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CROSS-SECTION CONFIGURATION COEFFICIENT IN THE ZHURKOV'S GENERALIZED EQUATION

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Statement of the problem. Studying the durability of construction materials in the aspect of thermal fluctuations is the most complicated, yet the most appropriate method. Considering that this concept does not take into account the changes of the physical structure, it becomes necessary to consider not the material alone but also the configuration of the structure. Therefore it is necessary to make a comparison of two structurally different elements — PVC and wood.
Results. The coefficient of the 2-layer composite cross-section (no special connection) is the same for the PVC and wood elements: $k_c = 2$. The derived coefficient of the 3-layer composite cross-section (no special connection) is within the following range: $k_c = 3.5…5.5$, which calls for a more precise definition.
Conclusions. Based on the above experiment, we have theoretically established and experimentally confirmed the regularities of deformation and destruction of PVC elements of the 2 and 3-layer solid and composite cross-section with no special connection. Identifying the thermal fluctuation relations allows us to appropriate the theoretical concepts of the capacity of the construction material in a structure to actual conditions.

Keywords: construction materials, breaking load, durability, deformation, failure, thermal fluctuation.

Introduction. For most materials in construction there is a dependence of strength on the temperature-time effect. This means that failure has a thermal fluctuation nature with thermal motion of an atom being a catalyst for failure as well as deformation. Mechanical influences only exarcebate this. Both processes are probabilistic as time does not play a specific role, it increases the number of thermal fluctuations that destroy bonds in the material preventing the critical phase [1, 10, 11, 17].

This concept is used to predict and investigate the performance and durability of materials in a range of operational parameters: durability of construction materials, long-term strength of construction materials, effect of thermal aging, thermal activation laws [2, 12, 13, 15, 17]. Due to the fact that most construction materials are composite compounds, the consideration of thermal fluctuation dependences considering not only the material, but also the configuration of the structure, would help to appropriate the idealized theoretical ideas about the performance of structures to actual conditions.

The thermal fluctuation concept in the classical case (direct beam) is expressed mathematically in the following way [14, 18]:

$$\tau = \tau_m \cdot \exp\left[\frac{U_0 - \gamma \cdot \sigma}{R} \cdot \left(T^{-1} - T_m^{-1}\right)\right], \quad (1)$$

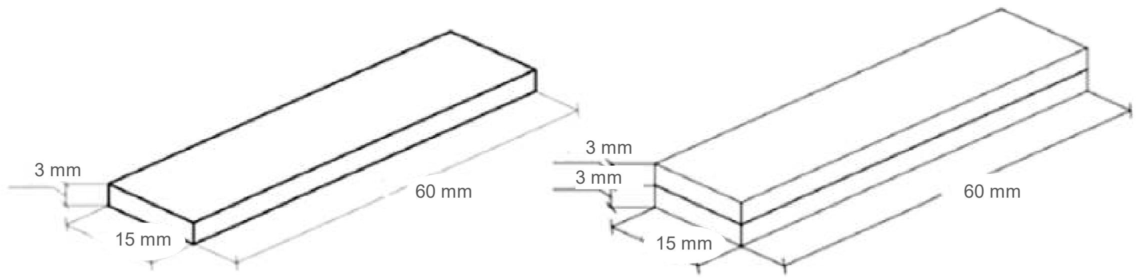
where τ is the durability of the material or the time to the beginning of one of the limiting states, s; R is the universal gas constant, kJ/mol·K; σ is stress, MPa; T is the temperature, K; τm, U_0, γ, T_m are thermal fluctuation constants.

Formula (1) is a modified Zhurkov formula and is referred to as the generalized Zhurkov equation. The modification was performed by S. B. Ratner and V. P. Yartsev by introducing into it the limiting temperature of the existence of a solid body, which did not cause a change in the physical interpretation of the thermal fluctuation constants included in the equation as well as the interpretation of the primary role of the thermal motion of kinetic units in the process of failure and deformation of solids. It should be noted that the above formula is insensitive to changes in the physical structure, which, in turn, causes a change in strength properties. There are various variants of special cases where there is a need to modernize the formula by introducing a coefficient [9].

