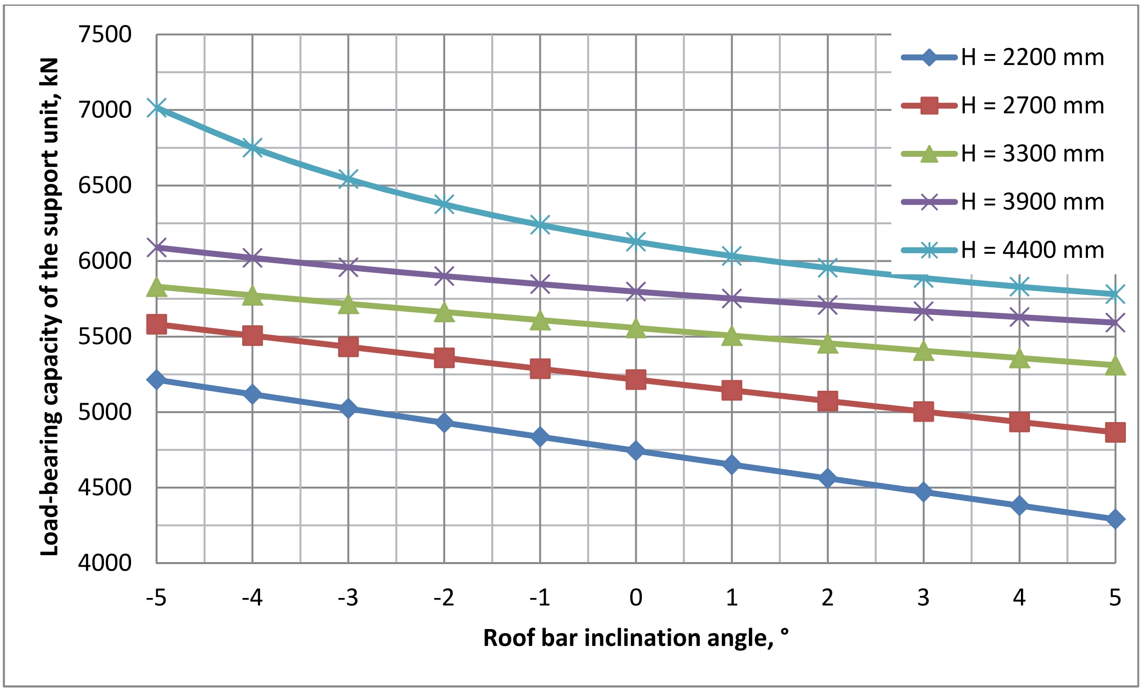

Fig. 5. Change in the load-bearing capacity of the CC unit in the function of the roof bar inclination angle [3]

Figure 6 features charts illustrating changes in the resultant force value in the bolt which connects the roof bar with the shield system in the BB support unit, designed for medium beds.

