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Influence of geometric parameters of the excavator working tool on cutting force and energy consumption in cutting rocky soils

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Abstract: This article scientifically investigates the influence of geometric parameters of an excavator working tool on cutting force and energy consumption during the excavation of rocky and semi-rocky soils. The high strength and low deformability of rocky soils lead to the occurrence of large resistance forces and significant energy losses in the cutting process. Based on theoretical models, the study analyzes the influence of the geometric parameters of the working tool, in particular the cutting angle, the shape of bucket teeth, and the contact area, on the cutting force. Using a mechanical approach, the relationship between cutting force and energy consumption is revealed. The obtained results scientifically substantiate the possibility of reducing energy consumption and increasing excavator operating efficiency through rationalization of the working tool design.

Keywords: rocky soil, cutting force, energy consumption, excavator, working tool, geometric parameters, cutting angle, bucket teeth, mechanical model, energy efficiency, soil mechanics, rationalization

1. Introduction

Excavation of rocky and semi-rocky soils in modern construction and mining industries is characterized by significant operational complexity, high energy consumption, and accelerated wear of technical equipment. Under such conditions, single-bucket hydraulic excavators remain among the most widely used earthmoving machines; however, their operational efficiency largely depends on the design characteristics of the working equipment. The high mechanical strength of rocky soils, their large internal friction angle, and limited deformability generate substantial resistance forces during the cutting process.

Practical experience indicates that a considerable portion of energy losses originates not from the excavator engine or hydraulic system itself, but from the mechanical interaction between the working tool and the soil medium. Therefore, the scientifically justified selection and optimization of the geometric parameters of the working equipment represent a critical factor in improving energy efficiency. This study specifically investigates, in a comprehensive manner, the influence of the geometric parameters of the excavator working tool on cutting resistance forces and energy consumption.

Literature Review

The earliest fundamental studies on the mechanics of rocky soil cutting were conducted by Reece and Hettiaratchi, who modeled the soil cutting process based on force equilibrium principles. Their research provided a scientific foundation for understanding the dependence of cutting resistance on soil strength characteristics and the geometric configuration of the working tool.

In his studies, McKyes evaluated the soil cutting process from an energy perspective and demonstrated that the non-uniform and pulsating nature of cutting forces constitutes one of the primary factors contributing to increased energy consumption. The theoretical approaches proposed by Balovnev further expanded this analysis by examining the influence of working tool geometry in greater depth, identifying tooth shape and cutting angle as critical design parameters.

In recent years, international research institutions and industrial engineering centers, including Caterpillar Inc., Komatsu, and Liebherr, have extensively applied computer modeling and digital simulation techniques to optimize the geometric parameters of excavation tools. These studies have shown that such optimization can reduce energy consumption by approximately 10–20%. However, most existing studies have not sufficiently developed a comprehensive mechanical model specifically adapted for rocky soil excavation conditions. The present study aims to address this research gap.

2. Research methodology

Problem Statement

During the excavation of rocky soils, the cutting forces acting on the excavator working tool are both high in magnitude and highly variable in nature. This leads to increased energy consumption, intensified loading of the hydraulic system, and accelerated wear of the working tool components. In practical engineering applications, the selection of working tool geometric parameters is often based on empirical approaches, which frequently result in technically and economically suboptimal design solutions.

In this context, the primary research problem can be formulated as follows: to provide a theoretical justification for the influence of the geometric parameters of the excavator working tool on cutting resistance and energy consumption, and to determine rational design parameters for improved operational performance. Solving this problem is of considerable scientific and practical importance for enhancing excavator efficiency and implementing energy-efficient excavation technologies.

Materials and Methods

The present study employs theoretical analysis and analytical modeling as the principal research methodologies. The physical and mechanical properties of rocky soils were

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systematized and generalized based on available literature sources. The excavation process was considered as a mechanical soil–working tool interaction system, and the cutting process was analyzed using force equilibrium principles and integral energy consumption formulations.

The following geometric parameters were selected as the primary variables of analysis:

- cutting angle;
- bucket tooth geometry;
- contact area between the working tool and the soil medium.

The results obtained from the theoretical models were compared with findings reported in international studies and practical engineering data in order to assess their reliability and validity.

Table 1

Main Physical and Mechanical Properties of Rocky Soils

Soil Type	Density, kg/m³	Compressive Strength, MPa	Internal Friction Angle, °
Semi-rocky soil	1900–2200	5–25	25–32
Sandstone	2400–2600	50–120	35–40
Granite	2600–2800	120–300	40–45
Basalt	2700–3000	200–350	42–48

Mechanical Essence of the Rocky Soil Cutting Process

The excavation process of rocky and semi-rocky soils is mechanically not a process based on simple plastic deformation, but rather a complex phenomenon accompanied by the fracture, cracking, and fragmentation of the soil structure. Since such soils have high strength and low deformability, large resistance forces are generated during the penetration of the working tool into the soil. Therefore, considering the cutting process as a “soil–working tool” mechanical system is scientifically justified.

