Unit with a device for directional feeding of rocks with a shale structure

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Abstract. The paper analyzes the properties of rocks with a shale structure, justifies the need to apply force in the direction of the lowest strength. The list of crushing equipment used in the process of obtaining cube-shaped crushed stone is given. It is established that the existing crushing equipment is not able to take into account the specific texture of the crushed materials and this does not allow obtaining cube-shaped crushed stone from shale materials. A description of the new design of the press-roll unit, which allows obtaining cuboid crushed stone from rocks with a shale structure, is given. The press-roll unit includes a device for directional feeding of shale materials to its working bodies, which create a force effect on the fed pieces of rock in the required direction. The design of the tooth of the working body is described, which allows to reduce significantly the replacement time of worn elements and reduce the bending loads acting on it. This leads to an increase in the reliability of the structure and reduces the metal consumption of repairs. A mathematical model of the directional movement of shale materials in a roll device is considered and an equation for calculating the required force is obtained. Graphical dependences of the influence of the roller installation angle and its horizontal and vertical displacement on the amount of deformation of the feed material layer are presented.

1. Introduction

Today, the country’s construction industry is experiencing a huge shortage of crushed stone materials. A partial solution to this problem can be the production of cube-shaped crushed stone from rocks with a shale structure, which are found in large volumes both in Russia and in countries of the near and far abroad and are currently poorly used in road construction due to the complexity of obtaining a cube-shaped material with the equipment used in the technology.

Today, in the world practice, cone, jaw and rotary crushers are widely used for the production of crushed stone, which make it possible to obtain crushed stone of various fractions, including cuboid from rocks with an anisotropic texture. However, when grinding rocks with a shale (anisotropic) structure, the yield of cuboid rubble is minimal and does not exceed 10-15% [1-3]. The analysis of national and foreign designs of the designed and operated crushing equipment showed that they are not adapted to account for the texture of crushed materials, which does not allow obtaining a high percentage of the output of crushed stone of a cuboid shape after grinding rocks with a shale structure [4-5].
2. Materials and methods

2.1. Materials
This research paper uses clay shale with the following physical properties:
- Average density – 2.71 g/cm³;
- Water adsorption – 0.97 %;
- Ultimate strength – 87.6 MPa;
- Abrasion resistance – 1.80 g.cm²;
- Hardness on the Mohs scale – from 3 to 6;

2.2. Methods
When grinding shale rocks in jaw, cone and other aggregates, the product has a low percentage of cuboid crushed stone at the output. In addition, they are characterized by high energy consumption and high specific consumption of rock in the production of tons of cubic crushed stone.

Analysis of the properties of rocks with a shale structure showed that they have an inhomogeneous density and strength, and when grinding them, in order to obtain a cube-shaped crushed stone, it is necessary to apply a force action along the largest axis of the piece with a certain step. [6-7].

Therefore, it is necessary to develop a design of the unit that allows for directional feeding and force action on these pieces when they are crushed.

3. Results
Scientists of BSTU named after V.G. Shukhov designed a press-roller unit with a device for the directional flow that allows creating directional movement of pieces of rock along its major axis to the working bodies of the assembly and to exercise a force in the desired direction, which allows to obtain crushed stone of cubical form with a large percentage of its output [8].

![Figure 1](image)

**Figure 1.** Press-roll unit with a device for directional feeding a) Experimental unit; b) unit scheme with a device for directional feeding: 1 - drive roll, 2 - teeth, 3 - holder, 4 - hopper, 5 - movable jaws, 6 - spring-loaded rollers, 7 - housing, 8 - driven roll.

The press roll unit (Figure 1) consists of a housing 7, in which there are two rolls 1 and 8 rotating towards each other, on which there are protruding wedge-shaped teeth. On the sides of the rolls there are ridges designed to hold the material in the working area of the rolls when it is fed and crushed [9].
Figure 2. View of the working bodies of the press roll unit with a device for directional feeding.

