

Economic efficiency growth of agricultural roads' construction in the region

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Abstract — The paper is devoted to the technical and economic justification of the automobile road construction of low intensity roads. The design choice offered for comparison presents the construction of roadway surfacing in which the role of the broken stone underlayer is carried out by over-compacted fine soil. In the Volgograd region fine loamy soils (sandy soils, clayly soils) occupy a considerable part of the surface. In this respect the technical and economic justification of the construction of automobile roads for agriculture with the use of over consolidated fine soils of such type in the road construction has a significant social and economic importance. The offered technique of technical and economic justification is founded on the calculation of an actual durability of road constructions using the forecasting of lineal evenness change. The technique of forecasting is based on the improvement of a well known linear multi factor model of the international roughness index (IRI) which forecasts changes in dependence of traffic density and initial state of roadway surfacing due to the inclusion of additional factors into the model. It is suggested to use as factors the data about the qualitative content of traffic load, specifically about the level of impact of heavy cargo vehicles, weather and climate effect on the surfacing and on the quality of automobile road maintenance. The experimental data were subjected to multivariate regression analysis in Excel. In compliance with the data of the test of a trial pavement section constructed in the Bykovskiy district of the Volgograd region, the authors

calculated the economic efficiency of the automobile road construction of the offered construction type. The conclusion is drawn on the technical and economic expediency of use of the suggested design solution.

Keywords — forecasting of road surfacing evenness, automobile roads, international roughness index (IRI), multivariate regression analysis, over-compacted soil, assessment of economic efficiency of design solutions.

I. INTRODUCTION

According to a number of researchers [1] one of significant reasons for the decline in the efficiency of the regional agro-industrial complex is quite noticeable losses during the transportation of agricultural products [2]. This situation is caused by quite specific requirements for the roads for the agro-industrial complex [3]. On the one hand the agricultural roads should provide the possibility of movement of vehicles of various types with the minimum allowable speed in different periods of the year. On the other hand their construction and maintenance should not require significant costs. In this regard the issues connected with the reduction in the cost of construction and operation of the lowest categories of roads when they ensure stable consumer properties [4]

acquire significant relevance. The provision of the agrarian regions of our country with the technology of construction of cheap and at the same time high-quality roads with low traffic intensity is one of the main conditions for the development of the regional economy [5].

It is known that in a large part of the territory of Russia there are no traditional road-building materials such as crushed stone and coarse sand. Quality bitumen also often has to be delivered from the regions with a developed petrochemical industry. At the same time the current situation is characterized by a constant increase in the estimated cost of basic materials used in road construction as well as an increase in transportation tariffs. All this makes it important to use soil concretes with various kinds of organic and mineral additives ensuring a reliable construction of road and structures' foundations [6].

The domestic regulatory classification of soil stabilizers is published in the source [7]. Obviously the stabilization of soils in Russia is carried out mainly by organic and mineral binders. It is also made in an integrated manner. An overview of the main methods of soil stabilization used abroad and in particular the use of lime, cement, chemical components, fly ashes, organic ashes, bitumen, thermal and electrical effects, as well as the stabilization with geotextiles and fabrics is described in the following scientific work [8].

In order to obtain the improved soil properties, a number of domestic experiments with the skeleton composition of the soil are known when there is an addition of sand shifting, crushed stone [9] or fly ash from thermal power plants [10].

Similar works carried out by foreign researchers in particular dealing with the stabilization of clay soils of low-intensity roads with ash from burning coal are described in the following scientific paper [13]. A significant economic effect from the use of such design solutions is obvious. An integrated soil stabilization for road construction with ash, lime and cement is published in the following paper [14]. It is established that for road construction it is recommended to use in the construction material 7% cement, 5% lime and 18% ash.

Separately, a very promising direction of research which should be noted associated with the strengthening of soil foundations based on the use of cohesive soils with a compaction factor of 1.05 and higher. It is known that clay soils cause significant problems in road construction [13]. The use of repacking technology can significantly reduce the cost of building and maintaining the road pavement due to an obstacle to a capillary ascension of water [14]. The study of the mechanism of formation of structural bonds in an over compacted soil of the foundation allows predicting the strength characteristics of the pavement design and energy costs [15].

In accordance with the source [16] in order to avoid the soil contamination, the use of organic and inorganic binders in road pavement structures of lower agricultural categories is significantly limited. It was found that the most important aspect of the life cycle of a road is the stability of the system "working layer of the roadbed - road pavement". The way out is the use of clay soils which predominate in many regions of

Russia and whose stabilization is achieved by using the wet overconsolidation technology at an optimum humidity [17]. For the purpose of practical application in the road construction of the technology patented by the authors, it is necessary to carry out a technical and economic study of the proposed solutions in comparison with traditionally applied ones. One of the aspects of scientific interest in the implementation of the feasibility study is the prediction of the working life of pavements of the suggested design.

Thus the purpose of this scientific work is a technical and economic study of the use of technology for the construction of highways of lower categories for agricultural purposes.

II. MATERIALS AND METHODS (MODEL)

The course of research by the authors was divided into two parts.

