CONTINUOUS DISTRIBUTION OF ELASTIC PARAMETERS OF THE SHALLOW QUATERNARY LAYERS ALONG THE 3C SEISMIC PROFILE EAST BUCHAREST

A. BALA¹, P. CRISTEA², V. RAILEANU¹, C. NITICA²

¹National Institute of Research and Development for Earth Physics, Bucharest-Magurele, bala@infp.ro
²Institute of Geology of Romania, 1 Caransebes str., Bucharest

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Abstract. Processing techniques were applied to seismic data acquired by reflection methods. The seismic methods are efficient research methods for civil engineering and environmental geology, which invite to develop specific methodologies. Therefore, soft-programs for processing data collected with refraction seismic techniques (based on head and transmitted waves) and by transmission tomography for velocity were made. The visual programming medium Borland Delphi was utilized to create the program MEDCONT, whose abilities, by menus and dialog windows, are both commanded and controlled. The accuracy and the adaptability of the program to field cases are validated by data resulted from forward models and also collected by applications on field objectives.

Key words: distribution, quaternary layers, seismic profile, elastic parameters.

INTRODUCTION

The seismic reflection profile recorded with 3 component sensors (3C seismic profile) in eastern Bucharest area (near Catelu village) had as primary target the investigation of geologic layers (up to 300 m depth for the P waves) by the multifolding seismic reflection method. The position of the seismic profile is given in Fig. 1.

The reflection seismic profile was performed by PROSPECTIUNI SA as part of the research contract CERES No. 34/2002, conducted by the National Institute for Earth Physics. The data acquisition was realised with a high resolution seismic station with 96 channels and a new type of triaxial seismic sensors. Different methodologies were employed to ensure the recording of both longitudinal and transverse waves. The complete description of the reflection seismic profile as well as the seismic sections of the shallow layers obtained on this profile and in boreholes C1 and C2 were published by Bala et al., 2005a.

The database gathered on this reflection profile included also refracted P and S waves, which are used in the present study to obtain the continuous distribution
of seismic wave velocities with depth and also the computing of principal dynamic parameters which characterize the shallow Quaternary sedimentary layers: Poisson’s ratio (ν) and shear modulus (G).

In order to obtain the sections with continuous distribution of seismic velocities, the methodology used in this paper is based on a procedure from the theory of continuously refracted waves. This recording procedure requires a detailed observation scheme, with a great number of pairs of traveltime graphs obtained from 2 successive shot points. The time difference values of these pairs of traveltime graphs are used, with the hypothesis of a geologic medium with a continuously increasing vertical gradient of the seismic velocities, which lead to a parabola type function (Averbuch, 1967).

The acquisition technology of multi-folding reflection data ensure the condition of performing a collection of successive traveltime graphs, which are strictly necessary to employ the technique of continuously refracted waves. The seismograms contain also in the first arrivals, as well as in a time interval up to 300 ms, the refracted waves that travel in the shallow sedimentary layers near surface.

The maximum offset of the source–receiver observation system in the multi folding seismic reflection method limits the observation depth of the refraction method to a maximum of 1/3 of the observation panel (24 m in our case).
THE LONGITUDINAL AND TRANSVERSE SEISMIC WAVES
RECORDED ON THE 3C SEISMIC PROFILE
IN THE ESTERN BUCHAREST SIDE

DATA ACQUISITION SYSTEM

In the eastern side of the Bucharest area, near Câtelu village, a 3C seismic profile was recorded, using special adapted recording methods for P and S waves, with the purpose of modeling the upper part section of the Quaternary sedimentary layers.

A modern multichannel equipment was used, Input/Output System II (USA), using 98 recording channels. Recording time was 1 s, with a sampling rate of 0.5 ms. This parameter enables the recording signals of up to 500 Hz, well beyond the anticipated frequency of longitudinal and transverse seismic waves recorded in this upper part section.

The reflection seismic profile was recorded using a distance of 1.5 m between 2 consecutive recording sensors (for a total of 48 recording sensors for one panel) and a seismic shot point in the middle of the recording panel, which resulted in a 72.5 m for each recording panel. The shots were performed using 12 g of detonation cord at each 1.5 m distance, which resulted in a 48-fold coverage seismic system.

The seismic recording points were numbered sequentially, beginning from 120, at the NE end of the seismic profile.

The collected signals, using procedures specially adapted to refracted waves, are recorded along a segment, between the recording points 120–320, that is a length of 300 m from the original seismic profile. In this way, the refraction profile presented in this study covers only 300 m from a total of 700 m of the seismic reflection profile presented by Bala et al., 2005a.

