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Strength and deformation conditions of large deformation-resistant asphalt slabs lying on an elastic base

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Abstract

This article discusses the stress and deformation conditions of high-deformation-resistant asphalt concrete slab coatings lying on an elastic base.

Keywords: stress-strain state, strength, stiffness, displacement, deflection, elastic modulus, dangerous section, differential equation, cylindrical bending, articulation, normal and tangential stresses, stiffness.

Introduction

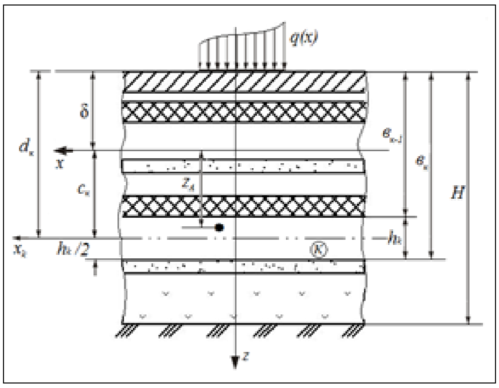
It is known that in our developing country, as in all areas, the President pays special attention to the development of road construction. In the development of the economy of our country, in the development of the new Uzbekistan, along with rail and air transport, the development of road and transport infrastructure also plays an important role in the delivery of household goods.

One of the most pressing issues is to improve the quality and long-term durability of roads in the Fergana Valley of Uzbekistan, to increase their resistance to dynamic deformation, freezing, corrosion and hot and cold external environment. That is why our state pays special attention to this issue.

One of the ways to improve the quality of highways is to increase the strength and durability of asphalt concrete pavements. Therefore, many foreign and domestic scientists are currently conducting research on this issue.

This research was carried out in accordance with the State Scientific and Technical Program for 2017-2021. In order to implement the issues provided for in the program of decrees and resolutions of the President of the Republic of Uzbekistan dated February 7, 2017 PF-4947 "On the Action Strategy for further development of the Republic of Uzbekistan, the program of further development of regional roads in 2017-2020." These studies have been conducted. This study examines the properties of asphalt pavement materials resistant to large deformation in the conditions of Uzbekistan and their application.

Today in many developed countries: USA, Germany. In countries such as France and Japan, special attention is paid to the creation of advanced modern technologies to increase the durability and long-term durability of asphalt pavements operated in different natural climatic conditions that meet modern requirements that improve road quality. In this study, the issues of strength and durability of asphalt concrete rough road surfaces made using local materials were analyzed.



We see a study of the stress-strain state of cylindrical bending under the influence of external forces on automobile asphalt concrete pavements lying on an elastic ground.

The differential equation of bending of multilayer plates in the cylindrical bent position lying at the base of the winch has the following form.

$$D_{11}\frac{d^4w}{dz^4} = q - kw \quad (1)$$

Here for multi-layer plates: D_{11} - cylindrical thickness of the plate;
w is the desired cooling function, q is the intensity of the external propagating force; k is the coefficient of elastic base inclination;
For the Kirchhoff hypothesis (flat section hypothesis) to be true, the cylindrical stiffness of a multilayer slab is determined as follows. $D_{11} = \sum_{k=1}^{n}\left(D_k + B_k \cdot C_k\right)$ (2)

Here is $D_k = \frac{E_k \cdot h_k^3}{12\left(1-v_k^2\right)}$ - the specific cylindrical virginity of the k-layer;

$B_k = \frac{E_k \cdot h_k}{1-v_k}$ - specific stiffness in the elongation of the k-th layer;

$\delta = \frac{\sum_{k=1}^{n} B_k \cdot d_k}{\sum_{k=1}^{n} B_k}$ – the distance from the top plane of the plate to the plane of the neutral layer (Figure 1)

The normal stress in the cross section of the slab is determined as follows.

$$\sigma_x^k \approx \frac{E_k}{1-v_k^2} \cdot \frac{M_x}{D_{11}} \cdot z_A \quad (3)$$

Where Mx (kH) is the bending moment in a given section.
z_A is the coordinate of point A, which determines the normal voltage.

