Seismic refraction survey in Bernburg, Germany: an application of the generalized reciprocal and phantoming methods

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Abstract. The paper presents a case study of a seismic refraction survey in Bernburg, Germany. The interpretation was made using the GRM method and phantoming concept. The aim of the survey was to map the depth of the bed-rock over a distance of 2 km. The survey was divided into five linear profiles ranging from 150 to 640 metres in length. The resulting interpreted sections show substantial variations in velocity (1300 to 4500 m/s) and depth (5 to 18 m) of bed-rock. Correlation with existing boreholes shows that the top of the bed-rock is located with an accuracy of the order of 1 metre.

Seismic refraction, which has been used for many years in engineering geology, remains one of the most popular techniques for determining the bed-rock depth. The classical interpretation methods utilizing intercept times (Kearey & Brooks 1992) or the one presented by Mota (1954) have inherent limitations (plane layers, homogeneous velocity) which can be avoided by using more sophisticated techniques such as the plus–minus method (Hagedoorn 1959) or the generalized reciprocal method (Palmer 1980). In this survey, we applied the Generalized Reciprocal Method (GRM) which allows the mapping of undulating refractors with lateral changes in velocity (Palmer 1981; Kilty *et al.* 1986; Demanet & Jongmans 1989).

Mapping an interface with GRM requires forward and reverse traveltime data at the surface for rays travelling along this refractor as well as the reciprocal time (traveltime between shotpoints) (Palmer 1980). From these traveltime values, the GRM method consists of calculating two functions – the velocity analysis and the time–depth functions – for different values of distance between forward and reverse geophones (xy). The basis of the method is to select the xy value for which the two rays leave the refractor at the same point rather than arriving at the same detector. In most engineering cases, xy ranges from 0 to a few metres. If the refractor is relatively deep, the time measurements can only be made along small interface distances or require very long profiles which are often not practically possible. As demonstrated by Lankston & Lankston (1986) longer continuous profiles can be obtained using the phantoming concept in conjunction with GRM. Phantoming is based on the fact that for a series of geophones, traveltimes from two different shotpoints but coming from the same refractor are separated by a constant amount of time (Δt). This fact is widely used when checking parallelism with data from offset shotpoints. For two different shotpoints (A and B), it is possible to evaluate Δt from a few common geophones and shift the rest of the data from shot B by this value to obtain the traveltimes as if the shot was performed at A. In this application, data from 100 metre long profiles were phantomed to obtain continuous sections of up to 640 m in length.

Geological setting and field testing

The survey was conducted around a decanting basin, or settling pond, belonging to SOLVAY S.A. in Bernburg, Germany. The geological sequence in this region consists of:

- 5 to 30 metres of sand, clay and gravel interbedded layers exhibiting rapid lateral facies variations due to channel deposits. This is underlain by;
- a Mesozoic bedrock composed of a succession of folded marl and limestone layers. Under the site, investigations have only indicated the presence of marl layers.

With the aim of avoiding leakage, Solvay, S.A. plans to build either a drain or a slurry wall around the decanting basin down to the top of the impermeable marls. Before selecting a final design, engineers wished to know the thickness variations of superficial layers as accurately as possible.

A seismic line of about 2 km long was performed around the basin (Fig. 1). The survey was divided in five linear profiles of 150, 450, 640, 300 and 490 metres, as shown in Fig. 1. A 24-channel ABEM Terraloc Mark III Seismograph was used for recording the seismic signals generated by an explosive source. The field layout consisted of placing 24 geophones 2.5 metres apart and

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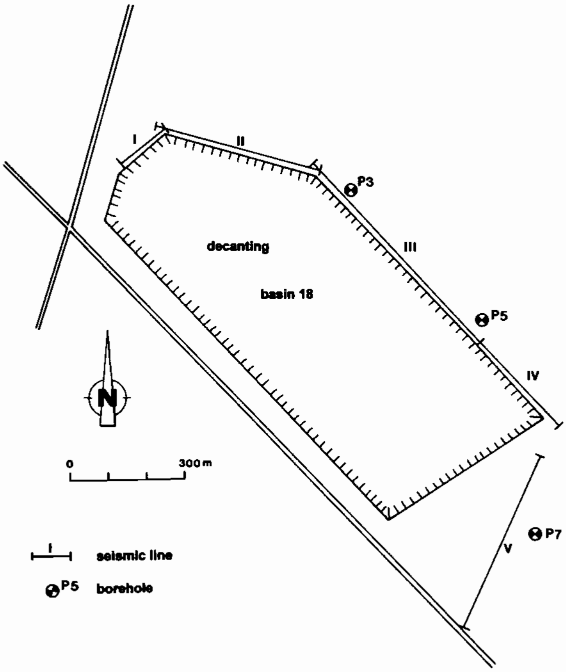

