Vibrocreep of concrete with a nonuniform stress state

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Abstract. We study the creep of concrete under stationary vibrations. Our considerations are connected with integral module of deformations. The influence of vibrocreep on bearing capacity of the reinforced concrete structure is considerable. Dependence between deformations and efforts is presented, structural damages of concrete are characterized by the temporary module of the line of deformations, the module of instant elastic deformations, nonlinearity function for efforts.

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Introduction

The creep of concrete was studied in many works, for example in [1-7]. It is known that the creep of statically loaded concrete increases under vibrational influence. This phenomenon is called the vibrocreep of concrete. On the basis of experiments the correlation was proposed [8]

$$C_v^*(\tau,t_0) = K \cdot C^*(\tau,t_0), \qquad (1)$$

where $C^*(\tau,t_0)$ and $C_v^*(\tau,t_0)$ are measure of creep and vibrocreep; τ is the current time; t_0 is the moment of loading; K is the vibrocreep factor.

Main part

The dependence between deformations and stresses is represented [9] by equality

$$\varepsilon_v(t,t_0) = \frac{\sigma(t) S_0[\sigma(t)]}{\mathrm{E}_v(t,t_0)}, \qquad (2)$$

$$\mathrm{E}_v(t,t_0) = \left[\frac{1}{E(t)} + \int_{t_0}^{t} \frac{C_v^*(t,\tau)}{\sigma(t)} d\sigma(\tau)\right]^{-1} \qquad (3)$$

Here $\mathrm{E}_v(t,t_0)$ is the temporary line module of deformations; $E(t)$ is the module of instantaneous elastic deformations; $S_0[\sigma(t)]$ is the function of nonlinearity for stresses, characterizing the structural damages of concrete.

At the end of half cycle the action

$$\sigma(\tau) = \sigma - \sigma_0 \cos\omega(\tau - t_0) \qquad (4)$$

implies the deformation

$$\varepsilon_v\left(t_0, t_0+\frac{\pi}{\omega}\right) = \left[\frac{\sigma+\sigma_0}{E\left(t_0+\frac{\pi}{\omega}\right)} + K\int_{t_0}^{t_0+\frac{\pi}{\omega}} \frac{C^*(t,\tau)}{\sigma\left(t_0+\frac{\pi}{\omega}\right)} d\sigma(\tau)\right] \cdot S_0\left[\sigma\left(t_0+\frac{\pi}{\omega}\right)\right] \qquad (5)$$

The factor $K(\omega,\gamma_1,\rho)$ is determined by the frequency ω, parameter γ_1, dependent on the open surface of concrete and asymmetry of stresses

$$\rho = \frac{\sigma_{\min}}{\sigma_{\max}}. \qquad (6)$$

By Davidenkov's invariant [10] is deduced [11] the equation

$$\frac{\partial K_v(\omega,\gamma_1,\rho)}{\partial\omega} + P(\omega,\gamma_1,\rho) K_v(\omega,\gamma_1,\rho) = 0 \qquad (7)$$

$$P(\omega,\gamma_1,\rho) = \frac{\partial Z(\omega)}{\partial\omega} \Big/ Z(\omega) \qquad (8)$$

$$Z(\omega) = \int_{t_0}^{t_0+\frac{\pi}{\omega}} \frac{C^*(t,\tau)}{\sigma\left(t_0+\frac{\pi}{\omega}\right)} d\sigma(\tau) \qquad (9)$$

As a consequence of (7) and (8) the quantity

$$I(\omega,\gamma_1,\rho) = K_v(\omega,\gamma_1,\rho) \cdot Z(\omega) \qquad (10)$$

is an invariant of ω andfrom $\lim_{\omega\to 0} K_v(\omega,\gamma_1,\rho) = 1$ we obtain

$$K_v(\omega,\gamma_1,\rho) = \frac{\lim_{\omega\to 0} Z(\omega)}{Z(\omega)} \qquad (11)$$

In a typical case $C^*(t,\tau)=C^*(\infty,t_0)\left[1-\beta\, e^{-\gamma_1(t-\tau)}\right]$ and the relation (9) implies

$$Z(\omega)=\frac{C^*(\infty,t_0)\left[(\sigma-\sigma_0)\gamma_1^2 e^{-\frac{\gamma_1\pi}{\omega}}-(\sigma+\sigma_0)\gamma_1^2+\sigma\omega^2\left(e^{-\frac{\gamma_1\pi}{\omega}}-1\right)\right]}{\gamma_1^2+\omega^2} \tag{12}$$

As $\lim\limits_{\omega\to 0} Z(\omega)=[2\sigma_0+(\sigma-\sigma_0)\beta_1]C^*(\infty,\mathrm{t}_0)$, taking into account $\gamma_1\approx 10^{-3}\div 10^{-2}$, from (11) and (12) we obtain

$$K_v(\omega,\gamma_1,\rho)=\frac{2\sigma_0+(\sigma-\sigma_0)\beta_1}{2\sigma_0(1-\beta_1)+\sigma\beta_1\left(1-e^{\frac{-\gamma_1\pi}{\omega}}\right)} \tag{13}$$

Now we explain the manifestation of vibrocreep for curved concrete rectangular beam with cross-section $b\times h$.