In the first part the search for an optimal working life of roads of the fifth technical category was carried out. They present a compacted clay soil reinforced with straw fiber and in accordance with the source [18], it is followed by an economic evaluation.

In the second part of research the authors assessed the economic effect from the construction of highways of the fourth technical category with a surfacing constructed on the basis of the over consolidated clay soil.

In order to provide a technical and economic study of various design options, it is necessary to have the costs and life cycles of the projects being compared. Having the information about the design of pavement, the design cost is easy to determine using the appropriate method of estimated pricing in construction. The calculation of project life cycles in relation to pavement structures is based on the determination of the actual service life of roads. Thus, the technical and economic justification of design solutions is reduced to the task of forecasting the actual service life of the structures of highways of the fourth and fifth technical categories.

At the first stage of research the authors used the well-known three-factor model [19]. As a result of statistical data processing in Deductor Studio Software, the following dependence was obtained:

$$IRI = 1,5 + 0,0096 \cdot IRI_0 + 7,4 \cdot 10^{-4} \cdot N + 0,552 \cdot t \quad (1)$$

IRI_0 – the value of the index of evenness according to the survey data for the previous period m / km ; N – reduced traffic flow cars/day; t – number of years since the last repair of the surfacing.

At the second stage of research, the traditional multifactor regression model for the forecasting of the surfacing evenness index was expanded by including and processing the additional variables. The authors suggested including an integral indicator of the impact of climatic factors on road evenness, percentage of heavy transport and the level of coverage as additional variables.

The integral indicator of the effect of a negative weather and climate impact on the change in the lineal evenness of the road surfacing estimated by the IRI index, was calculated using the well-known algorithm of the hierarchy analysis method. The data on variable (leaves) was taken on the basis of the information provided in the source [20].

It was stated that heavy freight transport has a significant adverse effect on the road. According to the research [21], a single passage of a loaded truck means harming roads, comparable to the passage of several thousand passenger cars. Thus, we can conclude that when modeling the effect of the external environment on the evenness of the surfacing, it is necessary to take into account the effect of the mobile load.

The works on composition have a positive control effect on the lineal evenness of the surfacing. In accordance with regulatory documents, the composition of road surfacing is differentiated into three levels, which are included in the model as discrete values: 0 is acceptable, 1 is medium, 2 is high.

In accordance with the sequence of studies described in the paper [22], the authors constructed five-factor models forecasting changes in the lineal flatness of surfacing assessed by the International Roughness Index (IRI) on the basis of correlation and regression analysis.

For low-intensity roads and a simplified pavement construction arranged on a over-compacted soil the index is:

$$IRI = 2,68 + 0,0065 \cdot IRI_0 + 7,1 \cdot 10^{-4} \cdot N + 0,552 \cdot t + 0,0367 \cdot K + 0,025 \cdot M + 7,5 \cdot 10^{-4} \cdot Tr \quad (2)$$

For roads of the fifth technical category with the pavement design made of over-compacted soil and straw fiber the index is:

$$IRI = 1,69 + 0,0049 \cdot IRI_0 + 7,5 \cdot 10^{-4} \cdot N + 0,742 \cdot t + 0,0681 \cdot K + 0,179 \cdot M + 6,1 \cdot 10^{-4} \cdot Tr \quad (3)$$

K – normalized level of exposure to external weather and climatic factors, unit fraction; M – maintenance of automobile surfacing (values are 0, 1, 2); Tr – heavy transport share, % .

III. RESULTS AND DISCUSSION

The design solutions for the construction of agricultural roads with low intensity which are traditionally used in the Volgograd are 4th or 5th technical categories with enhanced light-duty or intermediate road surfacing.

In accordance with the forecast of evenness reduction, the experimental section of the motorway of the fourth technical category with a surfacing arranged on the basis of over-compacted soil will require an overhaul after five years of operation. The service life of the standard design of a road will make up nine years. These data are quite consistent with the actual ones which were obtained during the diagnostics (Fig. 1).

Despite almost half the serviceable life, the proposed pavement design is much cheaper than the traditional one which provides a significant economic effect as it will be discussed later.

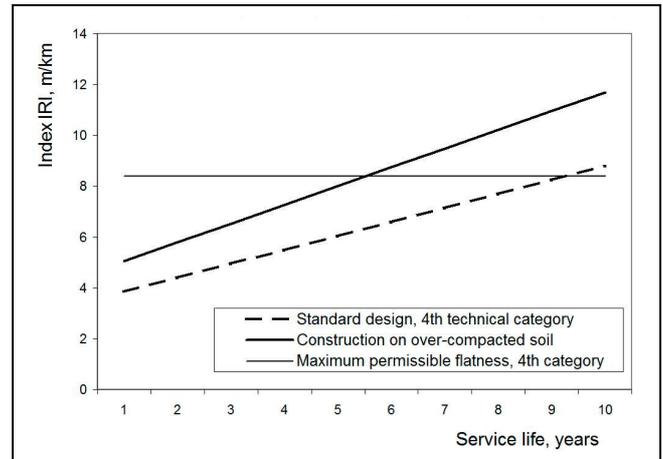


Fig. 1. Assessment of service life of the road of the 4th technical category with the surfacing made by a traditional way on an over-compacted soil

In accordance with the forecast of evenness reduction, the experimental section of the fifth-category technical road with a surfacing made from a complex material (an over-compacted soil with straw fiber) will require an overhaul after four years of operation. The service life of the standard design was less and amounted to three years. It should be noted that the cost of the road surfacing construction in a standard way is somewhat cheaper than in the variant that was proposed. The economic effect here is based on the growth of the service life of the offered construction (Fig. 2).

