GPR chloride inspection of a RC bridge deck slab followed by an examination of the results

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Abstract— **Chlorides applied to roads and bridges for de-icing can cause serious damage to concrete structures. On bridge deck slabs, there is usually a waterproofing membrane to prevent the ingress of water and chlorides into the concrete. If the waterproofing is damaged, the protection is insufficient and chloride ions and humidity penetrate into the concrete causing corrosion of steel reinforcing bars. This can finally result in a failure of the structure.**

GPR has been suggested as a method for detecting chloride contaminations in concrete bridge deck slabs. In laboratory experiments, the method has been applied and validated successfully. In addition, it has been applied to several bridge decks. However, on real bridges a detailed examination of the results is usually not possible.

In a field experiment, a bridge deck designated for demolition was inspected for chloride contamination using GPR. Afterwards the results were examined with an extensive probing programme. This paper presents a comparison between results of non-destructive (GPR) and destructive (probing) testing based on a detailed examination of measurement results.

Index Terms—**Chlorides, bridge decks, GPR, non-destructive testing, corrosion.**

I. Introduction

With the preservation of reinforced concrete bridges, the deck slab often represents the central question because its condition survey and rehabilitation regularly turn out to be cost intensive. Therefore, there is a need for non-destructive testing methods that can be implemented quickly and at a reasonable price and be evaluated reliably with the aim to precisely determine the condition and extent of rehabilitation expenditure. A method has been developed based on the evaluation of reflection amplitudes from the concrete surface and the top layer of rebar. This method verified by means of laboratory tests allows the non-destructive auscultation of chloride ion contents in RC bridge deck slabs [1] and [2]. The application of the method on several bridge deck slabs gave up to now plausible results, however, a detailed verification using destructive testing methods was not yet possible. To develop the method for a wide application, further bridge deck slabs showing different chloride ion contents should be examined with GPR and subsequently verified by means of intensive destructive sampling for the determination of chloride profiles by chemical analyses. The project described in this paper is the first step towards this aim. A bridge deck was tested with the method and a large number of samples were taken to verify the results.

II. Selection of Bridge

The first step was the selection of a suitable bridge. For this purpose, three criteria were defined. The bridge should allow for an intensive probing in about 50 locations and the probing should be carried out in 2013. In addition, a chloride contamination was considered as desirable. The first two criteria were defined as requirements, the chloride contamination was difficult or impossible to predict. The required intensive probing led to the conclusion that only a bridge designated for demolition was suitable. This, together with the need to carry out the probing in 2013, led to a very limited choice of objects. Finally, a bridge on National Road Nr. 13 near Splügen, Grisons, Switzerland was selected. The bridge deck had a length of 79 m, the width was 10.0 m. The selected bridge is presented in Figure 1. It was demolished in autumn 2013.

Figure 1: The selected bridge on National Road 13

III. GPR DATA ACQUISITION

Data were acquired in April 2013 using a mobile acquisition system based on a GSSI-SIR20 radar unit, a pair of model 4205 horn antennas, a Trimble model 5700 RTK GPS system and numerous accessories (Figure 2). Before data acquisition, lines parallel to the bridge axis were computed and later used for navigation. The distance between those acquisition lines was 0.5 m. Two different antenna orientations were used. In configuration 1 the electric field was orthogonal to the bridge axis, in configuration 2 it was parallel. The acquisition parameters can be summarized as follows:

Table 1: Data acquisition parameters

Traces per meter:	50
Trace length:	20 ns
Distance between acquisition lines:	0.5 m
Samples per trace:	1024
AD conversion:	16 bit
Max. vehicle speed:	10 km/h
Antenna conf. 1:	E-Field orthogonal to bridge axis
Antenna conf. 2:	E-Field parallel to bridge axis
Data processing during acquisition:	None

IV. DATA PROCESSING

Data were processed in 2D using the REFLEXW software [3] from Sandmeier Scientific Software from Karlsruhe, Germany. The processing was kept simple to avoid corruption of signal amplitudes. A simple processing sequence was applied to all data consisting of:

Bandpass filter
Static correction
Length correction with respect to GPS lengths
Running average

After the processing of the GPR data, reflections at the asphalt-concrete interface and at the top layer of rebar were picked and travel times and reflection amplitudes were output to files for further processing. A depth correction was applied to the amplitudes of the top of rebar reflections and mean values (+- 1.0 m) were computed for amplitudes.

