ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫНЫҢ
Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

Х А Б А Р Л А Р Ы

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
Казахский национальный исследовательский
технический университет им. К. И. Сатпаева

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF KAZAKHSTAN
Kazakh national research technical university
named after K. I. Satpayev

SERIES
OF GEOLOGY AND TECHNICAL SCIENCES

6 (438)

NOVEMBER – DECEMBER 2019

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

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«ҚР ҰҒА Хабарлары. Геология мен техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктенуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).
Қазақстан республикасының Мәдениет пен ақпарат министрлігінің Ақпарат және мұрағат комитетінде 30.04.2010 ж. берілген **№10892-Ж** мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Мерзімділігі: жылына 6 рет.
Тиражы: 300 дана.

Редакцияның мекенжайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., 220, тел.: 272-13-19, 272-13-18, http://www.geolog-technical.kz/index.php/en/

Редакцияның мекенжайы: Қазақстан, 050010, Алматы қ., Қабанбай батыра көш., 69а.
Қ. И. Сәтбаев атындағы геология ғылымдар институты, 334 бөлме. Тел.: 291-59-38.

Типографияның мекенжайы: «Аруна» ЖК, Алматы қ., Муратбаева көш., 75.

«Известия НАН РК. Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан (г. Алматы)

Свидетельство о постановке на учет периодического печатного издания в Комитете информации и архивов Министерства культуры и информации Республики Казахстан **№10892-Ж,** выданное 30.04.2010 г.

Периодичность: 6 раз в год
Тираж: 300 экземпляров

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, ком. 219, 220, тел.: 272-13-19, 272-13-18, http://nauka-nanrk.kz /geology-technical.kz

Адрес редакции: Казахстан, 050010, г. Алматы, ул. Кабанбай батыра, 69а.
Институт геологических наук им. К. И. Сатпаева, комната 334. Тел.: 291-59-38.

Адрес типографии: ИП «Аруна», г. Алматы, ул. Муратбаева, 75

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA "National Academy of Sciences of the Republic of Kazakhstan" (Almaty)
The certificate of registration of a periodic printed publication in the Committee of information and archives of the Ministry of culture and information of the Republic of Kazakhstan N 10892-Ж, issued 30.04.2010

Periodicity: 6 times a year
Circulation: 300 copies

Editorial address: 28, Shevchenko str., of. 219, 220, Almaty, 050010, tel. 272-13-19, 272-13-18,
http://nauka-nanrk.kz/geology-technical.kz

Editorial address: Institute of Geological Sciences named after K.I. Satpayev
69a, Kabanbai batyr str., of. 334, Almaty, 050010, Kazakhstan, tel.: 291-59-38.

Address of printing house: ST "Aruna", 75, Muratbayev str, Almaty

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 6, Number 438 (2019), 276 – 286 **https://doi.org/10.32014/2019.2518-170X.179**

UDC 621.878.879
MRNTI 55.55.31

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ICREASING THE RELIABILITY OF THE AUTOGRADER METAL CONSTRUCTION BY MODELING AND RE-ASSEMBLING OF THE WORKING EQUIPMENT

Abstract. The auto grader is a road machine in which its working bodies always work under conditions of critical loads on the metal structure and attachment points for components and parts. They are affected by hit, twist, kink, static and dynamic loads. Developed in this work, the 3D model for determining the limiting states of metal structures of the grader and mathematical model for determining the efforts arising on the working body and wheels during the grader operation allow comparing new designs of auto graders with traditional serial ones and evaluating the stress-strain state of their metal structures depending on the design positions.

The article presents a method for determining external power factors on the working body and the auto grader engine and their influence on the stress-strain state of the metal structure of auto grader. This technique allows finding and evaluate more realistic design positions and loads on the grader nodes in addition to already adopted.

Key words: auto grader, auto grader 3D model, auto grader mathematical model, auto grader stress-strain state, calculated positions of the auto grader, additional calculated positions of the auto grader.

1. Introduction. The active development of transport infrastructure, the growth of construction of residential and commercial real estate, increases the demand for road construction equipment. The need to improve the design of newly created technology is due to fierce competition from the outside and the desire to conform to the level of world technical progress. Therefore, the identification of new rational forms and methods of fastening and the location of units and structures of road-building machines by simulating their stress-deformable state is an important and urgent task.

The research results and solutions to this issue may be different, for example, the modernization of existing equipment, made according to traditional mounting and assembly schemes, or the creation and implementation of fundamentally new machines and equipment with better characteristics.

The purpose of the work is to optimize the design of the auto grader working equipment in terms of reducing the load on metal structure.

Well-known research optimization design of bulldozers [2], which describes how due to optimal location of the working equipment hinges of the bulldozers was achieved a significant effect from a technical point of view, and from an economic one. The methodology of these studies was taken as the basis of the newly developed algorithm for finding critical loads in the nodes of the auto graders metal structure.

The effect of stress reduction is achieved by reducing the bending moments in the steel structure of the grader, which is achieved by a certain arrangement of working equipment elements relative to other nodes.

The research objective is to determine and reduce the operational loads on the metal structure of the auto grader working equipment by rational re-assembling its units.

