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RESEARCH FOCUSED ON LOW CARBONATION OF CONCRETE UNDER OLD CEMENT-BASED RENDER

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Abstract.

In-situ research and laboratory study of the concrete of old bridges shows that despite the low strength classes of concrete and the long time of exposure to CO_2, it is possible to moderate the depth of their carbonation. Many old bridges were found during the in-situ survey in Slovakia, which showed negligible carbonation under an old cement render (PRC) even after more than 100 years of direct exposure to CO_2. At the same time, it was found that if this protective layer was significantly damaged or missing in some places, the depth of carbonation of the same concrete reached considerable depths, locally 70-80 mm. The article presents and summarizes the findings from in-situ and laboratory research with a possible explanation of this phenomenon.

Keywords: Carbonation, cement render, concrete.

1. Introduction

The carbonation of concrete is a slow process during which the atmospheric CO_2 reacts with the compounds of the cement matrix, especially with portlandite. Speed of carbonation is governed mainly by diffusion. It depends on the quality of concrete (the amount and type of cement used, water to cement ratio, used admixtures, etc.), environmental conditions (relative humidity, wetting and drying cycles, temperature, etc.) and amount of CO_2 concentration in the surrounding air [1–5]. Based on many research projects and experience, it could be stated that the better is the concrete quality, the lower is the speed of carbonation [6]. However, during the study of 100 years old bridges in Slovakia, it was observed that in some cases, also the poor quality concrete could have negligible carbonation. It has been found that a dense PRC applied 100 years ago was able to prevent the underlying concrete from carbonation. This unexpected result was observed on several bridges from the beginning of the 20th century when a PRC applied to the concrete surface was a common practice to enhance the aesthetic properties. However, this PRC has proven a feature to be also an effective carbonation barrier [7].

During in-situ research and residual life analyses of 125 years old Monier type concrete bridge in 2014, it was observed that a thin layer of cement render (2-4 mm thick) could protect the underlying concrete from carbonation, although it is a low-strength concrete. Subsequent repeated measurements in 2015 were reaffirmed by laboratory measurements (chemical and thermal analysis). With ongoing research, other bridges were found from the beginning of the 20th century in the following years, with similar results.

2. Measurement methods and results

In-situ measurements consisted of the following steps:

- The surface with the PRC was cleaned, and permeability measurements with the Torrent method were performed [8].
- Permeability was measured directly at the places from where drilled core samples were taken. By this means, it was possible to correlate the permeability measurements with measurements of carbonation depth.
- After drilling the core sample, it was cleaned correctly with water pouring in the direction from the top of the cylinder to avoid contamination of the carbonated layer by non-carbonated concrete dust particles. The sample was wiped, and a 1 % solution of phenolphthalein was applied to its surface in the direction from the outer surface of the cylinder.

By this procedure, the carbonation depth was measured in-situ at all drilled core samples, which were then taken to the laboratory for further chemical analyses by the TG-DTA method. In-situ research showed a significant dependence between the depth of the carbonation of the underlying concrete and its permeability, which is primarily moderated by the protective render coat (PRC). The graphs in Figures 1 and 2 show this dependence. According to the quality of the PRC, it can be seen that increasing the permeability of the surface also increases the depth of carbonation. In the case of 100-year-old concrete, the

