RATIONAL USE OF HYDRAULIC EXCAVATORS IN IRON ORE PITS

***V. K. Slobodyanyuk*[1]*, Yu. Yu. Turchin*[2]**

Ukraine, [1]Kryvyi Rih, SIHE "KNU", [2]"ME-CENTRE" LLC

Abstract. In the iron ore pits of Kryvyi Rih (Ukraine), only rope shovels were used until recently. Hydraulic excavators have both a number of technical advantages over mechanical shovels and significant drawbacks. Ukraine's regulatory framework for iron ore pit designing does not provide recommendations for their effective use. The question of determining the rational application of hydraulic excavators in deep iron ore pits is a topical issue. The use of hydraulic excavators proves to be the most successful in developing flooded horizons and reactivating temporarily non-mining pit walls. Combined technological schemes involving joint use of rope and hydraulic excavators are also highly efficient.

Keywords: hydraulic excavators, schemes of trenching, reloading platform, counterforce

ОБЛАСТ НА РАЦИОНАЛНОТО ИЗПОЛЗВАНЕ НА ХИДРАВЛИЧНИ ЕКСКАВАТОРИ НА ЖЕЛЕЗОРУДНИ КАРИЕРИ

***В. К. Слободянюк*[1]*, Ю. Ю. Турчин*[2]**

Украйна, гр. Кривой Рог, [1]ДВУЗ „КНУ", [2]"МИ-ЦЕНТЪР" ООД

РЕЗЮМЕ. На железорудните кариери в гр. Кривой Рог (Украйна) доскоро са използвани само кариерни въжени екскаватори. Хидравличните екскаватори имат редица технически предимства пред въжени екскаватори, но също така имат и ред съществени недостатъци. В украинската нормативна уредба, регламентираща проектирането на железорудни кариери, отсъстстват препоръки по ефективното им използване. Въпрос за оценка на рационалната област на приложение в дълбоки железорудни кариери на хидравлични екскаватори е актуален. Най-успешен е опита в прилагането на хидравлични екскаватори, свързани с разработването на обводнени хоризонти и минни работи по възобновяване на временно неработещи стени. Висока ефективност ще имат комбинираните технологични схеми, които предвиждат съвместното използване на механични и хидравлични екскаватори.

Ключови думи: хидравлични екскаватори, схема на изкопа, платформа за презареждане, контрафорс

Statement of the problem and its connection with practical tasks

The processes of open-pit mining are influenced by many factors that can be divided into production and non-production ones. Production factors include: availability of mining and transport equipment, efficiency of organization and interaction of related technological processes, formation of working benches and transport berms of the width necessary for the safe and economical operation of the mining equipment, availability of blocked-out reserves, etc. Climatic and hydrological conditions are referred to as non-production factors. The combination of production and non-production factors may create the conditions that will result in poor performance of the main complex of the mining and transport equipment and, thus, in failure to achieve the designed pit performance (Arsent'yev A. I., 2010).

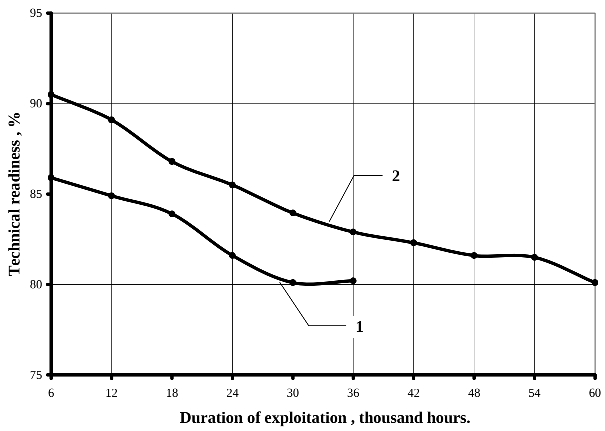
In the recent decade, hydraulic excavators have been used along with traditional mechanical shovels to excavate rock mass in iron ore pits. The question of determining the rational application of hydraulic excavators in deep iron ore pits is a topical issue.

As compared with mechanical shovels, hydraulic excavators have several advantages: lower specific capital costs, higher productivity and travel speed, the smaller weight of the excavator, the smaller body turning radius, the ability to excavate the rock layer below the excavator level (Bules, P., 2016; Poderni, R. Yu., P. Bules, 2015). Among the drawbacks, one should first note the dependence of hydraulic shovels on the quality of drilling and blasting operations.

