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SUPPORTED CONSTRUCTION FOR QUARRY EXCAVATOR TRAVERSERS

It has been established that repair of quarry excavators should be carried out directly on site. In this case, the use of jacks for weighing the rotary platform of excavators Bucyrus RH340 and Terex RH200 models for repair of running equipment is impossible because of their design features. This type of repair is suggested to be performed as an excavator based on the design developed by the authors. The installation of the excavator on the support structure is carried out by its working equipment. The supporting structure is suggested to be made in the form of two identical fragments for its unification regarding the base of excavators and the convenience of transporting to the site of work. The suggested method of fixing the excavator to the support structure prevents it from being displaced from the impact of seismic loads during blasting operations. The investigation of the stress-strain state of the supporting structure was carried out using the complex of finite-element analysis.

Keywords: hydraulic excavator, strength analysis, method of ultimate elements, strain state.

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ОПОРНА КОНСТРУКЦІЯ ПІД ТРАВЕРСУ КАР'ЄРНОГО ЕКСКАВАТОРА

Установлено, що при ремонті кар'єрних екскаваторів використання домкратів для виважування поворотної платформи для моделей Bucyrus RH340 і Terex RH200 неможливе через їх конструктивні особливості. Тому ремонт запропоновано виконувати на розробленій авторами опорній конструкції. Установлення екскаватора на опорну конструкцію виконано його робочим обладнанням. Запропоновано спосіб фіксації екскаватора на опорній конструкції, що запобігає його зміщенню від впливу сейсмічних навантажень при вибухових роботах. Дослідження напружено-деформованого стану опорної конструкції проведено з використанням комплексу скінченноелементного аналізу.

Ключові слова: гідравлічний екскаватор, аналіз міцності, метод скінченних елементів, деформований стан.

Introduction. Crawler moving equipment for quarry excavators is subject to heavy loads during the process of soil development and moving the machine. Also, metal surfaces of the propeller parts of are exposed to moisture, abrasive, and sometimes aggressive media. As a result of these factors, crawler tapes, sprockets, steering wheels, rollers and other components of the running gear are triggered and deformed, which leads to the repair work need.

Unlike pneumatic equipment (such as dump trucks, loaders, etc.) delivery of a crawler excavator in general or its separate element to a service center, even on a specially equipped platform for repair, is a complex task. Therefore, the maintenance and repair of the excavator directly on the site of work is actual. In turn, these types of technological influences are often associated with the need for unloading the running gear, that is, with a partial or complete weighting of the machine [1 – 3].

Analysis of recent sources of research and publications. The practice of performing such a type of work is tested, which is based on the disconnection of the rotary part of the excavator by lifting it over irreversible with the help of powerful hydraulic jacks [4, 5]. However, such a lift can only be made if the overall dimensions of the swing platform in terms of at least one of its positions exceed the overall dimensions of the crawler. This makes it possible to bring jacks or beams to the carving elements of the swing platform. In excavators of a number of models, for example, the Bucyrus RH340 and Terex RH200 [6, 7] (see Figure 1), the rotary platform does not go beyond the running gear and it is impossible to put it under the jack. Therefore, in this case, other ways to unload the running equipment, in particular, considering the excavator as a whole, should be applied.