To create a directional feed of rocks with a shale structure, a device consisting of two movable jaws 5 and spring-loaded rollers 6 is located in the hopper 4, which serve to create a directional feed of shale rock pieces [10].

Figure 3. The shape of a wedge-shaped tooth: 1 - roll, 2 - removable tip, 3 - the main part of the tooth.

The teeth themselves (Figure 3) consist of a holder 3, at one end of which there is a dovetail attachment to the bandage and at the other end there is a groove for installing the tip 2.

The quick-removable tip 2 is made in the form of a wedge-shaped tooth with a one-sided cut at an angle of 35-45°, this is necessary to reduce the contact area of its side surface with the crushed material, and therefore reduce the bending loads acting on the tooth [11-12].

This design of the tooth will significantly reduce the replacement time of worn elements without removing the bandage, increase the reliability of the structure and reduce the metal consumption of repairs [13].

The unit works as follows. Shale rock (Figure 4) is poured into the receiving hopper, where it is fed to the rollers along the movable jaws, captured by them, turned into a vertical position and sent to the
toothed rolls, where it is crushed and leaves the inter-roll space in the form of pieces having a cuboid shape with dimensions not exceeding the pitch of the teeth [14].

![Figure 4. Rocks with a shale structure a) before crushing at the experimental installation; b) after crushing at the experimental installation.](image)

However, to create a directed movement of shale materials to the working bodies of the unit, it is necessary to expend efforts, the lack of a scientifically based calculation of the value of which hinders the introduction of the proposed design into production. We consider a scheme that allows calculating the amount of force required to create a directional movement of shale materials (Figure 5). The initial data are: the radius of the roller $r$, the value of its displacement horizontally $-L$ and vertically $-l$. The value of the slope angle of the hopper wall $\alpha$, and the angle of material capture $\beta$ [15-16].

![Figure 5. Diagram for determining the amount of force: 1-roller; 2-hopper wall; 3-movable jaw.](image)
According to Figure 7, we determine the value of the slope angle of the AOB line to the horizontal \(\gamma\) by the following expression:

\[\tan \gamma = \frac{l}{L},\]  

(1)

The thickness of the rock layer \(h\) along the OD beam is equal to:

\[AO = \sqrt{L^2 + l^2},\]  

(2)

and

\[\sin(\alpha - \gamma) = \frac{OD}{AO} = \frac{h + r}{\sqrt{L^2 + l^2}},\]  

(3)

We express the value \(h\) from expression (3), we get:

\[h = \sqrt{L^2 + l^2} \sin(\alpha - \gamma) - r.\]  

(4)

The amount of compaction of the material changes from the moment its pieces hit the OE line, limited by the angle of capture of the roller. Assuming that the forces generated by the roller are proportional to the amount of deformation of the layer, we determine this value as it moves [17-18].

The equation of a straight line in polar coordinates can be written as follows:

\[\rho \cos(\varphi - \theta) = p,\]  

(5)

where \(\rho, \varphi\) – polar coordinates; \(\theta, p\) – parameters.

In this case, when the value of the angle \(\varphi\) originates from the line OA, then, its value on that line is equal, then we have:

\[\rho = OA = \sqrt{L^2 + l^2},\]  

(6)

at \(\varphi = \gamma + \frac{\pi}{2} - \alpha\), we get \(\rho = OD = r + h = \sqrt{L^2 + l^2} \sin(\alpha - \gamma).\)  

(7)

In order to determine the data of the values \(\theta, p\), we present expression (4) as the following system:

\[
\begin{cases}
\sqrt{L^2 + l^2} \cos(\theta) = p \\
\sqrt{L^2 + l^2} \sin(\alpha - \gamma) \cos(\gamma + \frac{\pi}{2} - \alpha - \theta) = p.
\end{cases}
\]  

(8)