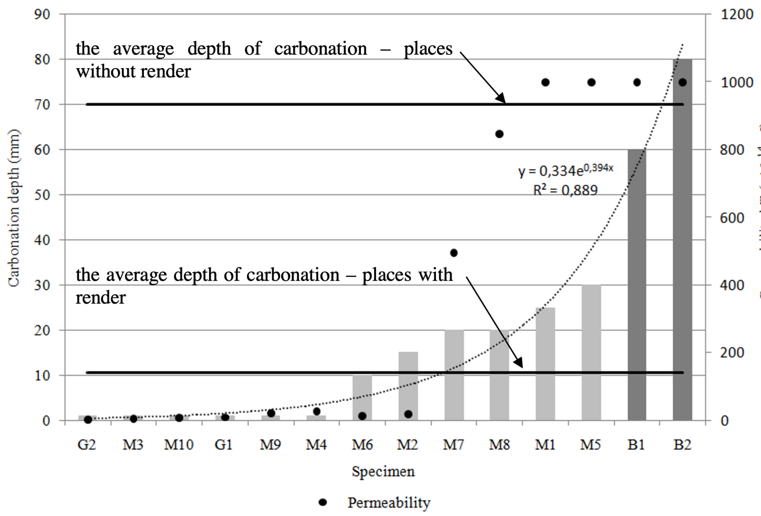

Figure 1. The results of in-situ measurements of the depth of carbonation and permeability at the Bridge in Sládkovičovo..

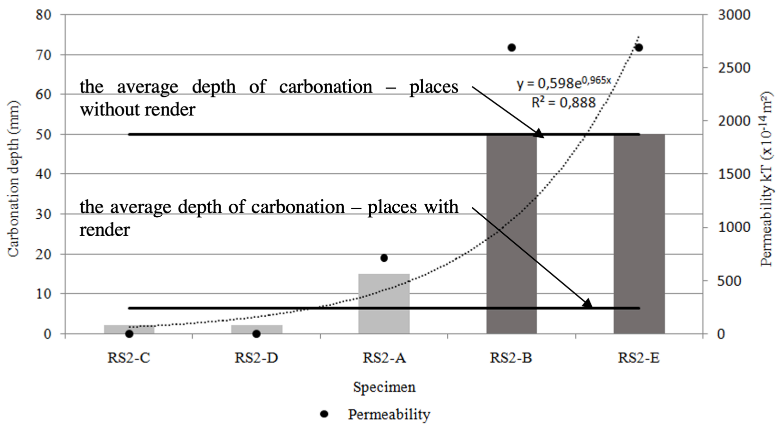

Figure 2. The results of in-situ measurements of the depth of carbonation and permeability at the Bridge in Sládkovičovo.

permeability is relatively high. If it is not protected by the PRC or this layer is considerably damaged, the carbonation reaches a considerable depth (dark bars of the diagrams). In contrast, if a 100-year-old concrete is protected by this layer (light bars in the diagrams), although this concrete has a high permeability, the PRC moderates the CO_2 ingress and the depth of carbonation.

It might be kept in mind that no chemical admixtures or additions were used at the manufacture of the PRC at the time of the bridge construction 100 years ago. It is stated that the observed low carbonation depth of underlying concrete can be explained by the protective effect of a thin cement render only, which is at some places almost non-permeable for CO_2. At the sites where the PRC was of good quality (Figures 4 and Figures 6), the carbonation of the underlying concrete was negligible (less than 2 mm). Even at the areas where the concrete was covered by a lower quality cement-based render, it had much lower carbonation depth than concrete at the places where the protective render coat spalled over time (Figures 5 and 7).

Figure 3. Places where drilled core samples were taken from the bridge abutment - on the left: the site with the protective render coat and on the right: the place where the render spalled over time (Bridge in Sládkovičovo).

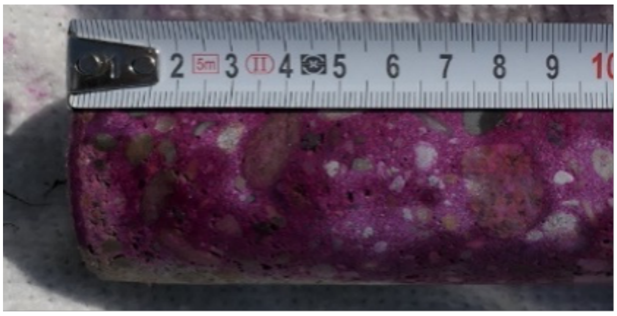

FIGURE 4. The carbonation depth of concrete at the places with a thin layer of PRC at the surface - sample selected from the measurements performed in 2018 (Bridge in Sládkovičovo).

