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2-C land streamer for high resolution shallow seismic investigations

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ABSTRACT: Land streamers are often used for seismic surveys in urban areas and paved surfaces, where conventional spike geophones can not be planted. With the development of shear-wave seismic methods, land streamers recording S-component also gained more importance. Due to their lower velocity, shear-waves provide a high-resolution seismic tool for the investigation of the shallow (0-20 m) subsurface. Worldwide examples of land streamer surveys and a novel P- and S-wave vibroseis source for engineering applications initiated the development of a modular 2-C land streamer system. Our goal was to develop a seismic land streamer which enables fast data acquisition on varying surfaces for different types of data processing, such as multichannel analysis of surface waves, turning ray tomography, reflection and refraction processing. Several surveys were carried out with the land streamer both in urban areas, on paved surfaces and out of urban areas, on agricultural fields in order to investigate the applicability of the system. P and SH waves were recorded simultaneously and data were processed with different methods. Field data examples will be shown demonstrating data quality and productivity.

Keywords: seismics; shear-wave; land streamer; vibroseis; MASW

1. Introduction

Land streamer is the onshore equivalent instrument of streamer cables used during offshore seismic surveys. Today, land streamers are common and widely used in seismic investigations, and especially in areas, where coupling cannot be guaranteed between the ground and conventional spike geophones, for example in urban areas and on paved surfaces.

The first land streamer was invented in the '70s [1, 2], named as Towed Land Cable. Since then, more and more researchers use and build land streamers.

With development of shear-wave seismic methods, S-wave type land streamers also got more importance. Due to their low velocity, shear-waves give us the opportunity to investigate the shallow (0-20 m) media with high resolution, using reflection seismic methods. Based on this fact, Inazaki [3] developed an S-wave type land streamer, which gave the opportunity to make ultra-high resolution seismic reflection surveys and it was successfully applied in urban areas for shallow structural investigations [4].

The results of [4] gave the motivation to build an in-house developed 2-C land streamer with Geomega Ltd. Our goal was to create an instrument which enables fast data acquisition on varying surfaces and the registered data should be used for several types of processing, for example multichannel analysis of surface waves, refraction tomography and reflection seismic data processing.

Several measurements were carried out with the developed land streamer, using an optimal S-wave source. We present two surveys where land streamer was applied, one survey from a paved, urban area in Kőbánya, Budapest X. district (Fig. 1.) with high noise level and another survey from an agricultural test site nearby Dunavecse, mid-Hungary (Fig. 2.). The two areas are

significantly different from each other both in terms of surface properties and environmental noise. Despite this difference the landstreamer provided good-quality data for processing in both areas.



Figure 1. The land streamer system with electromagnetic S-wave vibrator and P-wave hammer in urban area.



Figure 2. The land streamer system with electromagnetic S-wave vibrator and P-wave hammer on agricultural test site.

For each survey, different data processing methods were applied on the same dataset. We demonstrate the

comparison between the results of the different processing methods to examine the effectiveness of the developed device.

2. Applied processing methods

2.1. Urban area

During data processing, we applied three methods on the recorded dataset: multichannel analysis of surface waves (MASW) for Love-waves [5, 6], refraction tomography for P- and S-waves [7-9] and S-wave reflection seismic processing. The S-wave reflection processing contained the following main steps:

- Geometry assignment
- Refraction statics correction
- 5-15-90-110 Hz bandpass filter
- Pre-stack F-K filter
- Spiking deconvolution
- Amplitude control
- 1st velocity analysis
- NMO correction and CDP stacking
- Residual statics correction
- True amplitude recovery
- 2nd velocity analysis
- NMO correction and CDP stacking
- Post-stack F-K filter
- F-X deconvolution
- Time-depth conversion

2.2. Agricultural test site

The dataset collected on the agricultural test site was processed similar to the urban dataset. We applied refraction tomography for P- and S-waves, while S-wave reflection seismic processing was also executed. The following main steps were applied during the reflection seismic processing:

- Geometry assignment
- Refraction statics correction
- 5-12-90-120 Hz bandpass filter
- Pre-stack F-K filter
- Amplitude control
- Velocity analysis
- NMO correction and CDP stacking
- Post-stack F-K filter
- F-X deconvolution
- Time-depth conversion

3. Comparison of the results

3.1. Urban area

The data processing resulted two S-wave velocity fields, one P-wave velocity field and one S-wave reflection section. The results can be seen on Fig. 3..

