18th International Conference on the Application of Computer
Science and Mathematics in Architecture and Civil Engineering
K. Gurlebeck and C. Konke (eds.)
Weimar, Germany, 07–09 July 2009

ANALYSIS OF THE MODE OF DEFORMATION OF THE SUB-PULLEY STRUCTURES ON SHAFT SLOPING HEADGEAR STRUCTURES

A.Ye. Nechytailo* and Ye.V. Horokhov, V.N. Kushchenko

**Donbas National Academy of Civil Engineering and Architecture*
Derzhavin str., 2,
86123 Makeyevka, Ukraine

**Research Training Group 1462, Bauhaus-University Weimar,*
Research Training Group "Model Validation in Structural Engineering"
Berkaer Str. 9,
99425 Weimar, Germany
E-mail: ae.nechitaylo@mail.ru

Key words: shaft frame-type sloping headgear, sub-pulley structures, joint of a guide pulley resting, design diagram, mode of deformation, local stresses.

Abstract. *A numerical analysis of the mode of deformation of the main load-bearing components of a typical frame sloping shaft headgear was performed. The analysis was done by a design model consisting of plane and solid finite elements, which were modeled in the program «LIRA». Due to the numerical results, the regularities of local stress distribution under a guide pulley bearing were revealed and parameters of a plane stress under both emergency and normal working loads were determined.*
In the numerical simulation, the guidelines to improve the construction of the joints of guide pulleys resting on sub-pulley frame-type structures were established. Overall, the results obtained are the basis for improving the engineering procedures of designing steel structures of shaft sloping headgear.

1 INTRODUCTION

Sloping shaft headgear structures are crucial to the surface facilities of mines. Failure of the shaft headgears have disastrous consequences on the system and can lead to prolonged stoppages. The causes of failure are due to: a) heavy loads; b) intense dynamic loads; c) technical modifications of cables without a proper engineering study.

In the design of the frame supporting the sloping headgears, simplified computational models consisting of rod finite elements are used. The headgear calculations are carried out using equivalent static loading to simulate the hoisting cable tension. However, not all elements of the frame sloping headgears can be represented in the form of rods. For example, sub-pulley components, because these elements have a depth to length ratio ranging between: 1:2 and 1:5 (see Figs. 1-3).

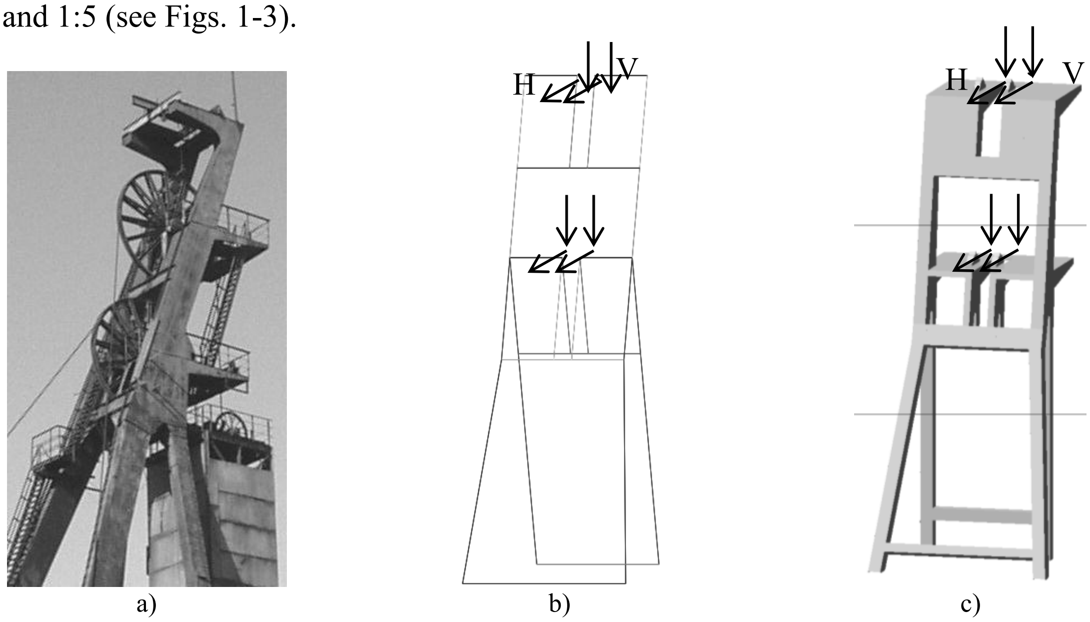


Figure 1: The general view and basic design models of the sub-pulley components:
a) a fragment of the general view of the typical sub-pulley components; b) a fragment of the design model of the sub-pulley rod components; c) a fragment of the design model of the sub-pulley of the lamellar elements (H, V are horizontal and vertical components of the resultant of the hoisting cable tension)

The parameters of the plane mode of deformation of bearing structures of shaft headgears are not calculated accurately enough, for example, in the joints of guide pulley resting on the sub-pulley construction, as well as in the areas of sudden changes in the sections of the structural elements. Thus, the analysis of the plane mode of deformation of the sub-pulley structure elements and their joints is a significant scientific task.

1.1 Object of the study

The object of the study is a sub-pulley structure of a typical sloping frame-type shaft headgear system. Sloping frame-type shaft headgears are a part of the shaft hoisting plant and consist of the following structural parts (see Fig. 2): 1 – sub-pulley structures; 2 – stay legs; 3 – vertical supports (pillars); 4 – a bench; 5 – a sub-headgear frame; 6 – a stay leg and pillar foundation.

