MAPPING POISSON'S RATIO OF UNCONSOLIDATED MATERIALS FROM A JOINT ANALYSIS OF SURFACE-WAVE AND REFRACTION EVENTS

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INTRODUCTION

Poisson's ratio (σ) of the near-surface materials is one of the key parameters in various types of geotechnical projects. It is usually associated with the integrity of the materials from the engineering perspectives. A two-dimensional (2-D) distribution map of σ , therefore, would have an invaluable value.

Seismically, σ can be determined if P- (V_p) and S-wave (V_s) velocities are known. This would indicate that two separate (P- and S-wave) surveys should be performed in order to obtain the separate maps for V_p and V_s. Running both types of survey for one project will be expensive in terms of equipment, data processing, and overall time. In addition, S-wave survey is generally known as being much more difficult to acquire good quality data than the P-wave survey.

We can obtain V_p and V_s fields by using several methods. However, each of these methods requires individual data acquisition and processing techniques. For example, the reflection method is not suitable for studying the very near surface because the shallower we aim our target of investigation the more expensive it becomes and the more our data will be contaminated by waves considered as noise. On the other hand, the refraction method is incapable of detecting "hidden layers" (Burger, 1992) such as a high velocity thin layer or a low velocity layer "sandwiched" between two high velocity layers. Such "hidden layers" cause erroneous interpretation of the data. An improved way of interpretation of refraction data is by using refraction tomography. Still, we need an initial model that is close to the true V_p distribution as well as smoothing constraints (Stork and Clayton, 1991.) in order to achieve reliable results during inversion.

Reflection and refraction V_s methods share the same problems as with the V_p field. In addition there are equipment and acquisition difficulties and there is the possibility for misinterpretation due to S-P-S wave conversion (Xia et al., 1999).

Recently, an economic seismic method has been used to produce a V_s profile (plot of V_s vs. depth) by analyzing surface waves (ground roll) on a multichannel record. This multichannel analysis of surface waves (MASW) method (Park et al., 1999a) can produce a 2-D near surface V_s map when the multichannel records (shot gathers) are acquired in a consecutive manner similar to conventional reflection survey (Miller et al., 1999a). Since the MASW method employs the conventional seismic approach in which vertical source and receivers are used the near-surface V_p information can be associated with the first arrivals from the shot gathers. Refraction tomography, for example, can be applied to the shot gathers to obtain the near surface V_p map.

The goal of this paper is to propose a method for obtaining accurate and reliable 2-D σ distribution map in the near surface in an economic manner. The economy is achieved by performing a single near surface seismic survey using a vertical source for acquiring data for two wave fields. The accuracy and reliability is achieved using the analysis results of one wave field (surface wave) as a priori information for the inversion of another (body wave).

MASW FOR VS MAP

MASW extracts a dispersion curve by analyzing all traces in a shot gather. This dispersion curve is then inverted for a 1-D depth-velocity (V_s) profile. By applying this sequence from one shot gather to another we generate a 2-D V_s distribution map. This map is acquired in an accurate manner by pursuing high signal to noise ratio during both acquisition and processing. During acquisition this is accomplished by using walkaway test for selecting an optimum window for obtaining the fundamental mode of the dispersion curve and avoiding those offsets where body waves and higher modes dominate (Park et al., 1999a). Multichannel analysis is essential in distinguishing fundamental mode of the dispersion curve from higher modes (Park et al., 1999b).

REFRACTION INVERSION FOR VP MAP

V_p map is obtained from the inversion of the first arrivals through forward modeling. There are various algorithms for calculating first arrivals, such as ray tracing, finite-difference and etc. We apply Schneider et al. (1992) algorithm for first-arrival travel time computation. It is capable of handling high velocity contrasts. Such contrasts are typical for the very near surface. Other methods, such as ray-tracing techniques and finite-difference eikonal solvers, require smoothly varying velocity field (Schneider et al., 1992).

Inversion is performed by modifying the model parameters, computing the forward model and comparing the modeled data with the observed data. Model parameter selection can be accomplished manually or automatically. Inversion solution is reached when there is sufficient match (minimal difference) between the modeled and observed data.

As many other non-linear inversion problems, refraction inversion has the problem of nonuniqueness. This problem can exist in several forms. There might be:

- A single minimum, corresponding to an inverse problem with a unique solution. Still, that unique solution may be difficult to find due to the existence of local minima.
- Two solutions (minima).
- Many solutions.
- Finite range of solutions

This indeterminacy can be resolved by adding a priori information (Menke, 1984). We can use that information as an initial guess that will bring us in the region of the true solution. This solution would then be found by the inversion process.

