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Implementation and application of ultralight vibrator in shallow seismic acquisition

Zastosowanie wibratora inżynierskiego w badaniach sejsmicznych przypowierzchniowej części ośrodka geologicznego

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Abstract: Optimal, subsurface imaging, especially in the areas with strong subsurface attenuation is still a challenge for shallow seismic techniques. The main problem connected with it is using an impact source whose energy is rapidly absorbed by gradual ground consolidation around the baseplate. This phenomenon has a great influence on data recording and its quality. The only solution is to send portions of seismic energy for longer time in the selected frequency spectrum, which can be transmitted through subsurface material. This paper presents an ultra-light, air-pressure vibrator as the answer to seismic needs connected with avoiding low effectiveness of impact sources in case of high near-surface heterogeneity. Experimental approach to the survey in space-limited urban area with high-level subsurface material disintegration is presented.

Treść: Wyzwaniem dla płytkich technik sejsmicznych jest zobrazowanie struktury przypowierzchniowej na obszarach o szczególnie dużym tłumieniu fal sprężystych. Głównym problemem z tym związanym są ograniczenia stosowania uderzeniowego źródła fali, którego energia jest szybko absorbowana przez grunt wokół płyty podkładowej. Zjawisko to ma bardzo znaczący wpływ na jakość rejestrowanych danych. Jedynym rozwiązaniem jest generowanie fali sejsmicznej przez dłuższy czas i w określonym przedziale częstotliwości. W artykule przedstawiono zastosowanie wibratora akustycznego jako źródła sejsmicznego o odpowiedniej wydajności, w przypadku badania strefy przypowierzchniowej o niejednorodnej budowie. Przedstawiono także eksperymentalne podejście do badań sejsmicznych na ograniczonej, zabudowanej przestrzeni miejskiej.

Key words:

seismic source, shallow seismic, seismic measurements in the urban area

Słowa kluczowe:

źródła sejsmiczne, sejsmika przypowierzchniowa, pomiary sejsmiczne na obszarze zabudowanym

1. Introduction

The vibroseis device was invented and successively developed by John Crawford, Bill Doty, and Milford Lee in the early 1950s, mainly for oil explorations [4]. An interesting summary of use vibrators and other seismic sources in engineering seismic applications was presented by [8]. It turned out that, vibrators had several key advantages over explosive sources, which were commonly used at the very beginning of seismic surveys. Most important feature of vibrator was allowing precise control over the seismic signal sent into the ground. The frequencies at the sweep band could be adjusted easily. In this way the total length of the generated sweep and the amount of source energy, which is sending into the ground, is controlled. Furthermore, the shape of the seismic wavelet might be changed by monitoring the time spent sweeping at each frequency for whole range of sweep spectrum. Moreover, group of vibrators were able to work simultaneously, which makes it possible to use more than one vibrator per record to enlarge the output energy, eventually to combine them spatially into source array to improve the signal-to-noise ratio (S/N). Thus, the vibrator quickly stayed the most universal seismic source, which provides more acquisition options than are getable with an impact source. Additional advantage of vibroseis, which must be underline, is the ambient/incoherent noise removal by the correlation process [4].

Vibroseis is a general name for whole devices works as seismic signal generators. For today, they have many modifications, including rebuilding to very small and ultra-light forms. In this paper, light, loudspeaker-based one is presented.

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Additionally, its application to shallow seismic investigation is shown.

2. Sweep generation and Klauder wavelet parameters

The emission and acquisition process using a vibratory source excited with sweep s(t) yields compression of long received signal to a short impulsive source-like record [9]

$$c(t) = R(t) * Q(t) * F(t) * F(-t) = R(t) * Q(t) * k(t) \quad [1]$$

where R(t) is the earth reflectivity function, Q(t) represents the ground absorption, F(t) is the reference signal (usually the ground force or its derivate) and k(t) is autocorrelation of this signal, known as Klauder wavelet

$$k(t) = F(t) * F(-t) \quad [2]$$

The wavelet k(t) acts as equivalent source signature and directly states the quality of seismic image. The signal F(t) emitted into the ground is never the same as the signal s(t) used to pilot the source because of the vibrator mechanical properties and of source-to-ground-coupling. The dependency s(t) -->F(t) may be expressed using the transfer function T(t). Two different Klauder wavelets are distinguished: the "ideal" $k_0(t)$, being the autocorrelation of sweep signal s(t) and the real $k_F(t)$, being the autocorrelation of the F(t) and: F(t) = s(t)*T(t) [9].

