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On the Rheological Model of Asphalt Concrete

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ABSTRACT

Since asphalt concrete exhibits elastic, plastic, and viscous properties in response to changes in temperature and external influences, establishing a relation-ship between stress and deformation is an important issue. The study of the elastic and viscosity properties of physical bodies began in 1868 with the introduction of the con-cept of relaxation by Maxwell. In 1890, Kelvin introduced the concept of retardation (subsequent effect). Different models have been proposed to establish the above-men-tioned relationship. Models such as Maxwell, Kelvin, Jeffries, Lesersich, Bingham, Burgers, Shvedov, Hutchek, and Crassus have been proposed. Despite the large num-ber of models offered, they are based on and are a combination of Hooke, Newton, and Saint-Venan models for elastic, viscous, and plastic bodies.

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INTRODUCTION

The Maxwell model consisted of the sum of the Hooke and Newton models (Fig-ure 1). The Maxwell model did not take retardation (delay of deformation) into acco-unt when considering relaxation. In the Kelvin-Foyxt model (Figure 2), relaxation is not observed [2]. Similarly, the advantages and disadvantages of the remaining mo-dels can be shown.

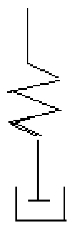	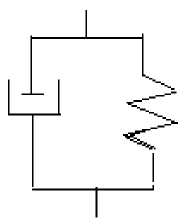	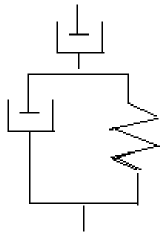
Fig.1. Maxwell model.	Fig.2. Kelvin-Foyxt model	Fig.3.Lesersich model.

In 1874, a general linear connection was proposed by L.Boltzmann, and all the models shown were described by L. Boltzmann. It can be obtained as a special case of the Boltzmann's connection [4].

The movement of a viscoplastic medium is characterized by peculiar features. Thus, when a viscoplastic medium is pushed through a round pipe, the central part of the flow is not deformed and moves like a solid, only a certain annular layer adjacent to the pipe walls is deformed.

The description of complex mechanical properties of materials requires the use of mul-tie-lement models characterized by a large number of parameters. The models discussed in

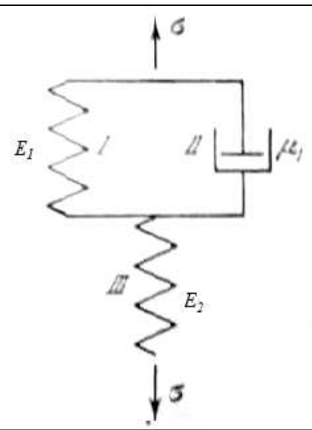	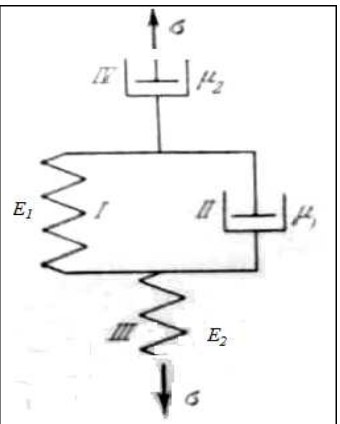
Fig.4.	Fig. 5.

the previous paragraphs contained two parameters (E, σ_s or E, μ or σ_s, μ). The model shown in Fig. 4. contains three parameters E_1 E_2, μ_1. The deformation law of such a medium can be obtained as follows: we write the deformation laws of simple elements I, II, III.

$$\sigma_s = E\varepsilon_1, \sigma_2 = \mu_1 \frac{d\varepsilon_2}{dt}, \sigma_3 = E\varepsilon_3 \qquad (1)$$

and conditions of equilibrium and continuity

$$\sigma_1 + \sigma_2 = \sigma \ , \sigma_3 = \sigma \ , \varepsilon_1 + \varepsilon_3 = \varepsilon, \varepsilon_1 = \varepsilon_2 \quad (2)$$

From here we easily find:

$$E_1\varepsilon + \mu_1 \frac{d\varepsilon}{dt} = \left(1 + \frac{E_1}{E_2}\right)\sigma + \frac{\mu_1}{E_2}\frac{d\varepsilon}{dt}. \qquad (3)$$

An example of a model with four parameters E_1, E_2, μ_1, μ_2 is shown in Fig.5. An example of a 2*n*-parametric model is shown in Fig.6.

With a large number of elements of the same type, it is convenient to switch to a model with a continuous distribution of parameters; deformation of such a model will be defined by some integral.

