ANALYSING THE VELOCITY OF GROUND-PENETRATING RADAR WAVES: A CASE STUDY FROM KOEKELARE (BELGIUM)

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Analysing the velocity of ground-penetrating radar waves: a case study from Koekelare (Belgium)

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ABSTRACT: When conducting a ground-penetrating radar (GPR) survey, initially only the two-way travel time of the electromagnetic waves is available. Knowing the propagation velocity of the waves in the ground is crucial for determining the depth of the archaeological features. There are several ways to determine the velocity. Four methods were compared at the site of Koekelare (Belgium).

Geophysical surveys with different instruments were carried out over a double and a single circular ditch, originally belonging to Bronze Age barrows. A survey with a fluxgate gradiometer and electromagnetic induction measurements did not reveal the structures or only partially. In the GPR measurements both structures were clearly visible.

For the velocity determination, time-domain reflectometry (TDR) measurements were taken, which were compared with two techniques, based on the presence of diffraction hyperbolas in the GPR data (hyperbola fitting and migration).

The wave velocities obtained with the three methods mostly matched rather well, the average velocity varied between 0.069 and 0.074 m/ns. The velocities were then used for the time-to-depth conversion. In most cases reflections were detected by the GPR at a greater depth than suggested by the augering results. This discrepancy merits further investigation.

1 INTRODUCTION

Since the beginning of the 1980s, the remains of over one thousand Bronze Age burial mounds have been discovered by aerial photography in the provinces of East- and West-Flanders (Belgium). These monuments belong to the Early and Middle Bronze Age (2000-1500 BC). Mostly, circular ditches are the only remnants of the monuments. The mounds themselves have not been preserved as a result of erosion and agricultural activity. The ditches have been filled up but remain visible as cropmarks on the mainly sandy soils. On some sites, augerings and excavations have been carried out (for a recent example: Cherretté & Bourgeois 2005).

The aim of the present study was to investigate the potential of geophysical techniques for the detection of the circular monuments, and for the estimation of their depth. The study area was part of a 500 by 225 m large cemetery, consisting of at least 9 circular structures, including two double circles. It is situated in Koekelare-Boutikel, West-Flanders (figure 1), at the foot of the slightly undulating plateau of Aartijke-Wijnendale. The site was discovered through aerial photography by pilot J. Semey in August 1990 (figure 1). One single and one double circle were selected for the geophysical survey.

2 METHODOLOGY

Over the double ditch, prospections were carried out with several instruments in an area of 50 by 50 m. To define the corner points, a differential GPS was used. A survey with a Geoscan FM256 fluxgate gradiometer did not reveal the structures, as probably the contrast in magnetisation between the ditch and the surrounding soil was too small. Electromagnetic induction measurements (conductivity and magnetic sus-
ceptibility) with a Dualem instrument gave similar results. Conductivity measurements with a Geonics EM38DD were able to reveal parts of the inner and outer ditch, although not very clearly. The GPR measurements (taken with a Sensors & Software pulseEKKO PRO) clearly revealed both ditches. Subsequently, the single circle was also investigated with the GPR.

With the GPR, a 500 MHz antenna was used. Measurements were taken with an inline distance of 0.05 m, the line separation was 0.25 m, the sampling interval was 0.2 ns. Processing included application of a de-wow-filter, a fixed gain and a band-pass filter with cut-off frequencies of 150 and 600 MHz. No topographical corrections were made since the terrain is virtually flat.

For the depth estimation, several techniques were applied (for a discussion of the methods for velocity and depth determination, see e.g. Conyers 2004). Two GPR data processing methods (migration and hyperbola fitting) rely on the presence of diffraction hyperbolas in the data. The hyperbolas are caused by the radiation pattern of the GPR antenna, which emits energy in a cone and not along a straight line. A range of velocities was used as input for a Kirchhoff migration algorithm until the best result was obtained, i.e. until the hyperbola tails were collapsed without any over-migrated reflectors (‘smiles’) appearing. In hyperbola fitting, computer-generated hyperbolas with known velocities are fitted to hyperbolas in the measured GPR profile until the right velocity is found.

Furthermore, time-domain reflectometry (TDR) measurements were carried out over the double ditch with a Campbell Scientific TDR100 instrument. The principles behind TDR are similar to GPR. TDR sends electromagnetic waves into the ground via metal rods. At the extremity of the rods, the signal is reflected. Since both the length of the metal rods (at Koekelare these were 0.23 m long) and the travel time are known, the velocity of the pulses can be calculated (Leckebusch 2003). The TDR measurements were taken at different depths, with intervals of 0.2 m, which resulted in a series of vertical velocity profiles.

