N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224-5278
Volume 6, Number 438 (2019), 64 – 69 **https://doi.org/10.32014/2019.2518-170X.156**

UDC 625.7/.8:691.16

A. I. Iskakbayev[1,2], B. B. Teltayev[2], G. M. Yensebayeva[1]

[1]Al-Farabi Kazakh National University, Almaty, Kazakhstan,
[2]Kazakhstan Highway Research Institute, Almaty, Kazakhstan.
E-mail: iskakbayeva@inbox.ru, bagdatbt@yahoo.com, Gulzat-y83@list.ru

MECHANICAL CHARACTERISTICS OF ASPHALT CONCRETE AT DIFFERENT LOADING RATES

Abstract. The results for experimental determination of characteristics have been given and analyzed in this article for deformation and failure of an asphalt concrete at two loading rates (0.058 and 0.652 MPa/s). Hot fine-grained dense asphalt concrete of type B prepared with viscous bitumen of grade BND 100/130 has been selected which is traditionally used in road construction. The tests have been performed at the temperature of 22-24°C in a specially invented and assembled device according to the scheme of direct tension. The asphalt concrete samples had a shape of rectangular beam with dimensions 5x5x15 cm.

It is found that loading rate effects greatly the characteristics of deformation and failure of an asphalt concrete: failure time and specific work of deformation are decreased in 8 times approximately, failure strain is decreased in 1.5 times and as much as that the strength is increased (failure at tension) at the loading rate increase in 11 times from 0.058 MPa to 0.652 MPa/s. From the moment of loading to the moment of failure the asphalt concrete is deformed nonlinearly. The rate of nonlinearity is increased with the load increase.

Key words: asphalt concrete, direct tension, loading rate, strain, specific work of deformation.

Introduction. Design conditions adopted for designing and calculation of pavement structures should as accurately as possible comply with real conditions where the sections of the designed highways operate. The load from vehicles and the speed of their movement play the defining part in the provision of strength and service life of the highway. It is known that the speed of vehicles on the road sections is varied considerably depending on specific road conditions [1-3]. It is also well known that deformability, strength and service life of many materials including the asphalt concrete ones depend on the value and load duration [4-6]. Thus, the matter of consideration of the deformability, strength and service life of the asphalt concretes at different loading rates (at various values and load durations) and various temperatures is practically of great importance.

An asphalt concrete has became an object of professional consideration since the 30s of the previous century. At present serious complex (experimental and theoretical) investigations are performed for the properties of asphalt concretes at different loading conditions and various temperatures in many countries of the world. The works of Kazakhstan scientists [7-21] can be included into the new direction of consideration for characteristics of strength and service life of asphalt concretes. This article is a continuation of the abovementioned works and it is devoted to the evaluation of the impact of the loading rate on the mechanical characteristics of an asphalt concrete.

Materials and method. In this paper bitumen of grade 100-130 has been used meeting the requirements of the Kazakhstan standard ST RK 1373-2013 [22]. The bitumen grade on Superpave is PG 64-40 [23]. Bitumen has been produced by Pavlodar processing plant from crude oil of Western Siberia (Russia) by the direct oxidation method.

Hot dense asphalt concrete of type B meeting the requirements of the Kazakhstan standard ST RK 1225-2013 [24] was prepared using aggregate fractions of 5-10 mm (20 %), 10-15 mm (13 %), 15-20 mm (10 %) from Novo-Alekseevsk rock pit (Almaty region), sand of fraction 0-5 mm (50 %) from the plant

"Asphaltconcrete-1" (Almaty city) and activated mineral powder (7%) from Kordai rock pit (Zhambyl region).

Bitumen content of grade 100-130 in the asphalt concrete is 4,8 % by weight of dry mineral material.

Samples of the hot asphalt concrete are prepared in form of a rectangular prism with length of 150 mm, width of 50 mm and height of 50 mm in two step procedures. The first step, the asphalt concrete samples were prepared in form of a square slab by means of the Cooper compactor (UK, model CRT-RC2S) according to the standard EN 12697-33 [25]. The second step, the samples were cut from the asphalt concrete slabs in form of a prism. Deviations in sizes of the samples did not exceed 2 mm.

