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USE OF GEOMETRICAL PARAMETERS OF ROUGHNESS FOR PREDICTING THE COEFFICIENT OF COUPLING IN ENGINEERING CALCULATIONS OF ROUGH SURFACE TREATMENT

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Statement of the problem. Presently the application of the rough surface treatment of pavings was widely adopted. A new edition of ODM "Recommendations on theDesign of Macrorough Pavings" assumes specification of a three-component chart for preliminary (estimated) determination of coefficient of coupling in designing new coverings with rough processing. Therefore the task of design of rough surface treatment with in advance set properties for rough pavings is becoming significant now.
Results. The three-component chart for preliminary determination of the coefficient of coupling in designing macrorough pavings is specified. The chart allows one to estimate the minimum in advance coupling coefficient which will provide rough surface treatment for specified geometrical parameters.
Conclusions. For design of a macrorough surface of a paving and a preliminary estimate its macrorouhghness it is possible to use an approximated value of coefficient of coupling with the help of the suggested specified three-component chart. This three-component chart can be a basis for creation by more exact with use of relative geometrical parameters of a macroroughness.

Keywords: coupling coefficient, macroroughness, rough surface treatment, road covering, highway, thin layers of wear.

Introduction

Macrorough road surfaces are independent construction elements of roadways and bridges which are designed in order to reduce emergency rates, improve the road safety, comfort, travelling intensity and stability thus providing required speeds and loading capacities. Surfaces should provide minimum contaminant exposure to adjacent areas as well as maintenance opportunities and long life cycles, be easy to use and cost-efficient.

Macrorough surfaces are rough surface treatments, nielloed crushed stone into cast asphalt concrete of bridge roadways, anti-skidding, paving of pedestrian bridges, anti-ice road pavings with maximum macroroughness, access to disabled individuals, etc.

Presently a modern method for designing macrorough road surfaces is distribution of crushed stone along a road paving surface using bitumen crushed stone distributors followed by rolling with lightweight rollers. Simultaneous distribution of crushed stone and binder causes them to bond well thus providing the required operational parameters of surface treatment of a roadway paving. Bitumen crushed stone distributors can operate backwards and forward (Fig. 1).

Fig. 1. Options for the backward and forward operation of bitumen crushed stone distributors

According to statistics, the adhesion of the wheel and surface contributes to fewer road accidents. The roughness parameters of a surface and adhesion coefficient φ are mutually dependent. Effect of macrorough roadway surfaces on changes in the adhesion coefficient (given a vehicle's travelling speed) is shown in Fig. 2.

Designing a macrorough surface is key to improving the skidding resistance of tires, which provides required adhesion coefficients. Therefore macroroughness parameters are crucial for road pavements. They make up different textures with their own unique properties [1, 2]. Therefore the issue of selecting new technologies and relevant materials involved in designing rough surfaces is gaining momentum. This is particularly the case for materials of rough layers of road pavements [3].

