Ground Penetrating Radar for condition survey of structures

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ABSTRACT: Systematic non-destructive condition surveys are essential to structural rehabilitation or modification of bridges. Condition survey implies information collection and analysis for performance evaluation of existing structures. Common condition surveys often require localized, invasive and destructive methods that may locally affect the structure and do not provide continuous spatial information such as cladding thickness and internal geometry. The use of non destructive techniques combined with external structure analysis can alternatively provide more precise and comprehensive information.

For more than 20 years, Ground Penetrating Radar (GPR) has been used in civil engineering to determine spatial and structural information such as layer thicknesses or defect mapping. This paper presents the application of Ground Penetrating Radar for the condition survey of an almost 100-year old massive concrete arch bridge with masonry piers. This railway bridge is intended to be modified for future traffic demands. Emphasis is placed on the determination of the natural stone masonry pier design and the internal dimensions of bridge arches. The results are presented and the benefits and limits of this condition survey method for massive bridge structures are discussed.

2 INTRODUCTION

Estimating and using the structural reserve of existing bridges to their maximum potential in order to satisfy new requirements is essential with respect to economic needs as well as environmental, cultural and social aspects [1]. For each project, this implies a precise assessment of the structure in question and an analysis of the rehabilitation project in order to guarantee structural safety and increase structural service life [2]. In such assessments, non destructive testing condition surveys provide important spatial and structural information to civil engineers [3]. This paper presents the application of Ground Penetrating Radar for the condition survey of a 100-year old massive concrete and masonry arch railway bridge which is to be modified for future traffic demands.

3 GROUND PENETRATING RADAR

Ground Penetrating Radar (GPR) is a non-destructive method that sends electromagnetic waves into an object and records backscattered variations of radar signal in time (Figure 1). The use of this method aims to localize objects in a structure [4] (e.g., reinforcement, joints, voids, delaminations) and, to determine their material electromagnetic properties.

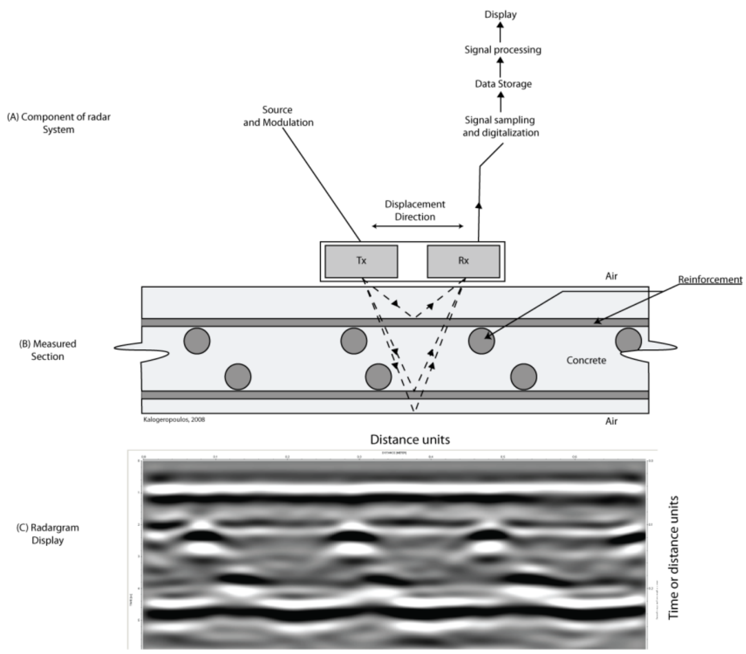

Figure 1. Principle of a GPR measurement.