1. Idenitfying a breaking load and durability. In this study, it is necessary to identify the transverse bending strength (breaking load) as well as the time from the moment a non-critical load is applied to the failure of the sample. For this purpose a number of tests are required [6, 16]. For the experiments, the RS-FOAM polyvinyl chloride material with a density of 0.55 g/cm^3 was adopted.

In order to identify the temperature-time-force equivalence, samples (in the form of beams) were made of polyvinyl chloride (Fig. 1). Experiments are conducted for a solid section and a composite section in two and three layers without the use of special bonds. The length of the samples was 6 cm. The cross section was rectangular ($b \times h$ = 1.5 cm × 0.3 cm).

a) b)



c)

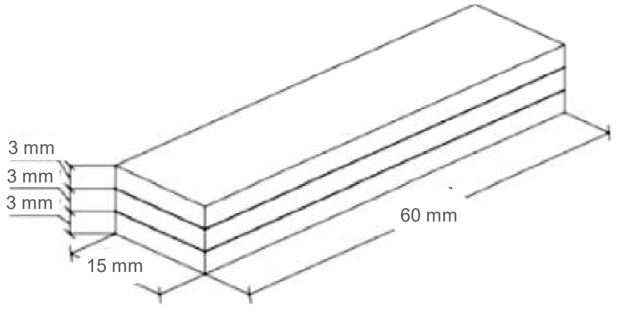


Fig. 1. Sample
for solid section tests (a)
and composite in two (b) and three layers (c)
with no special connections

For performing transverse bending and fracture tests, a six-position stand was employed (Fig. 2) [19, 20].

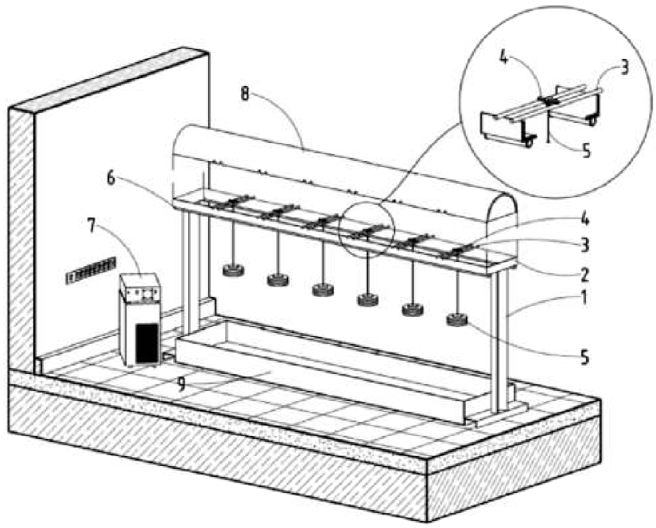


Fig. 2. Installation scheme
for testing:
1 — frame; 2 — support platform;
3 — roller bearings;
4 — test sample;
5 — cargo device;
6 — electric heater;
7 — LATR 1M 220V-9A
for temperature control;
8 — casing;
9 — damping tank with sand

The breaking load and durability (the time from the beginning of loading to the failure) are identified for three types of temperatures – 15, 30, 45 ºC. For each step of voltage reduction, at least 8 tests are performed under similar conditions followed by statistical processing. Then, based on the experimental data, graphs are plotted in the coordinates "lgτ – σ".