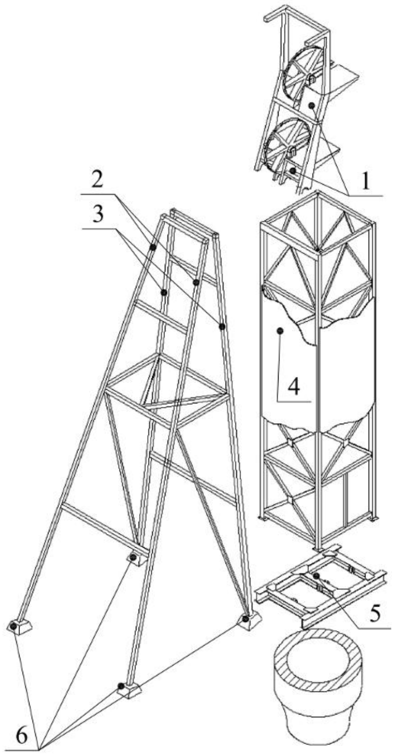


Figure 2: The arrangement of frame-type sloping headgears

Due to the nature of the connection between the above structural parts, there exist several frame-type sloping shaft headgears systems as follows (see Fig. 3):

• Semi-hipped (sub-pulley structures rest on a space frame consisting of a vertical support (pillar) and a stay leg, see Fig. 3a);

• Hipped (sub-pulley structures rest on a hipped roof consisting of two stay legs which form a space frame, see Fig. 3b);

• Combined (sub-pulley structures rest on a bench or on a heap-stead building, see Fig. 3c).

a) b) c)

Figure 3: The structural systems of the frame-type sloping shaft headgears:
a) semi-hipped system; b) hipped system; c) combined system

The most vital joints and elements of the frame-type sloping shaft headgears are depicted schematically in Fig. 4.

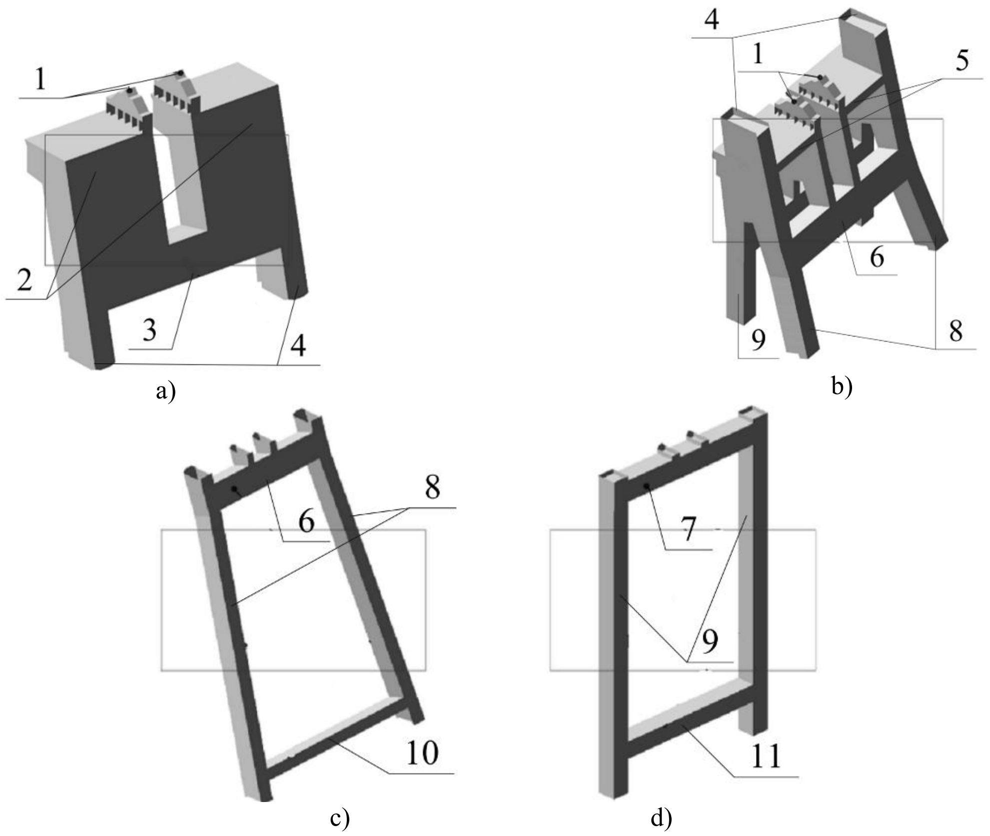


Figure 4**:** The major joints and elements of a frame-type box-like headgear: a) a segment of the upper sub-pulley structure; b) a segment of the lower sub-pulley structure; c) a segment of the upper part of a stay leg; d) a segment of the upper part of a vertical support (pillar). Component numbering: 1-support bearings of a pulley; 2 – a sub-pulley pillar of the upper sub-pulley platform; 3 – the main girder of the stay leg of the upper sub-pulley platform; 4 – the branches of the stay leg between the sub-pulley platforms; 5 – a pillar of the lower sub-pulley platform; 6 – the main girder of the stay leg of the lower sub-pulley platform; 7 – the main girder of the vertical supports of the lower sub-pulley platform; 8 – the stay leg branches; 9 – the vertical support body; 10 – the stay leg girder; 11 – the girder of vertical supports)

The sub-pulley structures of the frame-type sloping shaft headgears are for guide pulleys to rest on. In this paper, the sub-pulley structures of the upper pulley are considered. According to the arrangement of the sub-pulley structure, a frame with the vertical posts inclined to the horizontal is considered. In the place where a guide pulley bearing rests, a change of the frame girder section is provided by adding from above a T-section of 320 mm in height with a flange of 300 mm in width to the main section of the girder (see Fig. 5).