GENERATION OF POISSON'S RATIO MAP

Our main idea is to use the MASW solution of 2-D V_s map as a means to reduce the risk of nonuniqueness of the refraction inversion by making the following assumption; the variation pattern (trend) of V_p will follow the variation pattern of V_s.

Thus we reduce the risk of V_p refraction non-uniqueness which is inherent to all refraction inversion problems. We
However, the specific ration between V_p and V_s is considered through several hypotheses for the distribution of Poisson's ratio (σ):
- σ is constant,
- σ is a function of depth,.
- σ is a function of V_s,

We create an initial 2-D V_p model from the 2-D V_s model by choosing an appropriate functional relationship for σ that would provide a close match between the measured first arrivals and the calculated first arrivals. We then continue to improve the match by changing the V_p model. We take into account the above-mentioned possibilities for σ distribution and we use first-arrival travel time 2-D plots as a guiding tool.

We stop when there is sufficiently close match between the calculated and the measured first arrivals and when further manual change of the V_p model does not improve significantly or degrades the match.

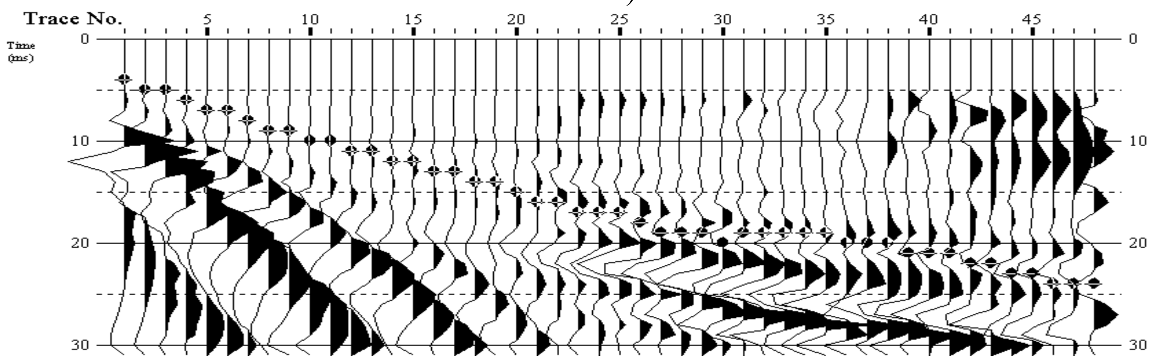
When the method is applied to field data, we assume that σ can be as high (or even higher than) as 0.45 (Suyama et al. 1984).

FIELD DATA, OLATHE, KANSAS

We use the MASW data collected in Olathe, Kansas (Miller et al., 1999a). Data were collected using a 60-channel Geometrics Strata View seismograph. Four impacts on a $0.9m^2$ plate were vertically stacked for each shot. The receiver station interval was 0.6m. The source to nearest receiver offset was 2.5m. Source locations were at 1.2m interval. A 2-D V_s distribution map obtained by analyzing this data set is shown on Figure 1a. We designed a 0.6mx0.6m sell grid to model the V_p first arrivals and we selected 10 shots for observing the match.

Initially we calculated a 2-D V_p distribution map using a constant σ =0.4556 (V_p/V_s=3.5) Figure 1b. Figure 2 shows the first arrivals calculated from this initial V_p map marked on the two shot gathers.

a)



b)

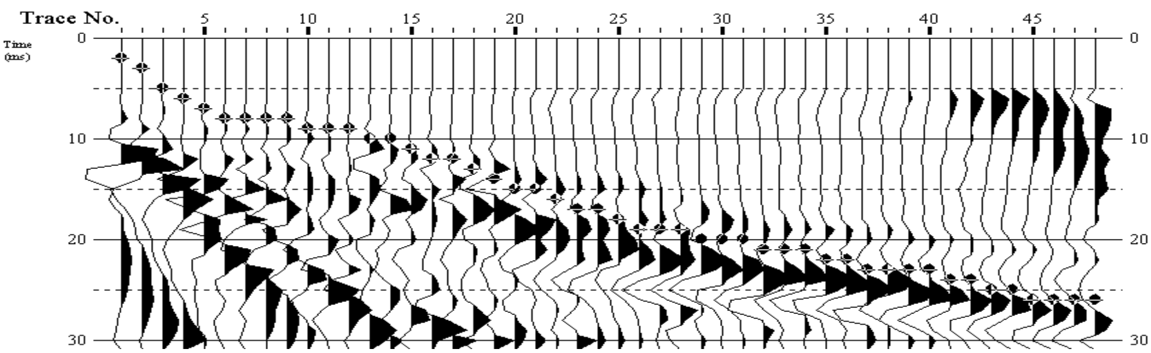


Figure 2. a) Shot at X=93m. b) Shot at X=107m. Spread length is 28m. Saturn marks show the calculated first arrivals.