The next step is the standard rebuilding of the family of fan-shaped lines in the coordinates "lgτ – 1000/*T*". For such a rearrangement, three arbitrary stress values are selected that intersect the direct temperatures of the graph "lgτ – σ" in the first positive half-quarter. The points of intersection of the selected stresses with direct temperatures yield the coordinates of the points of direct stresses in the coordinate system "lgτ – 1000/*T*". In the case of direct and backward beams in the coordinates "lgτ – 1000/*T*", a family of fan-shaped straight lines is obtained, converging to a point called the pole. The pole coordinates yield two thermal fluctuation constants of the generalized Zhurkov equation out of four: lg τm and Tm.

The constants U_0 and γ are identified using the graph plotted in the coordinates "U_0 – σ". The constant U_0 is the value formed along the ordinate (U_0, kJ/mol) by the point of intersection of the straight line, and γ is the slope of the straight line taken with the opposite sign. This straight line is designed using three points with coordinates (σ_i; U_i).

2. Experimental studies of the durability of polyvinyl chloride samples. The results of experimental studies of the durability of solid PVC specimens depending on the temperature and stress are summarized in Table 1.

Table 1

Values of the decimal logarithm of time [sec] at the specified voltages and temperatures for a solid section after statistical data processing

Average value of the logarithm of durability and the boundaries of the confidence interval at the temperature											
σ, MPa	15 °C			σ, MPa	30 °C			σ, MPa	45 °C		
	L	*M*	*H*		*L*	*M*	*H*		*L*	*M*	*H*
13.608	0.029	0.417	0.805	13.114	0.009	0.383	0.757	12.214	0.130	0.492	0.854
13.035	0.490	0.868	1.247	12.561	0.365	0.763	1.161	11.700	0.251	0.579	0.908
12.462	1.371	1.712	2.053	12.009	1.206	1.494	1.782	11.185	0.772	1.131	1.490
11.889	2.501	2.757	3.013	11.457	2.058	2.365	2.673	10.671	1.785	2.133	2.481
11.316	3.208	3.449	3.689	10.905	3.071	3.276	3.481	10.157	2.258	2.664	3.070

The graph in the coordinates "lgτ – σ" is shown in Fig. 3.

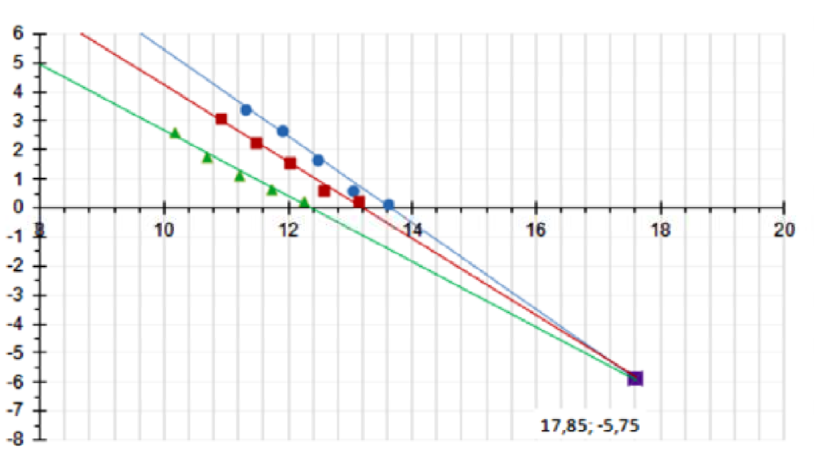


Fig. 3. "Direct beam" for samples of a solid section in the coordinates of the dependence of the logarithm of durability on the stress

For samples of a solid section, the straight-line dependence lg τ = *f* (σ) at the temperature of 15°C is described by the equation lg τ = –1.493(σ) + 20.365, the correlation coefficient is R^2 = 0.986. At the temperature of 30°C log τ = –1.324(σ) + 17.491 at R^2 = 0.988. At the temperature of 45°C log τ = –1.132(σ) + 14.012 at R^2 = 0.980.