3.1 Electromagnetic parameters

Electromagnetic (EM) waves can be presented as spatiotemporal variations of an electric field E and a magnetic field H that are perpendicular to one another and to the direction of the wave propagation. In a dielectric medium the wave velocity depends on the conductivity σ and the dielectric permittivity ε. Conductivity can be seen as energy losses and permittivity as the rebound capacity of the medium after an electromagnetic stimulation. Each material has a specific permittivity and conductivity parameter, this implies an EM wave transmitted by a GPR antenna propagates at different velocities in each different material (e.g., air, concrete, metal or water). At each interface, depending on the velocity difference between two adjacent materials, a part of the propagating wave is transmitted through the interface and another part is backscattered in the direction of the GPR antenna [5]; thus, each recorded EM wave reflection corresponds to a material change (Figure 1).

3.2 Technical aspects

GPR antennas are identified by their central frequency. This corresponds to the peak of energy distribution as function of frequencies. The antenna used in the following study has a central frequency of 1.6 GHz. The central frequency is used as the reference, because it gives an indication of the resolution (the size of detectable objects) and the covered depth of investigation. Because of their longer wavelength low frequency waves propagate further than high frequency waves. A high frequency antenna (e.g., 1.2 GHz to 3.0 GHz) will provide accurate information within a range of 0.25 m to 1 m for objects in orders of centimeters. Low frequency antennas (e.g., 25 MHz to 500 MHz) provide information about objects in the orders of meters within a range of 10 m to 4000 m (e.g., ice).

4 CASE STUDY: MASONRY ARCH BRIDGE

This study is part of a bridge inspection project to evaluate the condition of a Swiss railway bridge and to establish recommendations for its modification for future traffic demands.

4.1 Structure description

The bridge built in 1913-1914 is composed of a series of five plain concrete arches with a span of 8 m each supported by natural stone masonry piers and abutments. The bridge has a total length of 60 m long (Figure 2) and in plan view has an 80-m curvature radius.

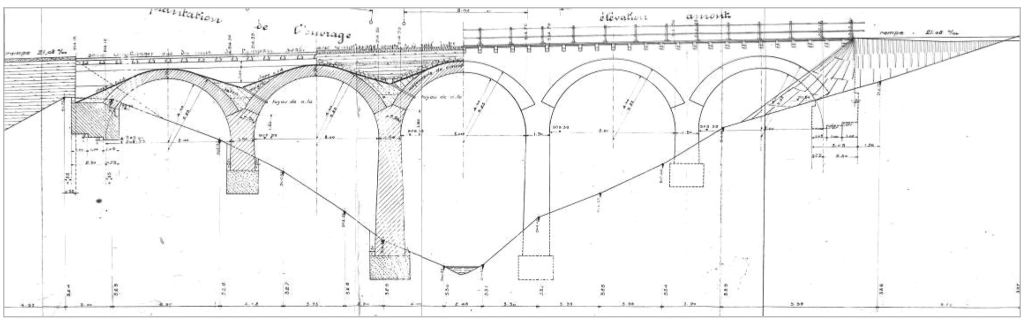

Figure 2. Bridge profile

The railway bridge is 4.11 m wide. This includes the width of concrete spandrel walls retaining layers of concrete between arch springers and fill material that evens the bridge surface. The 2.91 m wide layer of ballast and rails with wooden sleepers are placed over the fill material.

4.2 Ground Penetrating Radar measurements

Eleven ground penetrating radar profiles were recorded along one arch and on two piers (Figure 3) during a survey campaign in September of 2008. A Ramac MALÅ Ground Penetrating Radar system with a 1.6-GHz central frequency antenna was used. This provides depth of investigation of 1 m into the structural members. All radargrams were processed along seven signal processing steps.