The V_p model is then changed to make the calculated first arrivals better match pattern observed on the shot We used first-arrival travel time contour maps (Figure 6) as a guide to what parts of the V_p map need to be changed. After applying more then a dozen manual iterations we came with our final V_p solution, shown on Figure 4. Figure 3 shows the first arrivals calculated from this final map. Further attempts to improve the match manually led to slight improvements in some parts and/or degraded other parts of the match. At this stage we produce the 2-D σ distribution map of Figure 5. However, instead of plotting σ we preferred plotting V_p/V_s for a more pronounced display effect.

a)

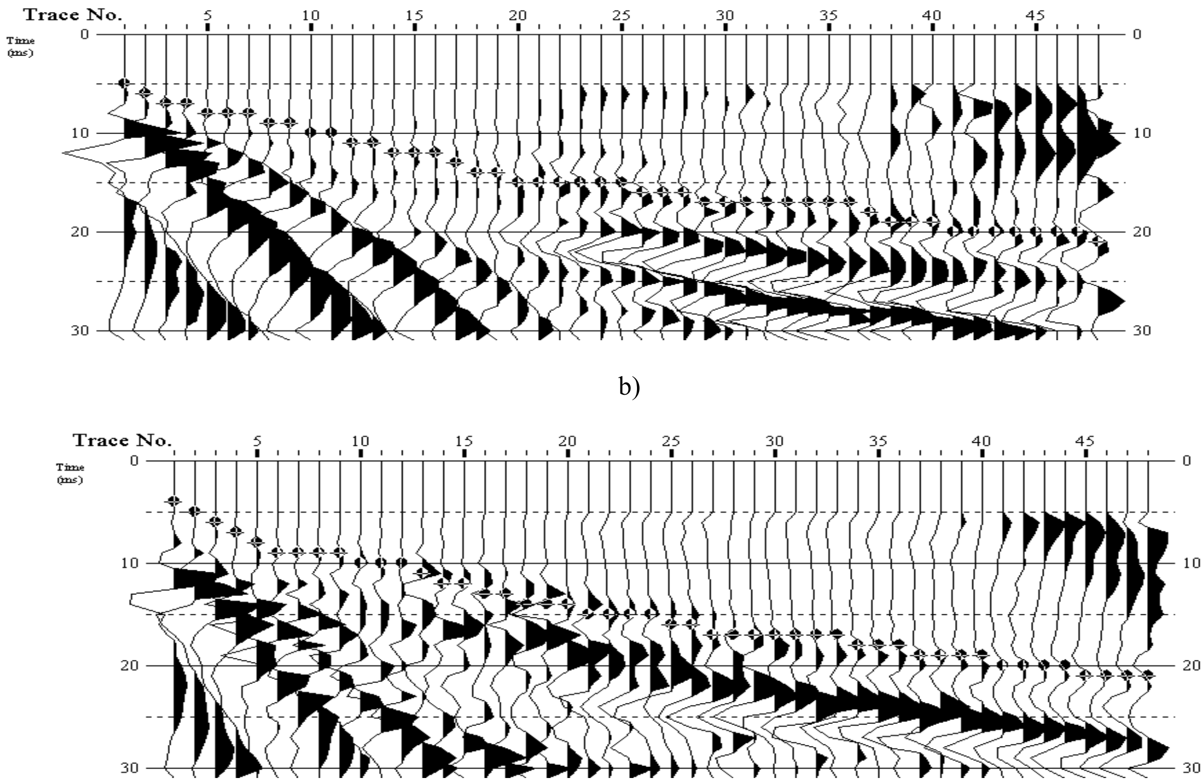


Figure 3. a) Shot at X=93m. b) Shot at X=107m. Spread length is 28m. Saturn marks show the calculated first arrivals.

