

Calculation of Bench Width for Backhoe Hydraulic Excavators Operated in Sinking Mining Systems

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Abstract: The study contains results of studies completed to determine the bench width for backhoe hydraulic excavators. Bench width is among the main parameters providing efficient operations in open pits and quarries now a days. Scientists have developed various methods to define this parameter, however, they are mostly based on the experience gained from operation of rope excavators with rack crowded shovel. At the same time, there is no clear system for defining these parameters provided that all required set of calculation elements is available. Hydraulic excavators require less space on the working bench compared to rope ones with a front shovel with the same standard size. Bench width along the mining front varies within an average range, however, it cannot be less than the design minimum one. The method shown in this study allows determining the balanced bench width at different levels of open pits.

Key words: Open pit, mining method, hydraulic excavator, bench width, slope angle of the pit wall, rope

INTRODUCTION

Now a days, maintaining sufficient width of working benches throughout operational period is one of the current provisions for normal operations in open pits. "Safety rules for mining and processing solid minerals" (Order No. 599 dated December 11, 2013, issued by Federal Service for Environmental, Technological and Nuclear Oversight of Russia (Rostekhnadzor)) is one of the main regulatory documents for open-pit mining operations. According to Item No. 533, "Bench width for open-pit mining operations considering their purpose as well as location of mining and transport equipment, transport communications, power supply lines and communication lines shall be specified in the project design".

Design bench sizes are the calculated values, averaged along the mining front length and to a certain extent, they depend on benching rate and

available rock mass to be mined. In reality, the bench width along the mining front varies around the average values due to the inconsistency of production processes (Yakubovskiy *et al.*, 2014a, b).

Bench width is the main parameter for operation of backhoe hydraulic excavators affecting the mining method parameters. Variations in the bench width cause the change of the pit wall angle (Yakubovskiy *et al.*, 2014a, b). Changing the pit wall angle (φ) is possible within the range of two extreme values: φ_{\max} and $\varphi=0$ (Fig. 1):

- Minimum bench width (B_{\min}) results in a maximum possible angle of pit wall (φ_{\max})
- Maximum bench width (B_{\max}) results in almost zero pit wall angle ($\varphi=0^\circ$)

Maximum pit wall angle and minimum bench width improves the efficiency of open-pit mining. Minimum pit wall angle ($\varphi=0^\circ$) is usually applicable for mining flat and

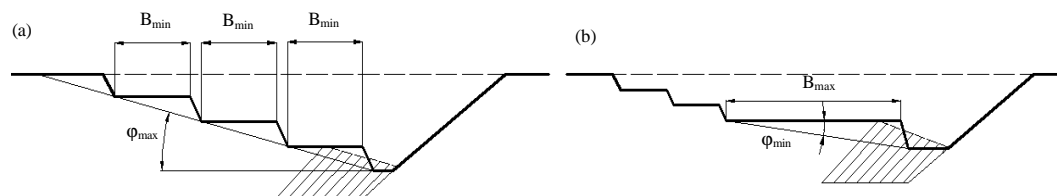


Fig. 1: Extreme possible open-pit mining scenarios: a) Minimum bench width B_{\min} at the maximum pit wall angle φ_{\max} and b) Maximum bench width B_{\max} at the minimum pit wall angle φ_{\min}