Arrange in the same plane, passing through the axis of symmetry of the turntable, the blade cutting edge and the axis of hydraulic cylinder carrying out the pull frame (figure 1).

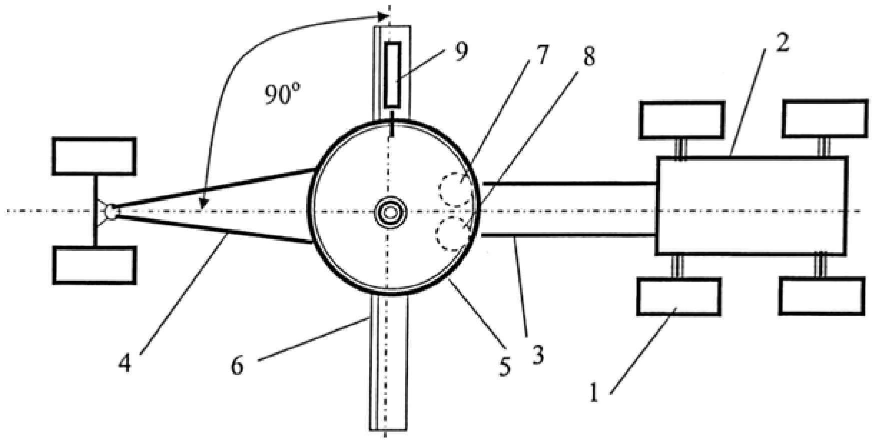


Figure 1 – Fastening scheme of the working equipment of the auto grader:
1- propulsion; 2 - podmotornaya frame; 3 - spinal beam; 4 - traction frame; 5 - turn circle;
6 - blade; 7 - hydraulic cylinders for raising / lowering the traction frame; 9 - hydraulic ram traction frame

The auto grader strength calculation is carried out according to the design provisions [1]. The search for additional design positions is reduced to finding the maximum of the goal function. In general:

$$\sigma = f(X_1, X_2, \dots, X_{i-n}, \dots, X_i)$$

where σ – equivalent stress at the most loaded point of the section; $X_1, \dots, X_i$ – variables of external forces; moments; parameters characterizing the position of the working body (cutting angle, angle of capture, folding angle of the articulated frame, etc.).

In this case, the goal function is

$$\sigma = f(P_1, P_i, P_{x1}, P_{y1}, P_{z1}, \dots, P_{x6}, P_{y6}, P_{z6}, G_z, G_p, \varphi_p, \varphi_b, f_k, m, n, \alpha, \beta, \gamma, \theta)$$

where G_z – part of the auto grader weight, falling on the rear truck; G_p – part of the auto grader weight, falling on the front axle; f_k – rolling resistance coefficient; φ_p – longitudinal traction coefficient; φ_b – lateral adhesion coefficient; α – angle of capture; β – angle of inclination; γ – cutting angle; θ – folding angle of the frame; $P_{x1}, P_{y1}, P_{z1}, \dots, P_{x6}, P_{y6}, P_{z6}$ – normal ground reactions of all wheels of the grader.

2. Materials and methods. To determine the position of the auto grader working body, it is needed to calculate the reactions on its wheels. According to the existing standards, the calculation of the steel structure of the auto grader for strength is made in three design positions, therefore, the reactions on the wheels are found from the equilibrium equations of the spatial force system.

To solve the equations (figure 2), we write the following equations:

$$O_y: \varphi_p * G_z - G_p * f_k - P_1 = 0;$$

$$O_z: R_2 + R_1 - G_z - G_p = 0;$$

$$M_x: R_1 * (l_0 - m) - R_2 * m + G_z * m - G_p * (l_0 - m) = 0;$$

When solving equations in the program Mathcad, the research results are:

$$R_2 = 102{,}5\ kN; R_1 = 43{,}5\ kN; P_1 = 65{,}5\ kN.$$

After that it is needed to recountR_1, R_2on all wheel reaction $P_{x1}, P_{y1}, P_{z1}, \dots, P_{x6}, P_{y6}, P_{z6}$.

