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# Seal the top layer of pavement

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**Abstract.** The purpose of the study is to improve the quality of the surface course compaction by optimizing the asphalt rollers utilization.

The proposed improvement is aimed at reducing the number of the asphalt roller passes when compacting the top dressing, depending on the types of compaction used, the thickness of the compacted layer and the type of the road topping.

The practicing of compaction methods proposed in this article in the road and construction industry is target-specific to enhance the quality of compaction of the top dressing of the stone mastic asphalt (SMA) and to optimize the number of passes of the compact equipment, depending on the types of compaction to be used.

The vibration compaction was proved to be the most effective method to compact all three grades of SMA.

For all three cases, six passes were proved to be adequate to ensure the standard values of  $K_v$  in the mode of vibration compaction.

The length of compaction process reduces as the number of passes is reduced down to six times. This results in saving of up to 20 % in depreciation costs when operating the rollers.

**Keywords:** compaction, road surface, asphalt compactor, number of passes, optimization, strength.

## 1 Introduction

Road surface compaction plays an important role in road engineering, along with base preparation and top dressing bitumen-concrete mix design [1-5]. Many Russian and foreign researchers are exploring qualitative compaction of the road base and hard covering [6-10].

Requirements for the strength and evenness of hard road surfaces tend to grow constantly. At the same time, the requirements for road base compaction are also increasing. Road base deformations caused by its instability and under-compaction take a lot of time, subsequently becoming one of the causes of hard top surface deformations that leads to its destruction.

Under-compaction of the black top surface is another significant reason for its destruction. Studies also revealed direct relationship between the surface evenness and the density of its compaction [8, 11-15].

Compaction of bitumen-concrete mix is the final and most important stage of road surface compaction, since the achieved degree of compaction shall provide the necessary strength and stability of the total road structure against operational and climate factors [7].

It is known that under-compacted bitumen-concrete mix leads to such damage as wheel tracking, flaking, cracks, potholes, and decreased unevenness [2].

There are various ways to reduce the appearance of the above road surface damage, namely:

- more accurate consideration of climatic and region conditions in design;
- detailed ordnance survey;
- using the best technologies available when levelling;
- attracting highly qualified specialists to the work sites;
- high-quality and well-minded selection of the composition of the road base material;
- determination of the aimed thickness and composition of the hard surface regarding climatic and region conditions.



As experience and results of road construction in Russian Federation, particularly in the Republic of Tatarstan, show that one of the most effective way to minimize damage of the top dressing is to use stone mastic asphalt (SMA) for top surfacing.

Since SMA is a relatively new material for surface course covering in the Russian Federation and its physical and mechanical properties are insufficiently explored, various in-depth studies of SMA mix features have been conducted in recent decades [2, 8, 16-20].

In recent years road construction companies in the Republic of Tatarstan have chosen SMA as the main material for surface course covering. The upper surfaces of the Tatarstan section of M7 Federal highway Moscow-Chelyabinsk between the cities of Kazan and Naberezhnye Chelny of 220 km, as well as the central streets of Kazan with the highest traffic flow were covered with this mix. SMA-20 and SMA-15 were mainly used in the Federal highway, and SMA-15 and SMA-10 – in the city roads.

Monitoring of the roads state has shown high performance of the used SMA mixes regarding occurrence of top dressing destruction and almost no wheel tracking.

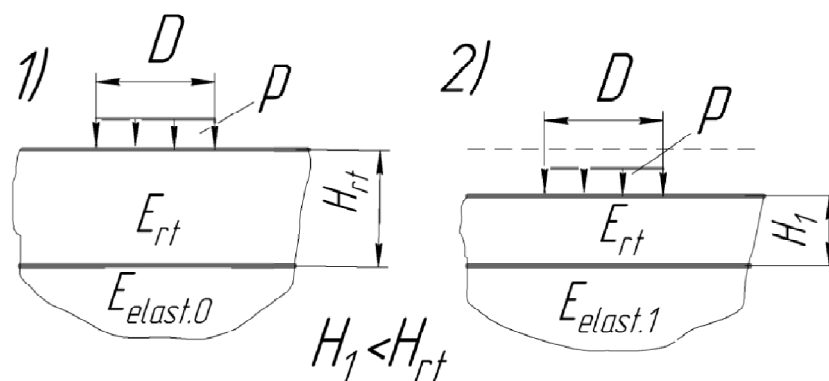
The wide use of SMA as a road surface coating material requires continuous research of its compaction as the key factor in ensuring high performance of the road surface.

Therefore, the operation of road equipment during SMA compaction will be optimized.

