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High Resolution Near Surface Reflection Measurements Using a Vertical Array Technique

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Abstract. A seismic reflection method is described which can be applied within the scope of engineering geophysics. Emphasis is laid on the presentation of the field technique. Four case histories are given to demonstrate the benefits of the field technique. The attainable resolution is about 1 ms.

The seismic wave is generated at the surface, whereas the receiver is attached to the wall of a small borehole, thus separating source and receiver vertically, resulting in an attenuation of surface waves and S-waves. If the receiver is attached at different depths, downgoing and upgoing waves can be separated. A borehole probe was developed for the use in dry holes. In the borehole probe an accelerometer acts as a seismic receiver. The processing of the digital data is straightforward. Essentially, homomorphic deconvolution and stacking of the seismogram traces were applied.

Key word: Engineering seismics – Reflection method – Seismic field technique – Vertical accelerometer array.

1. Introduction

The seismic reflection method has not yet prevailed within the scope of engineering activities. Certainly, economical considerations are the main reason why the seismic reflection method does not play an important role in engineering geophysics. Especially this is true, if the depth of investigation does not exceed, let us say, 50 m. When applying the seismic reflection method to solve engineering problems we can first try to make use of the reflection method in the same way, as it is used for the prospecting for hydrocarbons. But due to the necessarily higher resolution of near surface measurements the data processing has to be more sophisticated. Thus the total expenditure will be of the same order as for the prospecting for hydrocarbons. In this case the application of the seismic reflection method will be restricted to the solution of special problems.

Therefore, it seems worthwhile to investigate, if a simple survey method can be developed based on the principle of reflection seismic. Describing the theoretical aspects of the problem and the application of a new reflection technique to a field case a paper on this subject has been published by the author

(Schepers, 1975). The improvement of the reflection method is demonstrated by means of some case histories in the present paper. The increasing quality of the obtained results is mainly due to the development of a suitable field technique. The development of data processing programs, described in this paper, is closely connected to the development of the improved field technique. Though it was not the aim to develop a survey method, which can be applied routinely and economically, it was always kept in mind that such a development should be possible on the basis of the investigations described in this paper.

2. Accelerometers in Boreholes

Provided the seismic source and the receiver are separated in the vertical direction, and if we assume horizontal or slowly dipping interfaces, then only vertically travelling P-waves will reach the receiver. Such a vertical separation of source and receiver has the advantage that the coherent noise, namely S-waves and surface waves, can be attenuated to a great extent. Furthermore homomorphic filtering of seismograms being composed of P-waves only can yield an effective deconvoluting and suppression of multiples (Schepers, 1975)

A seismic method capable of resolving thin near surface layers must have a high resolution. Therefore a broadbanded signal is required. If the source and the receiver – or at least one of them – are coupled to the ground beneath the weathering layer, the amplitude spectra of the seismic signal will show a better high frequency content.

Employing a seismic source in a vertical borehole, and installing the receiver on the surface is one possibility to separate source and receiver in the vertical direction (Schepers, 1975). Another possibility is to use a surface source, and to attach the receiver to the wall of a borehole (Schepers, 1976). The last mentioned arrangement is used for all measurements described in this paper. Using a borehole probe has the advantage that the receiver can be easily attached at any depth within the borehole. Figure 1 depicts the principle of the borehole probe (Hardy, 1974). As we wanted to record seismic signals up to frequencies of 1 kHz, we used an accelerometer as a seismic receiver. The employed accelerometer Endevco 2219 E – has a linear frequency response up to 3 kHz. The accelerometer is mounted within an expandable rubber jacket. A contact plate firmly connected with the accelerometer is attached to the outside of the rubber jacket. When air is injected into the probe, it expands the rubber jacket, pressing the contact plate tightly against the wall of the borehole.

3. Near Surface Seismic Reflection Measurements Using Two Accelerometers at Equal Depth

3.1 The Test Site I

Seismic reflection measurements have been carried out in the vicinity of a waterworks. The waterworks is situated in the valley plain of the river Ruhr,

