Evaluation of the effectiveness of the soil-cement with hydrophobized surface for road construction

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Abstract. The paper presents an assessment of the effectiveness of the use soil-cement with hydrophobized surface by conducting a feasibility study. The work performed theoretical studies and the calculation part. The object of study is a soil-cement with hydrophobized surface at the base in road foundation of the road. The subject of the study is the economic efficiency of the use of modified soil-cement. Theoretical studies are based on the choice of methodology for assessing the economic efficiency of the use of this material with its subsequent description. The calculation part includes determining the benefits of road users, current and one-time costs from the use of various constructions of pavement for the billing period. The result of the calculations is a graph of the dependence of the economic efficiency of various structures on traffic intensity. The use of soil-cement with hydrophobized surface will reduce economic costs in the construction of roads, increase the speed and quality of work, increase the overhaul time of roads of federal and regional significance.

1. Introduction
In the process of operating roads with a discrete base material, a degree of rutting is developing at a rapid pace with exceeding the maximum permissible standards. One of the solutions of this problem is the build of a monolithic road foundation from fortified local soil (soil-cement). The idea of using local soils in road construction was put forward in the 30s of the last century by professors M.M. Filatov, P.D. Zemyatchensky, V.V. Okhotin, P.A. Rebinde. Later, scientists thought about improving the initial properties of various soils by mixing with various binders. A significant contribution to soil strengthening was made by Professor V.M. Bezruk, N.N. Ivanov, A.K. Birulya, L.N. Yastrebova and their many students [1-3]. Subsequently, major studies in the field of soil strengthening with various materials were carried out by V.M. Olkhovikov, E.M. Dobrov, V.M. Mogilevich, V.S. Prokopets, V.V. Siroyuk, A.N. Shuvaev, A.V. Linzer, Yu.N. Bogomolov. As foreign experts in the matter of soil strengthening, J.M. Gelst, J.P. Giroud, K. Rajagopal, N.R. Krishnaswamy, G.M. Latha, B. Indraratna, V. Ramachandran.

Currently, classic soil-cement requires modernization due to new requirements for materials and the expansion of target functions. For this reason, soil-cement is modified with various additives of volumetric and surface effects (stabilizers, polymer additives) [4-13].

According to the analysis of federal target programs for the development of the transport system of Russia, the profitability of the use of soil-cement in the construction of road pavement over the past 5 years has increased 3 times. This is due to an increase in the maximum permissible traffic loads, the need to introduce new materials in the construction of road pavement, and an increase in the overhaul time of federal and regional automobile roads.
The purpose of the work is to assess the effectiveness of the use of soil-cement with hydrophobized surface for road purposes by conducting a feasibility study.

2. Objects and methods of research
To assess the economic efficiency of the use of soil-cement with hydrophobized surface, there are several methods based on the calculation of the index of profitability, internal rate of return, and integral costs. The disadvantage of these methods is that they take into account only direct economic costs. In the work, the calculation of the integral effect was adopted, which allows us to approach the assessment comprehensively and take into account not only direct economic costs, but also the benefits of road users from eliminating defects when implementing specific solutions [14].

Integral Effect:

\[
E_{int} = \sum_{t=1}^{T} \frac{(R_t - Z_t)}{(1+T)^t} - \sum_{t=1}^{T} \frac{K_t}{(1+T)^t}
\]

Rt – benefits of road users from the use of various constructions for the calculation year t, rubles/km;
Zt – current expenses in year t, rubles;
Kt – one-time expenses in the year t, rubles;
T – the moment of the end of the calculated period, year.

If the integral effect Eint is positive, then the implementation of measures is effective. If Eint is negative, the considered option is inefficient and should not be realized.

The calculation of the integral effect is based on a comparison of the basic and proposed (tested) construction of the road pavement (figure 1). In April 2017, in the Yurginsky district of the Tyumen region, a full-scale experiment was carried out with a modified soil-cement foundation [15]. The survey results are given in scientific and technical reports. At the foundation of the basic construction, discrete material is adopted, the proposed construction contains a monolithic foundation.

