STATISTICAL ANALYSIS OF STRENGTH ASSESSMENT OF NONRIGID PAVEMENT SURFACING

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ABSTRACT

The authors examine the issues related to statistical processing of the results of measurement of elastic deflections on the surface of nonrigid pavement surfacing made by shock loading installation FWD. Based on these results the nature of distribution of elastic deflection was clarified and assessment of homogeneity for pavement surfacing in areas with different service life was carried out. It was found that with a sufficient degree of probability distribution of such deflections can be described by the lognormal law.

Keywords: car, nonrigid pavement surfacing, elastic deflection, modulus of elasticity, installation of shock loading, coefficient of variation, lognormal distribution.

Background. *The foundation of the long-term strength of nonrigid pavement surfacing is laid at the stage of its design. Constructing the pavement surfacing and determining main mechanical parameters of its individual layers, the designer carries out the calculation according to three criteria: calculation of the design as a whole on allowable elastic deflection, calculation of design on resistance of monolithic layers to fatigue fracture caused by bending tension, calculation on condition of shear-resistance of subsoil and lowly cohesive structural layers. Thus the only parameter which may be monitored at the operational phase, becomes elastic deflection on the pavement surface. And only then the second – calculated on its basis total modulus of its elasticity, which can be estimated with the use of static and dynamic loading equipment.*

Objective. *The objective of the author is to provide statistical analysis of strength assessment of nonrigid pavement surfacing.*

Methods. *The authors use general scientific and engineering methods, statistical analysis, mathematical calculation.*

Results.

Shock loading mechanism

It should be noted that the value of the common module of elasticity of pavement surfacing (and, accordingly, elastic deflection) in the proposed structure, laid at the design stage, is deterministic, while under real operating conditions its value is affected by considerable amount of various factors of probabilistic nature, involved in technological processes of construction, general mechanisms of degradation of bearing capacity of pavement surfacing, climatic conditions, etc. And to clarify the actual probalistic characteristics of distribution of elastic deflection (and with it the general module of elasticity of pavement surfacing) is possible only through extensive measurements at sites of operated highways.

The solution of this problem requires the use of high-performance equipment to assess the strength of nonrigid road constructions. As such it is possible to use the installation of shock loading FWD Primax 1500, which is a two-axle semi-trailer with mounted on it shock loading mechanism and a beam with geophone sensors for flexural bowl registration on the pavement surface. Shock loading mechanism allows to apply to the pavement surface load in the range of 20–110 kN at exposure time t = 0,03 s. In practice of use of such an installation on the roads of the Russian Federation tests are carried out under a load of 50 kN. Performance of FWD Primax reaches 40 km / shift in measurements in increments of 100 m, which expects to receive large amounts of data about the values of elastic deflection and total modulus of elasticity of pavement surfacing on extended road sections [1–5].

Availability of this information, of course, requires its processing and analysis, primarily based on statistical methods. Issues concerning the application of mathematical statistics methods in the study of uniformity and reliability of the roads are studied in the works of V. A. Semenov, I. A. Zolotar, V. V. Stolyarov, N. E. Kokodeeva [6–10] and other authors. In particular, these studies relate to the nature of distribution of such parameters of the pavement surfacing as elastic deformation, flatness (clearance under three-meter strip), thickness of layers of asphalt concrete, thickness of gravel layer. The findings, obtained in course of the analysis revealed that at sufficiently high homogeneity (i.e., with a coefficient of variation Cv <20%), regularities of distribution of considered parameters do not conflict with a normal distribution law, but at a higher heterogeneity (coefficient of variation Cv> 0,2) distribution of studied parameters can be described by the law of Weibull and exponential law [6].

The research results presented in this article, focus primarily on evaluation of deformation characteristics of pavement surfacing and aim to clarify the actual parameters of distribution of elastic deflections of the surface of modern nonrigid pavement surfacing. This is done on the basis of field measurements, which were carried out with the use of shock loading installation FWD.

Table 1

Basic statistical parameters of the results of measurement of elastic deflection of nonrigid pavement surfacing by groups of sections

Group of sections	Sample size (number of measurements), N	Average value of dynamic elastic deflection, mm	Standard deviation, s	Coefficient of variation – Cv
I group	1242	0.18	0.04	20
II group	328	0.26	0.08	28
III group	1346	0.36	0.14	39

Table 2

Assessment of conformity of actual law of distribution of elastic deflection of nonrigid pavement surfacing with lognormal law