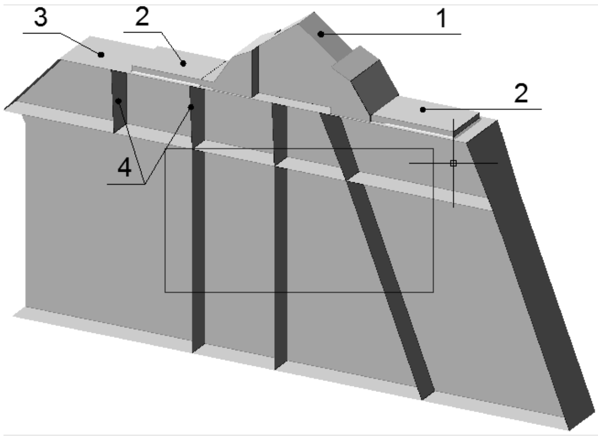


Figure 5: A supporting joint of the guide pulley (1 – a supporting bearing of the guide pulley; 2 – the front and back stops; 3 – the bearing surface area; 4 – the webbing of the supporting joint of the guide pulley)

The supporting joint of the guide pulley (see Fig. 4, 5) consists of a supporting bearing (position 1), the front and back stops (position 2), the bearing surface area (position 3), and the webbing (position 4). The supporting bearing of the guide pulley is secured vertically by bolts, and horizontally, it is secured by dressed wedges between the stops, which are fastened by fillet welds to the upper girder chord of the sub-pulley frame.
The photos of the sub-pulley structures and the resting nodes of the pulleys of the upper sub-pulley platform are shown in Fig. 6.

a) b)

Figure 6: The sub-pulley structures of the upper sub-pulley platform: a) View from below; b) Resting nodes of the guide pulley

1.2 Purpose of the work

The purpose of the work is to analyze the mode of deformation of the sub-pulley structures of a typical, frame-type, sloping, semi-hipped, shaft headgear and to improve the engineering design methods of the node structures of the guide pulley resting on the sub-pulley structures.

1.3 Research tasks

The research tasks are a) to reveal the areas of distributing local tensions in the resting node of a guide pulley at different parameters of the resultant of a hoisting cable tension; b) to determine of the parameters of a plane mode of deformation of the sub-pulley structures; c) establishment of the principles of the rational designing of sub-pulley structures.

2 EXPLORATORY PROCEDURES

A typical skip semi-hipped frame-type sloping shaft headgear was chosen for the study. The headgear has the following technical characteristics: the headgear height – 39.3 m; the spread of the stay leg branches – 11.0 m; the section of the stay leg branches – box-like; the structure material – steel C255 (see Fig. 7).

a) b)

Figure 7: The object of the study – a semi-hipped skip frame-type sloping shaft headgear: a) the general view of the headgear studied; b) the geometry of the headgear

To fulfill the assigned task, computer simulation techniques were implemented with the help of the software package LIRA. The investigation of the mode of deformation of the structure was investigated in two stages:

The 1st stage - The simulation of the mode of deformation of the structure on the spatial design model approximated by laminated finite elements.

The 2nd stage - The simulation of the mode of deformation of a separate sub-pulley structure on the spatial design model approximated by laminated and three-dimensional finite elements.

The design was completed for the following load scenarios: a) normal operating conditions (normal hoisting cable tension, pulley weight, and permanent load); b) emergency loading and breaking of the upper pulley cable, calculated in accordance with the regulations [2]. Loads on a cable are transferred to the nodes of the guide pulley in the form of vertical and horizontal components of the resultant of the hoisting cable branch tension (see Fig. 8).

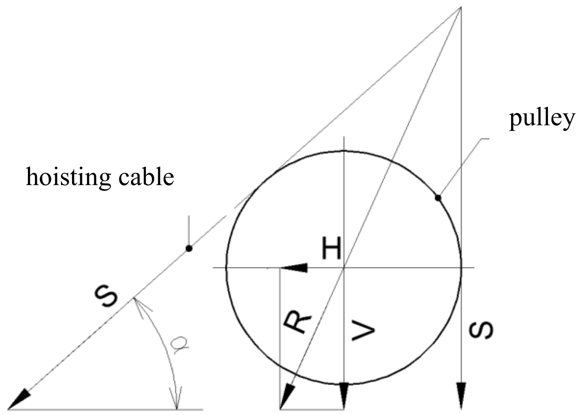


Figure 8: Diagram of load transfer of hoisting cable tension where S is the tension in a cable branch; R is the resultant of a hoisting cable tension; V is the vertical component of the resultant; H is the horizontal component of the resultant; α is the inclination of a hoisting cable to the horizon

The 1st stage. On the spatial design model approximated by laminated finite elements (see Fig. 9) it was obtained: the principal (σ_1, σ_2) and reduced ($\sigma_{red.}$) tensions; characteristics of the self-excited vibrations and elastic displacement of the elements.

Figure 9: The finite-element model generated in the software package LIRA

The 2nd stage. The sub-pulley frame of the upper pulley was thoroughly modeled as a spatial lamellar system in LIRA in the form of an add-on system with regards to the interaction boundary conditions (see Fig. 10).

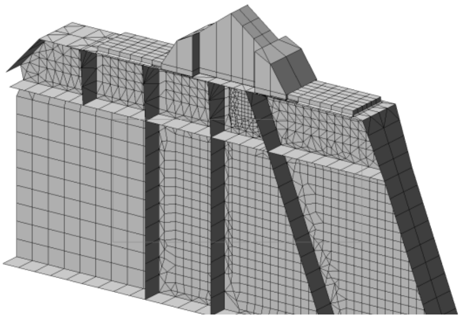


Figure 10: A segment of the design model approximated by plates

The elastic interaction of the sub-pulley frame and the rest of the stay leg structure was simulated by adding resilient flexing ties (FE 266), which simulated the axial and flexural rigidity of an abutment node.