While redesigning the "lgτ – σ" graph into the "lgτ – 1000/*T*" graph, stresses of 9, 10, 11 MPa were chosen. The straight-line dependence lg τ = *f* (1000/T) for the stress of 9 MPa is described by the equation lg τ = 9.455(1000/*T*) – 25.814 with the correlation coefficient R^2 = 0.989. The stress forward of 10 MPa is described by the equation lg τ = 8.356(1000/*T*) – 23.496, R^2 = 0.988. The stress forward of 11 MPa is described by the equation lg τ = 7.256(1000/*T*) – 21.178, R^2 = 0.986. From the position of the pole of the graph "lgτ – 1000/*T*", the first two constants are identified: log τm = –5.75 sec and Tm = 474 K.

The straight-line dependence for solid section samples $U^0 = f(\sigma)$ is described by the following equation: U_0 = –21.013(σ) + 369.831, R^2 = 1. The last two constants are identified using the equation: U_0 = 370 kJ/mol and γ = 21 kJ/(MPa · mol).

The results of the experimental studies of the durability of PVC samples of a composite cross section in two layers without special bonds depending on the temperature and stress are summarized in Table 2.

Table 2

Values of the decimal logarithm of time [sec] at the specified voltages
and temperatures for a composite section in two layers after statistical data processing

Average value of the logarithm of durability and the boundaries of the confidence interval at the temperature											
σ, MPa	15 °C			σ, MPa	30 °C			σ, MPa	45 °C		
	L	*M*	*H*		*L*	*M*	*H*		*L*	*M*	*H*
15.560	0.251	0.579	0.908	15.160	0.117	0.405	0.692	14.580	–0.088	0.270	0.628
15.232	0.380	0.872	1.364	14.841	0.172	0.589	1.007	14.273	0.147	0.559	0.970
14.905	1.350	1.671	1.992	14.522	0.645	1.157	1.669	13.967	0.568	0.953	1.337
14.577	2.673	3.098	3.523	14.203	1.553	2.035	2.516	13.660	1.404	1.794	2.184
14.249	3.395	3.682	3.969	13.884	2.817	3.201	3.586	13.353	2.471	2.790	3.108

The graph in the coordinates "lgτ – σ" is shown in Fig. 4.

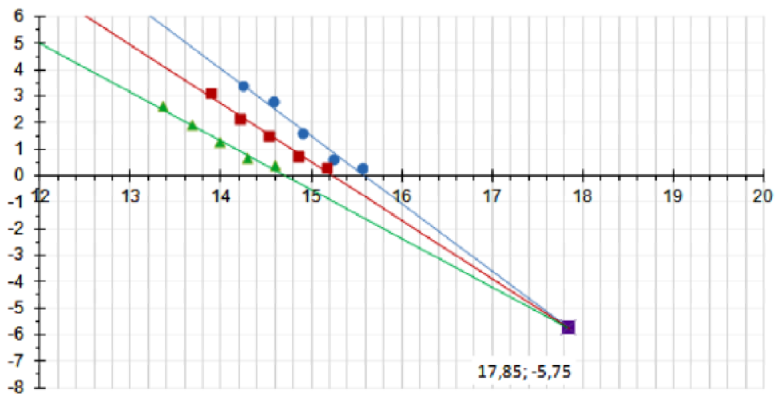


Fig. 4. "Direct beam" for specimens of compound section in two layers
in the coordinates of the dependence of the logarithm of durability on the stress

For specimens with a composite cross section in two layers, the linear dependence lg τ = *f* (σ) at the temperature of 15 °C is described by the equation log τ = –2.549(σ) + 39.747, the correlation coefficient is R^2 = 0.975. At the temperature of 30 °C log τ = –2.209(σ) + 33.668 at R^2 = 0.984. At the temperature of 45 °C log τ = –1.843(σ) + 27.154 at R^2 = 0.982.