The test voltage is determined as follows. $\tau_{xz} \approx f_k \cdot \frac{Q}{D_{11}}$ (4)

Where Q (kH / m) is the transverse force on the given section of the slab.

$$f_k(z) = \frac{E_k\left[\left(b_{k-1}-\delta\right)^2 - z_A^2\right]}{2(1-v_k^2)} - \sum_{k=1}^{k-1} B_k C_k \quad (5)$$

(5)the formula “k” represents the law of distribution of transverse stresses in the layer, if $k \geq 2$
at k = 1, i.e. for a single-layer slab we have the following

$$f_1(z) = \frac{E_1\left[\delta^2 - z_A^2\right]}{2(1-v_k^2)} \quad (6)$$

we solve the equation by the method of marginal subtraction [2, 3].

$$\left(6 + k^*\lambda^4\right)w_i^* - 4\left(w_{i+1}^* + w_{i-1}^*\right) + w_{i+2}^* - w_{i-2}^* = q\lambda \quad (7)$$

Where

$$w^* = wD_{11}; \quad k^* = \frac{k}{D_{11}}$$

Based on the boundary conditions for the λ-step “i” node by the free edge of the plate, (5) can be written as follows. Boundary conditions are mainly [2, 3]

$$\left(5 + k^*\lambda^4\right)w_i^* - 2w_{i+1}^* - 4w_{i-1}^* + w_{i-2}^* = q_i\lambda^4 - M_{i+1}\lambda^2 \quad (8)$$

Here Mi + 1 is equal to the bending moment in the longitudinal direction of the plate.
(7) For node "i" is written as follows, the boundary conditions are mainly [2]

$$\left(2+k^{*}\lambda^{4}\right)w_i^{*}-4w_{i-1}^{*}+2w_{i-2}^{*}=\frac{q_i\lambda^{4}}{2}+4M_i\lambda^{2}-2Q_i\lambda^{3} \quad (9)$$

w_i -In addition to the bending moment, there is also a transverse force distributed along the longitudinal edge.

For the edge of the hinged connection $w_a^{*}=0$ Basically (5) the node "i" also includes the value of the slope of the outer node, which it w_i - can be expressed through stiffness.

$M_a=D_{11}\frac{d^2w}{dx^2}=\frac{d^2w^{*}}{dx^2}$ this condition is equal to the following in the method of marginal deductions $M_a\lambda^2=w_i^{*}-2w_a^{*}+w_в^{*}$

From this, if $w_a^{*}=0$ given that

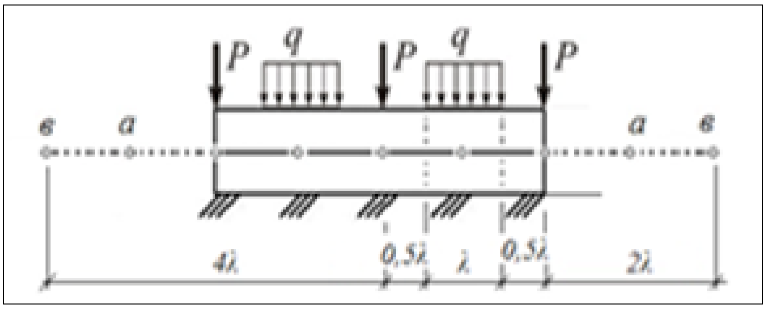
$$w_в^{*}=M_a\lambda^2-w_i^{*} \quad (10)$$

$M_a=0$ for $w_в^{*}=-w_i^{*}$ (11)

If the side of the plate is virgin, then for this case: $\frac{dw_a^{*}}{dx}=0$ or by the method of marginal deductions $\frac{\left(w_i^{*}-w_в^{*}\right)}{2\lambda}=0$

From this $w_в^{*}=w_i^{*}$ (12)