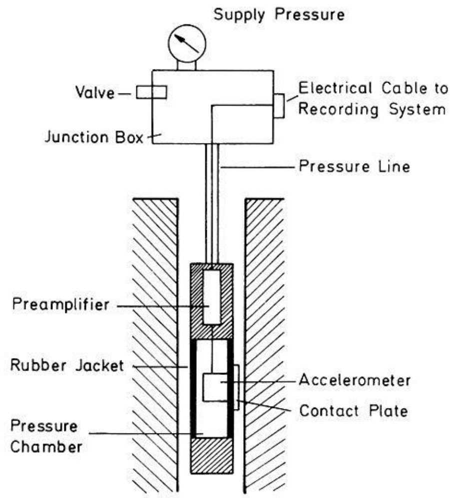

Fig. 1. Scheme of the borehole probe

the water being extracted out of the river gravel. The aquifer is confined below by impermeable bedrock. The bedrock is not deeply weathered. The depth to the bedrock is about 10 m in that area of the waterworks, where the water is extracted. In the same area the depth to the ground water surface is about 4 m. Being about 1 m thick there is a thin surface layer of fluviatile loam. Three seismic refraction profiles have been measured yielding the following P-wave velocities:

sandy loam	350 m/s–400 m/s
coarse gravel (dry)	680 m/s–790 m/s
coarse gravel (wet)	1450 m/s–1620 m/s
bedrock	3000 m/s–3500 m/s

Since the individual layers are only a few meters thick, the two-way traveltime of each layer is less than 5 ms in many cases. When surveying such shallow interfaces the expenditures for field work and for data processing must not be too high. If the costs are of the same order as for drilling, then the latter will be preferred, because results obtained from drilling are always thought to be more realiable.

3.2 Field Technique and Result at Test Site I

Figure 2 depicts the principle of the field technique. There are 2 boreholes close together. A seismic receiver is attached at the bottom of each borehole. A seismic disturbance is generated at the surface in the middle betwen the 2 boreholes.

For our measurements we used a weight drop as seismic source (Schepers, 1975). On test site I the 2 holes were drilled through the loam down to the top of the gravel. The distance between the two boreholes was 1 m in all

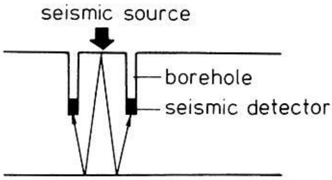

Fig. 2. Principles of the field technique using 2 accelerometers at equal depth

cases. Along the survey line the depth to the bottom of the borehole varied between 0.6 m and 1.4 m. The seismic signals, picked up by an accelerometer in each borehole, were recorded by a digital recording system (Schepers, 1975). This recording system improves the signal-to-noise ratio by means of an on-line averaging process. Using a band pass filter with a low-frequency cutoff at 3 Hz and a high-frequency cutoff at 1250 Hz the sample interval was taken to be 0.2 ms corresponding to a Nyquist frequency of 2.5 kHz.

Averaging 16 impacts of the weight drop a two channel seismogram was gained at each observation point. The final data were punched on a paper tape and the data processing was carried out in the computer center of the Ruhr-Universität Bochum. The main segments of the data processing program are the following ones: (i) Homomorphic deconvolution of the two traces of the seismogram (Schepers, 1975). In the deconvolution process values of the complex spectrum were used up to a frequency of 1250 Hz corresponding to a resolution of 0.4 ms in the time domain. (ii) Stacking of the two deconvolved traces. (iii) Suppression of the ghost reflections from the surface by inverse filtering. Knowing the travel time of the wave in the uppermost layer the approach to the filter design was a deterministic one. (iv) Reduction to a datum elevation.

The result of the data processing of one line of 36 observation points is plotted in the upper part of Figure 3 as a time section. The distance between 2 observation points was 50 m. Each trace of the time section is the filtered stack of the two deconvolved traces gained at each observation point. Deflections of the traces to the left are blacked-in indicating an increase of acoustic impedance.

Correlating well on all traces the first event is the reflection from the water surface. After this a second event can be recognized on all traces: it is the reflection from the bedrock. This reflection is quite poor on some traces. Some of the noise disturbing the reflection events is due to imperfect performance of the inverse filter. Yet the resolution of the reflection is satisfactory on all traces. One should be aware that the time difference between the 2 reflections is not more than 2 ms on some traces.

The geological section derived from the time section is shown in the lower part of Figure 3. The ground water surface is not flat, because the waterworks has produced water during the survey. But the depth to the water surface was known precisely, since the water level could be controlled at 10 observation pipes along the survey line. Therefore only the time difference between the two reflections and the P-wave velocity of the wet gravel enters into the computation of the depth to the bedrock. Considering the actual error of both values