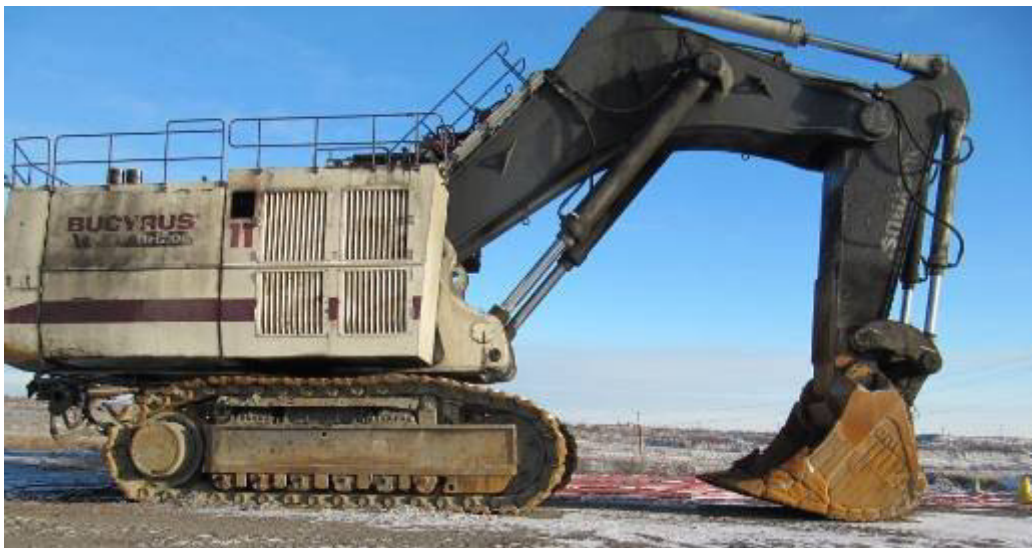


Figure 1 – Service object – quarry excavator Bucyrus

The complexity of this work type is due to the large mass of excavators (so the mass of Bucyrus RH340 is 542 tons) and the possibility of the impact of seismic loads during the performance of explosive work in a quarry on a machine that is in a weighted condition.

Identification of general problem parts unsolved before. The height of the excavator weighing is determined by the possibility of access to the main components of the running equipment and is relatively small. So for excavators Bucyrus and Terex models (see Figure 1), the height above the surface of the platform, which is 300 mm, is quite sufficient for maintenance.

In the process of digging, when immersing a bucket in a rock and turning it for scraping, the working equipment of these excavators develops considerable effort both in the horizontal and in the vertical directions. These efforts are quite sufficient for partial weighting

of the machine over the support surface [8]. Characteristics of the working equipment strength meet these requirements too. However, the full unloading of all running gear cannot be achieved. Maintenance of the machine in a weighed condition during a performance of repairs is extremely dangerous. Consequently, it is necessary to create a supporting structure of the required carrying capacity, which is supplied to the excavator not simultaneously, but consistently, as a partial weighing of the machine with the help of its own working equipment.

Considering this fact, it was decided to lift the excavator to the required height by installing the supports for the part of the excavator weighed out using its own working equipment. Thus, the **goal** is to reduce the design of the supporting structure of the required payload under the traverse of the excavator.

Basic material and results. In the analysis of the excavators traverse structure of the indicated models and considering the wishes of the customer, it was found that the optimum place for establishing the support structure under the traverse is its supporting platforms (see Figure 2).



Figure 2 – The location of the supporting platforms on the traverse of the excavator

It was decided to locate the support structure under the excavator between the crawler belt (see Figure 3). This is due to the need for access to the main components of the chassis, the location of the traversing support platforms, the dimensions of the chassis, namely the distance in the transverse direction between the crawler belts and the base, requirements for pressure on the support platform.

The permissible pressure on the soil was taken in the same way as the pressure created by the excavator itself. In this case, the required area of the supporting structure is approaching the area of the intergenerational space. The same basic structure is proposed to be made of two identical fragments in order to unify it with respect to the base of excavators and the convenience of transportation to the place of work (see Figure 4).

It was decided to carry out the positioning of the machine before weighing it by coming onto pre-exposed fragments of the supporting structure. This is due to the large mass of individual fragments of the supporting structure, and, consequently, the complexity of their placing under the excavator. However, the constructive feature of the traverse of the excavator

is that in the middle part it has the highest height above the level of the reference surface. At crawler tapes, in areas where the main platforms are located, the altitude is significantly reduced. Therefore, constructively, each piece of the supporting structure is executed with two mobile-bearing stands. The curbs on the excavator are shifted to the middle, which ensures unhindered movement of the excavator over the support structure. In the future, when weighing the excavator with its own working equipment, the main pillars are split into the sides, under the support of the traverse of the excavator. Such a constructive solution provides the necessary height of fixing a weighted excavator for repair of running gear.