Based on the given boundary conditions, we see the following three-layer asphalt concrete pavement (the structure of the layers is given in Figure 5 and the coefficient of elastic ground).P=30 кН, q=80 кН/м, λ=1м, E_1 =3,3·10^4 Мпа, E_2 =8·10^2 Мпа, E_3 =100 Мпа, $v_1=v_2=v_3$=0,3, h_1=0,16 м, h_2=0,26 м, h_3=0,4 м, d_1=0,08 м, d_2=0,29 м, d_3=0,62 м, k=50 МН/м^3



We determine the stiffness of each layer in elongation as follows. $B_1=\frac{E_1h_1}{1-v_1}=\frac{3,3\cdot10^4\cdot0,16}{1-0,2}=66\cdot10^2\,МПа\cdot м$

$$B_2=\frac{E_2h_2}{1-v_2}=\frac{8\cdot10^2\cdot0,26}{1-0,2}=2,6\cdot10^2\,МПа\cdot м$$

$$B_3=\frac{E_3h_3}{1-v_3}=\frac{100\cdot0,4}{1-0,2}=0,5\cdot10^2\,МПа\cdot м$$

Determine the state of the neutral layer affected by the largest tangential stresses:

$$\delta=\frac{B_1d_1+B_2d_2+B_3d_3}{B_1+B_2+B_3}=\frac{\left(66\cdot0,08+2,6\cdot0,23+0,5\cdot0,62\right)\cdot10^2}{\left(66+2,6+0,5\right)\cdot10^2}=0,092\ м$$

In this case, the distance of each layer to the center of gravity is as follows C_1=0,012 м, C_2=0,198 м, C_3=0,528 м.

We calculate the specific cylindrical virginity of each layer $D_1=\frac{E_1h_1^3}{12\left(1-v_1^2\right)}=\frac{3,3\cdot10^4\cdot0,16^3}{12\left(1-0,2^2\right)}=11,73МН\cdot м$;

$$D_2=\frac{E_2h_2^3}{12\left(1-v_2^2\right)}=\frac{8\cdot10^2\cdot0,26^3}{12\left(1-0,2^2\right)}=1,22MH\cdot м$$

$$D_3=\frac{E_3h_3^3}{12\left(1-v_3^2\right)}=\frac{100\cdot0,4^3}{12\left(1-0,2^2\right)}=0,56MH\cdot м$$

then we determine the cylindrical virginity of the plate;

$$D_{11}=\left(D_1+B_1C_1^2\right)+\left(D_2+B_2C_2^2\right)+\left(D_3+B_3C_3^2\right)=\left(11,73+66\cdot10^2\cdot0,012^2\right)+$$
$$+\left(1,22+2,6\cdot10^2\cdot0,198^2\right)+\left(0,56+0,5\cdot10^2\cdot0,528^2\right)=39,81MHм$$

Determine the coefficient of inclination of the elastic ground;

$$k^*=\frac{k}{D_{11}}=\frac{50}{39,81}=1,26\frac{1}{м^4}$$

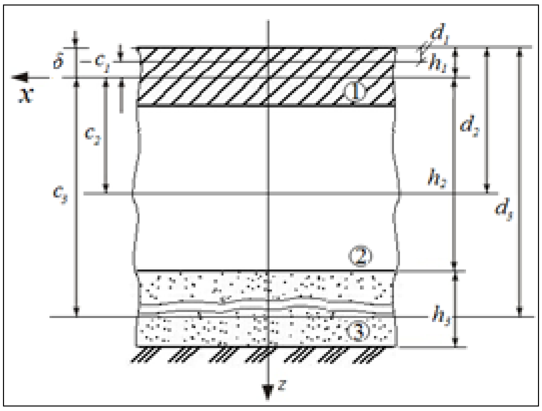
From the symmetry of the plate calculation form (Fig. 2) we determine the slope for only 3 nodes.
We write for 1 node. Given $q_1=2P/\lambda$ conditionally equation (7)

$$\left(6+k^*\lambda^*\right)w_1^*-4\left(w_2^*+w_2^*\right)+w_3^*+w_3^*=2P\lambda^4/\lambda$$

