Optimum compositions of crack-stability and waterproof concrete for the reliability and durable constructions of bridges

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OPTIMUM COMPOSITIONS OF CRACK-STABILITY AND WATERPROOF CONCRETE FOR THE RELIABLY AND DURABLE CONSTRUCTIONS OF BRIDGES

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ABSTRACT

Heavy concretes of high class on strength, which are used for bridges and other constructions, are often characterized by the promoted deformation of long-term creep. A long-term creep develops during the tens of years and results in impermissible deformations of constructions, which are exceeding norms. Such deformations were detected in Europe in the long spans of reinforced concrete bridges. The authors of report detected such deformations in the thin-walled container structures and other buildings. As a result of theoretical and experimental researches dependences of indexes of long-term creep are set on characteristics of composition of concrete. There were worked out and patented a method of determination of composition of crack-stability and water-unpermeable concrete.

1. Introduction

Modern reinforced-concrete constructions often are long bent. They are often exploited in the conditions of flooding, high cycle loading, aggressive action and electric current action. They are not durable and in 20-30 years acquire considerable damages.

At the same time ancient constructions from a concrete at the age of 5-7 thousand years were preserved in many countries. These are floors of the ancient dwellings, pyramids of Egypt, aqueducts, stadiums, temples and other buildings of Rome etc. Work of concrete only on a compression and absence of armature are the features of these durable constructions.

Reinforced-concrete bridges with large span of 100-200 m started to build in the world in 1950-60th. In 1990th in such spans were found out the large deflections (up to 200 and even 800 mm, fig.1). These deflections were developed during a long time and were not stabilized in 20-30 years [1, 2]. The increase of deflections even after additional tension of span at a reconstruction does not stop (fig.1). The authors have found analogical deformations from the creep of concrete in the thin-walled constructions of pools [3]. It was set that the reason of such deflections is a creep of concrete in the compressed area of construction [2, 3-7]. The authors named this creep as a over-normative long-term creep [3-5]. Such creep in the compressed area stipulates the formation of cracks in the stretched area [3, 4].

Imperfection of theories of a structure and long-term properties of concrete in such constructions, standard methods of determination of deformation and filtration properties, traditional methods of concrete composition determination for such terms causes this.

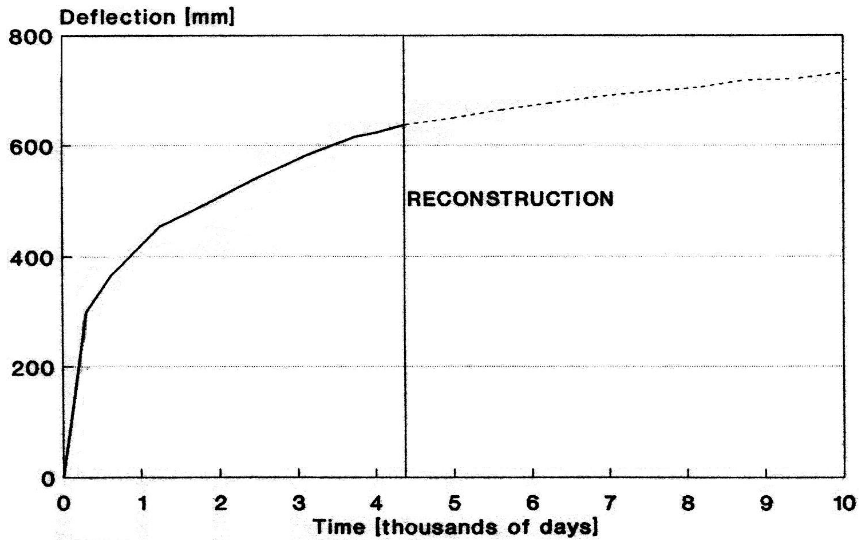


Figure 1. Diagram of deflection development of reinforced-concrete span of bridge in time. Parotts Ferry Bridge (California, USA) was built in 1978, span length – 195 m, the construction of span – light continuous beam [1]

2. Analysis of the applied methods of concrete composition determination

Usually composition of concrete is selected taking into account the providing of concrete strength and workability (flow or hardness) of concrete mix. It is provided by a water-cement ratio *W/C* and a water quantity, accordingly. Side by side with the different properties of aggregates it stipulates the different relations between the amount of fine aggregates and cement *FA/C* (from 0,3 to 3) and coarse and fine aggregates *CA/FA* (from 1,5 to 3) and, consequently, uncontrolled high ranges of density, water-permeability, deformability of concrete of different constructions.

