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Computational Methods for Verifying the Normative Requirements Regarding the Lateral Correction Force of a Powered Roof Support

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Abstract: The article discusses laboratory methods and the corresponding computational methods verifying compliance with the normative requirements regarding the lateral correction force of the powered roof support. The currently used flat model only allows for checking the normative requirement in relation to the sum of active forces of the correction cylinders installed in the roof support. Determining the required value of the active force of each cylinder is possible due to the simplified FEM model of a powered roof support, described in the research work, treated as a uniform weightless elastic body loaded with a concentrated force recreating the weight of the roof support located on an inclined longwall panel. The third analysed computational method involves determining the reaction in the four correction cylinders of the roof support, creating a spatial, statically indeterminate system of forces. It enables determining the range of variability of the response in the correction cylinders as a function of the distribution of floor pressure on the roof support base. The discussed computational methods were used to determine, for example, the lateral correction force of one of the types of powered supports used in a longwall panel inclined at an angle of 35°. The usefulness of the discussed calculation methods at various stages of the designing process of the powered support and its certification has been confirmed.

Keywords: mining; longwall system; powered roof support; lateral correction force

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1. Introduction

Powered supports are the main equipment of the longwall system. They ensure the safety of the longwall crew and, by moving the conveyor together with the shearer (or plow), enable the longwall to move forward. At the same time, they effectively cover the machinery area, protecting people and equipment in the system against rocks falling from the side of the roof and the gob. The roof supports primarily ensure proper driving of the longwall panel in very different geological and mining conditions. Especially difficult geological and mining conditions are in longwall panels located in strongly inclined seams (CLDA—coal seams with a large dip angle) [1]. Instability of the powered supports is one of the most common reasons for disasters in these conditions [2], posing a threat to safety of employees and the normal operation of the equipment. Position of the roof support's centre of gravity and the longwall inclination impact the roof support stability. It was found that the coupling of two neighbouring supports has a positive effect on the stability of such an assembly. Analysis of the ability of coal mining mechanization in highly inclined seams in the Quangninh Basin in Vietnam is presented in [3]. The technical parameters of powered roof support systems manufactured in China, Russia, the Czech Republic, and Slovakia, intended for strongly inclined seams, were taken into account.

An example of using the fuzzy logic in selecting the equipment for a longwall system in an inclined seam is discussed in [4]. Application of the fuzzy analytical hierarchical process (FAHP) method is presented to select a proper mining equipment in the Hamkar coal mine, taking into account the impact of the coal seam parameters (slope, thickness, and homogeneity), geological and hydrogeological conditions (faults, fractures, joints, and groundwater) as well as geo-mechanical properties of the coal seam and the surrounding rocks. Use of the UDEC 2D computer program to analyze the longwall panel stability under an exploited seam is discussed, for example, in [5]. The problem of measuring the geometry of the powered support using a dedicated monitoring system (Shield Support Monitoring System—SSMS) and its use for forecasting the geological hazards in the longwall operation is discussed in [6].

Stability of the powered support used in top coal caving systems was also analysed. Models of the roof support mechanical stability in the longwall, considering its overturning, slipping, and twisting in the seam plane, were developed [7]. Increasing the initial load-bearing capacity and working load-bearing capacity of the roof support has a significant impact on improving its stability due to slippage and twisting, while the angle of a seam and the height of the wall adversely affect the stability of the support. In [8], types of roof support instability in a longwall top coal caving in steep seams were analysed. It was found that the key criterion for controlling the stability of the support of a fully powered longwall face of steep coal seams is to maintain the seam angle at a level smaller than the critical angle of the support instability. Factors increasing the critical angle of the roof support instability are the following: increasing the initial and working load-bearing capacity of the support, ensuring a high friction coefficient between the roof support components and the roof and floor, controlling the mining height and longwall advance, as well as roof supports arrangement. Attention was paid to the proper use of side shields to reduce a distance between neighbouring supports and constant control of the roof support position and turning [8]. In [9], the characteristics of roof movement in an inclined coal seam mined with a top coal caving system was analysed, and a mechanical model of supporting the surrounding rocks and their stability was developed. Importance of the powered roof support stability was emphasized.

According to observations, the coal recovery rate in top coal caving systems is 10–15% lower than in high longwalls [2]. Development in mining equipment enabled longwall mining technology to be used in coal seams up to 7 m thick. In these highly inclined, ultra-high workings, stability of the roof supports is also very important. In [2], types of the support instability were analysed, distinguishing the roof support slippage, overturning, and side shield turning. A multi-parameter analysis of sensitivity of the specified types of roof support instability to changes in 11 analysed factors was made. It was found that the main technical measures improving the stability of the roof supports are the following: diagonal arrangement of the longwall face, stepped arrangement of the floor, timely movement of the roof supports, maintaining the (residual) pressure in legs, and increasing the initial load-bearing capacity. In [10], displacement and deformation of the roof of a very high longwall panel were analysed, and its working load was determined by introducing the concept of an equivalent direct roof. By analysing the coal lumps chipping away the longwall, coal lumps positions were identified, and the required roof supporting was determined to prevent this. At the same time, very high roof supports are more prone to instability. Using the mechanical model, stability of very high supports was analysed. It has been shown that the limit angle of overturning has a hyperbolic relationship with the position of centre of gravity; in conditions of a very high wall, increasing the width of the base significantly improves stability of the roof support, what in turn means reduced load to a floor; the roof support slip limit angle is positively correlated with its load and the friction coefficient between a support and a floor.

The problem of the stability of a powered support in coal face with large angles both along strike and dip (CLSD) requires a separate treatment. In [11] a mechanical model of the “roof support—surrounding rock” system was presented, taking into account impact of the seam dip angle on the stability of the roof support along the strike. The relationships between the critical overturning angle and the critical slip angle of the roof support along the strike in a coal face with a large dip angle, and the height of the support, its load-bearing capacity, friction coefficient, and other factors were determined. Analytical relationships derived from the static diagram of the roof support in CLSD. Variants of mining the transverse wall to the up or to the dip were taken into account. In each variant, the following three supports were considered: a freestanding roof support, a roof support set to load in the longwall, and a special condition with a partial load to the gob shield caused by a void in the caving.

Detailed analysis of the considered static diagrams of the roof support in a longwall with a large dip angle allowed researchers to formulate conclusions regarding technical measures to increase the stability of the roof support in these conditions. It was found that it is necessary to optimize the roof support structure by reducing the height of its centre of gravity and its mass, increasing length and width of the base, and reasonably increasing its initial and working load-bearing capacity [7]. To increase stability of the support threatened by slippage, the proper measures should be introduced to increase friction between a base and a floor and between a canopy and a roof, what is especially important for stability of a roof support when advancing [11].

Rotation range of the mover beam should also be limited, e.g., by using mechanical stops or, more preferably, a hydraulic cylinder with a safety valve. This prevents the scraper conveyor from slipping and the roof support from turning while moving [11]. An example analysis of the rib of the base lateral correction arm is presented in [12]. It was also proposed to install an additional corrective cylinder in the base and give each roof support a comprehensive function in terms of its stability [9].

In addition to the issues discussed above regarding the load to the powered roof support and technical measures ensuring the stability of the support in inclined workings, the safe mining in these workings requires taking into account a number of natural hazards, such as: roof collapse, rock mass burst, methane release, aerological hazards, and technical information regarding the mining technology in the longwall. This article covers only a small selection of factors affecting the safe mining in the inclined mines, namely, the lateral correction force of the roof support. Analysis of standard requirements for correction cylinders installed in the powered support in terms of its stability in workings inclined at an angle of >30° is the subject of this publication. Roof supports, treated as machines, are subject to the provisions set out in the Machinery Directive (2006/42/EC) [13] and to assessment of conformity with the detailed provisions of the dedicated harmonized standards of the EN 1804 series [14–16] by the Certification Body [17] presents the general principles of implementing the uniform technical requirements given in the harmonized standards for powered roof supports [14–16] and the process of creating the currently valid edition of the mentioned standards. In the powered roof support certification, which is required for introducing it to the market, meeting of all requirements included in the mentioned standards must be verified by tests in an accredited testing laboratory. In some cases, these requirements also include provisions enabling, under certain conditions, the replacement of laboratory tests with computer simulations—generally speaking, computational procedures. An example of a requirement, the meeting of which is not always verified in laboratory tests, is the lateral correction force of the roof support intended for operation in longwall with a longitudinal inclination greater than 30°. The lateral correction force of such a support should be greater than the force resulting from the impact of three neighboring supports that are not set to load and have lost stability in the freestanding state [14] (Figure 1). It follows that the discussed normative requirement concerns only the design features of the powered roof support and was formulated in isolation from the natural and technical conditions in the working.

In Figure 2 the facility for testing the lateral correction force for a powered roof support on inclination is presented [18].

Figure 1. Arrangement for the required lateral correction of the powered roof support.

Figure 2. Test for lateral correction force of powered roof supports [18].

In Poland, there is only one specialized facility for such tests Figure 3 [19]. Unfortunately, the functional parameters of this stand make it impossible to test the lateral correction force of majority of currently manufactured roof supports, due to the size of the support pitch and its height. It should therefore be concluded that further testing the lateral correction force is economically unjustified due to the need to significantly expand the test stand only to test lateral correction force, while in the case of other standard test procedures [20,21], there is no need to modify the testing facility. Moreover, in the case of testing newly manufactured roof supports, time and cost of testing significantly increases due to the need for manufacturing three prototype supports.