A detailed information about standard characteristics of the bitumen and the asphalt concrete and about the asphalt concrete samples one can find in the authors' work [11] published earlier.

The tests have been performed at the temperature of 22-24°C in a specially invented and assembled device according to the scheme of direct tension. The asphalt concrete samples had a shape of rectangular beam with dimensions 5x5x15 cm. The loading rates were equal to 0.058 MPa/s and 0.652 MPa/s. The values of average and individual loading rates of the tested asphalt concrete samples are represented in table 1.

Table 1 – Average and individual loading rates at the tests of the asphalt concrete samples

Average loading rate, MPa/s	Loading rate, MPa/s	Individual numbers of the asphalt concrete samples
0.058	0.062	85
	0.058	111
	0.057	113
	0.057	114
	0.057	115
	0.057	116
0.652	0.650	127
	0.650	128
	0.646	129
	0.648	130
	0.664	131

Results and discussion. According to the test results performed under the method described in Section 2 the graphs have been constructed for variation of stress, strain, specific work of deformation in time and the graphs of dependence "stress-strain" at the selected two loading rates. By way of illustration the mentioned graphs for loading rate $\dot{\sigma}$ =0.058 MPa/s are shown in figures 1-4. As it is seen, the strain is varied to a significant degree nonlinearly (figure 2) at linear variation of stress in time (figure 1). Nonlinearity of the asphalt concrete strain is increased with the stress increase. It is seen in Figure 3 that it is difficult to distinguish some initial section within the limits of which it could be possible to adopt linear strain and to introduce an elasticity modulus.

As a consequence of nonlinear deformation, the specific work of deformation is also varied in time to a significant degree nonlinearly (figure 4). Meanwhile, the biggest values of the specific work of deformation occur at the moment of failure. We can also note that approximately during the first half of loading at all loading rates the specific energy has relatively small values; it has the biggest values in the last quarter of the loading process.

Important characteristics of failure are time of failure, strain, stress (strength) and specific work of deformation of the material at the moment of its failure. These characteristics for the tested asphalt concrete at the considered loading rates are represented in table 2. As it is seen a loading rate impacts greatly on the characteristics of failure of the asphalt concrete. For example, at the loading rate increase in 11 times (to be precise in 11.24 times) from 0.058 MPa/s to 0.652 MPa/s failure time and the specific

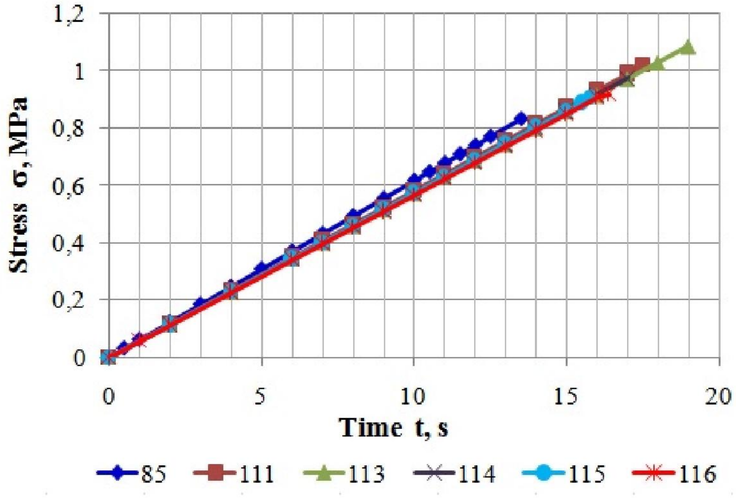

Figure 1 – Graphs for variation of stress in time
(average loading rate $\dot{\sigma} = 0.058$ MPa/s)

