Optimal Road Rollers Kit Selection for Asphalt-Concrete Mixture Compaction

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Abstract. Compaction is the final operation of the road construction. A set of road rollers is used for this operation. Compacting efficiency depends on the selected operation modes of the technique. The article obtained dependence of asphalt concrete mix physicomechanical parameters and road roller design parameters. Based on this dependence, an algorithm for selecting and calculating the operating modes of road rollers optimal kit has been developed. Coating compaction cost was taken as the optimization criterion.

1. Introduction

In recent years, Russia has seen a road construction sharp increase. The asphalt-concrete mixture is the most widespread for the construction of road top layer [1, 2]. Mixture layer compaction performed after its spreading. This operation is final and provides desired structure and properties of asphalt concrete. The quality of this operation affects coating durability [3, 4]. Asphalt mix compacting is produced by a road rollers kit. Each roller has a certain temperature range of effective work on the considered coverage area [5, 6, 7].

When asphalt concrete mixture compaction is produced, road builder main problem is to choose a value of force action on material, that provides maximum plastic deformation without disturbing material continuity [8, 9, 10]. This article solves the problem of determining roller kit optimal operating modes.

2. Setting boundaries of effective compaction

Mixture compaction effectiveness depends on the contact stress $\sigma_c$ developed by drum of a roller on the material surface. If the contact stress exceeds mixture compressive strength $\sigma_s$ asphalt layer continuity disrupts. There is also a lower limit of rational contact stress range, beyond which compaction becomes ineffective due to residual deformations absence. For effective asphalt mixture compaction the roller drum contact stress value must respond the following condition [11]

$$0.9\sigma_s \leq \sigma_c \leq \sigma_s, \quad (1)$$

where, $\sigma_s$ is the mixture compressive strength, MPa.

The experimental studies results of asphalt concrete mixture compressive strength, carried out by a number of authors [12, 13, 14, 15, 16], are presented in figure 1.
Figure 1. Compressive strength dependence on temperature for various types of asphalt concrete mixtures: 1 – type A; 2 – type B; 3 – type V.

As a result of data (figure 1) statistical processing, a general dependence of mixture compressive strength on the material physicomechanical characteristics was obtained

\[ \sigma_s = a \exp(-bT), \]  

where, \( a, b \) are the material properties coefficients determined from experiment, \( T \) is asphalt mix temperature, \(^\circ\)C.

The effective compaction interval (1) is shown in figure 2 as an area enclosed between pair of curves. In this case, the curve \( \sigma_s \) is performed on the basis of values obtained from equation (2).

Figure 2. Ranges of asphalt mixture effective compaction by various rollers.
In [12], it is proposed to estimate the roller drum stress effect on the coating by a complex indicator \( q/R \), where \( q \) is the roller linear pressure, \( R \) is the drum radius. Taking into account (2), we obtain the equations determining temperature range \([T_{si} - T_{ei}]\) of the roller efficient operation with a stress parameter \([q/R]\),

\[
T_{si} = \frac{1}{b} \ln \frac{0.9a}{[q/R]}, \quad T_{ei} = \frac{1}{b} \ln \frac{a}{[q/R]},
\]

where, \( i \) is the compaction stage number.

In this way, we obtain the mixture temperature ranges boundaries for preliminary \([T_{si} - T_{ei}]\), main \([T_{s2} - T_{e2}]\), and final \([T_{s3} - T_{e3}]\) stages of compaction. Using the obtained values, according to [17] we determine roller operating time at the appropriate stage (h)

\[
\Delta t = \frac{1}{m} \ln \frac{T_{si} - T_u}{T_{ei} - T_u},
\]

where, \( T_{si} \) is the mixture temperature at the compaction start at \( i \)-th stage, \( ^\circ C \), \( T_{ei} \) is the mixture temperature at the compaction end at \( i \)-th stage, \( ^\circ C \), \( T_a \) is the air temperature, \( ^\circ C \), \( m \) is the mixture cooling rate, 1/h.

The mixture cooling rate is determined by the equation [17]

\[
m = \frac{\alpha}{5pc},
\]

where, \( \alpha \) is mixture heat transfer coefficient, kcal/m·h·\(^\circ C\), \( c \) is the mixture heat capacity, \( \rho \) is the mixture density, g/sm\(^3\), \( h \) is the mixture layer thickness, sm.

3. Efficiency criterion determination

Currently, road rollers model range is very wide and selection of the optimal kit is a very difficult task. To solve this problem, the analytical expression of efficiency criterion was obtained

\[
P = \sum_{i=1}^{3} P_i' \Delta t_i \rightarrow \text{min},
\]

where, \( P \) is the area compaction cost, \( P_i' \) is the specific reduced costs at the compaction \( i \)-th stage.

We will take as the specific reduced costs the hourly cost of road roller renting including VAT. After analyzing the rental market for rollers Dynapac, Weber, Bomag, Ammann, Raskat (figure 3), a statistical dependence was obtained

\[
P_i' = 61098[q/R] - 379.51.
\]

![Figure 3](image-url) The road roller rental value dependence from its stress effect.
In view of (7), equation (6) is converted to
\[ P = \sum_{i=1}^{3} \left( 61098 \frac{q}{R} - 379.51 \right) \Delta t_i \to \min. \tag{8} \]

Figure 4 shows the algorithm block diagram that implements the selection of optimal kit according to the criterion of asphalt concrete pavement compaction minimum cost. In figure 4, \( n \) is the number of road roller models entered by the user to compose the optimal kit.

The developed algorithm was implemented as a software package. The software package initial information input window is shown in figure 5, and the package result window is shown in figure 6.

Figure 5 shows the case of calculating the effective operating modes of road rollers kit available to the user. In addition, the software package has the function of selecting the optimal kit composition from the rollers models range, specified by the user. This function allows carrying out the optimal acquisition of compacting equipment fleet for specified work conditions.
4. Conclusion
The suggested software package was used to assign technics compaction modes at the experimental area of highway construction in Khabarovsk. Studying the properties of obtained experimental coating, their compliance with the requirements [18, 19] was established. Consequently, the compaction of coating was performed qualitatively.

The developed algorithm, implemented as a computer program, allows you to:
- choose optimal operation modes of the available compacting equipment, taking into account the external conditions;
- form a technique fleet for the effective compaction under the specified work conditions.

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Figure 5. The input data window for calculation.

Figure 6. The software package calculation results.
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