Figure 3. The stand for testing the powered roof supports in KOMAG [19].

In engineering practice, various computational models are used to check whether the requirement for the roof support lateral correction force is met. They differ in the model complexity and in simplifying assumptions used. The aim of this publication is to analyse the mentioned computational methods in terms of their usefulness in the process of designing the powered supports.

2. Materials and Methods

All discussed calculation methods treat the roof support as either a perfectly rigid body or an elastic body with stiffness that makes it possible to ignore impact of any deformations on the value of forces in the correction cylinders. The elastic deformation of the floor is also neglected. The supporting reactions of the roof support set to load in a longwall at the installation points of its correction cylinders, maintain its balance in the set of three freestanding supports, which, located on a strongly inclined floor, would have lost its stability. The normative requirement [14] applies to the active force of correction cylinders (understood as the force resulting from the supply pressure of this cylinder and the piston surface area) installed in a freestanding support neighboring the support set to load in a longwall. Active force of these correction cylinders must be at least equal to the supporting reactions acting from the side of the support set to load in a longwall on the set of three freestanding supports.

2.1. Determination of the Resultant Reaction of the Correction Cylinders Using a Flat Model of the Powered Roof Support

The diagram of the flat system of forces acting on the set of freestanding powered supports is shown in Figure 4.

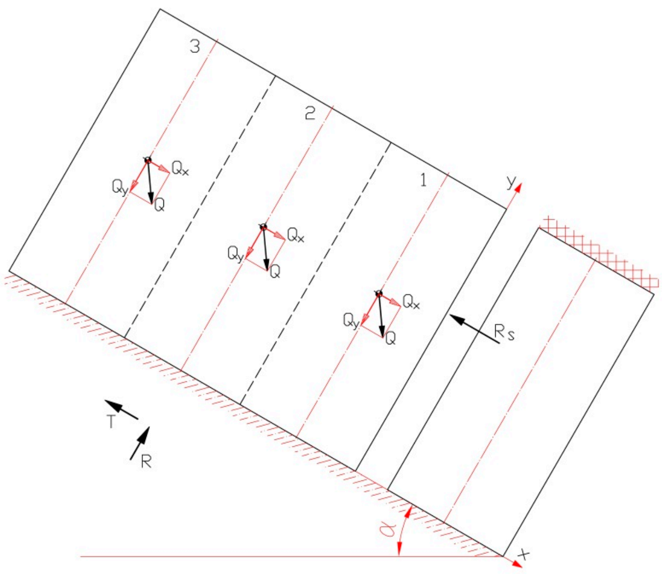

Figure 4. The diagram of the flat system of forces acting on the set of freestanding powered supports.

A flat model of the system of forces acting on a set of three supports not set to load in a longwall enables determining the resultant load-bearing capacity of the correction cylinders of the end support resting on the roof support set to load in a longwall. The set of three supports, standing above the roof support set to load in a longwall, is treated as a statically unchanging system of perfectly rigid bodies. Forces in the correction cylinders of these supports are treated as internal forces. The following forces act on the considered system of rigid bodies:

- Load—Q = m·g attached to the centre of mass of each support,
  Where:

  m—mass of the roof support, kg,

g—acceleration due to gravity, $m \cdot s^{-2}$

- Resultant reaction acting from the side of the roof support set to load in a longwall—Rs,
- Resultant reaction of the floor—R,
- Base-to-floor friction force—T, with the assumption that:

$$T = \mu \cdot R \tag{1}$$

Since the purpose of rough calculations is only to determine the resultant reaction in the correction cylinders, using the conditions of force projections balance (Figure 4), the following result was obtained:

$$R = 3 \cdot Q \cdot \cos(\alpha) \tag{2}$$

$$R_s = 3 \cdot Q \cdot sin(\alpha) - T \tag{3}$$

thus:

$$R_s = 3 \cdot Q \cdot (sin(\alpha) - \mu \cdot \cos(\alpha)) \tag{4}$$

where:

α—angle of a longwall inclination, °.

The standard requirement is met when:

$$P_{req} \geq R_s \tag{5}$$

where:

P_{req}—sum of active forces of the support's correction cylinders.

The presented model of the roof support assembly is very simplified. Therefore, it only enables an indicative check of whether the set of correction cylinders in the roof support meets the verified standard requirement. Its main disadvantage is the inability to determine distribution of forces in the correction cylinders, in particular as a function of the support height.

2.2. Determination of Reaction of the Corrective Cylinders Using 3D FEM Model of the Powered Roof Support

Modelling the powered roof support was carried out using the FEM module available in the INVENTOR program, commonly used in the process of designing the powered roof support (e.g., [22]). A simplified FEM model of the support is shown in Figure 5.

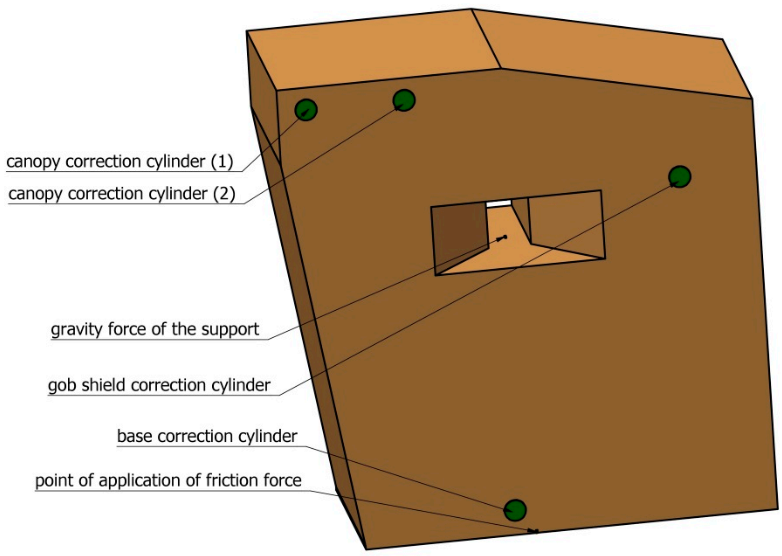

Figure 5. Simplified model of the powered roof support.

As the calculations neglect the impact of elastic deformations of the roof support components on the load to the correction cylinders, the support was modelled as a homogeneous solid with a geometric form and dimensions enabling the precise location of the center of mass of the physical model of the support and the points of application of forces in the correction cylinders. It was assumed that the calculations would not take into account the gravitational force acting on the finite elements modelling the support. The weight of the support was modeled as a concentrated force applied at the center of mass of the support. The line of action of this force creates an angle with the plane perpendicular to the floor, equal to the angle of inclination of the workings. Adopting such assumptions means that the shape of the support model has no impact on the calculation results. In the support model, you only need to determine position of the points of application of forces in the correction cylinders, the center of mass of the physical model of the support, and the point of application of the resultant friction force between the floor and the base. The forces in the correction cylinders and the resultant friction force were applied at proper points located on the side plane of the solid modelling the support (Figure 6).

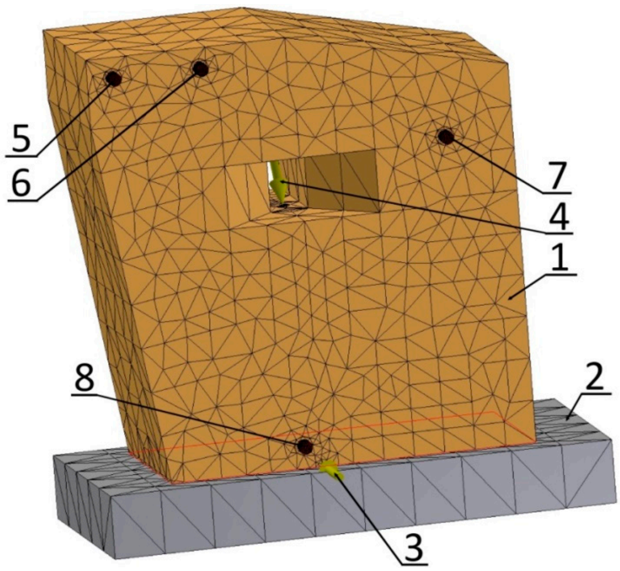

Figure 6. Computational model. 1—roof support, 2—floor, 3—friction force, 4—gravity force of the support in a longwall inclined at an angle α, 5, 6—operating points of the canopy correction cylinders, 7—action point of the gob shield correction cylinder, 8—operating point of the base correction cylinder).

In the node of the coordinates corresponding to the coordinates of the centre of mass of the physical model of the support, a concentrated force recreating the weight of the support acting on it in the longwall, the floor of which is inclined at an angle α, is attached. The coordinates of all highlighted points and the values of concentrated forces acting on the model presented in Figure 6 recreate the parameters and geometric features of the physical model of a support of a given height.