While redesigning the "lgτ – σ" graph into the "lgτ – 1000/*T*" graph, the stresses of 12, 13, 14 MPa were chosen. The linear dependence lg τ = *f* (1000/*T*) for the stress of 12 MPa is described by the equation lg τ = 12.571 (1000/*T*) – 34.431 with the correlation coefficient R^2=0.997. The stress forward of 13 MPa is described by the equation lg τ =10.419(1000/*T*) – –29.519, R^2 = 0.996. The stress forward of 14 MPa is described by the equation lg τ = 8.268 (1000/*T*) – 24.607, R^2 = 0.998. Based on the position of the pole of the graph "lgτ–1000/*T*", the first two constants are identified: log τ*m* = –5.75 sec and *Tm* = 438 K.

The straight-line dependence for the samples with a composite cross section in two layers U_0 = *f* (σ) is described by the following equation: U_0 = –41.122(σ) + 733.733, R^2 = 1. The last two constants U_0 = 734 kJ/mol and γ = 41 are identified using the equation kJ/(MPa · mol).

The results of the experimental studies of the durability of PVC samples of a composite cross section in three layers without special bonds depending on temperature and stress are summarized in Table. 3. The graph in the coordinates "lgτ – σ" is shown in Fig. 5.

For the samples with a composite cross section in three layers, the linear dependence lg τ = *f* (σ) at the temperature of 15°C is described by the equation log τ = –3.544(σ) + 56.275, the correlation coefficient is R^2 = 0.985.

At the temperature of 30 °C log τ = –2.801(σ) + + 43.274 at R^2 = 0.984. At the temperature of 45 °C log τ = –2.334(σ) + 35.099 at R^2 = 0.972.

Table 3

Values of the decimal logarithm of time [sec] at the specified voltages and temperatures for a composite section in three layers after statistical data processing

Average value of the logarithm of durability and the boundaries of the confidence interval at the temperature											
σ, MPa	15 °C			σ, MPa	30 °C			σ, MPa	45 °C		
	L	*M*	*H*		*L*	*M*	*H*		*L*	*M*	*H*
15.861	0.121	0.464	0.807	15.358	0.143	0.442	0.741	14.881	0.112	0.436	0.760
15.611	0.443	1.050	1.658	15.116	0.449	0.814	1.178	14.646	0.245	0.675	1.106
15.361	1.656	1.966	2.276	14.873	1.379	1.755	2.132	14.411	1.025	1.416	1.807
15.110	2.682	3.167	3.653	14.631	1.974	2.355	2.736	14.176	1.445	1.814	2.182
14.860	3.419	3.702	3.986	14.388	2.833	3.225	3.616	13.941	2.557	3.026	3.495

While redesigning the "lgτ – σ" graph into the "lgτ – 1000/*T*" graph, the stresses of 12, 13, 14 MPa were chosen. The straight-line dependence lg τ = f (1000/*T*) for the stress of 12 MPa is described by the equation lgτ = 20.404 (1000/*T*) – 57.285 with the correlation coefficient R^2 = 0.991. The stress forward of 13 MPa is described by the equation lg τ = 16.701 (1000/*T*) – 47.938, R^2 = 0.989. The stress forward of 14 MPa is described by the equation lg τ = 12.998 (1000/*T*) – 38.551, R^2 = 0.990. Based on the position of the pole of the graph "lgτ – 1000/*T*", the first two constants are identified: log *τm* = -5.75 sec and *Tm* = 397 K.