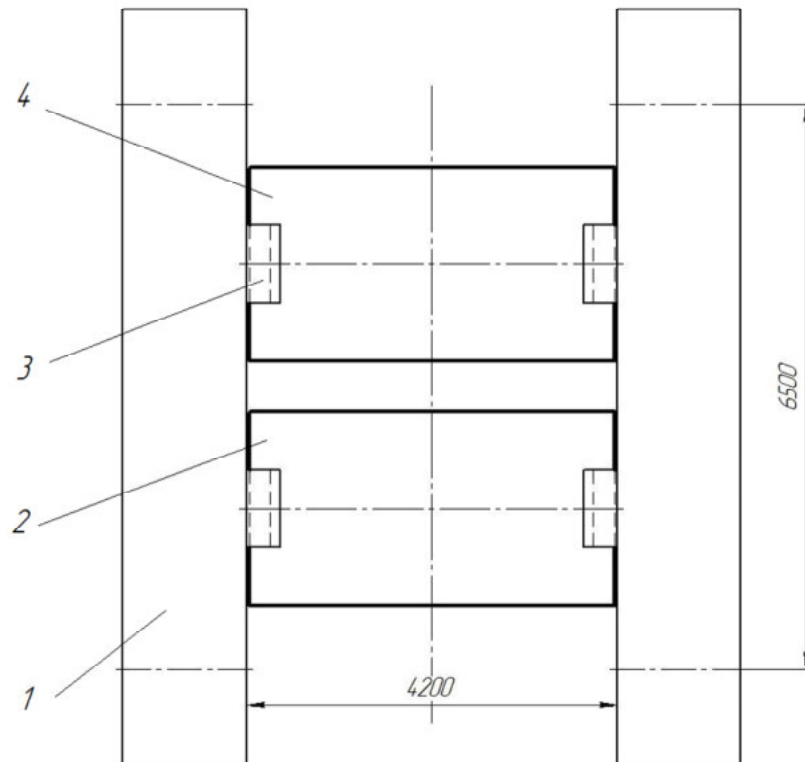


Figure 3 – The location of the supporting structure under the excavator (indicated by a thickened line): 1 – crawler tape; 2, 4 – fragments of the supporting structure; 3 – the main platforms of the traverse of the excavator

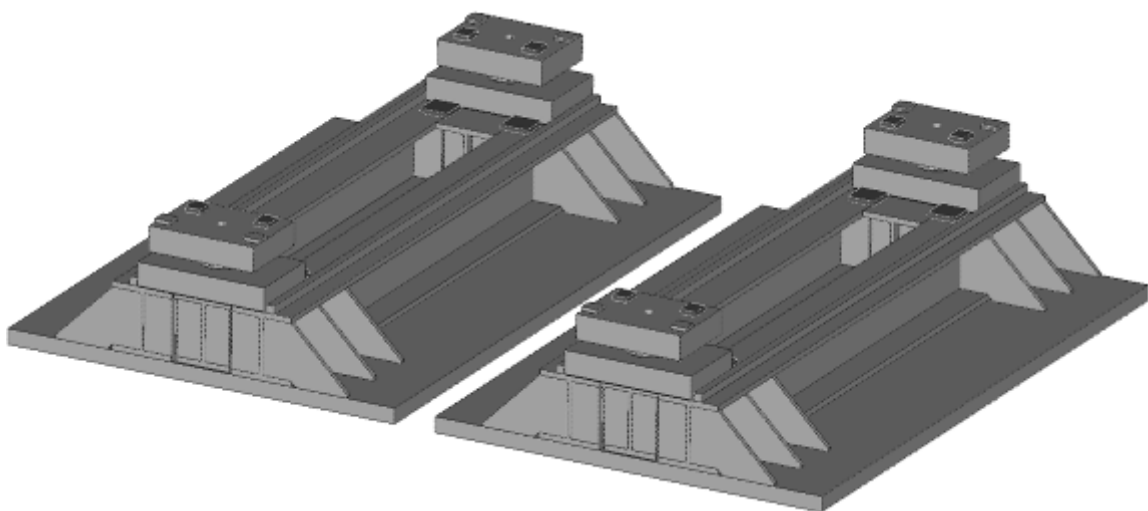


Figure 4 – The structure of the supporting structure under the traverse of the excavator

The significant weight of mobile stands does not allow them to be moved at the expense of the worker's efforts along the metalwork. Therefore, it was decided to use a screw mechanism, with the possibility of its reinstallation as the pedestal progressed to the working position (see Fig. 5). A characteristic feature of the mechanism design is in order to compensate for distortions when pushing the pedestal, the nut of the screw mechanism is made such that it has two degrees of freedom relative to the fixing position. Due to this fact, the distortions are compensated in the horizontal and vertical planes. Moving the pedestal to the working position is carried out in two resetting of the mechanism.

