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STUDY AND DETERMINATION OF THE STRESS-STRAIN STATE OF CONVEYOR BELTS

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Abstract. Relevance. Reducing the cost of mining and transporting rock in quarries is one of the main factors affecting the cost of finished products. Today, belt conveyors are the most cost-effective means of transporting rock worldwide. Therefore, their use provides significant economic advantages-specifically, a 30–40% reduction in transportation costs. Despite these undeniable advantages, conveyor systems face a critical issue that significantly reduces their overall efficiency. Objective. Determination of the stress-strain state of conveyor belts during interaction of rocks by mathematical modeling. Methods. The research is

based on modern computing tools – Ansys Workbench, MathCAD, and Maple – which enable the creation of 3D models, numerical calculations, and regression relationships. Single- and two-factor models were constructed to evaluate the stress-strain state under various operating conditions and identify optimal operating parameters. The stress-strain state of the conveyor belt occurs under the influence of powerful impact loads when rock falls from the transfer hopper. These dynamic forces cause localized damage, transverse cracks, and punctures, leading to premature and frequent belt ruptures. Therefore, the development of scientifically based approaches to optimizing the operating parameters of transfer units is needed. The results was established that optimizing the geometric parameters of a conveyor transport transfer point (a 5.4-meter-high belt conveyor hopper) can ensure minimal loads during contact between the rock mass and the conveyor belt for this design. The stress state of the conveyor belt was determined depending on the belt speed and the transfer point hopper height using single- and two-factor regression models.

Keywords: conveyor, stress-strain state, belt, Ansys Workbench, Maple, MathCAD, bunker

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КОНВЕЙЕР ТАСПАЛАРЫНЫҢ КЕРНЕУЛІК-ДЕФОРМАЦИЯЛЫҚ КҮЙІН ЗЕРТТЕУ ЖӘНЕ АНЫҚТАУ

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Аннотация. *Өзектілігі.* Карьерлерде тау жыныстарын өндіру және тасымалдау құнын төмендету дайын өнімнің құнына әсер ететін негізгі факторлардың бірі болып табылады. Бүгінгі таңда таспалы конвейерлер бүкіл әлемде тау жыныстарын тасымалдаудың ең тиімді құралы болып табылады. Сондықтан оларды пайдалану айтарлықтай экономикалық артықшылықтар береді, атап айтқанда, тасымалдау шығындарын 30-40%-ға төмендетеді. Осы даусыз артықшылықтарға қарамастан, конвейерлік жүйелер олардың жалпы тиімділігін айтарлықтай төмендететін маңызды мәселеге тап болады. *Мақсаты.* Математикалық модельдеуді қолдана отырып, тау жыныстарының өзара әрекеттесуі кезінде конвейерлік таспалардың кернеу-деформация күйін анықтау. *Әдістер.* Зерттеу заманауи есептеу құралдарына - Ansys Workbench, MathCAD және Maple - негізделген, бұл 3D модельдерді жасауға, сандық есептеулерді жүргізуге және регрессиялық қатынастарды құруға мүмкіндік береді. Әртүрлі жұмыс жағдайларында конвейерлік таспаның кернеу-деформация күйін бағалау және оңтайлы жұмыс параметрлерін анықтау үшін бір және екі факторлы модельдер жасалған. Конвейерлік таспаның кернеу-деформация күйі тасымалдау бункерінен тау жыныстарының құлауы кезінде күшті соққы жүктемелерінің әсерінен пайда болады. Бұл динамикалық әсерлер жергілікті зақымдануды, көлденең жарықтарды және тесілулерді тудырады, бұл таспаның мезгілсіз және жиі үзілуіне әкеледі. Сондықтан, тасымалдау қондырғыларының жұмыс параметрлерін оңтайландырудың ғылыми негізделген тәсілдерін әзірлеу қажет. *Нәтижелер мен қорытындылар.* Конвейерлік тасымалдау, тасымалдау нүктесінің (биіктігі 5,4 м таспалы конвейерлік бункер) геометриялық параметрлерін оңтайландыру осы конструкция үшін тау жыныстары массасының конвейерлік таспамен жанасуы кезінде минималды жүктемелерді қамтамасыз ете алатыны анықталды. Конвейерлік таспаның кернеу күйі таспа жылдамдығына және тасымалдау нүктесінің бункерінің биіктігіне байланысты бір және екі факторлы регрессиялық модельдерді қолдана отырып анықталады.

