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SELECTION OF TECHNOLOGY FOR HIGHWAY ROAD SURFACE OVERHAUL

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In the construction and overhaul of roads, the complex-mechanized method is widely used. It is based on modern technologies, machines, and mechanisms. It leads to the maximum productivity, minimum cost, and optimal terms of work. There are many approaches to choosing technologies for construction. One of them is the technical and economic comparison of different technologies, which helps to consider many factors affecting the construction process in the most complete way. The proposed paper considers the use of such an approach to the choice of technology for the overhaul of road surface. Cold in-place recycling technology is offered as an innovation. Based on the calculations done during the comparison of different technologies for a particular road section, the paper provides the list of recommended actions prior to the selection of a particular technology.

Key words: *road surface, overhaul, cold in-place recycling, strength calculations, feasibility comparison*

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INTRODUCTION

Constantly increasing intensity of traffic on the highways of general use, increased loads on the axle of trucks require an increase in the load-bearing capacity of the road surface of the operated roads, which is achieved by reconstructing or overhauling the roads. Nowadays, along with the traditional methods of overhaul, reconstruction, and strengthening of road surface, fundamentally new technologies have appeared that meet the latest requirements of ever-increasing traffic volume, based on the latest achievements of science and technology. One such technology that most fully meets the requirements for road surface reinforcement is "cold in-place regeneration" or "recycling" [1, 2]. This technology consists of crushing and mixing the existing asphalt concrete surface and a layer of the underlying material with the addition of binders in order to obtain a strong, homogeneous road base – asphalt granulated concrete, which is a composite material with new properties that differ significantly from the original [3]. A new asphalt concrete pavement or surface treatment layer is subsequently laid on this base [3]. The result is a new road with improved physical and mechanical characteristics.

The main task of this technology is solved with the help of high-tech machinery – a recycler (Fig. 1).

Fig. 1. Wirtgen 2500 recycler during an overhaul of road surface in Yaroslavl region

Fine tuning systems of the recycler allow to achieve high quality mixing of components in the right proportion, which is the key to the quality of the regeneration

RESULTS AND DISCUSSION

In order to substantiate the choice of cold in-place recycling technology, Wirtgen offers a certain algorithm of actions (Fig. 2) [3], which includes: collection and initial processing of data; preliminary and detailed studies to select the most rational composition of asphalt granulated concrete mixture; preliminary and final calculation of the road surface structure obtained after cold recycling; economic analysis of the efficiency of the designed reinforcement of road surface structure; comparing the proposed technology with known ones.

The determining factor when choosing a technology for road overhaul is primarily economic analysis. The choice stems from the need to reduce budget expenditures while reducing the time of construction and repair and minimizing the costs associated with the road closure or traffic reduction in the area of overhaul or reconstruction.

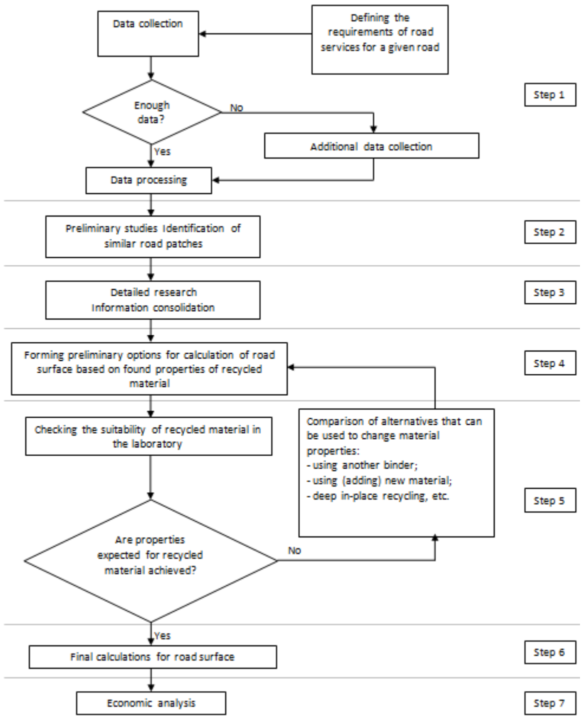

Fig. 2. Technology selection algorithm for road surface overhaul

The purpose of this paper is to develop a substantiation of the choice of the overhaul technology using technical and economic indicators.