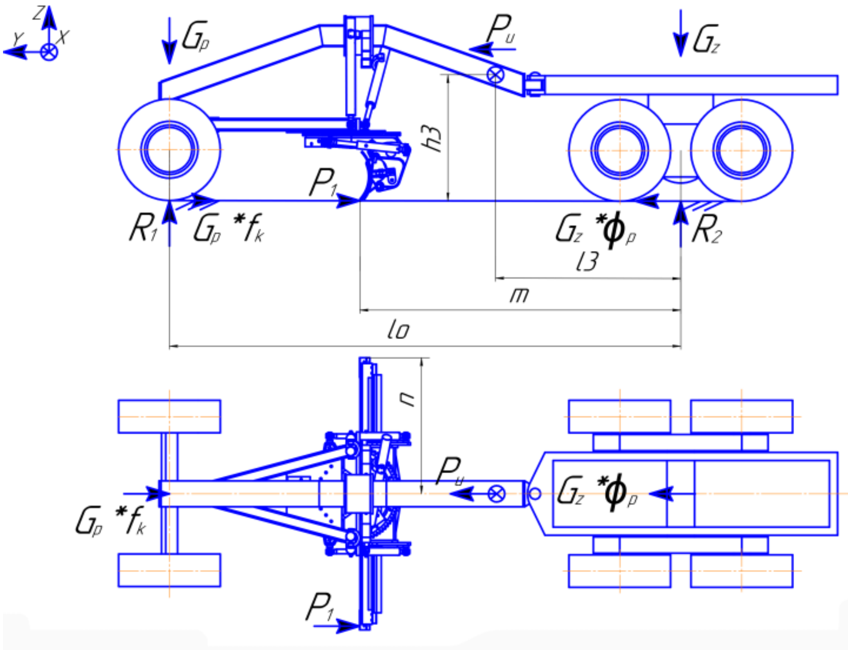


Figure 2 – Estimated scheme of application of loads on the motor grader

The resulting equations do not take into account the force of inertia, because the influence of inertial and static loads is spaced apart in time.

To confirm this, let us consider the oscillogram shown in figure 3, obtained during the experiment with the impact of the grader's blade into a hard obstacle [2].

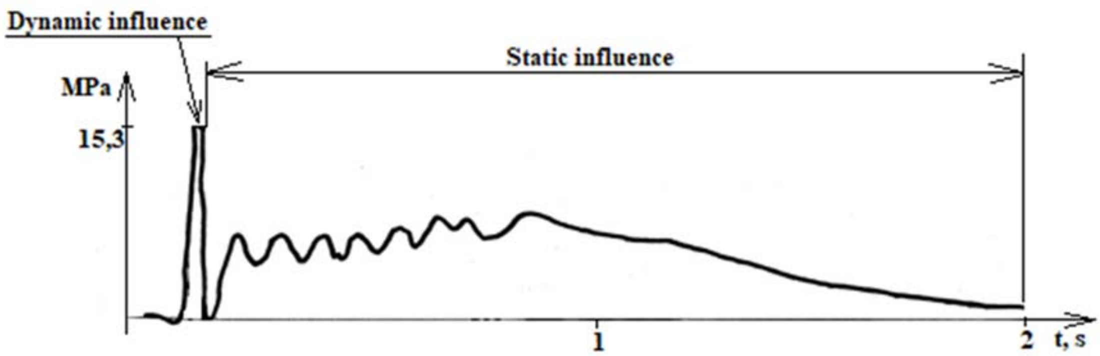


Figure 3 – Oscillogram of the impact by the center of the grader's blade into an insurmountable obstacle

The oscillogram shows that when the grader dumps into an insurmountable obstacle, peak loads first reach dynamic loads, and then the process of increasing static loads begins. They do not occur simultaneously, but one after the other. Thus, it is impossible to take into account the effect of static and dynamic loads at a time. It takes into account their influence separately, and then choose which of them is the most dangerous.

Inertia force is calculated using the formula:

$$P_u = (k_d - 1) * \varepsilon * G_z = 43{,}5\ kN.$$

where ε – adhesion coefficient.

Let us considering the calculation of objects only in statics insufficient, since it will be characterized by low accuracy of the results obtained and the conditions reflected. When calculating in statics, the change in the adhesion coefficient of the wheels to the ground, vibrations of tires, the resonance of the structural elements, the mutual influence of the structural elements on each other, the redistribution of loads under off-center loading and are not taken into account and etc.

As an example, we will describe one of the drawbacks of such a static calculation. When the calculation is carried out using the static equations, the reaction of the soil from the interaction with the wheel is applied along the axis of the wheel, perpendicular to the support surface, but in reality this is not always the case. Because of the irregularities of the support surface, the contact is different at each moment of time and not always symmetrical, hence the reaction from this contact acting on the wheels is often not directed along the axis of the wheel and not perpendicular to the supporting surface, as is the case in an idealized situation.

3. Model. Taking into account the shortcomings of the traditional method, it was decided to create a tool using the simulation in the MATLAB program, which would allow receiving the loads that occur during the entire work, as close as possible to the actual conditions.

Objects of modeling: the profile of the support surface, working environment – soil, machine design, engine, transmission, wheels, “driver”, machine operation modes – transport, technological and impact. Below will be described only some of the presented model objects in detail.

4. Modeling of ground profile. Behavior of the machine during the impact depends not only on its rigidity, the application place of the impact force, the magnitude of this force, but in most cases is determined by the machine adhesion to the supporting surface. As already described above, the design calculation in statics does not allow obtaining adequate values of support surface reactions and adhesion coefficient values, because at each moment in time they are different in direction and magnitude, and depends on many factors, one of which is the road profile.