Түйін сөздер: конвейер, кернеулі-деформациялық күйі, таспа, Ansys Workbench, Maple, MathCAD, бункер

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ИССЛЕДОВАНИЕ И ОПРЕДЕЛЕНИЕ НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ КОНВЕЙЕРНЫХ ЛЕНТ

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Аннотация. *Актуальность*. Снижение затрат на добычные работы и транспортировку горной массы на карьерах является ключевым фактором уменьшения себестоимости готовой продукции. В мировой практике ленточные конвейеры рассматриваются как наиболее экономичное средство перемещения горных пород, обеспечивающее снижение затрат на транспортировку на 30–40%. Однако конвейерные системы сталкиваются с проблемой возникновения напряжённо-деформированного состояния (НДС) ленты, вызванного ударными нагрузками, что приводит к преждевременному износу и выходу оборудования из строя. *Цель*. Определение напряженно-деформированного состояния конвейерных лент при взаимодействии с горной массой методом математического моделирования для выбора оптимальных эксплуатационных параметров. *Методы*. Исследования выполнены с использованием вычислительных комплексов Ansys Workbench, MathCAD и Maple, обеспечивающих построение трёхмерных моделей, численный

анализ и разработку однофакторных и двухфакторных регрессионных зависимостей. Определены особенности формирования НДС при ударных нагрузках, возникающих в момент падения горной породы на ленту через перегрузочный бункер. Установлены причины локальных повреждений, поперечных трещин и пробоев, связанных с динамической природой нагрузки. *Результаты и выводы*. Показано, что оптимизация геометрических параметров перегрузочного узла конвейера (для бункера высотой 5,4 м) позволяет существенно снизить пиковые нагрузки и минимизировать НДС ленты. Получены регрессионные модели, описывающие зависимость напряжённого состояния от скорости движения ленты и высоты падения груза. Результаты моделирования демонстрируют, что корректная настройка параметров системы снижает вероятность разрывов ленты и увеличивает ресурс работы конвейера.

Ключевые слова: конвейер, напряженно-деформированное состояние, лента, Ansys Workbench, Maple, MathCAD, бункер

Introduction. Conveyor transport is an integral part of the technological process at modern mining enterprises. In open-pit coal mining, belt conveyors demonstrate significant advantages over road and rail transport: they reduce transportation costs by 30-40%, increase labor productivity by 1.4-2.0 times, ensure continuous production, and enable comprehensive automation (Anistratov, 1995:350, Poderni, 2003:606). Belt conveyors with throughputs of up to 25,000 m³/h, travel speeds of up to 10 m/s, and installed drive power of up to 10 MW are used worldwide. Modern systems allow for the transport of rock mass over distances of over 5 km along routes with complex geometries, including sections with slopes of up to 16-18° (Rabatuly et al., 2025:11). However, despite the obvious advantages, conveyor transport has a number of significant disadvantages associated with the short service life of the belt and roller supports, high energy consumption, and material spillage and dusting. The conveyor belt, which is both a load-bearing and traction element, has a limited service life (3-5 years) and accounts for 50-60% of the total cost of the conveyor. Moreover, belt damage leads to downtime, the losses from which many times exceed its cost. Particularly critical are transfer points, where the rock mass is transferred from one conveyor to another. It is in these areas that the greatest belt wear is observed due to the intense stress-strain state (SSS), which occurs under the action of impact loads during rock fall. This leads to localized damage, the formation of transverse cracks, punctures, and ruptures of the conveyor belt (Toshov, 2024a:11, Donenbaev et al., 2023:9).