In accordance with Bernulli's hypothesis of plan sections

$$\varepsilon(z,v,t)=\left(\frac{z}{X}\right)\varepsilon_f(v,t), \tag{14}$$

where X is the height of compressed zone, $\varepsilon_f(v,t)$ is the deformation of fiber.

For the layer $b\times dz$ from (13) it follows that

$$K_v[\omega,\gamma_1,\rho(v,\tau)]=\frac{1+\frac{\rho(v,z)}{1-\rho(v,z)}\beta_1}{(1-\beta_1)+\frac{1+\rho(v,z)}{1-\rho(v,z)}\beta_1\left(1-e^{\frac{-\gamma_1\pi}{\omega}}\right)}, \tag{15}$$

$$\rho(v,z)=\frac{\sigma_{\min}(v,z)}{\sigma_{\max}(v,z)}. \tag{16}$$

V.M. Bondarenko introduced [12] the notion of integral module $E^{\text{int}}(v,t)$. Its modification $E^{\text{int}}(v,t)$ was proposed in [13] on the basis of dependence

$$\tilde\sigma(z,v,t)=\tilde E^{\text{int}}(v,t)\varepsilon(z,v,t) \tag{17}$$

By minimization of quantity

$$\tilde\alpha\left[\tilde E^{\text{int}}(v,t)\right]=\int_0^X b(z)\left[\sigma(z,v,t)-\tilde\sigma(z,v,t)\varepsilon\right]^2dz \tag{18}$$

In case of rectangular cross-section

$$\tilde E^{\text{int}}(v,t)=\frac{3\int_0^{\varepsilon_f(v,t)}\sigma(\varepsilon)\varepsilon d\varepsilon}{\varepsilon_f^3(v,t)}=\varPhi\left[\varepsilon_f(v,t)\right]\cdot E_f(v,t), \tag{19}$$

where

$$\varPhi\left[\varepsilon_f(v,t)\right]=\frac{3\int_0^{\varepsilon_f(v,t)}\frac{\sigma(\varepsilon)}{\sigma_f(v,t)}\varepsilon d\varepsilon}{\varepsilon_f^2}, \tag{20}$$

$E_f(v,t)=\sigma_f(v,t)/\varepsilon_f(v,t)$ is temporary line module of deformations for fiber.

When the stresses are represented by expressions [8], [14]

$$\sigma(\varepsilon)=E\varepsilon\cdot e^{-\varepsilon/\varepsilon_R}, \tag{21}$$

$$\sigma(\varepsilon)=R\sum_{i=0}^n a_i\left(\varepsilon/\varepsilon_R\right)^i, \tag{22}$$

then respectively

$$\varPhi[\varepsilon_f(v,t)]=6\left(\frac{\varepsilon_R}{\varepsilon_f}\right)^3\left[1-e^{-\varepsilon/\varepsilon_R}\left(1+\frac{\varepsilon_f}{\varepsilon_R}+\frac{1}{2}\frac{\varepsilon_f^2}{\varepsilon_R^2}\right)\right], \tag{23}$$

$$\varPhi[\varepsilon_f(v,t)]=\frac{3}{2}\frac{a_0}{\varepsilon_f\varepsilon_R}+\frac{a_1}{\varepsilon_R^2}+\frac{3}{4}a_2\frac{\varepsilon_f}{\varepsilon_R^3}+\ldots+\frac{3a_n\varepsilon_f^{n-1}}{(n+2)\varepsilon_R^{n+1}}. \tag{24}$$

In accordance with hypothesis of plane sections and (19) we come to the following expression for integral module of deformations with regard to the vibrations[15]

$$\tilde E_{ver}^{\text{int}}(v,t)=\frac{3\int_0^{\varepsilon_{fver}(v,t)}\sigma(\varepsilon)\varepsilon d\varepsilon}{\varepsilon_{fver}^3(v,t)}, \tag{25}$$

where $\varepsilon_{fver}(v,t)=\dfrac{S_0[\sigma_f(v,t)]\sigma_f(v,t)}{E_{ver}(t,t_0)}$.

In applications the function $S_0(\sigma)=1+V\left(\dfrac{\sigma}{R}\right)^4$ is used; V is the empirical parameter.

Conclusions

It is notable that module $\tilde E_{ver}^{\text{int}}(v,t)$ permits to take into account the vibrocreep of concrete on definition of the rigidity $D(v,\ t)$ for normal cross-section.

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