DISCUSSIONS AND CONCLUSIONS

When we compare the V_s and V_p maps (Figure 1 and Figure 4) we notice the general trend of V_p follows the general trend of V_s and it turned out to be close to a constant σ =0.4667 (V_p/V_s=4). Still, there are zones where V_s and V_p trends differ (Figures 4 and 5: the top 1m, the zone defined by depth between 1-2.5m and X between 116-130m, the zone defined by depth between 3.5-5.5m and X between 123-134m). This is exactly what we are after, since we use the general trend assumption only as a means to find the true solution of the V_p refraction method.

The maximum depth of investigation in the V_s map is 10m. However, the V_p refraction depth of investigation in this case turned out to be about one half of it, about 5.5m. This limits the meaningful depth of σ (V_p/V_s) map to 5.5m as well. That's why the V_p/V_s values on Figure 5 below 5.5m are constant.

We perform inversion by manually changing the model parameters. This seems sufficient at this stage of study as far as the main purpose of this paper is to propose a new method. However, future work would include automatic inversion. We plan to use the first or one of the following iterations from the manual inversion as an initial guess for the automatic inversion. In that way it would serve as a refinement tool. Another direction for development is to use the obtained 2-D V_p and σ maps for refining the inversion solution of MASW. Thus, we may create a global iterative V_s–V_p scheme in a way that the results from one method would improve those from the other.

The value of this technique is in its reliability and economy. It provides a highly probable 2-D distribution map of σ . The economy is achieved by collecting one data set for obtaining results from 2 wave fields. This technique can be valued by both near-surface engineers and oil industry seismologists. While the near-surface engineering community is interested in the 2-D σ map the oil seismologists are interested in a reliable near surface 2-D V_p map for the application of static corrections.

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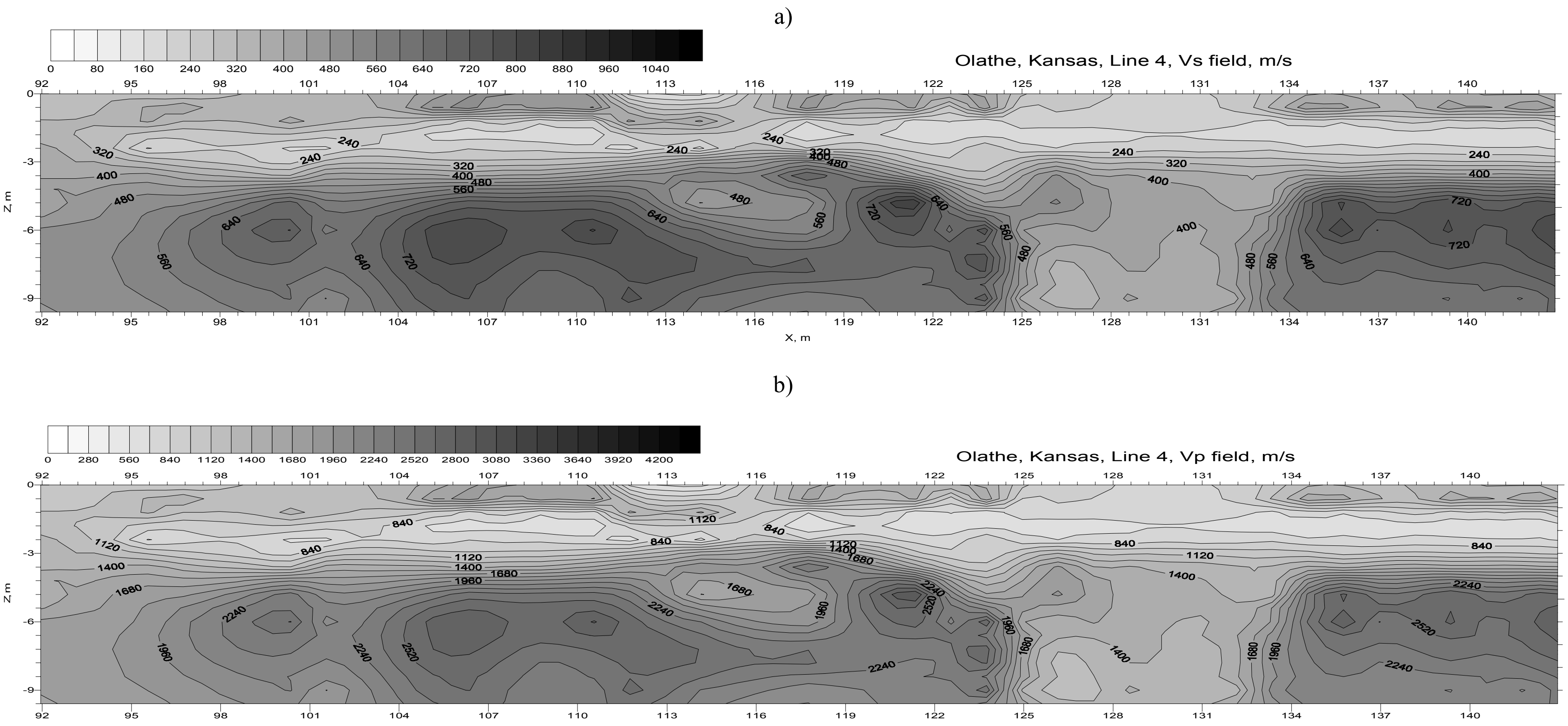