Fig. 1. Location map showing seismic lines and borehole locations.

in shooting at −50 m, 0 m, 25 m and 100 metres from the first geophone as depicted in Fig. 2. All the geophones were then moved by 50 metres and new shots fired. This systematic methodology led to a series of 100 metre long profiles with an overlapping of 50 metres. This overlapping was necessary to allow a phantoming of the data arriving from the last refractor whereas the 25 metres shot spacing was necessary to have a good lateral resolution for the superficial layers. A total of 239 shots, corresponding to 5736 seismic arrivals, was recorded.

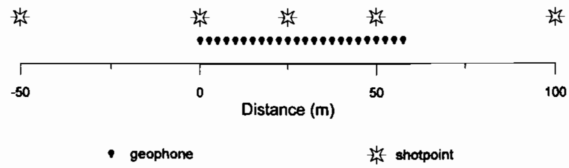

Fig. 2. Field configuration for the refraction profiles.

Seismic results

An example of a traveltime graph recorded along line IV is shown on Fig. 3 for a 300 metre line. Because of triggering time differences, the direct and reverse traveltimes measured at profile ends were checked and time values were shifted so that the segment corresponding to the first detected layer on the graph passes through the shotpoint location. These corrections were necessary as the GRM method needs absolute times to invert from time–depth (ms) to depth (m) and is very sensitive to the thickness of slow superficial layers.

All the profiles were interpreted as a three layer configuration. The first layer with a velocity of 300–400 m/s corresponds to the superficial soils, the next layer 550–850 m/s to a further near surface layer of

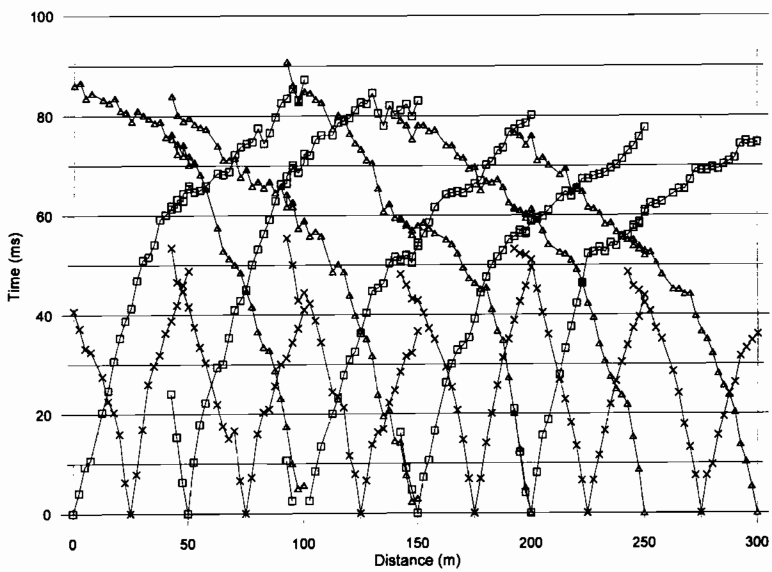

Fig. 3. Time–distance graph for line IV.

mixed sands, clays and gravels and the basal layer or bedrock with velocity in the range 1500 to 4000 m/s.

The thickness of the first layer and the velocities of first and second layers were determined by the method of Mota (1954), using small profiles of 25 or 50 metres long. As there was insufficient overlapping of forward and reverse data for this refractor, the GRM method could not be used to determine the first interface. However the 12.5 metres lateral resolution was considered small enough to give the lateral velocity variations within the superficial layers.