Section	Number of measurements	Nature of distribution	S_{Ω}	p-value	S_{Ω}	p-value	χ_n^2	p-value
I group								
414+700–464+300	397	Lognorm.	0.03	0.78	0.49	0.75	20	0.20
599+000–633+000	243	Lognorm.	0.04	0.74	0.36	0.89	6.46	0.60
907+000–913+000	198	Lognorm.	0.043	0.82	0.46	0.78	12.72	0.62
1207+000–1240+000	404	Lognorm.	0.031	0.82	0.23	0.97	9.9	0.35
II group								
287+200–296+500	60	Lognorm.	0.057	0.98	0.19	0.99	4.07	0.66
401+000–414+700	102	Lognorm.	0.07	0.65	0.54	0.70	8.93	0.26
1119+500–1134+500	104	Lognorm.	0.071	0.65	0.48	0.76	10.92	0.090
1134+500–1138+500	62	Lognorm.	0.07	0.90	0.35	0.89	6.12	0.632
III group								
1341+000–1351+000	82	Lognorm.	0.06	0.86	0.30	0.94	5.19	0.88
1537+000–1542+000	64	Lognorm.	0.036	0.99	0.13	0.99	2.25	0.94
299+000–308+000	184	Lognorm.	0.045	0.84	0.55	0.69	4.41	0.62
355+000–384+000	260	Lognorm.	0.044	0.70	0.62	0.63	5.6	0.35
460+000–463+000	62	Lognorm.	0.095	0.59	0.79	0.48	11.16	0.083
242+000–253+000	128	Lognorm.	0.053	0.85	0.28	0.94	7.0	0.95
315+000–325+300	162	Lognorm.	0.039	0.95	0.33	0.91	4.88	0.30
382–392	404	Lognorm.	0.036	0.65	0.45	0.80	14.69	0.32

Statistics and distribution laws

During 2015 evaluation has been carried out in relation to strength of nonrigid pavement surfacing on sections of highways M-4 «Don» and M-1 «Belarus». Surveyed areas were divided into three groups depending on their service life. The I group included sections of roads with a service life of up to 5 years (four sections), to the II – with a service life of 5–10 years (four sections), to the III group – areas that are in operation for more than 10 years (eight sections).

With the use of FWD installation was carried out registration of elastic deflection of pavement

Table 3

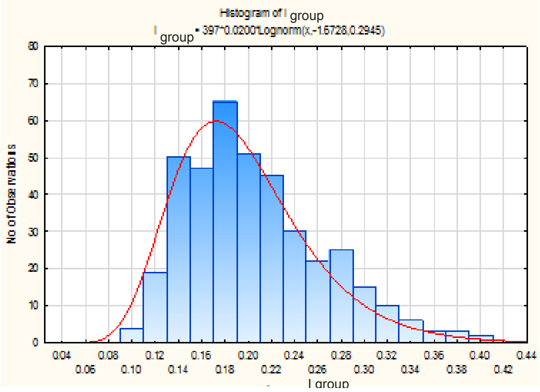
Assessment of conformity of actual law of distribution of elastic deflection of nonrigid pavement surfacing with normal law

Section	Number of measurements	Nature of distribution	S_{Ω}	p-value	S_{Ω}	p-value	χ_n^2	p-value
I group								
414+700–464+300	397	Norm.	0.081	0.00	4.54	0.004	57.70	0.001
599+000–633+000	243	Norm	0.077	0.105	2.02	0.088	12.53	0.128
907+000–913+000	198	Norm.	0.087	0.092	1.89	0.104	23.27	0.078
1207+000–1240+000	404	Norm.	0.047	0.316	0.97	0.372	10.41	0.317
II group								
287+200–296+500	60	Norm.	0.07	0.86	0.37	0.87	4.70	0.58
401+000–414+700	102	Norm.	0.05	0.92	0.30	0.93	10.17	0.17
1119+500–1134+500	104	Norm.	0.10	0.21	1.50	0.17	10.05	0.12
1134+500–1138+500	62	Norm.	0.09	0.65	0.56	0.68	13.22	0.10
III group								
1341+000–1351+000	82	Norm.	0.11	0.24	1.21	0.26	0.10	0.39
1537+000–1542+000	64	Norm.	0.10	0.48	0.93	0.39	3.81	0.80
299+000–308+000 (а.н.)	184	Norm.	0.06	0.41	1.07	0.31	8.22	0.22
355+000–384+000 (а.н.)	260	Norm.	0.11	0.01	6.41	0.06	38.15	0.00
460+000–463+000 (а.н.)	62	Norm м.	0.14	0.15	2.26	0.06	19.00	0.01
242+000–253+000	128	Norm.	0.16	0.00	22.77	0.00	183.4	0.00
315+000–325+300	162	Norm.	0.16	0.00	17.72	0.00	178.2	0.00
382–392	404	Norm.	0.09	0.02	5.04	0.02	49.30	0.00

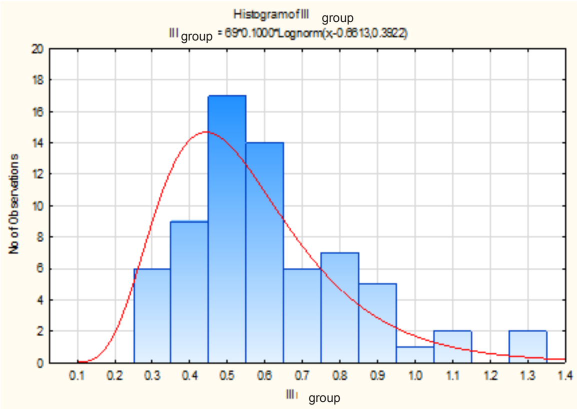
Table 4

The average values of parameters of lognormal distribution for various groups of sections

Groups of examined sections / Statistical parameter	I group (with service life less than 5 years)	II group (with service life 5–10 years)	III group (with service life more than 10 years)
m	–1.72	–1.01	– 0.94
σ	0.22	0.24	0.36



Pic. 1. Distribution of dynamic elastic deflections on the section of I group (km 414+700–464+300).