Assuming that the dependency s(t)→F(t) is linear, it may be expressed in spectral domain using the coupling function C(f) [2]

$$C(f) = \frac{s(t)}{F(t)}$$

The most important Klauder Wavelet Parameters are bandwidth (B), central frequency (f_0) and normalised bandwidth (B_n = B/f_0). The higher B_n value the better signal quality (Fig.1).

3. Equipment

Portable vibrators are well known for their flexibility and are cost-effective. Their main advantage is the possibility to control the emitted signal which is not the case for impulsive

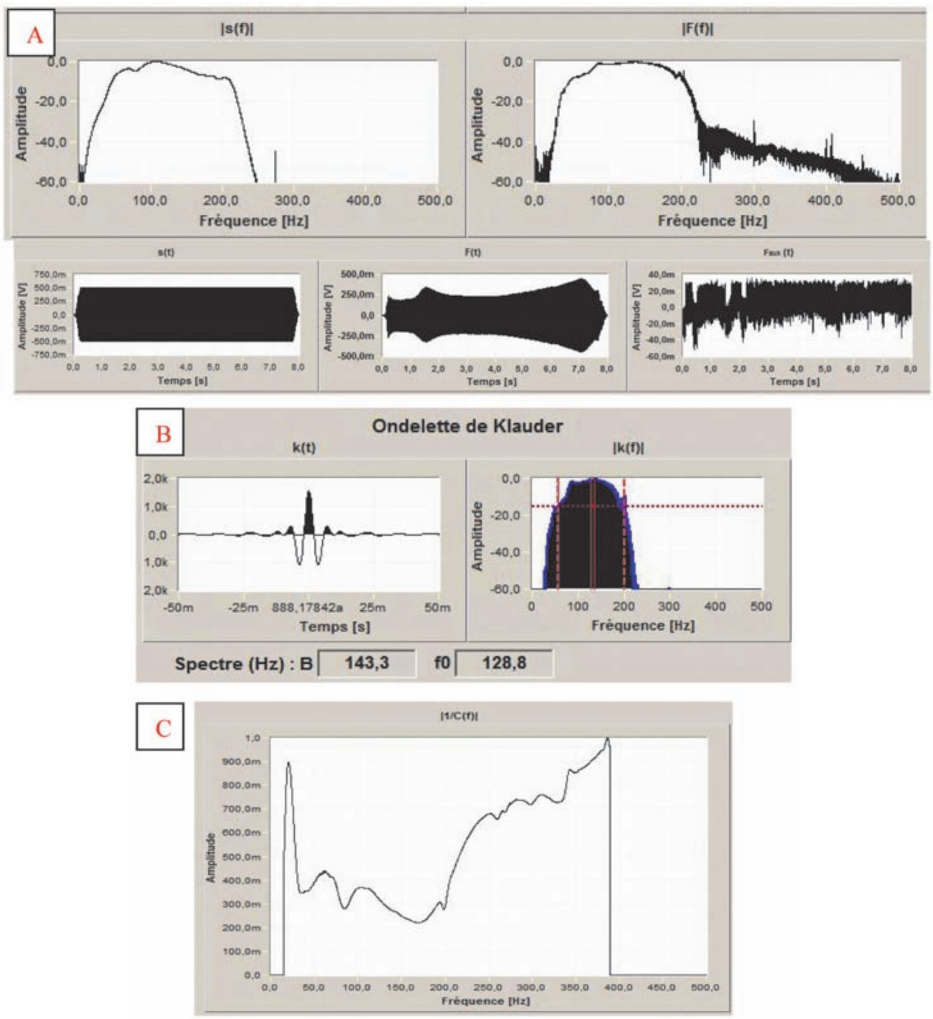

Fig. 1. A – an example of signal used as pilot s and signal emitted into the ground in frequency s(f), F(f) and time domain s(t), F(t), B – Klauder wavelet with two parameters: bandwidth and central frequency, C - the coupling function for signal from fig. 1A