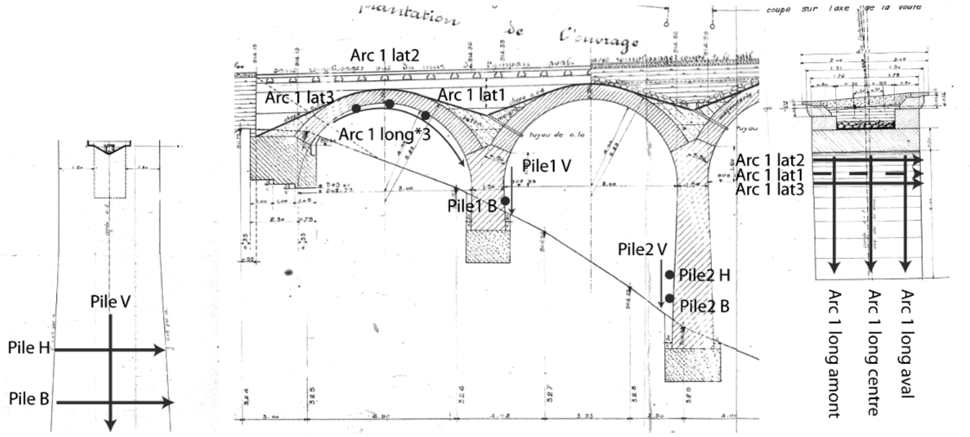

Figure 3. GPR profile measurements

4.3 Piers

The four natural stone masonry piers supporting the arches have a rectangular cross section with increasing dimensions from top to bottom. Irregularities of the stone masonry surface cause the antenna to tilt. Consequently, the reflections along the masonry-blocks/pier-core interface converge into a point shape reflection (Figure 4) instead of a regular line. The joint mortar between the blocks is not visible due to its perpendicular position to the propagating wave.

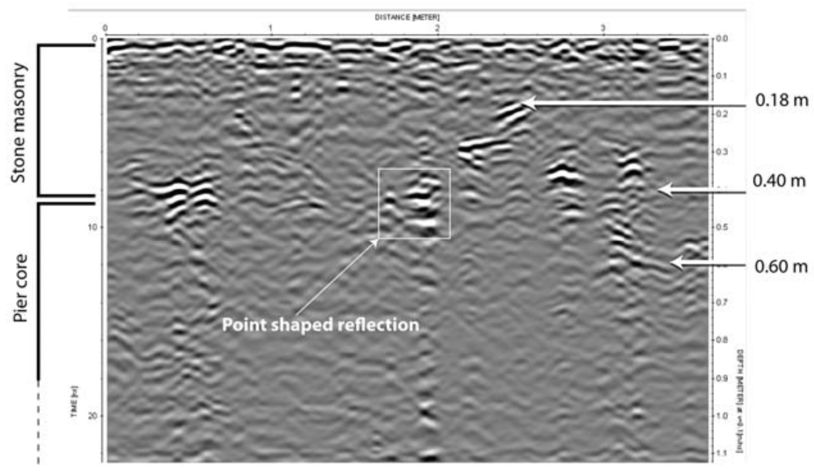

Figure 4. Radargram at the base of the second pier (i.e., Pile2 B)

Based on the GPR measurement, the average thickness of the stone masonry blocks is 40 cm. The blocks are homogeneous without any major cracks or voids. The core of the pier seems to be filled with rubble masonry as it is the typical case for most masonry bridges.

4.4 Arches

Supported by the piers, the arches carry the dead loads (their self weight and the weight of the railway, fill material and spandrel walls) and the live loads transferred to them through the ballast and fill material. Spanning 8 m, the arches have an inner radius of 4 m and a rise of 2.5 m from the top of each pier. Each arch is 3.57 m wide and has a thickness varying from 0.7 m to 0.9 m from the keystone to the springers. The existing construction plans show that over the piers the arches are thickened at their springers with a concrete fill; detailed structural analysis shows that this fill improves the structural behavior of the arches.

All GPR arch measurements reveal the presence of three continuous reflections at three different depths (0.15 m, 0.45 m and 0.75 m) (Figure 5). On the side of each radargram in Figure 5 a reference trace is presented showing the reflected wavelet at each interface.

Note that voids and delaminations act as air layers in concrete. EM waves propagate at different velocities in air and concrete (0.3 m/ns and 0.1 m/ns, respectively). As previously described in Section 3.1, a significant velocity difference generates an important reflection.