The guide pulley bearing was simulated by the three-dimensional finite elements (FE 34, 36) in such a way that the model dimensions correspond to the structure of the guide pulley supporting bearing. The bearing base resting on the frame, and operating at tension, was simulated with the help of the unilateral elastic tie elements (FE 262) that are horizontally compliant. The stops were three-dimensional elements (FE 36). The stop fastening was modeled by fillet welds with legs of 10 mm which, in turn, were simulated by the three-dimensional finite elements (FE 34).

Breaking cable load, operation tension, and weight of the guide pulleys were applied to a three-dimensional element of the design model, to the simulation bearing of the guide pulley in the form of the vertical and horizontal components of the resultant (see Fig. 11).

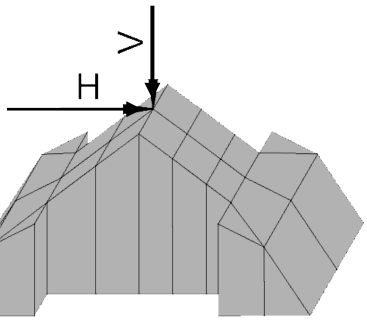
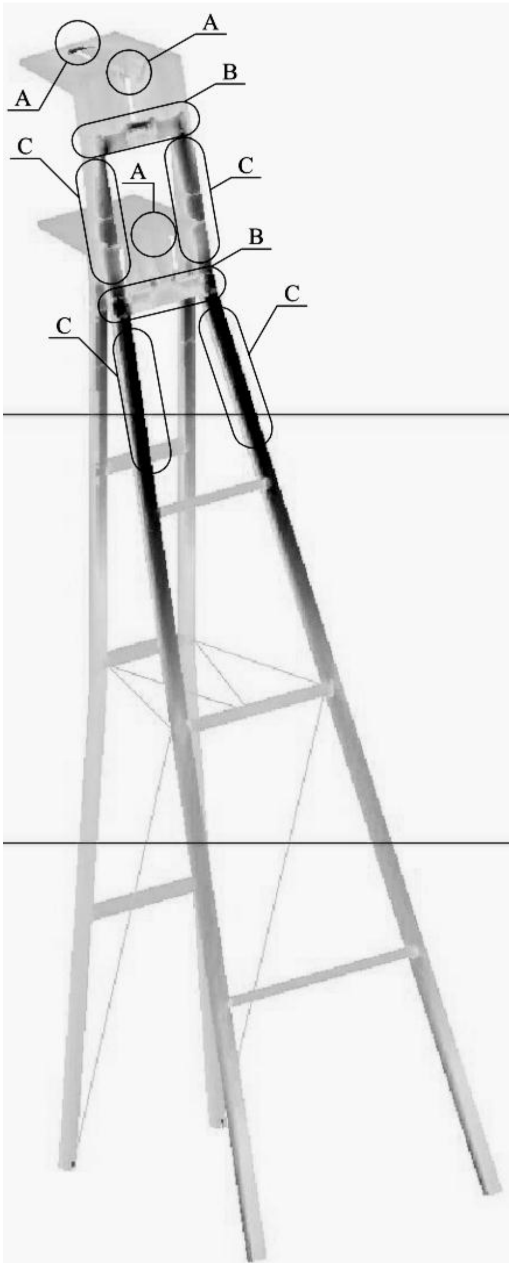


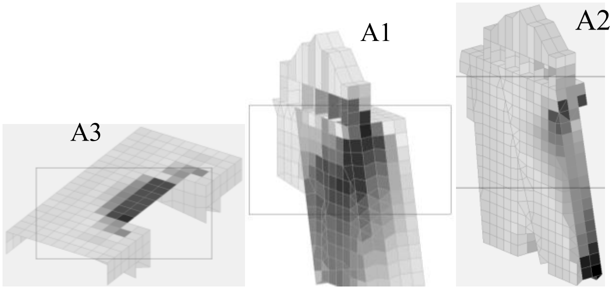
Figure 11: Load transfer diagram of the hoisting cable tension in the lamellar approximation where V – the vertical component of the resultant; H – the horizontal component of the resultant

Because of the varying processes of different shaft hoisting plants, the inclination of the cable can change. In the process of the numerical experiment, we evaluated the influence of the cable inclination on the plane mode of deformation. The inclination of the resultant of the hoisting cable tension varied within 30º and 65º in 5º increments.

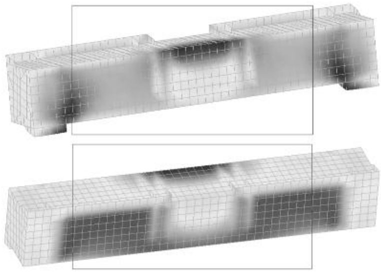
3 ANALYSIS

In the first stage, the main stresses (σ_1, σ_2), reduced stresses ($\sigma_{red.}$), normal stresses (σ_x, σ_y), and tangential stresses (τ_{xy}) were obtained. In the analysis of the mode of deformation, the headgear structures were zoned according to the nature and intensity of the mode of deformation (see Fig. 12 and Table 1).