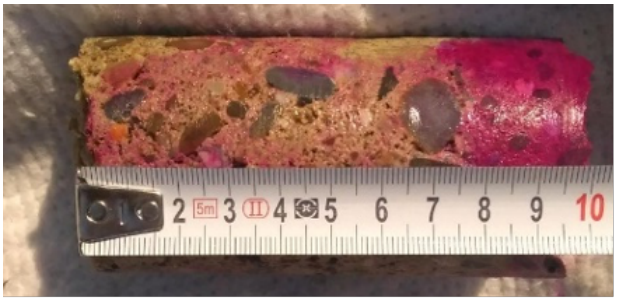

FIGURE 5. The carbonation depth of concrete at the places where the render was missing - sample selected from the measurements performed in 2018 (Bridge in Sládkovičovo).

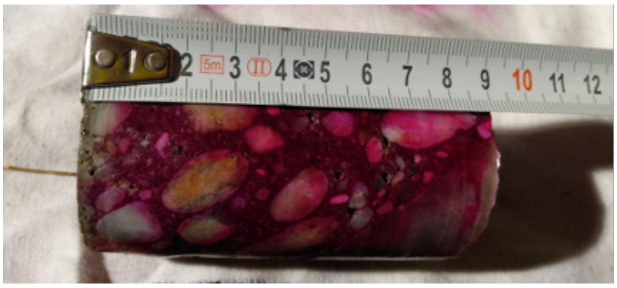

FIGURE 6. The carbonation depth of concrete at the places with a thin layer of PRC at the surface - sample selected from measurements performed in 2019 (Bridge in Rimavská Sobota).

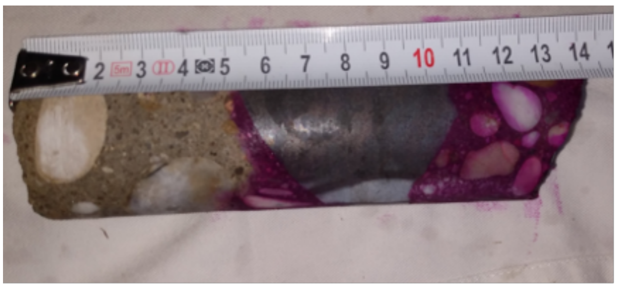

FIGURE 7. The carbonation depth of concrete at the places where this render was missing - sample selected from measurements performed in 2019 (Bridge in Rimavská Sobota).

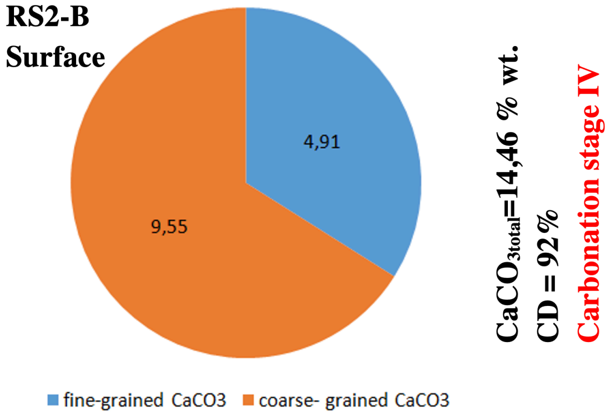

FIGURE 8. The amount of $CaCO_3$ (% wt.) in the surface layer of the unprotected concrete sample RS2-B.