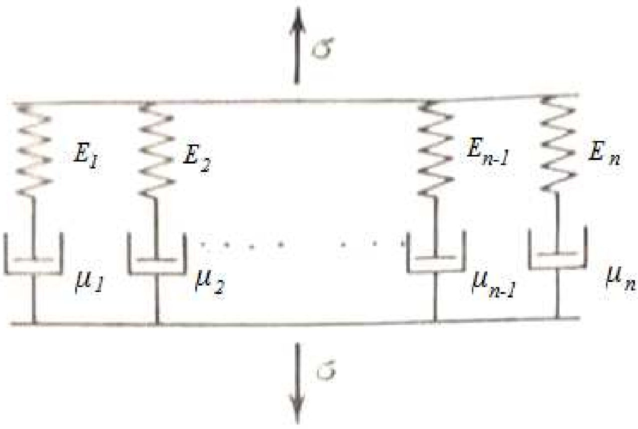

Fig.6.

The properties of many real materials cannot be satisfactorily described using the considered models, even with the introduction of a significant number of parameters. On the other hand, the use of complex multielement models is associated with the cumbersomeness of the mathematical apparatus.

A compact form of the general linear law of deformation was proposed by L. Boltzmann. This law is based on the principle of superposition of deformations.

Let the stress σ (τ) be applied to the body at the moment of time τ during a small time interval Δτ; the latter caused some deformation, which, when the stress is removed, will not disappear immediately, but will gradually decrease. Let us assume that this deformation at an arbitrary moment t> τ is proportional to the magnitude of the acting stress σ (τ), the duration of the action Δτ, and some decreasing function depending on the time elapsed since the moment τ. Thus, at the moment t> τ the deformation will have the value

$$\varphi(t-\tau)\sigma(\tau)\Delta\tau \qquad (4)$$

where $\varphi(t\text{-}\tau)$ is a monotonically decreasing function characteristic of a given material .

If, in addition, at the moment t the stress σ (τ) acts on the body, then the latter, according to Hooke's law, will cause instant deformation; total deformation at time t has the form:

$$\varepsilon(t) = \frac{\sigma(t)}{E} + \varphi(t-\tau)\sigma(\tau)\Delta\tau. \qquad (5)$$

By virtue of the superposition principle, the influence of the stress σ (τ) acting at the moment τ is not disturbed by the stresses applied at other moments of time. There-fore, if stresses σ (τj) acted at different times τj during time intervals Δτj, then the de-formation at time t is determined by the sum

$$\varepsilon(t) = \frac{\sigma(t)}{E} + \sum \varphi(t-\tau_j)\sigma(\tau_j)\Delta\tau_j \qquad (6)$$

Today, the above-mentioned complex properties of asphalt concrete are almost taken into account in the Boguslavsky model (Fig. 8), which generalizes the Maxwell (Fig.1), Kelvin-Foyxt model (Fig.2), Lesersich (Fig.3), and Burgers (Fig.7) models [3].

In the Boguslavsky model, the differential equation between the stress and deformation formed in asphalt concrete takes the following form [2]:

$$\theta\tau E \frac{d^2\varepsilon}{dt^2} + \frac{d\varepsilon}{dt}(2\eta + \tau E) + \varepsilon E = \theta \frac{d\sigma}{dt} + \sigma \quad (7)$$

The solution of this equation concerning eating a single load is as follows.

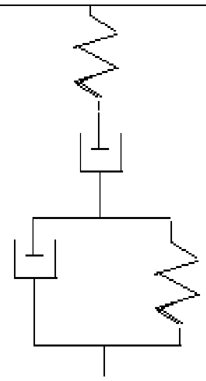	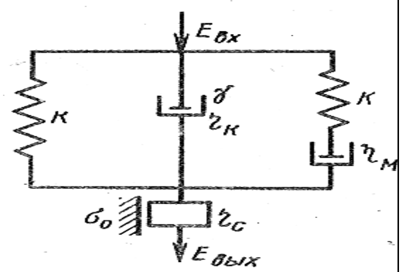
Fig.7. Burgers model.	Fig. 8. Generalized model.

$$\varepsilon_{\text{Д}} = \varepsilon_{\text{ЭК}} + \varepsilon_{\text{П}} = \frac{(1+P_1\theta)P_2}{(P_1-P_2)} \cdot \frac{\sigma}{E} e^{-P_1 t} + \frac{\sigma}{E}\left[1 + \frac{(1+P_2\theta)P_1}{P_1-P_2} e^{-P_2 t}\right] + \frac{\sigma t}{\eta}, \qquad (8)$$

The quantities involved in this equation and their units of measurement are as follows:

P_1 and P_2- kinetic characteristics of asphalt concrete, 1 / c;

$$P_1, P_2 = -\frac{\theta + 0{,}5\tau}{\theta\tau} \pm \sqrt{(\frac{\theta + 0{,}5\tau}{\theta\tau})^2 - \frac{1}{\theta\tau}} \quad (9)$$

θ- relaxation time, c; σ- stress, Mpa; τ - retardation time, c; t - stress expo-sure time, c; η – viscosity coefficient n.s / cm2; $\varepsilon_П$- plastic deformation; $\varepsilon_{ЭК}$- elastic- viscous part of deformation; $\varepsilon_Д$ – total deformation; E- modulus of elasticity, Мпа ; e- natural logarithm basis.