The recorded seismograms were transformed from the original SEG B files, usually used in seismic prospecting, in a .BLN file. The SURFER computer program was used to represent the selected seimograms at a proper scale. A recording time length of 150 ms was used for the P wave seismograms and 300 ms for S wave seismograms.

THEORETICAL APPROACH OF THE METHOD

The procedure which permits the use of the difference values of 2 consecutive traveltimes graphs in media with continuous velocity gradient, is described for the first time by Russian seismologists (Averbuch, 1967; Puzirev 1955) for the study of the deep structure of the lithosphere. Adaptation of this procedure to the study of
shallow seismic sections was done with the purpose of describing not only the velocity discontinuities, but also the image of seismic velocity isolines in a shallow vertical section.

The equation of the refracted wave in a medium with continuous velocity vertical gradient, is that of a parabola law:

$$T_{\text{cnt. refr.}} = t_{\text{front}} + a_2 (x - x_{\text{ini}})^2$$

in which: $t_{\text{front}}$ – the traveltime of the frontal refracted wave ($t_{\text{front}} = x \sin(i_{\text{crit}} \pm \varphi)/v_{\text{ini}} + + 2h \cos i_{\text{crit}}$); $x_{\text{ini}}$ – the offset of the initial point; $a_2$ – the correction factor generated by the presence of the continuously refracted medium.

After transformations, the following practical equations are obtained:

– the graph of the unparalleled character of the forward and reverse hodographs:

$$\Delta t = b_1 + b_2 x;$$

– the slope of this graph:

$$b = \delta(\Delta t)/L,$$

where $\delta(\Delta t)$ is the time difference at the ends of the hodographs of the length L;

– the correction factor:

$$a_2 = b_2/2l,$$

where $l$ is the distance between the generation points of the 2 hodographs;

– the velocity gradient: $\beta = 3.54(V_{\text{ini}} \ast a_2)^{2/3};$

– the real velocity at the depth level considered:

$$V(z) = V_{\text{ini}}(1 + \beta z^{2/3}).$$

EXAMPLES OF THE LONGITUDINAL WAVE RECORDINGS

Several types of seismic waves are identified on the seimograms, two types in the first arrivals and other two types in later arrivals.

The direct longitudinal wave, $t_{\text{dir}}$, is traveling with low velocities of 300–500 m/s and sometimes with higher velocities of up to 1,000 m/s, when it has a pronounced character of continuously refracted wave through the stack of shallow sediments. It appears in the first arrivals until 15 m from the shotpoint and then it can be easily correlated in later arrivals, from the first 24 channels.

The refracted wave, $t_1$, is obtained in the first arrivals of the other channels, until the end of the recording panel (maximum offset of 71.25 m).

Another wave obtained in later arrivals might be observed only on certain intervals, that is the frontal refracted converted wave, $t_{\text{PSF}}$, from the base of the low velocity zone (LVL).
Fig. 2 – Recordings of the longitudinal continuous refracted waves, traveling the low-velocity layer (P₀ pulse) and more compacted formations (P₁ pulse). Records performed from shot point (SP) position: a) 45 m; b) 70 m.
In later arrivals from greater distances, starting with the second recording panel (channels 25–48), an elastic wave is encountered with apparent velocity of 2,000 m/s, probably representing the reflected wave. This elastic wave, which is showing in the most part of the seismograms, might be due to an interface placed at shallow depth of 24–25 m.

The first step is to realize the traveltimes graphs for the refracted waves from the first arrivals, taking the pairs of 2 consecutive traveltimes graphs and then computing the difference of time values for 2 consecutive graphs in order to derive the variation of the seismic velocity in depth. Finally the vertical sections with isolines of velocity in depth are constructed.

The direct wave has different cinematic features along the profile. At a certain distance from the seismic source (greater than 30 m), the traveltimes graphs of the refracted wave \( t_1 \) are parallel, which means that the phenomenon of “intrusion” of the elastic waves is gradually disappearing.

A database of the picked times of the seismic signal is introduced as input in the MEDCONT computer program and the variation of the velocity in depth is obtained.

The computer program MEDCONT was constructed at the Institute of Geology of Romania and its performances are described with details by Cristea et al., 2002, 2004 and 2006 and Bala et al., 2005b.

In a further step the velocity values are computed for a certain step in the depth (Table 1) and these values are represented along the seismic profile.

The same procedure is applied also for the refracted wave \( t_1 \). The depth section obtained shows a higher gradient in the central part of the profile, as well as in the final part.

