CREEP FRACTURE OF CONCRETE IN PRESTRESSED CONCRETE MEMBERS DURING MANUFACTURE

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INTRODUCTION

Evaluation of the strength of prestressed concrete members during manufacture (at the moment of prestress transfer) is one of the practical problems encountered when designing prestressed concrete structures. Failure of concrete in this case may take place under the prestress force. Application of a formerly developed fracture mechanics method [1] is considered below for a more complex case, i.e. variable sustained load.

Generalizing the equation obtained in [1], which describes the change of total length of cracks, S, and introducing the related intensity of stress σ (applied at the moment t_o) $q_o = \sigma(t_o)/\sqrt{\pi E(t_o)\gamma_s(t_o)}$ we obtain:

$$S(t,t_o) = F\ q_o\left[\frac{R(t_o)}{m(t,t_o)R(t)}\sqrt{\frac{E(t)}{\tilde{E}}}\ \frac{\sigma(t)}{\sigma(t_o)}\right], \qquad (1)$$

where $1/\tilde{E}$ is an operator assumed in a general form according to [1], which takes into consideration creep strain of concrete; $R(t)$ and $E(t)$ represent the short term strength and the elastic modulus of concrete. Creep in the material near the crack tips not only increases the crack length, but reduces the stress concentration at the same time, which leads to an increase in strength $R(t)$, and $m(t,t_o)$ takes this effect into consideration.

In equation (1) factors $R(t_o)/m(t,t_o)R(t)$ and $\sqrt{E(t)/\tilde{E}}$ take into account (as in the case of constant load) the effect of the two opposing processes - hardening and loosening of the material structure.

The multiplier $\sigma(t)/\sigma(t_o)$ reflects the effect of load change at time t compared to the initial load at time t_o.

FAILURE OF CONCRETE UNDER TIME-VARIABLE SUSTAINED LOAD

Let us introduce a function:

$$M(t,t_o) = \frac{\sigma(t)}{m(t,t_o)R(t)}\sqrt{\frac{E(t)}{\tilde{E}}}, \qquad (2)$$

which allows us to simplify equation (1), representing the change of total length of cracks S, with respect to the process of concrete creep and ageing. The initial level of loading being denoted by $\rho = \sigma(t_o)/R(t_o)$, we obtain:

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$$S(t,t_o) = F[q_o\ M(t,t_o)/\rho] \tag{3}$$

Let us extend the assumption of [1] - the equality of critical total length of cracks S^* under short-term (S_s^*) and constant sustained load (S_c^*) - for the case of time-variable sustained load (S_ν^*).

If the initial intensity of such load is ρq_o then the following equality should be satisfied at the moment of failure under time-variable sustained load (similar to the case of short-term and constant sustained load):

$$S_\nu^*(t,t_o) = F[q_o/\rho], \tag{4}$$

i.e. in accordance with (3) for the moment of failure

$$M(t,t_o) = 1 \tag{5}$$

The change of the function $M(t,t_o)$ for the case of constant sustained load is shown in Figure 1, where η_* is related long-term strength. It can be shown that the values of $M(t,t_o)$ are always in the range 0 to 1, whereby $M(t,t_o) = 0$ for unloaded material ($\rho = 0$) and $M(t,t_o) = 1$ for the case of failure. Therefore the function $M(t,t_o)$ may be defined as the *measure of material destruction*.

The concept of the measure of destruction being introduced, the time to failure under time-variable load may be determined.

The following equality should be satisfied at the moment of failure according to equations (2) and (5):

$$\frac{\sigma(t)}{m(t,t_o)R(t)} \sqrt{\frac{E(t)}{\tilde{E}}} = 1 \tag{6}$$

The time to failure may be determined from equation (6), if all the time-dependent functions are known.

FAILURE OF PRESTRESSED MEMBERS SUBJECTED TO PRECOMPRESSION FORCES

Consider a prestressed concrete member, subjected to axial precompression forces. The total length of cracks is determined by (1) and (3) and the time to failure by equation (6). The change of stresses $\sigma(t)$ is mainly defined by prestress losses resulting from concrete creep. These losses under high stresses depend in their turn on the initial stress level.

Values of stress losses, as well as short-term strength $R(t)$, modulus of elasticity $E(t)$ and specific linear creep strain $C_o(t,t_o)$ may be obtained using the expressions given in [2, 3]. Thus all the necessary data are available for evaluation of prestressed concrete strength. Figure 2 shows changes of the measure of destruction $M(t,t_o)$ calculated according to the procedure mentioned above. Various prestress levels of axially prestressed

members were taken into consideration. Values of parameters necessary for the analysis were taken according to [2, 3].