For 2 nodes we construct equation (8). In this case, we take into account the condition M3 = 0 at q2 = q. In that case, the second equation is as follows.

$$\left(5+k^*\lambda^4\right)w_2^*-2w_3^*-4w_1^*+w_2^*=q\lambda^4$$

The third equation is constructed based on the given slope on the third node, which is similar in appearance to (9), that is, under the conditions q3 = 0, a Q3 = P, it follows. $\left(2+k^*\lambda^4\right)w_3^*-4w_2^*+2w_1^*=-2P\lambda^3$



Thus we have formed a system of equations with respect to the following three unknowns.

$$\begin{cases}\left(6+k^*\lambda^4\right)w_1^* & -8w_2^* & +2w_3^*= & 2P\lambda^3\\ -4w_1^*+\left(6+k^*\lambda^4\right)w_2^* & -2w_3^*= & q\lambda\\ 2w_1^* & -4w_2^* & +\left(2+k^*\lambda^4\right)w_3^*=-2P\lambda^3\end{cases}$$

If we put the values of λ and k * and multiply the second equation by 2, we get the following symmetric form.

$$\begin{cases} 7,26w_1^* & -8w_2^* + 2w_3^* = \quad 60 \\ -8w_1^* + 14,52w_2^* - 4w_3^* = 120 \\ 2w_1^* & -4w_2^* + 2,26w_3^* = -60 \end{cases}$$

Solving the equation is given in nodes $w_i^*, МН \cdot м^2$ -determine the magnitudes

$$w_1^* = 43,62 \cdot 10^{-3};\ w_2^* = 29,99 \cdot 10^{-3};\ w_3^* = -8,36 \cdot 10^{-3};$$

Actual values of stiffness,

$$w_i = \frac{w_i^*}{D_{11}}(i = 1,2,3) \quad ; \quad w_1 = \frac{43,62 \cdot 10^{-3}}{39,81} = 1,10 \cdot 10^{-3} м = 1,10 мм$$

$$w_2 = \frac{29,99 \cdot 10^{-3}}{39,81} = 0,75 \cdot 10^{-3} м = 0,75 мм \quad ; \quad w_3 = -\frac{8,36 \cdot 10^{-3}}{39,81} = 0,21 \cdot 10^{-3} м = -0,21 мм$$

We determine the normal stresses by determining the pressure in the slab floor.

$$\sigma_{z_i} = -kw_i \quad (i = 1,2,3); \quad \sigma_{z_1} = -50 \cdot 1,10 \cdot 10^{-3} = -55 \cdot 10^{-3} МПа;$$

$$\sigma_{z_2} = -50 \cdot 0,75 \cdot 10^{-3} = -37,5 \cdot 10^{-3} МПа; \ \sigma_{z_3} = -50 \cdot (-0,21 \cdot 10^{-3}) = 10,5 \cdot 10^{-3} МП$$

We determine the values of the bending moments at each node.

$$M_i = -D_{11}\frac{d^2 w_i}{dx^2} = -\frac{d^2 w_i^*}{dx^2} = \frac{w_{i-1}^* - 2w_i^* + w_{i+1}^*}{\lambda^2}; \ M_1 = -\frac{w_2^* - 2w_1^* + w_2^*}{\lambda^2} = \frac{-(2 \cdot 29,99 - 2 \cdot 43,62) \cdot 10^{-3}}{1^2} = 27,26 \cdot 10^{-3} МН$$

$$M_2 = -\frac{w_3^* - 2w_2^* + w_1^*}{\lambda^2} = \frac{-(-8,36 - 2 \cdot 29,99 + 43,62) \cdot 10^{-3}}{1^2} = 24,72 \cdot 10^{-3} МН; \ M_3 = 0$$