The indicated relations are connected with the structural parameters of concrete at the macro-, mezo- and micro-levels of structure - by the coefficients of moving apart of grains of coarse aggregate α, fine aggregate μ and W/C, accordingly:

$$\alpha = \frac{V_{csm}}{V_p^{la}}; \quad \mu = \frac{V_{cp}}{V_p^{sa}}, \tag{1}$$

where V_{csm} - a volume of cement-sandy mortar in a concrete; V_p^{la} - a volume of inter-grain pores in a coarse aggregate; V_{cp} – a volume of cement paste; V_p^{sa} – a volume of inter-grain pores in a fine aggregate.

3. Ground of opimum composition of concrete

The authors proposed the method of setting of concrete optimum composition to provide the minimum creep and water-permeability, high crack-stability of concrete and increase of bridges constructions durability [8-10]. The theoretical basis of this setting of concrete optimum composition is the notions of structure and properties of cement stone and concrete as disperse systems. The authors developed these notions on the basis of Colloidal chemistry and Physical-chemical mechanics of the disperse systems.

In accordance to these notions the structure of concrete is polydisperse. Such structure has different levels - macrolevel, mesolevel, microlevel and submicrolevel (fig.2). They differ from the sizes of structure-forming elements (SE). The grains of coarse aggregate have characteristic sizes of 10-15 mm and they are SE of macrolevel of concrete. The grains of fine aggregate have sizes of 0,2-0,5 mm and they are SE of mesolevel. The particle of cement have characteristic sizes of 10-50 μm and they are SE of microlevel. Submicrolevel of structure is presented by the particles of hydration products – crystalline hydrates by the size of 100-1000 nm (on average 450 nm) and gel by the size of 10-100 nm (on average 55 nm). Water (solution of electrolyte of $Ca(OH)_2$) is a dispersion medium that is in the gel and capillary pores at physical-chemical bound state.

The optimum composition of concrete provides an optimum structure of all levels. An optimum structure at every level corresponds to the most dense packing of particles of every next structural level in a layer between the SE (fig.3, *b*).