The data from the third layer was phantomed on each of the five linear profiles. Figure 4 presents the resulting time distance plot from the data of Fig. 3. The agreement between data from the two overlapping tests is fairly good. The velocity analysis on these data, Fig. 5,

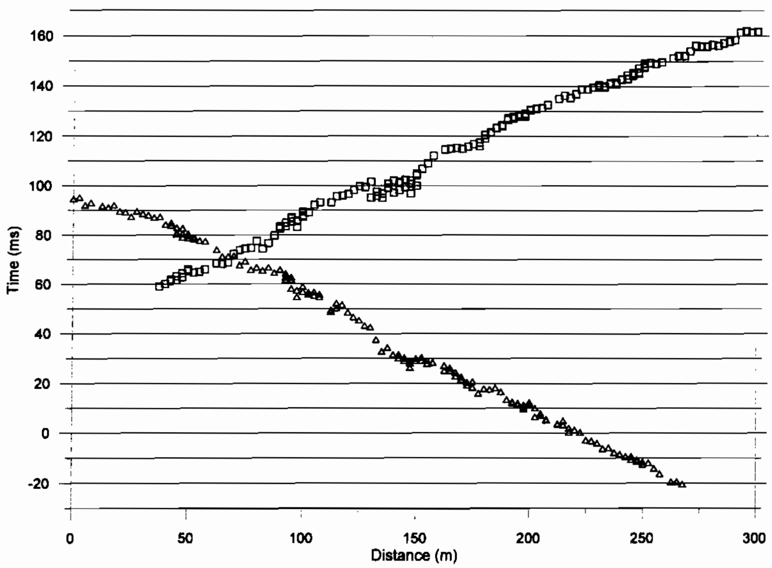

Fig. 4. Phantoming of the data of Fig. 3.

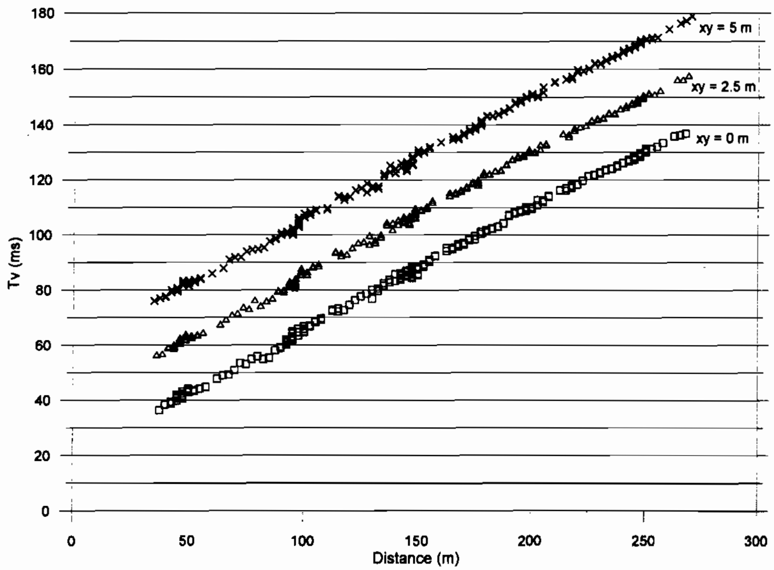

Fig. 5. Velocity analysis curves (line IV) computed by the GRM method for different xy values.

could have been interpreted using an average homogeneous velocity, but interpretation in terms of rapid lateral velocity changes was preferred because local low velocities can result from weathered or fractured zones more conducive to leakage under the slurry wall. From the velocity analysis and the time–depth graph, Fig. 6, $xy = 0$ was chosen for the final interpretation. The resulting cross section, Fig. 7, along line IV shows substantial variations in velocity, 280–415 m/s for the first layer, 545–850 m/s for the second one and 1450–4270 m/s for the bedrock. Corresponding depths of these interfaces vary from 0.8–3.5 m for the first layer and 7–18 m for the second layer. The results from the other survey lines are similar.

The lithological descriptions of three existing boreholes, P3 and P5 on line III and P7 on line V shown in Fig. 1, were compared to the seismic sections. The P3 log is displayed in Fig. 8 in conjunction with the seismic interpretation of line III. It demonstrates that the bedrock is located with an accuracy of approximately 1 metre. Comparison of the other boreholes with the seismic interpretation leads to similar conclusions.