We determine the transverse force values at each node in the plate calculation form.

$$Q_i = D_{11}\frac{d^3 w_i}{dx^3} = \frac{d^3 w_i^*}{dx^3} = \frac{2w_{i-1}^* - 2w_{i+1}^* + w_{i+2}^* + w_{i-2}^*}{2\lambda^3}$$

$$Q_1 = \frac{2w_2^* - 2w_2^* + w_3^* + w_3^*}{2\lambda^3} = 0 \quad ; \quad Q_2 = \frac{2w_3^* - 2w_1^* + w_2^* + w_a^*}{2\lambda^3} = 0$$

In this w_a^* value $M_3 = \frac{w_a^* - 2w_3^* + w_2^*}{\lambda^2} = 0$ conditionally.

$w_a^* = 2w_2^* - w_2^*$ In that case

$$Q_2^{сл} = \frac{w_2^* - w_1^*}{\lambda^3} = \frac{(29,99 - 43,62) \cdot 10^{-3}}{1^3} = -13,63 \cdot 10^{-3} \ МН/м \quad ; \quad Q_3^{сл} = -P = -30 \cdot 10^{-3} \ МН/м$$

$$Q_2^{сл} = \frac{w^* - w_2^*}{\lambda^3} = \frac{(43,62 - 29,99) \cdot 10^{-3}}{1^3} = 13,63 \cdot 10^{-3} \ МН/м \quad ; \quad Q_3^{сл} = P = 30 \cdot 10^{-3} \ МН/м$$

The bending moment in the dangerous section of the plate - M_{max} we construct a diagram of the stresses extending along the height of the plate for the cut obtained. σ_x^k -we use links (3) to determine.

$$\sigma_x^{(1)} \approx \frac{E_1}{1 - v_1^2} \cdot \frac{M_{max} \cdot z_1}{D_{11}} = \frac{3,3 \cdot 10^4 \cdot 27,26 \cdot 10^3 \cdot (-0,092)}{(1 - 0,2^2 \cdot 39,81)} = -2,16 МПа$$

$\sigma_x^{(2)} = 0$ so in $z_2 = 0$

$$\sigma_x^{(3)} = \frac{E_1}{1 - v_1^2} \cdot \frac{M_{max} \cdot z_3}{D_{11}} = \frac{3,3 \cdot 10^4 - 27,26 \cdot 10^3 \cdot 0,068}{(1 - 0,2^2) \cdot 39,81} = 1,6 МПа$$

$$\sigma_x^{(4)} = \frac{E_2}{1 - v_2^2} \cdot \frac{M_{max} \cdot z_4}{D_{11}} = \frac{8 \cdot 10^4 \cdot 27,26 \cdot 10^3 \cdot 0,068}{(1 - 0,2^2) \cdot 39,81} = 3,89 \cdot 10^{-2} МПа$$

$$\sigma_x^{(6)} = \frac{E_2}{1-\nu_2^2}\cdot\frac{M_{\max}\cdot z_6}{D_{11}} = \frac{800\cdot 27,26\cdot 10^{-3}\cdot 0,328}{\left(1-0,2^2\right)\cdot 39,81} = 18,7\cdot 10^{-2}\,МПа$$

$$\sigma_x^{(7)} = \frac{E_3}{1-\nu_3^2}\cdot\frac{M_{\max}\cdot z_7}{D_{11}} = \frac{100\cdot 27,26\cdot 10^{-3}\cdot 0,328}{\left(1-0,2^2\right)\cdot 39,81} = 2,34\cdot 10^{-2}\,МПа$$

$$\sigma_x^{(9)} = \frac{E_3}{1-\nu_3^2}\cdot\frac{M_{\max}\cdot z_9}{D_{11}} = \frac{100\cdot 27,26\cdot 10^{-3}\cdot 0,728}{\left(1-0,2^2\right)\cdot 39,81} = 5,19\cdot 10^{-2}\,МПа$$