At the initial stage of the cutting process, the bucket teeth come into direct contact with the soil surface. At this point, stress concentration occurs at the tooth tips, and microcracks begin to form within the soil structure. Since elastic deformation in rocky soils is limited, these microcracks quickly transform into macrocracks, and soil fracture begins. As a result, the cutting process has a more impact-like and discrete character rather than continuous sliding.

The mechanical scheme of the cutting process is shown in Figure 1, where the main forces acting on the working tool are presented: cutting force (Fk), normal force (N), and friction force (T). The interaction of these forces determines the stability and energy efficiency of the cutting process.

Theoretical Model of Cutting Force

The main mechanical parameter in the cutting process is the cutting force, which is defined as the force expended by the working tool to overcome soil resistance. In simplified form, the cutting force can be determined by the following expression:

$$F_k = \sigma_c \cdot A$$

where:

σ_c – soil cutting resistance,

A – contact (cutting) area between the working tool and the soil.

Although this expression represents the general essence of the cutting process, under real operating conditions the cutting force has a more complex character. In rocky soils, friction forces, impact effects, and inertia forces also arise between the working tool and the soil. Therefore, the cutting force is not constant over time, but has a pulsating character. This condition leads to accelerated wear of the working tool and an increase in energy losses.

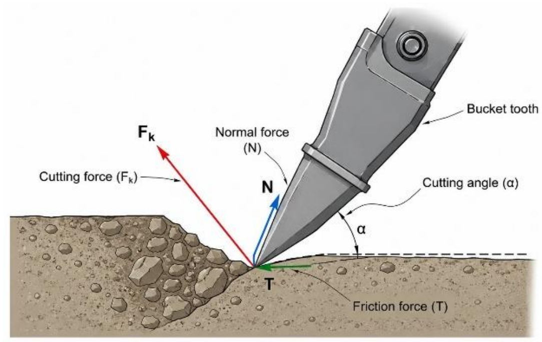
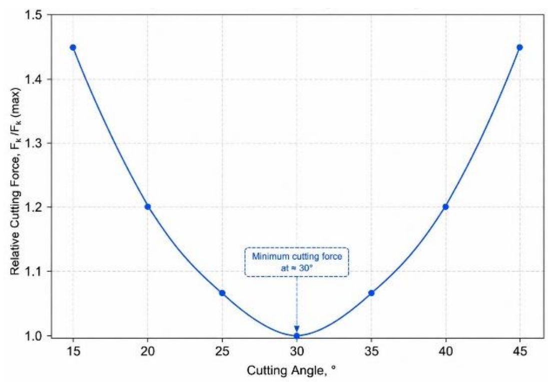


Fig. 1. Mechanical scheme of the rocky soil cutting process: Bucket tooth, Cutting angle (*α*), Cutting force (*Fₖ*), Normal force (*N*), Friction force (*T*)



Graph 1. Influence of cutting angle on cutting force: *X*-axis: Cutting angle (15–45°), *Y*-axis: Relative cutting force, F_k/F_k (max)

It is clearly observed in the graph that the minimum value of the cutting force is located in the range of 25–35° (approximately 30°).

The maximum values of the cutting force are observed precisely at the moments when soil fracture occurs. If the geometric parameters of the working tool are not selected rationally, these maximum values increase sharply, resulting in excessive loads in the hydraulic system.

Mechanical and Energy Influence of the Cutting Angle

The cutting angle is considered one of the most important geometric parameters determining the interaction between the working tool and the soil. When the cutting angle changes, the contact area between the working tool and the soil, as well as the direction and distribution of forces, also change. Theoretical analyses show that when the cutting angle is too small, the working tool tends to slide along the soil surface. In this case, cutting efficiency decreases, and energy losses increase relative to useful work.

Conversely, when the cutting angle is too large, the soil is subjected more to compression, and the deformation process becomes dominant rather than cutting. This leads to an increase in cutting force and a sharp rise in energy consumption. The theoretical model and available experimental data indicate that the rational cutting angle for rocky soils is generally within the range of 25–35°.

Graph 1 illustrates the influence of the cutting angle on cutting force, and it can be observed from the graph that the relative cutting force reaches its minimum value precisely within this range. This ensures a reduction in working tool loads and stabilization of the cutting process.

Influence of Bucket Tooth Geometric Shape

Bucket teeth are the primary contact elements between the working tool and the soil, and their geometric shape directly determines the mechanical nature of the cutting process. The tooth shape defines the contact area with the soil, the degree of force concentration, and the fracture mechanism.

Figure 2 presents the commonly used geometric shapes of bucket teeth, including wedge-shaped, conical, and combined configurations.