The MATLAB program has a generator unit of a normally distributed random signal, each time a program is started, a process called “white noise” is generated (figure 4a). From the blocks, a system of first order differential equations (2) is assembled, which can be transformed into a second order differential equation (1) [4].

$$\ddot{q}_1 + 2 * \alpha_v * \dot{q_1} + b^2 * q_1 = K * \dot{x}_{[0;1]} + b^2 * x_{[0;1]} \quad (1)$$

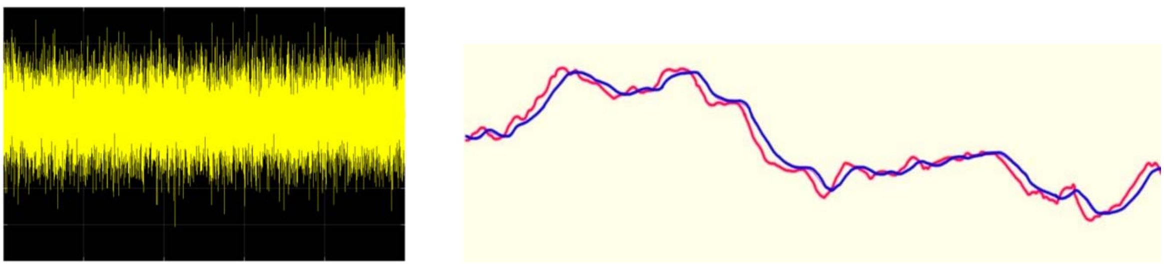
$$\begin{cases} \frac{df}{dt} = K * b * x_{[0;1]} - b^2 * q_1 \\ \frac{dq_1}{dt} = K * x_{[0;1]} - 2 * q_v * q_1 + f \end{cases} \quad (2)$$

$$b^2 = \alpha_v^2 + \beta_v^2; \quad (3)$$

$$K = \sqrt{\frac{2 * D_q * \alpha_v}{D_{x_{[0;1]}} * \Delta t}}; \quad (4)$$

$$\alpha_v = \alpha_\tau * v; \ \beta_v = \beta_\tau * v; \quad (5)$$

where Δt – the time interval for which the car traveled the path; q_1 – ordinate of the road profile; $x_{[0;1]}$ – “White noise” with a mathematical expectation of zero and a variance of one; v – the machine speed.



a *b*

Figure 4 – White noise (a) and the real profile at the filter output (b)

The solution of differential equations (2) allows obtaining the value of the ordinates of the desired profile of the support surface (figure 4, b).

The pink curve is obtained at the output of the second-order differential equation (from the shaping filter), and the lilac line is transformation of the cross-sectional profile of the road surface due to smoothing of disturbances (because the tire has its damping ability and contact patch of course). Those, the signal passes through another differential equation (a filter simulating the smoothing ability). And the model of the motor grader itself works taking into account the lilac line; it is the final result.

Thus, system (2) has the meaning of a shaping filter, which cuts a profile from the incoming signal - white noise coming to it, in accordance with the given coefficients of the initial data. The initial data determining the profile of the roadway: D_q is the dispersion of the roughness of the road surface, l is the length of the track; α_τ, β_τ - coefficients characterizing the degree of irregularity of the road profile.

5. Wheel modeling. When determining real loads (figure 5), there is always a mismatch between the current and given speed in the mathematical model due to the fact that the support base profile is not constant, and the resistance that occurs when wheels interact with the support surface will always be different.

$\alpha_{eq} = \frac{\sum_{i=1}^{n_T} \alpha_i dr_i}{\sum_{i=1}^{n_T} dr_i}$ – the angle at which the resultant interaction reaction of the wheel with the support base is located. The program splits the deformable part of the wheel into sectors with an angle α_i. On each side of the sector, the overlap dr_i is determined and the equivalent angle is calculated by the formula. Next, it is important to project the tangential and radial components on the coordinate axes and get reactions on the wheels.

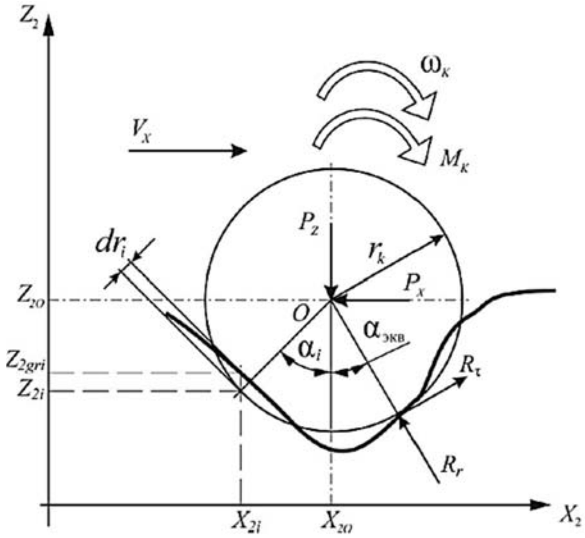


Figure 5 – Calculation diagram of the elastic wheel [4]

6. Modeling design. The visualization of the machine design is shown in figures 6 and 7. The machine itself is a collection of absolutely rigid, non-deformable bodies connected by hinges. Each hinge contains the coordinate axes and centers of mass of the bodies, also described by their coordinates. The definition of the relative position of the structural elements is a description of the location of all these coordinate axes, relative to the base coordinate system.

In addition to the coordinates for each body, the inertia tensor and mass are specified.