Rys. 1. A – przykład sygnału naprowadzającego i sygnał…

sources. Measurements were carried out with "Vib-PA" constructed at Ecole Centrale de Lille. "Vib-PA" is a prototype P-wave vibrator, made of a cylindrical steel frame housing the loudspeaker. In contrast to typical vibrators it does not use a base-plate for coupling to the ground. The vibrations of loudspeaker are transmitted to the ground by compression and decompression of air. This acoustic vibrator is powered by 700 W amplifier, its weight is 50 kg. A geophone placed close to the source is a reference signal source [3].

The special programme written in LabVIEW language by researchers from university Ecole Centrale de Lille was applied. This programme controls the vibrator, receives simultaneously the c(t), determines automatically all Klauder Wavelet Parameters and compares them with the required value.

The following procedure in this programme has been applied. The site parameters (ground attenuation, layers, geometry) and the targets (required resolution) were set. The relation between Source Sweep Parameters, Klauder Wavelet Parameters and a given sweep s(t) is defined. The next step is emission of the proposed signal s(t). Then the transfer function is determined during test emission and the compensation can be applied to s(t). Afterwards the compensated s(t) is emitted and theoretically provides the expected Klauder wavelet [1].

4. The aim of investigation and local geology

Historically, region of North France was covered by chalk exploitation. For years many outcrops were appearing and successively reclaimed without any information about position of excavation. Lack of chalk in deposit/bed after extraction was fulfilled by unconsolidated clay-chalk mixture and other, available waste materials.

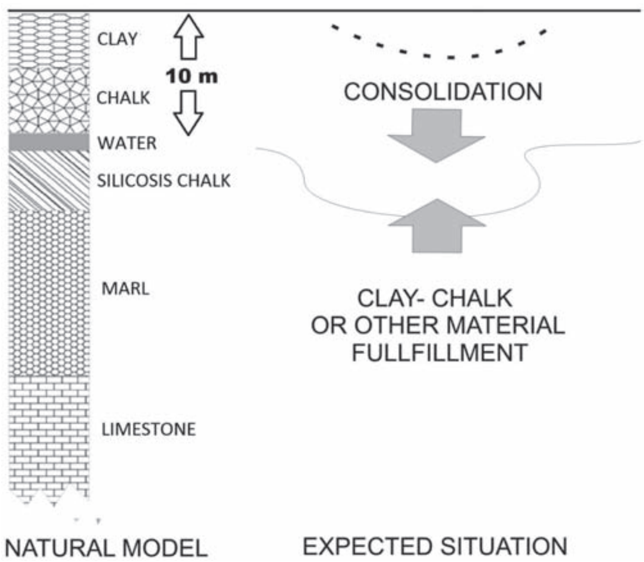

Fig. 2. In the left hand side general a model of the local geology, right part of picture represents possible underground condition and general aim of investigations

Rys. 2. Ogólny model lokalnego przekroju geologicznego…

This section illustrates a brief view of general geological model of survey area. As it is presented at Fig. 2, clay is the first layer under the surface. Its thickness varies from 2 to 3 meters. Beneath, up to 10 m follows poor-quality and highly disintegrated chalk (mud-formed) with water admixture. Underneath hard, silicosis chalk is present, dipping up to 25 m. This clay-chalk complex overlays the Marl and Limestone being outside of survey interests.

As it is exposed at Fig. 2, main refractor is connected with chalk complex, situated about 10 m depth. As it is shown on the right side of Fig.2, it can undulate in areas of historical chalk outcrops. In this case, any changes in elevation of ground in short time period, might be connected with rapid consolidation, as a result reaction of subsurface material for ambient, urban related vibrations.

For this reason an image of top of silicosis chalk layer must be performed. Its hypothetical variation in depth was an indicator of previous mine activity because natural, geological model is regularly layered.