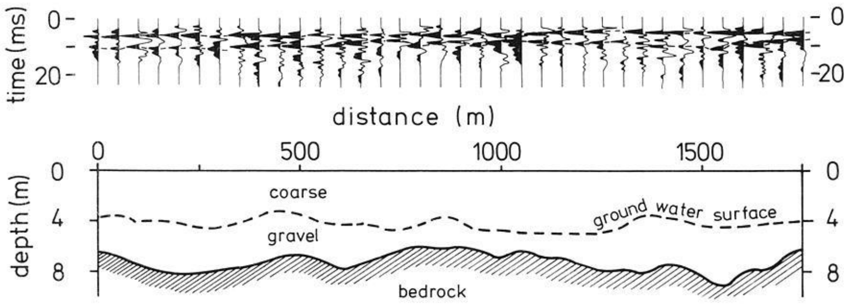

Fig. 3. Time section and the corresponding geologic section gained at test site I

a precision of ±0.5 m can be assigned to the depth of the interface between gravel and bedrock. This is confirmed by three boreholes drilled along the line. In all three cases the depth predicted by the reflection measurements differs not more than 0.4 m from the depth supplied by drilling.

3.3 The Test Site II

The waterworks of Mussum and Liedern near the town of Bocholt extract their water out of the uppermost layer consisting of Pleistocene sand and gravel. This permeable stratum is limited below by a thick silty clay layer. It was the aim of a seismic reflection survey to give the thickness of the permeable stratum along a line, which connects the waterwoks of Mussum to the waterworks of Liedern. The total lenght of the line was 6.5 km. From previous investigations the depth to the top of the clay could be expected to vary between 10 m and 40 m in this area. According to some observation pipes the depth of the ground water surface is about 2 m. After seismic refraction measurements at both ends of the reflection line the following P-wave velocities could be determined:

sand with fine gravel (dry)	400 m/s–450 m/s
sand with fine gravel (wet)	1350 m/s–1450 m/s
clay (silty)	1850 m/s

Since the length of the refraction profiles was 80 m, only one profile yielded the P-wave velocity of the clay. In this case the depth to the top of the clay layer was about 12 m. The wave velocity of the clay is however of minor importance for the evaluation of the reflection data.

3.4. Field Technique and Results at Test Site II

The distance between 2 observation points was normally 100 m. At each observation point the seismic reflection measurement was carried out in the same way as described for test site I. The 2 boreholes were sunk to the depth of

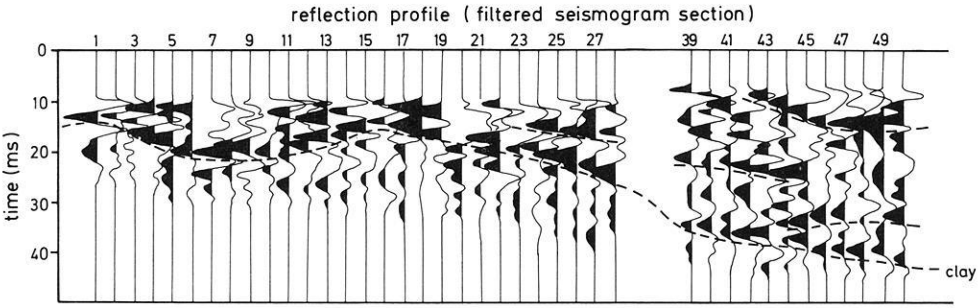

Fig. 4. Time section gained at test site II

the ground water surface. The accelerometers were placed in the boreholes at the water level. The depth to the water surface varied between 1.7 m and 3.2 m along the survey line.

The field data were processed in the same manner, as already explained in chapter 3.2. The only differences was that in the deconvolution process, values of the complex spectrum were used up to a frequency of 625 Hz corresponding to a resolution of 0.8 ms in the time domain. The final result is plotted as a time section in Figure 4. Evaluated reflections are marked by a dashed line. Besides the continuous reflection from the top of the clay, there are some reflection events at shorter traveltimes, which can be correlated on several traces. E.g. on the traces 43 to 50 a reflection is visible at a traveltime of about 12 ms. A shallow test boring revealed that this reflection is due to an interface seperating pure sand from sand with gravel. The P-wave velocity of pure sand is about 1300 m/s whereas the P-wave of sand with gravel is about 1450 m/s.

The traveltime of the seismic wave between the reflecting horizons is greater in the case of test site II as compared to test site I, thus facilitating near surface reflection measurements. On the other hand the involved reflection coefficients are much smaller.