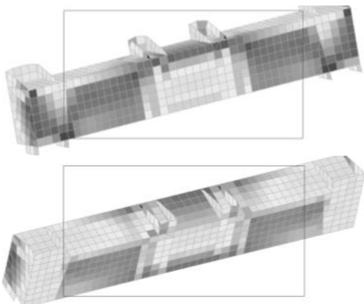




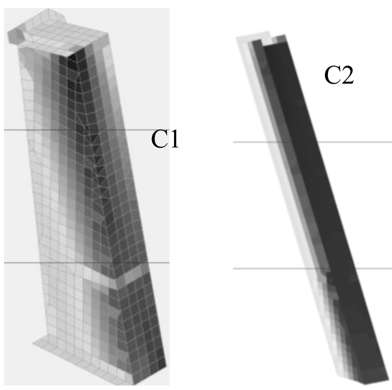
Zone – A



Zone – B (the girder of the upper sub-pulley structure on both sides B1)



Zone – B (the girder of the lower sub-pulley structure on both sides B2)



Zone – C

Figure 12: Zoning of the headgear structures by nature and intensity of the mode of deformation:
A – zones of local tension;
B – zones of tension concentration;
C – zones that showed highest stresses.

Table 1: Zoning according to type of plane mode deformation in the headgear elements and the maximum stress values obtained

Zone of stresses		Zone linear dimen-sions, m	Of the accident design load combinations				Of the operation design load combinations			
			σ_1, MPa	σ_2, MPa	Σ_{red}, MPa	τ_{max}, MPa	σ_1, MPa	σ_2, MPa	Σ_{red}, MPa	τ_{max}, MPa
A	A1 – the area of the upper pulley resting (connection of elements 1 and 2 Fig. 12a)	0.5x0.3	2.33	-33.6	34.8	18.0	0.48	-6.08	6.3	3.3
	A2 – the area of the lower pulley resting (connection of elements 1 and 5 Fig. 12b)	1.8x0.4	-2.6	-71.2	69.9	34.3	-0.43	-7.21	7.00	3.4
	A3 – the area where the sub-pulley platform section changes	2.2x0.4	-0.3	-67.0	66.9	33.4	-0.06	-16.5	16.42	8.2
B	B1 – the girder of the upper sub-pulley structure (element 3 Fig. 12a)	-	49.2	0.28	49.0	24.4	13.4	0.075	13.34	6.7
	B2 – the girder of the lower sub-pulley structure (element 6 Fig. 12b, c)	-	47.9	0.15	47.8	23.9	11.3	0.048	11.23	5.6
C	C1 – the stay legs between the sub-pulleys platforms (element 8 Fig. 12c)	3.1x2.2	-1.2	-70.3	69.7	34.5	-0.05	-6.8	6.86	3.4
	C2 – the stay leg branch (element 4 Fig. 12a,b)	8.4x0.8	0.34	-85.7	84.7	43.0	0.07	-6.46	6.64	3.4

From the above table, it is evident that the maximum values of σ_1 occur in the nodes of resting of the guide pulley and the maximum values of σ_2 were calculated in the stay leg branches in connection with the sub-pulley structures.

In the second stage, the mode of deformation was analyzed for the sub-pulley structures and the nodes of resting of the guide pulleys of the sloping shaft headgear. It was found that the typical parameters affected by cable inclination change were local stresses in the resting node of a guide pulley, the basic stresses (σ_1, σ_2), reduced stresses (σ_{red}), normal stresses (σ_x, σ_y), tangential stresses (τ_{xy}), and stress concentration coefficients (C_u). See Fig. 13.

Analysis of the mode of deformation of the given design model showed the following ranges in the local stress distribution in the resting node of a guide pulley: «*A*» – the range of the local stress distribution under the support bearing foot (see Fig. 13, Table 2, 3); «*B*» – the range of the plane mode of deformation in the wall of the pulley attachment point (see Fig. 13, Table 2, 3); «*C*» – the range of the plane mode of deformation in the girder wall (see Fig. 13, Table 2, 3); «*D*» – the range of the steady mode of deformation in the girder wall (see Fig. 13, Table 2, 3).