5. Measurements

Seismic acquisition was extremely focused on determining any changes of elevation and estimated P-wave velocity of buried chalk complex. In comparison to other similar surveys, measurements conditions were difficult, because of totally disintegrated structure of subsurface material and limited investigation space. Surveys were carried out in azimuthal schema, fitted to in-field conditions. The 28 Hz geophones, were laid out at regular, 1m intervals, in cross-line pattern is shown in Fig.3. 48- channels seismograph, StrataView was used to record seismic data. Each seismic spread had a 24 active channels during acquisition. Measurements the first arrivals of the refracted energy were conducted firstly at the end of each seismic spread L1 and L2. In consequence, refraction blind zone with dominating direct wave, was estimated as a value of approximately 7 m. Respectively offset of remote sources was define as compromise between methodologically needs and available space-yellow line at Fig. 3. Used 10 m distance from extreme geophones was enough to preserve and observe refraction arrivals on every active receivers.

The generated disturbance was created by ultra-light, speaker-based vibrator, which was more adequate to avoid subsurface attenuation and near-source heterogeneity. At the stage of projecting surveys it was known that using heavy impact sources would be problematic and not effective to solving discussing problem. In case, when subsurface is disintegrated or extremely changed, great amount of massive sledge-hammer energy goes to ground consolidation around base plate. For described condition, well-known relation that heavy source introducing into ground gives strong refraction signal, wouldn't work properly.

Application of long sweep was similar to releasing enormous energy per one shot and gave more possibilities to manipulating emanating seismic signal. Furthermore, not every frequencies were preferred to travel cross the subsurface medium. Because of this reason sweep was corrected due to this assumption, as was mentioned in previous sections.

After many testes the sweep based on the Hamming window, with frequencies from 10 to 250 Hz and 8 seconds long was chosen as the best one for these conditions.

Additionally, vibrator grouping was carried out at remote source positions. For this purpose, small round area -centered around distant source position was chosen. Figure 3 describes mentioned idea. Each record obtained for three, showed vibrator localization was summed to final record. The method of external geophones was not applied because of existence blind zone and less important refraction information than from remote sources.

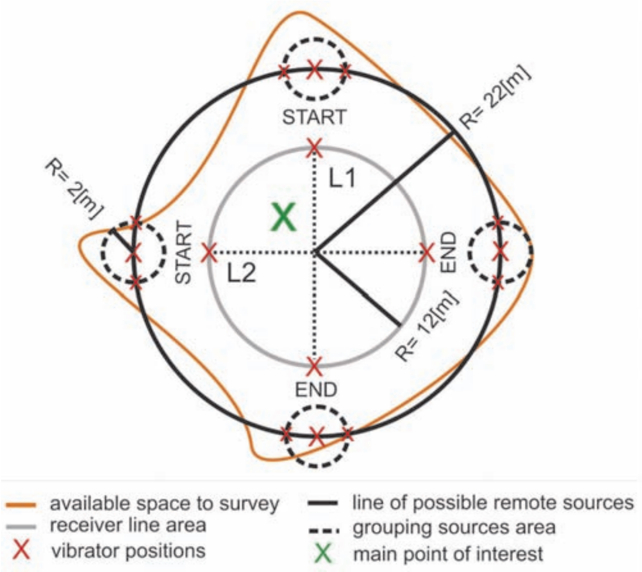

Fig. 3. Acquisition schema used during surveys
Rys. 3. Schemat dla…

6. Interpretation and results

Interpretation of obtained data was based on the Generalized Reciprocal Method by Palmer [6,7]. Simply, one refractor model was considered. Forward and reverse travel times was processed using standard GRM function from Seismic Unix Package. Figure 4 A and B presents interpretation results for L1 and L2 line. As it is shown velocity in the weathering zone was taken as an average from clay and poor quality chalk velocities- equal to 450 m/s [5]. Velocity in the refractory varies slightly around 1800 m/s. Fig. 4 A