4. The Vertical Array Technique

4.1. The Principle

Promising results have been obtained by attaching an accelerometer within a borehole and employing a surface source at the location of the borehole. Yet, to drill a hole is much more troublesome, than just to place a geophone on the earth's surface. Consequently, if one has decided to use such a field technique, several receivers should be attached at different depths within the borehole. Thus, a vertical geophone array is established, which has the advantage that primary reflections can easily be separated from ghost reflections. To explain this a very simple case is depicted in Figure 5. A borehole is sunk into a layer of constant wave velocity. There are 4 geophones at different depths

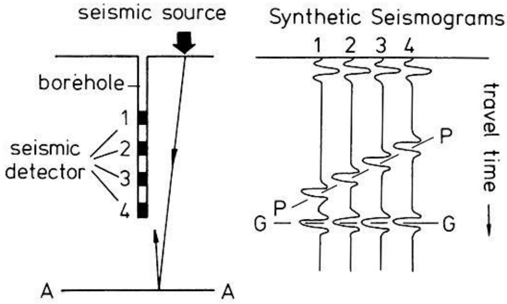

Fig. 5. Principles of the vertical array technique and synthetic seismograms in the case of one reflecting boundary beneath the array. *P-P* primary reflection from the boundary *A-A*, *G-G* ghost reflection from the surface

within the borehole. The line A-A shall indicate a reflecting interface some distance beneath the bottom of the borehole.

If a seismic wave is generated at the surface close to the borehole, the direct wave is the first event which arrives at the geophone array. Displaying the arrival times of the direct wave as a function of the depth of the corresponding geophone a straight line is yielded. The slope of it is 1/V, where V is the wave velocity of the material adjacent to the borehole. More generally, if the wavefront stikes the array obliquely, V is the apparent velocity V_a. But in the following considerations we shall assume $V = V_a$. The second event reaching the array is the reflection from the interface A-A. This event passes the array in the opposite direction, and its apparent velocity is -V. The next event will be the ghost reflection from the surface. As the ghost reflection is a downgoing wave just as the direct wave, the apparent velocity of this event will be V.

In the right part of Figure 5 synthetic seismograms for the four different geophone positions are plotted. The zero time of each seismogram is defined by the arrival time of the direct wave at the corresponding geophone. The primary reflection from the interface A-A is marked by the dashed line P-P. The ghost reflection if marked by the dashed line G-G. Concerning the suppression of ghost reflections we can summarize: (i) If V is the velocity of the downgoing waves, the velocity of the upgoing waves is -V. (ii) The time difference between the direct wave and the ghost reflection is constant for all traces. (iii) The moveout of the ghost reflection with respect to the primary reflection is different for different traces.

It is an important advantage of the vertical array technique that downgoing waves and upgoing waves can be discriminated definitely. Downgoing waves are the ghost reflections and those multiples, whose last reflection occurs at interfaces above the array. Disturbing considerably the primary reflections from interfaces below the array the suppression of the downgoing waves is essential. This suppression is simply achieved by applying static correction to each trace according to the position of the corresponding receiver, and then stacking the traces. The proper static corrections can be derived from the arrival of the direct wave.

Furthermore we can state that by this stacking process all events are suppressed displaying an apparent velocity other than that of the reflections from below the array provided the dips of the reflecting interfaces are not too large.

4.2. Automatic Processing of Vertical Array Data

A computer program was developed for the automatic processing of data gained by the vertical array technique. The main segments of this program are described in the following:

1. Picking of the first onsets on each trace and computation of the apparent velocity of the direct wave along the vertical array.
2. Deconvolution of the individual traces recorded at different receiver positions in the borehole. The deconvolution is achieved by homomorphic filtering (Schepers, 1975).
3. Application of static corrections. As reference datum the depth of one receiver within the array is used. The static corrections are computed according to the velocity determined in segment 1.
4. Assuming a specific subsurface model those time windows are computed, in which primary reflections may occur. The model is defined by the thickness of the layers, the P-wave velocities in the layers, and the expected errors of these values. These parameters are computed according to the results obtained at previous observation points (refer to segment 9). Otherwise the model has to be defined by input parameters.
5. Automatic determination of residual statics.
6. Stackings of the traces of the array.
7. Application of a reflection picking process to the stacked trace. Essentially, the trace is normalized, and then all amplitudes are suppressed, which do not exceed a predefined value.
8. Application of a static correction to reduce the trace to a common reference datum.
9. Prediction of a subsurface model for the next observation point by means of the arrival time of the reflections picked in segment 7 and by means of the velocities defined in segment 4. The subsurface parameters derived in this segment are used in segment 4, when the data of the next observation point is processed.

To elucidate some features of the data processing program, and to illustrate its efficiency the application of the described processing technique to synthetic seismograms will be presented in the next chapter.