The project of overhauling or reconstruction of a road section may be characterized by a number of technical and economic indicators that determine the degree of efficiency of the planned works, namely:

1. *Estimated cost of construction and repair work.*
2. *Labor costs of workers and machines.*
3. *Mechanization and automation of work.*
4. *Material intensity of work.*
5. *Efficiency of subsequent operation of the road.*
6. *Special work conditions.*

Estimated cost is the sum of money required for construction or overhaul according to the design materials. The estimated cost includes all construction costs, which are the purchase of materials, costs of operation of machines and mechanisms, labor costs of workers and machine operators, costs of administrative and managerial staff [4].

Estimated cost consists of the cost of works and estimated profit and it is calculated by the formula [4]:

$$C_{est} = C_{pr} + EP, \qquad (1)$$

where C_{pr} – prime costs, RUB, in thousands; EP – estimated profit, RUB, in thousands.

Prime cost is the cash cost of construction, production, and services. Depending on how they are included in the cost of production, these costs are divided into direct and overhead (indirect). The largest part of construction costs are direct costs. They are determined based on the scope of work, cost estimates, and prices.

The direct costs include: the basic salary of workers engaged in manual labor, the cost of materials, parts, and structures, the cost of operating construction equipment [4].

Overhead (indirect) costs are costs associated with the organization and management of construction and installation. Together with direct costs, they constitute the estimated cost of construction and installation [4].

The prime costs of construction and repairs is calculated [4]:

$$C_{pr} = DC + OC, \tag{2}$$

where DC – direct costs, RUB, in thousands; OC – overhead costs, RUB, in thousands.

Direct costs include expenditure items directly attributable to construction and repairs:

– the cost of materials;

– the cost of operating machines and mechanisms; wage fund (including salary costs for the main construction workers and machinery operators).

The formula for calculating direct costs is [4]:

$$DC = MC + MMC + WF, \tag{3}$$

where MC – cost of materials, RUB, in thousands; MMC – cost of operating machines and mechanisms, RUB, in thousands; WF – salary costs for construction workers and operators, RUB, in thousands.

Estimated profit is the sum of funds spent by the contractor on development of production, social services, and financial incentives for employees. Estimated profit, which are also called planned savings, as well as overhead costs, are calculated from the wage fund by type of work [4].

The cost of repairing one kilometer of road is calculated by the formula:

$$C_{km} = \frac{DC}{L}, \tag{4}$$

where DC – direct costs, RUB, in thousands; L – road length, km.

The cost of repairing 1000 m^2 of road is calculated by the formula:

$$C_{sq} = \frac{DC}{S} \tag{5}$$

where S – road surface, m^2, in thousands.

To determine the level of profitability, the following formula will be used [4]:

$$P = \frac{EP}{C_{pr}} \cdot 100 \tag{6}$$

The material capacity is calculated by the formula [4, 5]:

$$M_{mat} = \frac{MC}{C_{est}} \cdot 100, \tag{7}$$

where MC – cost of materials, RUB, in thousands.

Important technical and economic indicators are the total and specific labor intensity of repairs.

Labor intensity is quantity of working time of a person spent on a unit of production [4]. To determine labor intensity of all kinds of works, we use the State Elementary Estimates Norms (SEEN) to determine labor costs for each job and then summarize their averages in each working category provided in the Norms. Using the formula 8, we determine the weighted average category of workers needed to perform the work, which will help to understand the average qualification of workers for a particular method of road repairs.