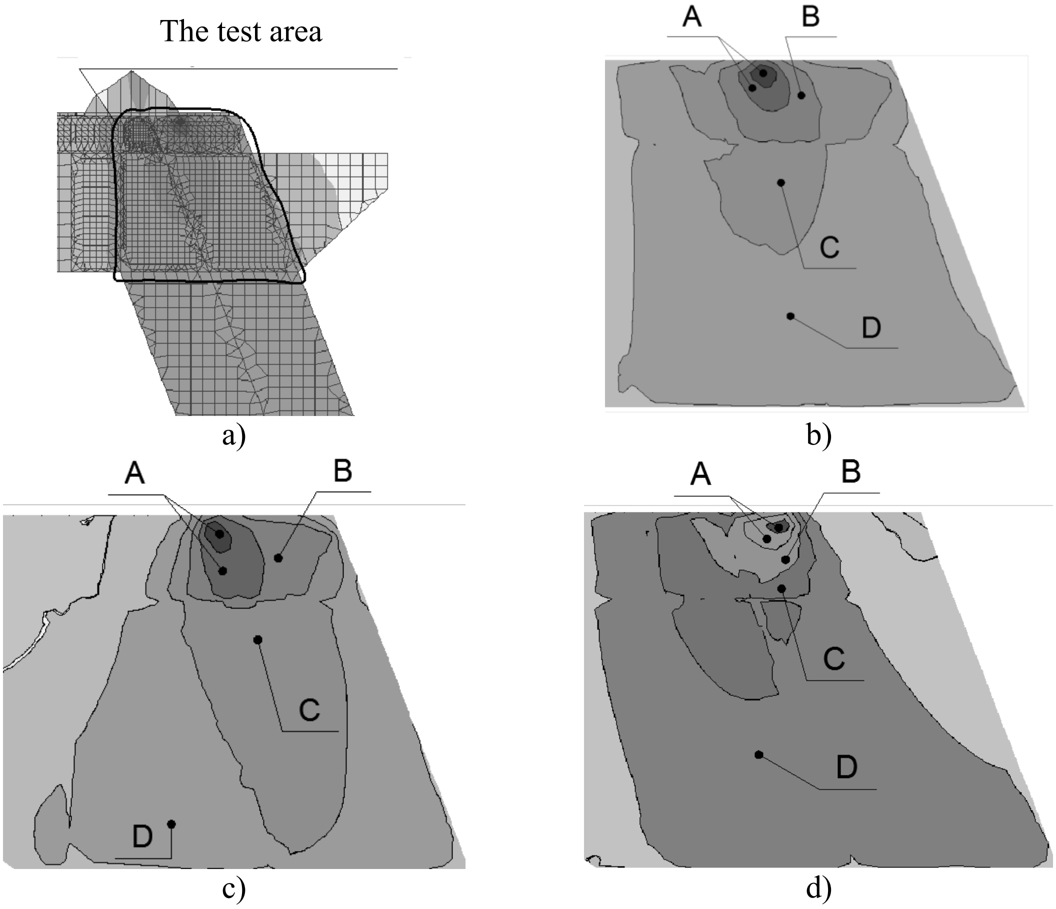


Figure 13: Areas of the local stress distribution in the resting node of the guide pulley (stress iso-fields): a) segment of the sub-pulley frame; b) σ_{red}; c) σ_x; d) τ_{xy}

From the above figure it is evident that the area of the local stress distribution (area «*A*») is under the front end of the guide pulley bearing. The area of the plane mode of deformation (area «*B*») is in the wall of the pulley attachment and is limited by a compartment under the front stop of the pulley bearing. The area of the plane mode of deformation (area «*C*») covers both the wall of the pulley attachment point and the girder wall. The area of the steady mode of deformation (area «*D*») covers the girder wall and connects to a slant leg of the sub-pulley frame.

The linear dimensions of the typical areas, connections to the pulley axis of rotation and the ratio of the height (*h*) and width (*d*) of the typical area to the length of the support bearing foot (*b*) are given in Table 2.

Table 2: Dimensions of local stress areas in the resting node of the guide pulley

Type of stresses	Area of stresses	Linear dimensions of the area (d x h), cm	Connection to the axis of rotation of the pulley, cm		d/b	h/b
			horizontally	vertically		
Σ_{red}	A	16 x 16	41	42	0.20	0.20
Σ_{red}	B	39 x 30	41	42	0.49	0.38
Σ_{red}	C	86 x 91	41	42	1.08	1.14
Σ_{red}	D	150 x 135	41	42	1.88	1.69
σ_x	A	20 x 13	38	42	0.25	0.16
σ_x	B	40 x 25	38	42	0.50	0.31
σ_x	C	60 x 69	38	42	0.75	0.86
σ_x	D	150 x 135	38	42	1.88	1.69
τ_{xy}	A	25 x 31	46	46	0.31	0.39
τ_{xy}	B	54 x 35	46	46	0.68	0.44
τ_{xy}	C	66 x 127	46	46	0.83	1.59
τ_{xy}	D	150 x 135	46	46	1.88	1.69

Note: b – the length of the guide pulley bearing foot; d – the area width; h – the area height. The intensities of the mode of deformation in the areas under study and the ratios of $\sigma_{Max1}/\sigma_{Max2}$, $\sigma_{xmax}/R_y\gamma_c$, $\sigma_{red}/1.15R_y\gamma_c$, and $\tau_{Max}/0.58R_y\gamma_c$ are given in Table 3.

Table 3. The extremes of the local stresses in the resting node of the guide pulley

Stress area	σ_{Max1}, MPa	σ_{Max2} MPa	σ_{red} MPa	σ_{xMax}, MPa	τ_{Max}. MPa	$\sigma_{Max1}/\sigma_{Max2}$	$\sigma_{Max}/\sigma_{aver}$	$\sigma_{xmax}/R_y\gamma_c$	$\Sigma_{red}/1.15R_y\gamma_c$	$\tau_{Max}/0.58R_y\gamma_c$
A	6.5	-361.0	364.3	-277.6	172.2	-0.018	3.8	0.99	1.1	1.1
B	49.5	-147.9	177.9	-163.7	105.6	-0.335	1.9	0.58	0.6	0.6
C	25.6	-121.2	135.8	-128.0	63.9	-0.212	1.4	0.46	0.4	0.4
D	9.0	-103.2	108.0	-81.7	47.7	-0.087	1.1	0.29	0.3	0.3

From the above table it is evident that areas «A» and «D» have a stress condition close to the mode of deformation with the ratios $\sigma_{Max1}/\sigma_{Max2}$ equal to 0.018 and -0.087, respectively. The areas «B» and «C» are the areas of the plane and stress state with the ratios $\sigma_{Max1}/\sigma_{Max2}$ equal to 0.335 and 0.212, respectively. The area «A» does not meet the strength requirements because of the tangential and reduced stresses in the case of a combination of loads that will result in failure.

The maximum values of σ_{Max1}, σ_{Max2}, σ_{red}, $\sigma_{x\ max}$, $\sigma_{y\ max}$, τ_{Max} in the resting node of the guide pulley at different parameters of the resultant of the cable tension and the ratios of the maximum to the average stresses in the area of study ($\sigma_{max}/\sigma_{aver}$) are given in Table 4 and Fig. 14.