![Figure 1. Basic and proposed construction of the road pavement.](image)

The length of the road with a lighter type of pavement is 1 km in Tyumen [16]. Traffic intensity is 2000 cars / day. According to the condition of the location of the material base, the distance of transportation of materials by road is 10 km. Due to the lack of stone materials in the region, the transportation of gravel was accepted by rail from the Asbest (Sverdlovsk region) and amounts to 306 km. Tyumen belongs to the 1st construction zone [17].

3. Theoretical research
Initially, it was necessary to determine the benefits of road users from using various constructions for the calculation year:

\[ R_t = \frac{365 \times N \times S \times L}{v_0} = \frac{365 \times N \times S \times L}{v}, \]  

(2)

N – average annual daily traffic intensity on the road in the calculation period, cars/day;
S – cost of transportation in road conditions at the current price level, rubles/cars-km;
L – length of the road, km;
\( v_0, v \) - average speeds of traffic flow before and after the measures, km/h.

4. Calculation research

In the calculations, the speed was adopted when driving on a road with a soil, gravel and soil-cement foundation (60, 80 and 100 km/h respectively). According to the results of the first year of operation of the road, the S and Rt parameters amounted to 281.89 rubles / cars-km and 857415.42 rubles / km for the basic construction and 244.69 rubles / cars-km and 1190824 rubles / km for the proposed construction. When calculating Rt for the 2nd year and another one should take into account the change in the average annual daily traffic intensity taking into account the change in the total intensity \( q_e = 1.03 \).

The end of the calculation period is accepted as the estimated work period of the road pavement and amounted to 11 for the basic and 13 years for the proposed. These periods are justified by the physic and mechanical characteristics of structural road materials and climatic zone.

At the next stage, we determined the current expenses \( Z_t \), which include the maintenance of the road in the spring, summer, autumn and winter periods. In this type of cost, it was necessary to take into account preventive maintenance to eliminate deformations and damage to the road pavement [18, 19]. Of the existing types of defects, it seems possible to calculate and predict only the process of rutting. To determine the quality of work types for each construction, the maximum rut depth was calculated with 85% coverage when forecasting for the 12th and 15th years.

Exceeding the acceptable rut values leads to an increase in the road accident rate, a decrease in the estimated vehicle speeds, as well as economic losses for users in case of untimely delivery of goods. Repair work is assigned at a rut depth of at least 50 mm. To ensure the estimated speed of vehicles on the site, the maximum permissible rut depth is 20 mm [20]. The values of the estimated maximum forecasted and maximum permissible rut with reference to the work period are presented in the form of a graphical dependence (Figure 2).

![Figure 2](https://example.com/figure2.png)

**Figure 2.** Dependence of the overhaul period on the rut depth. Where: 1 - basic construction; 2 - proposed construction.
The graph shows that the work to eliminate the ruts is characteristic only for the basic construction in 11th year of work. For the proposed construction, the overhaul period is 17 years, which goes beyond the calculation period and is due to the presence of a strength monolithic foundation with a high hydrophobicity index.

At the final stage, we calculated the one-time expenses $K_t$, combining the expenses of construction and installation works and the necessary road construction materials, taking into account their transportation to the facility.

The calculation of current and one-time expenses was carried out in the «GrandSmeta 7.0» in the form of local estimates (basic price level in 2001 year). The transition to the current level of territorial estimated prices was carried out using the maximum allowable indices of maintenance of the expenses of construction and installation works.

Based on the calculation results, the economic efficiency of the use of structures was formed (table 1).