Qмах –we see a diagram of the applied stresses along the plate height at the dangerous section of the plate obtained. $\tau_{\max}^{(k)}$ we determine the values at each point on which the values are determined based on (4) as follows.

$$\tau_{x2}^{(1)} = f_1\frac{Q_{\max}}{D_{11}} = 0\cdot\frac{30\cdot 10^{-3}}{39,81} = 0;\quad f_1 = \frac{E_1\left(\delta^2 - z_1^2\right)}{2\left(1-\nu_1^2\right)} = \frac{3,3\cdot 10^4\left(0,092^2 - 0,092^2\right)}{2\left(1-0,2^2\right)} = 0$$

$$\tau_{x2}^{(2)} = f_2\frac{Q_{max}}{D_{11}} = 145,9\cdot\frac{30\cdot 10^{-3}}{39,81} = 119\cdot 10^{-3}\text{МПа};\quad f_2 = \frac{E_1(\delta^2 - z_2^2)}{2(1-\nu_1^2)} = \frac{3,3\cdot 10^4(0,092^2 - 0^2)}{2(1-0,2^2)} = 145,9\text{МН}$$

$$\tau_{xz}^{(3)} = \tau_{xz}^{(4)} = f_3\frac{Q_{\max}}{D_{11}} = 66\cdot\frac{30\cdot 10^{-3}}{39,81} = 49,7\cdot 10^{-3}\,МПа;\ f_3 = \frac{E_1\left(\delta^2 - z_3^2\right)}{2\left(1-\nu_1^2\right)} = \frac{3,3\cdot 10^4\left(0,092^2 - 0,068^2\right)}{2\left(1-0,2^2\right)} = 66МН$$

$$\tau_{xz}^{(5)} = f_5\frac{Q_{\max}}{D_{11}} = 64,8\cdot\frac{30\cdot 10^{-3}}{39,81} = 48,82\cdot 10^{-3}\,МПа;$$

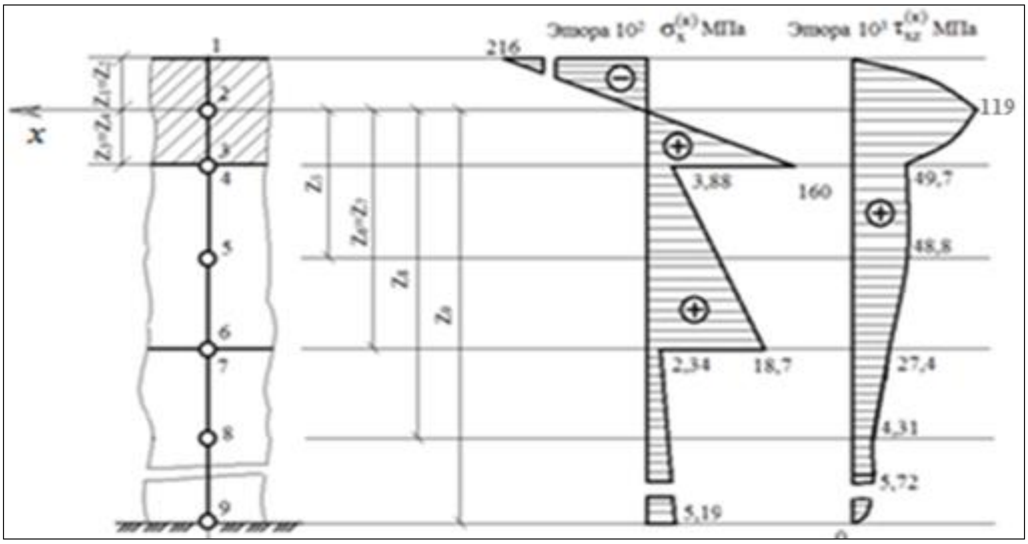
$$f_3 = \frac{E_2\left[\left(в_1 - \delta\right) - z_5^2\right]}{2\left(1-\nu_2^2\right)} - B_1C_1 = \frac{800\cdot\left[\left(0,18 - 0,092\right)^2 0,198^2\right]}{2\left(1-0,2^2\right)} - 66\cdot 10^2\left(-0,012\right) = 36,3МН$$