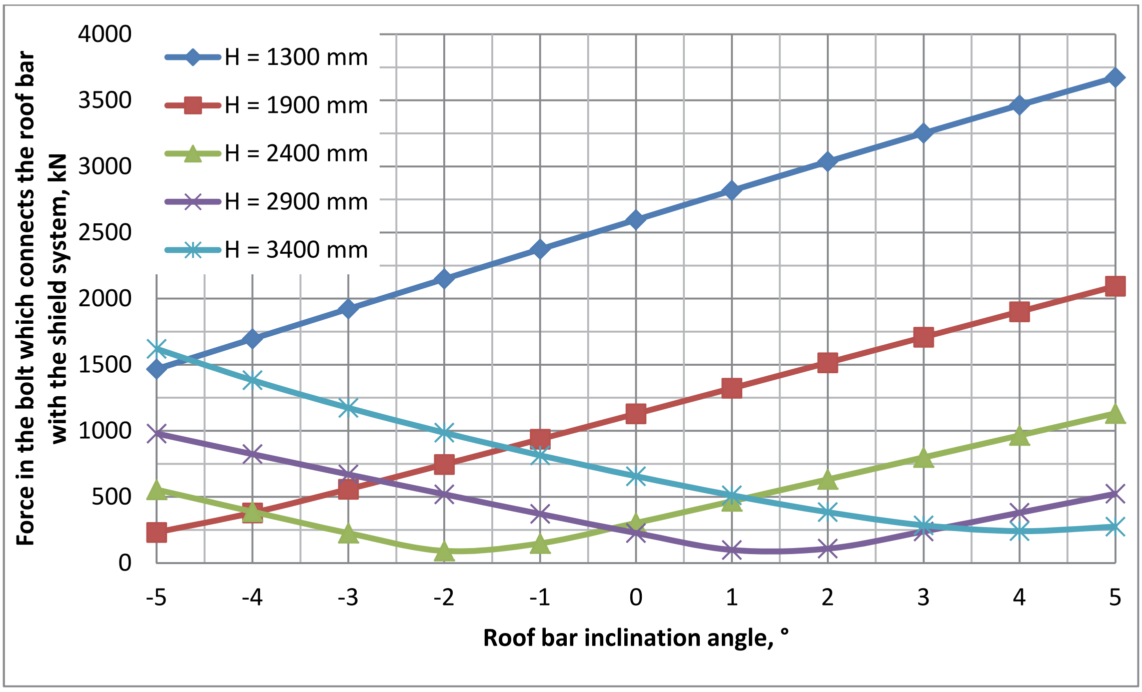

Fig. 6. Change of force A in the bolt of the BB unit in the function of the roof bar inclination angle [3]

In the case of application height which changes in the range of 2.4-3.4 m, the dependence of the *A* force in the bolt on the roof bar inclination angle is not monotonic. It is characterized by a minimal force in the bolt of a value contained within the range of 80-250 kN, which occurs at different inclination angles of the roof bar. The chart with $A(\alpha_4)$ for application heights 1.3 m and 1,9 m shows that this dependence is characterized also by a minimal force value in the hinge, yet it occurs for roof bar inclination angles below -5°. Table 1 features a percentage-based change of force in the joint with respect to the same force in a horizontal roof bar ($\alpha_4 = 0°$).

Table 1

Percentage-based change of force in the bolt with respect to the same force in a horizontal roof bar (authors' own elaboration based on [3])

AA unit		BB unit		CC unit	
Application height, mm	Percentage change of force A, %	Application height, mm	Percentage change of force A, %	Application height, mm	Percentage change of force A, %
950	-49 ÷ 46	1300	-44 ÷ 41	2200	-75 ÷ 77
1100	-57 ÷ 58	1900	-79 ÷ 85	2700	-54 ÷ 220
1300	-73 ÷ 77	2400	-90 ÷ 273	3300	-96 ÷ 294
1500	-98 ÷ 104	2900	-56 ÷ 332	3900	-72 ÷ 105
1700	-91 ÷ 158	3400	-63 ÷ 146	4400	-61 ÷ 111

The force in the front lemniscate joint increases monotonically with the change in the roof bar inclination angle. Charts in Fig. 7 feature the dependence of the force C_1 in the front joint on the roof bar inclination angle in the whole range of application heights of the CC unit. Due to the change in the roof bar inclination angle, the force in the joint changes its direction in the application height range of 3.3-4.4 m.