Installing the excavator on the support structure takes place in several techniques. The first step is to arrange the towers in the plan at the site clearly, which is selected and prepared in accordance with the requirements for repair work. Further, the excavator moves in its turn on the support structure to ensure the clear location of the supporting platforms of the traverses over the reference stands.

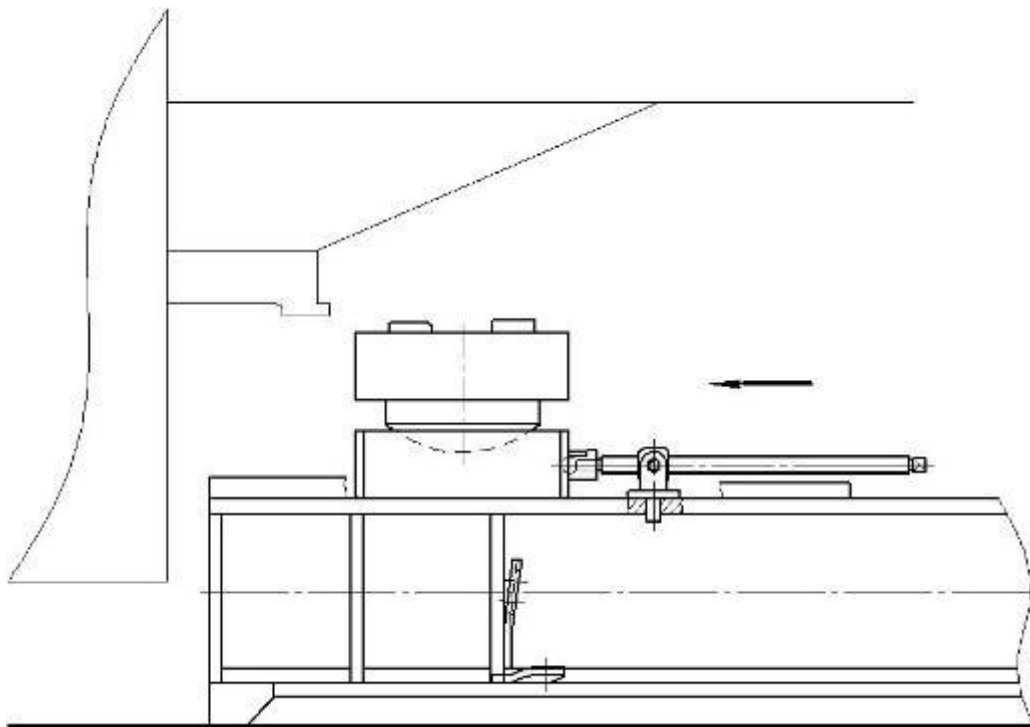


Figure 5 – Fitting the pedestal under the support of the traverse with the help of a screw mechanism

At the expense of its own working equipment, one side of the excavator is weighed to the height necessary for the installation of support posts under the supporting platforms of the traverse. When weighing the position of the excavator, with the help of screw mechanism, the digging of the stands in the working position is carried out, after which the excavator falls to the curbstones.

After turning the rotary part by 180° the steps are repeated - the opposite part of the excavator is weighed and fixed on the stands of the second piece of the supporting structure. In order to avoid self-propelled pivots with respect to the support plate during blasting, their fixation is foreseen. The removal of the excavator from the support structure after the repair work is carried out in reverse order.

Another characteristic feature of the support structure is the following: each of the stands has two assembly units that contact each other through a spherical surface (see Fig. 5). Such a constructive decision was made considering the support areas of the weights of the

weighted excavator are at a certain angle to the horizon (see Fig. 6), and, with further lowering of the excavator, the support surfaces of the platform traverses and pedestals have a small touch area. It causes significant specific loads in the point of contact, which can lead to deformation of these elements.