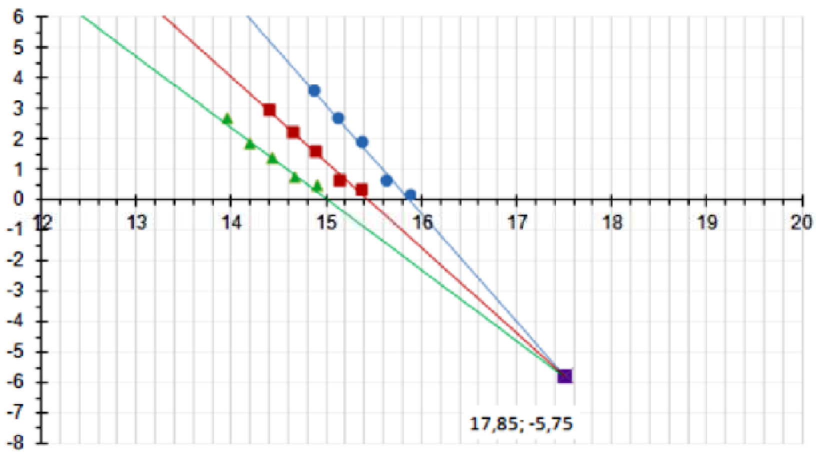


Fig. 5. "Direct beam" for the samples of compound section in three layers in the coordinates of the dependence of the logarithm of durability on the stress

The straight-line dependence for the samples with a composite cross section in three layers $U_0 = f(\sigma)$ is described by the following equation: $U_0 = -70.769(\sigma) + 1239.2$, $R^2 = 1$. The last two constants U_0 = 1240 kJ/mol and γ are identified using the equation = 71 kJ/(MPa · mol).

3. Identifying the coefficient for considering the configuration of the section in the generalized Zhurkov equation. The thermal fluctuation constants found using the above method for PVC elements of a solid cross section and a cross section in two and three layers with no special bonds are summarized in Table 4.

Table 4

Thermal fluctuation constants for solid PVC elements
and sections in two and three layers with no special connections

Section type	Empirical constants			
	$\lg\tau_m$, sec	T_m, K	U_0, kJ/mol	γ, kJ/(MPa · mol)
Solid section	–5.75	474	370	21
Composite with no special links in two layers	–5.75	438	734	41
Composite with no special links in three layers	–5.75	397	1240	71

In the all cases in question, the straight lines for PVC elements converge into a “direct beam”, which is a classical representation of the thermal fluctuation concept and thereby does not contradict it [10]. At the same time, the dependences for polyvinyl chloride samples of the solid cross section are similar to the previously obtained results [3]. These indicate a sufficient degree of reliability of the study and the adequacy of the results.

The results for wooden samples are based on those by previous researchers [4, 5, 8]. Thermal fluctuation constants for wooden elements of a solid section and sections in two and three layers with no special connections are presented in Table 5.

Table 5

Thermal fluctuation constants for solid wood elements
and sections in two and three layers with no special connections

Section type	Empirical constants			
	$\lg\tau_m$, sec	T_m, K	U_0, kJ/mol	γ, kJ/(MPa · mol)
Solid section	12.5	235	–172.14	–7.36
Composite with no special links in two layers	12.5	262	–359.00	–14.40
Composite with no special links in three layers	12.5	274	–1894.70	–40.06

As can be seen from Table 4 and 5, the constants lgτm and *Tm* (omitting the influence of the error) are insensitive to changes in the type of section (solid, composite of two and three elements) for both PVC and wooden elements. Moreover, the constants U_0 and γ for elements of composite sections in two layers with no special bonds differ exactly by a factor of two, regardless of the type of a material.

For elements of composite sections in three layers with no special bonds, there are differences of 3.5 times for PVC elements and 5.5 times for wooden samples. It is worth noting that the "–" sign of the constants U_0 and γ for wooden elements shows that the tree is characterized by a "reverse beam", which does not have any effect in the case of this work.