Analysis of the latest research works and publications

The issues of organization of effective operation of hydraulic excavators in difficult mining conditions have been considered in numerous works since the 1960s. In these works, insufficient attention is paid to the grounding of technological schemes that take into account the design features of hydraulic excavators and the mining and technical conditions of iron ore pits.

In (Seytbayev, Sh. A., 2005), statistical data on the operation of hydraulic and rope excavators in various conditions is analyzed. Technical and economic indicators of rope and hydraulic shovels operation in ore pits are significantly different. Under the conditions of hard rock, there is a rapid wear of the excavator systems, which reduces its technical readiness. The coefficient of technical readiness of hydraulic excavators after operating 30-36 thousand hours is reduced to 80%, while mechanical shovels reach this indicator after 60 thousand hours of operation. After 5-6 years of operation, hydraulic excavators lose their advantage over mechanical shovels (Fig. 1, Fig. 2) (ibid.; Bules, P., 2016).



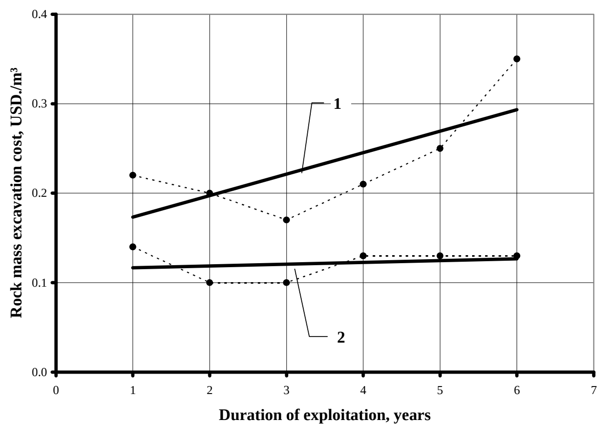


Fig.1. Dependence of technical readiness of hydraulic (1) and rope (2) excavators on the duration of exploitation of the ore pit
Fig.2. Dependence of rock mass excavation cost of hydraulic (1) and rope (2) excavators on the duration of exploitation of the ore pit

Based on the data from the directory "Mine and Mill Equipment Costs" (1995) that summarizes the technical and economic indicators of mining equipment, the diagrams of the dependence of operating and capital costs on the bucket capacity of the excavator are built. Analysis of the diagrams shows that hydraulic excavators, in comparison with mechanical shovels, are characterized by less capital costs, but greater operational costs (Fig. 3).

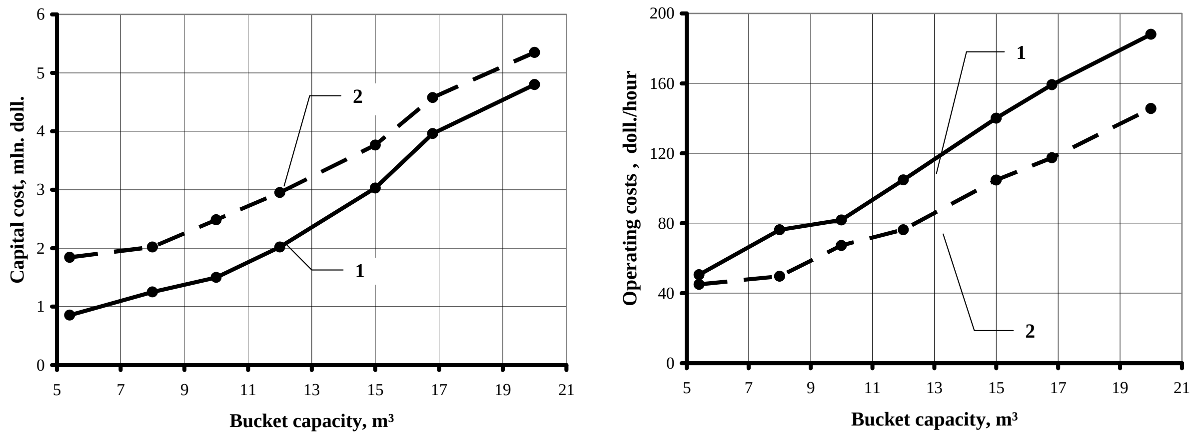


Fig. 3. Dependence of the capital cost of hydraulic (1) and rope (2) excavators on the bucket capacity