Table 4. The extreme values of local stresses in the resting node of the guide pulley as the resultant inclination changes

α, degrees	σ_1, MPa	σ_2, MPa	Σ_{red}, MPa	$\sigma_{x\ max}$, MPa	$\sigma_{y\ max}$, MPa	$\tau_{Max.}$ MPa	σ_1/σ_2	$\sigma_{Max}/\sigma_{aver}$
30	10.2	-369.7	374.9	-334.0	-56.5	171.2	-0.028	4.57
35	9.3	-369.2	373.9	-332.4	-58.3	172.3	-0.025	4.33
40	8.3	-367.1	371.3	-329.2	-59.8	172.7	-0.023	4.09
45	7.2	-363.1	366.8	-324.3	-61.1	172.3	-0.020	3.86
50	6.1	-357.4	360.5	-317.7	-62.2	171.1	-0.017	3.65
55	5.0	-350.1	352.6	-309.6	-63.1	169.2	-0.014	3.44
60	3.9	-341.1	343.0	-299.9	-63.7	166.5	-0.011	3.24
65	2.7	-330.6	332.0	-288.8	-64.1	163.0	-0.008	3.04

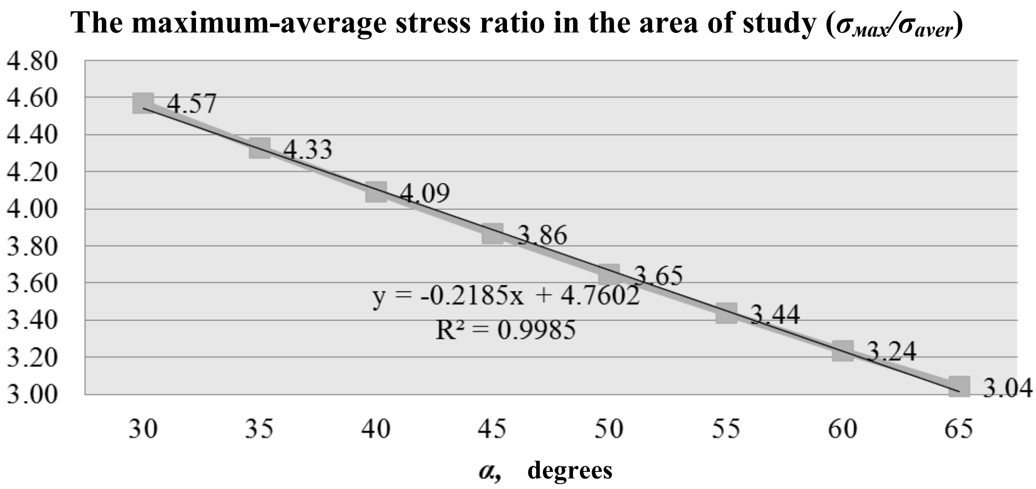
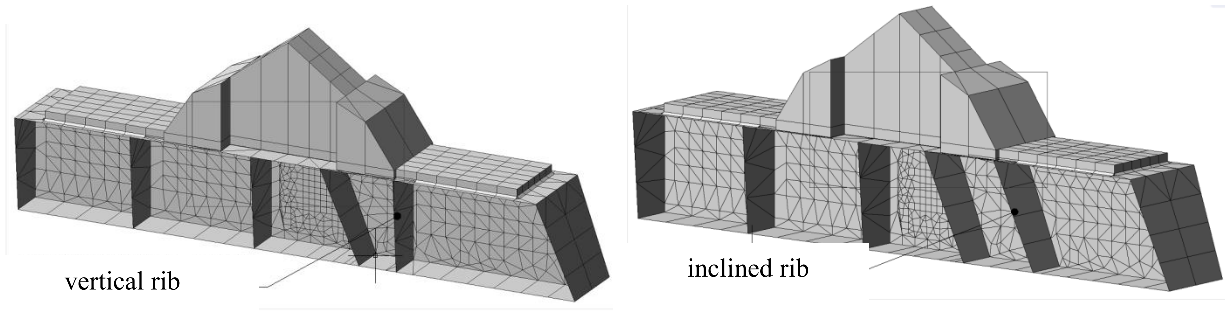


Figure 14: The maximum-average stress ratio in the area of study at different parameters of the resultant of the hoisting cable tension.

With regards to local stresses in the sub-pulley structures, it was discovered that strength capacity limits were reached due to tangential and reduced stresses. Two methods of enhancing the node were theorized. Additional cross ribs could be placed under the exposed face of the support bearing: a) vertical rib; b) inclined rib (the rib inclination corresponds to the inclination of the resultant of the cable tension), see Fig. 15 and Table 5.



a) b)

Figure 15: Cross ribs under the exposed face of the support bearing: a) vertical rib; b) inclined rib

Table 5. The extreme values of local stresses in the resting node of the guide pulley for two different additional cross ribs placements

Rib arrange-ment	σ_{Max1}, MPa	σ_{Max2} MPa	$\sigma_{прив.}$ MPa	$\sigma_{xMax,}$ MPa	$\tau_{Max.}$ MPa	$\sigma_{Max1}/\sigma_{Max2}$	$\sigma_{Max}/\sigma_{aver}$	$\sigma_{xmax}/R_y\gamma_c$	$\sigma_{red}/1.15R_y\gamma_c$	$\tau_{Max}/0.58R_y\gamma_c$
Vertical	72.5	-185.2	230.2	-153.8	117.8	-0.4	2.0	0.5	0.7	0.7
Inclined	145.6	-178.4	281.1	-169.7	121.0	-0.8	2.2	0.6	0.9	0.7

From the above table it is evident that a vertical rib arrangement under the exposed face of the support bearing is more effective than an inclined rib arrangement, because the maximum-average stress ratios ($\sigma_{Max}/\sigma_{aver}$) are lower in the area of study.

4 CONCLUSIONS

1. In the study, an excess of the reduced stresses in the sub-pulley structures was revealed. The reason for this lies in a zone of local stresses in the nodes of resting of the guide pulley bearings.