In addition to the described model of the roof support, the analyzed FEM computational model consists of a model of the floor and resistance elements in the places of operation of the correction cylinders (Figure 6). The reaction generated in a given resistance element is equal to the force in the respective correction cylinder. Respective contacts and bonds between the elements were assumed in the computational model. Fixed constraints were assumed to the floor and the retaining elements to the cylinders. Sliding, frictionless bonds were installed between the support and the floor and between the retaining elements and the support. The simplified model enabled discretization using TETRA finite elements. Elastic-plastic material with parameters specific to steel was assigned to the homogeneous finite elements of the model. The average size of a mesh element was 0.1 of the model size of a given element, the minimum size of a mesh element was assumed to be 0.2 of the average size, the mesh gradation coefficient was limited by a factor of 1.5, and the rotation angle of the mesh triangle was set to 60°. With the mesh parameters determined in this way, automatic discretization of the model was selected. Local automatic mesh refinement is not important in the calculation process because we do not analyse the number of reduced stresses, only the reactions in the resistance elements. Parameters of the real powered roof support with a height range from 1.6 to 3.4 m and a mass of 17,420 kg were assumed for the calculations. The coordinates of the position of each correction cylinder, result directly from the roof support design. Position of the centre of mass was determined based on a detailed computer model built using the Autodesk INVENTOR Professional 2024 program.

Calculations were carried out using the MES calculation module built into the INVENTOR program. The simplified model declares that it is made of steel. When loaded only with a force equal to the actual weight of the roof support, the model can be practically considered non-deformable. The displacements of the roof support points caused by such a load are negligible, because the weight of the section usually constitutes 3–4% of the load to which the roof support will be subjected during laboratory tests. Similarly, in the case of the floor model and trust points, steel construction was declared. Omitting the force of gravity in the calculations also allows the floor and trust points to be treated as non-deformable. The generated calculation report contains, among others, the forces in the elastic resistance elements, corresponding to the forces in the correction cylinders acting on the support model of a given height. In the case of a different assumed support height, determination of the forces in the correction actuators requires modifying the FEM model of the support. However, since the shape of the solid modeling the support does not affect the calculation results, the modification of the model consists only in changing the coordinates of the centre of gravity of the physical model of the support, the action points of the correction cylinders, and the resistance elements of the correction cylinders.

2.3. Determination of Reaction of the Correction Cylinders Using the Analytical Method for 3D Model of the Powered Roof Support

The diagram of each discussed roof support model is shown in Figure 7. When developing the roof support model, the following simplifying assumptions were made:

1. The powered roof support is treated as a perfectly rigid body.
2. The upper plane of the canopy, parallel to the floor, does not touch the roof of the longwall panel.
3. The support is in a longwall panel, strongly inclined, with an angle of inclination—α.
4. There is friction between the base and the floor, with friction coefficient—μ.
5. The pressure forces of the base on the floor are distributed on the floor surface; they are characterized by a unit pressure force—r(x, y) (see Figure 7).
6. The roof support is loaded only with its own weight; vector—Q of the support weight is attached to the centre of mass of the roof support with coordinates (x_C, 0.5·b, z_C); where: b—support's pitch.
7. The line of action of force Q penetrates the floor plane beyond the contact surface of the base with the floor, i.e., the following condition is met:

$$z_C \cdot \mathrm{tg}(\alpha) > 0.5 \cdot b \tag{6}$$

   Thus, each powered roof support is not stable.
8. The freestanding powered roof support is kept in balance by the pressure of the base on the floor, the friction force between the base and the floor, and four forces—P_1, P_2, P_3, P_4 in the correction cylinders placed in the canopy, gob shield, and the base of the neighbouring support.

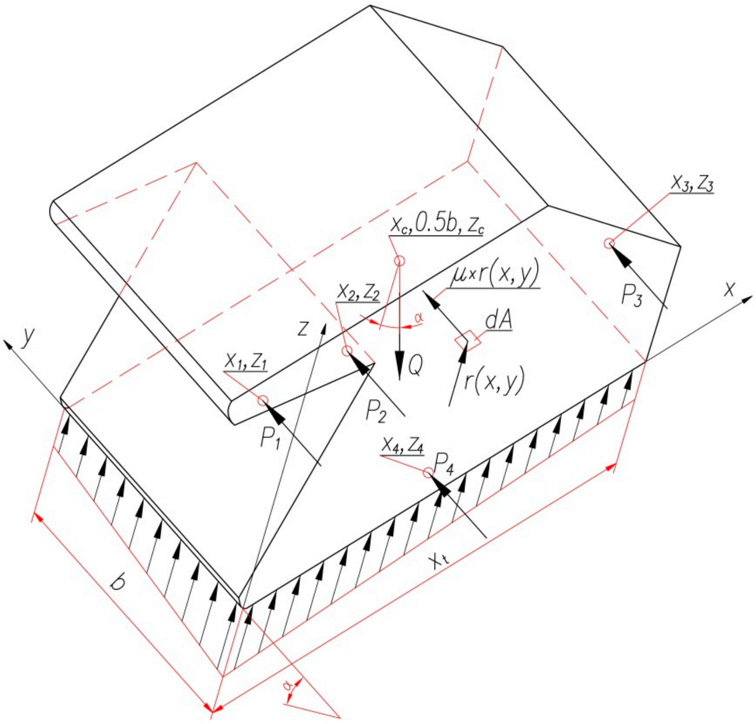

Figure 7. The static diagram of each powered roof support model.

Of the six equilibrium equations of the analysed spatial system of forces, the equilibrium equation of forces projections relative to the Oy axis is identically satisfied, while general information regarding the distribution of floor pressure on the support's base can be obtained by considering the following two equilibrium equations:

$$\sum F_{iz} = 0 = -Q \cdot cos(\alpha) + \int r(x,y) \cdot \mathrm{d}A \tag{7}$$

$$\sum M_{iy} = 0 = x_C \cdot Q \cdot cos(\alpha) - \int x \cdot r(x,y) \cdot \mathrm{d}A \tag{8}$$

thus:

$$\int r(x,y) \cdot \mathrm{d}A \ = Q \cdot cos(\alpha) \tag{9}$$

$$\int x \cdot r(x,y) \cdot \mathrm{d}A \ = x_C \cdot Q \cdot cos(\alpha) \tag{10}$$

The following relationships between the forces in the correction cylinders result from other three equilibrium equations:

$$P_1 + P_2 + P_3 + P_4 = Q \cdot sin(\alpha) - \int \mu \cdot r(x,y) \cdot \mathrm{d}A$$

$$P_1 + P_2 + P_3 + P_4 = Q \cdot sin(\alpha) - \mu \cdot Q \cdot cos(\alpha)$$

$$P_1 + P_2 + P_3 + P_4 = Q \cdot C_1 \tag{11}$$

where:

$$C_1 = sin(\alpha) - \mu \cdot cos(\alpha) \tag{12}$$

$$\begin{aligned} &P_1 \cdot z_1 + P_2 \cdot z_2 + P_3 \cdot z_3 + P_4 \cdot z_4 \\ &\quad = z_C \cdot Q \cdot sin(\alpha) - 0.5 \cdot b \cdot Q \cdot cos(\alpha) + \int y \cdot r(x,y) \cdot \mathrm{d}A \end{aligned} \tag{13}$$

In the case of the roof support that has lost stability, distribution of floor pressure on the base in planes parallel to the longwall panel is unknown. To determine the required force in the correction cylinders, it was assumed that under the impact of the support weight, forces in the correction cylinders, and the friction force between the floor and the base, the base is in contact with the floor over the entire surface, the base pressure distribution on the floor in a plane parallel to the longwall panel is determined by the following relationship:

$$\int y \cdot r(x,y) \cdot \mathrm{d}A \ = y_0 \cdot \int r(x,y) \cdot \mathrm{d}A = y_0 \cdot Q \cdot cos(\alpha) \tag{14}$$

Thus, the Equation (13) has the following form:

$$P_1 \cdot z_1 + P_2 \cdot z_2 + P_3 \cdot z_3 + P_4 \cdot z_4 = Q \cdot C_2 \tag{15}$$

where:

$$C_2 = \ z_C \cdot sin(\alpha) - (0.5 \cdot b - y_0) \cdot cos(\alpha) \tag{16}$$

$$P_1 \cdot x_1 + P_2 \cdot x_2 + P_3 \cdot x_3 + P_4 \cdot x_4 = x_C \cdot Q \cdot sin(\alpha) - \int \mu \cdot x \cdot r(x,y) \cdot \mathrm{d}A$$

$$P_1 \cdot x_1 + P_2 \cdot x_2 + P_3 \cdot x_3 + P_4 \cdot x_4 = x_C \cdot Q \cdot sin(\alpha) - \mu \cdot x_C \cdot Q \cdot cos(\alpha)$$

$$P_1 \cdot x_1 + P_2 \cdot x_2 + P_3 \cdot x_3 + P_4 \cdot x_4 = x_C \cdot Q \cdot C_1 \tag{17}$$