An interesting experiment on comparing technical and economic indicators of mechanical and hydraulic excavators was carried out at Muruntau gold ore pit (Uzbekistan) (Shemetov et al., 2005; Seytbayev, Sh. A., 2005). The use of powerful hydraulic excavators of different manufacturers (Caterpillar, Hitachi, O & K, Terex Mining) in the Muruntau mine, combined with heavy-duty dump trucks, made it possible to achieve high mining mass productivity with reduction in the total number of excavators in the first years of their operation. Assessment of the rope excavators' operation has enabled the conclusion that in many respects the differences in the operation indices are insignificant, and in some respects rope excavators outperform hydraulic excavators. Rope excavators are easier in manufacturing and maintaining, and their operation is cheaper considering their 20-30 years of service life. A comparative technical and economic assessment shows that within a period of 6-7 years of operation, the productivity decline rate of hydraulic excavators is substantially higher than that of rope excavators, mainly due to the increase in emergency downtime, leaving aside the fact that average costs of maintaining and repairing one hydraulic excavator are higher than those of a rope excavator. The prime cost of loading rock mass with hydraulic excavators significantly increases and after 6-7 years of operation this figure for rope excavators is exceeded more than twofold. In the course of the industrial experiment, it was established that rational areas for using hydraulic excavators are pit sectors with high concentration and intensity of mining.

Functionality of a straight hydraulic shovel basically corresponds to that of a mechanical shovel. The hydraulic backhoe is designed for working off the face below the excavator level. The digging depth does not usually exceed 7-10 m.

There are three main technological schemes of the independent operation of the hydraulic backhoe (Surface Mining, 1990). The first scheme of excavation is the development of the bench in one pass of the excavator provided that the height of the bench (Hb) does not exceed the maximum digging depth (D) of the excavator. Under the second scheme of excavation, the bench is worked layer by layer (Nl≥ Hb/D.) The third scheme of excavation is the development of the bench in one pass with the excavator placed on the sub-bench roof by sequential upward and downward digging. There also exist technological schemes of excavation with the use of a backhoe as auxiliary equipment for working off high benches, the excavator being placed on the roof of the bench. The most successful experience of using the hydraulic backhoe is the most efficient in developing flooded horizons, when working off the bench by a hydraulic backhoe can be the only possible option for mining operations. But in general, the independent use of hydraulic excavators complicates mining technology and increases deposit development costs.

Work objective

The main objective is the improvement of mining technology due to grounding the rational areas for using hydraulic backhoes in deep iron ore pits. The main task is to analyze and develop mining technologies, adapted to the deterioration of the hydro-geological and mining conditions of operations on lower horizons of the pits.

Material presentation

The combination of production and non-production factors may create conditions that will result in poor performance of the main complex of the mining and transport equipment and thus in failure to achieve the designed pit performance**.**

One of the solutions to this problem is the differentiation of the used extraction-and-loading equipment by selecting those excavators for which the existing trends of variation of mining and hydro-geological conditions are not unfavorable.

Trenching at the bottom of deep pits is associated with a decrease of the depression cone of ground waters. Here, the trenching time is determined by the hydrogeological conditions of the deposit (the depression cone development rate), not by the geometric volume of the trench and the excavator's productivity. Ukraine's climate is currently characterized by abundant rainfalls. Considering the significant geometric size of pits (the daylight surface area of iron ore pits makes 400-1000 hectares), the risk of rapid rainfall flooding of the pit bottom is rather high. Technological schemes of trenching using only a rope excavator become inefficient due to the impossibility of its efficient operation in flooded conditions. This prevents pits from reaching the designed indicators of the deepening rate and ore productivity, and entails an increase of costs of the stripping of the horizon.

Combined schemes have been developed (Slobodyanyuk and Turchin, 2016) for trenching the bottom horizon of a pit in difficult hydrogeological conditions. The idea of combined schemes is based on the fact that the task of a hydraulic backhoe is to create conditions for the productive operation of a rope excavator. The following order of works on trenching is suggested: The hydraulic excavator forms part of a trench end face to the full height of the bench by advanced heading (Fig. 4).