4.3. Automatic Processing of Synthetic Seismograms

Assuming the density of all layers to be equal the parameters of a subsurface model are given in the left part of Table 1. The model was constructed according to a field case, which will be presented in the next chapter. A vertical array of four geophones was assumed. The depths of the geophones of traces 1

Table 1. Model parameters for the computation of the synthetic seismogram

Depth of the upper and lower boundary of the layer	P-wave velocity of the layer
0– 2 m	400 m/s
2–25 m	1450 m/s
25–31 m	1300 m/s
31 m –	1850 m/s

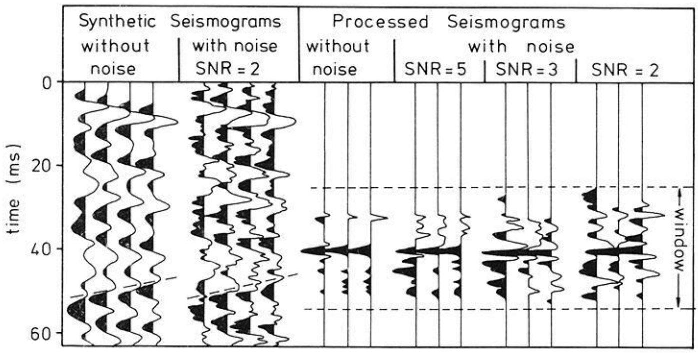

Fig. 6. Synthetic seismograms without and with noise computed for the subsurface model, which is defined by the parameters given in Table 1. The 4 traces of each seismogram correspond to the depths from left to right 0.5 m, 1.0 m, 1.5 m, and 2.0 m. Applying the processing program with the parameters given in Table 2 the 4 processed seismograms are obtained. In each of those 4 cases the 3 different output traces correspond to the deconvolution parameters b from left to right 0.99, 0.98, and 0.97 (Ulrych, 1971)

to 4 are 0.5 m, 1 m, 1.5 m and 2 m. Computing a synthetic seismogram trace for each of the geophone positions a four channel seimogram is yielded. The results of the computation are shown in the left part of Figure 6. The trace most to the left is trace 1 according to Table 1. To estimate the influence of noise on the processing, broad-banded noise of different signal-to-noise ratio SNR has been added to the synthetic seismogram. The signal-to-noise ratio SNR is defined by

$$\mathrm{SNR} = \sqrt{\sum_n x^2(n) / \sum_n u^2(n)},$$

where x(n) is the signal trace and u(n) is the noise. The synthetic seismogram with additive noise of SNR = 2 is also plotted in Figure 6. In both synthetic seismograms of Figure 6 the arrival time of the reflection from the third interface (see Table 1) is marked by a dashed line. At least in the case of additive noise, this reflection cannot reliably be identified referring to the unprocessed array data. In both cases the reflection from the second interface is not visible.

Table 2. Model parameters for the processing of the synthetic seismogram

Number of the layer	Depth to the lower boundary of the layer	Assumed depth error	P-wave velocity	Assumed velocity error
1	2 m	±0.2 m	400 m/s	50 m/s
2	31 m	±9 m	1400 m/s	100 m/s

The processing described in the previous chapter was applied to the synthetic seismogram without noise and to three synthetic seismograms with additive noise of different signal-to-noise ratios. The results are shown in the right part of Figure 6. For three different choices of the deconvolution parameter b, three output traces are plotted in each case. The parameter b specifies the exponential weighting of the time series (Ulrych, 1971), which is applied before the homomorphic filtering (segment 2 of the data processing program). Exponential weighting involves the multiplication of a time series x(n) by a time series of the form $v(n)=b^n$. For the three different output traces – in Figure 6 from left to right – the parameter b is 0.99, 0.98, and 0.97.

According to segment 4 of the data processing program a rough model of the subsurface has to be specified. For a two-layer-model the parameters and their corresponding errors are given in Table 2. A reflection from the second interface of the model specified by Table 2 can be expected within a fixed time window. The boundaries of this time window are marked by dashed lines in the right part of Figure 6. Deflections of the output traces to the left – the blacked-in area – indicate a negative reflection coefficient corresponding to an increase of wave velocity. In case of the processed seismogram without noise the positive reflection from the second interface at about 30 ms and the negative reflection from the third interface at about 40 ms can clearly be identified. Using a parameter $b=0.99$ the performance of the processing program is bad in all cases. Obviously the best performance is yielded with a deconvolution parameter $b=0.98$, which refers to the middle trace of the three output traces.

At least the reflection from the third interface is visible in all processed seismograms with noise even in the case of a signal-to-noise ratio SNR = 2. The positive reflection from the second interface cannot be detected with the same certainty as in the noisefree case. The identification of such a small event will be easier, if it can be correlated on several traces within a seismic section. The example in Figure 6 demonstrates that the data processing program is very efficient even in the case of SNR = 2. The achieved signal enhancement enables us to pick the main reflection automatically.