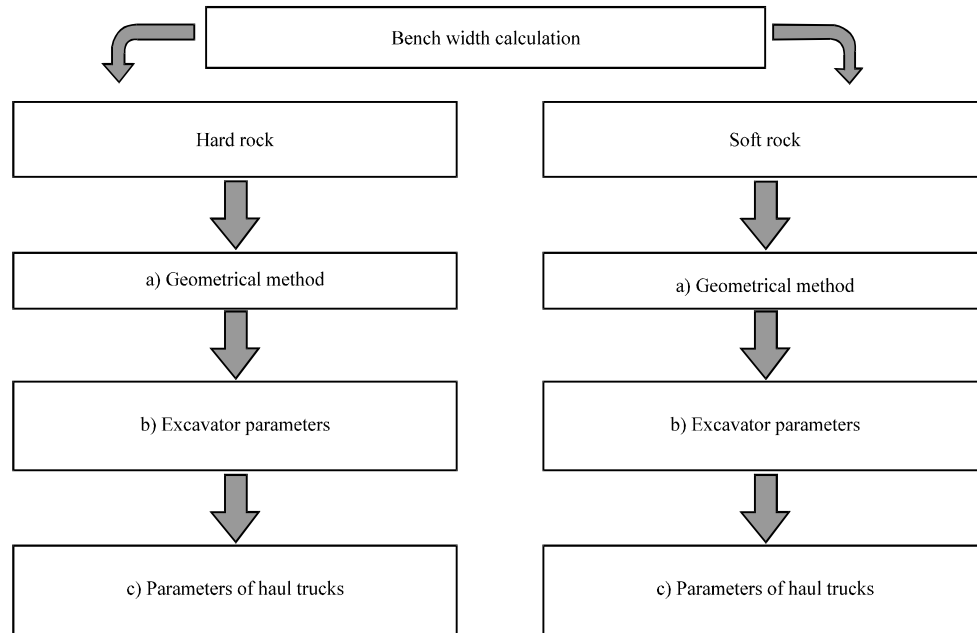


Fig. 2: Classification of methods to determine the work bench width: a) Geometrical method (main parameter is the pit wall angle (ϕ)); b) Method based on the parameters of mining and loading equipment (main parameter is specifications of a single-bucket excavator) and c) Method based on the parameters of transport equipment (main parameters are haul trucks specifications)

horizontal deposits. The main criterion that limits the maximum bench width is the impossibility to operate at steeply dipping and inclined deposits at $\phi = 0^\circ$ as mining operations will be performed on one bench until it is completely depleted, then operation will start at a lower bench prepared beforehand. In this case, the deposit is mined layer by layer. This method is not used in current steeply dipping deposits (Argimbaev and Kholodjakov, 2013). During the study, methods for determining bench width were classified (Fig. 2):

- Calculation method for hard rocks mined by drill and blast method (main parameter: B_x -shot pile width of once blasted)
- Calculation method for unconsolidated, soft rocks mined without preliminary fragmentation (main parameter: A-benching width).

MATERIALS AND METHODS

During the study, various methods intended to define the bench width were reviewed. Bench width should be determined in a way to provide required parameters of work face and consistent production rate, maximum pit wall angle which will consequently result in a minimum bench width. Based on classification methods for bench width, the most significant differences occur during mining soft or hard rocks.

Designed bench dimensions of are calculated values averaged by the mining front length and to a certain extent they depend on benching rate and rock mass to be mined in the pit. In reality, the bench width along the mining front varies around average values due to the inconsistency of production processes (Kaerbek and Kholodjakov, 2016).

The bench width limits providing location of appropriate mining equipment, structures and clearances without consideration of rock amounts ready for extraction was carried out for operations using single-bucket excavators in combination with haul trucks.

The obtained values parameters serve as limiting factors when it comes to reducing the bench size during the open pit mining.

For specific production scenarios, required set of elements was specified to determine the bench width in the area of the operating pit. Minimum bench width was defined based on the technical specification of mining and hauling equipment (excavator-haul truck). Working bench width for operation of backhoe hydraulic excavators should be determined based on the advantages of this equipment.

There are several types of process layouts (Loginov, 2015; Kaerbek and Maya, 2016; Argimbaev, 2016; Argimbaev and Alexandrovich, 2016) for mining solid mineral deposits using backhoe hydraulic

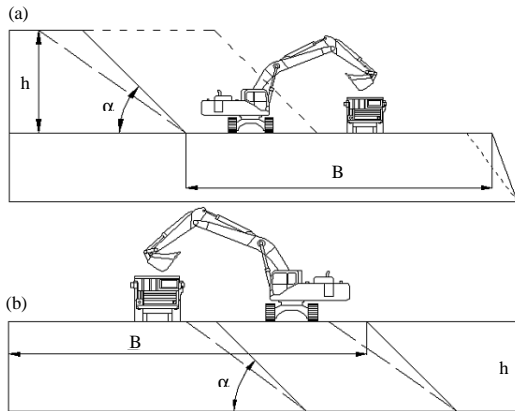


Fig. 3: Process layout for backhoe hydraulic excavators:
a) Upward digging and b) Downward digging; (h, bench height; B, bench width and α , bench angle)