Research materials and methods. The issues of improving conveyor transport have been the subject of the works of many researchers. Significant contributions to the development of the theory and practice of belt conveyors were made by Anistratov Yu.I., Galkin V.I., Dmitriev V.G., Poderni R.Yu., Rzhevsky V.V., Sheshko E.E., as well as foreign scientists Gabriel Fedorko, Lech Gładysiewicz, Robert

Krol and others (Dmitriev et al., 2011:11, Reshetnyak, 1998:423, Fedotenko et al., 2020:6, Lagerev et al., 2017:384, Dolgikh, 2018:7, Korneev et al., 2014:4). The works of these authors considered the issues of calculating the main parameters of conveyors, selecting the type of belt, determining the traction forces and power of drives. However, the issues of optimizing the design of transfer points taking into account the dynamic interaction of falling rock with the belt remain insufficiently studied. To solve the assigned problems, a finite element method was used using the ANSYS Workbench 2021 software package, Explicit Dynamics module. This software enables nonlinear dynamic analysis taking into account large deformations, contact interactions, and complex material models (Fimbinger, 2021:98, Ogden, 1972:20).

Figure 1. Belt conveyor transfer point in open-pit mining

Belt reliability and stability play a key role in transporting rock by conveyors. To ensure the smooth and safe operation of the conveyor, it is essential to consider the belt's stress-strain state (SSS), which serves as an important indicator of its technical condition, service life, and reliability. SSS analysis allows one to identify belt sections experiencing the greatest internal stresses and deformations under the impact of the transported rock mass. This is especially important when the belt is subject to external factors, such as high speed, impact loads from rock falling from the hopper, and the geometric features of the transfer section. For example, significant loading heights increase the impulse load, which can cause fatigue damage and accelerated belt failure. To conduct engineering analysis and obtain accurate quantitative characteristics of the stress-strain state, it is recommended to use modern software and computing tools such as MathCAD and Maple 18. These systems offer extensive mathematical modeling capabilities and allow:

– Develop adequate models of belt behavior under load, taking into account its physical and mechanical properties;

– Perform numerical solutions to continuum mechanics equations;

– Perform parametric studies, varying design and operational parameters;

– Visualize the results in the form of graphs and stress distributions, simplifying data interpretation.

The use of such software packages makes it possible to optimize the design of handling units, select rational conveyor operating parameters, and, as a result, improve the overall reliability and efficiency of the transport system at a mining facility. This is especially relevant when developing new sites or upgrading existing facilities, where complex mining, geological, and technological conditions must be taken into account. Using Ansys Workbench software, 3D models of a loading and unloading bin located between two sections of conveyor lines were developed using precise geometric parameters. Analysis of the resulting 3D models revealed a number of factors that contribute to damage and rupture of the main conveyor belt. Specifically, graphical and numerical calculations revealed that the bin's design features, rock fall height, trajectory deviation angle, and uneven material distribution on the receiving end of the belt are key factors influencing the occurrence of critical loads.

Stage 1. Creating a Geometric Model

1. A 3D model of the transfer point was created, including:
2. A hopper made of 30 mm thick steel sheet (height varied: 3.5 m, 5.4 m, 7.8 m);
3. A section of conveyor belt 8.4886 m long;
4. A system of roller supports with installation pitches of 0.25 m, 0.5 m, and 1.0 m;
5. A rock mass weighing 143.17 kg.

Step 2. Determining the properties of materials

To accurately describe the behavior of the rubber-cord belt, the Ogden hyperelastic model was used, which adequately describes the nonlinear behavior of rubber-like materials under large deformations. The strain energy density in the Ogden model is determined by the expression:

$$W = \sum_{i=1}^{N} \frac{\mu_i}{\alpha_i}\left(\lambda_1^{\alpha_i} + \lambda_2^{\alpha_i} + \lambda_3^{\alpha_i} - 3\right) + \sum_{i=1}^{N} \frac{1}{D_i}(J-1)^{2i} \qquad (1)$$

where μ_i, α_i, D_i – material constants; λ_1, λ_2, λ_3 – main extensions; J – volume ratio.

The following parameters were used for the STAHLCORD® ST 1600 conveyor belt:

1. Young's modulus of steel cables: E = 200 GPa;
2. Poisson's ratio of rubber: ν = 0.49;
3. Density: ρ = 1200 kg/m³;
4. Number of cables in the belt: 114 pcs.;
5. Cable diameter: 11.2 mm;
6. Cable pitch: 17.2 mm.

The rock was modeled as a perfectly solid body with a density of 2000 kg/m³, which corresponds to the overburden of a coal mine. The bin is made of structural steel with a Young's modulus of E = 200 GPa and a Poisson's ratio of ν = 0.3.