2. As a result of the numerical experiment, the following typical areas of distribution of local stresses in the resting node of the guide pulley were revealed: : «*A*» – the area of the local stress distribution under the support bearing foot close to the linear stressed state ($\sigma_{Max1}/\sigma_{Max2}$ = -0.018); «*B*» – the area of the plane mode of deformation in the wall of the pulley attachment point ($\sigma_{Max1}/\sigma_{Max2}$ = -0.335); «*C*» – the area of the plane mode of deformation in the girder wall ($\sigma_{Max1}/\sigma_{Max2}$ = -0.212); «*D*» – the area of the steady mode of deformation in the girder wall close to the linear stressed state ($\sigma_{Max1}/\sigma_{Max2}$ = -0.087).

In the area of local stresses «A» in the girder wall of the sub-pulley structure an area for which no strength by tangential and reduced stresses (σ_{red} $/1.15R_y\gamma_c$=1.1; $\tau_{Max}/0.58R_y\gamma_c$=1.1) was provided in case of the accidental combination of loads.

3. To provide the strength of the girder walls in the resting nodes of the guide pulley, it is recommended to place additional double vertical ribs under the exposed face of the support bearing in accordance with the diagram given in Fig. 15.

4. The maximum-average stress ratio ($\sigma_{Max}/\sigma_{aver}$) in the girder wall of the sub-pulley structure in the zone of local stresses «A» changes from 4.57 to 3.04 as the inclination of the resultant of the hoisting cable tension changes in the range of $30^0 \dots 65^0$.

5. The connection between the center of the area of local stresses (area «A») to the pulley axis of rotation is constant as the inclination of the resultant of the hoisting cable tension changes. Both the width and height of this area increases 1.7 times as the inclination of the resultant changes. This relationship has linear characteristics.

REFERENCES

[1] Standard II-23-81*. Codes of design. Steel structures /— M.: CITP Gosstroy of the USSR, 1991. — 96 p.

[2] Standard 1.2-2:2006. Loads and effects. – Kyiv: Minstroy of Ukraine, 2006 – 78 p.

[3] Standard 12.005-94. Metal structures of the shaft headgears. Operation demands. K.: Gosugleprom of Ukraine, 1994. — 68 p.

[4] Standard 12.003-92. The order and organization of observation of bearing metal structures of shaft headgears. K.: Gosugleprom of Ukraine, 1993. — 102 p.

[5] Standard 12.011-96. Buildings and structures of the technological complexes of the mining site. Operation demands. K.: Gosugleprom of Ukraine, 1996. — 75 p.

[6] Standard 46-75. Instructions to determine loads on buildings and structures of the coal mining industry. Donetsk, 1977. – 89 p.

[7] Instructions to determine the normative loads and coefficients of overloads for mine yard and structures of the coal mining industry. K.: Budivel'nyk, 1964. – 81 p.

[8] Gorokhov E.V., Kushchenko V.N. Reserves of the bearing ability of steel structures under short-time dynamic effects // Proc. Prospects of the development and ways of increasing the efficiency of using light and specially light metal structures. – K., 1984. – P. 103-104.

[9] Kushchenko V.N., Nechitailo A.E. Analysis of the mode of deformation of the main bearing elements of the frame-type sloping shaft headgears // Metal Structures. – Vol. 17. – No.3. – Makiyivka, 2011. – P. 151-165.

[10] Zherbin M.M. Development of the civil engineering science and technique in the UkSSR: in 3 volumes // AS UkSSR. – K.: Naukove Dumka, 1989. – 308 p.

[11] Zherbin M.M., Vladimirsky V.A. Investigation of the static effects of the wind flow on the tower headframes / Abstract information about the completed researches at the universities. – Civil Engineering, Architecture, Building materials and items. Vol. 6. –

K.: Higher School, 1972. – P. 22-25.

[12] Kushchenko V.N., Kostritsky A. S. An experimental study of the dynamics of the shaft headgear structures. – Visnyk DonDABA 2003-2 (39). Vol. 2. Building structures: materials, structures, technologies. – P. 46-52.

[13] Kushchenko V.N., Kostritsky A. S., Nekrasov Yu.P. Methods and results of the dynamic tests of the sloping shaft headgear // Visnyk DonDABA. Building structures. 2003-2 (39). – P. 116-125.

[14] Balkarey I.M. Determination of the extreme dynamic loads on the structures of shaft headgears // Proc. III Conference of Young Civil Engineering Scientists. Issues of the Up-to-date construction and architecture // K.: Budivel'nyk, 1965. – P. 274-283.

[15] Balkarey I.M. Special loads on the structures of mine and shaft headgears // In: Dynamics and strength of structures. K.: Budivel'nyk, 1965. – P. 60-63.

[16] Balkarey I.M., Koltakova G.V. Vibrations of sloping headgears at a special fracture of the mine hoisting rope // In: Dynamics and strength of building structures. K.: Budivel'nyk, 1965. – P. 50-64.

[17] Perel'muter A.V., Slivker V.I. Design models of structures and a possibility of their realization. – K.: Kompas, 2001. – 446 p.

[18] Metal Structures. In 3 vol./ Ed.: V.V. Kuznetsov (N.L. Mel'nikov DNIIproektstal'konstruktsiya). – M.: ACB Publishing House, 1998. – (Designer's Handbook).

[19] Murgewski J. Reliability: State-of-Art, EX International Conference on Metal Structures,. Final Report. – Krakov, Poland, 1996. – P. 99-112.

[20] Recommendation for Loading and Safety Regulations for Structural Design Nordic Committee on Duilding Regulations, 1978.