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# Evolution of Strain Fields in Young Concrete Structure

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## ABSTRACT

Young concrete will undergo sophisticated evolution of physical properties after it is placed. For a concrete structure mechanical property of material is of the most significance. However, stresses developed in a member of a concrete structure dominate its performance in some extent.

The stress state of cast-in-place concrete will vary with ageing. Thermal stress in a concrete member would be induced both from accumulated hydration heat of cement and from exchange with boundary of structural member. At the interface with atmosphere moisture of concrete would be evaporated. Loss of free water in cast concrete would lead to shrinkage during maturity. When the free deformation is confined stress in concrete member would present. Nevertheless, construction loads will produce stress directly. All of these phenomena would affect the evolution of strain field in young concrete member, and early age cracks would appear with the accumulation of detrimental strains.

Theoretically, thermal field under hydration heat and boundary conducting can be calculated in the light of heat conduction theory, which gives in a differential equation

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y \frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z \frac{\partial T}{\partial z}\right)+\frac{f(t)}{c\gamma}=\frac{\partial T}{\partial t} \tag{1}$$

where $T$ is temperature of concrete (K), $k_x$, $k_y$, $k_z$ is the diffusion ratio along three different directions, $c$ is the specific heat ratio (J/kg*K), and $\gamma$ is the density of concrete (kg/m$^3$). Function *f(t)* describes heat generation from cement hydration

$$f(t)=mWQ_0\exp(-mt) \tag{2}$$

where $W$ is the cement content per unit volume (kg/m$^3$), $Q_0$ is the heat per unit cement content (J/kg), $m$ is the hydration rate. The boundary condition can be either the first type or the second type.

Strains due to thermal variation in a concrete member is assumed to be

$$\varepsilon_T=\alpha\cdot\Delta T \tag{3}$$

where $\alpha$ is thermal dilation coefficient of concrete, generally it depends on the moisture state of the pore system at early age.

Generally, concrete shrinking is mainly from the shrinkage of cement paste. Drying shrinkage of concrete is major part of shrinkage and can be defined as the time dependent deformation due to loss of water at constant temperature if relative humidity of less than 100%. It is the most important part on considering deformation and cracking of concrete members after cast-in-place. However, it is more complicated to express the diffusion of moisture due to the complex pore structure within concrete.

As drying shrinkage is closely related with vapor in pore, change of relative humidity within concrete can substitute the expreession of moisture field. A proposed differential equation [1] gives

$$\frac{\partial}{\partial x}\left(k_x \frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y \frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z \frac{\partial h}{\partial z}\right)+k_h \frac{\partial q}{\partial t}+k_T \frac{\partial T}{\partial t}=\frac{\partial h}{\partial t} \tag{4}$$

where $h$ is the pore moisture content volume per unit concrete volume ($m^3/m^3$), $k_x$, $k_y$ and $k_z$ are the diffusion ratio, $T$ is the temperature, $k_h$ and $k_T$ is the two coefficients to reflect the hydration and temperature effects on the moisture content separately. It is of the similar form with heat diffusion, hence, solution can be gived if coresponding boundary condition is setted.

Deformation due to drying shrinkage can be derived from the assumption on vapor pressure of capillary, which is associated with relative humidity.

Conventionally, displacement of concrete member under loading can be analysed through nonlinear Finite Element Method. Attention should be given to the change of mechanical properties of concrete with time after placing. A prediction model for strength evolution with maturity is

$$f_{cx} = f_c^{'}(1-e^{-\gamma m}) \tag{5}$$

where, $f_{cx}$ is the strength at specific maturity (MPa); $f_c^{'}$ is strength at 28-day(MPa); $\gamma$ is a constant; and m is related with maturity, it is a composition of temperature and age.

Therefore, to predict the strain fields of a concrete member in the early period of construction with age, a step-by-step method is necessary. At the beginning of each time step, deformation due to thermal variation (hydration and environment), drying shrinkage, and loading at current time interval is imposed. This imposed incremental strain[2] on any point at *i-th* time interval is defined as

$$\Delta\varepsilon_i^{ToT} = \Delta\varepsilon_i^{sh} + \Delta\varepsilon_i^{th} + \Delta\varepsilon_i^{ld} \tag{6}$$

where, $\Delta\varepsilon^{sh}$ is the shrinkage strain at time $t_i$, $\Delta\varepsilon^{th}$ is the thermal strain, $\Delta\varepsilon^{ld}$ is the loading strain, and the interval *i*th is the one between setting time *(i)t* and *(i+1)t*.

The multi-physical process during concrete maturity would induce a complex strain field. Though lack of fundamental data on field tests the evolution of concrete properties, theoretical analysis displays that the approach could be applied to predict the early age behaviour, even more to evaluate performance after concrete placing.

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