Having solved this system of equations, we obtain an expression that allows calculating the amount of layer deformation carried out when creating a directed movement of shale materials to the working bodies of the unit.

\[\Delta \rho(\varphi) = \frac{4(h + r) \cos \left(\alpha - \gamma + \frac{\varphi + \beta}{2}\right) \sin \left(\frac{\varphi - \beta}{2}\right)}{(\cos(\varphi - \beta) - \cos(2(\alpha - \gamma) + \varphi + \beta))}.\]  

(9)

The resulting equation (8) allows calculating the amount of layer deformation carried out when creating a directional movement of shale materials to the working bodies of the unit [19]. In order to study the influence of the angle \(\varphi\) and displacement of the roller horizontally \(L\) and vertically \(l\) on the amount of deformation, we construct a graphical dependence \(\Delta \rho(\varphi)\) on the height \(l, \varphi, L\) Fig. 8-9.
Figure 6. Dependence of material deformation value on angle φ: 1 – l=10 cm; 2 – l=13 cm; 3 – l=16 cm; 4 – l=19 cm.

Initial data for the calculation: \( \alpha = 50^\circ \), \( \beta = 17^\circ \), \( L = 55 \text{ cm} \), \( r = 20 \text{ cm} \). Assuming a deformation coefficient equal to 1.19; 1.24; 1.29 and 1.35.

Figure 7. Dependence of the amount of deformation of a material with an anisotropic texture on the angle φ.

The graphical dependence \( \Delta \rho (\varphi) \) on the angle of inclination of the hopper wall \( \alpha \) is shown in Fig. 7. Initial data for the calculation: \( \beta = 17^\circ \), \( l = 13 \text{ cm} \), \( L = 55 \text{ cm} \), \( r = 20 \text{ cm} \).

The amount of distributed force applied to the roller can be determined by the following expression:

\[
F = \int_S q \, ds,
\]

where \( S \) – the platform on which the effort operates.

In the process of deformation without destruction of the initial pieces of shale rocks, the change in force occurs in proportion to the decrease in the thickness of the layer \( \Delta \rho \) (Fig. 7). Then the value of the change in force \( q \) is represented as the expression:

\[
q = \mu \Delta \rho,
\]

where \( \mu \) – coefficient depending on the properties of the compacted material, N/m\(^3\).

4. Discussion
The analysis of the structures of designed and operated crushing equipment allowed to establish that these units are widely used in the production of stone materials, are not adapted to consideration of the
specific texture of crushed rocks and it is not possible to obtain cubical form of crushed shale materials.

As a result of the analysis of the properties of rocks with a shale structure, the necessity of applying force in a given direction is justified in order to obtain cube-shaped crushed stone. The developed design of the press-roll unit includes a device for the directed supply of shale materials to its working bodies, which create a directed force effect on the fed pieces, which allows obtaining cube-shaped crushed stone from rocks with a shale structure. The proposed design of the tooth of the working body allows reducing the bending loads acting in the process of destruction, which will significantly increase the reliability of the structure and reduce the metal consumption of repair. A model describing the movement of shale materials in the roll unit is developed and mathematically investigated, and an equation is obtained for calculating the force required to create a directed movement of materials to the working bodies of the press-roll unit. According to equations (7-9), based on the properties of rocks, it is possible to determine the force required to create a directed movement of them to the working bodies of the press-roll unit [20].

The impact of the roller installation angle and its horizontal and vertical displacement on the amount of deformation of the feed material layer, and, consequently, the amount of energy consumption, is studied.

5. Summary

The developed design of the press-roll unit with a device for directional feeding of shale materials to its working bodies, allows creating a directional movement and force action on the fed pieces provides the possibility of obtaining cuboid crushed stone from rocks with a shale structure.

A model describing the movement of shale materials in a roll device is investigated and an equation is obtained for calculating the force required to create a directed movement of materials to the working bodies of the press-roll unit.

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