Equations (10), (15) and (17) show that the considered system of forces is statically indeterminate. To determine the forces in correction cylinders, the condition of consistent displacements of their piston rods should be taken into account. When considering the condition of displacement compliance, it was assumed that as a result of elastic deformations of the correction cylinders, the side planes of the adjacent supports, treated as perfectly rigid bodies, remain flat. Therefore, the ends of the sections—Δ_1, Δ_2, $\Delta_{3,}$ and Δ_4, illustrating the displacement of the piston rods in the correction cylinders, lie on the same plane (see Figure 8), and the condition of displacements consistency takes the following general form:

$$\Delta_2 = f(\Delta_1, \Delta_3, \Delta_4) \tag{18}$$

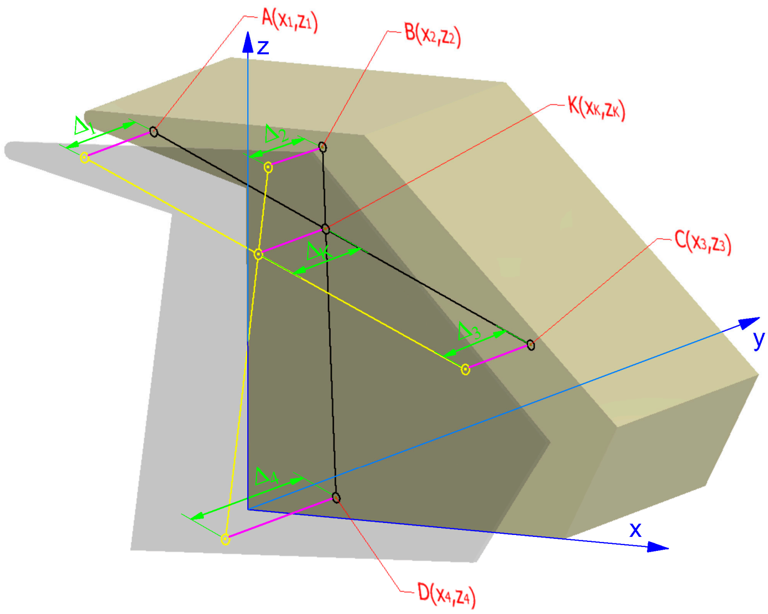

Figure 8. Condition of displacements consistency of piston rods in cylinders—Δ_1, Δ_2, $\Delta_{3,}$ and Δ_4.

Using the geometric relationships presented in Figure 8, the following was obtained:

$$\Delta_2 = \varepsilon_1 \cdot \Delta_1 + \varepsilon_3 \cdot \Delta_3 + \varepsilon_4 \cdot \Delta_4 \tag{19}$$

where:

$$\varepsilon_1 = \frac{L_{BD} \cdot [L_{AC} - L_{AK}]}{L_{KD} \cdot L_{AC}} \tag{20}$$

$$\varepsilon_3 = \frac{L_{AK} \cdot L_{BD}}{L_{KD} \cdot L_{AC}} \tag{21}$$

$$\varepsilon_4 = \frac{L_{KD} - L_{BD}}{L_{KD}} \tag{22}$$

L_{AC}, L_{AK}, L_{BD}, L_{KD}—distance between points A, B, C, D, and K, respectively.

Coordinates of point K (Figure 8) are determined by the following relationship:

$$x_K = \frac{(x_1 \cdot z_3 - x_3 \cdot z_1) \cdot (x_2 - x_4) - (x_2 \cdot z_4 - x_4 \cdot z_2) \cdot (x_1 - x_3)}{(z_2 - z_4) \cdot (x_1 - x_3) - (z_1 - z_3) \cdot (x_2 - x_4)} \tag{23}$$

$$z_K = \frac{(x_1 \cdot z_3 - x_3 \cdot z_1) \cdot (z_2 - z_4) - (x_2 \cdot z_4 - x_4 \cdot z_2) \cdot (z_1 - z_3)}{(z_2 - z_4) \cdot (x_1 - x_3) - (z_1 - z_3) \cdot (x_2 - x_4)} \tag{24}$$

After taking into account the equal length and compression stiffness of the correction cylinders, the Equation (19) takes the following form:

$$\varepsilon_1 \cdot P_1 - P_2 + \varepsilon_3 \cdot P_3 + \varepsilon_4 \cdot P_4 = 0 \tag{25}$$

Finally, forces in the correction cylinders are determined from a system of linear algebraic Equations (11), (15), (17) and (25).

The determined forces in the correction cylinders of the considered roof support constitute an additional load on the adjacent support below. Therefore, in accordance with the standard requirements, the correction cylinders operating at the junction of the free-standing support and the roof support set to load in a longwall—$P_{1.3}$, $P_{2.3}$, $P_{3.3}$, $P_{4.3}$, are three times greater than the corresponding force in the correction cylinder of a single support, resulting from the system of Equations (11), (15), (17) and (25).

$$P_{1.3} = 3 \cdot P_1 = 3 \cdot \frac{D_1}{D} \tag{26}$$

$$P_{2.3} = 3 \cdot P_2 = 3 \cdot \frac{D_2}{D} \tag{27}$$

$$P_{3.3} = 3 \cdot P_3 = 3 \cdot \frac{D_3}{D} \tag{28}$$

$$P_{4.3} = 3 \cdot P_4 = 3 \cdot \frac{D_4}{D} \tag{29}$$

where:

$$D = det \begin{bmatrix} 1 & 1 & 1 & 1 \\ z_1 & z_2 & z_3 & z_4 \\ x_1 & x_2 & x_3 & x_4 \\ \varepsilon_1 & -1 & \varepsilon_3 & \varepsilon_4 \end{bmatrix} \tag{30}$$

$$D_1 = det \begin{bmatrix} QC_1 & 1 & 1 & 1 \\ QC_2 & z_2 & z_3 & z_4 \\ Qx_C C_1 & x_2 & x_3 & x_4 \\ 0 & -1 & \varepsilon_3 & \varepsilon_4 \end{bmatrix} \tag{31}$$

$$D_2 = det \begin{bmatrix} 1 & QC_1 & 1 & 1 \\ z_1 & QC_2 & z_3 & z_4 \\ x_1 & Qx_C C_1 & x_3 & x_4 \\ \varepsilon_1 & 0 & \varepsilon_3 & \varepsilon_4 \end{bmatrix} \tag{32}$$

$$D_3 = det\begin{bmatrix} 1 & 1 & QC_1 & 1 \\ z_1 & z_2 & QC_2 & z_4 \\ x_1 & x_2 & Qx_C C_1 & x_4 \\ \varepsilon_1 & -1 & 0 & \varepsilon_4 \end{bmatrix} \quad (33)$$

$$D_4 = det\begin{bmatrix} 1 & 1 & 1 & QC_1 \\ z_1 & z_2 & z_3 & QC_2 \\ x_1 & x_2 & x_3 & Qx_C C_1 \\ \varepsilon_1 & -1 & \varepsilon_3 & 0 \end{bmatrix} \quad (34)$$

To select the required active force of the correction cylinder, the following forces should be determined: $P_{1.3} \div P_{4.3}$ in the entire roof support height range in which the free-standing support has lost stability.

3. Results

For each of the analyses described in Sections 2.1–2.3, a proper methodology was used. The common part for all three methods is the determination of the roof support model and its characteristic dimensions, according to the diagram presented in Figure 9. The next step is to determine the model of loading, i.e., determining the position of the centre of mass, the size of the roof support, the limit angle of its inclination, and the friction coefficient for the roof support base and the floor. These two steps allow determining the input data for further calculations. The next steps are specific to each calculation method:

- Calculations using the flat model involve substituting the input data into the formulas given in Section 2.1.
- Calculations using the FEM model require adapting the geometric parameters of the model to the determined geometric input data, and then imposing the boundary conditions on the model characterizing the supporting methods and load parameters (contacts, bonds, external forces).
- The algorithm of the calculation method based on the equilibrium equations of the spatial system of forces is presented in point 2.3.

Calculations were made on the example of a powered support with a height range of 1.6 to 3.4 m and a pitch of 1.5 m, used in one of the Polish mines. According to the manufacturer's declaration, the roof support can be used in longitudinal longwall workings with a dip angle of up to 35°. Therefore, the support correction cylinders must meet the standard requirements [14] with regard to the required correction force. Mass of this support is 17,420 kg. The physical model of the support (Figure 9), taking into account the spatial location of all its components, was used to determine the position of its center of gravity and the position of action points of each correction cylinder.

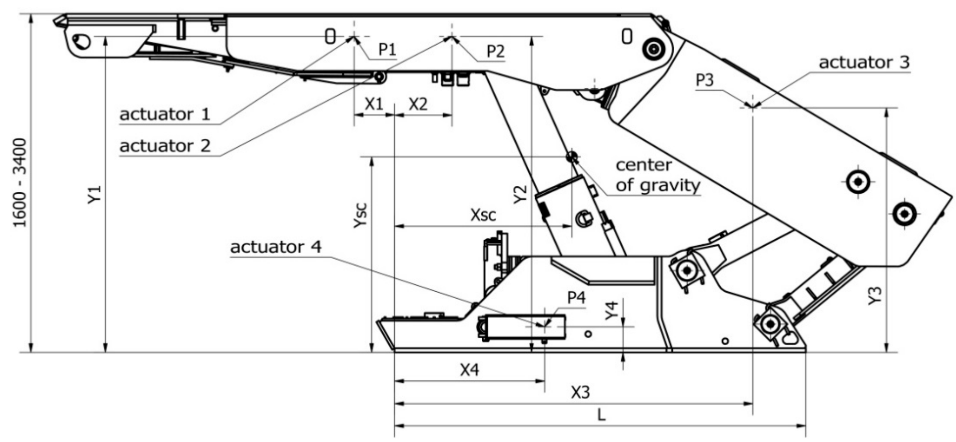

Figure 9. Position of characteristic points of the powered roof support.