## 2 Materials and methods

The goal is to assess the economic effect of the change in the rated degree of compaction of the road base. Since the strength and deformative properties of the ground increase as its density increases, equivalent pavements should be compared. To do this, the equivalent module of elasticity ( $E_{elast.}$ ) is calculated of the initial version of the road structure (road topping + earth work), the thickness of the road topping for other options is calculated by the value ( $E_{elast.}$ ). The sub-grade within the active zone is considered.

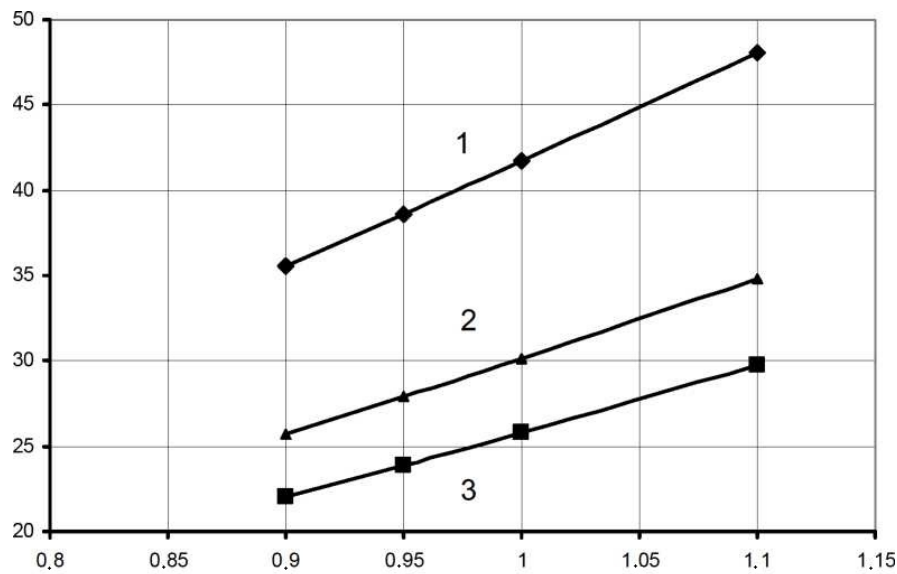
Calculations are made in compliance with the standard method of ODN 218.046-01 (Industry Road Codes), including parameters of the standard vehicle, road surface and earth work soil. The design diagram is shown in Figure 1. The road topping with the soil compaction to  $K_{comp.} = 0.90$  is taken as the basic one. If another degree of compaction is taken as the basis, it will not affect the study results. The calculation results is shown in Table 1. It is assumed that the elastic modulus of the road topping material  $E_{rt} = 300$  MPa (as per ODN 218.046-01).



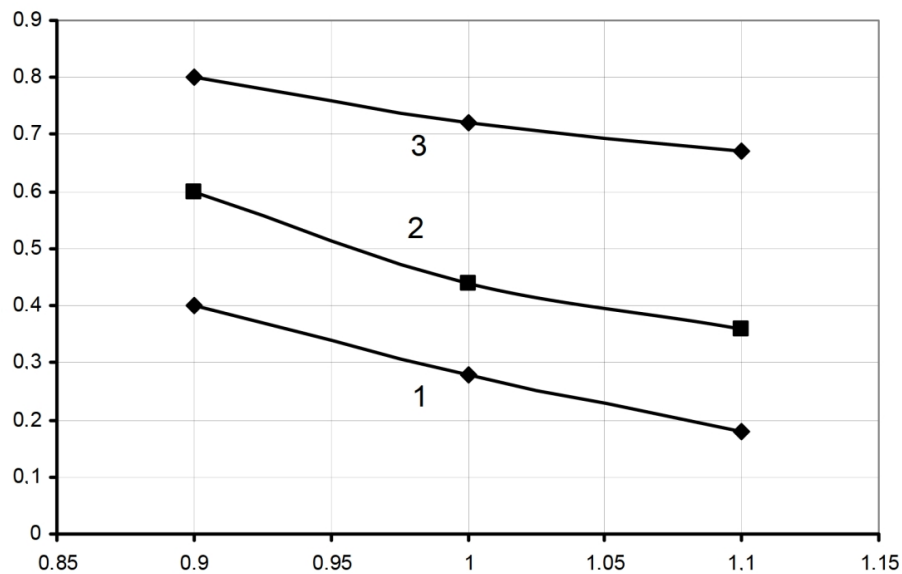
**Figure 1.** Design diagram of the road structure: 1 - with  $K_{comp.} = 0.90$ ; 2 - with  $K_{comp.} > 0.90$

To determine the effectiveness of measures to increase the soil compaction, the road topping should be re-assessed for the soil properties upon its compaction. The road topping may be estimated as per the ODN 218.048-01.