Step 3. Setting boundary conditions and loads

The process of rock falling from the hopper of a face conveyor (speed 5 m/s) onto the belt of a main conveyor (speed 5.6 m/s) was simulated. The edges of the belt were secured longitudinally to simulate an endless belt. The roller supports and hopper were fixed. The coefficient of friction between the rock and the belt was assumed to be 0.2.

Step 4. Building a finite element mesh

To discretize the model, 8-mm-sized hexahedral volume elements were used. In areas of rock-belt contact, local mesh refinement to 4 mm was applied to improve calculation accuracy. The total number of nodes was 4,300, and the number of elements was 2,040 (Kassenov, et al., 2022:6, Toshov, et al., 2023b:13, Sagitov, et al., 2023:12). In the graph (Figure 2), the maximum stress value is shown in green, the average stress value is shown in blue, and the minimum stress value is shown in red. According to this graph, the maximum stress of 6.881 MPa is reached at 4 seconds, which is caused by improper use of the conveyor belt, which reduces its reliability.

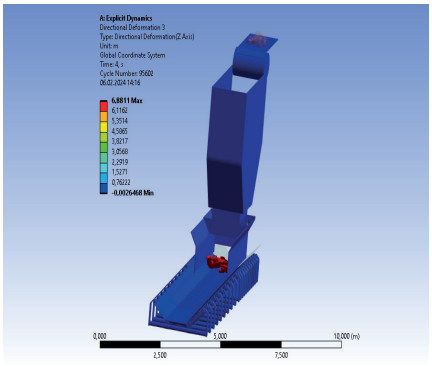

Figure 2. General view of the transfer point model, stress-strain state of the conveyor belt

The graph shows the dependence of the movement of rock along a conveyor (Figure 3) from a 7.8 m high bin on time. Numerical values of rock stress are given in Table 1.

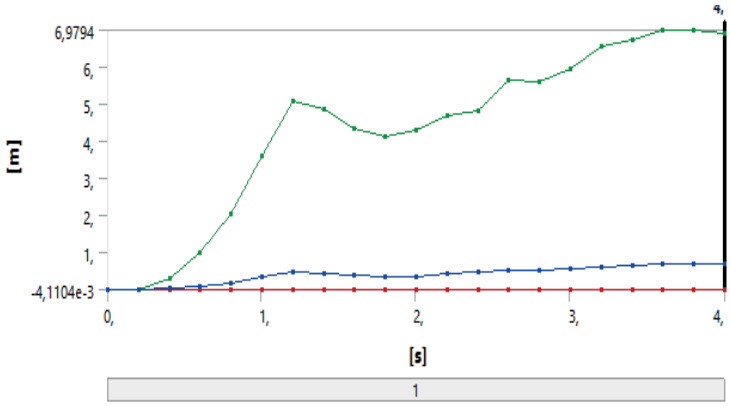

Figure 3. Graph of voltage versus time during loading of a hopper with rock

Table 1. Numerical values of rock stress (7.8 m)

Time (s)	Minimum (MPa)	Maximum (MPa)	Average (MPa)
1,1755e-038			
0,2	8,2027e-005	2,1574e-003	-7,4216e-005
0,4	8,3377e-005	0,28732	2,179e-002
0,6	0	0,97651	8,3257e-002
0,8		2,043	0,18428
1	8,7678e-005	3,6078	0,32728
1,2	8,6954e-005	5,087	0,47641
1,4	0	4,8652	0,43775
1,6	7,0919e-005	4,3137	0,38328
1,8	1,078e-004	4,1191	0,35089
2	0	4,2917	0,36165
2,2		4,6891	0,41616
2,4	1,0919e-005	4,8137	0,46946
2,6	6,6299e-004	5,6519	0,52721
2,8	6,2206e-004	5,5866	0,5351
3	2,3985e-004	5,9213	0,56474
3,2	8,0004e-004	6,5554	0,61902
3,4	3,7188e-004	6,7116	0,65906
3,6	8,0968e-004	6,9736	0,67127
3,8	3,1114e-004	6,9794	0,68129
4	2,6468e-003	6,8811	0,67522