From the geometrical analysis of the support, it results that in the case of longwall dip angle—α = 35° and the support height—H meets the following condition:

$$H \geq 2000 \text{ mm} \quad (35)$$

The line of action of the support weight penetrates the floor plane beyond the area where the base contacts the floor. This means that a single freestanding powered roof support is not stable under these conditions. Since the requirement of loss of stability for three free-standing roof supports, formulated in the standard requirement [14], is met for α = 35° and the height of the support meets the condition (35), forces in the roof support correction cylinders were calculated using all three methods described only for the support height varying from 2000 mm to 3400 mm.

3.1. Determination of the Resultant Reaction of Corrective Cylinders Using a Flat Model of the Powered Roof Support

The following data were assumed to determine the resultant reaction acting on a set of three supports which lost stability from the side of the support set to load in a longwall:

- Roof support weight m = 17,420 kg,
- Gravity acceleration g = 9.80665 $m \cdot s^{-2}$,
- Longwall dip angle α = 35°,
- Friction coefficient between base and floor μ = 0.3

Roof support weight—Q, is:

$$Q = m \cdot g = 170.832 \text{ kN} \quad (36)$$

According to the Formula (4) the following is obtained:

$$R_s = 168.012 \text{ kN}$$

According to (5), the standard requirement is met if the sum of correction cylinders forces—P_{req} meets the following condition:

$$P_{req} \geq 168.012 \text{ kN}$$

The analysed support is equipped with four corrective cylinders: two with a diameter of 90 mm in the canopy, one with a diameter of 90 mm in the gob shield, and one with a diameter of 120 mm in the base. With the minimum supply pressure in the hydraulic system of the support at the level of 25 MPa, the sum of the active forces of the correction cylinders is 759.7 kN, what is much higher than the required value.

3.2. Determination of the Resultant Reaction of Corrective Cylinders Using Calculations Based on the Finite Element Method (FEM)

In calculations a simplified 3D model of the powered support, presented in Section 2.2, was used. When building the FEM model of the roof support, parameters and geometric features of the physical model of the support presented in Figure 9 were taken into account. Due to the possibility of calculating the required correction force for each of the cylinders depending on the height of the roof support, calculations were carried out for the range of heights of the roof support resulting from the condition (35), with an advance of 200 mm. For each considered support's height, position of its characteristic points was determined based on the complete physical model of the roof support. The force in the correction cylinders of each roof support, obtained on the basis of appropriately modified supports FEM models, are given in Table 1 and shown in Figure 10.

Table 1. Forces in the correction cylinders of a single roof support depending on the support's height.

Roof Support's Height, mm	2000	2200	2400	2600	2800	3000	3200	3400
P_1, kN	7.58	7.98	8.56	8.91	9.17	9.47	9.99	9.79
P_2, kN	15.61	15.79	15.73	15.47	15.54	15.54	15.35	15.64
P_3, kN	21.42	21.76	22.15	22.41	22.72	23.06	23.42	23.08
P_4, kN	11.39	10.47	9.57	9.20	8.58	7.94	7.25	7.49
Total required correction forces, kN	56.01	56.00	56.01	56.00	56.00	56.00	56.00	56.01

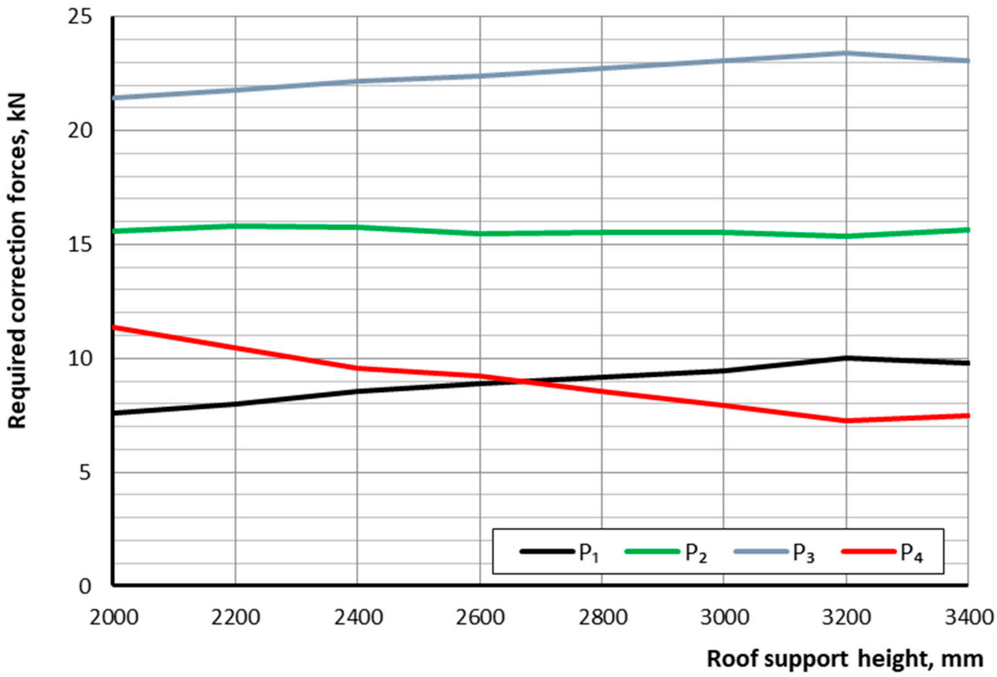

Figure 10. Graph of forces in the correction cylinders of a single roof support depending on the support's height.

The standard requirement [14] concerns the correction force in relation to the correction cylinders located at the contact of the support not set to load and the support set to load in a longwall. Required forces—$P_{1.3}$, $P_{2.3}$, $P_{3.3}$, and $P_{4.3}$—in each corrective cylinder of the support adjacent to the roof support set to load, are determined after taking into account the internal forces acting between the three roof supports not set to load and are listed in Table 2 and shown in Figure 11.

Table 2. Required forces in each correction cylinder in the support adjacent to the support set to load.

Roof Support Height, mm	2000	2200	2400	2600	2800	3000	3200	3400
$P_{1.3}$, kN	22.74	23.95	25.67	26.74	27.50	28.42	29.97	29.38
$P_{2.3}$, kN	46.83	47.38	47.19	46.42	46.61	46.62	46.04	46.93
$P_{3.3}$, kN	64.27	65.28	66.44	67.23	68.17	69.17	70.26	69.24
$P_{4.3}$, kN	34.17	31.40	28.72	27.61	25.73	23.81	21.75	22.48
Total required correction forces, kN	168.02	168.01	168.02	168.01	168.01	168.01	168.01	168.02

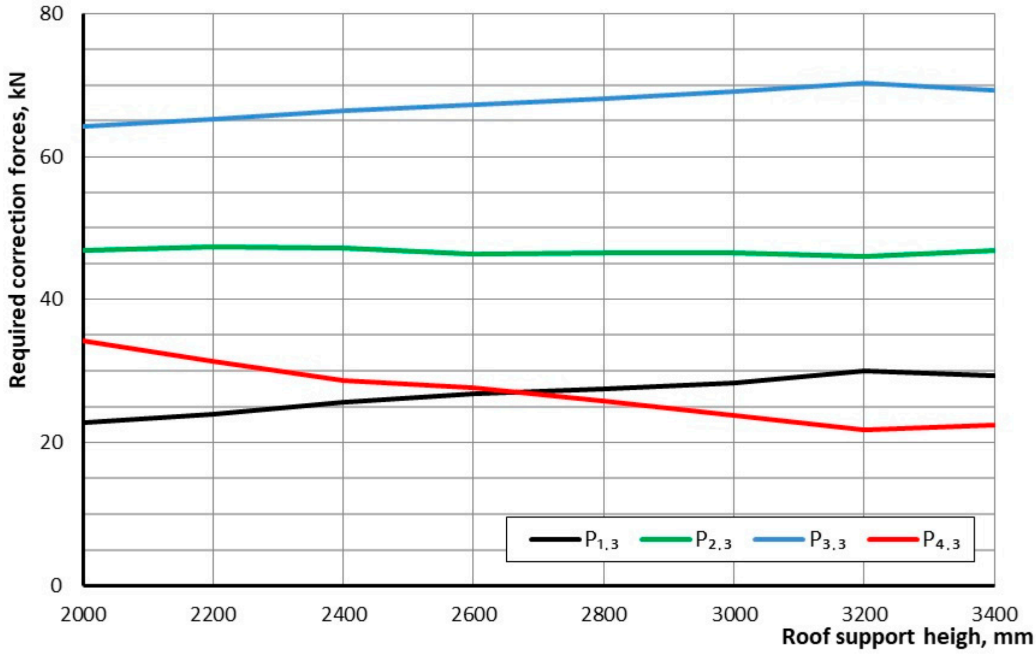

Figure 11. Required forces in each correction cylinder of the roof support adjacent to the roof support set to load, depending on the roof support height.