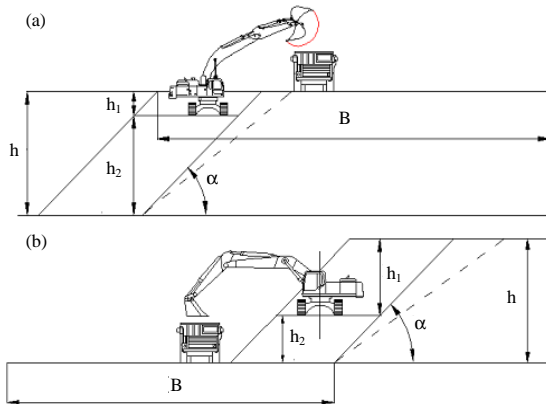


Fig. 4: Process layout for backhoe hydraulic excavators:
a) Loading to the upper bench and b) Loading to the lower bench; (h, bench height; h₁, upper sub-bench; h₂, lower sub-bench; B, bench width and α , bench angle)

excavators. During the study, three major process layouts (Rafkatovich and Mironova, 2018; Ligotsky and Kristina, 2018; Burmistrov *et al.*, 2017) were identified. According to the first procedure (Fig. 3a), hydraulic excavator is located on the back of the mining bench for downward digging. According to the second layout (Fig. 3b), an excavator is located on the lower bench for upward digging. There is also a third layout (Fig. 4a, b) which could be considered as combined one where an excavator is located on the sub-bench to combine advantages of upward and downward digging.

Bench width is determined based on the method described in book. Bench width for haul trucks (according to the data of Tsentrproshakhta R&D Institute) B (m) is calculated by Eq. 1:

$$B = A + C_2 + E + P_1 + c_1 + b_s, \text{ m} \quad (1)$$

Parameter A, benching width of excavator makes a fundamental difference for defining the bench width for a backhoe hydraulic excavator. Classical method of determining the benching width for rope excavators is $A = (1.5-1.7) R_h$. For downward digging with backhoe hydraulic excavators, this parameter is determined by Eq. 2:

$$A = 1.7(B_x + 3) + I_d \text{ctg} \alpha, \text{ m} \quad (2)$$

Where:

R_h = Horizontal digging radius m

B_x = Track centers of the excavator (m)

I_d = Downward digging depth m

α = Bench angle ($^\circ$)

RESULTS AND DISCUSSION

Once all required calculations were completed, we acquired bench width for CAT 6020B backhoe hydraulic excavator based on specific work schemes (Fig. 3):

$$\text{CAT 6020B } B = A + C_2 + E + P_1 + c_1 + b_s = 39.4 \text{ m}$$

$$\text{CAT 6020B } B = A + C_2 + E + P_1 + c_1 + b_s = 45 \text{ m}$$

$$\text{CAT 6020B } B = A + C_2 + E + P_1 + c_1 + b_s = 39 \text{ m}$$

Bench width for EKG-12 rope excavator with front shovel is calculated as:

$$\text{EKG-12 } B = A + C_2 + E + P_1 + c_1 + b_s = 42.3 \text{ m}$$

Minimum bench width was calculated based on the parameters of hauled trucks being operated and excavator parameters. To provide efficient operation of the mining and hauling equipment (excavator-haul truck), excavator parameters were taken as the baseline for reducing the bench width.

In case of combined benching, backhoe hydraulic excavators perform both downward and upward digging with haul trucks loading on the upper bench. This research layout has several advantages: efficient use of backhoe hydraulic excavators, decrease of haulage distance.

Specific feature of mining operations involving backhoe hydraulic excavators with downward digging for combined benching is the possibility to place the transport equipment either on the bench where the excavator is stationed or on the upper bench. This solution provides reduction haulage distance and productions costs.

