JUSTIFICATION OF THE CAM ROLLER PARAMETERS FOR DESTRUCTION OF THE ROAD COATINGS FOR OBTAINING THE LUMPY ASPHALT SCRAP

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Resume

Cam rollers can be used to break up cold asphalt pavements. In Kazakhstan, about 70% of roads have such coatings. It is most effective to open at temperatures above 20 °C. To reduce the traction force and uniform movement of the roller, it is necessary to eliminate the resistance of the coating to the exit of the cams, when rolling the drum by pivoting the cams in the roller's direction. The reliability of the theoretical studies' results was confirmed by production tests of the cam rollers during the opening of the asphalt concrete pavement on the Gulshad-Akchatau highway.

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1 Introduction

Highways are of a great importance in the socio-economic development of the country. Therefore, much attention is paid to development of the road network in the country. More than 10000 km of paved roads are built and overhauled annually. The development of the country's economy requires an increase in the intensity and carrying capacity of the traffic flow, which is impossible without improving the quality of road construction [1-2].

Currently, more than 70% of highways of republican significance with asphalt concrete pavement are subject to reconstruction and this is over 50000 km of roads, which will require 55 to 65 million tons of asphalt concrete. To restore the working capacity of roads in Kazakhstan, it is mainly necessary to reconstruct the most material-intensive structural element - road pavement, which contains over 150 million tons of asphalt concrete as useless ballast.

The world practice of reusing asphalt scrap of old pavements shows that countries such as the USA, England, Germany and France, reuse all asphalt scrap, Japan, Hungary and Poland - 60% and 50%, respectively and much less in Kazakhstan [3-5].

To restore the entire network of highways in Kazakhstan with a minimum of fuel, energy and material resources, it is necessary to reuse the entire mass of pavement materials, the reserves of which are sufficient. One of the main reasons for the slow implementation of the technology of reusing the old asphalt concrete pavement is the imperfection of the mechanisms used to destroy the pavement [6].

To facilitate the opening of the asphalt concrete pavement, it is proposed to use a cam roller with some improvement of the cams to prevent the resistance of the asphalt pavement when the cams enter and leave the surface [7-9].

At the same time, the use of a cam roller would avoid mixing of coating and base materials, as happens when using a ripper.

Asphalt concrete pavements are destroyed to pieces of a certain size, taking into account the location of the cams at a given distance from each other in a checkerboard pattern. Usually, during the reconstruction of roads, the "old" coatings are destroyed, which are almost all covered with a network of cracks, so lumpy asphalt scrap should not exceed 500 mm in size.

2 Materials and methods

There are two fundamentally different methods of opening the old asphalt concrete pavement - milling and breaking by scraping. Milling is usually performed to a shallow depth and scarification, mainly, to the full thickness of the coating [10-12].

Milling is carried out by special machines using the milling cutters installed in most cases on a drum. When milling, the so-called cold and hot methods are used. Recently, only the cold milling method has been used, since bitumen does not burn out and liquefied gas, which is a scarce and expensive energy carrier, is not used. However, during the cold milling, cutter cutters wear out 5-10 times more intensively than during the hot milling, which leads to a rapid wear of expensive hard alloys used on cutters [13-14].

The destruction of old asphalt concrete pavements that have lost their operational qualities is still regarded as the simplest technological operation. Destruction is carried out with the help of traditional road machines - medium and heavy type motor graders with scarifies, bulldozers with rippers on tractors weighing 10 tons or more, as well as special hydraulic hammers or concrete breakers of hydraulic or pneumatic action [15-16].

The main disadvantages of machines for opening asphalt concrete pavements are: the accepted principle of loosening and scarifying the asphalt concrete pavement requires significant energy consumption, since the destructive force is directed along the entire length of the asphalt concrete slab; the impossibility of emergency adjustment of the depth of scarification by rippers according to the thickness of the slab being destroyed, as a result of which the coating and base materials are mixed, thereby reducing the quality of the products obtained subsequently; the method of rough and fine milling is the least effective for opening the coating and with fine milling, stone fractions of crushed stone are crushed, which limits the use of the resulting material; lumpy asphalt scrap, obtained as a result of scarification, has different sizes and requires additional costs for breaking them down to the required dimensions acceptable for feeding into the crushing plant.

