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The inspection of retaining walls using GPR

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ABSTRACT

In hilly regions, retaining walls along roads, motorways and railway lines are numerous. In some cases the knowledge of the details of the construction is limited. If rehabilitation work becomes necessary, a detailed knowledge of the construction is desirable for the improved planning of maintenance and repair. This paper describes the application of Ground Penetrating Radar (GPR) for the inspection of retaining walls. The work was carried out in two steps. First, an investigation was carried out on large retaining walls at a Swiss motorway within the framework of a service contract. This included the development of an apparatus enabling high precision positioning of the antennas on the walls. Second, a pilot study was performed on a smaller wall with optimized acquisition and processing parameters. This included the use of antennas with different orientations and the fusion of the two corresponding datasets as well as true 3-D data processing. This paper describes the approaches to data acquisition and processing in the form of the two case studies. Results from different acquisition and processing strategies are compared and the benefits and limits are discussed.

1. Introduction

The Swiss A9 motorway was built in the early seventies of the last century. It runs along the northern shore of Lake Geneva where there is a steep slope from the mountains towards the lake. As a result there is a large number of retaining walls particularly on the uphill side of the motorway. After more than 30 years in service, many of those walls are in need of repair and/or inspection. In order to evaluate the benefit of GPR as an inspection tool for those walls, a pilot study was carried out on one of the walls within the framework of a service contract. After the completion of this project, a second project was carried out on a smaller wall for the purpose of testing the benefits of enhanced data acquisition and processing.

GPR inspections of various concrete structures such as bridges, bridge decks and tunnel walls have been reported frequently (Taffe et al., 2003; Daniels, 2004; Hugenschmidt and Mastrangelo 2006; DGZfP, 2008) and can, in many cases, be considered routine applications of the radar method. The inspection of retaining walls poses challenges such as the controlled positioning of the antenna (s) on the wall face or the trade-off between the time required for data acquisition and data density. Limited literature is available on this subject.

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2. Case study 1

A photograph of the wall and the westbound lanes of the motorway is presented in Fig. 1. The wall consists of 4 different levels, the heights of the different levels are varying between 6.5 m and 4.0 m. In the following text, the levels of the wall will be numbered from bottom to top with level 1 being the bottom level and 4 the top level.

In Fig. 2 the coordinate system used throughout this paper is shown. All data presented will be named as “*A*”-slices with *A* being the axis perpendicular to the slice.

2.1. Data acquisition

Data acquisition was carried out with a GSSI SIR-20 system in spring 2006. As this was a pilot study, three different antennas were tested. As one of the aims of this study was a test of the capability to locate the heads of rock anchors, a high accuracy of the antenna position was required. In order to achieve this, a semi-automated survey apparatus was developed. It consists of a rail system sitting on the copings of the different levels of the wall, an antenna box, a ladder-like guiding system for the antenna box, an electric motor for moving the box up and down the face of the wall, a survey wheel for controlling the vertical position of the box and triggering the data acquisition and an electronic protractor for monitoring the angle between the guiding system and the vertical line thus controlling the lateral position of the antenna. In Fig. 3 the top of the apparatus is shown together with the antenna box in the guiding system on the face of the wall.

Fig. 1. Retaining wall.

Data were acquired along vertical lines corresponding to the *X*-direction in Fig. 2 on the face of the retaining wall. All antennas were orientated such that the E-field was pointing in the *Y*-direction. Line spacing was varied between 0.04 m and 0.1 m and the in-line sampling rate was 0.005 m. Apart from a gain function applied to ensure the optimal use of the dynamic range of the radar system, no data processing was performed during acquisition. The equipment used for data acquisition and the acquisition parameters are listed below.

Radar unit:	GSSI SIR-20
400 MHz antenna*:	GSSI model 5103
900 MHz antenna*:	GSSI model 3101-D
1500 MHz antenna*:	GSSI model 5100
Apparatus for data acquisition:	Empa custom-built

*antenna frequencies as provided by manufacturer.

Acquisition parameters:	
Samples per scan:	512 (400 MHz model 5103 and 900 MHz model 3101-D antennas)
	1024 (1500 MHz model 5100 antenna)
Line spacing:	0.04 m (1500 MHz model 5100 antenna)
	0.1 m (400 MHz model 5103 and 900 MHz 3101-D antennas)
In-line sample rate:	0.005 m
Scan-length:	40 ns (400 MHz model 5103 antenna)
	25 ns (900 MHz model 3101-D antenna)
	20 ns (1500 MHz model 5100 antenna)

After the equipment had been set-up, up to 30 vertical lines were acquired per hour. Depending on the line spacing this corresponds to a horizontal distance between 1.2 m and 3.0 m per hour.

2.2. Data processing

Data were copied to a personal computer and processed using REFLEXW software (Sandmeier, 2007). The 2-D processing sequence for the model 5100 antenna can be summarized as follows:

1. Bandpass filtering (lower cutoff 200 MHz, lower plateau 400 MHz, upper plateau 2700 MHz, upper cutoff 2900 MHz).
2. Static correction of picked direct wave.
3. Kirchhoff migration using $v = 0.11$ m/ns.
4. Gain correction using a linear gain function (0 dB at 0 ns and 20 dB at 20 ns).
5. Time cut to the same number of samples per scan for each dataset (corresponding to 12 ns for the 1500 MHz model 5100 antenna).
6. Resampling to 0.04 ns to reduce the size of the datasets.
7. Background Removal by subtraction of a mean trace (2-D data were transferred into 3-D datasets with and without Background Removal).

No corrections concerning the position of lines or traces were applied. This was unnecessary due to the high accuracy of the positioning made possible by the apparatus described in section 2.1. Following the 2-D processing sequence data were merged into 3-D files. All interpretation was based on 3-D files.

2.3. Interpretation and results

2.3.1. Antennas

In general, it can be assumed that high frequency antennas provide better resolution but less depth of penetration than low frequency antennas. As far as the resolution is concerned, this assumption can be easily confirmed by a comparison of the datasets obtained with the three antennas on level 2 of the retaining wall. In Fig. 4-a the time

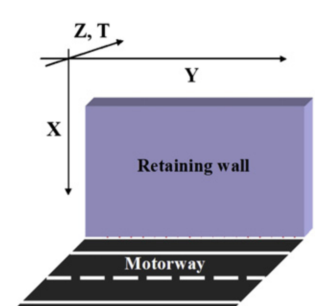

Fig. 2. Coordinate system.