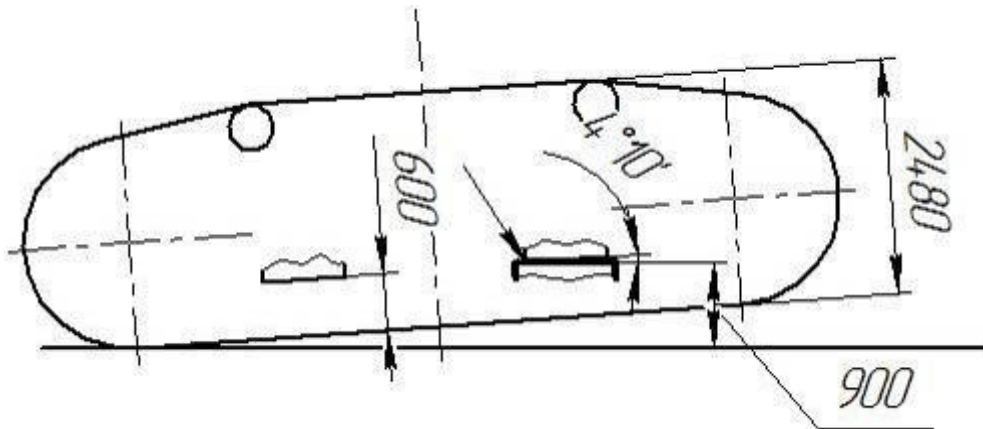


Figure 6 – Scheme for calculating the deviation angle of the excavator traverse site from the horizontal at the moment of contact with the bearing surface of the curb

Damage to the support can lead to loss of durability and drop of the excavator causing significant material damage and is hazardous to the health and life of the maintenance staff. This explains the high requirements for calculations.

The use of traditional analytical techniques for theoretical mechanics and material resistance to perform a precise analysis of the stress-strain state (NDS) of the supporting structure is not possible due to the practical impossibility of determining the exact values of stresses in the zones of their possible concentrations. The research of the NDs of the supporting structure, most expediently to carry out using finite-element analysis, which perspective in solving various tasks of the mechanics of a deformable solid, has recently been increasingly confirmed in the works of both foreign and domestic authors [9 – 12].

The idea of the Finite Element Method (FEM) consists in representing the geometry of the supporting structure as a set of individual elements of rather simple geometric forms, which are described by the well-known theoretical and experimental dependencies of the deformable solid mechanics. The combination of elements is carried out by satisfying the conditions of continuity of movements and equilibrium conditions. In this case, there are used three groups of equations: static, describing the system equilibrium state; geometric, linking deformation and displacement; and physical, which bind forces and deformations among themselves.

Mathematical modeling was performed using well-tested modeling complex and a finite-element analysis of MSC / NASTRAN designed for implementation in Windows environment at the PC. The package by which the model data is created and analyzed on the basis of the finite-element procedure determines the movement of each node of the finite element by three coordinate axes, the normal and tangential stresses, as well as the equivalent stresses that are calculated according to the well-known equation of the energy of the Von Mises modification energy the formula

$$\sigma_{equ} = \sqrt{0,5[(\sigma_x - \sigma_y)^2 + (\sigma_y - \sigma_z)^2 + (\sigma_z - \sigma_x)^2 + 6(\tau_{xy}^2 + \tau_{yz}^2 + \tau_{zx}^2)]},$$

where $\sigma_x, \sigma_y, \sigma_z$ – normal stress acting on the axes respectively x, y and z ;
 $\tau_{xy}, \tau_{yz}, \tau_{zx}$ – tangential stresses arranged in planes accordingly xy, yz, zx .

The MSC / NASTRAN for Windows Simulation and Finite Analysis package has advanced geometric modeling and data exchange tools with well-known CAD programs: AutoCAD, SolidWorks, Solid Edge, Pro Engineer, etc.

For any machine-building design, the typical calculation involves the following stages of constructing finite-element models: the development of a geometric model; description of materials properties; creation of a finite-element grid; formation of loads and boundary conditions; execution of various types of settlements; analysis of the calculations.