The most rational way to open the coating slab is the method of pressing a wedge on top of the slab, in which the destruction force will be directed along its smallest size - the thickness of the slab.

In view of the foregoing, it is proposed to use the cam rollers for destruction and opening of asphalt concrete pavements. The specific pressure of medium-type cam rollers ranges from 2 MPa to 6 MPa or more, which is sufficient to press the cams into the old coating, the strength of which is much lower due to cracking from its long-term operation.

The maximum effect can be achieved only with a rational choice of parameters of the rink's working equipment.

The analysis carried out allows to conclude that there is no holistic concept for increasing the efficiency of the road rollers by creating an information bank of their technical parameters, identifying the main trends in development of machines using probabilistic-statistical methods, predicting promising directions in the design of working bodies and developing a methodology for substantiating the main parameters of the cam rollers at the stage of their design. and applications, taking into account the nature of their interaction with destructible material for opening old asphalt concrete pavements during the reconstruction of roads.

The possibility of using the cam rollers for destruction of the old asphalt concrete pavement of roads during their reconstruction, with development of an engineering method for calculating their main parameters (roller weight, dimensions and number of cams) is justified. A cam 2 with a spring-loaded latch 3 is pivotally attached to the roller structure 1 and is accepted as the base for further operation (Figure 1). Depending on the type of the working body, the nature and conditions of its interaction with the destructible material, various types of deformations and their combination take place. The most effective is the vertical introduction of wedges and dies, which is ensured by use of the cam rollers for the destruction of asphalt pavements with production of the lumpy scrap of a given size.

For effective opening of old asphalt concrete pavements during their reconstruction, the most effective is the vertical introduction of wedges and dies, which is ensured by using cam rollers to obtain lumpy scrap of specified sizes, while the following requirements must be met with a roller mass of at least 5 tons: the number of cams in one row should not exceed from 4 to 5 pieces [3-6, 10-12, 16]: the distance between them should not be more than 0.4 m; the number of cams along the perimeter must be at least 15 pcs.; the distance between them is not more than 0.35 m; cams should be staggered; The height of the cams should be 250 to 300 mm, thickness - no more than 40 mm and width - no more than 100 mm at the top.

Consider the case of an elastic-viscous state of asphalt concrete. Let a wedge with side faces under the action of a statically applied vertical force P enter an elastic-viscous medium (Figure 2) and the length of an infinitely small element of the wedge section in the direction perpendicular to the plane of the drawing will be taken as unity. Typically, the depth of penetration or destruction of asphalt concrete is equal