Figure 1. a) Vs 2D distribution map. b) Initial Vp 2D distribution map

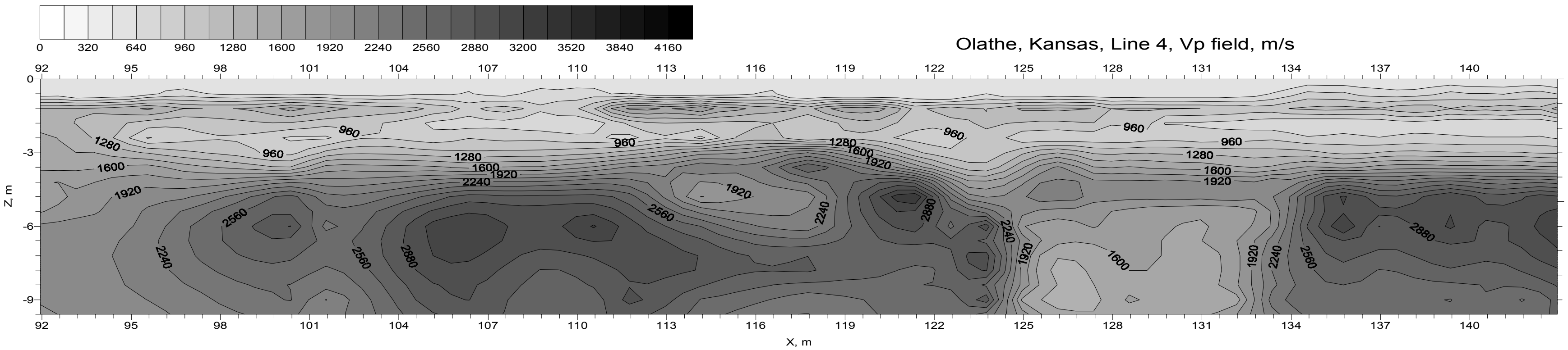

Figure 4. Final Vp 2D distribution map