Varying the input parameters of the program the processing of synthetic seismograms can help to estimate the influence of the input parameters on the resultant output trace. In the next chapter two case histories are given. Before evaluating the field data, synthetic seismograms of many models matched to the expected subsurface geologic condition have been processed with different input parameters to yield an optimum parameter estimation.

5. Case Histories

5.1. Determination of the Thickness of an Aquifer

Near the waterworks of Liedern seismic reflection measurements have been carried out within the scope of hydrogeological investigations to supply the thickness of the water bearing stratum. The subsurface geologic conditions are the same as described for test site II. The profile, which will now be presented, intersects the profile shown in Figure 4 of this paper.

Measurements have been carried out at 20 locations. Since from previous investigations one could expect the top of the clay layer to vary slowly with depth, the distance between the observation points was chosen to be about 500 m. Consequently this great distance between the observation points requires reliable results at each point. This is a challenge, which is more stringent than the requirements of normal reflection surveys where the method of continuous profiling is applied.

At each observation point one borehole was drilled and the accelerometer was attached within the borehole at four different positions. The deepest receiver position was always at the water level. The depth of the water surface varied between 2 m and 3.5 m. Depending on the depth of the deepest receiver the distance between the receiver positions was 0.4 m or 0.5 m. The sampling interval of the recording system was set to be 0.2 ms according to a Nyquist frequency of 2.5 kHz. The frequency band of 0 Hz to 830 Hz was used for the deconvolution process.

As the depth of the water could be derived from the borehole data, the only interface of interest was the top of the clay layer. Predicting the rough subsurface model of the next observation point by means of two different versions of segment 4, the data processing program described in the previous chapter was applied to the field data twice. Using a constant error of ± 9 m for the prediction of the depth to the clay layer the time section plotted in the upper part of Figure 7 was obtained. Yielding the seismic section in the lower part of Figure 7 a very rough model of the subsurface at the observation point 1 was given as starting point: The top of the clay layer was expected at a depth of $25 \text{ m} \pm 20$ m. If the depth of the interface changes less than the preset error, the value of the error was automatically stepwise reduced.

Both program versions deliever nearly equal results thus demonstrating that the model parameter prediction is not critical at all. In both that the model parameter prediction is not critical at all. In both sections of Figure 7 those amplitudes are suppressed, whose absolute value is less than 15% of the maximum absolute value of the trace.

On trace 10 a prominent event exhibits about 10 ms before the small event which we may expect to be the reflection from the top of the clay. The latter event correlates with the adjacent traces. A borehole was drilled at the observation point 10 and a clay layer—about 1 m thick—was found 7.5 m above the actual clay layer. The prominent event on trace 10, therefore, is the reflection from this thin clay layer.

In both sections of Figure 7 a positive reflection (deflection of the trace to the right) can be correlated at about 25 ms at least on the 2 to 5. A positive

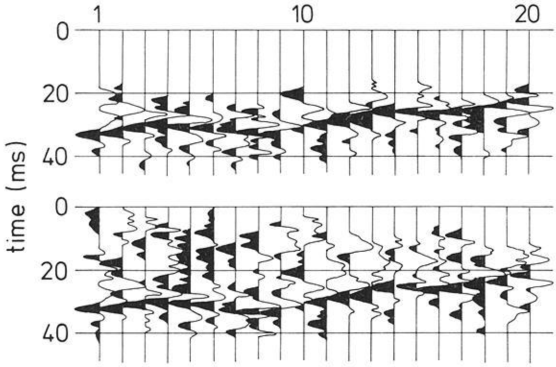

Fig. 7. Results of the reflection measurements at the waterworks Liedern. Two time sections are shown corresponding to two different versions of the segment 4 of the data processing program

reflection means a decrease in velocity. To prove this interpretation a borehole was drilled at the observation point 3. Indeed, a transition from sand with gravel to fine sand was found at a depth of 22.8 m. According to the seismic data a velocity decrease was predicted for a depth of 23.2 m.

5.2. The Determination of Static Corrections for Vibroseis Reflection Surveys

If the near surface layers exhibit low velocities, and if the thickness of these layers changes rapidly along the seismic line static corrections may be troublesome. Sometimes bad quality seismic sections are due to inadequate static corrections. If after basic static corrections no reflection event of sufficient quality can be correlated along the seismic section, then additional information has to be provided for better static corrections. We wanted to investigate if in those cases the seismic reflection method can yield the additional information. For this first investigation our results should be compared with the results obtained from seismic refraction measurements and with the static corrections derived from reflection events in the vibroseis section.

