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EXPERIMENTAL INVESTIGATION OF AN ASPHALT CONCRETE DEFORMATION UNDER CYCLIC LOADING

Abstract. In the paper results of experimental investigation of an asphalt concrete deformation under cyclic loading on the scheme of direct tension are presented. Two series of the conventional hot dense asphalt concrete were tested. Durations of loading and rest periods were equal to 600 seconds. A stress has been applied to the tested sample quickly (within 1 second) and kept constant for the following 600 seconds. Then the stress was removed quickly and the sample was free of stress for the following 600 seconds. In the next cycle a stress greater than the preceding one was applied to the sample. In the first and second series 10 an 12 samples of the asphalt concrete were tested. In the first of them cyclic stresses were equal to 0.041; 0.111; 0.148; 0.183 and 0.219 MPa, in the second one stresses were equal to 0.744; 1.448; 2.232 and 2.976 MPa. Test temperature was 22-24°C. The tests were carried out in an equipment constructed especially. The sample strain was measured by means of two clock typed indicators and was recorded in a video camera.

Results of the tests showed that in each cycle maximum creep strain of an asphalt concrete occurs in the end of loading period and maximum recovered strain occurs in the end of relax period. Both these strains increase with the growth of cycle number, but the increase rate of the first one is higher than of the second one. In the considered test conditions (durations of loading and relax periods equal to 600 seconds, values of applied stresses from 0.041 MPa till 3.0 MPa, temperature T=22-24°C) an asphalt concrete is a very plastic body: the total amount of plastic strain is equal to 80-87% from the strain achieved in the end of loading period in each cycle.

Key words: asphalt concrete, cyclic loading, loading period, rest period, stress, strain.

Introduction. An asphalt pavement of a highway mainly affected by multiple actions of mechanical stresses from truck wheels. Therefore experimental investigation of deformation and failure of an asphalt concrete under cyclic loadings with parameters close to real ones on highways is practically important.

Regarding asphalt concrete the specialists know well so-called the viscoelastic continuum damage mechanics approach (VECD) which is based on the extended elastic-viscoelastic correspondence principle proposed R.A. Schapery [1]. This approach, used for the first time by Little D.N. and Kim Y.R. [2-5], has been often applied by other researchers for characterization of asphalt concrete fatigue considering non-linear strain and healing [6, 7]. In the VECD- approach the physical strain and physical stiffness of the viscoelastic material (asphalt concrete) are replaced for their pseudo similarities, i.e. for pseudo strain and pseudo stiffness respectively, which are varied from one loading cycle to another. Calculation of pseudo strain requires knowledge of dynamic modulus and phase angle, which can be determined experimentally by appropriate devices.

In recent years experimental and theoretical investigations of deformation and failure processes of asphalt concretes under different conditions of loading were started by us [8-13]. This paper is a continuation of the above mentioned our works and it contains results of testing of an asphalt concrete under cyclic loadings.

Materials. In this paper bitumen of grade 100-130 has been used meeting the requirements of the Kazakhstan standard ST RK 1373-2013 [14]. The bitumen grade on Superpave is PG 64-40 [15]. 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 [16] 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 [17]. 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 [12] published early.

Experiment. Tests of hot asphalt concrete samples in a form of rectangular prism on cyclic creep were carried out according to the direct tensile scheme until a complete failure.

Two parts of cyclic tests were realized. In the first of them 10 asphalt concrete samples were tested. A stress has been applied to the tested sample quickly and kept constant for 600 seconds (figure 1). Then the stress was removed quickly and the sample was free of stress for the following 600 seconds. In consequent cycles values of the stress were equal to 0,041; 0,111; 0,148; 0,183 and 0,219 MPa respectively. In the second part 12 asphalt concrete samples were tested. In the test all conditions were the soune only excluding that values of the applied stress were 0,744; 1,448; 2,232 and 2,976 MPa. The test temperature was equal to 22-24 °C. The tests were carried out in a special assembled equipment, which allows applying a load to an asphalt concrete sample within 1 second. The sample strain was measured by means of two clock typed indicators and was recorded in a video camera. More detailed information about the equipment one can find in the authors' works [12].