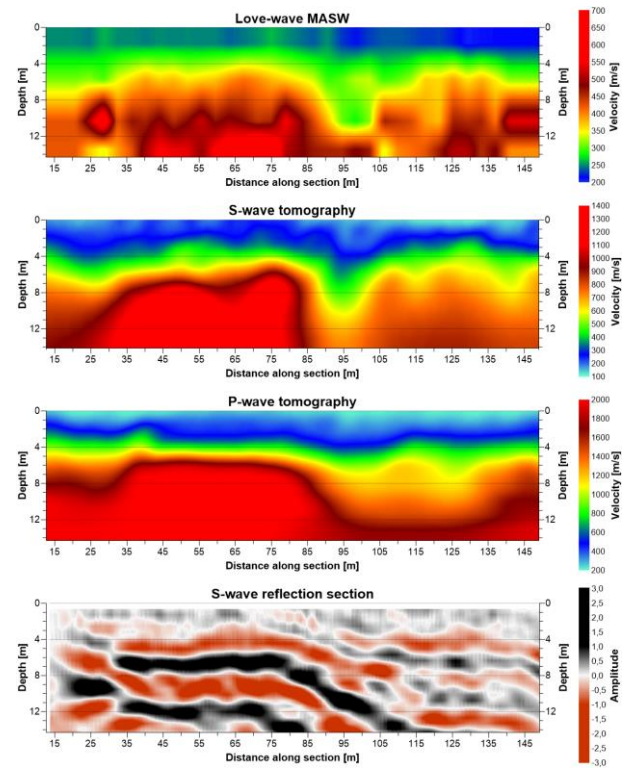


Figure 3. Results derived from the urban dataset using different processing methods: Love-wave MASW, S-wave tomography, P-wave tomography and S-wave reflection seismic processing. Love-wave MASW and S-wave tomography velocity fields show similar anomalies, while the P-wave velocity section is quite similar to the S-wave reflection section.

The Love-wave MASW and the S-wave velocity profiles appear similar and show noticeable velocity decrease at 15 m and 95 m distances along section. The lower, high-velocity layer's surface is quite similar on both sections and may delimit the surface of a shallow limestone layer. The P-wave tomography section also contains velocity decrease at 15 m and 95 m, but these changes are not as sharp as the S-wave velocity profiles' anomalies. This fact can be explained by the lower resolution of P-waves compared to the resolution of S-waves.

On the S-wave reflection section a strong event can be observed between 4 and 8 m depth. This reflection seems faulted at 35 m and it shows higher dip value from 95 m distance along section. The P-wave tomography and the S-wave reflection section shows powerful correlation. Fig. 4. is representing the velocity sections compared to the reflection section.

We must notice that the MASW method is creating one-dimensional velocity functions and the two-dimensional velocity field is created by interpolation between the velocity functions. In this way we can see sharp anomalies, which should be smoother in fact.

Overall we can say, that the strong reflection event, which can be seen between 4 and 8 m depth, correlates well with the different velocity fields' anomalies. This reflection is representing the surface of the shallow limestone layer, which is covered by unconsolidated quaternary sediments and anthropogenic deposits.