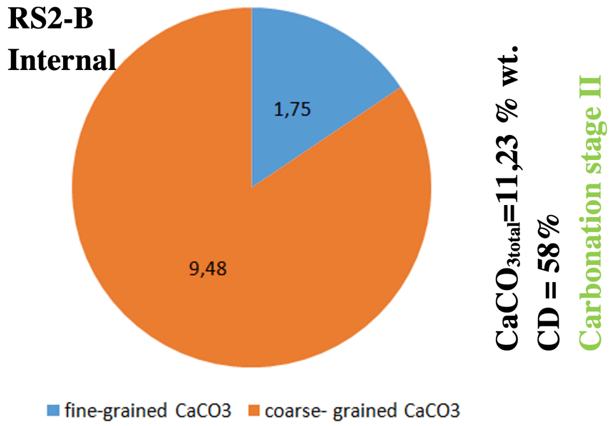

FIGURE 9. The amount of $CaCO_3$ (% wt.) in the internal layer of the unprotected concrete sample RS2-B.

The chemical and TG-DTA analysis was performed on the concrete samples to prove the in-situ results of the depth of carbonation. Concrete cylindrical specimens taken from the bridge were analyzed at depths of 0-20 mm (designated as surface) and at 280-300 mm (defined as internal) deep from the surface of the cylinder. The amount of $CaCO_3$ was calculated for each layer by chemical and TG DTA analysis. The degree of carbonation (CD) and the extent of CO_2 attack, characterized by the carbonation stages (I - IV), was calculated for each layer according to [7]. As can be seen from Figure 8, the surface of unprotected concrete is specific for the increased amount of both the total amount of $CaCO_3$ and the increased ratio of coarse-grained and fine-grained $CaCO_3$ compared to the PRC-protected ones in Figures 10 and 12.

Its high CO_2 attack also characterizes carbonation stage IV of the concrete surface sample compared to the internal part of the concrete in Figure 9. In contrast, PRC-protected concrete (Figures 10 and 12) is characterized by a reduced amount of $CaCO_3$ in the surface zone, compared to the unprotected sample RS2-B, and approximately the same ratio of coarse-

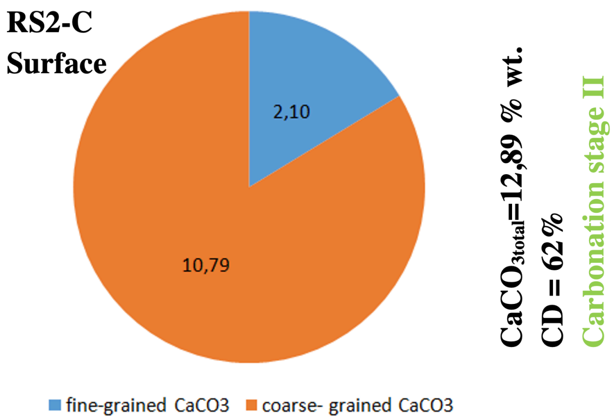

FIGURE 10. The amount of $CaCO_3$ (% wt.) in the surface layer of the protected concrete sample RS2-C by PRC.

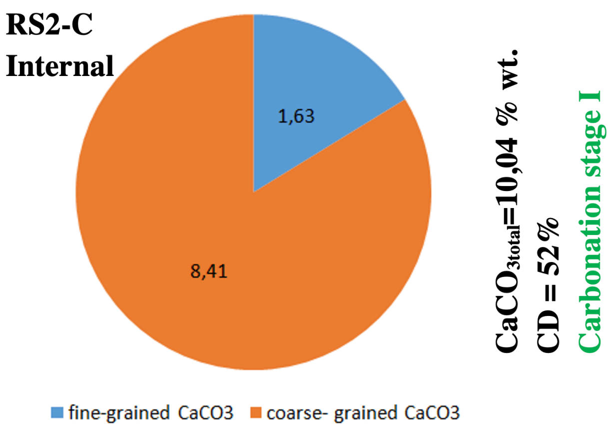

FIGURE 11. The amount of $CaCO_3$ (% wt.) in the internal layer of the protected concrete sample RS2-C by PRC.