On quarry roads the road topping is normally of double coat. For the cost-benefit analysis, the accuracy of which for engineering purposes can be accepted within  $\pm 10-15$  %, it is reasonable to arrange the double coat model of the road structure (topping + earth work).



**Figure 2.** Dependency of the value of the soil elastic modulus on the compaction coefficient: 1 – with the soil humidity  $W_i=0.7$ ; 2 –  $W_i=0.8$ ; 3 –  $W_i=0.9$ .



**Figure 3.** Dependency of the required road topping thickness on the soil compaction coefficient: 1 – with the rated thickness of the road topping  $H_{rt}=0.4$  m; 2 –  $H_{rt}=0.6$  m; 3 –  $H_{rt}=0.8$  m

To get quite overall results with minimal costs, the math modeling is rational to apply using the theory of experiment planning. The model is taken for this purpose as follows:

$$C_{rw.} = f(K_{comp.}, H_{rt.}) \tag{1}$$

where,  $C_{rw.}$  - capital costs for the construction of 1 km of roadbed and earth work;  $K_{comp.}$  - coefficient of the earth work soil compaction;  $H_{rt.}$  - equivalent thickness of the road topping required by the strength conditions.

When planning the experiment, the variable factors are required to be independent on each other, and so  $H_{rt}$  - is the thickness of the road topping rated per the strength depending on the volume and replication of the load, the properties of the materials used, and at the certain degree of soil compaction.  $H_{rt}$  is not provisionally calculated (not required), the equivalent thickness of the road topping is specified, and all other options are obtained by building the equivalent pavement (the changes in soil density are given). This condition is satisfied as follows: the equivalent (common modulus) of elasticity of the road structure must be constant. Herewith, the standard method is used to measure the strength of the road topping according to ODN 218.046-01. The task complexity and the true accuracy of the cost-benefit analysis are given, the average values of properties are used for calculations. The design diagram is shown in Figure 1.

Math modeling was applied in accordance with the planning matrix of the two-factor experiment. The dependency of the module of elasticity and other soil characteristics on the compaction coefficient is taken by the formula proposed by Prof. O.T. Batrakov, written as (soil - clay or loam):

$$E_{elast.} = 35046 K_{comp.}^{-1,5} \cdot \exp[-15,78W_r + 8,36W_r^2]m \quad (2)$$

where,  $W_r$  - the rated soil moisture in the active zone;  $m$  - coefficient that considers climatic features of the construction area,  $m$  for the Republic of Tatarstan = 1.24.

Calculations are made for the properties proposed by Professor V. N. Efimenko. The values of the coefficient  $t$  are obtained by comparing the results of calculations using the formula by Professor O.T. Batrakov jointly with the data by Professor V.N. Efimenko.  $W_r = 0.7$  (with the compaction coefficient 0.95) for the clay soil in response to the road building climatic zone III.X.4 and the terrain of Type 2 by the moisture requirements. Using the formula (2), we get:

$K_{comp.}$	0.90	1.00	1.10
$E_{elast.}$ , MPa	35.6	41.7	48,1.

Formula (2) shows that the soil moisture considerably affects the value of its elastic modulus (Figure 2, Figure 3).

The value of the cost impact (E) was found by the formula:

$$E = (C_1 - C_2) T_v, \quad (3)$$

where,  $C_1$  - the costs for the construction of 1 km of earth bed and road topping using the basic (conventional) method;  $C_2$  - the same, using the proposed method by the higher soil compaction;  $T_v$  - the total volume of the applied technology of higher soil compaction, km.

Since the Formula (3) specified the difference in costs for various structure options, the same result can be obtained if not total costs are identified, but only those that differ in considered options. For example, the estimation of the entire earth work may be avoided except its section which will be highly compacted.

### 3 Results

The experiment was conducted on a testing site of a Tatarstan road construction company involved in road construction, repair and maintenance. It was aimed at determining an effective compaction method ensuring the achievement of the required density with possible reduction in the number of used rollers and their passes during SMA mix laying and compaction.

**The objective of the experiment and the research** was to determine the effect of various compaction methods on the density of SMA-20, SMA-15 and SMA-10.

**The experiment was carried out** using a road roller on a road section of 4 m wide and 70 m long. The laid road-building material of 5 cm thick was compacted separately by three rolling modes with the main indications noted.