These relationships enable us to speak about the possibility of introducing a certain coefficient into the Zhurkov equation taking into account the configuration of the section while identifying the thermal fluctuation dependences and thus the overall durability of the structure. Hence the essence of the method is to introduce a coefficient into the generalized Zhurkov equation that considers changes in the constants U_0 and γ. The numerical value of the coefficient should be applied depending on the number of elements in the compound section with no special connections. Due to the fact that the factor (U_0 – γ σ) has a linear dependence and thus a linear relationship between the constants U_0 and γ, bracketing the factor can be considered correct. Hence the generalized Zhurkov equation will take the following form:

$$\tau = \tau_m \cdot \exp\left[k_c \cdot \left(\frac{U_0 - \gamma \cdot \sigma}{R} \cdot \left(T^{-1} - T_m^{-1}\right)\right)\right]. \quad (2)$$

It has been found that the factor k_c in the equation for a composite section of two layers with no special bonds for any type of material is $k_c = 2$. The factor k_c for a composite section of three layers with no special bonds varies from 3.5 to 5.5. Due to the fact that the meaning is not specific, it calls for some clarification. But based on the available information, it can be assumed that due to the complexity of the section, the tendency of PVC to isotropy, and wood, in turn, to anisotropy, may start having an effect. While performing studies aimed at identifying the thermal fluctuation constants of the generalized Zhurkov equation for wooden elements of solid and composite sections, it is necessary to make use of samples from the same batch, which is not always possible. The use of samples from different batches impacts the value of the resulting coefficient.

Conclusions

1. Based on the study, the patterns of deformation and failure of PVC elements of solid sections and composite sections with no a special connection in two and three layers are theoretically substantiated and experimentally identified.

2. Based on a comparative analysis with the values for wooden samples obtained in previous studies, it is suggested that a coefficient is introduced taking into account the configuration of the section of elements. For composite sections with no special bonds in two layers, this coefficient is $k_c = 2$. For elements of a composite section in three layers with no special bonds, the coefficient varies from 3.5 to 5.5 and calls for further clarification.

References

1. Andrianov K. A. *Prognozirovanie dolgovechnosti (rabotosposobnosti) penopolistirola v ograzhdayushchikh konstruktsiyakh zdanii*. Avtoref. diss. kand. tekhn. nauk [Forecasting the durability (operability) of expanded polystyrene in the enclosing structures of buildings. Cand. eng. sci. diss. abstr.]. Penza, 2002. 24 p.
2. Bondarev B. A., Korneeva A. O., Korneev O. O., Saakyan A. G., Vostrikov I. A. Vynoslivost' polimernykh kompozitsionnykh materialov karkasnogo tipa v elementakh konstruktsii deformatsionnykh shvov mostovykh sooruzhenii [Endurance of polymer composite materials of frame type in structural elements of deformation joints of bridge structures]. *Construction and Geotechnics*, 2020, vol. 11, no. 3, pp. 29—40.
3. Drannikov R. N., Erofeev A. V., Gorokhov T. I. [Determination of the initial data for calculating the thermal fluctuation constants of the generalized Zhurkov equation of polyvinyl chloride plates]. *Sovremennaya nauka: teoriya, metodologiya, praktika: materialy 2-i Vseros. (natsional'noi) nauch.-prakt. konf.* [Modern science: theory, methodology, practice: materials of the 2nd All-Russian. (national) scientific and practical conference]. Tambov, Izd-vo IP Chesnokova A. V., 2020, pp. 55—59.
4. Erofeev A. V., Skvortsov S. P., Mukhortov P. A. Mekhanizm razrusheniya tsel'nykh i sostavnykh derevyannykh balok bez spetsial'nykh svyazei s termofluktuatsionnoi pozitsii [The mechanism of destruction of solid and composite wooden beams without special connections from the thermal fluctuation position]. *Vestnik Kyrgyz-skogo-Rossiiskogo Slavyanskogo universiteta*, 2017, vol. 17, no. 12, pp. 80—84.
5. Erofeev A. V., Mukhortov P. A., Gorokhov T. I. [Thermofluctuation constants of wooden beams of composite section consisting of three elements]. *Sovremennoe sostoyanie i perspektivy raz-vitiya stroitel'noi nauki: materialy stud. konf.* [Current state and prospects of development of construction science: materials of the student. conf.]. Rasskazovo, Zvezdopad Publ., 2017, pp. 55—59.
6. Mamontov S. A., Yartsev V. P., Monastyrev P. V. Iskusstvennoe i estestvennoe starenie drevesno-voloknistogo kompozita [Artificial and natural aging of wood-fiber composite]. *Izvestiya vuzov. Tekhnologiya tekstil'noi promyshlennosti*, 2017, no. 1 (367), pp. 95—101.
7. Mikul'skii V. G., Sakharov G. P. *Stroitel'nye materialy (Materialovedenie. Tekhnologiya konstruktsionnykh materialov)* [Building materials (Materials Science. Technology of structural materials)]. Moscow, ASV Publ., 2011. 520 p.
8. Mukhortov P. A. Analiz termofluktuatsionnykh konstant obobshchennogo uravneniya Zhurkova derevyannykh elementov sostavnogo secheniya [Analysis of the thermofluctuation constants of the generalized Zhurkov equation of the elements of a composite section]. *Derzhavinskii forum*, 2019, pp. 150—159.