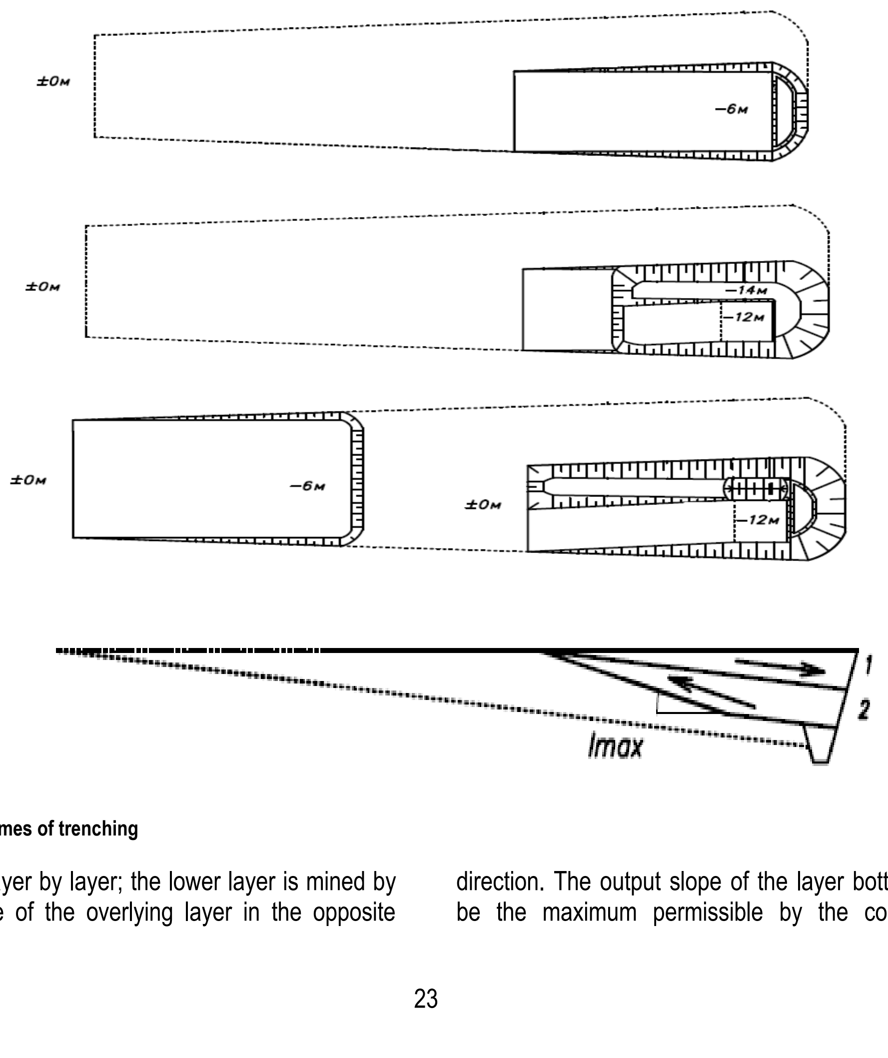


Fig.4. The combined schemes of trenching

The work is done layer by layer; the lower layer is mined by undercutting the base of the overlying layer in the opposite direction. The output slope of the layer bottom is assumed to be the maximum permissible by the condition of normal operation of crawler machines. Such mining parameters contribute to the concentration of the working area of the hydraulic backhoe and reduce the costs of the horizon stripping. After the decrease of the depression cone, the mechanical shovel performs the longwall driving of the trench along the full height of the bench. It makes technical and economic indicators of the excavator operation closer to those in unflooded conditions.

One of the main types of combined transport in the iron ore pits of Kryvbas is road-rail transport. The bulk of overburden is transported to the dumps by this type of transport. The introduction of deep rail transport in the 1970s-1980s became one of the factors that led to the reduction in the distance of transportation by trucks and the increase in mining efficiency. The excavator reloading platform is a key element of this type of transport. When using a direct mechanical shovel on the reloading platform, it is divided into two equal sectors along its length, which alternately are the places of dump trucks unloading and places of loading on the railway transport. To place the reloading platform, it is necessary to reserve the area on the pit wall (the length of the transfer platform with the sidetrack is 300-400 m, the width – 100-150m). Sometimes the pit productivity is limited due to failure to place the required number of transfer platforms.

A hydraulic backhoe is known to be used at a reloading platform. The excavator is placed on a mound inside the receiving trench and loads the railway transport by digging below the standing level. But this technology has retained a number of shortcomings inherent in technological schemes using mechanical shovels on transfer platforms. To plan the surface of the transfer platform, it is necessary to use a bulldozer; the transfer platform is also divided into two sectors along its length. The division of the reloading platform into the unloading sector and the loading sector increases the length of the receiving trench and the reloading platform area.