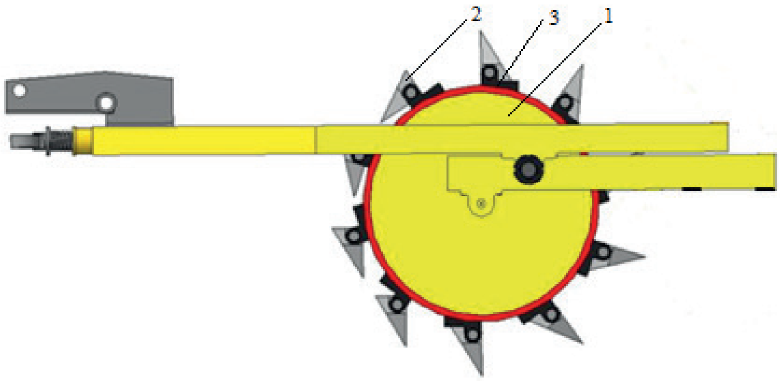

***Figure 1** General view of the cam roller [8]: 1 - road skating rink; 2 - cam; 3 - spring-loaded latch*

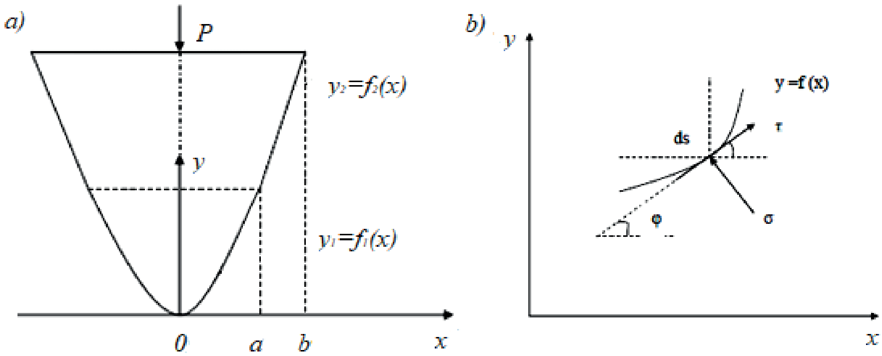

***Figure 2** The introduction of a wedge into an elastic-viscous medium:*
a) a wedge with side faces under the action of a statically applied vertical force P;
b) to the equilibrium condition of an elementary wedge

to the thickness of the pavement layer. We believe that to open the old coating, it is enough to pierce it with the cams of the roller for its entire thickness.

The side faces of the wedge are described by two surfaces (or two functions)

$$y_1 = f_1(x), y_2 = f_2(x)). \tag{1}$$

Let, for example, the function $f_1(x)$ describe the face of the wedge in the interval $0 \le x \le a$ and the function $f_2(x)$ in the interval $0 \le x \le b$. Consider the equilibrium condition for an infinitely small elementary section of the wedge. On the side faces of the wedge, from the side of the elastic-viscous medium, act the normal and shear stresses σ and τ, the resultants of which are the reactive resistance forces of the medium. If μ is the coefficient of viscoelastic friction of the medium on the metal, then

$$\tau = \mu\sigma. \tag{2}$$

As known, the differential of the arc length of a plane curve is determined from the expression

$$ds = \sqrt{1 + y'^2}dx. \tag{3}$$

The pressing force of the wedge is determined by the formula:

$$\int_s \sigma ds \cos\phi + \tau ds \sin\phi = p/2. \tag{4}$$

We substitute the expression for ds and, taking into account Equation (2), we obtain for an elastic-viscous medium

$$\int_0^b \sigma(\cos\varphi + \mu\sin\varphi)\sqrt{1 + y'^2}dx = p/2; \tag{5}$$

taking into account the geometric meaning of the derivative

$$y' = tg\varphi, \tag{6}$$

we have:

$$\varphi = arctgy'. \tag{7}$$

Using the trigonometric identities of the function $\cos\varphi$ and $\sin\varphi$ Equation (5), it is transformed to the form:

$$\int_0^b (1 + \mu y')\sigma dx = p/2 \tag{8}$$

To use equation (8) in practical calculations, it is necessary, firstly, to have the equation of the curvilinear wedge face $y = f(x)$ and secondly, to know the law of distribution of normal and shear stresses along the wedge faces. Usually, in the theory