9. Ratner S. B., Yartsev V. P. [Influence of chemically active media on the physical constants of thermoplastics determining their resistance to mechanical destruction]. *Doklady AN SSSR* [Reports of the USSR Academy of Sciences], 1978, vol. 240, no. 6, p. 1394.
10. Ratner S. B., Yartsev V. P. *Fizicheskaya mekhanika plastmass. Kak prognoziruyut rabotosposobnost'?* [Physical Mechanics of Plastics. How do they predict performance?]. Moscow, Khimiya Publ., 1992. 320 p.
11. Chuvil'deev V. N., Viryasova N. N. *Deformatsiya i razrushenie konstruktsionnykh materialov: problemy stareniya i resursa* [Deformation and destruction of structural materials: problems of aging and resource]. N. Novgorod, NNGU Publ., 2010. 67 p.
12. Yartsev V. P. Zakonomernosti termofluktuatsionnogo razrusheniya vysokonapolnennykh rezinovykh smesei i rezin [Regularities of thermal fluctuation destruction of highly filled rubber mixtures and rubbers]. *Kauchuk i rezina*, 1989, no. 3, pp. 17—20.
13. Yartsev V. P. *Fiziko-tekhnicheskie osnovy rabotosposobnosti organicheskikh materialov v detalyakh i konstruktsiyakh*. Diss. d-ra tekhn. nauk [Physico-technical foundations of the operability of organic materials in parts and structures. Dr. eng. sci. diss.]. Voronezh, 1998. 350 p.
14. Kiseleva O. A., Yartsev V. P. *Physical basis of the performance of building materials made of wood*. Tambov, 2007. 236 p.
15. Korneeva A. O., Saprykin R. Y., Bondarev A. B. The influence of structure-forming factors on the properties of polymer composite material under static loading. *Solid State Phenomena*, 2018, vol. 284 SSP, pp. 163—166.
16. Loganina V. I., Uchaeva T. V., Monastyrev P. V. The method to estimate the surface appearance quality of the paint applied to the cement. Journal of engineering and applied sciences, 2016, vol. 11, no. 11, pp. 2409–2410.
17. Regel V. R., Slutsker A. I., Tomashevsky E. E. *The kinetic nature of the strength solids*. Moscow, Science Publ., 1974. 560 p.
18. Yartsev V. P., Kuznetsov V. A. The influence of density of mineral original plates on the sound insulation of partitions with a shell of cement-bonded wood boards. *The World of Science without Borders*, 2020, pp. 239—242.
19. Zhurkov S. N. The question of the nature of physical strength. *Solid State Physics*, 1980, vol. 22, no. 11, p. 3344.
20. Zhurkov S. N., Abasov S. A. The temperature and the time dependence of the strength of polymer yarns. *Polymer Science. Series A*, 1999, vol. 41, no. 12, pp. 1276—1282.