We calculate the weighted average of working categories as the arithmetic mean weighted by the formula [4, 5]:

$$X = \frac{\sum_i^n a_i \cdot x_i}{\sum_{i-1}^n x_i}, \tag{8}$$

where a_i – labor costs of workers of the x_i-th category, man-hours; x_i – worker category.

The average number of workers is calculated by the formula:

$$N = \frac{Q \cdot K_{con}}{8 \cdot t}, \tag{9}$$

where Q – total labor costs, from SEEN, man-hours; t – work completion period, shifts; K_{con} = 1,08 – contingency factor [6].

An important indicator is the specific labor intensity of work, i.e. labor costs per 1 RUB. of the estimated cost of construction and installation – K_T. The indicator of specific labor intensity reflects the costs of labor in the construction and installation and characterizes the manufacturability of structural solutions of the object under construction and the level of mechanization of construction and installation.

The specific work intensity can be calculated by the following formulas [4]:

$$K_{Test} = \frac{T_0}{C_{est}}, \tag{10}$$

$$K_{Tv} = \frac{T_0}{L} \tag{11}$$

where T_0 – total labor costs, man-hours; C_{est} – estimated repairs cost, RUB, in thousands; L – road length being repaired.

Another important indicator is the mechanical equipment ratio, which is the ratio of the cost of operation of machines and mechanisms (MMC) required to perform work to the cost of construction and installation. A good mechanical equipment ratio is about 10-18%. This indicator is calculated by the formula [4]:

$$M_w = \frac{MMC \cdot 100}{C_{est}}. \tag{12}$$

Determining the composition of the brigade is an important element in the organization of the construction process. The overall efficiency of the work depends on the choice of the brigade elements.

The shift cost of brigade operation is a sum of the products of the cost of one hour of equipment operation, the number of required units, and the work duration per shift [4, 5]:

Indicator	*Repair method*

	Traditional method	*Existing method from submittals*	*Cold in-place recycling*
Strength characteristics of the finished roadway structure, MPa	*291*	*299*	*399**
Strength reserve factor	*1.19*	*1.16*	*1.6**
Direct costs, RUB, in thousands: *– full road length* *– per 1 km* *– per 1000 m²*	 *73 823.62* *10 851.63* *1 808.61*	 *89 724.77* *13 189.00* *2 198.17*	 *65 087.52** *9 806.62** *1 634.44**
Materials, RUB, in thousands	*64 394.39*	*83 213.87*	*53 600.14**
Operation of machines and mechanisms, RUB, in thousands	*9 109.26*	*6 174.57**	*11 133.08*
Wage fund, RUB, in thousands	*733.68**	*658.97*	*732.58*
Overhead expenses, RUB, in thousands	*1 013.80*	*913.12**	*1 037.48*
Estimated profit, RUB, in thousands	*569.85*	*519.16*	*589.43**
Prime cost, RUB, in thousands	*74 837.42*	*90 637.89*	*66 125**
Estimated cost, RUB, in thousands	*75 407.27*	*91 157.05*	*66 714.43**
Profitability, %	*7.5*	*5.7*	*8.8**
Material intensity, %	*86.0*	*91.8*	*81.1**
Average-weighted worker category	*3.4*	*3.8*	*3.4**
Average number of workers	*21**	*21**	*23*
Specific labor intensity indicator *– K_{Tc}* *– K_{Tv}*	 *0.069* *760.0**	 *0.057** *763.0*	 *0.085* *838.0*
Mechanical equipment ratio, %	*12.2*	*6.8*	*16.8**
Total number of units of equipment in the brigade	*29*	*17*	*16**
Cost of one shift of the brigade operation, RUB, in thousands	*260.36*	*239.99**	*315.56*
Number of technological operations	*39*	*29**	*31*
Technological break, days	*–*	*–*	*7*
Maintenance cost, RUB, in thousands	*1 085.1*	*1 314.2*	*958.8*
Special work conditions	*Road closure and a temporary bypass*	*Traffic on one half of the roadway**	*Traffic on one half of the roadway**
*Note: *– optimal values for different overhaul technologies*			

***Table.** Summary table of technical and economic indicators of methods of overhaul of a road section*

$$C_{sift} = \sum_{i=1}^{j} C^{i}_{mch} \cdot n_i \cdot t_i, \qquad (13)$$

where C^i_{mch} – operation cost of one machine-hour, RUB; n_i – number of operated equipment units; t_i – work duration per shift, hours.

