Amplitudes Variation of GPR Rebar Reflection Due to the Influence of Concrete Aggregate Scattering

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Abstract

Dense GPR measurements of rebar reflection amplitudes show relative variations, which can be in the order of more than 10% - 20%. Former investigations demonstrated that these variations are caused by the heterogeneity of concrete, i.e. due to the inclusion of aggregates in concrete. These amplitude variations make it difficult to analyse single reflection amplitudes in order to determine the rebar diameter or to estimate the concrete deterioration state. In a systematic study we have quantified the statistical variation of the rebar reflection amplitude for concrete covers of 6 cm, 9 cm, 12 cm, 15 cm and 18 cm, for two different grading curves and for the rebar diameters 12 mm and 28 mm. Also the influence of the wavelength has been investigated by using antennas with different centre frequencies in relation to the aggregate size. The results are discussed with regard to a quantitative amplitude evaluation of GPR measurements and also the potential of using these variations for a characterization of concrete material properties.

Keywords: ground penetrating radar, concrete, rebar, aggregate scattering

1. Introduction

Ground penetrating radar (GPR) in the frequency range above 1 GHz is well suited for the detection and location of the internal structure of reinforced concrete and is a good non-destructive testing (NDT) practise for more than 25 years. Typical objects for the detection are rebars or tendon ducts in bonded post-stressed concrete. The locations of these objects are determined by images which represent depth slides or cross sections of the reconstructed radar measurement data. The images visually show the location of the origin of the electromagnetic wave reflections. The absolute strength of the reflections is normally not evaluated for the detection and location of reinforcement. The strength of the reflections only needs to be sufficiently high in order to discriminate them from areas without reflecting objects.

For the condition assessment of reinforced bridge decks research has been conducted within the last years. The aim was mostly to evaluate the deterioration level of the concrete using the absolute values of the reflection amplitudes of the first reinforcement layer [1]. Another application based on the evaluation of the absolute amplitudes of rebar reflections is the estimation of rebar diameter [2].

Own investigations have shown, that the heterogeneity of concrete due to the aggregates causes continuously weak scattering of the electromagnetic radar wave [3]. This weak scattering was measured along very dense grids with trace distances of 5 mm in x and y direction and the antenna being placed very close to the surface of the test specimen. Our data demonstrate that the reflection amplitudes obtained on a rebar having a constant concrete cover with no variations of the concrete quality feature significant variations. The findings of this work will be presented and discussed below.
2. Measurements

2.1 Specimens

For our study we used a set of three concrete blocks. The dimension of each concrete block is 1.5 m x 1.5 m x 0.66 m having embedded five rebars at 60, 90, 150, 180 and 120 mm depth (centre rebar – surface). A reference specimen was built with rebar diameter of 12 mm and a maximum aggregate size of 16 mm. Only one of these two parameters (diameter, maximum aggregate size) changes to 28 mm rebar diameter or 32 mm for maximum aggregate size. Figure 1 shows the specimens. The number of specimens in the figure 1 is larger than three due to other parameters, which are changing, but were not used in this work.

![Figure 1: Set of eight concrete specimens. Each of them features five rebars being embedded at different concrete covers.](image)

2.2 Set-up

For the GPR measurements we used two different antennas with centre frequencies of 1.5 GHz and 2.6 GHz. The antennas and the control unit SIR-20 are from GSSI. We chose trace distances of 5 mm in x as well in y direction to acquire a dense measurement grid, which enables us to measure almost continuously the spatial changes of all reflections. For each specimen and antenna centre frequency we scanned the surface in three different orientations of the antenna (0°, 45° and 90°) to alter the antenna polarisation with respect of the alignment to the rebars.

For this purpose we used an automated scanning system for the movement of the antenna. The scanning system is required to assure the precision of the trace locations and to acquire the traces within an appropriately short time. We developed and assembled a scanning system for fast automated GPR measurements. It provides a maximum speed for the movement of the antenna of about 1 m per second. Horizontal lines are collected along meander paths making vertical lines (common in manual data collection for 3D acquisitions) unnecessary as the line distances are 5 mm in each direction and the antenna is rotated. The automated scanning system is shown in figure 2 mounted to one of the test specimens. This way a complete set of measurements with one antenna in three different orientations could be done in less than 30 minutes.
Figure 2: Scanning system for automated movement of the radar antenna mounted on one of the specimens.

For the verification of the results we obtained with the scanner we repeated some of the measurements manually. In order to avoid influences of the scanning system itself (i.e. due to vibrations during the automated movement of the antenna) single lines directly above the rebars were recorded. The manual measurements are shown in figure 3 for two different antenna orientations.

Figure 3: Manual measurements along a single rebar with two different antenna orientations (left: 0° and perpendicular to rebar; right 90° and parallel to the rebar).