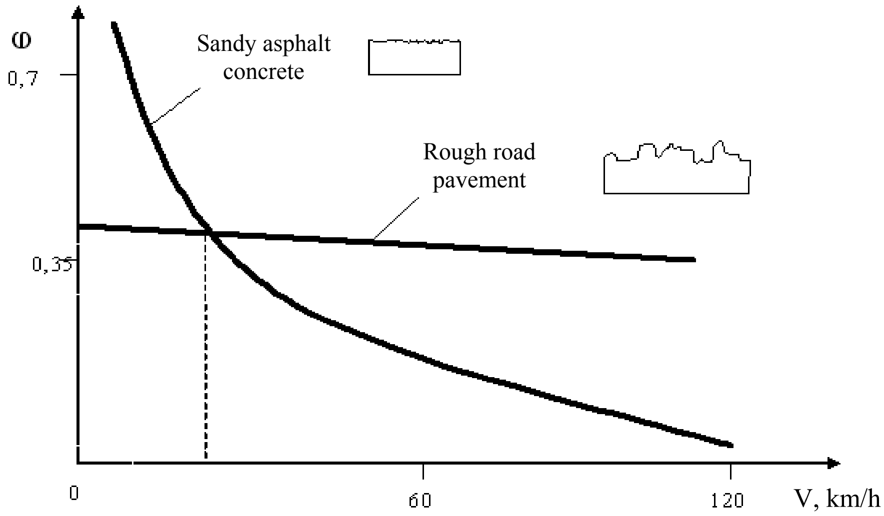

Fig. 2. Graph of the adhesion coefficient φ for different rough surfaces of road pavements (at different travelling speeds according to Yu.N. Kuznetsov)

1. Designing geometric parameters. The adhesion coefficient is an individual characteristics of road pavements influencing dynamic properties of vehicles (speed, driving force, braking distance, acceleration) which depend on a type of a vehicle, wheel loads, travelling speed, quality and size of tires, condition of tracks, tire pressure as well as type of a pavement material, its smoothness, roughness and weather conditions (dry, wet, snowy, muddy, icy). Therefore the adhesion coefficient depends on the properties of vehicles and road pavements. It can be significantly increased due to a roadway component by increasing the tire adhesion of a road pavement material, making it reasonably rough, the surface clean and even and so can dynamic characteristics of a vehicle and safety. As can be seen, it is daunting to estimate the adhesion coefficient in a particular roadway area. While designing macrorough road surfaces, it is necessary to provide appropriate adhesion coefficients. This takes four stages: [3, 4]:

1) collecting and analyzing original data;

2) designing major constructional and operational properties of a surface layer;

3) designing a technology of laying a surface layer;

4) developing guidelines for maintenance of a surface layer of roadways.

In a new project "Guidelines on Macrorough Road Surfaces" developed under the author's supervision as part of a task designed by the Federal Road Agency there is a table of adhesion coefficients depending on a specified macroroughness level (Table 1).

Elements and geometric parameters of roughness are in Fig. 3 [5].

Table 1

Classification of road pavements according to macroroughness levels

Macroroughness level	Activity of a macroroughness element surface (point)	Relative activity of a contact $Q_к$	Relative density of a contact $N_к$	Root-mean-square deviation of macroroughness σ_{acp}, mm	Density of a macroroughness element ρ	Transport operational characteristics for adverse conditions of a surface				
						Minimum adhesion coefficient, no less than	Traffic resistance coefficient, no more than	Sound level, dB, no more than	Maximum travelling speed, km/h, no more than	Braking distance, m, no less than
Non-rough	1	1,0	1,0	Less than 1,0	From 0,5 to 0,7	0,35	0,05	50	90	90
Rough	2	From 1,0 to 1,5	From 1,0 to 1,5	From 1,0 to 2,0	From 0,4 to 0,65	0,40	0,06	60	100	86
Average rough	3	From 1,5 to 2,0	From 1,5 to 2,0	From 2,0 to 3,0	From 0,3 to 0,65	0,45	0,07	70	110	77
Extremely rough	4	More than 2,0	More than 2,0	More than 3,0	From 0,2 to 0,6	0,50	0,08	80	110	64

In addition there are new major geometric parameters of macroroughness:

1) an average rut depth (height of uneven surfaces);

2) an average macroroughness step;

3) macroroughness density;

4) relative density of macroroughness contacts;

5) different heights of active macroroughness protuberances;

6) different depths of macroroughness protuberances;

7) different distances between crushed stone aggregates.

The last three parameters are evaluated using root-mean-square values (dispersion) and correlation coefficient [6, 7].