Let us consider the application of the given approach for the selection of technology of overhaul using a section of a highway Tunoshna - Burmakino as an example. This highway is in the Yaroslavl region, technical category IV, 6,803 km long [7].

Let us consider three construction technologies: traditional [8], from submittals [7], and cold in-place recycling [3]. The traditional method of repairs includes disassembling the asphalt concrete surface and the base, installing a new layer of crushed stone base and a two-layer asphalt concrete surface. The technology from the existing submittals includes the milling of the existing road surface, the levelling of the asphalt concrete mixture and the construction of a two-layer asphalt concrete surface. Cold in-place recycling technology includes the recycling of the existing asphalt concrete surface and base layer to produce an asphalt granulated concrete mixture. In this example, let us consider the method of roadway strengthening by cementing [9] with the addition of 3% of CEM I 42,5N grade cement. Based on the experimental studies [10-12] conducted in the laboratory of road facilities of YSTU, we selected the cement quantity and the ratio of asphalt concrete mass to the mass of crushed stone base, which is captured by a cold planer installed on the recycler.

For each technology, the road surface was calculated using PNST 265-2018 [13]. Recommendations of PNST 184-2019 and GOST 58406.2-2020 were taken into account in the development of roadway structure. After that, construction operations were compiled in a list, their scope was determined, construction equipment was selected, process flowcharts were drawn up. Process flowcharts for the traditional method of overhaul and technology from existing submittals were developed with the recommendations of SP 78 [8] taken into account. Then, based on the federal estimate and regulatory framework of 2001 in the 2017 edition with changes No. 4, as well as the base index method with the index of conversion to the current prices for the 1st quarter of

2020, local cost sheets have been composed for each repair method.

The results of calculations are summarized in Table.

Table shows the indices from 1 to 19, which are determined by strength and technological calculations and calculations that follow the formulas above. The contents of indices 20-22 require some clarification.

Cement was chosen as the binder for the cold in-place recycling technology with a mineral binder. Laboratory research has shown that a seven-day technological break is required to set up a recycled base of sufficient strength. During this period, the structural layer will gain initial strength which will not allow the material to collapse under the influence of internal stresses at the strength gain of asphalt granulated concrete and the load of construction equipment. For other methods, no technological breaks are required One of the most important factors is the cost of maintaining the road.

Scheduled and quality road maintenance ensures maximum service life of the roadway, keeping its main technical parameters at the normative level.

The scope of work includes (Recommendations of GOST 33180-2014. Automobile roads of general use. Requirements for summer maintenance level, GOST 33181-2014. Automobile roads of general use. Requirements for winter maintenance level):

1. Work on right-of-way, earth bed, and drainage system:

- *removing debris from the right-of-way, the curb;*
- *cleaning and profiling of roadside ditches;*
- *backfilling and layout of the natural side of the road;*
- *cleaning culverts, drains;*
- *planning of embankments and excavations with damage correction of the reinforced part.*

2. Work on road surface:

- *cleaning up the garbage and dirt on the roadway;*
- *restoring the adherence of the coating;*
- *eliminating deformation and damage to the coating such as potholes, paintwork, cracks;*
- *eliminating the rut;*
- *restoring the transverse profile and evenness of the road.*

3. Work on artificial and protective road structures:

- *cleaning the bridges and sidewalks, spans, staircases from dust and dirt;*
- *fixing culverts, drainage trays;*
- *painting metal structures of spans and supports;*
- *restructuring cracks, deformation joints on the bridge bed.*