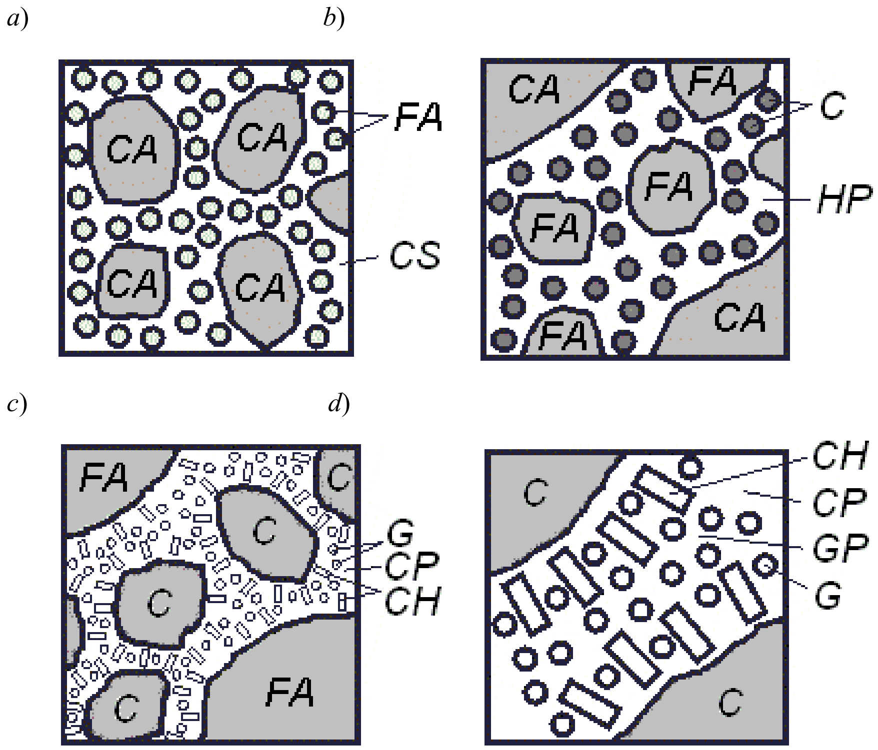
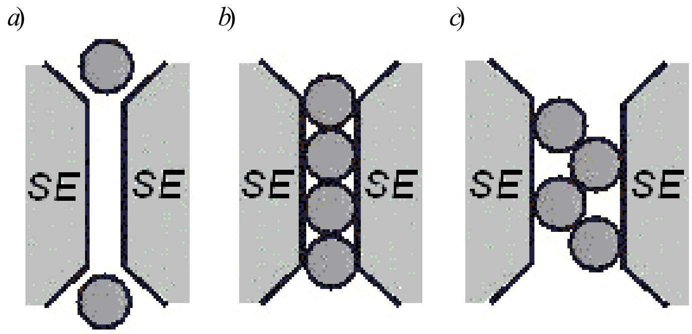


Figure 2. Scheme of concrete structure on levels: *a* – macro-level, *b* – meso-level, *c* – micro-level; *d* – submicro-level; *CA* are grains of coarse aggregate (10÷15 mm); *FA* are grains of fine aggregate (0.2-0.5 mm); *CS* is cement stone; *C* are particles of cement (10-50 μm); *HP* are hydrate productions; *CH* are particles of crystalline hydrates (100-500 nm); *G* are particles of gel (0-100 nm); *CP* are capillary pores; *GP* are gel pores



macro-level - *CA - FA - CA*
meso-level - *FA - C - FA*
micro-level - *C - CH,G - C*

Figure 4. Scheme of layers between the structure-forming elements *SE*: *a*, *c* - not optimum; *b* - optimum

Optimum values of coefficients of moving apart of grains coarse α_{opt} and fine μ_{opt} aggregate provide such packing on a macro-level and meso-level. Optimum values of coefficients of moving apart α_{opt} and μ_{opt} are determined as follows:

$$\alpha_{opt} = 2{,}1 \cdot \left(1 + \frac{d_{fa}}{d_{ca}}\right)^3 - 1{,}1\,; \quad \mu_{opt} = 2{,}1 \cdot \left(1 + \frac{d_c}{d_{fa}}\right)^3 - 1{,}1\,, \tag{2}$$

where d_{fa}, d_{ca}, d_c - characteristic middle sizes of grains of fine and coarse aggregate and particles of cement, accordingly.

Observance of α_{opt} (μ_{opt}) provide the forming on the average of one complete row of grains of fine aggregate (particles of cement) in layers between grains of coarse (fine) aggregate (fig.3, *b*). At non-observance of α_{opt} (μ_{opt}) in a layer between SE the incomplete rows of particles of the next structure level are formed (fig.3 *a*, *c*). Shown on a fig.3 schemes are statistically most probable for the middle sizes of grains of coarse and fine aggregate and particles of cement.