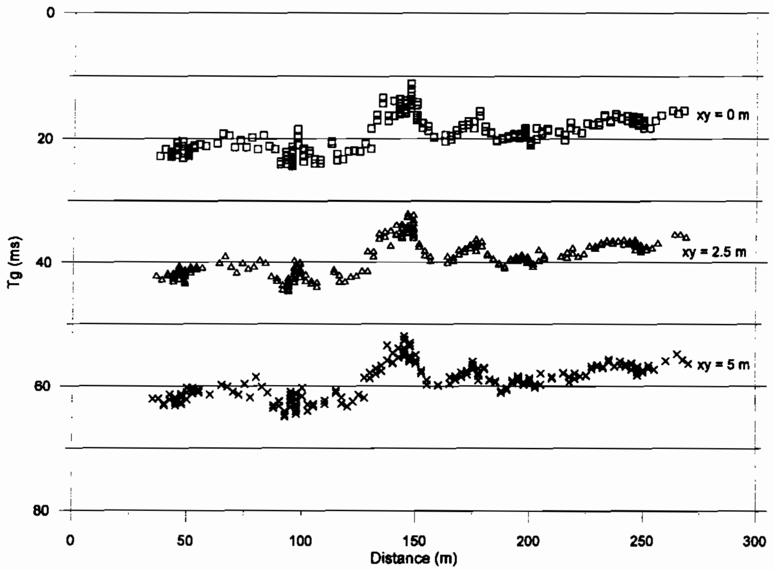

Fig. 6. Time–depth graph for different xy values.

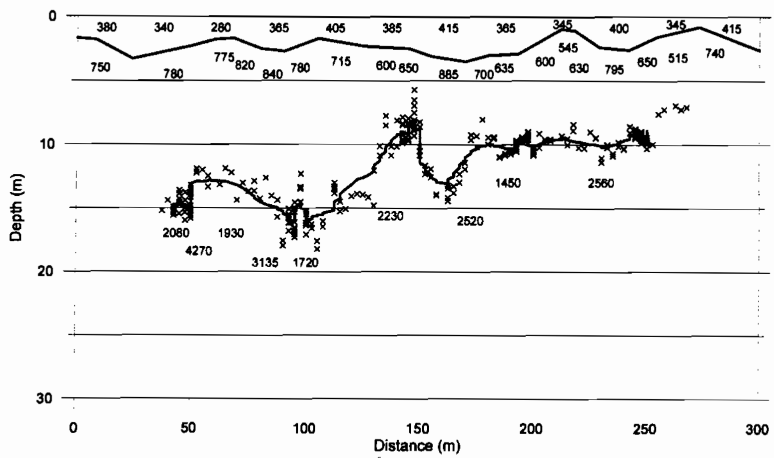

Fig. 7. Interpreted seismic cross-section along line IV.

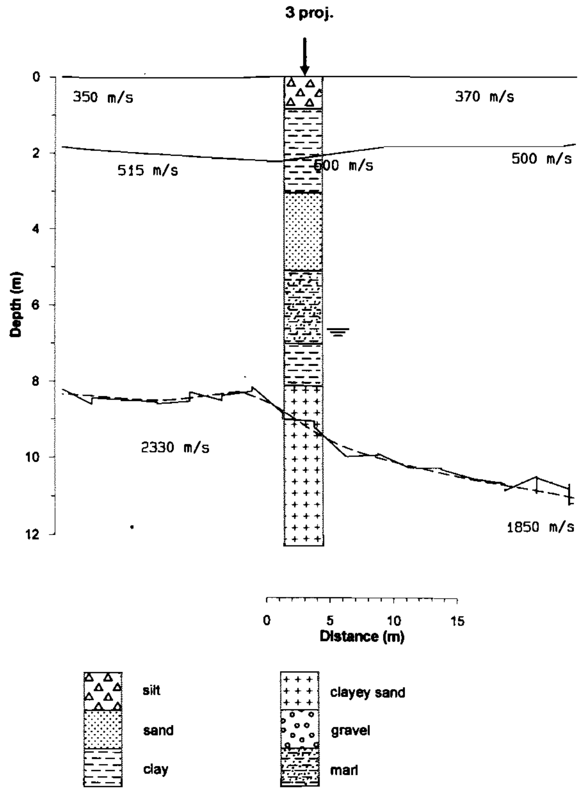

Fig. 8. Comparison between borehole P3 log and refraction data (line III).

Conclusions

The seismic refraction survey performed around a decanting basin at Bernburg has been interpreted by the application of the generalised reciprocal method (GRM) in conjunction with the phantoming method. In this experiment it was possible to map the bedrock surface along continuous profiles up to 600 metres in length by combining several refraction profiles of 100 metres length. This appears to be a very convenient approach and is efficient as single refraction spreads longer than 200 metres are often difficult to carry out from a practical and economical point of view. Comparison of interpreted sections with existing boreholes, shows that the difference between the calculated bedrock depth from seismic data and borehole values is less than 1 metre. An advantage is that calculations are very fast and do not require heavy computations. In an interactive way, the combination of GRM and phantoming facilitates the interpretation. Raw data quality is, however, very important and attention must be paid to the absolute arrival time values in order to correctly invert from time-depth (ms) to depth (m).

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