4. Work on elements of arrangement of roadways:

- *cleaning and washing road signs, pedestrian, barrier, rope fences;*
- *repainting and restoring the old road markings;*
- *painting the elements of furnishing and arrangement of roadways.*

5. Work on winter maintenance:

- *maintaining permanent snow protection structures;*
- *preparing, installing, relocating and cleaning temporary snow protection structures;*
- *mechanized snow clearing with snow removal;*
- *fighting against winter slipperiness, distributing anti-icing materials;*
- *cleaning culverts in spring.*

According to Supplement N 14 [5], annual road maintenance costs range from 0,68 to 1,5% of the cost of road surface.

In this example, only one road is considered, and it is repaired by different methods, therefore, the elements of arrangement, artificial structures, and the earth bed do not change, and respectively, the cost of maintaining these elements will be equal.

Based on this information, it is possible to compare the annual maintenance costs of a road after its overhaul by calculating the annual maintenance cost using the formula [4]:

$$C_{maint} = \frac{C_{pr} \cdot K_{yr}}{100}, \tag{14}$$

where K_{yr} – annual maintenance costs, %.

According to Supplement N 14 [5], the technical category IV road with an asphalt concrete pavement K_{yr} will be 1,45%. Respectively, we will calculate the cost of annual road maintenance after major repairs by each method:

$$C^{TR}_{maint} = \frac{74{,}837.42 \cdot 1.45}{100} = 1{,}085.1 \text{ thousand rubles;}$$
$$C^{Subm}_{maint} = \frac{90{,}637.89 \cdot 1.45}{100} = 1{,}314.2 \text{ thousand rubles;}$$
$$C^{CIR}_{maint} = \frac{66{,}125 \cdot 1.45}{100} = 958{,}8 \text{ thousand rubles;}$$

As a result, it will turn out that the cost of maintaining a section of the road repaired using the technology from submittals is 37% more expensive than the cold in-place recycling method and 21% more expensive than the traditional method, which indicates the lack of efficiency of this repair method. The cold in-place regeneration method wins the traditional method by about 13%.

An important factor in the economic efficiency of a roadway is the work conditions. When performing work using the traditional method, it is necessary to close a road section or organize temporary roads, which is an additional cost of large volumes of imported material (sand, sandy soil), work on the embankment of a temporary road, remove them after the main work and then restore the roadside. All this entails additional costs. If the road is fully closed, it affects the economic component of the area, as the efficiency of transport links decreases.

In case of overhaul using technology from existing submittals and cold in-place recycling, the repair can be done in lanes. Yes, it reduces the economic efficiency of the road, as the capacity of the road becomes reduced, but if the contractor works properly, this reduction is minimal.

The structure of the roadway repaired by cold in-place recycling has greater strength, the elasticity modulo of the resulting structure is almost 35% higher than other methods. The strength reserve factor shows that such a design has a large safety margin (60%) in strength compared to other design solutions. This will ensure the required overhaul time.

In terms of direct costs and prime costs of construction, cold in-place recycling technology is also the most profitable. The cost of this method is 13% and 37% lower than the cost of the traditional method and the method chosen in the existing submittals respectively. For the customer's services, these figures are a great help in case of any doubts about the selection of the overhaul method.

Indices of profitability also show cold in-place recycling as the most profitable repair option, allowing to receive the planned profit at a rate of 8.8% from cost of construction; it is 14% higher than traditional repair and 54% higher than a method from the existing submittals.

Materials make up a huge share of direct costs when working with the method from submittals. In this type of repair, there is an increased consumption of asphalt concrete mixtures, which have the highest price of all materials used in the construction and repair of roadways. This method, as well as the traditional method, has increased volumes of imported materials, as old materials are not used, as opposed to cold in-place recycling.

The traditional method of repair requires a large amount of removal of old material and delivery of new inert materials, which leads to the need to use a large number of dump trucks. According to this indicator, cold in-place recycling also saves on technology, as all work is done on site without unnecessary transportation costs.