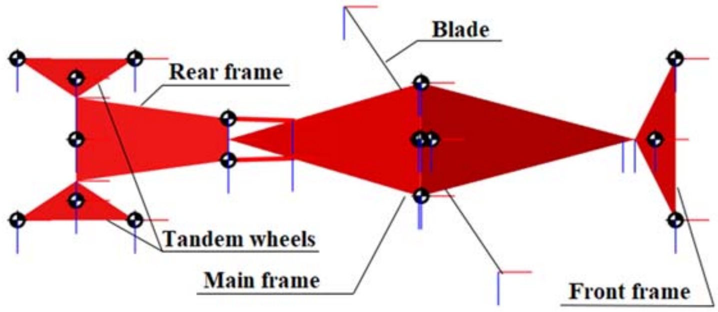


Figure 6 – Mathematical model of the auto grader top view

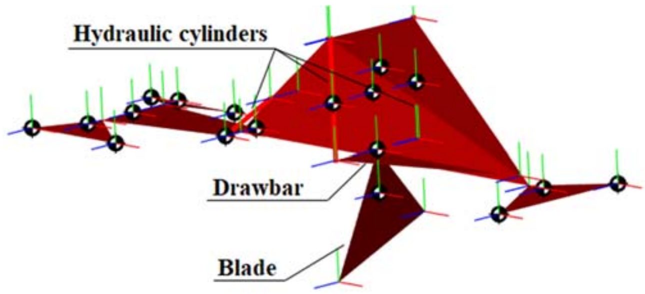


Figure 7 – Mathematical model of the auto grader in isometric view

7. Modeling modes of operation. To simulate the technological mode of operation, we will mathematically set the forces arising on the heap during "slaughter".

$$W_o = W_p + W_{pr} + W_в + W_m + W_{tr}$$

where W_p – cutting resistance;W_{pr} – resistance to movement of theground prism in front of the blade; $W_в$ – resistance to movement of the groung up the dump;W_m – resistance to grader movement;W_{tr} – resistance to friction of the grader's knife against the ground.

To simulate the situation of the grader's blade impact into an insurmountable obstacle, Newton's second law formula, written in the form of a force impulse, is used (figure 8).

$$\vec{F} * \Delta t = M * \vec{V}$$

And in the form of a function, the change of impact force over time was recorded.

The metal structure strength of the grader is determined by the calculation of the main, random and emergency loads.

Existing regulations consider three design provisions [1]:

1) the end of the cutting, the front axle is hung and rests on the ditch edge, the rear wheels are stalled, the work is done on a cross slope with angle λ;

2) hitting the blade edge, pushed to the side, on an insurmountable obstacle;

3) auto grader in transport mode, there are vertical and horizontal loads from the mass of the nodes.

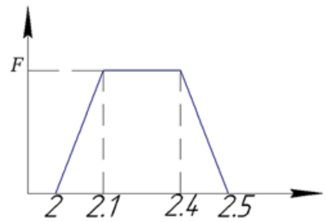


Figure 8 – A sequence diagram of the change in time of the shock force

Modern auto graders are exploited more intensively and in a much more aggressive environment. By virtue of high-quality hydraulic system, powerful engines, the availability of all-wheel drive and ease of control, they began to have greater maneuverability and the range of categories of soil development increased.

Therefore, the existing calculation, including the above design positions, cannot reflect all possible loads acting on the motor grader and, if an unaccounted load appears at any positions, this will affect the quality of operation and, possibly, the durability of the steel structure. Therefore, it is necessary to include additional design provisions in the calculation of the auto grader, the analysis of which will give a more complete picture of the stress-strain state of its metal structure in any working position.

In this work, figures 1 and 2 show the estimated position of the grader in transport mode, at a speed of 10 km/h, and it hits the dump edge on an insurmountable and absolutely rigid obstacle. It is precisely this position that is chosen here because it is more often realized in life. For example, when the auto grader is passed from site to site, and because this position where dangerous stresses arise that leads to the destruction of the metal structure.

Firstly, it is needed to find the reaction on the wheels and select the mode of operation, in this case it refers to clearing, and not to profiling.

When running a mathematical model, the greatest effort on the blade is obtained: $P_1 = 12 \cdot 10^4 N$ (figure 9).

To determine the magnitude of the voltage reduction in the grader steel structure during its operation, the analysis on 3D models made in the Solid Works program is done.

Consider two models, the traditional and the new, working in the same conditions, with the same design position described above.

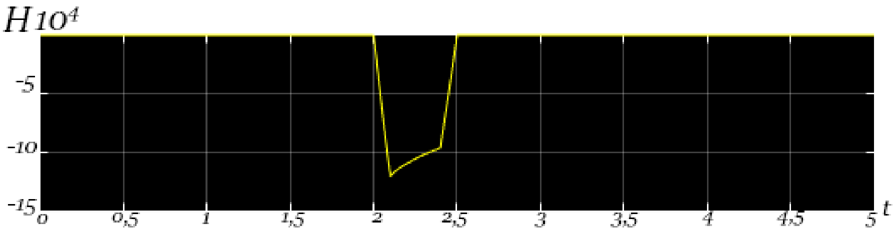


Figure 9 – Graph of force change on the blade at impact

There is an application of force values on the blade and reaction on wheels in the finite-element model of the auto grader obtained at the start of the mathematical model.

To begin with, there is a comparison the maximum stresses in calculating models with the basic and new designs (table).

Voltages in the base and new designs of the auto grader at the described design position

Base design	New design
15348,5 MPa	12672,2 MPa

Maximum stresses decreased by 17% when using a new design.