The authors propose another way of organizing a reloading platform when using a hydraulic backhoe. The receiving trench is conventionally divided into two sectors across the width: unloading and loading ones. Unloading of dump trucks and loading of railway trains are carried out on the opposite walls of the receiving trench (unloading and loading walls). In general, the unloading one is the trench wall closest to the underlying horizons of the pit, the loading one is the pit wall closest to the upper pit horizons (as a result, the railway and the road do not intersect) (Fig. 5).

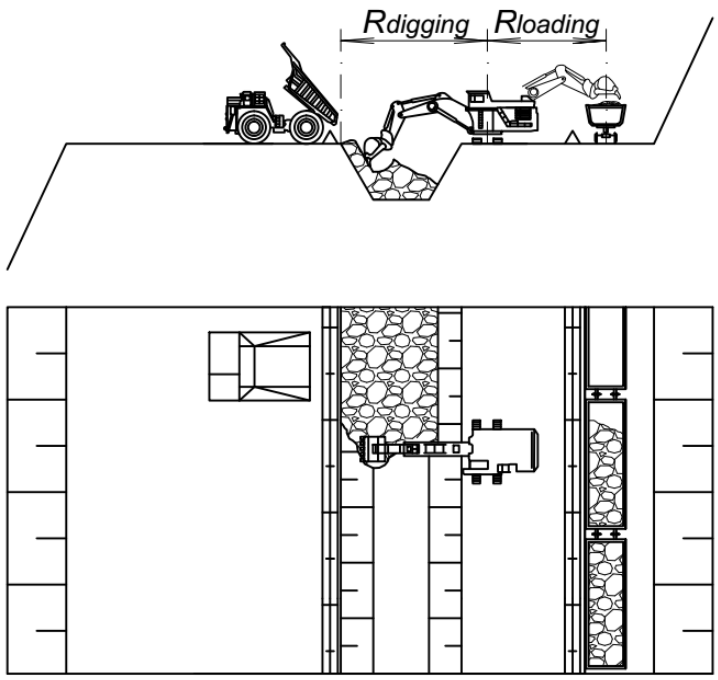


Fig.5. The technological scheme of operating a hydraulic backhoe on a reloading platform

The railway track is laid along the trench loading wall. A hydraulic backhoe is located between the trench loading wall and the railway. The excavator performs frontal digging of the rock mass from the receiving trench and loads it on the railway transport. While loading dump cars, the backhoe moves along the receiving trench wall.

When using a hydraulic backhoe on a reloading platform, there is no need to lift the rock mass one bench above the level of the railway tracks. The transport work economy is determined by the formula:

$$z = VH/i \text{ ; th. km}$$

where
V is the volume of rock transported by road and rail, [t];
H is the height of reload when using mechanical shovels (usually 15 m), [m];
i is the road slope, [thousandths].

The proposed method allows combining, in time and in space, of the unloading of dump trucks on the reloading platform and the loading of railway dump cars. At the same time, there is no intersection of road and rail transport. Such a way of organizing the reloading platform is characterized by compact dimensions, high safety of mining operations and allows increasing the productivity of the equipment. To increase the receiving capacity of the reloading platform, the excavator re-excavates the rock mass from the unloading side of the trench to its loading side in the period between train exchanges. The receiving capacity of the reloading platform can be increased by forming a trench with larger slope angles.

In the proposed method, the length of the reloading platform is primarily determined by the length of the train. The length of the receiving trench is only determined by the condition of ensuring the minimum level of independence of the performance of the related technological processes.

A number of measures are implemented at pits to prevent landslides and to ensure the safety of mining operations. Constructing rock counterforces and slope filtering cantledges is the simplest of them. According to VIOGEM, the cantledge of slopes by rock mass leads to a redistribution of pressure near slopes and, ultimately, to an increase of the stability margin factor by 20-25%.