At the first stage in the modeling package and finite-element analysis of MSC / NASTRAN, designed for implementation on a personal computer results in the Windows environment, a full-fledged elastic three-dimensional model of support structure was created. The developed three-dimensional model is divided into a fairly small finite-element grid of tetrahedral elements in the sizes from 10 to 100 mm (for the entire construction used 97184 volumetric elements with 193954 nodal points).

The physical and mechanical characteristics used in the subsequent calculations of the structural components of the finite-element model of supporting structure are given in Tab. 1.

Table 1 – Physical and mechanical characteristics of supporting structure finite element model structural components

Material	Modulus of elasticity, E, MPa	Poisson's coefficient
Steel Ст3сп3	$2,1 \cdot 10^5$	0,30
Base under the support	50	0,30

Accordingly [13], the yield strength for structural elements made of steel Ст3сп3 thickness from 20 to 40 mm $R_{yn} = 235$ MPa and elements with a thickness of more than 100 mm $R_{yn} = 205$ MPa, then according to [14] the design resistance: $R_y = R_{yn} / \gamma_m = 235 / 1,025 = 230$ MPa – for steel elements in the thickness from 20 to 40 mm; $R_y = R_{yn} / \gamma_m = 205 / 1,025 = 200$ MPa – for steel elements in the thickness exceeding 100 mm.

Considering the presence of contact surfaces both in the hinges of mobile stands, and between mobile slides and longitudinal beams, the coefficients of friction for dry contact steel surfaces are taken to be equal to 0.15, and for steel surfaces with a lubricant – 0.05, respectively.

As the main evaluation criterion, the maximum values of equivalent stresses in the reference structure, which arise under the action of the calculated values of loads, are accepted.

The basis for the proposed supporting structure is a pre-prepared site on the rubble gravel with a slope that does not exceed 3° . As the calculated load values, four different load variations that occurred at different stages of the weighting of the excavator were considered.

The first boot option occurs when one-sided lift and installation of the excavator on the support structure. Given the lack of exact coordinates of the center of gravity of the excavator, as the most unfavorable load, the calculated value of the vertical load from the gravity of the excavator, divided into two hinged supports, is assumed. Considering the possibility of an asymmetrical position of the excavator gravity center between the two hinged supports during rotation of the rotary platform is carried out by distributing 60% of the calculated vertical load per resistance and 40% of the load to the other.

The second variant of the support structure loading occurs when the one side of the excavator is tied to the support structure and weighing the other side with the boom arm. In this case, in addition to the vertical component of the excavator own weight load, the horizontal component of the load, directed along the line of the excavator, may appear. For the most adverse combination of these two components, a combination of a vertical load equal

to 90% of the calculated net weight and the maximum horizontal load, corresponding to the value of the friction force between the traverse of the excavator and the support structure (the beginning of the excavator traverse slipping on the support structure, the coefficient of friction between the steel surfaces $k_f = 0.15$). The possibility of an asymmetrical position of the excavator gravity center between the two hinged supports is considered by allocating 60% of the calculated load per resistance and 40% of the load to the other.

The third version of the supporting structure loading considers the possibility of seismic loads occurrence during blasting during the excavator stay on the support structure. According to the results of the instrumental measurements of the seismic fluctuations and shock airwaves intensity during the mass explosion in the Yaristovsky GOK, LLC, the maximum value of horizontal seismic influences is 0.109g, and the vertical seismic influences 0.159g (g – free acceleration) on distance 450-550 m from the epicenter of the explosion. The direction of a horizontal load from seismic influences is taken along the excavator axis, considering the previously most unfavorable location of the excavator gravity centre.

The fourth variant of the loading of the supporting structure differs from the third variant only in the direction of the horizontal load from seismic influences, which is taken perpendicular to the excavator axis.

Influences of wind and snow loads in calculations for the strength of the supporting structure were not considered due to the insignificance of their estimated values in comparison with the estimated values of seismic loads.

Calculations of the strength of the proposed supporting structure are made for the four above variants of its loading. In all four cases, the loading of the maximum equivalent stress occurring in the lower part of the hinge support is 191 MPa, 156 MPa, 181 MPa and 196 MPa, respectively, in the field of equivalent stresses distribution in the lower part of the hinge support for the most unfavorable fourth loading variant, are shown in Figure 7. As can be seen from this figure, the maximum values of equivalent stress occur on the side of the hinge on the inner side of the hinge support lower part.

