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Increasing load-bearing capacity of bridge structures by reducing cover thickness as a result of changing cement type

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Abstract

This paper discusses how cover thickness is selected based on values of diffusion coefficients regarding its durability by obtaining the limit concentration of chlorides at its surface, typical for Portland cement CEM I 42.5R and Portland cement with low alkali content CEM I 42.5N/SR3/NA, and considering the example of a beam bridge structure - the impact of cover on load-bearing capacity as a function of span.

Keywords: cover, load-bearing capacity, diffusion coefficients, durability, beam bridge structure

1. Introduction

Reconstruction of bridge structures is often related to a problem on ensuring the minimum vertical clearance. For the purpose of considerably reducing the scope of works on access to the structure and avoiding expensive rising of the road grade line, attempts are made to reduce to minimum the grade line level defined by the recommended vertical clearance under the structure and its construction depth. However, increasing the construction depth of the load-carrying structure is not always possible due to the minimum datum of the structure bottom and maximum datum of the grade line. In such case, a structure of mid-depth should be built to provide the proper load-bearing

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capacity. The capacity depends on effective depth which, besides the above factors, is also affected by the cover thickness. The most significant impact of cover thickness on load-bearing capacity can be observed for structures of short spans, and consequently low depth of load-carrying structures. The greater the depth of the structure is, the lower its impact is. Cover thickness is selected considering, among other things, the required durability. Chloride ions, a major component of agents for road de-icing, are currently the main cause of reinforcement corrosion in bridges due to their aggressive - depassivation action. Cements in concrete influence its protective properties, such as diffusion rate of chlorides posing the risk for reinforcing steel. Diffusion rate also affects the minimum cover thickness, as this parameter has to ensure the required minimum durability. By using cements that improve protective properties of concrete to reinforcement steel, the required thickness of cover can be reduced, load-carrying capacity of structures can be increased and consequently, material consumption can be reduced. The impact of cover thickness required for Portland cement CEM I 42.5R and Portland cement with low alkali content CEM I 42.5N/SR3/NA, and considering the example of a beam bridge structure - the impact of cover on load-bearing capacity as a function of span was analysed. The required thickness of cover was determined on the basis of values of diffusion coefficients regarding the expected durability, taking into account the limit value of chloride concentration at steel surface.

2. Selection of cover thickness

Diffusion coefficients are required to specify cover thickness. Diffusion coefficients were determined from the thermodynamic model of chloride ingress into concrete [1,2]. Values of D^1 coefficient were obtained on the basis of Cl^- ions distribution in concrete specimens exposed to electric field, which was to accelerate the process. The following expression was used [3,4]:

$$D^1 = \frac{\bar{j}^{\,1}(a)\,a\Delta t}{\frac{z^1 FUg}{RTh}\left[\bar{\rho}^{\,1}_1 + \bar{\rho}^{\,1}_2 + \ldots + \bar{\rho}^{\,1}_n\right]\Delta t - B}, \qquad B = \int_0^a Q_x\left[\rho^1(x,t+\Delta t) - \rho^1(x,t)\right]dx. \tag{1}$$

where $\bar{j}^{\,1}(a)$ is the value of chloride ions flowing through the plane within the distance x = a, averaged over time Δt, $\bar{\rho}^{\,1}_1$, $\bar{\rho}^{\,1}_2$, and $\bar{\rho}^{\,1}_n$ averaged over time Δt densities of Cl^- within the consecutive intervals [0, g], [g, 2g], …, [(n-1)g, a]. The first term of the dominator determines the steady state of chloride ion flux, whereas the second one refers to the non-steady state.

The paper [5] presents coefficient values of concrete with cement CEM I 42.5 R cement – Portland cement with high early strength and high hydration heat, and with cement CEM I 42.5 N/SR3/NA with low content of alkalies Na_2O, tricalcium aluminate C_3A and alumina Al_2O_3, recommended in accordance with the Regulation [6] to perform bridge structures of high chemical resistance, particularly to sulphate corrosion. Concrete strength was higher than B35 [5], which is acceptable to be used for all elements of bridge structures according to the Regulation [6]. For concrete with such cements, the minimum cover thickness was determined assuming that the risk of reinforcement corrosion was caused by critical concentration of chloride ions at 0.4% by cement mass, and the required durability of the load-carrying slab structure was 100 years.

Changes in chloride concentration between reinforcement and concrete cover x = c were calculated according to the following relationship [7]:

$$\rho^1_{cal}(x,t) = \rho^1_0\left(1 - erf\,\frac{x}{2\sqrt{D^1 t}}\right) \qquad D^1 = D^1_s \tag{2}$$