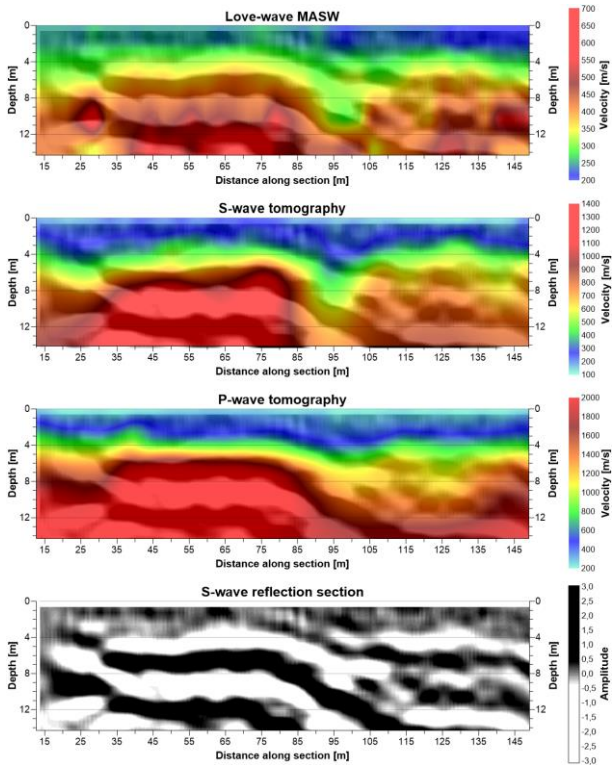


Figure 4. Velocity sections compared to the reflection section. The best correlation can be seen with the P-wave velocity field, but S-wave velocity fields are also similar to the reflection section.