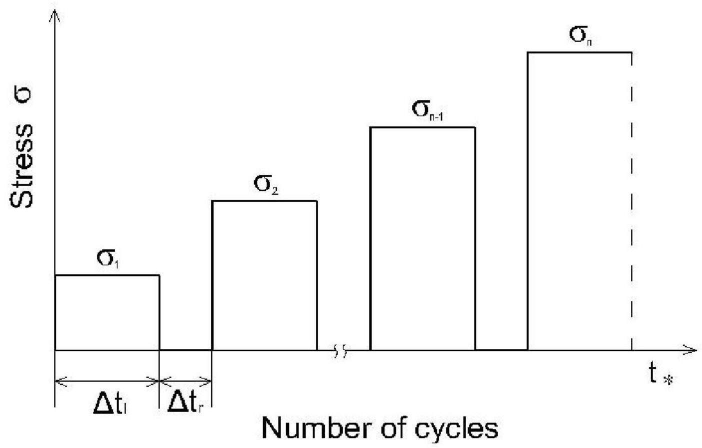

Figure 1 – Scheme of cyclic loading

Results and discussion. Figures 2 and 3 show the graphs of cyclic deformation for two asphalt concrete samples from the above mentioned tests parts respectively. The first sample (figure 2) have resisted to full 5 cycles "load-relax" and it was failed in the 6th cycle. The second of them (figure 3) have resisted to full 3 cycles, it was failed in the 4th cycle. Failure times were equal to 6067 and 3892 seconds respectively. Each cycle consists of loading period and relax period. The graphs, showing increasing of strain under stress and its recovery during relax period in cycles, are presented in figures 4-7. It is clearly seen how the increase of creep strain rate unde stress as well as the rate of its recovery during relax period increase with the growth of cycle number.

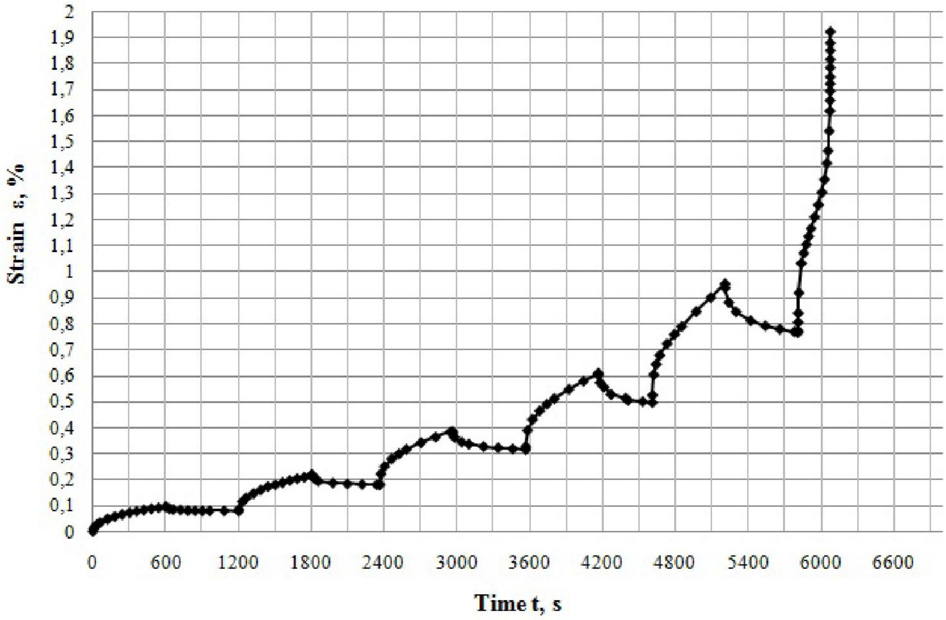

Figure 2 – Cyclic deformation of the asphalt concrete (sample No. 258)