Then, there is a stress state comparison of the base (figure 10) and the new (figure 11) design, stress state of the working equipment of the base (figure 12) and the new (figure 13) design.

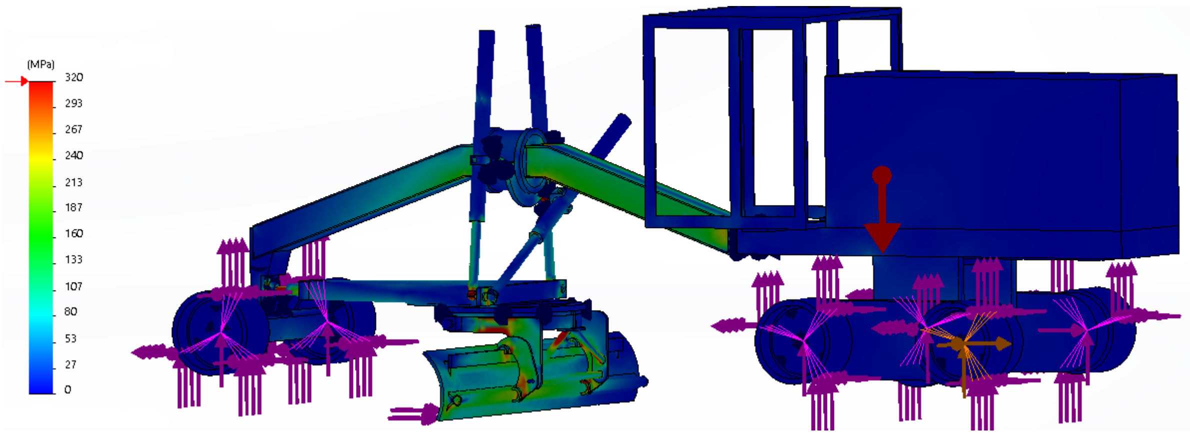


Figure 10 – The stress state of the basic structure

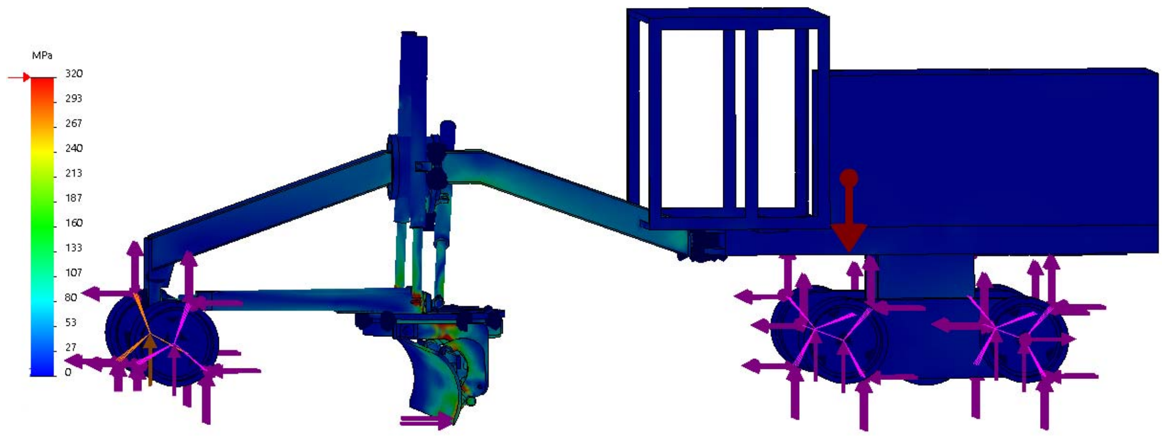


Figure 11 – Stress state of new construction

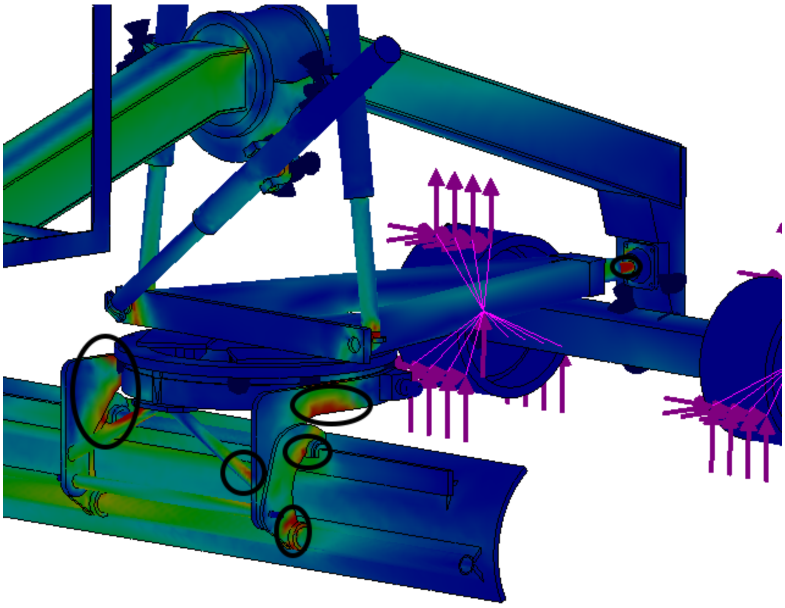


Figure 12 – The stress state of the working equipment of the grader basic design

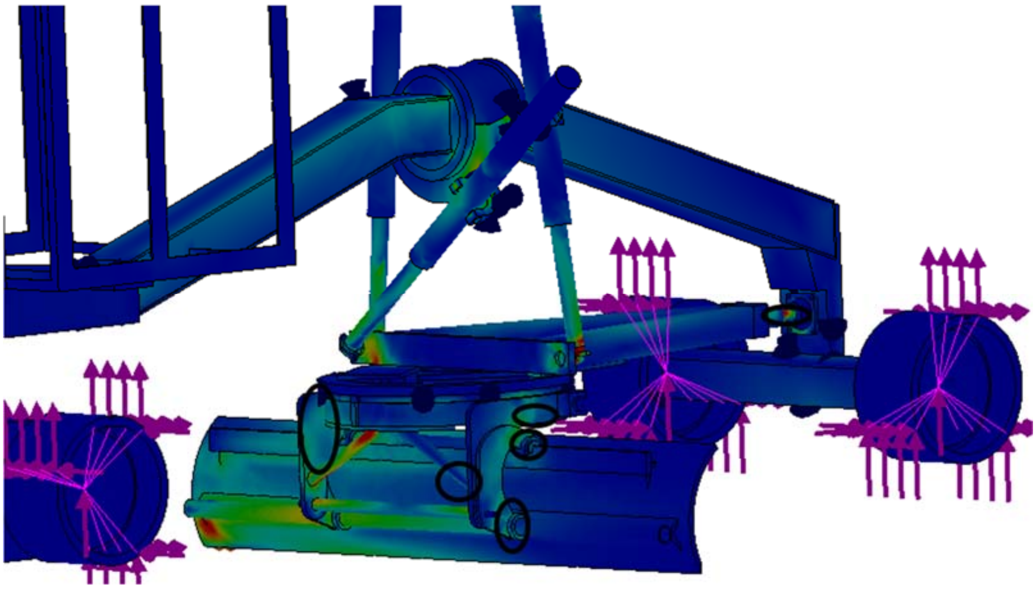


Figure 13 – The stress state of the working equipment of the new grader design

The stress state of the mounting bracket for hydraulic cylinders of the basic (figure 14) and the new (figure 15) design of the motor grader.

In figures 12, 13, 14 and 15 black oval marked places where there are dangerous voltages (highlighted in red) in the basic design and where they are no longer in the new design (highlighted in green, blue).