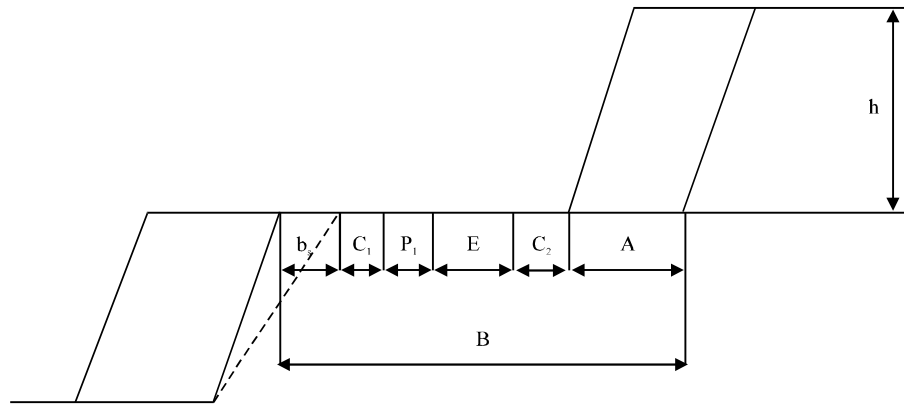


Fig. 5: Bench width calculation: A) Benching width of excavator (m); C_2) The distance from the road axis to the lower crest of the bench or shot pile (m); E) The distance between lane axes on the two-lane road (m); P_1) Space for additional equipment (m); DC_1) The distance between the space for auxiliary equipment and safety zone (m); b_s) Safety zone width (m) and h) Bench height

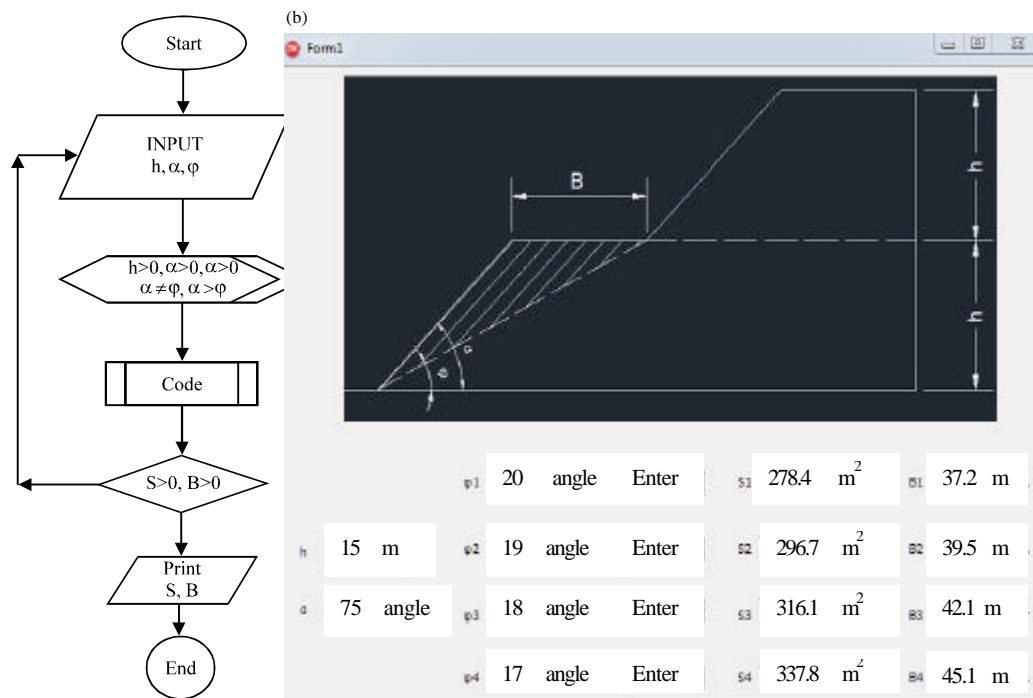


Fig. 6: Bench width calculation during the sinking mining mode software: a) Software logic and b) Program window

During the study, the certificate of state registration was obtained for Software No. 2017617003 bench width calculation during the sinking mining mode.

Bench width calculation during the sinking mining mode software was designed to determine the balanced bench width considering average stripping ratio. Average value is usually calculated by variations in the angle of pit wall over time by changing the bench width which affects the amount of recovered stripping soils. Reduction of the

stripping soil amount will decrease operational costs, production costs and improve cost efficiency of mining operations at the deposit.

This software can be used in universities when preparing course and graduation projects, calculations and charts of postgraduates for research purposes. Bench width calculation during the sinking mining mode software (Fig. 5 and 6) provides the following features:

- Calculation of the area for the zone limited by the bench, bench face and wall of the pit
- Calculation of bench width at different levels

CONCLUSION

This software takes into account area of the zone limited by the upper and lower benches, bench slope and pit wall (S).

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