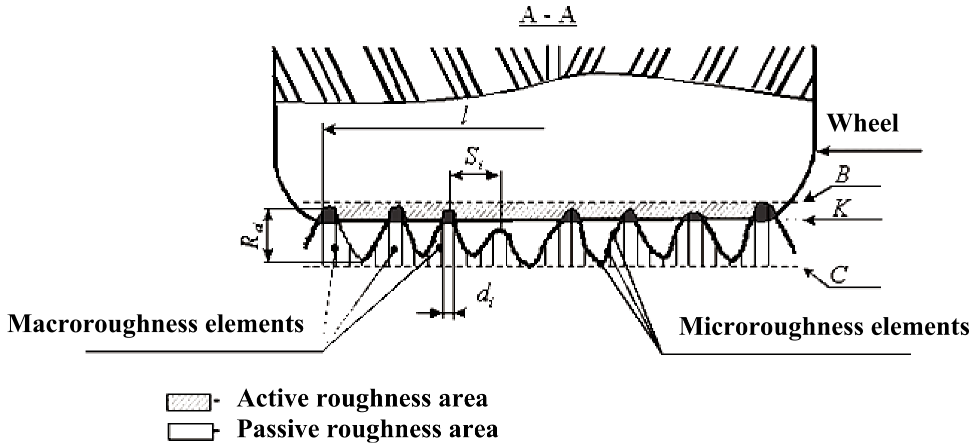

Fig. 3. Elements and parameters of macroroughness:
K — basic density of a wheel surface in a contact area with macroroughness elements;
C — flatness of the largest protuberances in a wheel contact area; *B* — flatness of the largest protuberances of a profile of a wheel contact area; *l* — basic length, mm; $D_м$ — size of a wheel track imprint of a design car, mm;
S_i — step of local protuberances within a basic length, mm;
d_i — step of a wheel contact within a basic length, mm;
R_{ai} — specific rut depth (distance between adjoining tops and rut onto a vertical axis), mm

2. Trigrams for determining macroroughness levels. Trigrams (Fig. 4) were previously proposed by A.A. Serbienko and A.V. Kochetkov for operational control of adhesion of macrorough road surfaces as well as wear and tear of a rough surface [8]. But this trigram cannot evaluate geometric parameters of macroroughness using the adhesion coefficient. According to A.A. Serbinenko, in order to evaluate qualitative characteristics of macroroughness of road surfaces using a specified adhesion coefficient, the following will suffice:

1) height of a roughness protuberance, mm, which is determined in relation to a basic surface using a nominal section profile within a basic length. The height of protuberances can be identified using a dot roughness profile gauge (similarly to SoyuzdorNII PKSh-4 device);

2) density of roughness elements, el/dm^2 which is determined using the number of roughness protuberances within a tire imprint on a rough pavement surface. It is identified according to the number of imprints of roughness elements on an area of 10×20 cm on an imprint surface;

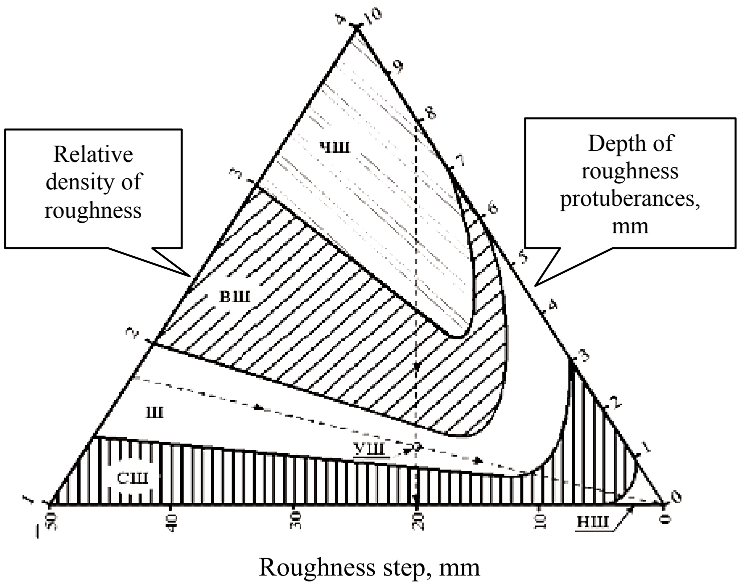

Fig. 4. Trigram for evaluating a macroroughness level of a road pavement surface:
ЧШ — area of an extemely rough structure; ВШ — area of a quite rough structure;
Ш — area of a rough structure; СШ — area of a slightly rough structure; НШ — area of a non-rough structure

3) activity of a rough surface determined using a conditional activity index taking into account a type of a microroughness structure and relative support length.