The GPR and TDR measurements were compared with augerings. Different hand augers were used: a half-cylindrical gouge auger with a diameter of 0.03 m and a length of 1.3 m and an Edelman auger with a diameter of 0.05 m and a length of 0.2 m, which reached a depth of 1.2 m. For the TDR measurements, a Riverside auger was used.
3 RESULTS AND INTERPRETATION

3.1 General remarks

Figure 2. (top left) GPR depth slice 0.67-0.75 m; (top right) depth slice 0.97-1.05 m (double circle); (bottom left) depth slice 0.67-0.75 m; (bottom right) depth slice 1.11-1.18 m (single circle). White represents a strong GPR reflection, black a weak reflection or the absence of reflections.

The most striking features on the GPR depth-slices shown in figure 2 are a series of parallel drains in brick, causing strong reflections at different depths. The traces of the circular ditches are much more subtle. Remarkably, they are visible as a negative mark (absence of reflections) from 0.5 m to 0.75 m below the surface. Probably this is because the ditches have been dug into a soil which is more reflective, for example because of accumulation horizons of iron or clay (Podzols, mostly occurring in degraded form: Postpodzols), than the loose ditch fill. Only the inner circle of the double ditch does not show as a negative mark.

At deeper levels, the ditches were detected as a positive mark (from around 0.8 to 1.25 m below the surface). That the ditches are visible down to a considerable depth can be explained by the soil type causing a low attenuation of the radar waves. On the soil map, the area of both circles is described as ‘moderately dry loamy sand on a sandy-clayey substratum’. 
The double ditch structure is rather large in size: the diameter of its outer circle is nearly 40 m, whereas the average size of the monuments with concentric circles is about 30 m. The diameter of the inner circle is 22 m. The single circle has a diameter of 33.5 m. The majority of the single structures in East- and West-Flanders have a diameter between 20 and 35 m (Ampe et al. 1996). There are no visible interruptions of the ditches. At a depth of around 0.85 m, the ditches are around 0.7 m wide. Near the single circle, a rectangular feature of ca. 8.5 by 12 m can be observed, which is also clearly visible on the aerial photographs (figure 1). Most probably, it belongs to the Iron Age. Often, Bronze Age cemeteries continued into the Iron Age or the Roman period (Bourgeois et al. 1998).

3.2 Depth estimation

The drainpipes caused strong hyperbolas in the GPR profiles, which facilitated the application of hyperbola fitting and migration. For the double monument, a velocity of 0.069 m/ns proved the most correct for hyperbola removal and was used for the time to depth conversion. For the single circle, the appropriate velocity was slightly higher, around 0.074 m/ns. Since both structures were surveyed with an interval of nearly 3 weeks, a change in soil conditions may explain this difference. There was little variation in the velocity within the lines or between the lines. Most drainpipes occur at a depth of 0.7 m to 1.10 m. At other depths, few hyperbolas were available for migration or hyperbola fitting. As the ditches mainly occur at this depth, the velocity in the deeper levels was of less importance and the velocities obtained in shallower levels were also used there.

The velocity obtained for the double circle corresponded well with the results of the TDR measurements. On average, the velocity was around 0.08 m/ns in the shallowest layers, around 0.07 m/ns from 0.6 to 1 m below the surface, and less than 0.07 m/ns in the layers below 1 m. Perhaps surprisingly, there were no big differences in the water content (and the velocity) between the ditch and the surrounding soil. The depth estimation based on these velocities shows reflections (positive, white marks in figure 2) at a depth of 0.8 to 1.25 m, as described earlier. From excavations, it is known that the ditches are on average 1 to 1.5 m deep. Often the filling of the ditches consists of three layers: on the bottom rests a small humus enriched layer, which accumulated when the ditch was still in use. On top of this, yellow sandy material can be observed, probably originating from the mound and suggesting a fast filling of the ditch when it was no longer in use. After a stabilization phase, the final filling consists of a dark layer, rich in humus (Ampe et al. 1996). Possibly, the reflections observed in the GPR results are caused by the transition between the lower, humus enriched layer and the original soil. However, in most cases the results of the augering seem to contradict the presence of such a humus layer below 0.85 m.

4 CONCLUSION

At the site of Koekelare, the loamy sandy soils and the corresponding low attenuation of GPR waves allowed the detection of several circular ditches, belonging to Bronze Age funeral monuments. TDR measurements, as well as methods based on the analysis of the GPR data themselves (migration) resulted in a consistent velocity determination. The deepest reflections visible on the GPR depth slices are not entirely confirmed by the results of the augering. They may also be caused by soil processes. This point merits further investigation.

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6 REFERENCES