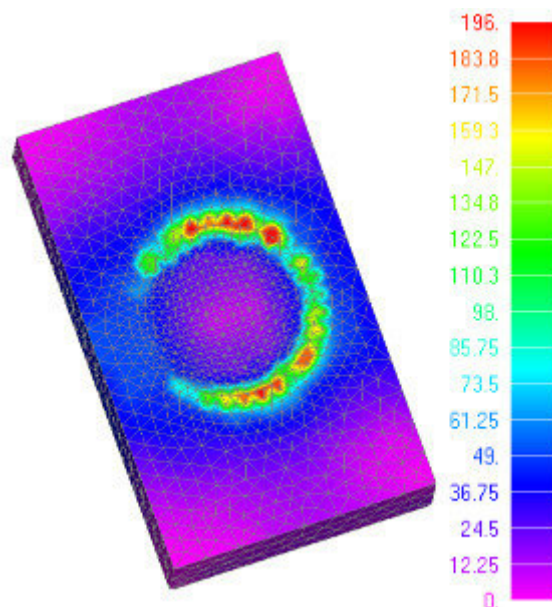


Figure 7 – Fields of distribution of equivalent stresses in the lower part of the hinge support in the case of the fourth boot option

The maximum values of the equivalent stresses occurring in the support plate and longitudinal beam for all four cases of loading are 186, 188, 202 and 157 MPa, respectively.

The fields of the equivalent stresses distribution in the base plate and longitudinal beam for the most unfavorable third loading variant are shown in Figure 8. As shown in this figure, the maximum values of equivalent stresses are observed in stress concentration zones both under the reference stands and in the middle parts of the longitudinal beam.

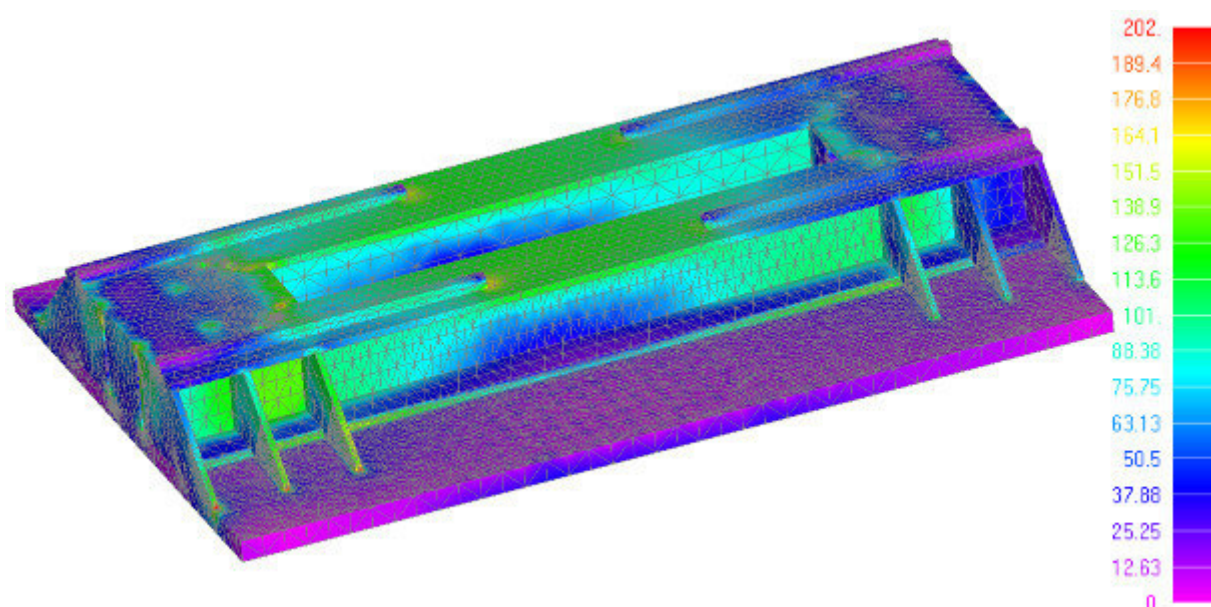


Figure 8 – Distribution fields for equivalent stresses in the case of the third boot option

Considering that the maximum values of equivalent stresses occurring in the reference plate and the longitudinal beam for all cases of loading do not exceed the rated resistance $R_y = 230$ MPa, and the maximum values of equivalent stresses in the reference pedestal do not exceed $R_y = 200$ MPa the strength of the supporting structure is ensured.