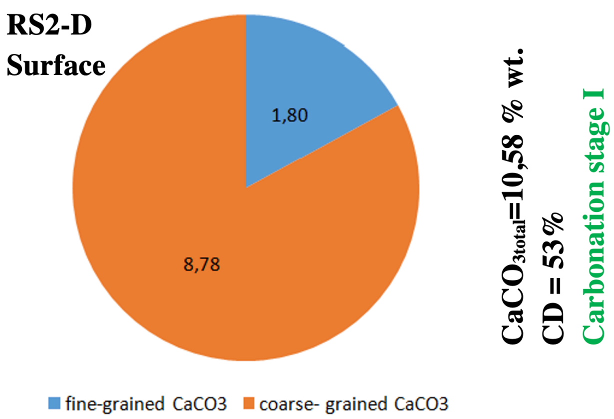

FIGURE 12. The amount of $CaCO_3$ (% wt.) in the surface layer of the protected concrete sample RS2-D by PRC.

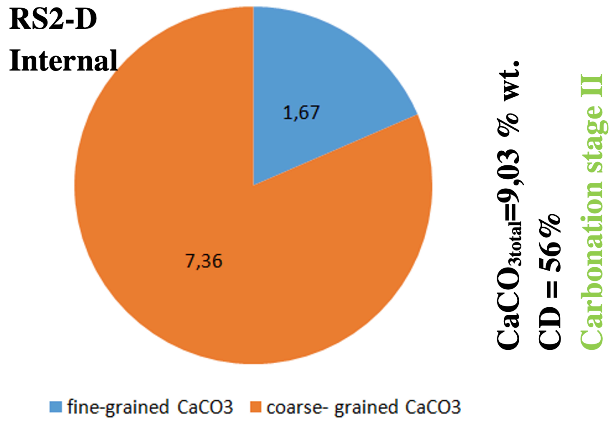

FIGURE 13. The amount of $CaCO_3$ (% wt.) in the internal layer of the protected concrete sample RS2-D by PRC.

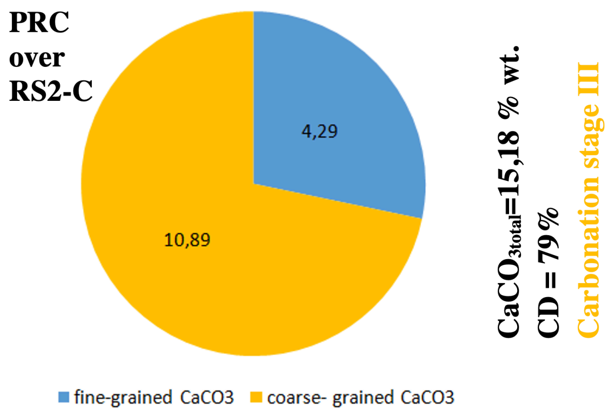

FIGURE 14. The amount of $CaCO_3$ (% wt.) in the PRC sample over RS2-C.

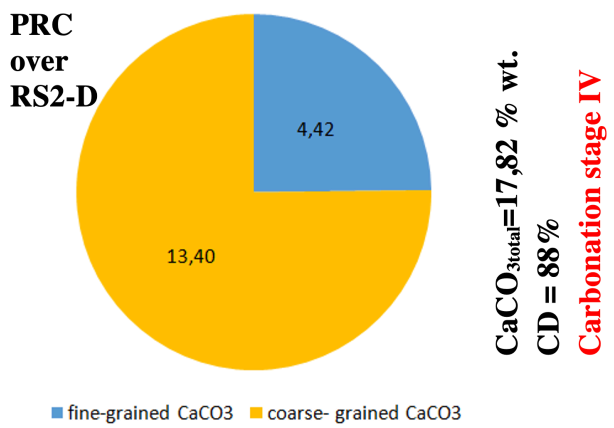

FIGURE 15. The amount of $CaCO_3$ (% wt.) in the PRC sample over RS2-C.