In Figure 5, it is difficult to follow a straight line in all the radargrams due to the poor electromagnetic contrast between the different layers. This indicates that these layers are in contact and that no major defect or delamination is present between them.

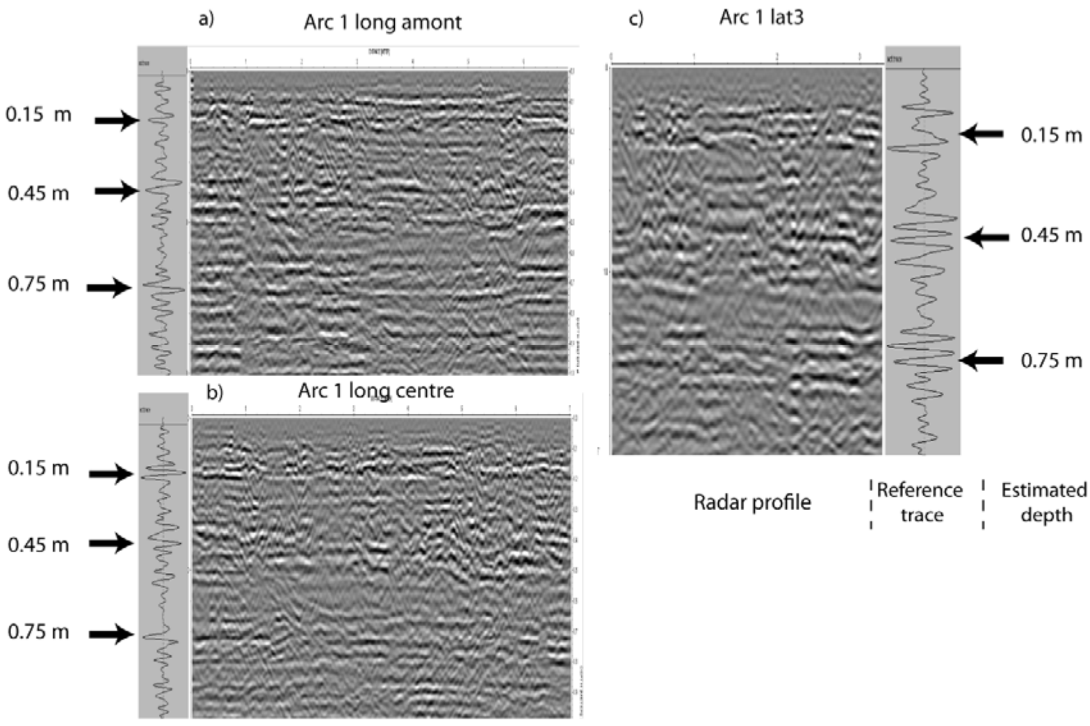

Figure 5. Radargrams of the arch 1: a) and b) longitudinal profiles, c) transversal profile

According to the 1900's building procedures, the non-destructive measurements, and field observations, the concrete arches appear being cast in three different stages. In this procedure, after curing, each layer improves the capacity of the initial wooden formwork and participates in carrying the dead load of the additional layers of concrete (similar to a stay-in-place formwork). This procedure allows designing a light-weight initial formwork with a minimum bearing capacity and reducing the volume of concrete transported at each construction phase.

5 CONCLUSIONS

The combination of visual inspection with Ground Penetrating Radar provides detailed and accurate information on the bridge condition in this case study:

a) First, it is observed that no major defects were present in the inspected piers and arches.

b) Second, it is possible to determine the constructional detail and inner geometry of the plain concrete arches (built in three layers) and the size of the bearing stone masonry blocks of the piers.

All the geometrical information (thicknesses, layered construction of the arches) were taken into account in the limit-state structural analysis of the existing bridge based on the philosophy of Swiss Society of Engineers and Architects (SIA) in the new SIA 269 code.

The encountered limitations involved the piers surface regularity that caused distortions to appear in the radargrams. A solution will be developed in future studies to minimize this effect. Future work will emphasize on the optimization of GPR data collection.

6 REFERENCES

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