As a result of checking the possibility of stability loss of the supporting structure, the magnitudes of the critical load factors exceeding 3 are obtained, which means that the stability of the supporting structure is ensured.

Conclusions. Thus, the repair and maintenance of the running gear equipment of the Bucyrus RH340 and Terex RH200 career excavators are proposed to be carried out directly on the open mine site, by installing the machine on the supporting structure using its own working equipment.

References

1. Ефимов В. Н. *Карьерные экскаваторы: справочник* / В. Н. Ефимов, В. Л. Цветков, Е. М. Садовников. – М. : Недра, 1994. – 381 с.
2. *Экскаваторы на карьерах. Конструкции, эксплуатация, расчет* / В. С. Квагинидзе, Ю. А. Антонов, В. Б. Корецкий, Н. Н. Чупейкина // *Успехи современного естествознания*. – 2010. – № 9. – С. 66-67.
3. Jacek M. *Czaplicki. Mining Equipment and Systems: Theory and Practice of Exploitation and Reliability* / M. Jacek. – Taylor & Francis, 2009. – 296 p.

4. Пат. 14664 Україна, МПК (2006) E 21C 29/00. Спосіб виваження модулів важкого кар'єрного обладнання / Ковальов В. І.; власник Ковальов В. І. – u200511942; заявл. 13.12.2005; опубл. 15.05.2006, Бюл. №5.
5. Пат. 33450 Україна, МПК E21C 35/06 (2008.1). Пристрій для підйому екскаватора над його ходовою частиною / Турченко О. В., Солоніченко Ю. М., Білай В. І., Микитась А. П., Черноусов А. М., Мелащенко В. А.; власник Солоніченко Ю. М. – № u200801416; заявл. 04.02.2008; опубл. 25.06.2008, Бюл. № 12.
6. RH200 Hydraulic mining excavator. [Electronic resource]. – Mode of access: https://www.eltrakbulgaria.com/uploads/Terex/RH200_DataSheet_english.pdf
7. RH340 Hydraulic mining excavator. [Electronic resource]. – Mode of access: http://www.haein.com/userfiles/haein/RH340_DataSheet.pdf
8. Jayasekara P. G. Obstacle Surmounting by Arm Maneuver for Unmanned Power Shovel / P. G. Jayasekara, H. Arisumi // Intern. Conf. on Intelligent Robots and Systems. – 2015. – P. 5540 – 5547.
DOI: 10.1109/IROS.2015.7354162
9. Рычков С. П. Моделирование конструкций в среде Femap with NX Nastran / С. П. Рычков. – М. : ДМК Пресс, 2013. – 784 с.
10. Рудаков К. Н. UGS Femap 10.2.0. Геометрическое и конечно-элементное моделирование конструкций / К. Н. Рудаков. – К. : КПИ, 2011. – 317 с.
11. Dębski H. Application of fem in the analysis of the structure of a trailer supporting frame with variable operation parameters / H. Dębski, G. Koszałka, M. Ferdynus // Eksploatacja i Niezawodność – Maintenance and Reliability. 2012. – Vol. 14, № 2 – P. 107 – 114.
DOI: dx.doi.org/10.17531/ein /
12. Paszkiewicz M. Selected problems concerning determination of the buckling load of channel section beams and columns / M. Paszkiewicz, T. Kubiak // Thin-Walled Structures. – 2015. – Vol. 93. – P. 112 – 121.
ISSN: 0263-8231.
13. ГОСТ 14637-89. Прокат толстолистовой из углеродистой стали. Технические условия. – М., 1990. – 18 с.
14. ДБН В.2.6-198:2014. Сталеві конструкції. Норми проектування. – К. : Мінрегіон України, 2014. – 199 с.

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