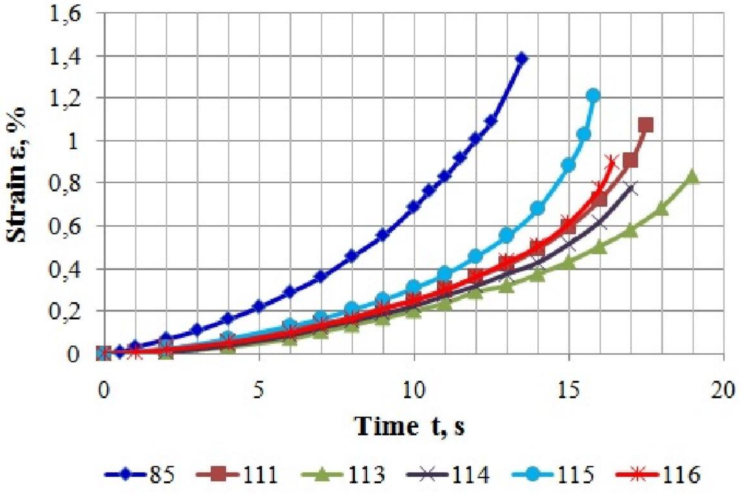

Figure 2 – Graphs for variation of strain in time
(average loading rate $\dot{\sigma} = 0.058$ MPa/s)

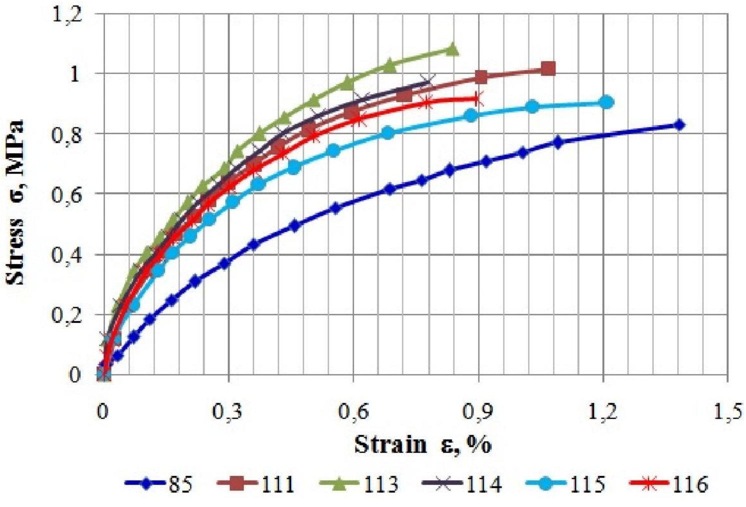

Figure 3 – Graphs of “stress-strain” relationship
(average loading rate $\dot{\sigma} = 0.058$ MPa/s)

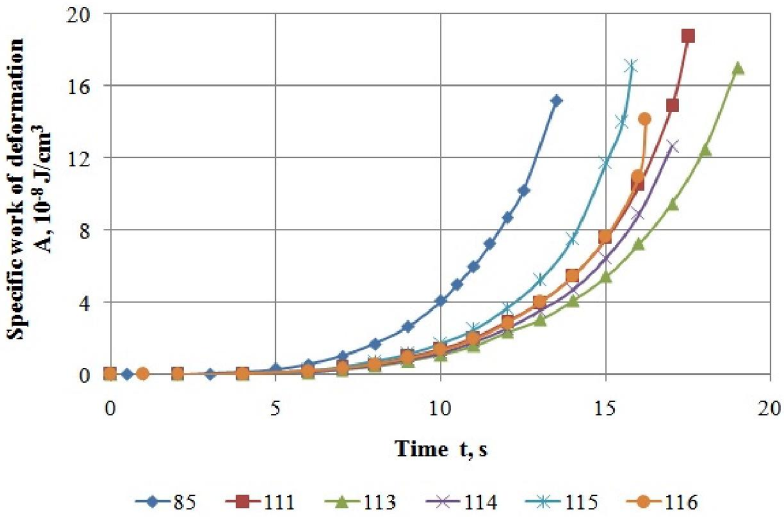

Figure 4 – Graphs for variation of specific work of deformation in time
(average loading rate $\dot{\sigma} = 0.058$ MPa/s)

Table 2 – Mechanical characteristics of the asphalt concrete at the moment of failure

Average loading rate $\dot{\sigma}$, MPa/s	Failure time t_f, s	Failure strain ε_f, %	Strength σ_f, MPa	Specific work of failure A_f, 10^{-8} J/cm^3
0.058	16.5	1.04	0.96	15.80
0.652	2.14	0.69	1.40	1.93
increase in 11.24 times	decrease in 7.71 times	decrease in 1.52 times	increase in 1.46 times	decrease in 8.19 times

work of deformation are decreased approximately in 8 times (to be precise in 7.71 and 8.19 times respectively); failure strain is also decreased, but far less – in 1.52 times; the strength is increased nearly in 1.5 times.