Sum of the required correction forces of the roof support remains the same regardless of the support height, and its value differs from the value obtained as a result of calculations when using a flat model by a maximum of 0.003%. This negligible difference in the resultant value of the correction force results from the fact that trace displacements of the model's characteristic points (of the order of 0.0001 mm) were taken into account during FEM calculations, which is not taken into account by the calculations of the flat model. The required forces in each cylinder change as the height of the roof support changes and the required force of the given cylinder reaches its maximum. Therefore, the maximum required correction force of the roof support, valid in the entire analyzed support's height range, is determined by the following Formula (37):

$$P_{req}(2000 \leq H \leq 3400) = \sum_{i=1}^{i=4} max(P_{i.3}(2000 \leq H \leq 3400)) \quad (37)$$

$$P_{req}(2000 \leq H \leq 3400) = 188.926 \text{ kN}$$

The maximum required correction force for the roof support, determined in this way, is 12.4% higher than the required correction force calculated using a flat model of a set of three supports not set to load, which have lost stability in a strongly inclined longwall. It should be noted, however, that theaximum required correction force, equal to 188.926 kN, is much lower than the sum of the active forces of the correction cylinders installed in the analysed powered roof support, equal to 759.7 kN (at the cylinder supply pressure of 25 MPa).

The results presented in this article concern the roof support that has been approved for use in workings with an inclination angle of up to 35°, and therefore the calculations were performed for an angle of 35°. Of course, the required correction force changes as the angle of inclination of the roof support changes. To illustrate impact of the angle of inclination of the roof support on the required correction forces, calculations were made for the roof support with a height of 3400 mm, shown in Figure 9, with an inclination angle in the range of 30° to 40°. The results of calculations of the required correction forces under the impact of three sections, in accordance with the standard provisions [14], are given in Table 3 and shown in Figure 12.

Table 3. Forces in the correction cylinders in the powered roof support depending on its inclination angle.

Longwall Dip Angle, °	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
P_1	24.05	25.19	26.27	27.35	28.41	29.38	30.51	31.55	32.57	33.59	34.60
P_2	36.97	38.51	40.01	41.49	42.95	46.93	45.84	47.26	48.67	50.06	51.44
P_3	54.54	57.19	59.94	62.66	65.35	69.24	70.69	73.32	75.94	78.53	81.09
P_4	7.71	11.26	14.97	18.69	22.40	22.48	29.81	33.50	37.18	40.85	44.51
Total required correction forces. kN	120.09	132.15	141.19	150.18	159.12	168.02	176.85	185.63	194.36	203.03	211.64

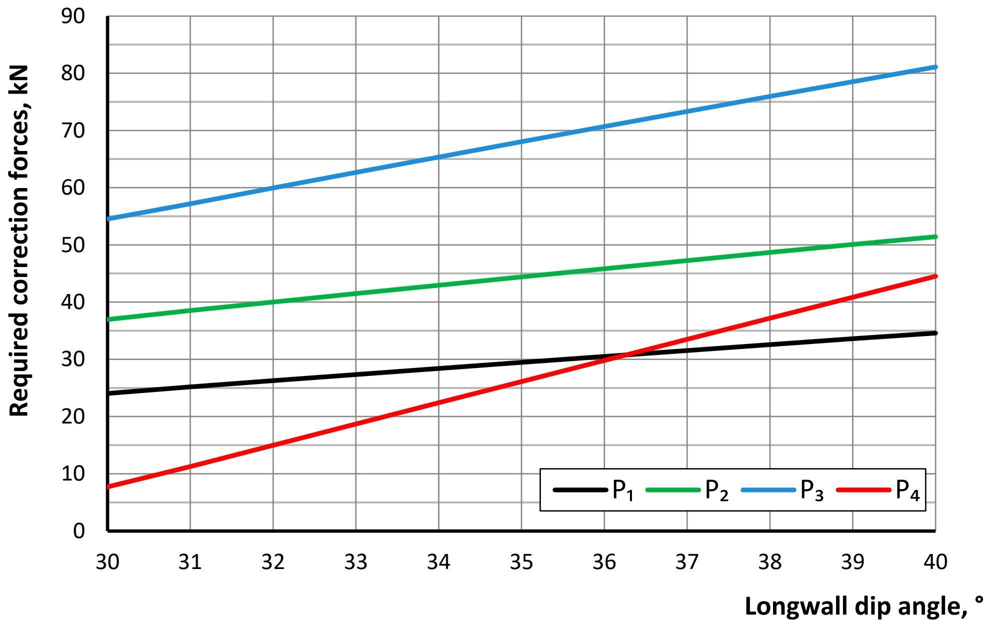

Figure 12. Required forces in each correction cylinder of the roof support neighbouring with the roof support set to load in a working depending on its dip angle.

As expected, the required forces of the correction cylinders increase with the increase of the roof support inclination angle. More intense increase in the required force of the cylinder located in the roof support base results from the decreasing friction force of the floor against the base, along with the increase in the angle of inclination of the roof support.

3.3. Determination of the Resultant Response of Correction Cylinders Using the Analytical Method for the 3D Model of the Powered Roof Support

As the correction cylinders installed in the powered roof support, analysed in this article, have different diameters, the relationship between the displacements—Δ_1, Δ_2, Δ_3, Δ_4, of their piston rods (see Figure 8), and forces—P_1, P_2, P_3, P_4, have the following form:

$$\Delta_1 = \frac{P_1 \cdot L}{E \cdot A_1} \qquad \Delta_2 = \frac{P_2 \cdot L}{E \cdot A_1} \qquad \Delta_3 = \frac{P_3 \cdot L}{E \cdot A_1} \qquad \Delta_4 = \frac{P_4 \cdot L}{E \cdot A_4} = \frac{P_4 \cdot L}{E \cdot A_1} \cdot \nu_4 \tag{38}$$

where:

$$\nu_4 = \frac{A_1}{A_4} = \left(\frac{d_1}{d_4}\right)^2 = \left(\frac{90}{120}\right)^2 = 0.5625 \tag{39}$$

So, in the case of analysed powered roof support, the Equation (25) has the following form:

$$\varepsilon_1 \cdot P_1 - P_2 + \varepsilon_3 \cdot P_3 + \varepsilon_4 \cdot \nu_4 \cdot P_4 = 0 \tag{40}$$

and the elements of the equation systems (11), (15), (17) and (38) are determined from the following formulas:

$$P_1 = \frac{D_{1(4)}}{D_{(4)}} \qquad P_2 = \frac{D_{2(4)}}{D_{(4)}} \qquad P_3 = \frac{D_{3(4)}}{D_{(4)}} \qquad P_4 = \frac{D_{4(4)}}{D_{(4)}} \tag{41}$$

where:

$$D_{(4)} = det\begin{bmatrix} 1 & 1 & 1 & 1 \\ z_1 & z_2 & z_3 & z_4 \\ x_1 & x_2 & x_3 & x_4 \\ \varepsilon_1 & -1 & \varepsilon_3 & \nu\varepsilon_4 \end{bmatrix} \quad D_{1(4)} = det\begin{bmatrix} QC_1 & 1 & 1 & 1 \\ QC_2 & z_2 & z_3 & z_4 \\ Qx_C C_1 & x_2 & x_3 & x_4 \\ 0 & -1 & \varepsilon_3 & \nu\varepsilon_4 \end{bmatrix}$$

$$D_{2(4)} = det\begin{bmatrix} 1 & QC_1 & 1 & 1 \\ z_1 & QC_2 & z_3 & z_4 \\ x_1 & Qx_C C_1 & x_3 & x_4 \\ \varepsilon_1 & 0 & \varepsilon_3 & \nu\varepsilon_4 \end{bmatrix} \quad D_{3(4)} = det\begin{bmatrix} 1 & 1 & QC_1 & 1 \\ z_1 & z_2 & QC_2 & z_4 \\ x_1 & x_2 & Qx_C C_1 & x_4 \\ \varepsilon_1 & -1 & 0 & \nu\varepsilon_4 \end{bmatrix} \tag{42}$$

$$D_{4(4)} = det\begin{bmatrix} 1 & 1 & 1 & QC_1 \\ z_1 & z_2 & z_3 & QC_2 \\ x_1 & x_2 & x_3 & Qx_C C_1 \\ \varepsilon_1 & -1 & \varepsilon_3 & 0 \end{bmatrix}$$

For example, Figure 13 shows the force diagram in the correction cylinders of a single roof support not set to load, determined for the parameter y_0 = 460 mm.