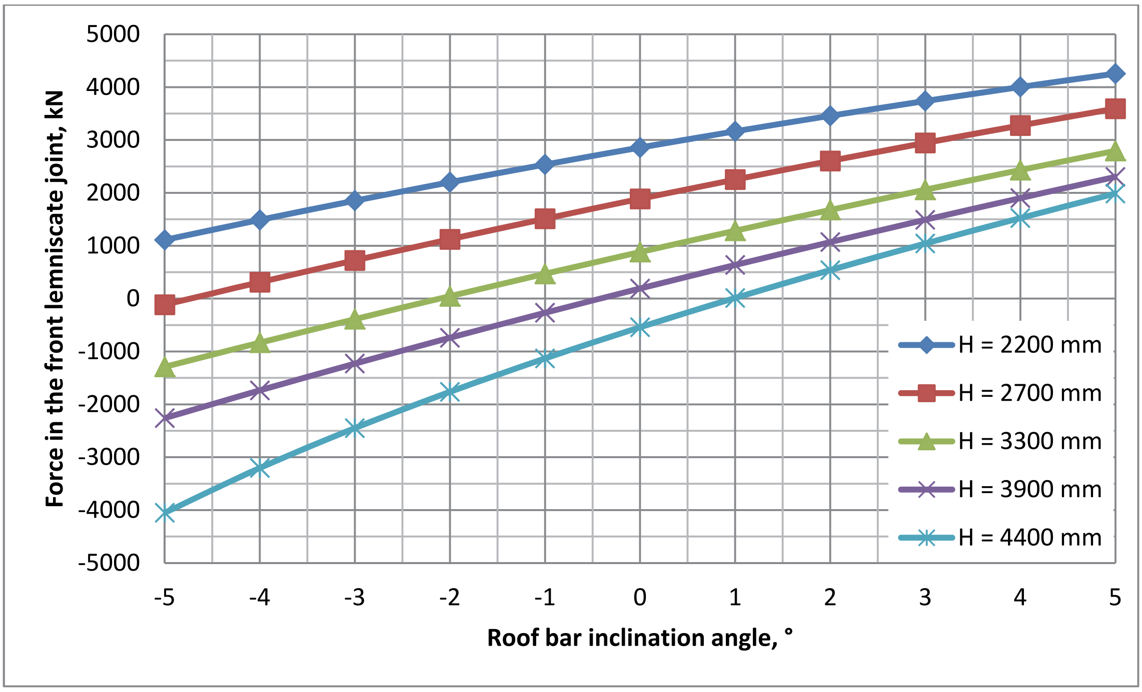

Fig. 7. Change of force C_1 in the front joint of the CC unit in the function of the roof bar inclination angle [3]

In the case of the remaining considered units, the maximal percentage changes of the force in the joint, caused by the change of the roof bar inclination angle in the range from -5° to +5°, were achieved for the maximal application height of the support unit. They are the following: for the AA unit from -64% for α_4 = -5°, to 53% for α_4 = 5°; for the BB unit, an analogical change is from -465% to 358%.

It is important to note, however, that the values of the force in the front joint are relatively low when the roof bar is horizontal. For the biggest application height they are the following: for the BB unit – 601 kN and for the CC unit – 542 kN. For this reason, the determined percentage changes in the values of the forces in the joint, caused by the change in the roof bar inclination angle, are big. In the process of designing a powered support unit, the value of the force transmitted by the joints, bolts and basic elements of the unit is determined based on the analysis of 16 external load variants of the unit. This way the maximal force transmitted by the joint is compared with the values of forces in the front joint in the case when the roof bar is not horizontal. This way it is possible to determine the permissible variability range of the roof bar inclination angle, with respect to the permissible force in the front joint.

The biggest recorded changes in the value of the internal force, caused by the change of the support unit inclination angle in the range of -5° ÷ +5°, refer to the rear lemniscate joint.

Figures 8 and 9 feature charts of force changes in the rear joint, in the whole range of application heights of the AA and CC support units. For example, for the CC unit, the force in the rear joint, with the roof bar inclined at the angle α_4 = -5°, is seven times bigger than the analogical force operating with the horizontal roof bar. However, it is important to note that the force in the rear joint at α_4 = 0° is small, as it equals 281 kN (for H = 3,900 mm).

Due to a significantly big change in the value of the force C_2, it is necessary to take into account the change in the roof bar inclination angle while designing the joint and its hinges. For example, if the rear joint of the CC unit was designed for the load of 1,100 kN, the design of the support unit should consider blockages that would prevent the roof bar downward inclination at an angle bigger than α_4 = -1°.

In addition, the determined changes of the force in joints will result in the changing values of inner forces that are transmitted by the shield and roof bar of the unit. The issue how to design such elements requires a separate study, though.