A large part of the budget is spent on road maintenance. These savings will make it possible to direct the remaining funds to the running repair of another part of the road. The cold in-place recycling method saves money on road maintenance.

Closure of roads is a big problem that occurs during major repairs. The construction of temporary roads is not always possible due to the impossibility of placing these roads within the right-of-way, as well as in terms of material costs and work on construction and liquidation of these roads, and repair of the roadside. In this case, the lane-by-lane work is a huge advantage. Both the existing method from the submittals and the cold in-place recycling have these advantages.

CONCLUSION

When choosing technologies for road overhaul, it is advisable to select technologies that will strengthen the structure of the road surface. For a reasonable choice of technology and road equipment, it is reasonable to perform a set of preliminary and final studies and calculations. The performed technical and economic analysis has shown that cold in-place recycling is undoubtedly promising when used in the overhaul of road surface.

REFERENCES

1. ***Gornaev N.A.*** *Technology of cold regeneration of asphalt concrete. Nauka I tekhnika v dorozhnoj otrasli. 2005. N 3. P. 43-44. (in Russian).*
2. ***Evstegneeva V.N., Stepanets V.G.*** *Repair and reconstruction of asphalt-concrete pavements by cold in-place recycling. Molodoi uchenyj. 2017. N. 38. P. 21-28. (in Russian).*
3. *Cold in-place recycling technology. Wirtgen manual. 2012. 370 p.*
4. ***Gavrish V.V.*** *The economy of road construction. Part 1. Krasnoyarsk: Sib. fed. un-t. 2013. 478 p. (in Russian).*
5. ***Avseenko A.A., Kikava N.P.*** *Methodological guidelines for the economic justification of decisions in road design. M.: MADI. 2011. 59 p. (in Russian).*
6. *MDS 81-35.2004. Methodology to determine the cost of construction products in the Russian Federation. M: Gosstroy Rossii. 2004. 61 p. (in Russian).*
7. *Repair of the Tunoshna-Burmakino roadway section in Yaroslavl Municipal District, Yaroslavl Region. The project. URL: https://zakupki.gov.ru/epz/order/notice/ea44/view/documents.html?regNumber=0171200001920000006&backUrl=1ee573f9-7006-4e97-b512-819d9b08e330 (in Russian).*
8. *SP 78.13330.2012. Automobile roads. M: Standardinform. 2012. 99 p. (in Russian).*
9. ***Dudin V.M., Ignat'yev A.A.*** *Soil stabilization in highway construction: monogr. Yaroslavl: YSTU Publishing House. 2016. 165 p. (in Russian).*
10. ***Artemyeva L.A., Dudin V.M.*** *Selection of mixture composition at cold in-place recycling. Sb. mat. 73 vseros. nauchn.-tekhn. konf. stud., magistr. i aspir. vvyssh. uchebn. zaved. s mezhd. uch. Yaroslavl. 2020. P. 632-637. (in Russian).*
11. ***Rytyakov M.A., Verbin V.Yu., Dudin V.M.*** *Volumetric design methods based on the selection of particle size distribution of the mixture during cold in-place recycling. Sb. mat. 72 vseros. nauch.-tekhn. konf. stud., magistr. i aspir. vyssh. uchebn. zaved. s mezhd. uch. Yaroslavl. 2020. P. 660-665. (in Russian).*
12. ***Krivchikov Yu.I., Dudin V.M.*** *Influence of the mineral binder on the strength of asphalt granulated concrete in cold in-place recycling. Matematika i estestvennye nauki. Teoriya i praktika. Sci. works compilation. Yaroslavl: YSTU Publ. House. 2020. V. 15. P. 164-168. (in Russian).*
13. *PNST 265-2018. Automobile roads of general use. Flexible pavement design. M.: Standartinform. 2018. 79 p. (in Russian).*

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