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Case study

# Low carbonation of concrete found on 100-year-old bridges

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## ABSTRACT

This work investigates an unexpectedly low carbonation depth found in two bridges. A protection against carbonation is ensured by approximately 2–3 mm thick dense plaster coat covering the outer surface of concrete. The plaster coat consists prevailingly of compact carbonate micro particles, showing no open pores and such a density, which gives this extremely thin layer non-permeability property for carbon oxide penetration over time.

## 1. Introduction

A carbonation leads to a reduction in a total porosity whereas a molar volume of a reaction product $CaCO_3$ is higher (36.93 $cm^3$/mol) than a primary reactant $Ca(OH)_2$ (32.29 $cm^3$/mol) [1]. $Ca(OH)_2$ is gradually converted into $CaCO_3$, which reduces the alkalinity of the concrete [2]. Due to the reduction in a total porosity, carbonation reaction firstly reduces the permeability [3], increases the micro hardness of the cementitious matrix [4], changes a pore size distribution at the same time by increasing the proportion of capillary pore sizes greater than 30 nm [5]. Due to an increase in capillary porosity, further progressing carbonation increases the diffusivity of ions through the cementitious matrix and finally the permeability [6]. This results in more extensive carbonation shrinkage connected with crack propagation. Four carbonation stages were determined by XRD and TG-DTA techniques combined with the set of 4 indicators and steel corrosion measurements by potentiodynamic method as shown in Table 1 [7,8]. Various colored changes respond to different pH values [9]. The rate of carbonation was determined by a degree of carbonation (DC) and degree of modification changes [DMC was given by $CaO_{CARB}/CaO_{TOTAL}$ ratio (% wt)] [10,11]. Three distinct regions of fully carbonated, partly carbonated and non-carbonated zones in carbonated concrete were distinguished by Cheng-Feng Chang [12]. The fully carbonated zone was identified by the degree of carbonation greater than 50% wt. (pH $<$ 9.0). The degree of carbonation in the partly carbonated zone lied between 0% wt. and 50% wt. (9.0 $<$ pH $<$ 11.5).

The non-carbonated zone occurs where the test specimen shows no signs of carbonation. Rates of carbonation for reinforced concrete bridges were investigated for three localities in South Africa. Carbonation data from approximately 90 in-service bridges aged between 11 and 76 years showed average carbonation rates approximately 0.3–0.7 mm/year. The carbonation coefficients correlated well with the permeability for each of the binders [13]. Assessment of carbonation resistance through the use of Torrent air permeability test was performed [14]. Carbonation depth and carbonation-induced steel corrosion of the concrete bridge depended on the concrete quality: sound, cracked and joint parts [15]. Organic coatings on the concrete surface substantially reduce the risk of carbonation. Under real circumstances, the coatings degrade naturally as a result of heat, moisture and ultraviolet radiation [16].

Degradation of concrete was studied on 100-year-old bridges. The objective of this work was to investigate the unexpectedly low carbonation depth found in two bridges.

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**Table 1**
Assessment of carbonation attack of concrete.

| TG-DTA, XRD (SEM, MIP) | | 4 indicator´s method | Carbonation stage | | Potentiodynamic method | |
|---|---|---|---|---|---|---|
| Degree of carbonation (% wt.) | Carbonation stage | pH in profile | | | pH of concrete extract | Electrochemical state of steel |
| < 55 | I | pH > 11.5 | 0 | 0–I | pH > 11.7 | passive |
| | | 10 < pH < 11.5 | I | | 11 < pH < 11.7 | non-stable |
| 55–65 | II | 9 < pH < 10 | | II | | |
| 65–80 | III | 8 < pH < 9 | | III | pH < 11 | active-corroded |
| > 80 | IV | pH < 8 | | IV | | |

**Fig. 1.** Reinforced concrete bridge Krásno nad Kysucou before reconstruction in 2014.

## 2. Experimental investigations

### *2.1. Materials*

The first investigated road bridge is situated above the river Bystrica in the city Krásno nad Kysucou. It is believed to be the oldest preserved reinforced concrete bridge in Slovakia and one of the oldest Monier Arches in Central Europe, which are still in service. The bridge was completed in 1892 as one of the series of Monier Arches built in the former Austrian-Hungarian monarchy. It has survived two World Wars without large damage and served till 2014 without any major repair. The bridge consists of two reinforced concrete arches built on stone abutments and stone pier, which were a part of the previous stone arch bridge. Each of arch has a span of 16.8 m and a span to raise ratio of 0.138 m. The thickness of primary arch varies from 400 mm in the springing to 150 mm in the crown of the first arch and only 130 mm at the crown of the second arch. Above the primary arch, which is reinforced at both surfaces, there is also an unreinforced overfill that reaches the thickness of up to 600 mm near the springing and gradually diminish towards the crown. Complete reconstruction of the bridge started in 2014 (Fig. 1) and finished in 2016 (Fig. 2). The carbonation depth was measured only by phenolphthalein test before and after reconstruction, when the origin concrete surface was covered by a modern covering plaster.

The second investigated road bridge with evidently reduced carbonation is located on the III. class road nearby the city Sládkovičovo over a small creek (Fig. 3). The bridge has a single span of 4 m; its superstructure was reconstructed in 1965. Thus from the contemporary structure only the concrete abutments remained original of the age of approximately 100 years.

The measured carbonation depths at the bridges are reported in Table 2.

### *2.2. Research methodology*

In-situ tests applied in the current project concerned the following procedures: 1) testing concrete by hardness method using