In the final part of the work, the authors evaluated the economic efficiency of the implementation of the proposed design solutions for road surfacing structures.

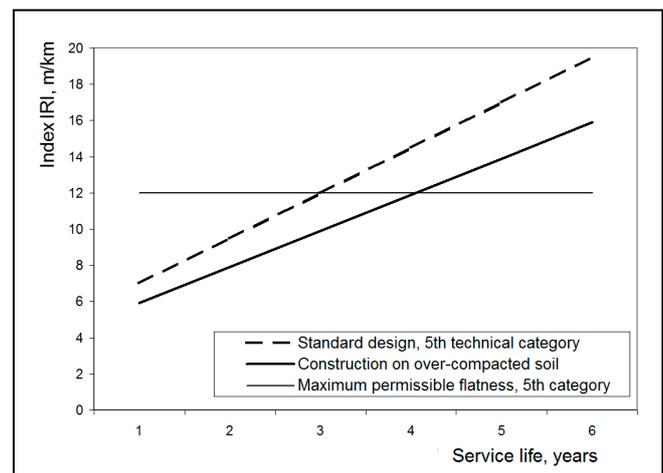


Fig. 2. Assessment of service life of the road of the 5th technical category with a surfacing constructed in a traditional way and form the over-compacted soil with straw fiber

Since the considered design options are characterized by different periods of service which do not coincide in time and the current costs are variable over time, the sum of the reduced costs for the entire service life of the project was calculated in accordance with the formula presented in the source [23]:

$$P_{np} = K_{np} \cdot E_n \sum_1^{t_c} \frac{1}{(1+E_n)^t} + \sum_1^{t_c} \frac{C_t}{(1+E_n)^t} \quad (4)$$

where K_{np} – one time costs reduced to one base point of time for this variant; E_n - standard coefficient of comparative efficiency of capital investments; C_t - current costs for this option in year t ; (t_c - term of comparison of options in years; t – number of years between the base year and the year when the expenditures were made.

Non recurrent expenditures for the options for design solutions in road surfacing were calculated on the basis of estimates and financial calculations of resource methods according to the Regional Center for Pricing in the 3rd quarter of 2018 per 1 km of the road. The term of comparison of discounted costs and effects was taken 9 years. According to the option the costs for over-compacted soil are assumed to be renewable after 4 years of operation. This was due to the requirements of the ODN 218.0.006-2002 methodology. In the regulation the need to maintain the road surfacing in a relatively good condition is mentioned under the condition of ensuring the maximum operational efficiency of the work while optimally minimizing the cost of the work. The discount rate was taken at 12%.

In the result of calculations it was established that in the nine-year comparison period the relative economic efficiency of the road surfacing use constructed on the basis of over-compacted soil (estimated predicted service life is 4 years) relative to the traditionally accepted classical variant (estimated predicted service life is 9 years) is 15% or 3 million rubles per specific kilometer of the road.

The economic effect of the construction of automobile roads of the fifth technical category on the basis of over-compacted soil and straw fiber in comparison with traditional structures makes up 11% or 1.2 million rubles per specific kilometer of the road.

With an increase in the period of comparison of discounted costs the effect tends to increase.

IV. CONCLUSION

A technical and economic assessment of the use of technology of the construction of automobile roads of the lowest categories was carried out. This technology significantly reduces the cost of agricultural infrastructure construction. The proposed methodology is based on the forecasting of the actual service life of road surfacing, and the results of its use contribute to the effectiveness of the development of the regional economy, in the following way:

A. A multifactor correlation model for the forecasting the lineal evenness of the road surfacing is presented to determine the actual service life of the fourth and fifth technical categories of agricultural roads, which allow specifying the

service life taking into account the changes in the road structure operating mode (load size, traffic intensity, climate).

B. The economic assessment of the use of technology for the road construction of the fifth technical category of agricultural purpose with the use of the over-compacted clay soil and straw fiber was carried out. The specific economic effect of the construction of roads with a similar pavement design makes up 1.2 million rubles per kilometer, and the relative economic efficiency is 9-11% in comparison with the traditional construction of the base.

C. The assessment of the economic efficiency of construction technology use for roads of lower categories of agricultural purpose on the basis of over-compacted clay soil was carried out. The specific economic effect of road construction with a similar pavement design makes up 3 million rubles per kilometer, and the relative economic efficiency makes up 15% in comparison with the traditional design.

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