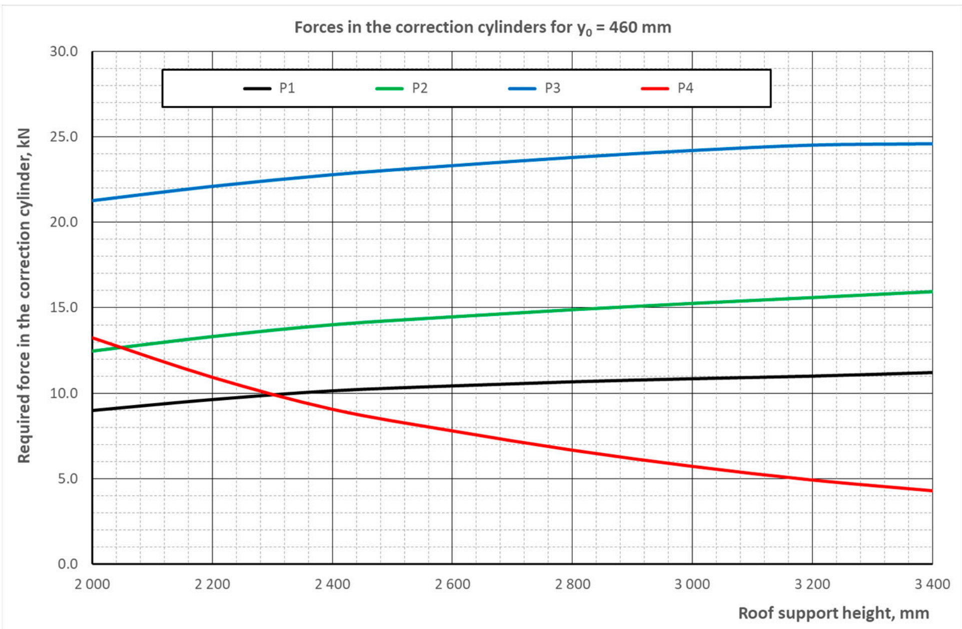

Figure 13. Diagram of forces in each correction cylinder depending on the roof support height.

From the relationships (14) ÷ (16) it follows that the force in the correction cylinders depends on the distribution of base pressure on the floor. The measure of this distribution is the initially assumed parameter—y_0, interpreted physically as a coordinate defining the distance of the resultant pressure of the base from the floor edge—from the O_x axis (see Figure 7). For example, Figures 14 and 15 show graphs of the dependence of the force P_1 and P_4 on the coordinate y_0.

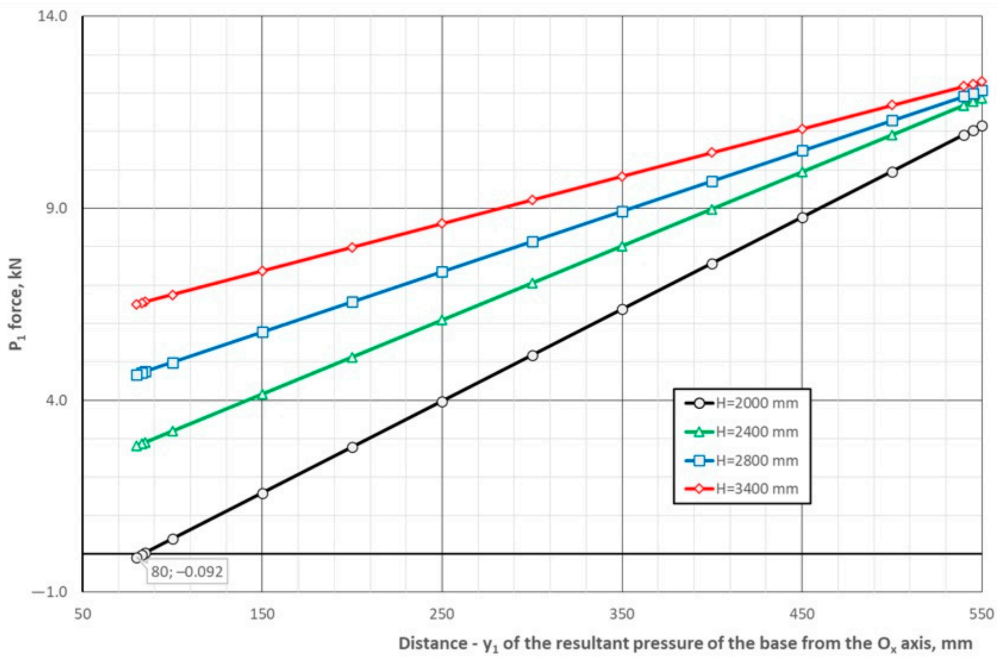

Figure 14. Graph of the force—P_1 in the previous correction cylinder in the canopy in a function of parameter—y_0.

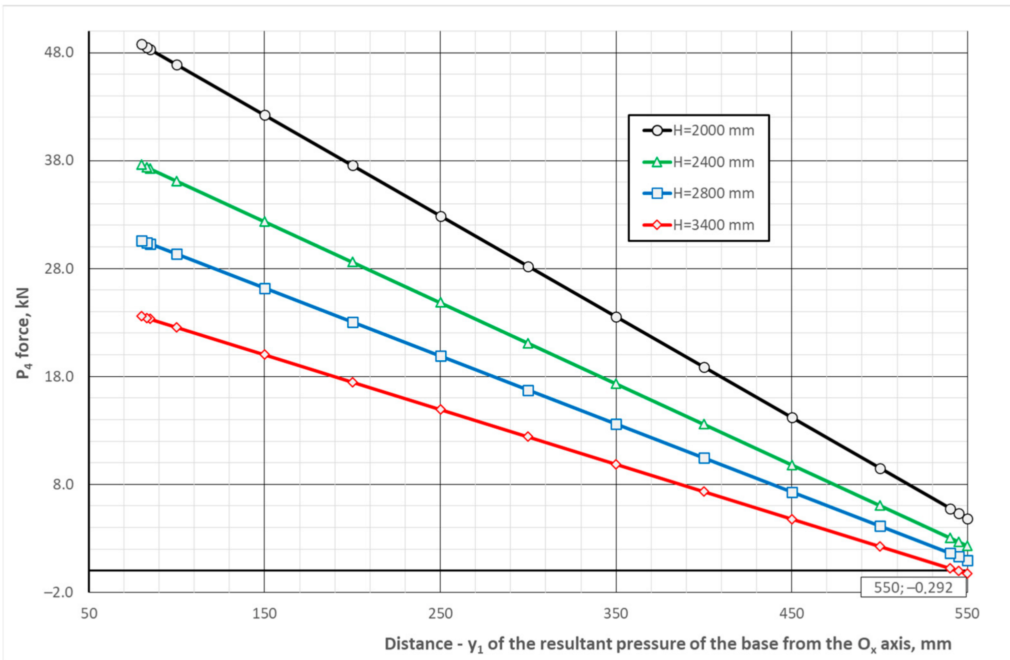

Figure 15. Graph of the force—P_4 in the base's correction cylinder in a function of the parameter—y_0.

Bonds between the side surface of the roof support set to load and the side surface of the adjacent support that has lost stability are one-sided. Therefore, the reactions acting from the support set to load, applied in the places where the correction cylinders are installed, cannot be less than zero. This results in a limitation on the type of distribution of floor pressure on the base, which can be balanced by action of the correction cylinders on the roof support. In the case of the analyzed powered roof support, the y_0 coordinate characterizing the distribution of floor pressure on the base should meet the following condition (43):

$$85 \text{ mm} < y_0 < 540 \text{ mm} \tag{43}$$

Thus, the set of forces—$P_{1.3}$, $P_{2.3}$, $P_{3.3}$, i $P_{4.3}$—in the cylinders of the roof support not set to load adjacent to the support set to load in a longwall, determined for y_0 coordinate meeting the condition (43). Limitations of the variability range of forces $P_{1.3}$, $P_{2.3}$, $P_{3.3}$, and $P_{4.3}$, within the entire range of the support height in which the supports not set to load lost their stability is presented in Figure 16 and in Table 4.

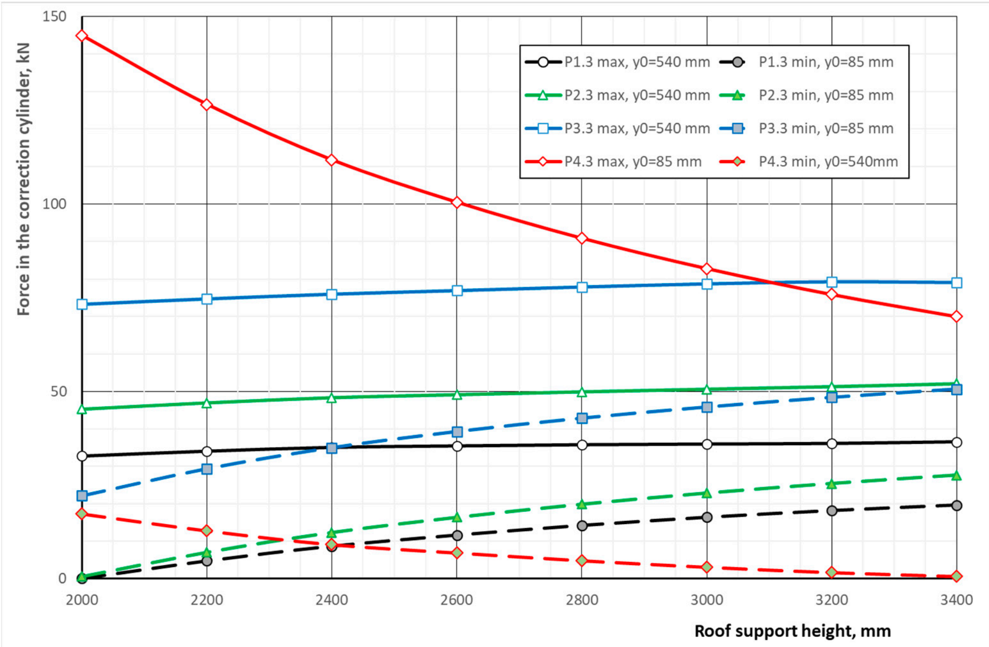

Figure 16. Ranges of variability of reactions—$P_{1.3}$, $P_{2.3}$, $P_{3.3}$, and $P_{4.3}$—acting on the roof supports, which lost stability from the side of the support set to load in a longwall.