We conducted a detailed study and analysis of the operational challenges of conveyor transport during stripping operations in quarries. This analysis revealed that the main problems in transporting overburden stem from various causes of belt breaks. Therefore, a scientific study was conducted, which identified one of the

main problems: frequent belt conveyor breaks during operation, caused by both the structural and technical features of the belt itself, as well as the impact force of the mined rock from the conveyor's loading and unloading hopper. Detailed modeling has shown that with an increase in the hopper height by 20–30%, the stress concentration in the receiving zone of the conveyor belt increases by more than 40%. An unfavorable combination of drop height and hopper shape leads to localized impact loads, which causes accelerated wear, the appearance of microcracks, and subsequent belt ruptures (Mityushov et al., 2005:176). the study also examined in detail the specifics of conveyor operation during stripping operations at open-pit coal mines. Analysis of practical data and modeling revealed that belt damage on main conveyors is caused not only by the design and technical characteristics of the belt itself (strength, thickness, reinforcing materials), but also by the impact loads generated when rock mass falls from the hopper. The scientific study confirmed that the combination of these factors-belt design features and dynamic loads-is the key cause of frequent accidents and ruptures of main conveyor belts during operation.

Results. Thus, modeling and analysis confirmed the need for an integrated approach to the design and operation of conveyor transfer units, which will significantly increase the service life of the equipment and reduce repair costs. The results of the studies of the belt stress-strain state depending on various transfer point bin heights are shown in the table 2.

Table 2.

Conveyor line speed	**Bunker height**		
	3,5 м	**5,4 м**	**7,8 м**
6-6,6 м/с	5,461 МПа	4,421 МПа	7,387 МПа
3,15-4 м/с	5,161 МПа	4,339 МПа	6,881 МПа
5-5,6 м/с	0,483 МПа	0,433 МПа	1,203 МПа

The results of these studies are reflected in the graphs of the stress-strain state of the belt depending on the fall of rock from various heights of the bunker per unit of time (Figure 4).

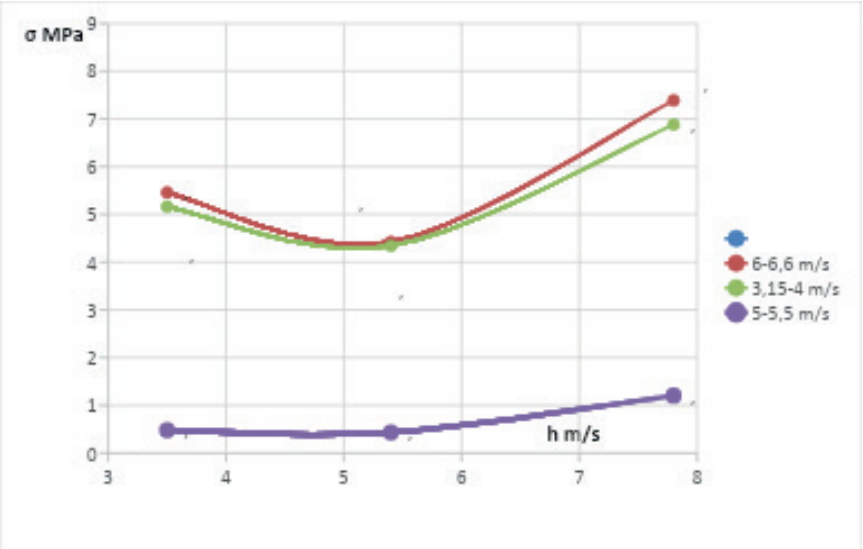

Figure 4. Graph of the dependence of the stress-strain state of the tape on the height of the rock mass fall

As a result of such determination of the optimal height of the bunker for this technological process, the following formulas were obtained:

$$\sigma = \{0{,}415h^2 - 4{,}238h + 15{,}215 if speed v = 6 - 6{,}6\frac{m}{s}\ 0{,}347h^2 - 3{,}52h + 13{,}232 if speed v$$
$$= 3{,}15 - 4\frac{m}{s}\ 0{,}081h^2 - 0{,}745h + 2{,}101 if speed v = 5 - 5{,}5\frac{m}{s} \quad (2)$$

Formulas for quadratic sigma-h relations obtained by processing with linfit in MathCAD.