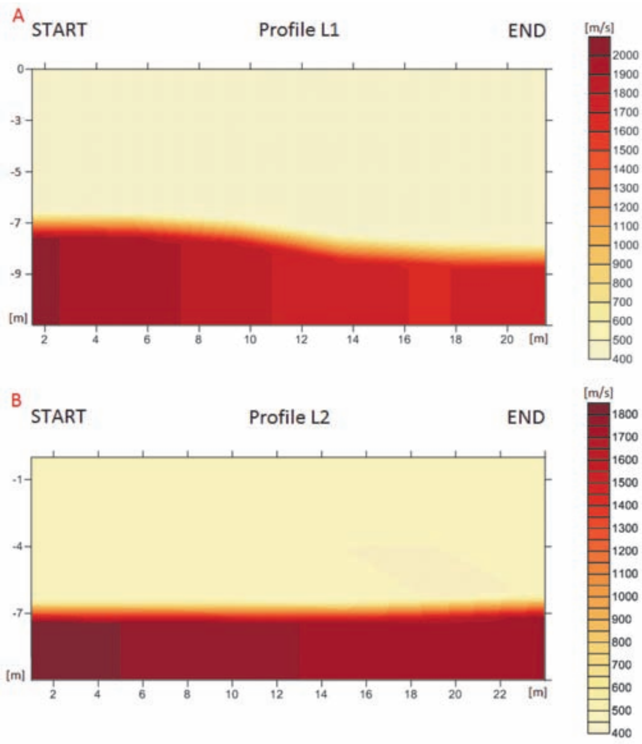

Fig. 4. Estimated velocity models exposed in depth domain, respectively, for L1 (A) and L2 (B) seismic spreads
Rys. 4. Szacowane modele prędkości ze względu…

shows gently dipping surface of refractor - changes no greater than 10%. Model in Fig. 4B is regularly layered without any significant disturbances. Velocity in bedrock is similar to estimated on previous subsurface model and almost constant at all offsets range. Values of velocities in range from 450 to 1700 m/s are connected with interpolation tool used to graphical expositions of results. Both models are convergent in depth as well as velocity domain. Application of crossed receiver lines geometry remarkably reduces seismic ambiguity and obviously proves obtained models. No rapid fluctuation in P-wave velocity and shape of bedrock suggests that extracted model is generally natural. Local changes in subsurface morphology has no connection with geological discontinuities. Refraction first breaks were observed constantly along offset, so avoiding any bedrock interruption during interpretation is very low.

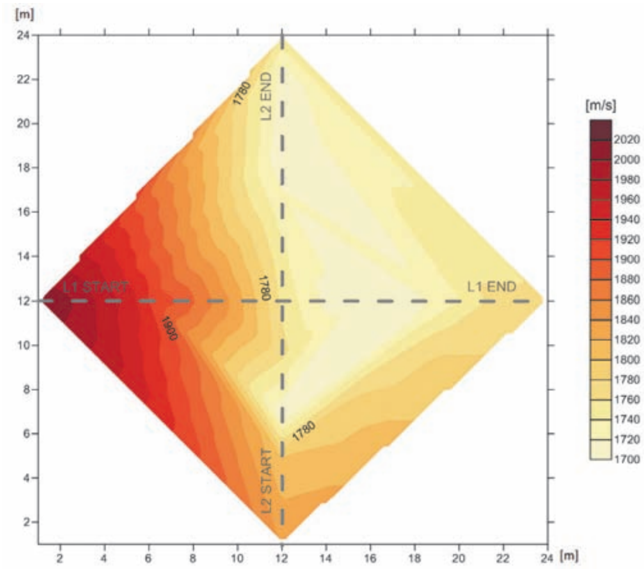

Fig. 5. Velocity distribution on refractor surface
Rys. 5. Rozkład prędkości na…

Figure 5 shows interpolated velocity distribution form line L1 and L2. In this view it is possible to observe distinction into two areas with differences in velocity, approximately equal to 250 m/s. Hypothetically this fact can be connected with changes in compaction (or silica content), but observing slightly dipping refractor, probably water content must be taken into consideration. Finally must be state that silicosis chalk layer imaged in hereby articles differs from pure chalk due to its velocity. Nominal refraction velocity for mentioned sediments is about 2300 m/s [6]. But this case describes a boundary between highly disintegrated chalk – related complex with overburden silica – enriched chalk. It has physical meaning and stay with quite accurate correlation with general model showed in Fig. 1. Estimated, geophysical model in comparison to drilled/ geological one in Fig. 2 is shifted on about 1m, what means that enough acoustic impedance between layers to observe refraction, appears earlier than it should be expected from geology.

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