According to the illustrations, the proposed solution by locating the cutting edge of blade and axle of the outrigger hydraulic cylinder (figure 1) in one plane can significantly reduce stresses and, in some elements, even prevent destruction, with minimal cost to upgrade the structure.

Also, as proof of the fact that the stresses on the 3D models of the grader are obtained in those parts of the steel structure where breakdowns actually occur during the operation of the machine, practice example is given (figure 16).

Figure 16 shows the crack welded by electric arc welding on the hydraulic cylinder mounting bracket, caused by unregistered real loads during the operation of the auto grader.

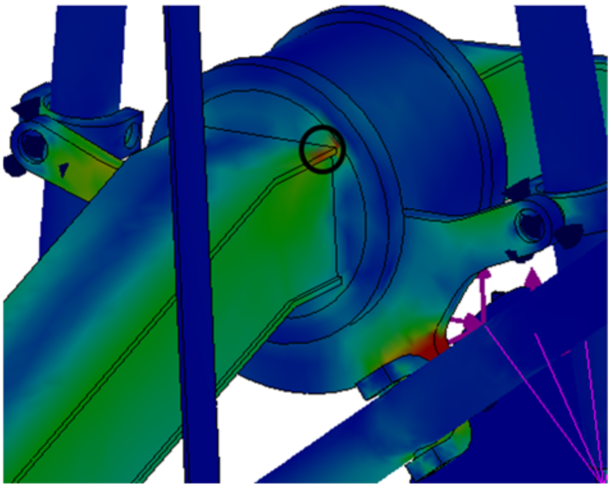


Figure 14 – Stress state of the mounting bracket of hydraulic cylinders of the grader basic design

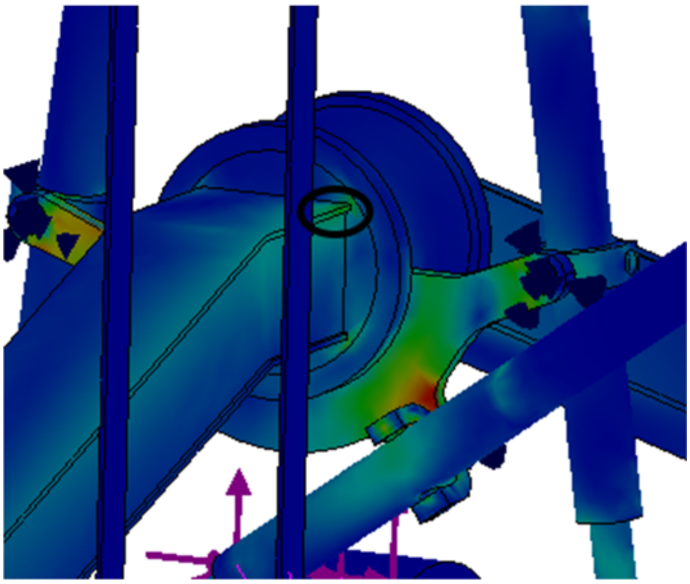


Figure 15 – Stress state of the mounting bracket of hydraulic cylinders of the grader new design