Table 4. Limitations of the variability range of forces—$P_{1.3}$, $P_{2.3}$, $P_{3.3}$, i $P_{4.3}$—in the cylinders of the roof support not set to load adjacent to the support set to load in a longwall.

Correction Force	Range Limit	Roof Support Height, mm							
		2000	2200	2400	2600	2800	3000	3200	3400
$P_{1.3}$, kN	Max	32.74	34.04	35.04	35.44	35.75	35.94	36.10	36.54
	Min	0.08	4.79	8.72	11.67	14.25	16.42	18.22	19.69
$P_{2.3}$, kN	Max	45.26	46.96	48.34	49.15	49.92	50.62	51.30	52.08
	Min	0.64	7.10	12.37	16.41	19.89	22.86	25.42	27.65
$P_{3.3}$, kN	Max	73.23	74.68	75.93	76.90	77.86	78.69	79.26	79.06
	Min	22.15	29.37	34.98	39.29	42.84	45.81	48.38	50.58
$P_{4.3}$, kN	Max	144.92	126.56	111.77	100.48	90.88	82.78	75.87	69.97
	Min	17.33	12.82	9.14	6.93	4.86	3.12	1.68	0.65

According to the standard requirement [14], the correction cylinder should transfer the impact of three not set to load supports that have lost stability. Therefore, the active force of the adequate correction cylinder should meet the following condition:

$$P_{1.req} = max(P_{1.3}) = 36.54 \text{ kN} \quad (44)$$

$$P_{2.req} = max(P_{2.3}) = 52.08 \text{ kN} \quad (45)$$

$$P_{3.req} = max(P_{3.3}) = 79.26 \text{ kN} \quad (46)$$

$$P_{4.req} = max(P_{4.3}) = 144.92 \text{ kN} \quad (47)$$

With a minimum supply pressure in the roof support's hydraulic system of 25 MPa, the active force of the correction cylinders with a diameter of 90 mm, installed in the canopy and a gob shield, is 159 kN. A correction cylinder with a diameter of 120 mm, installed in the base, generates at this pressure an active force of 282.7 kN. Formulas (38) ÷ (41) show that the correction cylinders of the analysed powered roof support meet the standard requirements.

4. Discussion

Problem of stability of the powered roof supports in a longwall located in strongly inclined seams is the subject of many research studies. Operating conditions of roof supports in CLDA, CLSD, in ultra-high longwalls and in longwalls operated with a top coal caving system are analyzed. Considering the available technical measures to protect supports against loss of stability, much attention was paid to the problem of optimizing the roof support design to reduce its mass and the height of the support's center of gravity, the use of devices connecting each roof support, the methods of increasing the friction force between the canopy and roof and between the base and the floor, as well as the measures for protecting the conveyor against sliding. The role of correction cylinders ensuring the proper force of correction of the side support, what is especially important in positioning the support in a longwall, was marginally treated.

Among the technical measures mentioned, only in relation to the lateral correction force, standard requirements were formulated in [14], the fulfillment of which is a condition for introducing the new powered roof support to the market. This work presents three computational methods enabling the verification of the standard requirement regarding the correction force of the side roof support, without the need of laboratory tests. Analyzing the usefulness of these methods in the design and certification of powered roof supports, the following conclusions were formulated:

1. The method based on a flat model of three supports not set to load, which lost stability, only allows checking whether the sum of the active forces of the correcting cylinders is greater than the resultant reaction acting on the set of three supports, from the side of the roof support set to load. The advantage of this method is elementary calculations and a small number of input data for calculations—the weight of the support, the angle of the longwall inclination, and the coefficient of friction between the base and the floor. Information only about the resultant active force of the correction cylinders is its disadvantage.
2. Unlike the method based on a flat model of three supports, the other two analysed calculation methods require collecting a set of input data extended by the support pitch as well as coordinates of the roof support centre of gravity and the points of application of forces in the correction cylinders to the side surface of the support, determined for the entire range of the support heights in which, for a given longwall inclination angle, the support loses stability.
3. The method based on a simplified FEM model of the powered roof support enables determining the required reaction of each of the correction cylinders used and comparing it with its active force. There are the following advantages of this method:
    - Using the INVENTOR 2024 software environment in designing the roof support.
    - Relatively easy modification of the FEM model, enabling the analysis of any number of correction cylinders in a roof support or changing the coordinates of points of their force application.
    - Calculation procedures implemented in the FEM module facilitate generating the contacts and bonds, e.g., between the floor and the base, which is an advantage from the point of view of the program user.

    A disadvantage of this method is a need to build a separate FEM model for each height for the analysed roof support, but it should be emphasized that the necessary model modifications are easy.
4. The method based on the equilibrium conditions of a 3D model of the support also enables determining the required reaction of each of the used correction cylinders, but

as a function of the parameter—y_0, characterizing the distribution of the floor pressure on the base in a plane parallel to the longwall face. This method, described in item 2.3, enables considering the equilibrium conditions of a roof support equipped with four correction actuators. There are the following disadvantages of the discussed procedure:

- The need to re-derive the system of linear algebraic equations, the unknowns of which are the reactions of the correction cylinders, if a number of correction cylinders other than four is used in the analysed support.
- Dependence of the determined reaction in the correction cylinders on the type of distribution of floor pressure on the base, what means that in the result we obtain the range of variability of the reaction in the cylinder.

This feature of the method based on the support equilibrium conditions can also be treated as its advantage, as it allows analysing the impact of a larger number of natural factors on the response value of the correction cylinder. This is important because many natural and technical factors affect the physically possible distribution of pressure from the floor to the base. The only factor limiting the physically possible type of this distribution, characterized by the parameter—y_0, is the one-sided nature of the bonds between the side surfaces of adjacent roof supports.

The advantage of the discussed method is the ease of analyzing the impact of the position of the correction cylinders actuators on the actuator response value, within the entire range of a roof support height variations.

5. Distribution of floor pressure on the base, in the method based on the simplified FEM model of the roof support, is one of the physically possible types of distribution of this pressure on the base surface considered in the method based on the support equilibrium equations.

It should be emphasized that both the method based on a simplified FEM model of the powered roof support, as well as the method based on the equilibrium conditions of the spatial system of forces, enables determining the required force separately in each of the correction cylinders. Since information about the required value of the sum of forces in all correction cylinders is not sufficient in the process of optimal selection of technical parameters of the correction cylinders, further calculations using the flat roof support model should be neglected.

In the process of roof support designing, at the stage of selecting the technical parameters of correction cylinders, the most useful method is based on a simplified FEM model of the roof support, as it allows in a relatively simple way to analyse the features of many variants of the correction system, differing not only in the diameter of the cylinder piston, but also in the number of used cylinders and their spatial configuration. In the product-certification process, calculations of the lateral correction forces of the roof support using this method will be sufficient evidence of compliance with the normative requirements by the roof support manufacturer.

In turn, when developing the technology for operating the longwall in a working in which the strength properties of the floor are known, it will be possible to verify the required forces in the correction cylinders using the method based on the conditions of equilibrium of the spatial system of forces, taking into account the proper value of the parameter—y_0, characterizing the distribution of floor pressure on the base.

Based on the analysis of the required side support correction force presented as an example, in relation to a given type of roof support used in a strongly inclined longwall, it can be concluded that the discussed calculation methods have confirmed their usefulness at each stage of the research work on a new roof support design, starting from the initial design analysis and ending with the product certification process.

5. Conclusions

Computational procedures are used to determine the side roof support correction force, enabling verification of the normative requirement regarding the lateral correction force, without the laboratory tests. The following conclusions were formulated:

1. Based on the example analysis of the required lateral correction force for the roof support, used in a strongly inclined longwall, it can be concluded that the discussed calculation methods have confirmed their usefulness at each stage of the work on a new roof support design, starting from the initial design analyses and ending with the product certification.
2. Calculations for the sample powered roof support show that the active force generated by its correction cylinders is much greater than the force required by the standard regarding the lateral correction force.
3. If only the requirement for safe use of the support regarding the lateral correction force was taken into account, diameters of the correction cylinders could be much smaller than those currently used.

Therefore, use of the presented computational methods at the stage of designing the roof support may result in a reduction of its weight and manufacturing costs.

As already noted, the calculation methods presented in this article enable confirmation that the manufactured roof support meets the standard requirements regarding the lateral correction force. In this respect, the condition for obtaining the product certification by the roof support manufacturer is met. It should be noted, however, that the standard [14] specifies only the minimum requirements for the lateral correction force of the roof support. For example, when developing the mining technology in a longwall located in a strongly inclined seam, it will be necessary, in addition to the correction cylinders in the roof support, to take into account other technical means for correcting the position of the powered roof support and other components of the longwall complex. These include, for example, cylinders and rods connecting adjacent roof supports into groups, or devices protecting the conveyor against sliding.

The design of these technical means, taking into account practical experience in mining operations in a strongly inclined longwall, in particular, movement of the powered support and the conveyor, is the subject of further research work of the authors and will be presented in the next publication.

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