The relative deformation after multiple loads is determined as follows [3]:

$$\varepsilon_{Д\Sigma} = \frac{K_r\sigma}{E}(0{,}5 - e^{-P_2 t})T_1 \sum_{i=0}^{i=n-1} (0{,}5 e^{-P_1\lambda})^i + \frac{K_r\sigma\tau'}{\eta}(1 - e^{-(\tau')^{-0,5}}) \quad (10)$$

K_r- coefficient of reduction of vertical stress to horizontal stress, T_1 - the number of loads of imported vehicles, $T_1 = K_0 K_П\ m_1\ m_2$, n- the number of downloads per hour, m_1- coating temperature 50^0C and the number of hours per day that are higher, m_2 - coating temperature in three years 50^0C and the number of days higher, K_0 - co-efficient taking into account the number of arrows, $K_П$ - a factor that takes into account the width of the pavement and the location of the plot. λ - rest duration between downloads, τ' - total duration of downloads,

$$\tau' = tnT_1$$

P_1, P_2 are the kinetic characteristics of the deformation process (9) spreading the equation to Taylor's row, dropping infinitely small terms, we obtain the following.

$$P_1 = -\frac{0{,}5}{\theta},\ P_2 = -\frac{2}{\tau},\ \text{and } P_1/P_2 = 0{,}25\ \tau/\theta \quad (11)$$

The result (10) looks like this:

$$\varepsilon_{Д\Sigma} = \frac{K_r\sigma}{2E}(1 - e^{\frac{2t}{\tau}})T_1 \sum_{i=0}^{i=n-1} (0{,}5 e^{\frac{0.5\lambda}{\theta}})^i + \frac{K_r\sigma\tau'}{\eta}(1 - e^{-(\tau')^{-0,5}}) \quad (12)$$

After unloading

$$\varepsilon^0_{Д\Sigma} = \frac{K_r\sigma}{2E}(1 - e^{\frac{2t}{\tau}})T_1 \sum_{i=0}^{i=n} (0{,}5 e^{\frac{0.5\lambda}{\theta}})^i + \frac{K_r\sigma\tau'}{\eta}(1 - e^{-(\tau')^{-0,5}}) \quad (13)$$

This is the denominator under the sum sign in the equation $0{,}5 e^{\frac{0.5\lambda}{\theta}} < 1$ is a geo-metric progression. Use the formula for the sum of the steps, instead (12) we create an equation

$$\varepsilon_{Д\Sigma} = \frac{K_r\sigma}{2E}(1 - e^{\frac{2t}{\tau}})T_1 \frac{(0{,}5e^{\frac{0.5\lambda}{\theta}})^{n-1} - 1}{0{,}5e^{\frac{0.5\lambda}{\theta}} - 1} + \frac{K_r\sigma\tau'}{\eta}(1 - e^{-(\tau')^{-0,5}}) \quad (14)$$

To verify this equation, a sample (similar to practical experiments) was calcula-ted by taking the problem.

$\tau = 46\ c$, $\theta = 4000c$; $\frac{P_1}{P_2} = 0{,}003$; $E = 70МПа$; $\sigma = 0{,}8\ Мпа$; $\eta = 280000МПа \cdot c$; $t = 0{,}05c$ (speed 30km / h); $K_r = 0{,}3$; n=40/соат ; $\lambda = 60c$; m_1 =2; m_2 =124; $T_1 = 50$; $\tau' = 100$ in values, after some simplification, the numerical expression of (12) is equal to:

$$\varepsilon_{Д\Sigma} = \frac{0.24}{140}(1 - e^{\frac{0.1}{46}})\sum_{i=0}^{39}[(0{,}5\ e^{\frac{3}{400}})^0 + \ldots + (0{,}5 e^{\frac{3}{400}})^{39}] + \frac{0.24}{280000}(1 - e^{-\frac{1}{10}}) = 0{,}00172 \quad (15)$$

After unloading according to(13), $\varepsilon^0_{Д\Sigma}$=0,00078+0,00002=0,0008.

The calculations using the equation (14) overlapped with the results of the equ-ation in which the sum was involved.

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