The pairs of forward and reverse hodographs of \( t_1 \) wave lead to the construction of the \( t_0 \) curve which was used to the construction of the interface of velocity jump. This interface is represented in Figs. 4–7, and it separates two main compartments of the variation of seismic velocity in depth. A certain trend of rising of the zone with higher velocities is shown in the central and final part of the profile (Fig. 4 and Fig. 5).

**EXAMPLES OF TRANSVERSE WAVE RECORDINGS**

In Fig. 3, the seismograms of the shot point at 7.5 m, 80 m and 280 m are selected to show the general information content of the records with the horizontal geophones.

In the first arrivals, on the channels 1–9, a direct continuously refracted wave is recorded – \( P_0 \), which has great amplitude, even on the horizontal components of the recording system. This wave is travelling through shallow unconsolidated sedimentary deposits.
Shallow quaternary layers along the 3C seismic profile.
Fig. 3 – Seismograms recorded with horizontal receivers. S₀, later arrival of the shear wave by surface layer. Records performed from shot point (SP) position: a) 7.5 m; b) 80 m; c) 280 m.
Further on, the refracted wave $P_1$ is recorded with a smaller amplitude, until the end of the seismogram, which is assigned to the upper part of the bedrock.

The $S$ seismic waves are also continuously refracted waves encountered in the second part of the seismograms.

The $S_0$ wave is travelling through the upper deposits of several meters with velocities between 120–140 m/s in the 5th–8th channels and 200 m/s in the last channels. The latter seismic velocity is relatively constant, for the channels 24–48, which shows quasi constant seismic velocities in the upper part, down to watertable level. The velocity value is an average on this depth interval. On the first segment of the $S_0$ wave, the energy is high and the time pickings were done on the first “breaking point”, which marks the abrupt change in amplitude level.

The graphs of nonparallel character of the hodographs were done for an interval of 7.5 m (5 recording points).

The $S_1$ wave represents the second arrivals in these recordings on horizontal geophones.

The pulse correlation is done easily on the second peaks (Fig. 3) and the parallelism of the hodographs further away from the recording point shows that this signal has an undoubted character of a refracted wave, which travels at lower levels, under the low velocity level (LVL).

However, because the first phase of the $S_1$ wave is diminishing with the distance, using the second peak of $S_1$ wave in the time picking could be affected by errors.

Note that the $S_0$ wave can be overlapped, with the surface wave of the Rayleigh type, which appears usually on seismic recordings as the seismic sources are placed at the ground surface. Taking into account this possibility, a lower value might be considered for $S_0$ wave velocities, by multiplying it with 0.9, this being the value of the ratio between the surface wave velocity and the transverse wave velocity (Enescu, 1970). As a direct result, a slight increase of the Possion coefficient might appear, which shows the reduced compactation of the surface sedimentary layer.

The described procedure was used for computing the difference time graphs of the $P_0$, $S_0$ and $P_1$ continuously refracted waves, which led to computing of the seismic velocities within two depth intervals: 1–8 m (Table 1) and 8–24 m (Table 2).

Because in most of the seismograms the time picking for the $S_1$ wave is uncertain, the shear wave velocity values for the depth interval 8–24 m were derived from the longitudinal wave velocity at the same depth level in a ratio of 1/6. This ratio was suggested previously by recent seismic measurements (downhole method) in the boreholes C1 and C2, at the ends of the seismic line (Fig. 1), and presented by Bala et al., 2005a.

The velocity values were converted as input data files, which permitted further interpolation with the SURFER software program and constructing the vertical sections of 300 m length with continuous variation of seismic velocity up to 24 m depth.
Table 1

Vp, Vs and Poisson ratio (v) values along the eastern part of the C3 Bucharest seismic line, characterising the low-velocity layer – LVL

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Table 2

Vp, Vs and Poisson ratio (v) values along the eastern part of the C3 Bucharest seismic line beneath the low-velocity layer (LVL)

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The first interval of the section, down to the water table, is characterized by S
velocity values from 130 m/s in the upper part, to 230–240 m/s in the lower part of
the shallow section (Fig. 5).

The variation of the $S_1$ velocity in the middle part of the section is important,
as a tendency of a complex domain with larger velocity values. This tendency is
also encountered in the velocity values section of $P_1$ longitudinal waves (Fig. 4 and
Bala et al., 2005a).

The $S_1$ wave has velocity values in the interval 230–350 m/s, the larger value
being at the 24 m depth (Fig. 5). This level is considered as the lower limit of the
investigation depth, being limited by the length of the recording panel of 72.5 m.