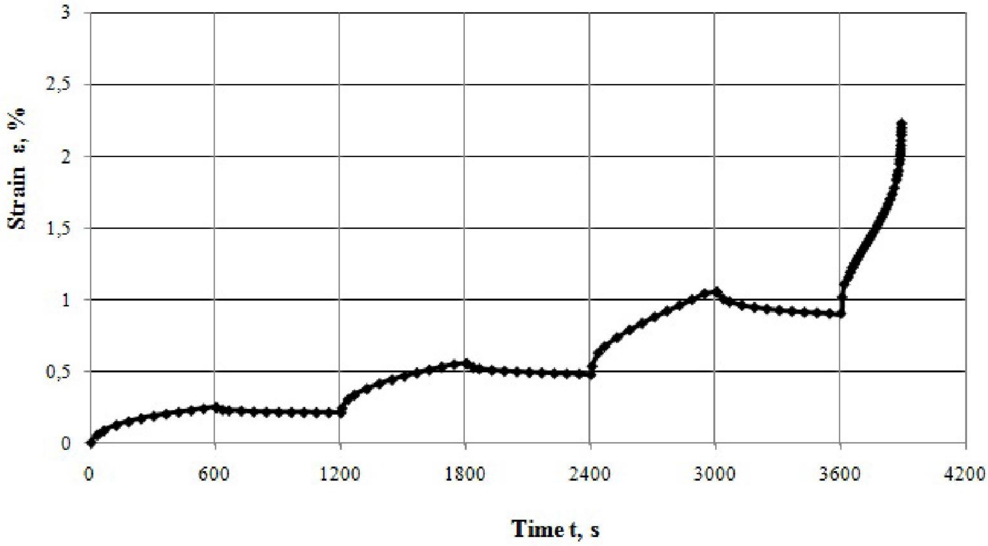

Figure 3 – Cyclic deformation of the asphalt concrete (sample No. 76)

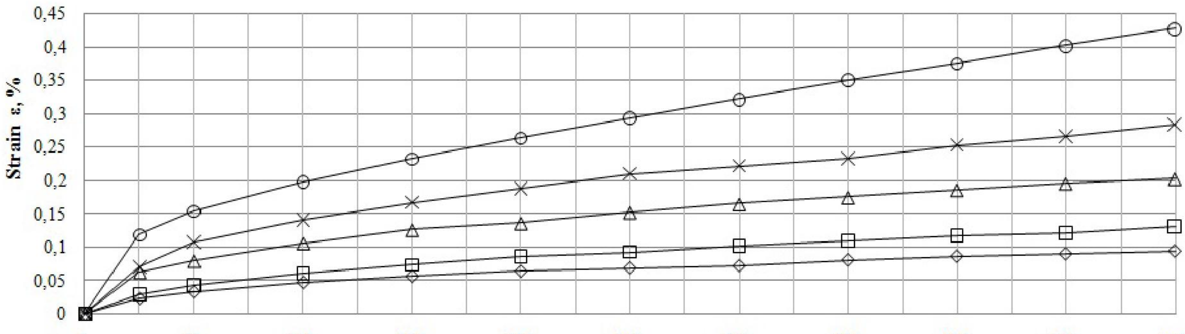

Figure 4 – Deformation of the asphalt concrete under stress in different cycles (Sample No.258)