Pic. 2. Distribution of dynamic elastic deflections on the section of II group (km1119+500–1138+000).

covering, and then was made a calculation of general modulus of elasticity. The measurements were performed in increments of 100 meters on the road sections with the same pavement surfacing structure. At the same time they were carried out during the spring and autumn periods of the year.

Altogether on sections of I group were recorded 1242 values of elastic deflection, of II and III groups, respectively, 328 and 1346 values. Descriptive statistics are given for each sample in Table 1.

On each section was analyzed the nature of distribution of elastic deflection of covering of nonrigid pavement surfacing according to criteria of chi-square of Pearson (1), Kolmogorov–Smirnov (2) and Anderson–Darling (3).

$$\chi_n^2 = n\sum_{i=1}^{k}\frac{(n_i/n - P_i(\theta))^2}{P_i(\theta)}, \qquad (1)$$

where n is a number of measurements; $P_i(\theta)$ is probability of measurement falling in the interval.

$$D_n = \sup_x |F_n(x) - F(x)|, \qquad (2)$$

where Sup S is least upper bound of the set $S = |F_n(x) - F(x)|$;

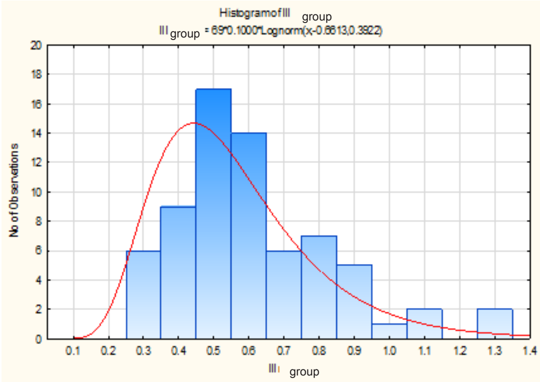
F is estimated model.

$$S_\Omega = -n - 2\sum_{i=1}^{n}\left\{\begin{aligned}&\frac{2i-1}{2n}\ln(F(x_i,\theta)) + \\ &+(1-\frac{2i-1}{2n})\ln(1-F(x_i,\theta))\end{aligned}\right\}, \qquad (3)$$

where $F(x_i, \theta)$ is theoretical distribution of a studied value; n is sample size; $x_1, x_2, \ldots x_n$ are arranged by increase elements of the sample.

Analysis of the actual distribution of elastic deflection was carried out for its compliance with normal, lognormal, exponential distribution law and Weibull distribution law. For comparison, in Table 2 and Table 3 (through the example of lognormal and normal distributions as the best describing the actual distribution) shows the results of evaluation of the statistics for each of the criteria for compliance and their reliability levels (p-value), characterizing the probability of error in case of rejection of the hypothesis for distribution law (errors of the first kind).

A comparison of values of the statistics and levels of reliability calculated for each of the criteria leads to the conclusion that the lognormal law adequately describes distribution of elastic deflection, and thus general modulus of elasticity of road structure at



Pic. 3. Distribution of dynamic elastic deflections on the section of III group (km 1341+000–1351+000).

different stages of its operation. Examples of the results are shown in Pic. 1–3.

It is known that the density of lognormal distribution is described by the law:

$$f(t)=\frac{1}{\sigma t\sqrt{2\pi}}e^{-\frac{(\ln t-m)^2}{2\sigma^2}},$$

where m and σ are parameters of lognormal distribution, called parameters of scale and form of distribution.

The average values of parameters that allow to describe distribution of elastic deflection of nonrigid pavement surfacing at different stages of its operation, have been calculated on the basis of field studies for each of the groups of areas (Table 4).

Using these parameters, it seems possible to describe the nature of distribution of elastic deflections on the surface of road structure at various stages of its operation.

Conclusion. *Application of shock loading installation FWD on the sections of roads with different service life allows to:*

1. Assess the actual uniformity of values of elastic deflections on the pavement surface for areas with different service life. Thus, for sections of the I group coefficient of variation was 28%, of II and III groups – 36% and 58%.

2. Clarify the nature of distribution of actual elastic deflections on the surface of nonrigid road construction for road sections with different service life. As the results of processing of measured values of elastic deflections showed, with a sufficient degree of probability their distribution can be described by the lognormal law.

3. Set the average parameters of density of the lognormal distribution, allowing to describe the nature of distribution of the elastic deflection on the pavement surface for road sections taking into account service life.

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Article received 18.02.2016, accepted 25.05.2016.