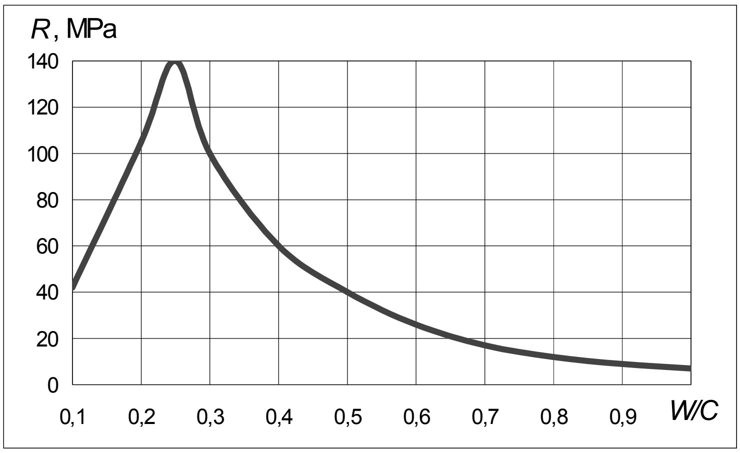


Figure 3. Dependence of cement stone strength on 28 days of hardening R from the water-cement ratio W/C

The water-cement ratio W/C determines a structure on a micro-level. Experimental dependence of cement stone strength R from W/C is presented on a fig.4. As shown on a fig.4, the greatest strength of cement stone corresponds to the value of $W/C_{opt} \approx 0.25$. At such W/C a structure (thickness) of layers of new formations from crystalline hydrates between the not fully hydrated particles of cement is optimum (fig.2 *d*, 3 *b*). The increase of W/C causes the increase of free-water amount and, accordingly, to porosity of cement stone. Reduction of W/C results in decrease of cement hydration degree. Consequently, at the selection of concrete composition with maximal strength and impenetrability it is necessary to accept the true values of W/C_{opt} (taking into account the water-necessity of aggregate), close to 0.25 (depends on normal density of cement). The necessary mobility of such concrete compositions should be provided by the help of addition - superplasticizer.

4. The method of determination of concrete optimum composition

Optimum nominal (for dry aggregates) concrete composition which provides a minimum creep and water-permeability, high crack-stability, is determined as it shown below.
Flow rate of coarse and fine agregate on 1 m^3 of concrete:

$$CA = \frac{1}{\frac{\alpha_{opt}}{\rho_a^{ca}} \cdot P^{ca} + \frac{1}{\rho^{ca}}}; \qquad FA = \frac{1 - \frac{CA}{\rho^{ca}}}{\frac{\mu_{opt}}{\rho_p^{fa}} \cdot P^{fa} + \frac{1}{\rho^{fa}}}, \tag{3}$$

where ρ_a^{ca}, ρ_a^{fa} - apparent density of coarse aggregate and fine aggregate, accordingly, kg/m^3; P^{ca}, P^{fa} - intergrain porosity of coarse and fine aggregate, accordingly; ρ^{ca}, ρ^{fa} - veritable density of coarse and fine aggregate, accordingly.

Flow rate of cement and water on 1 m^3 of concrete:

$$C = \frac{1 - \frac{CA}{\rho^{ca}} - \frac{FA}{\rho^{fa}} - CA \cdot W^{ca} - FA \cdot W^{fa}}{\frac{W/C_{opt}}{\rho^{w}} + \frac{1}{\rho^{c}}}, \qquad W = C \cdot W/C_{opt} + CA \cdot W^{ca} + FA \cdot W^{fa}, \tag{4}$$

where W^{ca}, W^{fa} - water-necessity of coarse and fine aggregate, accordingly; ρ^w - density of water, kg/m^3; ρ^c - veritable density of cement, kg/m^3.

Flow rate of addition-superplasticizer on 1 m^3 of concrete:

$$SP = C \cdot SP/C_{opt}, \tag{5}$$

where SP/C_{opt} - optimum quantity of addition-superplasticizer (mass stake from the charge of cement).

Conclusion

In the developed optimum compositions of concrete flow rates of coarse and fine aggregate of CA and FA and water W for identical materials are permanent. Marked above relations CA/FA , FA/C and W/C are permanent and optimum, that provides stability of concrete properties, minimum creep and water-permeability, maximal strength of concrete, and also maximal durability of constructions from it. Optimum compositions of concrete are used at the repair of bridges and other structures on the railways of Ukraine.

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