It can be seen from Figure 2 that the main features of function $M(t,t_o)$ essentially depend on the percentage area of prestressed reinforcement μ_{pr}. When the value of μ_{pr} is high ($\mu_{pr} > 0.02$), stresses losses resulting from concrete creep are significant, while the process of destruction under rapidly decreasing load is slightly in evidence. Accordingly, right from the start, the measure of destruction $M(t,t_o)$ is decreasing irrespective of the prestress level.

When the value of μ_{pr} is low, stress loss proceeds more slowly and material loosening processes are of great importance. Under such conditions, the prestress level being high enough, equation (6) is supposed to be satisfied, i.e. failure of concrete takes place (see the top curve when $\rho = 0.98$ in Figure 2). The same may be obtained for the case of an eccentric pre-compressed member. The danger of destructive processes in prestressed members with a low percentage area of reinforcement under a high prestress level is confirmed experimentally too.

The results of analyses carried out by the procedure mentioned above for concrete with a range of cubic strength ($R = 20 \div 50$ MPa) and using various values of specific (volumetric) water content in the concrete mix w ($w = 0.18$ and $w = 0.25$) are given in Figure 3. The lines in this figure reflect the higher boundary of safe (in regard to long-term concrete strength) prestress level ρ_{max}, related to the short-term concrete strength at the moment of prestress transfer. Within these boundaries the bearing capacity of concrete cannot be exhausted, i.e. $M(t,t_o) < 1$. Results obtained above have been used in the new Building Code of the USSR.

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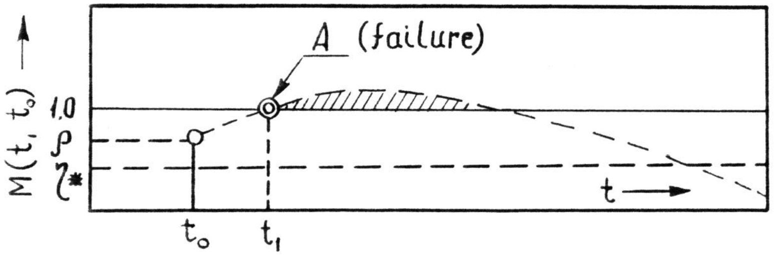

Figure 1 Criterion of Failure of Concrete Under Constant Sustained Load (Measure of Destruction)

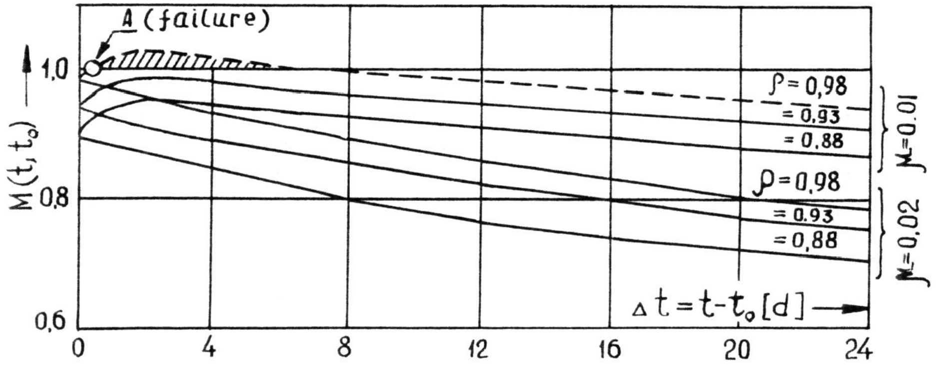

Figure 2 Criterion of Failure of Prestressed Concrete Members Subjected to the Prestressing Force

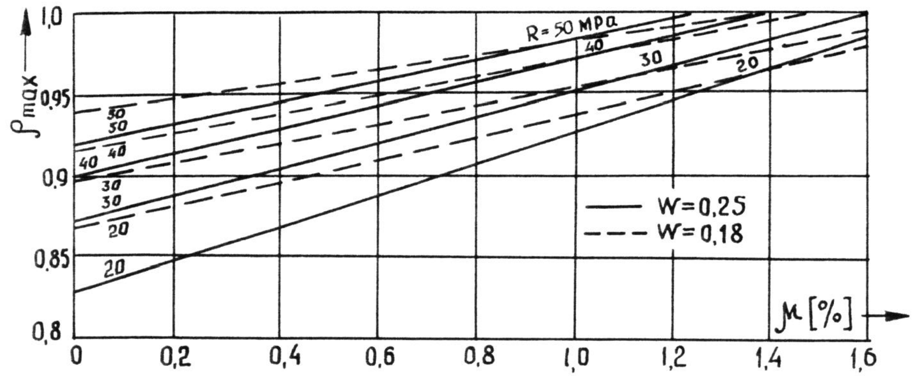

Figure 3 Higher Boundary of a Prestress Level, Calculated as Described