The following technology is usually applied to constructing rock cantledge. Dump trucks are unloaded in the mined-out area of the excavator and pass under the lower edge of the formed slope of the bench. Since the bench is composed of weak rocks, the unloading of trucks transporting hard rock mass to the cantledge area is carried out on the lower operating floor of the bench. The unloading of dump trucks is carried out perpendicular to the bench slope. After delivering rock in an amount sufficient to form a bench cantledge with the designed parameters, the excavator transports part of the rock overburden from the bottom of the bench to its slope, forming a retaining prism. Hard rock with a high density is used as a material for constructing counterforces and cantledges. In flooding conditions, to prevent filtration deformations, the cantledge prism is formed immediately, as the face advances. The drawback of the generally accepted technology for constructing cantledges to prevent landslides is that the rope excavator has a relatively small unloading height and it cannot construct a cantledge of the bench height. Counterforces can be created using a technology that is close to the technology of area-based dumping. The main problem is that to place the above-mentioned objects, the area on the lower operating floor of the bench is used, which could have another technological purpose (for example, a transport berm). It is of interest to develop a technology for the formation of anti-landslide structures, which will not reduce the area of the operating floors of pit benches.

The authors propose the following technological scheme for the construction of anti-landslide structures using the hydraulic backhoe. Initially, dump trucks pour off a mound of rock along the front slope of the bench. This mound will be used as an operating floor for a hydraulic excavator, and the rock from this mound will be re-excavated into the body of the counterfort being constructed. If necessary, as rock overburden is re-excavated from the mound, dump trucks will resume pouring it (Fig. 6).