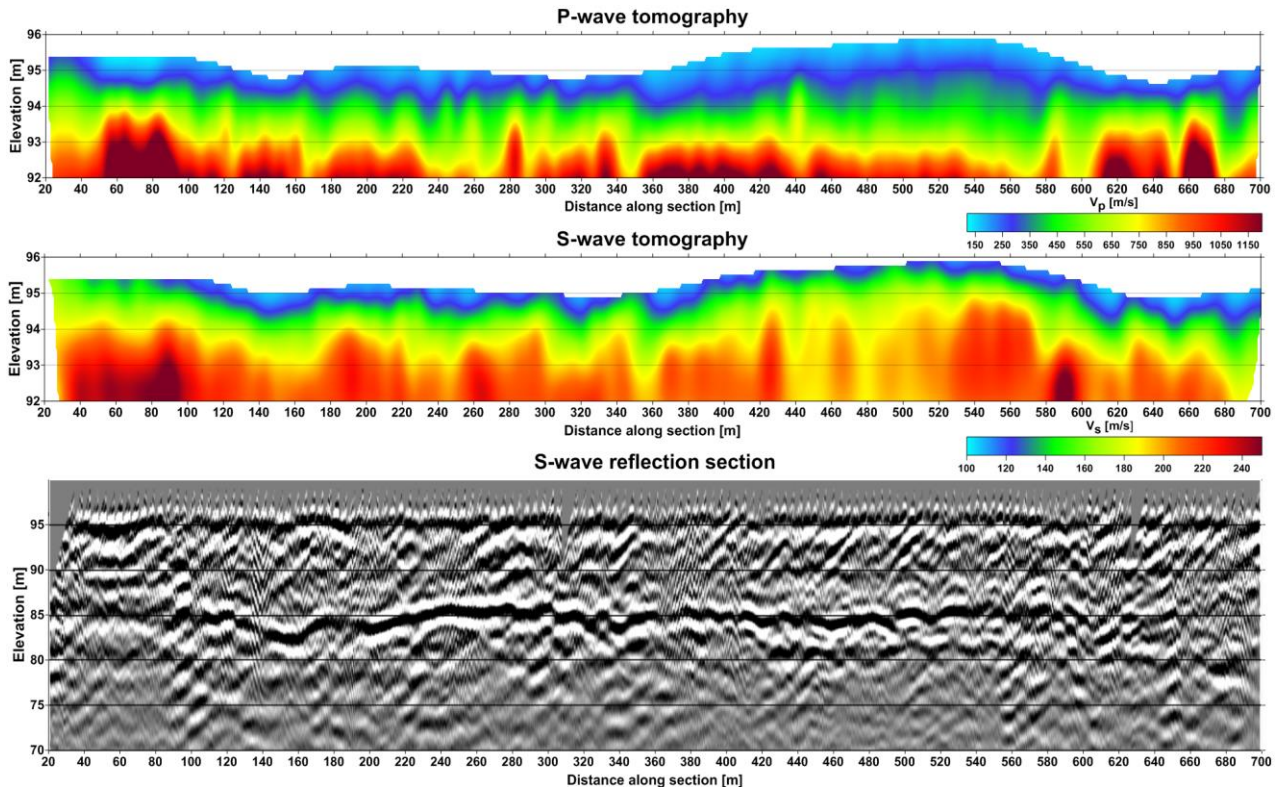


Figure 5. P- and S-wave velocity sections calculated by seismic refraction tomography and the S-wave reflection seismic section. Slight correlation can be seen between the P- and S-wave velocity fields, main differences can be observed. The S-wave reflection section does not show strong similarity with the velocity fields. At 85 m elevation a strong seismic event can be observed. Please note, that the vertical distortion value of the P- and S-wave velocity fields is 20, while the vertical distortion of the reflection section is 5!

The S-wave velocity field contains a trend which is following the variations of the topography. This trend is disconcerted by some salient anomalies, mostly matching with the anomalies of the P-wave velocity field. As shear-waves are not sensitive to any fluids filling the pore

3.2. Agricultural test site

The processing of the dataset collected on the agricultural test field derived a P-wave velocity field, an S-wave velocity field and one S-wave reflection section. The results of the processed data are presented by Fig. 5..

The P-wave and S-wave velocity profiles show minimal correlation at 60-80 m distances along section, another similarity can be observed between 180-220 m and 320-440 m distances along section.

The most significant difference between the P- and S-wave tomography sections is that the variation of P-wave velocity field does not correlate with the topography along the section, while S-wave velocity is varying with the topography. The P-wave velocity field is representing a flat subsurface feature with some salient anomalies, which anomalies also appear in the S-wave velocity field.

The flat trend in the P-wave velocity field can be legated to the effect of the ground water table. Although the velocity values are keeping away from the velocity values of the certain presence of the water at the bottom of the section, the capillary action could influence the soil moisture in the close environment of the ground water table, thus affecting the P-wave velocity in the porous subsurface media.

volume of the subsurface media, on the S-wave velocity field we can observe only anomalies of solid materials' physical properties. In this way, the presence of the trend of topography can be explained with the cultivation process of the soil. The uppermost, approximately 60-90

cm thick layer on the S-wave velocity section is represented with 100-130 m/s velocity values with a sharp velocity increase at its bottom. Probably, this layer consists of pretty loose soil which can be related to the zone of deep plowing processes, that usually affect the uppermost 90 cm thick layer of the soil.

The salient anomalies of the S-wave velocity field, which approximately are in correlation with the anomalies of the P-wave velocity section, could indicate inhomogeneities of the solid subsurface materials.

The S-wave reflection profile contains a strong seismic event, which can be observed around 85 m elevation along the whole profile. This 85 m level could not be imaged by the refraction tomography method because of the limited length of the land streamer, so we cannot compare safely this reflection seismic event to the P- and S-wave velocity fields, although minimal correlation can be discovered with the morphology of the S-wave velocity field between 100 and 300 meters along section. Probably, this strong reflection event is corresponding to the base of quaternary sediments. The S-wave reflection seismic section illustrates that shallow seismic reflection imaging can be performed with proper resolution.

The results show that the land streamer can collect valuable data which can be processed by independent methods to increase the certainty of the solution of a shallow geological question.

4. Conclusions

In conclusion we can say that the developed 2-C land streamer is a powerful tool for fast land seismic data acquisition. The custom designed recording system and the dedicated software enables simultaneous recording of P- and S-wave data with less than 1 minute per shot point production rate. The system can be used on varying surface types and found to be especially good in urban areas, where it gives us the opportunity to collect high resolution seismic data from the near-surface media.

S-wave measurements are less sensitive to urban noise, which is contaminating P-wave records with higher noise level. Combining the land streamer with an optimal shear-wave source, deeper penetration can be reached, but the high resolution also can be held.

The data recorded by the land streamer is suitable for several processing methods, thereby one seismic measurement can provide various kind of information about subsurface media, decreasing the uncertainty of the geological interpretation.

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