A trigram for estimating the adhesion coefficient was designed by A.A. Serbinenko, A.V. Kochetkov and A.A. Sykhov using the three characteristics of roughness of road pavement surfaces (Fig. 5) [7].

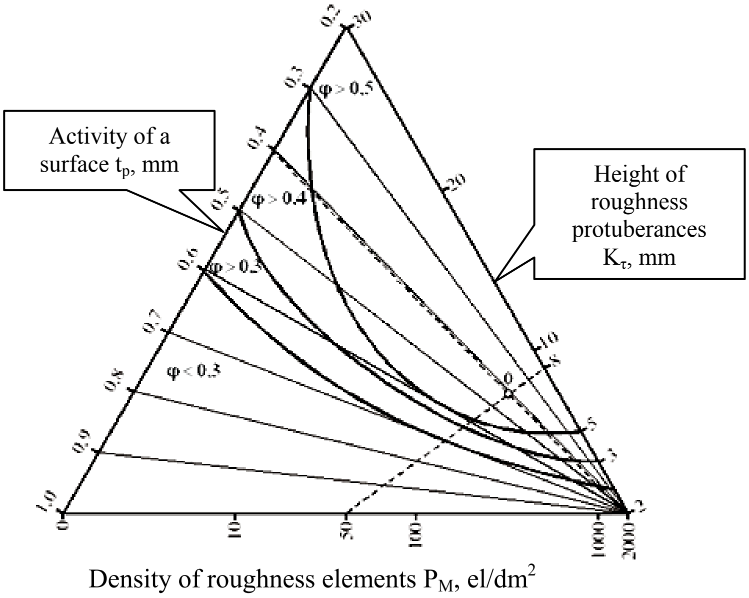

Fig. 5. Trigram for determining a specified adhesion coefficient depending on the roughness characteristics

3. Three-component diagram for determining the adhesion coefficient. In the process of preparing a new project "Guidelines on Designing Macrorough Road Pavements" it became necessary to changes the names of cathetuses of a three-component diagram as the names of the parameters were altered in a new version.

The left cathetus of a three-component diagram (Fig. 6) should be replaced from activity of a surface t_p to the macroroughness density ρ which is given by

$$\rho = Q_{cp} / S_{cp},$$

where ρ is the macroroughness density; Q_{cp} is an average diameter of macroroughness elements, mm; S_{cp} is an average macroroughness step, mm (Fig. 3). The classification of surfaces depending on the geometric parameter "macroroughness density" is in Table 2.

Table 2

Classification of surfaces depending on the density of a macroroughness structure

Group	Ranges
Dense	From 1 to 0,8
Condensed	From 0,8 to 0,6
Rare	From 0,6 to 0,4
Very rare	From 0,4 to 0,2
Structureless	Less than 0,2

The parameter of macroroughness density describes a horizontal linear characteristics of the distribution density of crushed stone.

The right cathetus (height of roughness protuberances) of a three-component diagram (Fig. 5) in a new version of the guidelines is called differently, i.e. "an average depth of a macroughness rut R_{acp}". This geometric parameter is also responsible for a linear characteristics of a surface but now in relation to a surface normal.

The parameter of the foundation of a triangle (density of roughness elements) is now called "an average number of crushed stone aggregates m" which is determined by a number of aggregates in standard frame of 10×20 cm. This parameter is also responsible for a volumetric characteristics of a contact of crushed stone with a tire surface.

Using these new three geometric parameters of macroroughness of road surfaces, a clarified three-component diagram to evaluate the adhesion coefficient is designed (Fig. 6).

The calculation is similarly according to the above three-component diagram. For example [8]:

– an average number of crushed stone aggregates m = 50 agg/dm^2;

– an average depth of macroroughness ruts R_{acp} = 9 mm;

– macroroughness density ρ = 0,4.