Figure 16 – Welded crack on the mounting bracket of the grader hydraulic rams, caused by unaccounted real loads

8. Conclusion.

1. In order to increase the strength and durability of the grader metal structure and determine critically loaded nodes and fasteners in standard calculations it is necessary to further consider the actual and calculated positions of the working bodies. For example, changing the wheels adhesion coefficient to the ground during movement, redistribution of loads under non-central loading, etc., this will allow more fully taking into account the effect on the machine processes that are not taken into account in the static calculation.

2. The results obtained in mathematical modeling, such as reactions on the machine wheels, can complement the finite element model and perform strength calculations of the stress-strain state of the motor grader's structure, which will give more real stresses in the critical components of the structure.

3. Stresses obtained and considered using models should be checked on a full-scale sample to ensure the reliability of the created tool. According to the research results, it is possible to give appropriate recommendations to the manufacturers of road machinery.

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ЖҰМЫС ЖАБДЫҒЫН МОДЕЛЬДЕУ ЖӘНЕ ҚАЙТА ҚҰРАСТЫРУ ЖОЛЫМЕН АВТОГРЕЙДЕРДІҢ МЕТАЛЛ КОНСТРУКЦИЯСЫНЫҢ СЕНІМДІЛІГІН АРТТЫРУ

Аннотация. Автогрейдер – жол машинасы, онда оның жұмыс органдары металл конструкциясына және тораптар мен бөлшектерді бекіту тораптарына қиын жүктеме жағдайында жұмыс істейді. Оларға соққы, бұрау, сыну, статикалық және динамикалық жүктемелер әсеретеді. Автогрейдер металлоконструкцияларының шекті жағдайын анықтауға арналған 3D модель және автогрейдер жұмысы кезінде жұмыс органында және дөңгелектерде пайда болатын күштерді анықтауға арналған математикалық модель автогрейдерлердің жаңа құрылымдарын дәстүрлі сериялық құрылымдар мен салыстыруға және есептік жағдайларға байланысты олардың металл конструкцияларының кернеулі-деформацияланған жағдайын бағалауға мүмкіндік береді.

Жұмыста жұмыс органында және автогрейдер қозғағышында сыртқы күш факторларын анықтау әдістемесі және олардың автогрейдер металл конструкциясының кернеулі-деформацияланатын жай-күйіне әсері әзірленді. Бұл әдістеме автогрейдер тораптарына қабылданған қосымшане ғұрлымнақты есептеу жағдайлары мен жүктемелерін табуға және бағалауға мүмкіндік береді.

Түйін сөздер: автогрейдер, автогрейдердің 3D моделі, автогрейдердіңматематикалықмоделі, автогрейдердің кернеулі-деформацияланатын жағдайы, автогрейдердің есептік жағдайы, автогрейдердің қосымша есептік жағдайы.

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ПОВЫШЕНИЕ НАДЕЖНОСТИ МЕТАЛЛОКОНСТРУКЦИИ АВТОГРЕЙДЕРА ПУТЕМ МОДЕЛИРОВАНИЯ И ПЕРЕКОМПОНОВКИ РАБОЧЕГО ОБОРУДОВАНИЯ

Аннотация. Автогрейдер – дорожная машина, в которой ее рабочие органы всегда работают в условиях критических нагрузок на металлоконструкцию и узлы крепления узлов и деталей. На них действуют удар, скручивание, излом, статические и динамические нагрузки. Разработанная в данной работе 3D-модель для определения предельных состояний металлоконструкций автогрейдера и математическая модель для определения усилий, возникающих на рабочем органе и колесах при работе автогрейдера, позволяют сравнивать новые конструкции автогрейдеров с традиционными серийными и оценивать напряженно-деформированное состояние их металлоконструкций в зависимости от расчетных положений.

В работе разработана методика определения внешних силовых факторов на рабочем органе и двигателе автогрейдера и, их влияние на напряженно-деформируемое состояние металлоконструкции автогрейдера. Эта методика позволяет находить и оценивать более реальные расчетные положения и нагрузки на узлы автогрейдера в дополнение к уже принятым.

Ключевые слова: автогрейдер, 3D модель автогрейдера, математическая модель автогрейдера, напряженно-деформируемое состояние автогрейдера, расчетные положения автогрейдера, дополнительные расчетные положения автогрейдера.

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www:nauka-nanrk.kz

ISSN 2518-170X (Online), ISSN 2224-5278 (Print)

http://www.geolog-technical.kz/index.php/en/

Верстка *Д. Н. Калкабековой*

Подписано в печать 15.11.2019.
Формат 70x881/8. Бумага офсетная. Печать – ризограф.
19,7 п.л. Тираж 300. Заказ 6.

Национальная академия наук РК
050010, Алматы, ул. Шевченко 28, т. 272-13-19, 272-13-18