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Durability assessment of concrete bridge deck considering waterproof membrane and epoxy-coated reinforcement☆

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Summary The effect of waterproof membrane and steel reinforcement protection on the concrete bridge deck is modeled. The attention is paid to the durability prediction related to steel reinforcement corrosion initiation based on the chloride penetration. Thus 2-D finite element chloride ingress model is applied. The transient finite element model serves to solve Fick's second diffusion law using the computer tool compatible with the Matlab environment. The model focuses on the transport of chloride ions through a reinforced concrete bridge deck with and without the effect of waterproof membrane and on an estimate of the concentration of chlorides at the reinforcement level or in places with damage to the epoxide coating of the reinforcement. The model allows the incorporation of damage to the waterproof insulation under the asphalt coating. The time to chloride induced onset of corrosion is predicted and results are compared. The effect of water proof membrane reinforcement protection strategy typical for Central Europe and epoxy-coating protection widely used in North-Western United States is evaluated.

Introduction

The reliability of reinforced concrete bridge structures is, in many cases, predetermined by durability. Many structures require premature repairs, rehabilitation or replacement as a result of defects caused by e.g. the effect of environment as well as the long-term actions of loads including chemical actions. Shortened lifespan leading to increased costs over the life cycle of the structure contributes indirectly to high costs to public budgets. The production of more durable construction systems may contribute to reduction of the overall costs of the structure. These can be better proposed with knowledge of the progress of the degradation process brought on by the long-term actions of environment and structural loading.

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The models capable of chloride related corrosion process evaluation are being developed worldwide (see e.g. Stewart and Rosowsky, 1998; Tikalsky et al., 2005; Benz and Thomas, 2001; Konečný et al., 2007; Novák et al., 2014; Konečný et al., 2011; Vořechovská et al., 2015). From the above mentioned, the 1-D ideal bridge deck probabilistic models (Stewart and Rosowsky, 1998; Tikalsky et al., 2005) are based on the analytical formulation of chloride ingress (Collepardi et al., 1972). The work (Stewart and Rosowsky, 1998) represents comprehensive analysis ranging from corrosion initiation to ultimate flexural resistance, where corrosion current is input parameter. The other probabilistic analysis is limited to corrosion initiation only (Tikalsky et al., 2005). Whereas, Tikalsky et al. (2005) is based on the extensive data from filed study by Sohangpurwala and Scannell (1998). It is focused on initiation only. Konečný et al. (2007) model extends the work (Tikalsky et al., 2005) by the evaluation of epoxy-coated reinforcement and concrete bridge deck cracking effect. The effect of crack width on the penetration of chlorides into concrete is discussed in ACI 222 (2001). There are works supporting the relationship between cracks and the capability of concrete to facilitate the passage of chlorides which leads to a more rapid propagation of corrosion include (Djerbi et al., 2008; Bentz et al., 2013). In the introduction to the work (Djerbi et al., 2008) with reference to Francois et al. (2005) it is stated that the concentration of chlorides in a crack wider than 205 μm is equal to the concentration of chlorides at the surface. Djerbi et al. (2008) carry out an analysis of the effect of the width of cracks on the penetration of chlorides with the use of a modified accelerated test of the penetration of chlorides. (AASHTO T277, 1993). These tests determine the capability of concrete to resist the penetration of chlorides. Through the passage of an electric charge it can also determine the diffusion coefficient describing its capability to prevent the penetration of chlorides into concrete (Andrade, 1993).

Concrete is prone to cracking thus considering the crack effect on the chloride ion penetration shall be paid attention. The 2-D interaction of crack in the bridge deck with steel reinforcement durability was modeled by Konečný et al. (2007). Comparison of 2D experiments and numerical analysis was conducted by Marsavina et al. (2009) and Bentz et al. (2013). Marsavina et al. (2009) and Konečný et al. (2007) applied boundary conditions of a concentration of chlorides directly in crack. In contrast Bentz et al. (2013) model the effects of cracks in the form of changes in the material parameters in the area of the crack. The crack width effect important for the chloride ion penetration into concrete is discussed by Djerbi et al. (2008).

This incorporation of crack effect into chloride ion penetration allows for the corrosion initiation assessment of bridge deck with crack; however, modification of the model is necessary in order to address the effect of waterproof barrier bellow asphalt overlay.

Motivation

The aim of the author herein is to briefly introduce tool for comparison of the directly exposed bridge deck with the bridge deck protected by water proof insulation under an asphalt overlay. The work aims in particular on the preparation of possibilities to compare variants of directly exposed bridge decks and bridge decks protected by waterproof insulation. An innovation is the preparation of the model of a reinforced concrete bridge deck from ordinary Portland concrete with steel reinforcement protected by waterproof insulation under an asphalt overlay.

Modeling the durability of reinforced concrete bridge decks

The paper discusses the durability assessment of reinforced concrete bridge decks considering the actions of chlorides. The durability of reinforced concrete bridge decks can be affected by many factors, such as alkalinity, acids, repeated changes of humidity, cyclical temperature changes, carbonation, the action of chlorides, UV radiation, sulphides, fatigue and other influences including cracks. The action of de-icing agents is generally most detrimental for bridged decks. Chlorides penetrate through the surface to the steel reinforcement, causing corrosion of the reinforcement. It is one of the most important factors lowering the life span of bridge decks both in Central Europe and also in the North East of the USA. The typical solutions are epoxy-coating on the reinforcement or waterproof membrane above concrete bridge deck. The protection strategies are given in Fig. 1.

It is possible to use analytical or numerical models to model the durability of reinforced concrete bridge decks from the point of view of chloride action, which describe the risk of reinforcement corrosion occurring and thus the risk of the occurrence of degradation processes. If corrosion caused by the penetration of chlorides to the steel reinforcement is regarded as the dominant parameter affecting its durability then its lifespan can be recorded according to Tutti (1982) as:

$$t_{\text{service}} = t_{\text{initiation}} + t_{\text{propagation}}, \tag{1}$$

where the time to the occurrence of corrosion is $t_{\text{initiation}}$ and $t_{\text{propagation}}$ which corresponds to the time in reaching an unacceptable level of corrosion in reinforced concrete reinforcement.

The corrosion of steel reinforcement is primarily controlled by the diffusion of chlorides. The effect of hydraulic pressure and capillary sorption is not considered in the model described as in most cases it can be ignored. Diffusion is thus the most common way in which chloride ions are brought into contact with the reinforcement of reinforced concrete bridges decks. Diffusion occurs as a result of concentration gradients. See e.g. Collepardi et al. (1972) and Hooton et al. (2001).

Whether the analytical or numerical model is used to determine the concentration of chlorides at the level of reinforcement or at the point of damage to the epoxide covering, the output is the concentration of chlorides $C_{x,t}$. Through a comparison of the chloride threshold C_{th} with the actual concentration at a given time it is possible to calculate whether the corrosion has begun or not. The durability of bridge decks describable by the reliability function RF_t is expressed as a time dependent crossing of the corrosion threshold C_{th}, by the concentration of chlorides $C_{xy,t}$ which is locally dependent on the parameters of the cover of the