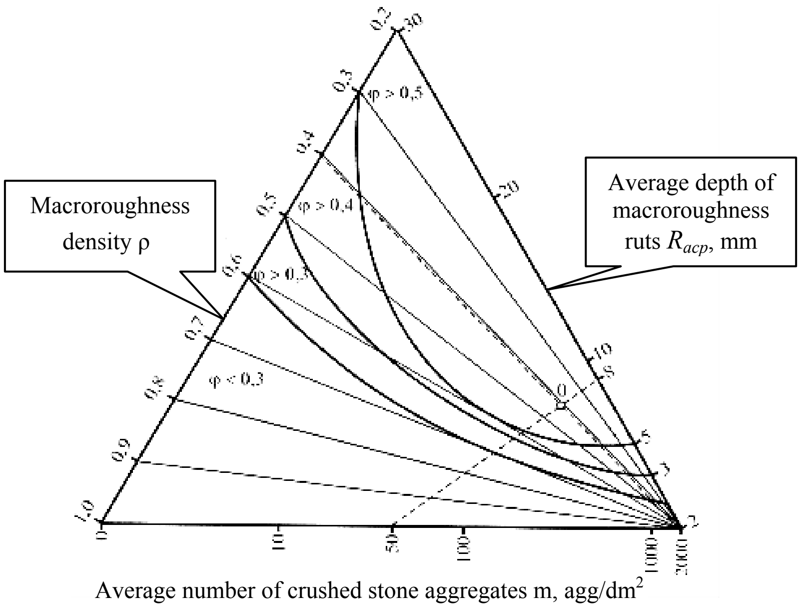

Fig. 6. Three-component diagram to determine the adhesion coefficient depending on geometric parameters of macroroughness

The obtained lines cross at 0 which determines a sector of a three-component diagram with a specified adhesion coefficient. In this case φ > 0,5 for an unfavorable condition of a surface [8].

It should be noted that each of the parameters of the diagram has its own effect on physical processes in a contact area of a tire with a road surface as a car is moving.

A drawback of this diagram is that it uses average macroroughness. It is daunting to automatically calculate these parameters for a large amount of measurements.

The sides of a three-component diagram can be responsible for three new relative geometric characteristics also accepted in the "Guidelines on Designing of Macrorough Road Surfaces".

The density of macroroughness is responsible for physical macroroughness for the length (different lengths), an average depth of macroroughness ruts is responsible for a surface normal (different depths and heights). A root-mean-square deviation (dispersion) is used to evaluate all of these parameters.

The foundation of the diagram is responsible for a volumetric characteristics (segregation or sequences of signs), which can be evaluated using a correlation coefficient.

Therefore as there are new data on the use of these characteristics (in their relation to the adhesion coefficient), a new clarified three-component diagram based on more informative relative geometric parameters can be designed.

Relative geometric parameters can be easily determined using special equipment of mobile road laboratories to automatically calculate and make the adhesion coefficient more accurate.

Conclusions

1. In order to design a macrorough road surface and give a preliminary evaluation of its macroroughness, an approximated adhesion coefficient can be used with the proposed clarified three-component diagram.

2. This three-component diagram can be the foundation for a more accurate one using relative geometric parameters of macroroughness.

References

1. Nemchinov M. V. *Tekstura poverkhnosti dorozhnykh pokrytiy: v 2 t. T. 1. Obosnovanie, normi-rovanie i proektirovanie parametrov tekstury poverkhnosti dorozhnykh pokrytiy* [The surface texture of road surfaces: in 2 vol. Vol. 1. Justification, regulation and design parameters of surface textures of road surfaces]. Moscow, TekhPoligrafTsentr Publ., 2010. 380 p.