The importance of the simultaneous computing of the velocities for the
longitudinal and transverse seismic waves is strengthened further by computing
and representing the elastic parameters *in situ* for sedimentary rocks: Poisson’s
ratio ($\nu$) and shear modulus ($G$). These important parameters have a distinctive
significance in the *in situ* characterization of seismic microzonation of the
Bucharest City area and they bring new data values for engineering geology in
Quaternary sedimentary rocks.

The Poisson’s ratio is computed according to the following formula:

$$\nu = \frac{\left( V_P^2 - 2 * V_S^2 \right)}{2 \left( V_P^2 - V_S^2 \right)}$$

Its continuous variation in depth is given in Fig. 6, based on the values
presented in Tables 1 and 2.

In the upper layer (1–8 m depth) its values lies in the domain 0.39–0.42,
showing some lateral variations. In the depth interval 8–24 m, beneath the LVL,
Poisson’s ratio has values of 0.47–0.48, proving that weak sedimentary rocks are
present.

In Fig. 7 the variation in depth of the shear modulus ($G$) is given. In the
upper part, the values are between 60–120 MPa, while in the lower part of the
section, beneath LVL, some greater values of 120–280 MPa are encountered. The
density value was chosen 1900 kg/m$^3$, for the upper part and 2000 kg/m$^3$ for the
lower part of the section, for the purpose of computing of the shear modulus:

$$G = \rho V_S^2$$

### 3. CONCLUSIONS

In seismic prospecting, the information based on the transverse waves is of
the highest interest. At present, the application of the continuously refracted wave
theory on the pairs of forward and reverse traveltimes graphs, using the data of
multi-coverage seismic recordings has a novelty character.
Fig. 4 – Longitudinal wave velocity section along the Eastern part of the 3C East Bucharest seismic line. Seismic velocity in m/s. LVL: low-velocity layer constructed by seismic refraction information.
Fig. 5 – Shear wave velocity section along the Eastern part of 3C E Bucharest seismic line. Seismic velocity in m/s. LVL: low-velocity layer constructed by seismic refraction information.
Fig. 6 – Poisson’s ratio vertical section along the eastern part of NE Bucharest seismic line. LVL: low-velocity layer constructed by seismic refraction information.
Fig. 7 – Shear modulus vertical section – eastern part of the 3C East Bucharest seismic line. LVL: low-velocity layer constructed by seismic refraction information. The density was chosen 1,900 kg/m$^3$ for the upper part and 2,000 kg/m$^3$ for the lower part of the section. The values of the shear modulus in the section are given in [MPa].
This application is introduced by computing P and S wave velocities continuously in depth by a parabola law, using a new computer program – MEDCONT.

On the seismic profile 3C from the eastern Bucharest area, a high resolution recording system with 96-fold coverage, made possible a complete wave analysis for the separation of continuously refracted waves, for both longitudinal and transverse waves, resulting in a detailed image of velocity distribution in depth for the P and S waves.

The depth interval of the seismic velocity sections was limited to 24 m depth, given by the length of the recording panel (72.5 m).

The vertical sections for the seismic velocities present similarities, showing the same form of a dome with higher velocity values in the center lower part of the considered profile and another secondary dome at one end of the profile.

Both sections for seismic velocities put into evidence a low velocity level (LVL) which lies around 8–9 m depth and which can represent also the depth to the water table (Figs. 4 and 5).

Values of the longitudinal wave velocity and their variation in depth down to 24 m are almost the same as those previously obtained by downhole seismic method applied in boreholes C1 and C1.

Values of the shear wave velocity can be considered reliable down to 8–9 m depth (LVL) and they are also consistent with the downhole measurements. They are very important in particular because in situ measurements of shear wave velocity are scarce and seldom reported and their importance is one of the greatest impact in the microzonation of the Bucharest City.

From these 2 sections (Fig. 4 and Fig. 5), the vertical section with continuous variation of Poisson ratio is constructed in Fig. 6. In the upper layer (1–8 m depth) its values lies in the domain 0.39–0.42. In the depth interval 8–24 m, beneath the LVL, Poisson’s ratio has values of 0.47–0.48, proving that weak sedimentary rocks are present, probably plastic shales with large content of water. These values are consistent with the in situ velocity values, as well as Poisson’s ratio values obtained by downhole measurements in the boreholes C1 and C2, at both ends of the seismic profile (Bala et al., 2005a).

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REFERENCES