**Table 1.** The economic efficiency the use of various constructions (traffic intensity is 2000 cars/day).

| Year | Benefits of road users from the use of various constructions $R_t$, rubles/km | Current expenses $Z_t$, rubles | One-time expenses $K_t$, rubles | Benefits of road users from the use of various constructions $R_t$, rubles/km | Current expenses $Z_t$, rubles | One-time expenses $K_t$, rubles |
|------|-------------------------------------------------|--------------------------------|-----------------------------|-------------------------------------------------|--------------------------------|-----------------------------|
| 0    | -                                               | 13491261.38                   | -                           | 9727521.44                                       | -                               | -                           |
| 1    | 857415.42                                       | 150630.86                     | 1190824.67                   | 150630.86                                       | -                               | -                           |
| 2    | 883137.88                                       | 150630.86                     | 1226549.41                   | 150630.86                                       | -                               | -                           |
| 3    | 909632.02                                       | 150630.86                     | 1263345.89                   | 150630.86                                       | -                               | -                           |
| 4    | 936920.98                                       | 150630.86                     | 1301246.27                   | 150630.86                                       | -                               | -                           |
| 5    | 965028.61                                       | 150630.86                     | 1340283.65                   | 150630.86                                       | -                               | -                           |
| 6    | 993979.46                                       | 150630.86                     | 1380492.16                   | 150630.86                                       | -                               | -                           |
| 7    | 1023798.85                                      | 150630.86                     | 1421906.93                   | 150630.86                                       | -                               | -                           |
| 8    | 1054512.81                                      | 150630.86                     | 1464564.14                   | 150630.86                                       | -                               | -                           |
| 9    | 1086148.20                                      | 150630.86                     | 1508501.06                   | 150630.86                                       | -                               | -                           |
| 10   | 1118732.64                                      | 150630.86                     | 1553756.09                   | 150630.86                                       | -                               | -                           |
| 11   | 1152294.62                                      | 542176.16                     | 1600368.77                   | 150630.86                                       | -                               | -                           |
| 12   | -                                               | -                              | 1648379.84                   | 150630.86                                       | -                               | -                           |
| 13   | -                                               | -                              | 1697831.23                   | 150630.86                                       | -                               | -                           |
| Total| 10981601.48                                     | 2048484.76                    | 13491261.38                 | 18598050.10                                     | 1958201.18                     | 9727521.44                  |
| Eint | -379845.39 rubles                               | 576027.29 rubles              |                             |                                                 |                                 | 576027.29 rubles            |

According to the calculation results, the value of the integral effect for the basic construction, taking into account the calculation period $T = 11$ years, is negative (-379845.39 rubles), which in turn indicates the inefficiency and inappropriateness of using this construction. For the proposed construction for the 13-year calculation period, the integral effect is 576027.29 rubles and its implementation is effective.

To analyze the changes in the rut depth and the value of the integral effect, we performed additional calculations at a traffic flow of 1000 and 3000 auto / day. The calculation results are presented in table 2 and figure 3.
Table 2. Dynamics of changes in rut depth.

| Construction       | Calculation year | Maximum rut depth with 85% coverage, mm for traffic intensity, cars/day |
|--------------------|------------------|------------------------------------------------------------------------|
|                    | 1000             | 2000                      | 3000                      |
| Basic (T=11 years) | 5                | 8.4                       | 9.8                       | 11.5                      |
|                    | 10               | 16.3                      | 19.7                      | 21.6                      |
|                    | 12               | 18.1                      | 22.3                      | 24.5                      |
| Proposed (T=13 years) | 5               | 7.4                       | 8.5                       | 9.4                       |
|                    | 10               | 13.0                      | 15.6                      | 17.2                      |
|                    | 15               | 17.2                      | 19.5                      | 22.1                      |

The value of the maximum permissible rut depth is characteristic at a traffic intensity of 3000 cars/day and is for:
- the basic construction - 19.58 mm (in 9 year of operation of the road).
- the proposed construction 19.16 mm per (12 year of operation of the road).

Figure 3. Dependence of economic efficiency on traffic intensity. Where: 1 - basic construction; 2 - proposed construction.

The graph shows that for road with a lighter type of pavement, the proposed construction is economically effective at an intensity interval from 1300 to 3000 cars/day.

5. Conclusion
The application of the proposed construction with modified soil-cement at the foundation of the road construction in comparison with the basic construction will allow:
- increasing the benefits of road users due to the timely delivery of goods by 69.35%;
- extending the overhaul period for federal and regional roads by 5-8 years;
- reducing one-time and current economic expenses during the construction of the road by 1.5-2 times due to the use of local soils;
- achieving a positive value of the integral effect with a traffic intensity of 1300 cars/day.

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