2. Nemchinov M. V. *Tekstura poverkhnosti dorozhnykh pokrytiy: v 2 t. T. 2. Opisanie i kolichestvennye rezul'taty eksperimental'nykh issledovaniy. Primery raschetov. Metodika rascheta glubiny tekstury poverkhnosti sloya iznosa (po tipu poverkhnostnoy obrabotki)* [The surface texture of road surfaces: in 2 vol. Vol. 2. Description and quantitative experimental results. The examples of calculations. The method of calculating the depth of the surface texture of the wear layer (surface treatment)]. Moscow, TekhPoligrafTsentr Publ., 2010. 156 p.

3. Yankovskiy L. V., Kochetkov A. V., Trofimenko Yu. A. Metodika vybora materiala dlya ustroystva sherokhovatykh sloev dorozhnogo pokrytiya [The method of selection of the material for device of rough layers of the road surface]. *Nauchnyy vestnik Voronezhskogo GASU. Stroitel'stvo i arkhitektura*, 2015, no. 1 (37), pp. 99—111.

4. Chvanov A. V. Normirovanie, ustroystvo i kontrol' kachestva makrosherokhovatykh dorozhnykh pokrytiy. Diss. kand. tekhn. nauk [Rationing device and quality control macro-rough road surfaces. Cand. of technical Sci. Diss.]. Volgograd, 2010. 178 p.

5. Susliganov P. S. Sovershenstvovanie metodov kontrolya kachestva ustroystva dorozhnykh po-krytiy s sherokhovatoy poverkhnost'yu. Avtoref. diss. kand. tekhn. nauk [Improving methods of quality control of pavements with rough surface. Autoabstract Cand. of technical Sci. diss.]. Volgograd, 2006. 16 p.

6. Kochetkov A. V., Yankovsky L. V., Kadyrov Zh. N. Standardization of Roughness of Products of the Machine-Building Industry on the Basis of Variable Height Indicator of Ledges and Variable Depth Indicator of Hollows as an Extension of State Standard GOST 2789-73. *Chemical and Petroleum Engineering*, 2014, vol. 50, iss. 1—2, pp. 50—57.

7. Kochetkov A. V., Yankovskiy L. V., Sukhov A. A. Normirovanie makrosherokhovatosti poverkhnostey [Rationing of mikroheranhvatho surfaces]. *Vestnik grazhdanskikh inzhenerov. Arkhitektura. Stroitel'stvo. Transport*, 2012, no. 1, pp. 137—144.

8. Sukhov A. A. Sovershenstvovanie metodov issledovaniya bezopasnosti dvizheniya s uchetom va-riativnosti koeffitsienta stsepleniya makrosherokhovatykh dorozhnykh pokrytiy. Avtoref. diss. kand. tekhn. nauk [Improved methods for the study of traffic safety taking into account the variability of the coefficient of adhesion macro-rough road surfaces. Autoabstract Cand. of technical Sci. diss.]. Volgograd, 2014. 20 p.

9. Yankovskiy L. V. Parametry dlya kontrolya kachestva dorozhnykh pokrytiy s makrosherokhovatoy poverkhnost'yu [Options for controlling the quality of road surfaces with surface mikroheranhvatho]. *Tekhnicheskoe regulirovanie v transportnom stroitel'stve*, 2015, no. 4 (12), pp. 108—114.
10. Yankovskiy L. V. Nauchno-tekhnicheskiy obzor voprosov primeneniya sovremennykh makrosherokho-vatykh dorozhnykh pokrytiy i tekhnologiy po ikh ustroystvu [Scientific and technical review of the application of modern macro-rough road surfaces and technology in their device]. *Tekhnicheskoe regulirovanie v transportnom stroitel'stve*, 2015, no. 3 (11), pp. 24—42.
11. Seredin P. V., Glotov A. V., Domashevskaya E. P., Lenshin A. S., Smirnov M. S., Arsentyev I. N., Vinokurov D. A., Stankevich A. L., Tarasov I. S. Structural and spectral features of MOCVD $Al_x Ga_y In_{1-x-y} As_z P_{1-z}$/GaAs (100) alloys. *Semiconductors*, vol. 46, iss. 6, pp. 719—729.