HAMM HD75 medium-sized smooth drum road tandem roller (Germany) **was selected for the research.**

This roller is the most common in the Russian Federation and, moreover, many road construction organizations of the Republic of Tatarstan have this roller model and a number of its modifications.

HAMM HD75 is structurally equipped with two vibration rolls, one of which operates with oscillation which enables to increase the number of roller operations to 3 modes: static mode (with vibrators turned off), vibration mode (with vibrators turned on) and oscillation mode (with the oscillating vibrator turned on). In addition, the possibility of separate activation of the vibration generator on each roller enables to use "static-vibration" and "static-oscillation" patterns.

Under the standards the number of the average roller passes carried out during compaction of the road surface from bitumen-concrete mixes is from 4 to 8. During the experiment, there were also 8 passes along the compaction section. Compaction degree was measured after 2, 4, 6 and 8 passes using PAB-1 asphalt concrete density indicator.

In the course of field tests the compaction of test sections was performed in three modes: static, vibration, and oscillation one.

The results obtained during the tests are systematized and represented in Tables 1-3.

Comparing the values obtained during the experiment, it can be concluded that the appropriate compaction method for all three test SMA mixes is the vibration compaction.

**Table 1.** Measurement results of compaction value  $C_v$  of crushed-stone asphalt concrete SMA-20.

Number of passes of a skating rink	Compaction factor of asphalt covering			Regulatory requirements
	Static compaction	Vibration compaction	Oscillation compaction	
After the racker	0.91	0.92	0.91	0.92
2 passes	0.93	0.94	0.935	0.94
4 passes	0.95	0.96	0.955	0.96
6 passes	0.965	0.99	0.98	0.98
8 passes	0.98	1.01	0.99	0.99

**Table 2.** Measurement results of compaction value  $C_v$  of crushed-stone asphalt concrete SMA-15.

Number of passes of a skating rink	Compaction factor of asphalt covering			Regulatory requirements
	Static compaction	Vibration compaction	Oscillation compaction	
After the racker	0.91	0.91	0.915	0.92
2 passes	0.925	0.94	0.93	0.94
4 passes	0.95	0.96	0.955	0.96
6 passes	0.97	0.985	0.975	0.98
8 passes	0.98	1.01	0.99	0.99

**Table 3.** Measurement results of compaction value  $C_v$  of crushed-stone asphalt concrete SMA-10.

Number of passes of a skating rink	Compaction factor of asphalt covering			Regulatory requirements
	Static compaction	Vibration compaction	Oscillation compaction	
After the racker	0.91	0.91	0.91	0.92
2 passes	0.925	0.94	0.93	0.94
4 passes	0.95	0.97	0.955	0.96
6 passes	0.97	1.0	0.975	0.98
8 passes	0.985	1.02	0.99	0.99

Test results showed that under the vibration method the required compaction rates were obtained faster comparing to other modes. Moreover, the regulatory compaction value  $C_v = 0.9$  was obtained already after the sixth roller pass.

Thus, comparing the values obtained during the experiment, it can be concluded that the appropriate compaction method for all three test SMA mixes is the vibration compaction.

#### 4 Discussions

The results of the experimental compaction performed by the selected roller with three compaction modes may be summarized as follows:

1. Vibration compaction as a result of double loading of "static + dynamic compression" type was the most effective way to compact all three selected brands of SMA.
2. In all three cases the regulatory  $C_v$  values in the vibration compaction mode were ensured already after sixth roller pass.
3. It was observed that a further increase of passes leads to the destruction of SMA crushed stone due to excessive compaction [20-22].
4. The value of  $C_v$  of the static compaction of crushed-stone asphalt concrete in the mix by an average roller was below the required level. This is due to the high percentage of crushed stone which makes the frame structure of the compacted material more rigid.
5. Consequently, to achieve regulatory  $C_v$  values of the static compaction an increased number of roller passes is required. This leads to the increased amortization and operation costs of used rollers and increases the compaction process time, which is economically and technologically impracticable.
6. The measured values of the crushed-stone asphalt concrete compaction carried out under oscillation method were intermediate against the results of compaction under static and vibration methods.

The practical implementation of the proposed compaction approaches in the road engineering industry is aimed at improving the quality of the SMA top dressing compaction and optimizing the number of compaction equipment passes based on the types of compaction used. At the same time the use of the most practical compaction method increases the general efficiency of rollers utilization. Fewer roller passes need less time for compaction and, thus, increases efficiency of asphalt rollers operation and reduces related general amortization expense.

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