It is known that depending on specific and traffic conditions the vehicles move with different speeds along the highways (on various road sections). The results of experimental investigations performed in this work show that the characteristics of deformation and failure of an asphalt concrete depend greatly on the loading rate. The above regulations cause the idea that the highways should be divided into sections with the fixed estimated speeds for vehicles and the mechanical characteristics of asphalt concrete layers of an should be defined considering these estimated speeds at designing of pavement structures.

Conclusion. The results for determining of characteristics of deformation and failure of the asphalt concrete at direct tension at the temperature of 22-24°C at two loading rates differing in 11 times allowed drawing the following conclusions:

1. From the beginning of loading to the moment of failure the asphalt concrete is deformed non-linearly. The rate of nonlinearity is increased with the load increase. It is difficult to distinguish some initial section on the graph “stress-strain”, within the limits of which it could be possible to postulate linear strain and introduce elasticity modulus.

2. The loading rate impacts greatly on the characteristics of deformation and failure of the asphalt concrete: failure time and specific work of deformation are decreased approximately in 8 times at the loading rate increase in 11 times from 0.058 MPa/s to 0.652 MPa/s, in 1.5 times the strain of failure is decreased and as much as that the strength is increased.

3. On the designing stage highways should be divided into sections with the fixed estimated speeds of vehicles and mechanical characteristics of asphalt concrete layers should be defined considering these estimated speeds at designing of pavement structures.

4. As in real road conditions vehicles (medium and heavy) move along highways with the speeds varied within the wide limits (from 0 to 140-160 km/h and more), it is necessary to continue investigations for evaluation of loading rate impact on the characteristics of deformation and failure of asphalt concretes at other loading rates, temperatures and schemes of strain.

Ә. Ы. Ысқақбаев[1,2], Б. Б. Телтаев[2], Г. М. Еңсебаева[1]

[1]Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан,
[2]Қазақстан жол ғылыми-зерттеу институты, Алматы, Қазақстан

ЖҮКТЕУДІҢ ӘРТҮРЛІ ЖЫЛДАМДЫҒЫНДАҒЫ АСФАЛЬТБЕТОННЫҢ МЕХАНИКАЛЫҚ СИПАТТАМАЛАРЫ

Аннотация. Мақалада жүктеудің екі жылдамдығы кезінде (0,058 және 0,652 МПа/с) асфальтбетонның деформациялануы мен бұзылуының сипаттамаларын тәжірибелік анықтау нәтижелері берілді және талданды. Жол құрылысында дәстүрлі қолданылатын МЖБ 100/130 маркалы тұтқыр битумды қолданып әзірленген Б типті ыстық ұсақ түйіршікті тығыз асфальтбетон таңдалды. Сынақ жұмыстары 22-24 °С температурада тіке созылу схемасы бойынша арнайы жасалған қондырғыда орындалды. Асфальтбетон сынамалары өлшемі 5х5х15 см тікбұрышты арқалық пішінінде жасалды.

Жүктеме жылдамдығы асфальтбетонның деформациясы мен бұзылуының сипаттамасына қатты әсер етеді: жүктеу жылдамдығы 0,058 МПа/с-тан 0,652 МПа/с-қа дейін 11 есе өскен кезде бұзылу уақыты мен меншікті деформациялану жұмысы шамамен 8 есе азаяды, бұзылу деформациясы 1,5 есе кемиді және сонша есе беріктік (бұзылу кезіндегі кернеу) өседі. Жүктеу басталғаннан бұзылу сәтіне дейін асфальтбетон сызықсыз деформацияланады. Сызықсыздық дәрежесі жүктеменің артуымен бірге артады.