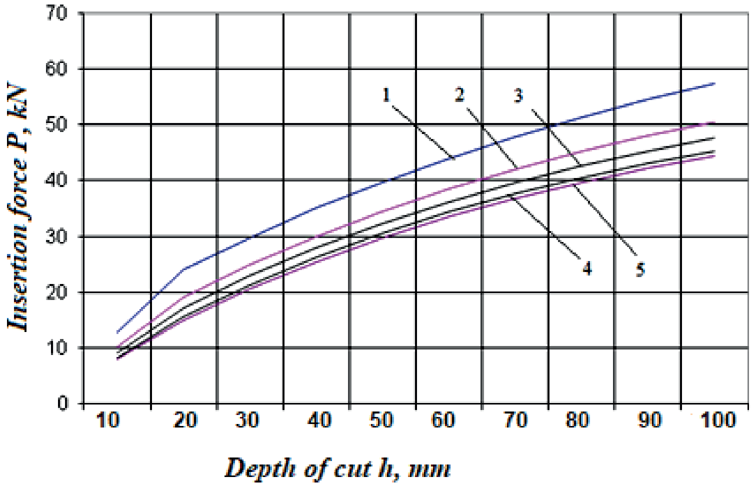

***Figure 3** Dependence of the cam insertion force on the depth at various values of the coefficient μ: 1- μ=0.72; 2 - μ=0.374; 3 - t μ=0.232; 4 - μ=0.116; 5- μ=0.065*

of elasticity and plasticity, the law of distribution of normal and shear stresses is given by the stress functions, which must satisfy the equilibrium equations, boundary conditions and strain continuity equations. Hence, it follows that the problem of equilibrium of a wedge in an elastic or viscoelastic medium is solved ambiguously: the set of suitable stress functions is very extensive.

The stress distribution law can be approximated according to the experimental data of Bocharov [17] function of the form

$$\sigma = Ae^{-Bh}, \tag{9}$$

where h - is the penetration depth of the wedge, A and B are constant coefficients.

As the experience of other researchers shows, recently the most common are cams in the form of: a truncated cone, a truncated pyramid, cams with side surfaces formed by second-order curves (involutes, spirals, cycloids) or complex curves with a trapezoidal shape, [3, 7, 9, 11].

Calculation of penetration forces into an elastic-viscous medium of different variants of cam profiles, with varying coefficient of viscoelastic friction of the medium against metal and penetration depth has been performed. A graphical interpretation of the calculation results for the considered cam profile is shown in Figure 3, where μ is the coefficient of viscous-elastic friction of the medium on the metal in the asphalt concrete layer.

The criterion for the destruction of the asphalt concrete pavement is the ratio

$$\sigma_y \geq R_{compres}, \tag{10}$$

where is σ_y - the vertical compressive stress; $R_{compres}$ - compressive strength of asphalt concrete.

The strength properties of asphalt concrete depend on temperature, with its increase, the pressing force of the wedge decreases. The most intense changes are in the positive temperature range from 10 to 35 °C, when the indentation force is reduced by almost 3 times. This property depends on the amount and viscosity of bitumen in asphalt concrete and bituminous rocks. Comparing the strength indicators of asphalt concrete pavements to the specific pressure created by the cam rollers, we conclude that medium and heavy rollers can be used to open asphalt concrete pavements of highways during their reconstruction to obtain lumpy scrap of given sizes.

3 Results and discussions

The analysis of technical literature showed that cams with concave or convex curvilinear side surfaces formed by second-order curves are the most appropriate for road rollers [1-9].

Studies show that the degree of fulfillment of all the requirements largely depends on the correct choice of the geometric shape of the cam and the design parameters of the working body itself, but there is still no consensus on this issue. This is evidenced by a wide variety of geometric shapes of the cam and a significant discrepancy in the size of the working bodies used on rollers of various companies. It was mainly the shape or profile of the cam that was changed, since they have a significant impact on the compaction parameters, as well as on the degree of loosening of the soil or other material.

As experience of researchers from different countries shows, recently the most common are cams in the form of a truncated cone and a truncated pyramid. Cams with lateral surfaces formed by second-order

Figure 4 *Cam roller with opening of the asphalt concrete pavement*

Figure 5 *General view of the crushed asphalt scrap padfoot roller*

Table 1 *Results of testing crushed scrap when pressed by a press and rollers*

No.	The composition of the crushed scrap (%)	Addition of water (over 100 %) (%)	Density (kg/m^3)	Coefficient seals
1	20-40 mm - 60 10-20 mm - 20 0-10 mm - 20	5	2320	0.97
2	10-20 mm 50 0-10 mm - 50	6	2360	0.98
3	Production composition of crushed asphalt	5.5	2350	0.98-1

curves (involutes, spirals, cycloids) or complex curves are beginning to be widely used.