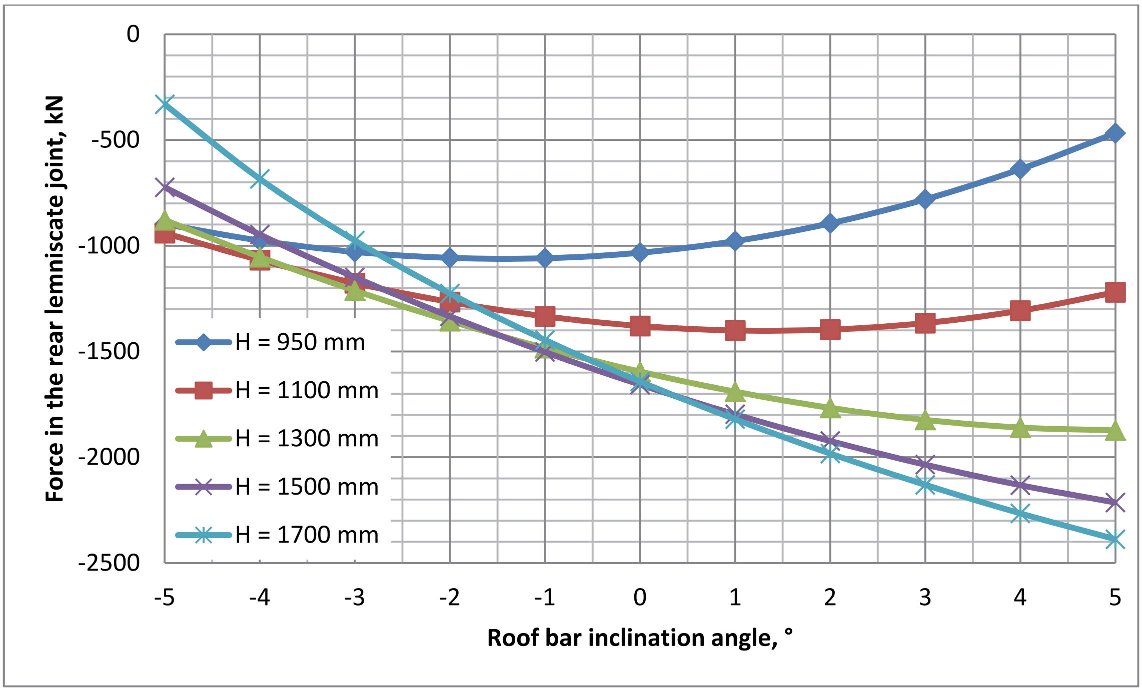

Fig. 8. Change of force C_2 in the rear joint of the AA unit in the function of the roof bar inclination angle [3]