Using the vertical array method near surface reflection measurements have been carried out in the Bavarian molasse region in southern Germany. By means of these measurements static corrections should be determined with an accuracy of ± 4 ms. At 124 locations distributed on four lines measurements have been carried out in a similar way, as described in the previous chapter. The total length of the four lines was 37 km. Along the same lines Short-Refraction profiles have been measured. On line V-331 near surface reflection measurements have been carried out at 70 locations. For this line the average distance between the observation points was 200 m and it was about 450 m for the three other lines.

Previously, we had little information about the subsurface geologic conditions. The depth of the borehole at each location was planned to be 3 m. In most cases the uppermost layer in that region consisted of loam. Since

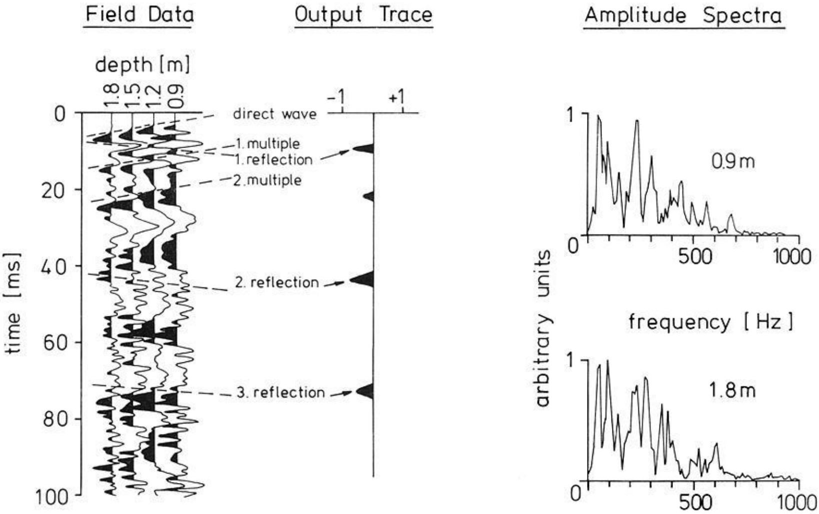

Fig. 8. Field seismogram obtained at observation point 186, the amplitude spectra of the traces recorded at the depths of 0.9 m and 1.8 m, and the resultant output trace after application of the data processing program

the drill operated with water as circulating fluid, the hole often was in bad condition due to collapse of the borehole wall. Therefore, the depth of the deepest receiver and the distance between the four receiver positions within the hole were not constant along the lines. The maximum attainable depth was 2.4 m, whereas the minimum depth was 0.7 m. Additional difficulties arose from the fact that due to the low permeability of the loam, the borehole often remained filled with water. The borehole probe which was constructed for dry holes did not work satisfactorily in some of those cases.

The four seismogram traces gained at one specific location of line V-331 are plotted in the left part of Figure 8. The depth of the receiver is written on top of each trace.

The amplitude spectra of the two traces recorded at a depth of 1.8 m and 0.9 m are shown in the right part of Figure 8. Both spectra have a fairly flat envelop, and they reveal a good high frequency content of the signals. Applying the data processing the resutant→output trace is plotted in the middle of Figure 8. If a reflection event is very clear, the output trace can reach the maximum value of +1 or −1. Since we are only interested in interfaces, where the wave velocity increases – that means negative reflection coefficients – all amplitudes greater than −0.3 have been suppressed. The output trace shows three clear reflection events. Comparing the output trace with the seismogram traces on the left of Figure 8 the benefits of the vertical array technique combined with an adequate data processing is evident. Dashed lines in the seismogram indicate the arrival times of waves according to the interpretation of the output trace.