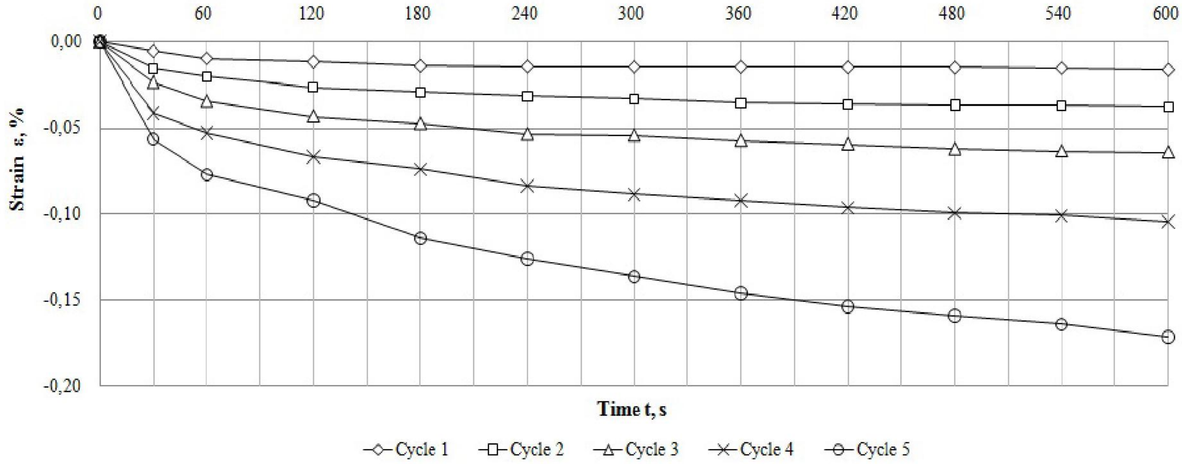

Figure 5 – Recovery of the asphalt concrete strain after removing of the stress in different cycles (Sample No. 258)

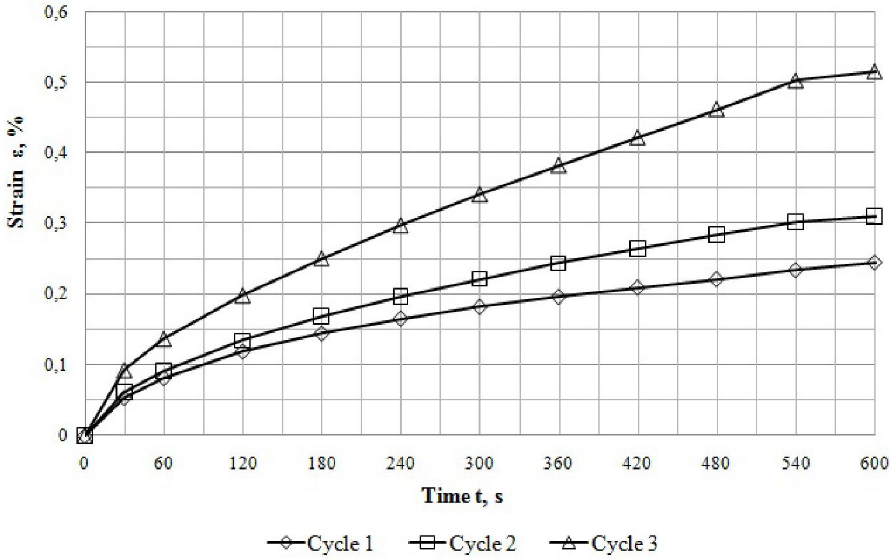

Figure 6 – Deformation of the asphalt concrete under stress in different cycles (Sample No.76)