To obtain analytical relationships suitable for engineering calculations, statistical processing of the modeling results was performed using regression analysis. We constructed a single-factor regression model. Thus, the problem is reduced to solving the following system of equations:

$$\begin{bmatrix} 1 & v_0 & v_0^2 \\ 1 & v_1 & v_1^2 \\ 1 & v_2 & v_2^2 \end{bmatrix} \cdot \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} \sigma_0 \\ \sigma_1 \\ \sigma_2 \end{bmatrix}. \quad (3)$$

According to the obtained results (Table 2), the coupling function that allows solving equation (4) and determining the values of the belt tension depending on the change in the linear speed of the conveyor for different bin heights has the following form:

$$\sigma = \begin{cases} 2{,}94004662v^2 - 31{,}04910956v + 82{,}31669232 & at \quad h = 3{,}5\,м \\ 1{,}277082112v^2 - 11{,}82723901v + 26{,}85108066 & at \quad h = 5{,}4\,м \\ 3{,}575710954v^2 - 37{,}70792074v + 100{,}5013077 & at \quad h = 7{,}8\,м \end{cases} \quad (4)$$

Using the Maple 18 program, a graph (Figure 5) was constructed of the belt tension depending on the change in the linear speed of the conveyor for different bin heights.

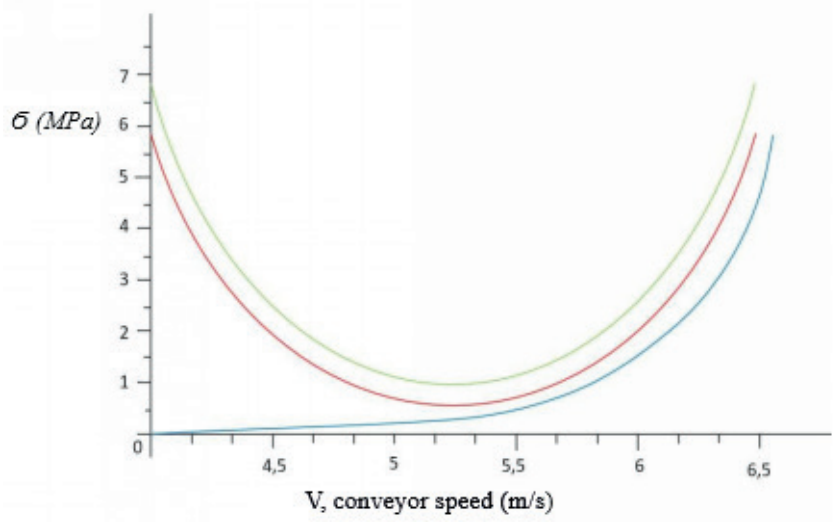

Figure 5. Graph of the stress-strain state of the belt depending on the change in the linear speed of the conveyor for different bin heights

Now let's construct a two-factor regression model, that is, determine a single-valued correlation function describing changes in conveyor belt stress depending on bin height and belt speed. To do this, we construct a two-factor function in nonlinear form. In this case, we use the least-squares method to make the model usable. In general, force is defined as follows:

$$\sigma = a + bh + cv + dh^2 + ev^2 + fhv + kh^2v + lhv^2 + mv^3 \quad (5)$$

Here a, b, c, d, e, f, k, l, m are the coefficients that need to be determined, calculated and determined using the Maple 18 software package based on the data given in Table 2.

The problem is reduced to solving this system of equations:

$$\begin{bmatrix} 1 & h_0 & v_0 & h_0^2 & v_0^2 & h_0v_0 & h_0^2v_0 & h_0v_0^2 & v_0^3 \\ 1 & h_1 & v_1 & h_1^2 & v_1^2 & h_1v_1 & h_1^2v_1 & h_1v_1^2 & v_1^3 \\ \square & \square & \square & \square & \square & \square & \square & \square & \square \\ 1 & h_8 & v_8 & h_8^2 & v_8^2 & h_8v_8 & h_8^2v_8 & h_8v_8^2 & v_8^3 \end{bmatrix} \cdot \begin{bmatrix} a_0 \\ a_1 \\ \square \\ a_9 \end{bmatrix} = \begin{bmatrix} \sigma_0 \\ \sigma_1 \\ \square \\ \sigma_9 \end{bmatrix}. \quad (6)$$

Now we define the following two-factor correlation function:

$$\sigma = 0{,}013h^2v + 0{,}173hv^2 + 592{,}547v^3 + 0{,}207h^2 - 1{,}974hv - 9538v^2 + 2{,}570h + 50167{,}8 - 85975{,}509 \quad (7)$$

Using this objective function (4), the belt stress is determined using a single value for various changes in bin height (h) and conveyor speed (v). The accuracy level of the Fisher criterion is P = 0.93–0.96% for the function (Figure 5).