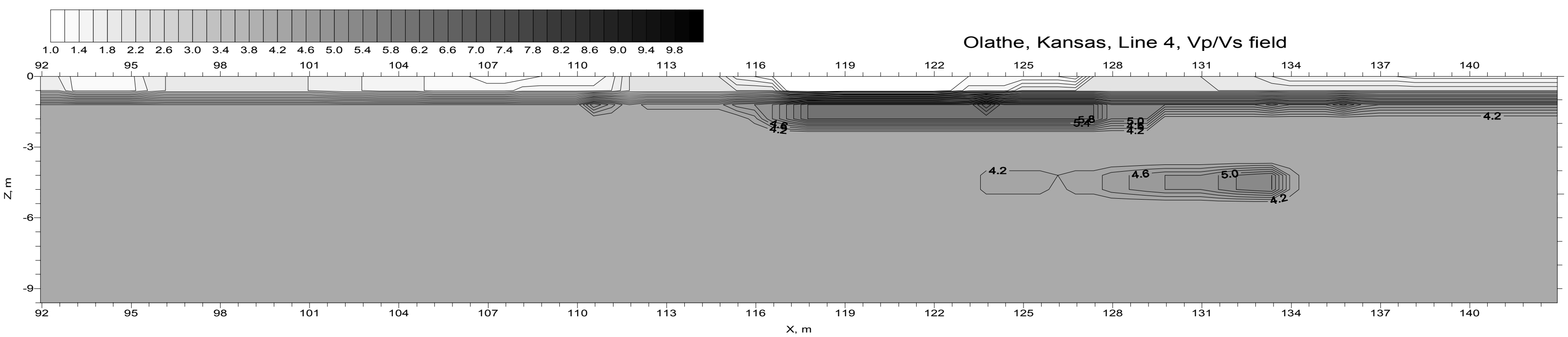

Figure 5. Vp/Vs 2D distribution map

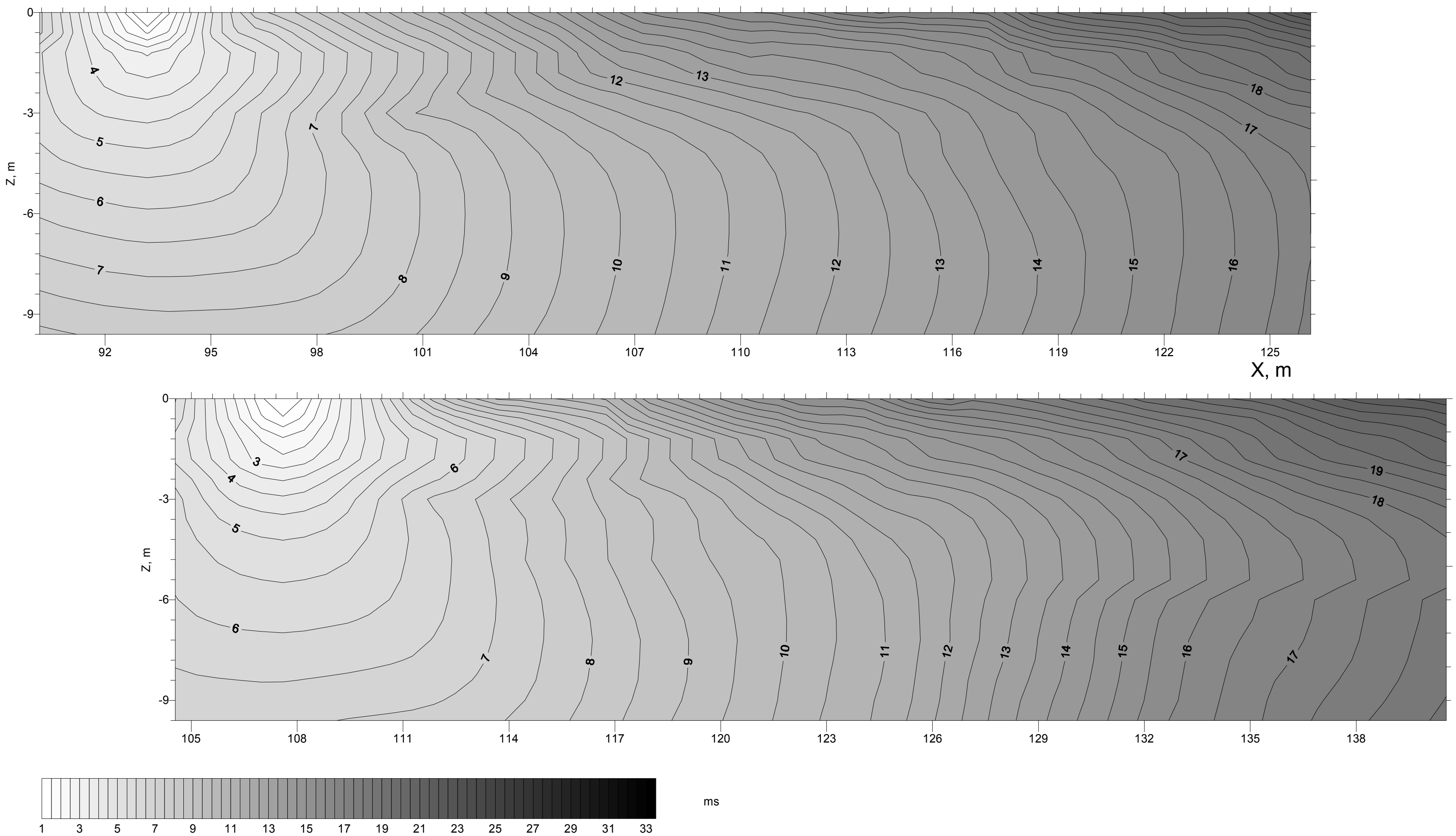

Figure 6. First arrival time contours for Shots at X=93 and 107.