Based on the approach described by [1] and [2], the quotient of the top of concrete/top layer of rebar reflection amplitudes was computed. This approach is based on the assumption that chlorides and moisture in concrete increase the electrical conductivity and thus, damping. The result is presented in ***Figure 1*** for the GPR data acquired with the E-field orthogonal to the bridge axis. The main areas of increased quotients, suggesting increased contents of chlorides and moisture, are located at the northwestern edge of the bridge deck.

Figure 2: Mobile acquisition system

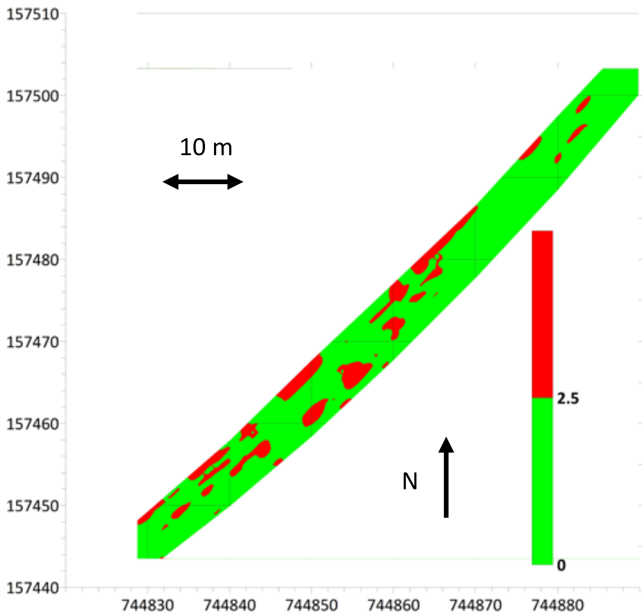

Figure 3: Quotients of amplitudes top of concrete/top layer of rebar

V. PROBING AND LABORATORY RESULTS

Based on a first visual inspection of the GPR data and the computed quotients, 40 probing positions were defined. In order to be compatible with the demolition work that was running in parallel, 20 probes were carried out when the asphalt was still on the bridge and 20 probes were carried out after the asphalt had been removed. During the first series of probing (with asphalt) the following steps were carried out on site and in the laboratory:

On site:

- Mark probing position of surface using an RTK-GPS system
- Open a window of 0.8 x 0.8 m
- Remove sealing
- Measure pavement thickness (including sealing)
- Mark rebar position using electromagnetic device and magnet
- Measure self-potential in six locations
- Remove concrete to expose rebar
- Measure concrete cover of rebar
- Measure rebar diameters
- Secure and seal concrete specimen for measurement of moisture in laboratory
- Inspect rebar for corrosion
- Carry out carbonation test
- Take two cores for chloride analysis in laboratory

After each step, a photograph was taken.

In the laboratory:

- Measure electrical resistivity of core
- Measure chloride content using cores, using depth steps of 1 cm
- Measure moisture of specimen using drying test.

The situation during the probing is presented in Figure 4, one location after the completion of the probing is shown in Figure 5.

Figure 4: Probing on bridge

Figure 5: Location 15 after completed probing

In summary, it turned out that the bridge had very little corrosion problems (relevant corrosion in one location only) and also very small chloride contents in most locations. In only four locations, chloride contents above 0.4 % were found. A content of 0.4 % is considered as the threshold value for an acceptable chloride contamination. In three of the four locations the relevant contamination was limited to the top 10 mm. A summary of the chloride contents on the bridge deck is presented in Figure 6. As described above, the large majority of the probes resulted in chloride contents below the threshold of 0.4 % (green and yellow marks). The four locations with chloride contents above the threshold are located at the northwestern edge and near the southwestern end of the bridge deck.

As described in chapter II, the ideal bridge for this project would have been one with a relevant chloride contamination. Unfortunately this was not the case on the inspected bridge. As described above, a large number of parameters were recorded during the field and laboratory tests. In the following the description will focus on the chloride content.