All automated measurements are summarized in table 1.
Table 1. Overview of the automated measurements

<table>
<thead>
<tr>
<th>Specimen characteristics</th>
<th>Antenna</th>
<th>Antenna Orientation in °</th>
</tr>
</thead>
<tbody>
<tr>
<td>rebar diameter: 12 mm</td>
<td>1.5 and 2.6 GHz</td>
<td>0, 45, 90</td>
</tr>
<tr>
<td>max. aggregate size: 16 mm</td>
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3. Results

We analysed a 1 m long and 0.1 m wide area above each of the five rebars, so that the minimum distance to the edges of the specimen is at least 0.25 m. This minimum distance is needed to make sure the edge reflections are not affecting the reflection amplitudes. The position of the analysed areas for the five rebars is shown in figure 4. Each of these five areas was analysed separately.

Figure 4 Test specimen (1.5 m x 1.5 m x 0.66 m) with five rebars at five different installation depths; green rectangles show the areas, where the reflection amplitudes were analysed.

For each A-scan the first maximum of the rebar reflection was picked and normalized to the maximum value within its area. The normalized amplitude values are plotted in a 2D coloured image representing the distribution of the first maximum rebar reflection amplitudes above a single rebar. The coloured images of the three investigated specimens are shown in figure 5.
Figure 5 Normalized maximum rebar reflection amplitudes of each trace; white lines mark the position of maximum rebar reflection also in x direction.

Top: specimen with 12 mm rebars and maximum aggregate size 16 mm;
Middle: specimen with 28 mm rebars and maximum aggregate size 16 mm;
Bottom: specimen with 12 mm rebars and maximum aggregate size 32 mm;
Fig. 5 shows that the maximum amplitudes is not necessarily detected right above the rebar but also left or right of it. The white lines indicate the positions of the maximum reflection amplitude along one rebar. With increasing concrete cover the displacements of the maximum amplitudes are shifted more and more away from the centre line of the rebar. Comparing the absolute values along the white lines of figure 5 with the values taken from the parallel line above a rebar is shown in figure 6 for the rebar with cover thickness 120 mm. The values taken from the parallel line above the rebar (blue line) are always below the absolute maximum values along a rebar (red line) and the blue line shows more variation than the red line.

Figure 6: Maximum reflection amplitude along a parallel line above a rebar (blue line) compared to the absolute maximum values along a rebar (red line); cover thickness 120 mm; maximum aggregate size 16 mm.

Figure 5 plots the relative difference between the average maximum amplitudes for the five rebars and along a parallel line above each rebar. All amplitudes vary at least by 10% of the average amplitudes along a rebar with constant concrete cover. This minimum variation can increase up to 40%. The reason is probably again the heterogeneity of concrete due to the aggregates.

Figure 7: Maximum reflection amplitudes along a parallel line above a rebar for five different concrete cover thicknesses between 60 and 180 mm.
The influence of the antenna orientation is displayed in figure 8. It shows the amplitude variations for the three antenna orientation of 0°, 45° and 90° measured along a profile right above the rebar. The amplitude values for the antenna orientation of 90° are the largest, followed by those obtained for the orientations of 45° and 90°. This is expected as the polarization of the electromagnetic field is then parallel to the rebar and causes the largest reflections compared to the other antenna orientations. In order to compare the three curves in a relative rather than absolute manner, their respective averages have been removed and only the deviations been plotted in figure 9.

Figure 8: Maximum reflection amplitude along a parallel profile above a rebar for three different antenna orientations. Concrete cover thickness 120 mm.

Figure 9: Relative (average removed) maximum reflection amplitudes for a profile above a rebar for three different antenna orientations. Concrete cover thickness 120 mm.

The amplitude differences show comparatively similar behaviors/trends. The differences are rather dependent on the absolute rebar reflections than on the antenna orientation. This supports the assumption that the aggregates have here main influence. For these specimens
rounded gravel was used as aggregate material. It is most likely that round aggregates have less impact on the antenna orientation than asymmetric shaped aggregates.

Finally we compared the amplitude values measured with the scanning system with those we obtained in manual measurements. Figure 10 shows the results of the two measurements (profiles recorded manually/automated) for four rebars with different concrete cover thicknesses (90 mm, 120 mm, 150 mm, 180 mm) The two diagrams of the absolute maximum reflection amplitudes along a rebar are shown for four rebars with different concrete covers (90 mm, 120 mm, 150 mm, 180 mm) in figure 10.

![Figure 10: Maximum reflection amplitudes recorded manually and automatically along a profile right above a rebar; cover thicknesses: 90 mm (top left), 120 mm (top right), 150 mm (bottom left) and 180 mm (bottom right).](image)

The manual measurements show always higher amplitudes than the automated measurements but the relative trends are very similar. This evidences that the variations of the amplitudes along a rebar are physically caused by the specimens (or in particular the spatial distribution of the aggregates).

4. Conclusion

This work establishes a base for quantitative amplitude analysis of GPR measurements. With dense GPR grids has been shown that the amplitudes of the reflections from reinforcement between two different locations can vary up to 40% even when the concrete quality and the concrete cover are constant. These variations are reproducible and their diagrams show a unique pattern like a fingerprint. The amplitude variations differ little for different antenna orientations. The absolute reflection amplitudes are fairly reproducible in automated and manually collected surveys which gives rise to the assumption that the aggregates have the biggest control over the signal patterns.
References