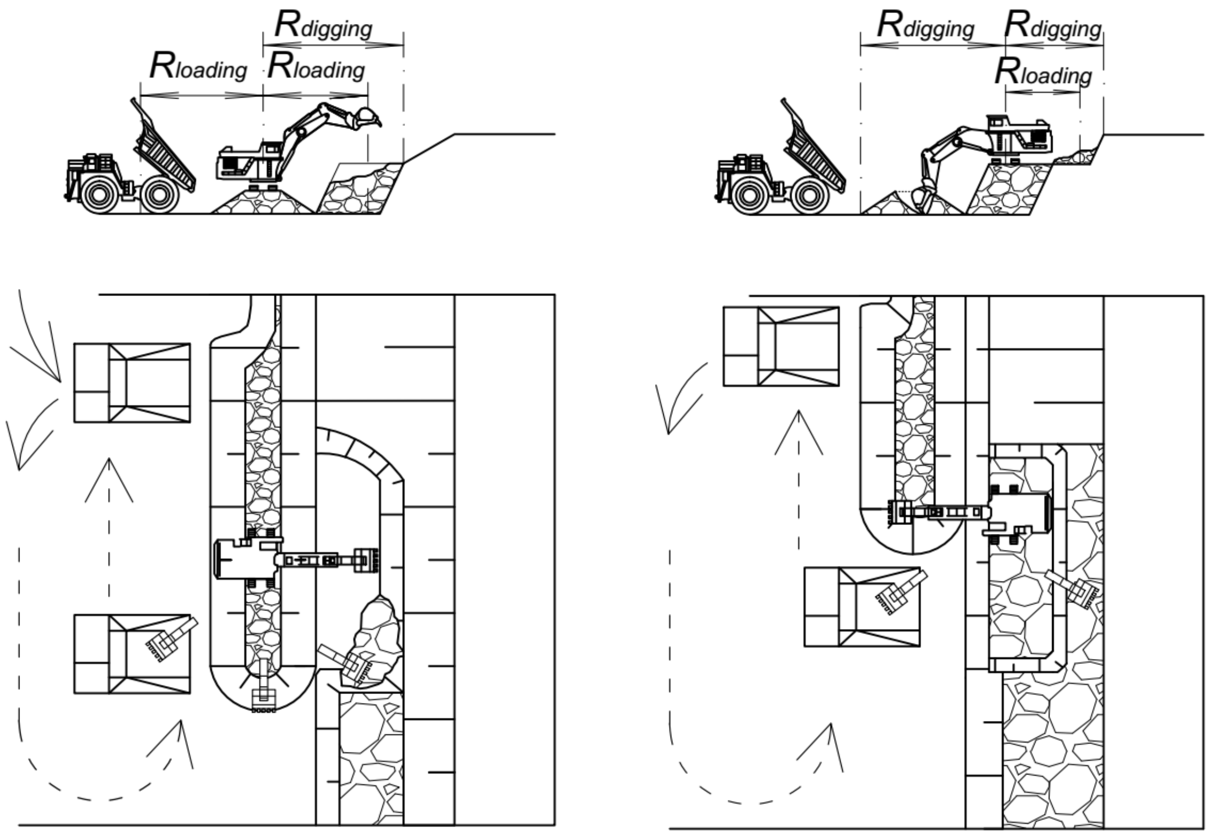


Fig 6. Technology for constructing the counterforce using the hydraulic backhoe

The main idea of the proposed technological scheme is the use of a hydraulic excavator placed on a mound (extended-bench) from the rock overburden, for excavating the loose overburden from a reinforced bench into dump trucks, and for reloading rock overburden from the extended-bench into the mined-out part. If necessary, several stopes can be worked out successively on the loose overburden, the worked-out area will be filled with rock overburden by a hydraulic excavator. This technology enables strengthening all landslide areas of benches along the perimeter of the pit without reducing the area of the operating floors of the benches, which will ensure the formation of the designed transport scheme.

Conclusions and directions for future research

The area of rational use of hydraulic backhoes in the iron ore pits is conditioned by the stable trend for deterioration of mining conditions (tightness of the working zones of the pit, flooding of the lower horizons, development of dangerous geo-mechanical processes) in which extraction-and-loading equipment and mining technology provided for by deposit development designs become inefficient. In a further research, it is planned to analyze the mining and geological conditions of the iron ore pits of Kryvbas for determining the rational area of applying the developed technologies.

References

Арсентьев, А. И. Разработка месторождений твердых полезных ископаемых открытым способом: учебник. СПб. гос. горн. ин-т (техн. ун-т), 2010. – 115 с. (Arsent'yev, A. I. Razrabotka mestorozhdeniy tverdykh poleznykh iskopaemykh otkrytym sposobom. Sankt Pb. gos. gorn. in-t, 2010. - 115 p.).

Шеметов, П. А., С. К. Рубцов, А. Г. Шлыков. Опыт эксплуатации канатных и гидравлических экскаваторов в условиях карьера Мурунтау. - Горная промышленность, 5, 2005. – 46-50 с. (Shemetov, P. A., S. K. Rubtsov, A. G. Shlikov. Opyt ekspluatatsyi kanatnyh i gidravlicheskih ekscavatorov v usloviyah kar'yera Muruntau – Gornaya promishliennost', 5, 2005. – 46-50 p).

Сейтбаев Ш.А. Опыт применения экскаваторов различных модификаций в условиях карьера Мурунтау. - Горный вестник Узбекистана 3, 22, 2005 – 83-86 с. (Seytbayev, Sh. A. Opyt primeneniya ekscavatorov razlichnih modifikatsiy v usloviyah kar'yera Muruntau. – Gorniy vestnik Uzbiekistana 3, 22, 2005 – 83-86 p).

Mine and mill equipment costs. Western Mine Engineering, Inc. Washington, Copyright 1995.

Булес, П. Обеспечение надежности работы карьерных гидравлических экскаваторов при их эксплуатации на открытых разработках России: дис. на соискание ученой степени кандидата технических наук: 05.05.06 М., 2016 – 146 с. (Bules, P. Obespecheniye nadezhnosti rabotiy karyerniyh gidravlicheskih ekscavatorov pri ih ekspluatatsiy na otkrityh razrabotkah Rossii: diss. na soiskaniye uchienoy styepeni kandidata technicheskih nauk: 05.05.06. M., 2016 – 146 p.)

Подэрни, Р. Ю., П. Булес. Сравнительный анализ гидравлических и механических экскаваторов с прямой лопатой. - Горный журнал 1, 2015. – 55–61. (Poderni R. Yu., P. Bules. Sravnitielniy analiz gidravlicheskih i mehanicheskih ekskavatorov s pryamoy lopatoy. – Gorniy zhurnal 1, 2015. – 55-61 p.)

АС 111446U Украины МПК E21C 41/26 (2006/01) Способ вскрытия рабочих горизонтов карьеров в сложных гидрогеологических условиях / Слободянюк В. К., Турчин Ю. Ю.; заявл. 10.04.2015; опубл. 25. 04. 2016 (AS 111446U Ukrainiy MPK E21S 41/26 (2006/01) Sposob vskrytiya rabochih gorizontov karyerov v slozhnyh gidrogeologicheskih usloviyah / Slobodyanyuk V. K., Yu. Yu. Turchin; zayavl. 10.04.2015: opubl. 25.04. 2016).

Surface Mining (2nd edition), Society for Mining, Metallurgy and Exploration, Inc., Littleton, Colorado, 1990.

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