$$\tau_{xz}^{(8)} = f_8\frac{Q_{\max}}{D_{11}} = 18,8\cdot\frac{30\cdot 10^{-3}}{39,81} = 14,2\cdot 10^{-3}\,МПа;\quad f_8 = \frac{E_3\left[\left(в_2 - \delta\right)^2 - z_8^2\right]}{2\left(1-\nu_3^2\right)} - \left(B_1C_1 + B_2C_2\right) =$$

$$= \frac{100\cdot\left[\left(0,42 - 0,092\right)^2 - 0,528^2\right]}{2\left(1-0,2^2\right)} - \left[66\cdot 10^2\left(-0,012\right) + 2,6\cdot 10^2\cdot 0,198\right] = 18,8МН$$

$$\tau_{xz}^{(9)} = f_9\frac{Q_{\max}}{D_{11}} = 5,72\cdot\frac{30\cdot 10^{-3}}{39,81} = 4,31\cdot 10^{-3}\,МПа;\quad f_9 = \frac{E_3\left[\left(в_2 - \delta\right)^2 - z_9^2\right]}{2\left(1-\nu_3^2\right)} - \left(B_1C_1 + B_2C_2\right) =$$

$$= \frac{100\cdot\left[\left(0,42 - 0,092\right)^2 - 0,728^2\right]}{2\left(1-0,2^2\right)} - \left[66\cdot 10^2\left(-0,012\right) + 2,6\cdot 10^2\cdot 0,198\right] = 5,72МН$$



Slab contraction joints should intersect at the openings for columns σ_x normal and τ_{xz} – tangential stresses $\tau_{xymax} = 119$ МПа we build the diagrams (Figure 4)

We check the strength of the concrete layer on the top layer of the slab for elongation and shear..

Elasticity module $E_1=3,3\cdot10^4$ Мпа concrete type V40 corresponds to the accepted, in this case the limit normative strength in elongation at bending is equal to $R_u^{(н)} = 5,7$ МПа. The calculated tensile strength of concrete is as follows [1, 4]

$R_{pu} = 0,85 \cdot R_u^{(н)} \cdot k_u$ (11)

Here 0,85 - k_u –coefficient taking into account the size of the standard beam-sample due to the coefficient taking into account the increase in strength of concrete over time, $R_u^{(н)}$–normative strength of concrete grade to elongation in bending (QMQ II - 47 - 80 «Aerodromy») In that case for V40 concrete

$$R_{pu} = 0.85 \cdot 5.7 \cdot 1.15 = 5,57 \text{ МПа}$$

In that case $\sigma_{max} = \sigma_x^{(3)} = 1.6\text{МПа} < R_{pu} = 5,57\text{МПа}$ $\tau_{max} = \tau_x^{(2)} = 1.19\text{МПа} < [\tau] = 3,12\text{МПа}$

We can see that the result of the given calculation fully satisfies the stability conditions. This indicates that multi-layer pavements can be widely used in road construction in the design of rough pavement structures and in the design work of pavements, checking the resistance of concrete to bending and elongation.

Special additives have been added to these asphalt concrete pavements. This, in turn, has led to an increase in the strength of coatings, improvement of long-term durability, deformation work and an increase in the level of resistance to the external environment of the Fergana Valley by 20-30%.

Several types of special asphalt concrete pavements have been developed, and it turned out that the properties of asphalt pavements resistant to large deformations that we offer have good performance in all physical and mechanical parameters compared to works produced abroad. These parameters were tested experimentally using a new device created [4].

Compared with theoretical studies, the results of the study showed that the relatively high strength of asphalt concrete pavements resistant to large deformations increased the impact on shear deformation by 15-20%.

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