Түйін сөздер: асфальтбетон, тіке созылу, жүктеу жылдамдығы, деформация, меншікті деформациялану жұмысы.

А. Ы. Ыскакбаев[1,2], Б. Б. Телтаев[2], Г. М. Енсебаева[1]

[1]Казахский национальный университет им. аль-Фараби, Алматы, Казахстан,
[2]Казахстанский дорожный НИИ, Алматы, Казахстан

МЕХАНИЧЕСКИЕ ХАРАКТЕРИСТИКИ АСФАЛЬТОБЕТОНА ПРИ РАЗЛИЧНЫХ СКОРОСТЯХ НАГРУЖЕНИЯ

Аннотация. Рассматриваются особенности асфальтобетонного покрытия при двух скоростях нагружения (0,058 и 0,652 МПа/с). Даны результаты практического определения характеристик деформаций и разрушений. Использован вяжущий битум марки МЖБ 100/130, традиционно примененяемый в дорожном строительстве.

Выбран горячий мелкозернистый плотный асфальтобетон типа Б. Испытательные работы прямые – при температуре 22-24 °С выполнены на специально разработанной установке по схеме растяжения. Скорость загрузки сильно влияет на характеристики деформации и разрушения асфальтобетона Асфальтобетонная смесь с начала загрузки до момента разрушения нелинейно деформируется. Степень нелинейности увеличивается вместе с увеличением нагрузки.

Ключевые слова: асфальтобетон, прямая растяжка, скорость загрузки, деформация, собственная деформация, работа.

Information about authors:

Iskakbayev A. I., Doctor of Physical and Mathematical Sciences, Professor, Department of Mechanics, Al-Farabi Kazakh National University, Almaty, Kazakhstan; Kazakhstan Highway Research Institute, Almaty, Kazakhstan; iskakbayeva@inbox.ru; https://orcid.org/0000-0001-8730-9737

Teltayev B. B., Doctor of Technical Sciences, Professor, President of JSC "Kazakhstan Highway Research Institute", Almaty, Kazakhstan; bagdatbt@yahoo.com; https://orcid.org/0000-0002-8463-9965

Yensebayeva G. M., PhD-student, Department of Mechanics, Al-Farabi Kazakh National University, Almaty, Kazakhstan; Gulzat-y83@list.ru; https://orcid.org/0000-0002-8175-1644