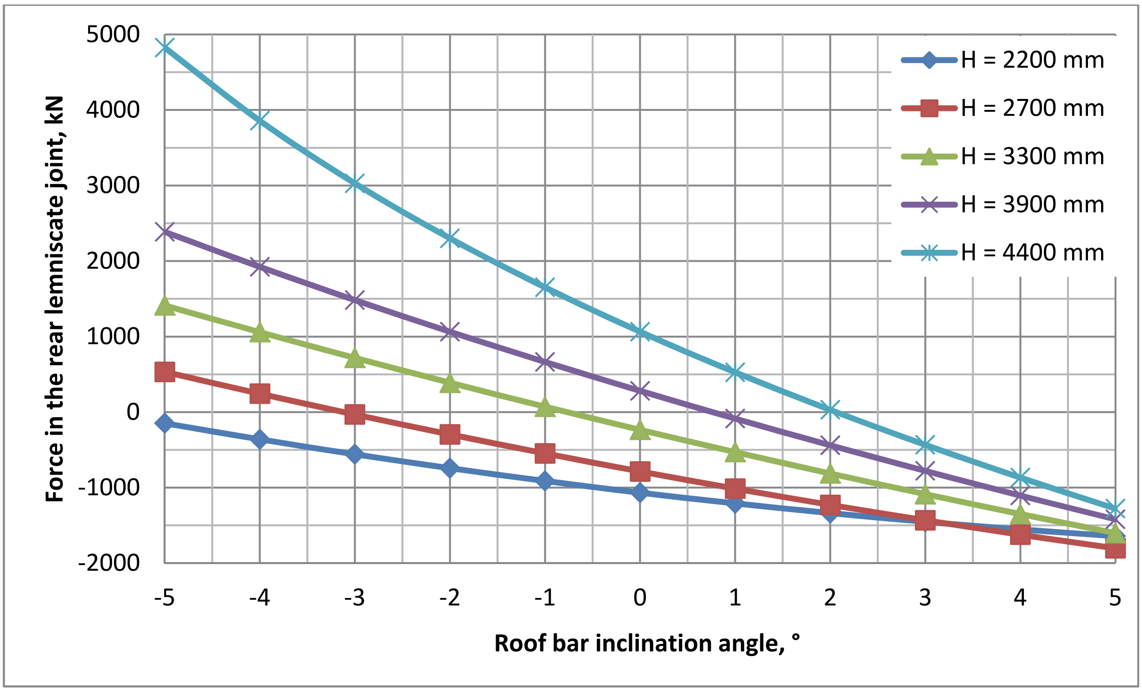

Fig. 9. Change of force C_2 in the rear joint of the CC unit in the function of the roof bar inclination angle [3]

4. CONCLUSIONS

It is necessary to adapt the height of the excavation to the constantly changing bed thickness and to deal with disturbances in the coal bed. This results in a situation when the angle between the lower plate and the upper plate of the roof bar may change within a certain range. This issue is not considered in the bench testing of the unit and in the design calculations either.

From the calculations presented in this paper one can see that the impact of the roof bar inclination angle in the range of -5° ÷ +5° on the inner forces and load-bearing capacity of the support unit cannot be treated as unsignificantly small. The relevance of this impact depends on the unit application height (i.e. its geometrical features) and the considered physical quantity (force in the hinge which connects the roof bar with the shield, force in joints, or load-bearing capacity of the unit). It can be acknowledged that:

- the load-bearing capacity of the support unit decreases proportionally to the increase of the value of the roof bar inclination angle,
- the force in the hinge, which connects the roof bar with the shield system, takes a minimal value for the given value of the roof bar inclination angle and the given height, in the case of each type of the tested support units, ,
- the percentage value of the change of force in the hinge, which connects the roof bar with the shield system, changes in the range of -44% ÷ 332%, with respect to an analogical force at a horizontal roof bar, depending on the type of the unit and the application height,
- the change in the roof bar inclination angle results in an even seven-times-bigger force in the lemniscate joint. Therefore it is necessary to consider in the designing process the changes of force values in the joints caused by the inclination of the roof bar. Significant impact of the changes in the roof bar inclination angle on the changes of force values in the hinges of basic elements of the unit makes it necessary to consider these changes in the desgning process of powered support units. This can be done, for example, by installing blockages that would prevent excessive inclination of the roof bar. The results of calculations presented in this paper confirm one more necessity, i.e. the support unit should be set in the excavation in such a way as to secure the horizontal position of the roof bar.

In this paper the authors presented the calculated percentage changes of the value of forces in the support unit hinges, caused by the changes in the roof bar inclination angle. Though these changes are quite big, they do not necessarily imply significant reductions of the support unit exploitation safety. As it was mentioned before, hinges are designed to bear loads which are calculated after analyzing many variants of the external load of the support unit. These variants differ in terms of the value and direction of the force in the roof bar abutment as well as the load of the shield system. Thus, the reduction of the safety coefficient of the considered connection, caused by the roof bar inclination, could be confirmed, for example, by the relation between the change of the force value in the hinge connecting the roof bar with the shield system and the force value for which the given connection was designed. This does not koncern the force at the horizontal bar and the assumption related the support unit load variant presented in item 2.

In the presented calculation examples it was assumed that the load-bearing capacity of props is equal to their working load limits. As during the exploitation of the support unit the pressure in under-piston compartments of props rarely achieves the value equal to the working pressure, the values of the support unit internal forces decrease proportionally to the pressure in props. Therefor the damages of hinges and joints of the support unit will not be as frequent as it would result from the percentage change in the force transmitted by these elements – which was presented in this paper.

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