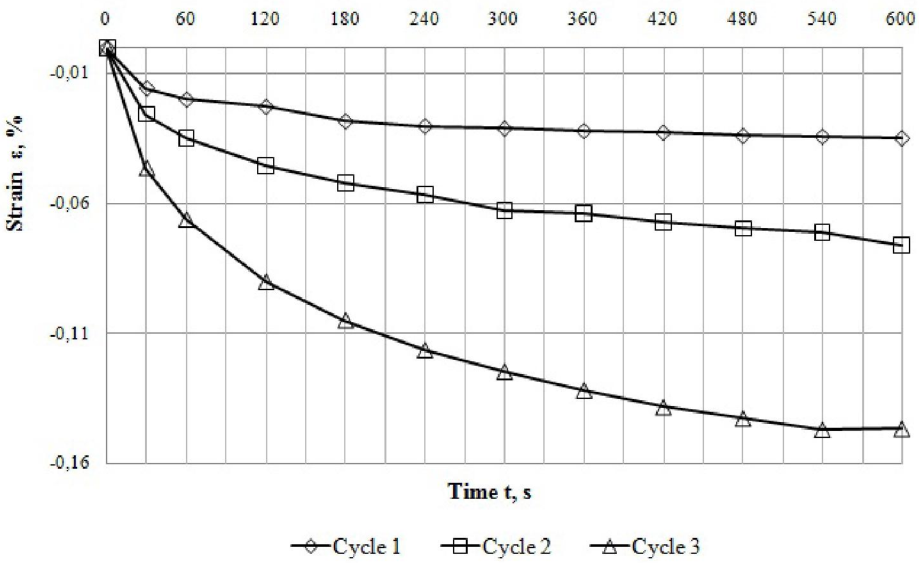

Figure 7 – Recovery of the asphalt concrete strain after removing of the stress in different cycles (Sample No. 76)

It is clear that maximum creep strain of each cycle occurs in the end of loading period and maximum recovered strain occurs in the end of relax period. As it is seen from the Figures 8 and 9, both these strains increase with the growth of cycle number, but the increase rate of the first one is higher than of the second one.

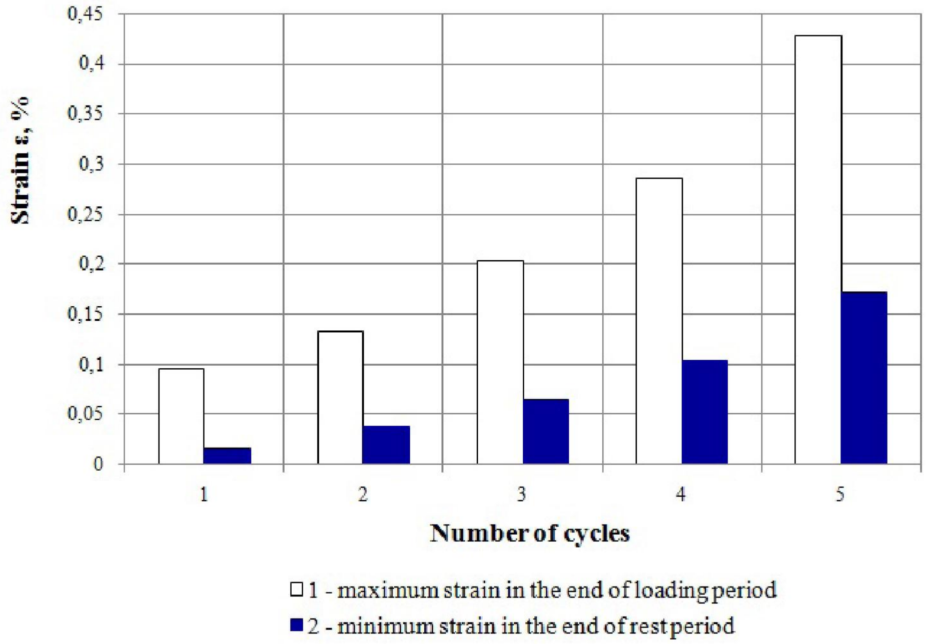

Figure 8 – Values of the maximum strain in the end of loading period and the minimum strain in the end of rest period (Sample No. 258)