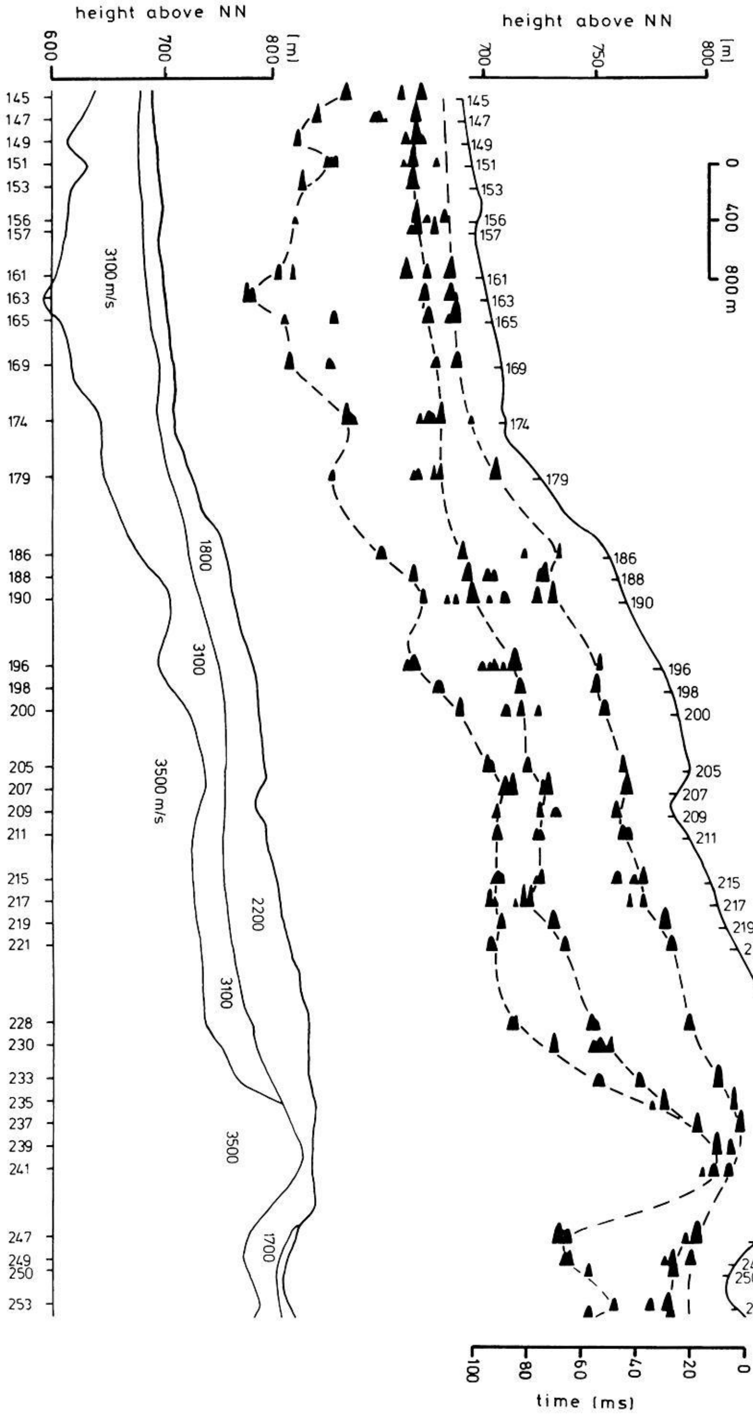

Fig. 9. The time section and the corresponding depth section of one half of line V-331. The traces in the time section are shifted according to the elevation of the observation point

Using the velocities derived from the Short-Refraction profiles the depths to the reflecting interfaces can be computed. The subsurface model derived from the output trace in Figure 8 is in good agreement with the subsurface model derived from the Short-Refraction profile. Furthermore, the difference between the static correction computed from the output trace in Figure 8 and the static correction derived from clearly correlating reflection events in the Vibroseis section is only 1 ms at this location.

The resultant output traces for all other observation points were plotted in the same way as depicted in Figure 8. In the upper part of Figure 9 the time section and in the lower part the corresponding subsurface model are shown for one half of line V-331. The uppermost continous line of the time section gives the surface elevation along the section. The zero time of the output trace of each observation point corresponds to this surface line. Thus, the correlation of reflection events from the same interface is easier. The altitude scale is given at the left end of the section, whereas the time scale is given at the right end. The dashed lines in the time section indicate how the reflection events have been correlated. In the case of greater gaps between successive observation points the reflections cannot be correlated with certainty. Desiring a continuous profiling of the subsurface boundaries the distance between the observation points is too great.

The uppermost dashed line in the time section connects reflections from the ground water surface. The ground water surface is not depicted in the subsurface model below, because the depth to the water surface varies only between 1.5 m and 5 m. The P-wave velocity above the water surface is about 350 m/s.

Supposing the static corrections derived from the Vibroseis reflection data are correct the error of the static corrections derived from the near surface reflection survey is less than 4 ms for 60 per cent of the observation points of line V-331. If the data had to be qualified as bad, or if the distance to the adjacent observed points was too large, greater errors occurred (Schepers 1977). The static corrections based on the reflection measurements are comparably good as the static corrections derived from the Short-Refraction profiles. Adaptation of the field technique and carrying out measurements at more closely separated points can improve the results.

Besides the problem of getting information for better static corrections the described reflection method has proved to be a quick survey method within the scope of engineering investigations.

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