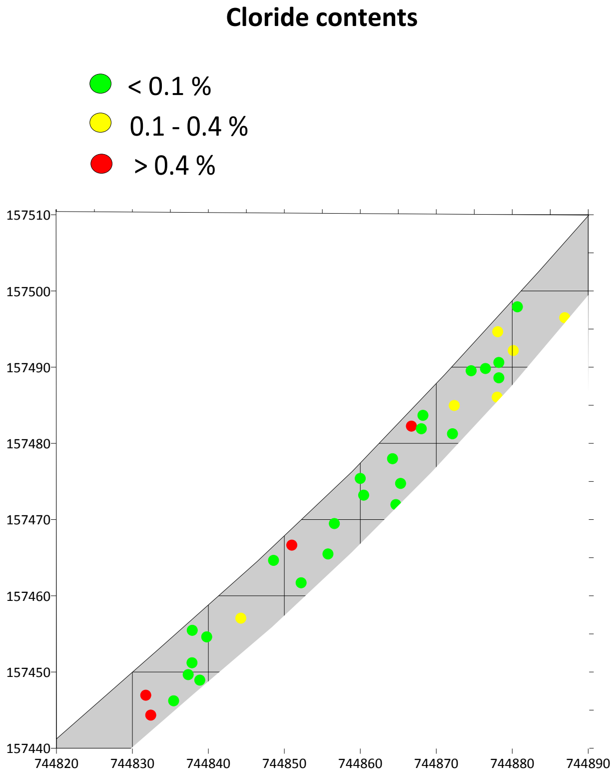

Figure 6: Chloride contents on bridge deck

VI. Comparison between GPR and laboratory results

In Figure 7, the combination of quotients as obtained from the GPR data and chloride contents from laboratory results is presented. The four locations where increased chloride contents (> 0.4 %) were found are marked as A, B, C and D. Please note that the color scale for the quotients is in a way arbitrary. During "real" inspections of bridge decks this color scale is calibrated using a very limited number (1-4) of probes. Locations A, B, C and D are in areas with increased quotients and would have been recognized as areas of possible contamination. Altogether the comparison can be summarized as follows:

Table 2: Comparison between GPR quotients and laboratory results for chlorides

	GPR quotient	
Laboratory chlorides	< 2.5	>2.5
> 0.4 %	0	4
0.1-0.4 %	3	3
< 0.2 %	18	5

All probes with relevant (>0.4 %) chloride contents are within areas of increased GPR quotients. Half of the lab probes with slightly increased chloride contents (0.1-0.4 %) are lying within areas of increased quotients and half of them are lying outside. The vast majority (18) of the lab probes without increased chloride contents (< 0.1 %) are lying outside areas of increased quotients, only 5 are within.

In summary, all areas with increased chloride contents have been detected by the quotient method but some areas without increased chloride contents show also increased quotients.

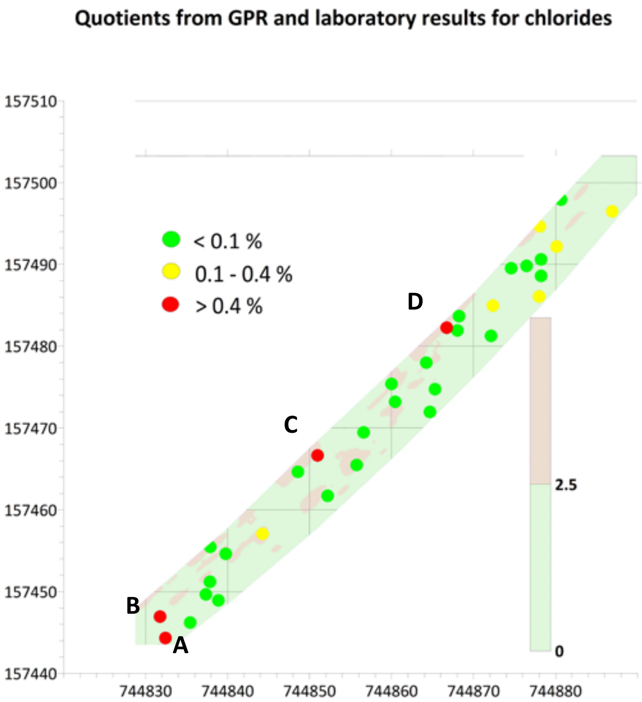

Figure 7: GPR quotients and laboratory results for chlorides

VII. Conclusions

Chlorides in bridge decks are one of the most important reasons for corrosion and thus, a main cause for expensive repair or replacement work and annoying obstruction to traffic.

A method for testing bridge decks covered with asphalt non-destructively for areas with increased chloride contents is therefore desirable.

A study has been carried out for the evaluation of a non-destructive testing method using GPR. GPR data were acquired on a bridge designated for demolition. The data were processed and results were produced based on the quotient between concrete surface and top of rebar reflection amplitudes. A large number of destructive probes were taken and evaluated.

The comparison between GPR results and destructive testing shows, that the non-destructive approach has detected all contaminated areas. However, few areas that were not contaminated caused false alarms.

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