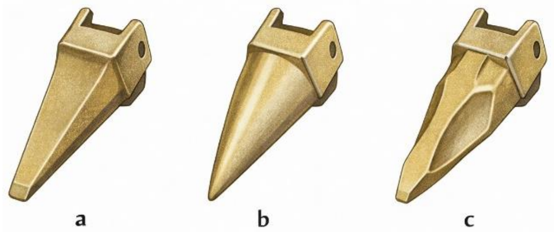


Fig. 2. Main geometric shapes of bucket teeth: a – wedge-shaped, b – conical, c – combined

Wedge-shaped teeth have the ability to penetrate the soil rapidly, reducing the cutting area within a short period of time. However, this shape may lead to increased impact loads and accelerated tooth wear. Conical teeth, in contrast, distribute forces laterally, making the cutting process relatively more stable. Combined shapes integrate the advantages of these two approaches, ensuring an optimal balance between cutting efficiency and structural strength.

Theoretical analyses show that the use of bucket teeth with rational geometric shapes makes it possible to reduce the cutting force by 10–15%. This not only extends the service life of the working tool components but also significantly reduces energy consumption.

Theoretical Analysis of Energy Consumption

The energy consumed during the cutting process is determined by the work performed by the working tool. Energy consumption can be expressed by the following integral equation:

$$E = \int F_k ds$$

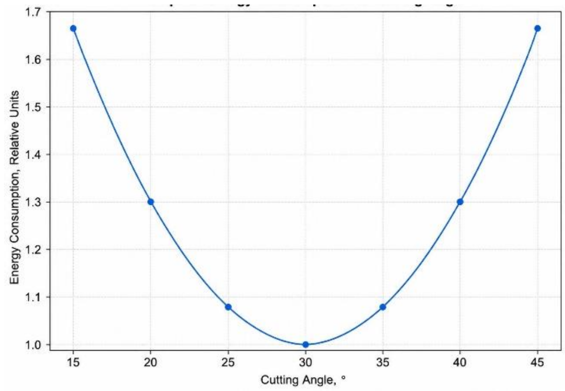
where:

F_k – cutting force,

ds – elementary displacement path of the working tool.

It follows from this expression that energy consumption depends not only on the cutting force, but also on the distance traveled by the working tool within the soil. In rocky soils, the pulsating nature of the cutting force causes energy consumption to also become non-uniform. This condition leads to additional losses in the engine and hydraulic system.

Graph 2 presents the variation of energy consumption as a function of the cutting angle. Analysis of the graph shows that energy consumption reaches its minimum value precisely within the cutting angle range of 25–35°. Deviation from this range leads to an increase in cutting force and excessive movement of the working tool.



Graph 2. Energy consumption as a function of cutting angle: Axes: X-axis – cutting angle; Y-axis – energy consumption, relative units

“The variation of energy consumption depending on the cutting angle is shown in Graph 2. It can be seen from the graph that energy consumption reaches its minimum value within the range of 25–35° (approximately around 30°).”

The above theoretical analyses show that the proper selection of the geometric parameters of the excavator working tool is one of the main factors determining the mechanical and energy efficiency of the rocky soil cutting process. By rationalizing the cutting angle, bucket tooth shape, and contact area, it is possible to reduce the maximum values of cutting force, stabilize the process, and decrease energy consumption by up to 10–15%.

These theoretical results can be further refined in subsequent stages through mathematical modeling, computer simulation, and practical experiments. At the same time, they provide a reliable scientific basis for improving the working tool design and implementing energy-efficient technologies.

3. Conclusion

The research results show that the proper selection of the geometric parameters of the excavator working tool directly affects the cutting force and energy consumption during the excavation of rocky soils. Energy efficiency can be achieved by selecting the cutting angle within a rational range, optimizing the shape of the bucket teeth, and reducing the contact area. The obtained theoretical conclusions serve as a solid scientific basis for developing practical recommendations aimed at improving the excavator working tool and increasing energy efficiency.

Table 2

Results of Optimization of Working Tool Geometric Parameters

Parameter	Conventional Value	Rational Value	Energy Reduction, %
Cutting angle	45°	30°	12–15

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Parameter	Conventional Value	Rational Value	Energy Reduction, %
Tooth shape	Flat	Conical	10–12
Contact area	Large	Reduced	8–10

References

[1] Reece A.R. The Mechanics of Cutting Soil. Journal of Agricultural Engineering Research, 1964.
[2] Hettiaratchi D.R.P., Reece A.R. Soil Failure Patterns in Cutting. Journal of Terramechanics, 1975.
[3] McKyes E. Soil Cutting and Tillage. Elsevier, 1985.
[4] Balovnev V.I. Soil Cutting Mechanics. Balkema, 1983.
[5] Vyalov S.S. Mechanics of Soils. Moscow, 1986.
[6] Kashтанов A.N. Theory of Soil Cutting. Moscow, 1983.
[7] Caterpillar Inc. Performance Handbook. USA, 2019.
[8] Zhang Q., et al. Energy Consumption in Excavation of Hard Soils. Automation in Construction, 2018.

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