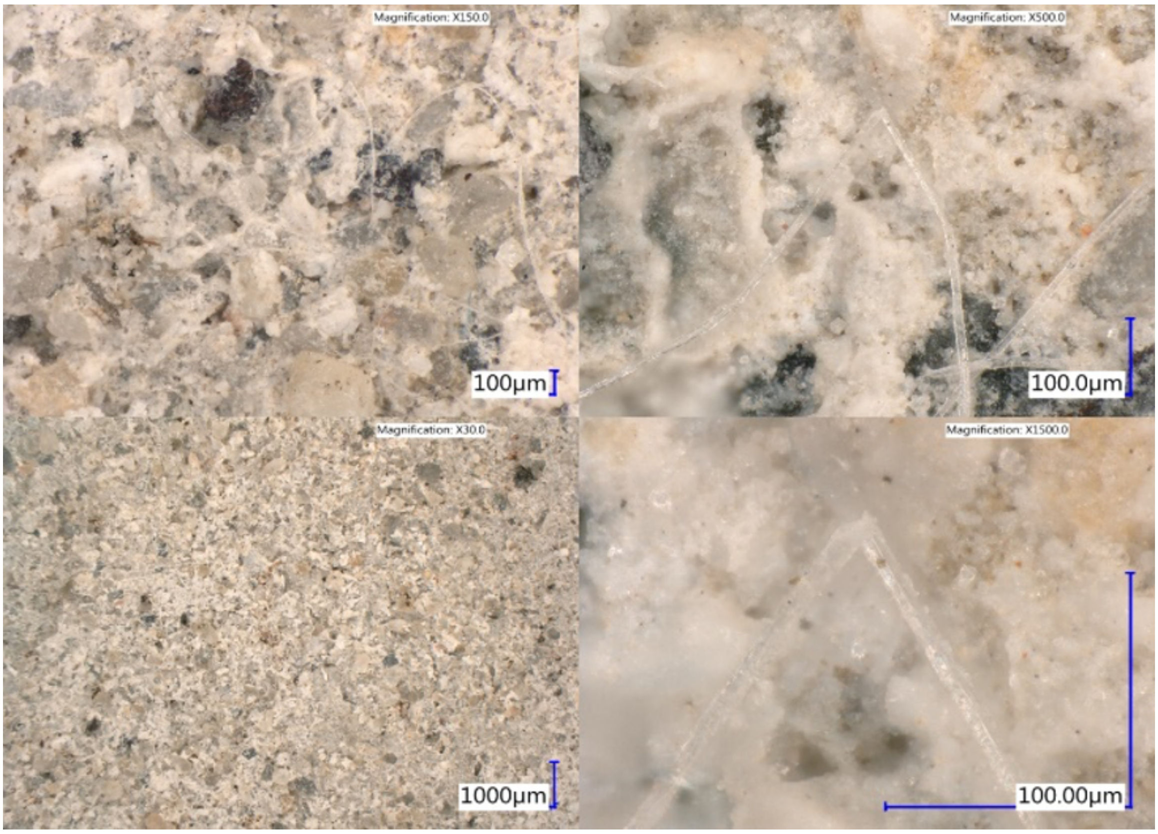

FIGURE 16. Optical microscope image of cement renders (PRC) at various magnifications.

grained and fine-grained $CaCO_3$ for the surface and internal part of the sample (Figures 11 and 13). This is due to the efficiency of the PRC to moderate the CO_2 ingress into the concrete below it. The effectiveness of PCR to protect the concrete beneath it lies in the absorption of CO_2 into its structure to such an extent that the resulting carbonates gradually clog the entire system until it becomes impermeable.It can be seen in Figures 14 and 15 that the PRC samples are characterized by a large amount of $CaCO_3$ in a layer only a few millimetres thick. This corresponds to the low permeability values in Figure 2. If such a clogged structure is damaged by cracks observed in the PRC over RS2-A sample (Figure 2), there is an increase in the permeability of the PRC, which is reflected in the increased depth of carbonation of the concrete. Despite the prolonged exposure to CO_2, the depth of carbonation is significantly lower than in the case of unprotected concrete.