Cams with involutes side surfaces are more efficient in terms of achieved soil density, self-cleaning and other indicators compared to cams of a different shape.

Experimental tests of a cam roller for destruction of the asphalt concrete pavement were carried out during the reconstruction of the Akchatau-Gulyshad section of the highway, 192 km long.

The existing structure of the pavement consists of a 130 to 140 mm asphalt concrete pavement and a base of crushed stone with a fraction of 200 to 400 from 120 to 180 mm. The width of the pavement is 8 m and the shoulder is 1.5 m each.

The design of the pavement consists of the following layers: pavement of two-layer asphalt concrete, 130 mm thick, of which 40 mm is fine-grained asphalt concrete and 90 mm is coarse-grained asphalt concrete; base made of crushed old asphalt concrete (with the addition of crushed stone of a fraction of 20 to 40 mm, if necessary), with a thickness of 150 to 180 mm; leveling layer of sand-gravel mixture.

The volume of asphalt scrap to be processed was more than 505 thousand tons. To open the old asphalt concrete pavement, up to 140 mm thick and grind asphalt scrap, they used the recommendation of the manufacturer of the DU -94 cam rollers weighing 5 tons (Figure 4).

The opening and grinding of the asphalt concrete pavement was carried out directly on the road in the following technological order. The cam rollers cracked and crushed the coating in several passes, then the resulting material was mixed with a disk mixer. Then, the final grinding of the material was carried out in 2 and 3 passes with cam rollers. A general view of crushed asphalt concrete is shown in Figure 5.

During the first passes of the roller, due to the resistance to the exit of the cams, the movement of the K-700 tractor was slow. After partial destruction of the cover over the entire area, the speed of the K-700 tractor was from 3 to 5 km/h.

To reduce the resistance of the cams when leaving the coating, a technical solution was developed that made it possible to freely exit the coating by means of hinged fastening of the cams.

After the final grinding, the resulting asphalt material presents fractions from 0 to 70 mm, consisting of the sand-crushed stone granules coated with an asphalt binder, i.e. bitumen mixed with mineral powder. According to the grain composition, the crushed material was granules: crushed stone fractions from 5 to 70 mm from 65 to 75 %, sandy from 1.25 to 5 mm from 20 to 30% and less than 1.25 mm about 5 %. Taking into account that the grain composition is close to the required one and when the crushed material is compacted, further crushing of weak granules will occur, it was decided to carry out a test rolling by pressing samples on a press at a load of 20 MPa. The molding of the samples was carried out at the optimum moisture content of the mixture, while comparing to the structural densities of asphalt concrete (Table 1).

Production tests of compacted pulverized asphalt have shown that the required density is achieved.

4 Conclusions

Based on the experimental tests of the cam rollers during the reconstruction of the Gulshad-Akchatau highway, it seems possible to draw the following conclusions: mathematical dependencies have been obtained that allow calculating the necessary efforts for destruction of the old asphalt concrete pavement by the cam rollers during the reconstruction of roads, taking into account the physical and mechanical properties of the medium and the geometric dimensions of the working body; an engineering method has been developed for calculating the main parameters of a cam roller (mass of the rink, dimensions and number of cams necessary for the destruction of an asphalt concrete pavement with the production of lumpy scrap of a given size) used to open and destroy the old asphalt concrete pavement of reconstructed roads; to reduce the rolling resistance of the roller, the cams are hinged to ensure their free exit from the pavement. The pilot tests of the cam roller, during the destruction of the old asphalt concrete pavement during the reconstruction of the road, confirmed the efficiency and reliability of theoretical calculations and scientific points made in the work.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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