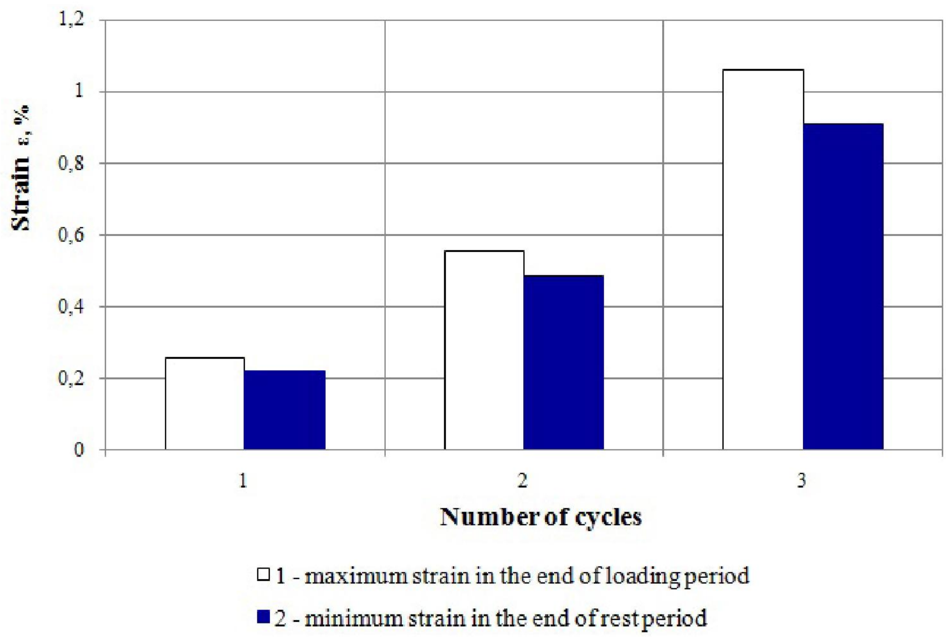

Figure 9 – Values of the maximum strain in the end of loading period and the minimum strain in the end of rest period (Sample No. 76)

It was found that in the considered test conditions (durations of loading and relax periods, values of applied stresses, temperature) the asphalt concrete is a very plastic body: the amount of the plastic strain is equal to 80-87% from the total one achieved in the end of loading period in each cycle (tables 1 and 2).

Table 1 – Values of viscoelastic and plastic strains in cycles (Sample No. 258)

Number of cycle	Strain, %*	
	viscoelastic	plastic
1	17.8	82.2
2	17.3	82.7
3	18.0	82.0
4	18.2	81.8
5	19.6	80.4
*% from the maximum strain achieved in the end of loading period.		

Table 2 – Values of viscoelastic and plastic strains in cycles (Sample No. 76)

Number of cycle	Strain, %	
	viscoelastic	plastic
1	15.0	85.0
2	13.0	87.0
3	14.2	85.8

Conclusions. In the work on the basis of the results obtained by experimental investigation of asphalt concretes deformation under cyclic loading the following conclusions may be made:

1. In each cycle maximum creep strain of an asphalt concrete occurs in the end of loading period and maximum recovered strain occurs in the end of relax period. Both these strains increase with the growth of cycle number, but the increase rate of the first one is higher than of the second one.
2. In the considered test conditions (durations of loading and relax periods equal to 600 seconds, values of applied stresses from 0.041 MPa till 3.0 MPa, temperature T = 22-24°C) an asphalt concrete is a very plastic body: the total amount of plastic strain is equal to 80-87% from the strain achieved in the end of loading period in each cycle.