The surface layer of the PRC was examined with an optical microscope. Figure 16 shows a structure formed predominantly of fine-grained carbonates, which is particularly noticeable at higher magnification. Crystallized coarse-grained carbonates (shining needles) are compressed in render thickness (2-4 mm) and, together with fine-grained carbonates, form a very dense structure. This finding is in good agreement with the chemical and TG-DTA analysis demonstrated in Figures 14 and 15.

3. Conclusions

The possible explanation of the extremely low permeability of the cement render and thus its superior protection of the underlying concrete could be summarized as follows:

- The in-situ measurements of carbonation depth, which were also demonstrated by thermal (TG-DTA) and chemical analysis showed that a good quality thin cement-based render (PRC with a thickness of only 2-4 mm) can sufficiently protect the old concrete against carbonation in case if its integrity is maintained.
- If the PRC layer was damaged at an unknown time during the entire life of the structure, the permeability of the surface was still lower than in the case of unprotected concrete as well as its depth of carbonation.
- During the study, a dependence of the permeability of the PRC and the depth of carbonation of the base concrete was observed, which consists in the gradual clogging of the PRC structure with carbonates.
- One of the possible explanations for this phenomenon could be the self-sealing effect. The pore structure of PRC is gradually clogged during the chemical reaction that occurs between CO_2 and hydration products in a cement matrix. The self-sealing of the PRC open pore system is caused by

the accumulated fine-grained carbonates compressing the coarse-grained carbonates in the process, which gradually reduces permeability to the point where CO_2 is no longer able to penetrate its structure.

In this way, the amount of coarse-grained carbonates is reduced because they are not able to grow in such a small space formed by the dense structure of the PRC. As a result, the remaining clearance in the structure is filled with fine-grained carbonate, which can cause the observed significant reduction in the permeability of the PRC.

Acknowledgements

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References

[1] C. F. Chang, J. W. Chen. The experimental investigation of concrete carbonation depth, *Cement and Concrete Research* **3**6(9):1760-1767, 2006. doi:10.1016/j.cemconres.2004.07.025.

[2] V. G. Papadakis, C. G. Vayenas, M. N. Fardis. Experimental investigation and mathematical modeling of the concrete carbonation problem. *Chemical Engineering Science* **46**(5-6):1333-8, 1991. https://doi.org/10.1016/0009-2509(91)85060-b.

[3] Physical and Chemical Characteristics Affecting the Durability of Concrete. *ACI Materials Journal* **88**(2), 1991. https://doi.org/10.14359/1993.

[4] L. J. Parrott, D. C. Killoh. Carbonation in a 36 year old, in-situ concrete. *Cement and Concrete Research* **19**(4):649-56, 1989. https://doi.org/10.1016/0008-8846(89)90017-3.

[5] G. Villain, M. Thiery, G. Platret. Measurement methods of carbonation profiles in concrete: Thermogravimetry, chemical analysis and gammadensimetry. *Cement and Concrete Research* **37**(8):1182-92, 2007. https://doi.org/10.1016/j.cemconres.2007.04.015.

[6] S. Matthews. Design of durable concrete structures. *IHS BRE Press*, Glasgow, 2014.

[7] I. Janotka, M. Bačuvčík, P. Paulík. Low carbonation of concrete found on 100-year-old bridges. *Case Studies in Construction Materials* **8**:97-115, 2018. https://doi.org/10.1016/j.cscm.2017.12.006.

[8] R. Torrent, G. Frenzer. Study on methods to determine and judge characteristic values of the coverconcrete on site Report No. 516, Bern, 1995.