A graph of the change in the stress-strain state of the belt depending on the speed and height of the conveyor bin was obtained (Figure 6).

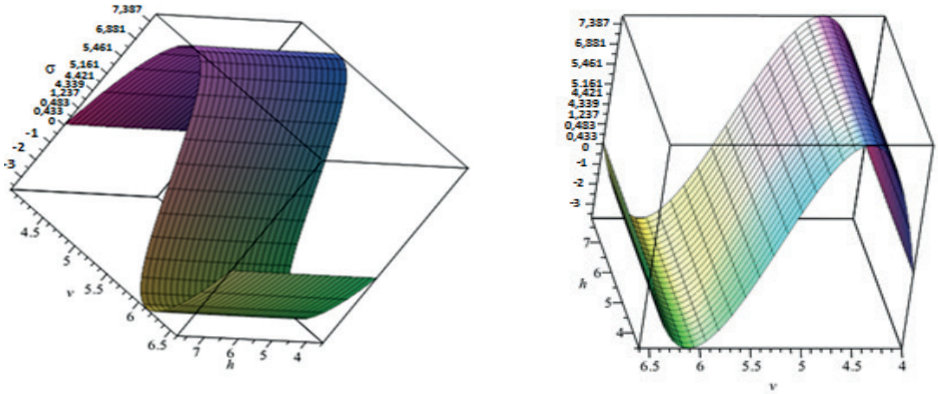

Figure 6. Graph of changes in the stress-strain state of the belt depending on the speed and height of the conveyor hopper

The obtained results are consistent with the research of other authors in the field of conveyor transport optimization. In particular, the work of Lech Gładysiewicz and Robert Krol (Lech, et al., 2021:6) showed that optimizing the design of transfer points can reduce dynamic loads on the belt by 25-40%, which is close to our results (a reduction of 64% when moving from a height of 7.8 m to 5.4 m).

Research by Gabriel Fedorko et al. (Gabrie et al., 2018:12) confirmed the effectiveness of the finite element method for analyzing the stress-strain state of conveyor belts. However, their work focused on analyzing cable frame defects during operation, while our study focuses on optimizing the design to prevent damage. The Ogden model used to describe the behavior of the rubber elements of the belt showed good agreement with the experimental data, which is consistent with the conclusions of (Miriam et al.,2019:11). The model coefficients determined for a specific type of belt made it possible to describe its behavior under large deformations with high accuracy. Theoretical and numerical studies demonstrated that accounting for the stress-strain state (SSS) of a belt, depending on changes in operational factors such as conveying speed and transfer height, provides important

engineering data for subsequent design and technological improvements to belt conveyors. The calculation results not only identified potentially hazardous areas with increased stress concentrations but also suggested approaches to optimizing equipment operation to minimize wear and tear and increase its service life. The use of MathCAD and Maple 18 computational programs demonstrated extensive capabilities in modeling complex processes arising during the interaction of rock with a moving belt. The flexibility of setting calculation parameters, the high accuracy of numerical solutions, and the visualization of results ensured a high-quality analysis of the structure's behavior in various operating modes. Thus, the conducted research forms the basis for further engineering research aimed at improving the reliability and efficiency of conveyor transport systems, which is essential for mining companies facing increasing demands on productivity and process stability.

Conclusion. It was established that the primary causes of conveyor belt damage are associated with high conveyor speeds and large rock drop heights from the hopper.

Modeling in Ansys Workbench identified critical stress concentration zones and provided recommendations for optimizing the design of handling units.

Regression models constructed in MathCAD and Maple confirmed the relationship between hopper height, conveyor speed, and SSS with a high degree of reliability (P = 0.93–0.96).

To reduce belt damage, the following is recommended:

- Optimize hopper height and belt speed;
- Use guide devices to evenly distribute rock;
- Use shock-absorbing inserts in the impact zone;
- Select belt materials with increased wear resistance.

These results can be used in the design and modernization of belt conveyors to improve their reliability and durability in mining environments.

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