REFERENCES

[1] Babkov V.F. Road and traffic conditions of the vehicles. Moscow, Transport, 1967, 224 p. (in Russ.).
[2] Drew D. Theory of traffic flows and their management. Moscow, Transport, 1972, 424 p. (in Russ.).
[3] Siliyanov V.V. Theory of traffic flows in designing of roads and organization of traffic. Moscow, Transport, 1977, 303 p. (in Russ.).
[4] Grushko I.M., Korolyov I.V., Borshch I.M., Mishchenko G.M. Road building materials. Moscow, Transport, 1991, 357 p. (in Russ.).
[5] Gezentswei L.B. Road asphalt concrete. Moscow, Transport, 1985, 350 p. (in Russ.).
[6] Zolotaryov V.A. Service life of road asphalt concretes. Kharkov, Visha Shkola, 1977, 116 p. (in Russ.).
[7] Iskakbayev A., Teltayev B., Alexandrov S. Determination of the creep parameters of linear viscoelastic materials. Journal of Applied Mathematics, 2016, pp. 1-6 (in Eng.).
[8] Alibay Iskakbayev, Bagdat Teltayev, Femistokl Andriadi, Kayrat Estayev, Elena Suppes, Ainur Iskakbayeva. Experimental research of creep, recovery and fracture processes of asphalt concrete under tension, Proceedings of the 24th International Congress of Theoretical and Applied Mechanics (XXIV ICTAM), 2016, Monreal, Canada, pp. 1-2 (in Eng.).
[9] Teltayev B.B., Iskakbayev A., Rossi C. Oliviero. Regularities of creep and long-term strength of hot asphalt concrete under tensile. Proceedings of the 4th Chinese-European Workshop on Functional Pavement Design, Cew 2016, Delft, The Netherlands, pp.169-178 (in Eng.).
[10] Iskakbayev A., Teltayev B., Oliviero Rossi C. Deformation and strength of asphalt concrete under static and step loadings. Transport Infrastructure and Systems. Proceedings of the AIIT International Congress on Transport Infrastructure and Systems (TIS 2017), Rome, Italy, 10-12 April 2017, pp. 3-8 (in Eng.).
[11] Iskakbayev A., Teltayev B., Rossi C. Oliviero. Steady-state creep of asphalt concrete. Applied Sciences, 2017, 7, p. 2-13 (in Eng.).
[12] Iskakbayev A., Teltayev B., Rossi C.O. Modeling of cyclic strength for the asphalt concrete considering damage accumulation. Applied Sciences, 2017, 7, pp. 2-11 (in Eng.).
[13] Teltayev B.B. Fresh approach to low temperature cracking in asphalt concrete pavement. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2016, 5 (419), p.161-178 (in Eng.).
[14] Teltayev B.B., Amirbayev Y.D. Experimental evaluation of strength for asphalt and polymer modified asphalt concretes at low temperatures. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2017, 1 (421), p.167-176 (in Eng.).
[15] Teltayev B.B. Evaluation of fatigue characteristics of hot mix asphalt with polymer additives. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2017, 1 (421), p.141-148 (in Eng.).
[16] Teltayev B.B. Importance of rocks in road construction. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2017, 3 (423), p.283-292 (in Eng.).
[17] Teltayev B.B. Fatigue failure of asphalt concrete pavement. 1. Self-organization and mechanical interpretation. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2017, 3 (423), p.256-275 (in Eng.).
[18] Teltayev B.B. Fatigue destruction of asphalt concrete pavement. 2. Thermodynamics. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2017, 4 (424), p.148-169 (in Eng.).
[19] Iskakbayev A., Teltayev B.B., Rossi CO., Yensebayeva G.M. Experimental investigation of an asphalt concrete deformation under cyclic loading. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2018, 2 (428), p.104-111 (in Eng.).
[20] Iskakbayev A., Teltayev B.B., Rossi CO., Estayev K. A new simple damage accumulation model for predicting of an asphalt concrete cyclic strength. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2018, 5 (431), p.38-47. doi.org/10.32014/2018.2518-170X.8 (in Eng.).
[21] Iskakbayev A., Teltayev B.B., Yensebayeva G.M., Kutimov K.S. Computer modeling of creep for hereditary materials by abel's kernel. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences, 2018, 6 (432), p.66-76. doi.org/10.32014/2018.2518-170X.36 (in Eng.).
[22] ST RK 1373-2005, Bitumen and bituminous binders. Oil road viscous bitumens, Technical specifications, Astana, Kazakhstan, 2005 (in Russ.).
[23] Superpave series No. 1. Performance graded asphalt binder specification and testing, Asphalt Institute, Lexington. 2003 (in Eng.).
[24] ST RK 1225-2013. Hot mix asphalt for roads and airfields. Technical specifications. Astana (in Russ.).
[25] EN 12697-33 (2003). Bituminous Mixtures. Test Methods for Hot Mix Asphalt. Part 33: Specimen prepared by roller compactor. European Committee for Standardization. Brussels (in Eng.).
[26] Sklyarov V., Skliarova I., Utepbergenov I., Akhmediyarova A.T., et al. Hardware accelerators for information processing in high-performance computing systems // International journal of innovative computing information and control. 2019. Vol. 15, Issue 1. P. 321-335.
[27] Akhmediyarova A., Kassymova D., Utegenova A., et al. Development and research of the algorithm for determining the maximum flow at distribution in the network // Open computer science. 2016. Vol. 6, Issue 1. P. 213-218.
[28] Karboz Zh.A., Dossayeva S. K. Issledovaniye vodorodopronitsayemosti membran, pokrytykh razlichnymi metallicheskimi plenkami (obzor) // Complex Use of Mineral Resources. 2019. N 3(310). P. 48-54 (in Russ.). https://doi.org/10.31643/2019/6445.28