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АСФАЛЬТБЕТОННЫҢ ЦИКЛДЫҚ ЖҮКТЕУДЕГІ ДЕФОРМАЦИЯЛАНУЫН ТӘЖРИБЕЛІК ЗЕРТТЕУ

Аннотация. Мақалада асфальтбетонның созылудағы циклдық деформациялануын тәжрибелік зерттеу нәтижелері берілген. Дәстүрлі тығыз асфальтбетон үлгілерінің екі сериясы сынақтан өтті. Жүктеу және тынығу периодтарының ұзақтықтары 600 секунд болып қабылданды. Асфальтбетон үлгісіне жылдам (1 секундтың ішінде) кернеу жүктелді және ол келесі 600 секунд бойы тұрақты қалпында сақталды, одан кейін кернеу жылдап алынып, келесі 600 секунд бойы үлгі кернеусіз күйде болды. Келесі циклда үлгіге бұрынғыдан үлкен кернеу жүктелді. Бірінші және екенші серияларда 10 және 12 асфальтбетон үлгілері сыналды. Бірінші серияда кернеу мәндері 0,041; 0,111; 0,148; 0,183 және 0,219 МПа, ал екенші серияда 0,744; 1,448; 2,232 және 2,976 МПа болды. Сынақ температурасы 22-24°С. Сынақтар арнайы жасалған қондырғыда жүргізілді. Үлгілердің деформациялары сағат тәрізді индекаторлар көмегімен өлшенді және бейнекамераға жазылды.

Сынақ нәтежелері әр циклда асфальтбетонның ең үлкен деформациясы жүктеу периодының соңында, ал ең үлкен қайту деформациясы тынығу периодының соңында болатынын көрсетті. Бұл деформациялар циклдар санының артуына қарай өседі, бірақ олардың алғашқысының өсу жылдамдығы соңғысынікінен үлкен. Қарастырылған жағдайда (жүктеу және тынығу периодтарының ұзақтығы 600 секунд, кернеулер мәні 0,041-3,0 МПа аралығында, температура Т = 22-24 °С) асфальтбетон өте пластикалық дене болып табылады: пластикалық деформация мөлшері жүктеу периодының соңындағы жалпы деформацияның 80-87%-ын құрайды.

Түйін сөздер: асфальтбетон, циклдық жүктеу, жүктеу периоды, тынығу периоды, кернеу, деформация.

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ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ДЕФОРМИРОВАНИЯ АСФАЛЬТОБЕТОНА ПРИ ЦИКЛИЧЕСКОМ НАГРУЖЕНИИ

Аннотация. В статье представлены результаты экспериментального исследования деформирования асфальтобетона при циклическом нагружении по схеме прямого растяжения. Было испытано две серии образцов традиционного плотного асфальтобетона. Продолжительности периода нагружения и периода отдыха были выбраны равными 600 секунд. Образцу асфальтобетона быстро (в течение 1 секунды) прикладывалось напряжение и в течение 600 секунд оно сохранялось постоянным, затем напряжение быстро снималось и в течение последующих 600 секунд образец оставался свободным от напряжения. В следующем цикле образцу прикладывалось напряжение большее чем предыдущее. В первой и второй сериях были испытаны 10 и 12 образцов асфальтобетона. В первой серии напряжения в циклах были равными 0,041; 0,111; 0,148; 0,183 и 0,219 МПа, а на второй серии – 0,744; 1,448; 2,232 и 2,976 МПа. Температура испытания 22-24°С. Испытания были проведены в специально созданной установке. Деформации образцов измерялись посредством двух индикаторов часового типа и записывались видеокамерой.

Результаты испытаний показали, что в каждом цикле максимальная деформация асфальтобетона имеет место в конце периода нагружения и максимальная восстанавливаемая деформация имеет место в конце периода отдыха. Обе эти деформации увеличиваются с увеличением числа циклов, но скорость увеличения первой из них больше, чем у последней. В рассмотренных условиях (длительности периодов нагружения и отдыха равны 600 секунд, значения приложенных напряжений от 0,041 МПа до 3,0 МПа, температура Т = 22-24 °С) асфальтобетон является очень пластическим телом: величина пластической деформации составляет 80-87 % от общей деформации, достигнутой в конце периода нагружения.

Ключевые слова: асфальтобетон, циклическое нагружение, период нагружения, период отдыха, напряжение, деформация.

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